



Vol. XIV &amp; Issue No.04 April - 2021

INDUSTRIAL ENGINEERING JOURNAL

## DESIGN AND DEVELOPMENT OF WORK STATION TO IMPROVE PRODUCTIVITY OF CRANKSHAFT MAINTENANCE ASSEMBLY IN LOCO SHED

Dr. Pramod N Belkhode

Dr. Kanchan V Borkar

Dr. Manish S Giripunje

### Abstract

*Loco shed workers are exposed to all kinds of machine and environmental hazards. Workers are subjected to more stresses. Ergonomics tries to achieve comfort to the man and accomplish the work efficiently. Ergonomics deals with man and his working environment, tools, materials and process. Present performance or evaluation of maintenance operation in Loco Shed is not satisfactory. The overall performances of their work activity are not regularly monitored leading to the limited success. Paper details the approach to assist the maintenance managers to optimize maintenance.*

**Keywords:** Maintenance, Loco shed, crank shaft, ergonomic, human energy, productivity.

### 1. INTRODUCTION

The maintenance activities are difficult to plan and involve high costing. The variables involved in the maintenance activities are correlated to formulate mathematical model which improves the human energy and repair time. Maintenance of various engine parts carried out as per prescribed schedule in the loco shed. Time and human energy consumption involved in crank shaft assembly of engine block is more with less productivity. Data of maintenance activities are collected based on sequence of maintenance activity by direct measurement. From this data input and output variables are decided and models are formulated with dimensionless pie terms using regression analysis. There are many approaches to develop or upgraded industrial activity such as method study (motion study), work measurement (time study), productivity and work study etc. Present approach suggests the field data based modelling to resolve the consumption of time and human energy of maintenance activities of the loco shed. Dependent and independent variable of an activity can be compared with cost-effect for improving present method. The approach predicts the behaviour of mathematical model by substituting known inputs for every observation and observed response. Further these responses can be compared with actually observed responses which give us the pattern of distribution of error and frequency of its occurrence<sup>[1]</sup>. The paper details the technique to solve the field problem and further this approach will motivate to the resolve field activities.

### 2. OVERVIEW

**1.1. Present Maintenance Approach:** Present maintenance approaches mostly consist of a pre-defined activities carried out at regular intervals (scheduled maintenance) or by periodic or continuous condition monitoring (predictive maintenance). This maintenance policy may be quite inefficient due to costing and less component lifetime. Field data based mathematical

modelling is the most cost-effective method used to improve the maintenance activity<sup>[2]</sup>. The engine block of locomotive is one of the most important parts of locomotive which is used to generate and transmit power to the locomotive through transmission unit. Engine crank shaft assembly maintenance plays vital role to convert one motion into another. The proper power generation depends on working of crank shaft. The maintenance of crankshaft assembly is one of the primary tasks and makes up 50 -60 % of total time and human energy as compared to other activities. It is repetitive task that involved awkward postures and can be physically demanding on the neck, shoulder, back and forearms. Again, improper maintenance will result lubrication problem in engine, heat generation, vibration and other several problem causing reducing in engine efficiency and productivity. Furthermore, its maintenance involves disassembling/assembling of all other parts of engine which can affect engine alignment. So it consumes more time and more human energy<sup>[3]</sup>. So the various variables affecting this phenomenon is find out by studying the sequence of phenomenon.

**1.2. Research Methodology:** Formulation of mathematical model of the most critical crankshaft activities are identified and studied using maintenance schedule, past failure data and their experiences can be taken into consideration. Identification of problem details the effectiveness of crankshaft maintenance activity depends on various factors such as human factors, workstation data tools used by workers, specification of crankshaft, solvents used for maintenance activity and extraneous variables such as temperature, humidity, light and noise. Theory of Experimentation as suggested by Hilbert (1961) is decided to apply. This approach will give a new insight to optimization of parameters for crank shaft maintenance activity. Once the model is formulated for such a phenomenon it gives clear idea about the variation of dependent variables in terms of interaction of various independent variables. Methodology of

experimentation includes application of Dimensional analysis. Dimensional approach adopted for formulating generalized field data based model.

Normally, the approach adopted for formulating generalized field data based model suggested by Schenck H. Jr., has been proposed in the present investigation which involves following steps:

- a. Identification of variables or parameters affecting the phenomenon
- b. Reduction of variables through Dimensional analysis
- c. Direct data collection for the activity from work station
- d. Rejection of absurd data
- e. Formulation of the model

**1.3 Benefits:** In the present method, the productivity is less and requirement of human energy is substantial. Therefore, the factors influencing the maintenance activities have been identified, so as to optimize the productivity and conserving human energy in this activity. The generalized mathematical model has been formulated using theories of experimentation for the crankshaft maintenance activity. Field data based model for a man machine system will decide strengths and weaknesses of present method of performing any maintenance activity. Once weaknesses are known corrective action can be decided.

**2.4 Literature Review:** The field of ergonomics and scheduling a maintenance task has carried out work on ergonomics aspects and maintenance field. Their work has been reported through the various published articles. A systematic study of these articles is carried out. Many researchers have given recommendations for ergonomics design and mechanization of loco shed maintenance activities. These articles are grouped here in the following for the review purpose

**2.4.1 Ergonomics issues in maintenance field:** According to PC Schutte and JR Smith (2001) the major objective of the ergonomics is to enhance the effectiveness and efficiency with which human task are carried out to improve desirable human values. enhancing safety, reducing fatigue, increasing comfort with improved job satisfaction while enhancing effectiveness in carrying out the tasks

**2.4.2 Scheduling a Maintenance Activity:** Hussain, S. and Naikan V. N. A (2010), analyzed the maintenance of the industrial repairable systems. The future issues were addressed in the mathematical modeling for maintenance. They attempted to review the models which are available in the research literatures to deploy appropriate model for effective maintenance planning and implementation.

Endrenyi J. (1999) and other members were found that the impact of maintenance strategy on reliability. The author suggested that the optimized probabilistic maintenance models would provide the highest savings and also the highest flexibility in exploring and utilizing the effects of changes in any of the parameters.

Narkhede B.E., (2014) studied the implications of manufacturing

strategy practices on manufacturing and business performance. Author details the action plan composed of decisions in improvement activities. The author further suggest to assess the implications of organizational knowledge, source of information and functional orientation, resource based view of the manufacturing and global orientation, on manufacturing practices which include advanced manufacturing technology.

Kulkarni S D, Dhake R J, Raut R D, Narkhede B E, (2014) details the procedure for achieving operational excellence through Integrated Approach of Lean Manufacturing and TPM Methodology in Mechanical Cluster Line through the case study.

Many researchers have given recommendations for ergonomics design and mechanization of maintenance activities. The problems of scheduling maintenance are also investigated by some researchers. Therefore establishment of scientific, comprehensive maintenance system are faced with today's challenges.

**2.5 Field Data Based Model:** It is not possible to formulate a logic based model correlating causes and effects of any phenomenon. Formulation of relationships amongst causes and effects (in other words inputs and outputs) however is essential. Formulation of such relationships highlights the short comings or strengths of present method. 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 / activity performance it is absolutely essential to form such analytical cause – effect relationships conceptualized in this research work as Field Data Based Models<sup>[4-6]</sup>.

Identification of dependent and independent variables of the phenomenon is to be done based on known qualitative physic of the phenomenon. If the system involves a large number of independent variables then the experimentation becomes tedious, time consuming and costly. So by deducing the dimensional equation for the phenomenon, which reduce the number of independent variables and it gets confirmed that all variables are considered. The exact mathematical form of this equation could be obtained based on the field data. This mathematical form is the targeted model.

**2.6 Maintenance Activity Of Crankshaft:** Various maintenance operations for overhauling of crank shaft can be enlisted chronologically as under.

- 1) Taking out Split Pin by Cutting pliers.
- 2) Taking out Side Alen Bolt by Spanner.
- 3) Taking out Small Alen Bolt by Spanner.
- 4) Taking out Saddles by Tummy Bar.
- 5) Cleaning of Main Journal and Saddle by Kerosene.
- 6) Polishing of Main Journal and Saddle by Emery Belts.
- 7) Fitting of new Main Journal Bearing and fitting of Saddle.
- 8) Measuring of Clearance of Fitted Bearing by Dial Gauge.
- 9) Fitting of Small Alen Bolt by Spanner.
- 10) Checking all Bearing Alignments and resetting it properly.
- 11) Tightening of all Saddle Nuts.
- 12) Lightning of Side Bolt by Spanner.
- 13) Fitting of new Split Pin by Plyor.

3. IDENTIFICATION OF VARIABLES

**3.1 Description of Crankshaft variables:** Following variables are identified from the crankshaft maintenance activity. Variables as listed below to formulate quantitative relationship between the dependant and independent Pi terms of the dimensional equation [7][8].

**Table 1: List of variables of crankshaft**

S.N	Description of Variables	Type of variable	Symbol
1	Overhauling time of crankshaft	Dependent	$T_{cs}$
2	Consumption of Human energy	Dependent	$HE_{cs}$
3	Productivity of crank shaft overhauling	Dependent	$Pd_{cs}$
4	Age of worker	Independent	$Ag_s$
5	Experience of worker	Independent	$Ex_s$
6	Skill of worker	Independent	$Sk_s$
7	Enthusiasm of worker	Independent	$En_s$
8	Habbits of worker	Independent	$Hb_s$
9	Health of worker	Independent	$hl_s$
10	Anthropometric data of worker	Independent	$Ant_s$
11	Temperature of work station	Independent	$Tmp_s$
12	Humidity of workstation	Independent	$Hmd_s$
13	Noise of workstation	Independent	$Noi_s$
14	Illumination of work station	Independent	$ilm_s$
15	Diameter of split pin	Independent	$Dsp_s$
16	Length of split pin	Independent	$Lsp_s$
17	Diameter of saddle nut	Independent	$Dsn_s$
18	Length of saddle nut	Independent	$Lsn_s$
19	Diameter of saddle bolt	Independent	$Dsb_s$
20	Length of saddle bolt	Independent	$Lsb_s$
21	Diameter of small alen bolt	Independent	$Dsmab$
22	Length of small alen bolt	Independent	$Lsmab$
23	Diameter of side alen bolt	Independent	$Dsiab$
24	Length of side alen bolt	Independent	$Lsiab$
25	Diameter of saddle cap	Independent	$Dsc$
26	Length of saddle cap	Independent	$Lsc$
27	Diameter of main journal of crankshaft	Independent	$Dmj$

28	Length of main journal of crankshaft	Independent	$Lmj$
29	Diameter of crankpin journal of crankshaft	Independent	$Dcpj$
30	Length of crankpin journal of crankshaft	Independent	$Lcpj$
31	Diameter of bend ring	Independent	$Dbr$
32	Length of bend ring	Independent	$Lbr$
33	Diameter of small alen spanner	Independent	$Dsmasp$
34	Length of small alen spanner	Independent	$Lsmasp$
35	Diameter of side alen spanner	Independent	$Dsisp$
36	Length of side alen spanner	Independent	$Lsisp$
37	Diameter of barring rod	Independent	$Dbrr$
38	Length of barring rod	Independent	$Lbrr$
39	Diameter of main journal bearing	Independent	$Dmjb$
40	Thickness of main journal bearing	Independent	$Tmjb$
41	Length of main journal bearing	Independent	$Lmjb$
42	Diameter of crank pin journal bearing	Independent	$Dcpjb$
43	Length of frame	Independent	$Lfrm$
44	Length of crank pin journal bearing	Independent	$Lcpjb$
45	Thickness of crank pin journal bearing	Independent	$Tcpjb$
46	Width of frame	Independent	$Wfrm$
47	Height of frame	Independent	$Hfrm$
48	Kerosene (solvent) in litre	Independent	$Ker$
49	Emery belt in Meter	Independent	$Eb$
50	Compressed air in kg	Independent	$Ca$
51	Axial clearance of main journal	Independent	$Ax mj$
52	Axial clearance of crank pin	Independent	$Axcp$

**3.2 Formulation of dimension less pi terms for crankshaft:** This system involves a large number of independent variable. So these Independent variables have been reduced into a group of pi terms. Following is the list of dimensionless Independent and dependent Pi term of crankshaft activity [9].

Table 2 : List of dimensionless equation of crankshaft

SN	Description of Pi terms	Establishment of dimensionless Equation of Pi term
1	Pi term relating anthropometric data of worker	$\Pi 1 = [(a*c*e*g)/(b*d*f*h)] = Ad$
2	Pi term relating data of worker	$\Pi_2 = [(Ags/Exs),(sks/Ens),(hls/Hbs)] = wd$
3	Pi term relating specification of crankshaft	$\Pi 3 = [(Dsps/Dsns)*(Lsps/Dsns)*(Dsmab/Dsns)*(Lsns/Dsns)*(Dsbs/Dsns)*(Lsbs/Dsns)*(Lsmab/Dsns)*(Dsiab/Dsns)*(Lsiab/Dsns)*(Dsc/Dsns)*(Lsc/Dsns)*(Dmj/Dsns)*(Lmj/Dsns)*(Dcpj/Dsns)*(Lcpj/Dsns)*(tmjb/Dsns)*(Dmjb/Dsns)*(Dcpjb/Dsns)*(tcpjb/Dsns)] = slm$
4	Pi term relating specification of tools	$\Pi 4 = [(Dbr/Lbr),(Dsmasp/Lbr),(Lsmasp/Lbr),(Dsisp/Lbr),(Lsisp/Lbr),(Dbr/Lbr),(Lbr/Lbr)] = slt$
5	Pi term relating specification of solvent ,lube oil and compressed air	$\Pi 5 = [(ker/l\ oil),(Ca/Eb)] = ss$
6	Pi term relating specification of Axial clearance of crank pin and Saddle bolt elongation	$\Pi 6 = [(Axcp/Elsb),(Axmj/Elsb)] = sax$
7	Pi term relating specification of workstation	$\Pi 7 = [(Hfrm/Lfrm),(wfrm/Lfrm)] = sfrm$
8	Pi term relating specification of temp.	$\Pi 8 = temp = temp$
9	Pi term relating specification of, humidity	$\Pi 9 = \text{humidity in \%} = \text{hum}$
10	Pi term relating specification of illumination	$\Pi 10 = [(ilms* Ags/wt)] = ill$
11	Pi term relating specification of noise	$\Pi 11 = \text{noise in db} = \text{noise}$
13	Pi term relating to overhauling time	$Z1 = (\text{field time})^2 \times g / \text{length of saddle}$
14	Pi term relating HE	$Z2 = (\text{field energy}/(\text{field time} * 1.341 \times 10^{-3}))$
15	Pi term relating productivity	$Z3 = (\text{crankshaft overhauling time}/ \text{total engine overhauling time}) = \text{field time}/21600\text{min}$

3.3 Formulation of Dimensional Equation for Response

Variable: The Exact Mathematical Form of This Equation Will Be Targeted Model.

Dependent Pie Term (z) =  $K * [(Ad)]^a * [(wd)]^b * [(slm)]^c * [(slt)]^d * [(ss)]^e * (sax)^f * (frm)^g * (Tmps)^h * (Humd)^i * (illmus)^j * [(Noise)]^k$

3.4 Actual record of field data of crankshaft maintenance activity: Actual field data is recorded in following tables and

computation of pi terms is given as follows:-

a) Pi term relating to anthropometric dimensions of operator for crankshaft (p1)

The ratio of various anthropometric measures of an operator is taken as shown in table 3 and dimensionless pi term p1 is calculated as below

$$\Pi 1 = [(a*c*e*g)/(b*d*f*h)]$$

Table 3: Data related to anthropometric data of worker for crankshaft (p1)

S N	Age	weight	Stature	shoulder height	elbow height	eye height	finger tip height	shoulder breadth	hip breadth	Hand breadth across thumb	p1=[(a*c*e*g)/(b*d*f*h)]
	yr	kg	(a) mm	(b) mm	(c) mm	(d) mm	(e) mm	(f) mm	(g) mm	(h) mm	
1	43	65	1676	1372	1036.3	1524	670.56	487.7	128.06	128	1.143135
2	45	66	1676	1341	1036.3	1424	640.08	518.2	121.9	121.1	1.131234
3	45	70	1646	1372	1127.8	1524	701.04	457.2	118.87	118.8	1.362632
4	46	68	1585	1311	944.88	1493.5	335.28	487.7	125.92	124.7	0.531259
5	47	72	1737	1433	1097.3	1554.5	670.56	457.2	128.01	128.2	1.253709
6	42	71	1707	1433	1127.8	1585	670.56	457.2	131.06	131.1	1.243331
7	32	73	1798	1433	1097.3	1676.4	853.44	518.2	134.112	134.1	1.353348
8	43	65	1615	1341	1005.8	1524	609.56	457.2	128.02	128	1.060013
9	43	74	1646	1372	1036.3	1524	670.56	487.7	128.11	128	1.122789
10	42	70	1707	1372	1036.3	1615.4	670.56	457.2	124.96	125	1.170874

**b) Pi term relating to workers dimensions of operator (p2)**

as below

The ratio of various variables measures of an operator is taken as shown in table 4 and dimensionless pi term p2 is calculated

$$\Pi_2 = [(Ags/Exs), (sks/Ens), (hls/Hbs)]$$

**Table 4: Data related to workers factors for crankshaft (p<sub>2</sub>)**

S. N.	Avg age	Avg exp	Avg skill	Enthu	Habbits	Health	P2= (age*sks*hls)/(Exs*Ens*hbs)
1	40	16.33	8.33	8.666	6.766	8.23	2.863967
2	39.66	18.66	7.9	7.3	7.25	8.266	2.622423
3	40.33	18	8.33	7.66	6.8	8.933	3.200813
4	44.33	15.33	7	6.2	7.16	7.766	3.541166
5	43	20.333	8.5	6.533	6.9	8.4	3.349681
6	40.33	16.333	8.5	8.233	7.26	8.466	2.972793
7	39.66	17	7.833	8.2	7.2	8.1	2.507094
8	43.6	18.333	7.833	8.1	7	8.566	2.814337
9	44.6	18	7.833	6.866	6.66	6.166	2.617074
10	40.33	16.333	8.33	7.2666	6.9	8.033	3.295374

**c) Pi term relating to specification of crankshaft of overhauling (p<sub>3</sub>)**

$$\Pi_3 = [(Dsps/Dsns) * (Lsps/Dsns) * (Dsmab/Dsns) * (Lsns/Dsns) * (Dsbs/Dsns) * (Lsbs/Dsns) * (Lsmab/Dsns) * (Dsiab/Dsns) * (Lsiab/Dsns) * (Dsc/Dsns) * (Lsc/Dsns) * (Dmj/Dsns) * (Lmj/Dsns) * (Dcpj/Dsns) * (Lcpj/Dsns) * (tmjb/Dsns) * (Dmjb/Dsns) * (Dcpjb/Dsns) * (tcpjb/Dsns)]$$

The ratio of various linear dimensions of the crank shaft is taken as shown in table 5 and dimensionless pi term p3 is calculated as below

**Table 5: Data related to specification of crankshaft overhauling (p<sub>3</sub>)**

	split pin dia	l(split pin)	l(saddle nut)	d(saddle bolt)	l(saddle bolt)	d(small alen bolt)	l(small alen bolt)	d(side alen bolt)	l(side alen bolt)	d(saddle cap)	l(saddle cap)	d(main journal)	l(main journal)	d(crankpin)	l(crankpin)	d(j.bearing)	t(j.bearing)	d(c.bearing)	t(c.bearing)	P3
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
1	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
2	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
3	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
4	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
5	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
6	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
7	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
8	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
9	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90
10	5	70	28	30	385	16	27	24	200	192	72	180	80.4	170	80	180.2	6	170.2	6	1898.90

**d) Pi term relating to specification of tools used for overhauling of crank shaft (p<sub>4</sub>)**

as below

The ratio of various linear dimensions of the crank shaft is taken as shown in table 6 and dimensionless pi term p4 is calculated

$$\Pi_4 = [(Dbr/Lbr), (Dsmsp/Lbr), (Lsmsp/Lbr), (Dsisp/Lbr), (Lsisp/Lbr), (Dbr/Lbr), (Lbr/Lbr)]$$

**Table 6: Data related to specification of tools used for crankshaft overhauling (p<sub>4</sub>)**

S. N.	d(bend ring)	l(bend ring)	d(spanner small)	l(spanner small)	d(spanner side)	l(spanner side)	d(barring rod)	l(barring rod)	P4
	mm	mm	mm	mm	mm	mm	mm	mm	
1	55	570	12	135	19	190	25	1000	54.73918
2	55	570	12	135	19	190	25	1000	54.73918
3	55	570	12	135	19	190	25	1000	54.73918
4	55	570	12	135	19	190	25	1000	54.73918
5	55	570	12	135	19	190	25	1000	54.73918
6	55	570	12	135	19	190	25	1000	54.73918
7	55	570	12	135	19	190	25	1000	54.73918
8	55	570	12	135	19	190	25	1000	54.73918
9	55	570	12	135	19	190	25	1000	54.73918
10	55	570	12	135	19	190	25	1000	54.73918

**e) Pi term relating to specification of solvents used for crankshaft overhauling of (p<sub>5</sub>)**

as shown in table 7 and dimensionless pi term p4 is calculated as below

The ratio of various linear dimensions of the crank shaft is taken

$$\Pi 5 = [(ker/l \text{ oil}), (Ca/Eb)]$$

**Table7: Data related to specification of solvents used for crankshaft overhauling (p<sub>5</sub>)**

S. N.	kerosene	l/oil	c/air	emery belt	emery belt	P5
	lit	lit	kg	meter	kg	
1	2	0.5	7	6	0.21	133.3333
2	2.5	0.5	8	5	0.17	235.2941
3	2	0.5	6	5.5	0.19	126.3158
4	2	0.4	8	6.5	0.23	173.913
5	2	0.8	7	7	0.24	72.91667
6	2	0.8	7	8	0.28	62.5
7	2.5	0.6	8	6	0.21	158.7302
8	2	0.5	8	5.6	0.19	168.4211
9	2	0.6	7	7	0.24	97.22222
10	2	0.6	7	6	0.21	111.1111

**f) Pi term relating to specification of axial clearance of crankshaft overhauling of (p<sub>6</sub>)**

as shown in table 8 and dimensionless pi term p6 is calculated as below

The ratio of various linear dimensions of the crank shaft is taken

$$\Pi 6 = [ (Axcp/Elsb), (Axmj/Elsb)]$$

**Table 8 Data related to specification of axial clearance of crankshaft overhauling (p<sub>6</sub>)**

SN	c.pin axial clearence	m.j axial clearence	bolt elong.	P6
	mm	mm	mm	
1	0.21	0.18	0.54	0.12963
2	0.21	0.18	0.53	0.134567
3	0.22	0.18	0.54	0.135802
4	0.18	0.2	0.54	0.123457
5	0.91	0.18	0.54	0.561728
6	0.21	0.18	0.53	0.134567
7	0.21	0.21	0.54	0.151235
8	0.21	0.18	0.54	0.12963
9	0.2	0.18	0.54	0.123457
10	0.21	0.25	0.56	0.167411

**h) Pi term relating to extraneous variables of crankshaft overhauling - workstation specification (p7), temperature (p8), humidity (p9) noise (p11)**

The ratio of various dimensions of the crank shaft is taken as shown in table 10 and dimensionless pi term p1 is calculated as below

- P7= workstation dimension
- P8= temp/100
- P9=hum %
- P10= (lumens\*age)/wt
- P11=Noise

**Table 9 Data related to extraneous variables of crankshaft overhauling**

SN	workstation of crankshaft overhauling	temp(*c)	temp/100	humidity	noise	(lumens*age)/wt
	P7		P8	P9	P11	P10
1	4.287195	31.2	0.312	31	62.75	211692.3
2	4.287195	26	0.26	31	72	205207.4
3	4.287195	32.8	0.328	27	70	206213.4
4	4.287195	34	0.34	27	85	284469.2
5	4.287195	36	0.36	30	80	265977.8
6	4.287195	38.1	0.381	30	84	217171
7	4.287195	43	0.43	24	79	218019
8	4.287195	35.3	0.353	24	73	326645.7
9	4.287195	39.3	0.393	27	76	307085.3
10	4.287195	39.8	0.398	27	77	242484.2

**4. MODEL FORMULATION**

**4.1 Model Formulation for crank shaft Maintenance Activity**

The multiple regression analysis helps to identify the indices of the different pi terms in the model aimed at, by considering eleven independent pi terms and one dependent pi term. Let model aimed at be of the form [10]

$$(z1) = K1 *[(\pi_1)^a * (\pi_2)^b * (\pi_3)^c * (\pi_4)^d * (\pi_5)^e * (\pi_6)^f * (\pi_7)^g * ((\pi_8)^h * (\pi_9)^i * (\pi_{10})^j * (\pi_{11})^k)] \tag{1}$$

$$(z2) = K 2 *[(\pi_1)^a * (\pi_2)^b * (\pi_3)^c * (\pi_4)^d * (\pi_5)^e * (\pi_6)^f * (\pi_7)^g * ((\pi_8)^h * (\pi_9)^i * (\pi_{10})^j * (\pi_{11})^k)] \tag{2}$$

$$(z3) = K3 *[(\pi_1)^a * (\pi_2)^b * (\pi_3)^c * (\pi_4)^d * (\pi_5)^e * (\pi_6)^f * (\pi_7)^g * ((\pi_8)^h * (\pi_9)^i * (\pi_{10})^j * (\pi_{11})^k)] \tag{3}$$

This is known as exponential form of model

There are twelve unknown terms in the equator viz. curve fitting constant k1 and indices a1,b1,c1,d1,e1,f1,g1,h1,i1,j1,k1.to get the values of these unknowns we need minimum 12 sets of values of p1,p2,p3,p4,p5,p6,p7,p8,p9,p10,p11.we have 30sets of these values any arbitrary 12 set from pi terms tables are selected and the values of unknown K,a1,b1,c1,d1,e1,f1,g1,h1,i1,j1,k1.are computed, then it may not result in one best unique solution representing a best fir unique curve for the remaining sets of the values. To be very specific we can find out <sup>30</sup>C<sub>r</sub> combinations of r sets taken together out of available n sets of the values. The value in this case will be <sup>30</sup>C<sub>12</sub>. Solving these many sets and finding their solutions will be a Herculean task. Hence it was decided to solve this problem by curve fitting technique to follow this method it is necessary

to have the equation in the form as under

$$Z_1 = a + b*x + c*y + d*z \text{ ----}$$

Thus the to form such equation we will take log on both side

Taking log on the both sides of equation for z1 we get eleven unknown terms in the equations,

$$\text{Log } z_1 = \text{log } k1 + a_1 \text{log } p_1 + b_1 \text{log } p_2 + c_1 \text{log } p_3 + d_1 \text{log } p_4 + e_1 \text{log } p_5 + f_1 \text{log } p_6 + g_1 \text{log } p_7 + h_1 \text{log } p_8 + i_1 \text{log } p_9 + j_1 \text{log } p_{10} + k_1 \text{log } p_{11}$$

Let, Z<sub>1</sub>= log z1, K<sub>1</sub>= log k1, A = log p<sub>1</sub>, B = log p<sub>2</sub>, C = log p<sub>3</sub>, D = log p<sub>4</sub>, E = log p<sub>5</sub>, F= log p<sub>6</sub>

G = log p<sub>7</sub>, H = log p<sub>8</sub>, I = log p<sub>9</sub>, J = log p<sub>10</sub>, K = log p<sub>11</sub>

Putting these values in log equation the same can be written as

$$Z_1 = K_1 + a_1 A + b_1 B + c_1 C + d_1 D + e_1 E + f_1 F + g_1 G + h_1 H + i_1 I + j_1 J + k_1 K$$

This is a regression equations of Z on A,B, C, D, E, F, G, H,I,J, K .in an n dimensional coordinate system this represents a regression hyper plane as

$$\sum z_1 = n K_1 + a_1 \sum A + b_1 \sum B + c_1 \sum C + d_1 \sum D + e_1 \sum E + f_1 \sum F + g_1 \sum G + h_1 \sum H + i_1 \sum I + j_1 \sum J + k_1 \sum K$$

$$\sum z_1 A = K_1 \sum A + a_1 \sum A^2 + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum z_1 B = K_1 \sum B + a_1 \sum AB + b_1 \sum B^2 + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum BK$$

$$\sum z_1 C = K_1 \sum C + a_1 \sum AC + b_1 \sum BC + c_1 \sum C^2 + d_1 \sum CD + e_1 \sum CE + f_1 \sum CF + g_1 \sum CG + h_1 \sum CH + i_1 \sum CI + j_1 \sum CJ + k_1 \sum CK$$

$$\sum Z_1 D = K_1 \sum D + a_1 \sum AD + b_1 \sum AB + c_1 \sum AC + d_1 \sum D^2 + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 E = K_1 \sum E + a_1 \sum AE + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum E^2 + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 F = K_1 \sum F + a_1 \sum AF + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum F^2 + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 G = K_1 \sum G + a_1 \sum AG + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum G^2 + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 H = K_1 \sum H + a_1 \sum AH + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum H^2 + i_1 \sum AI + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 I = K_1 \sum I + a_1 \sum AI + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum I^2 + j_1 \sum AJ + k_1 \sum AK$$

$$\sum Z_1 J = K_1 \sum J + a_1 \sum AJ + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum J^2 + k_1 \sum AK$$

$$\sum Z_1 K = K_1 \sum K + a_1 \sum AK + b_1 \sum AB + c_1 \sum AC + d_1 \sum AD + e_1 \sum AE + f_1 \sum AF + g_1 \sum AG + h_1 \sum AH + i_1 \sum AI + j_1 \sum AJ + k_1 \sum K^2$$

In the above equations the values of the terms Z on LHS and the multipliers of  $K_1, a_1, b_1, c_1, d_1, e_1, f_1, g_1, h_1, i_1, j_1,$  and  $k_1$  on RHS side are tabulated and calculated. The above equation can be verified in the matrix form.

$$Z_1 \begin{matrix} 1 \\ A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \\ I \\ J \\ K \end{matrix} = \begin{matrix} n & A & B & C & D & E & F & G & H & I & J & K \\ A & A^2 & BA & CA & DA & EA & FA & GA & HA & IA & JA & KA \\ B & AB & B^2 & CB & DB & EB & FB & GB & HB & IB & JB & KB \\ C & AC & BC & C^2 & DC & EC & FC & GC & HC & IC & JC & KC \\ D & AD & BD & CD & D^2 & ED & FD & GD & HD & ID & JD & KD \\ E & AE & BE & CE & DE & E^2 & FE & GE & HE & IE & JE & KE \\ F & AF & BF & CF & DF & EF & F^2 & GF & HF & IF & JF & KF \\ G & AG & BG & CG & DG & EG & FG & G^2 & HG & IG & JG & KG \\ H & AH & BH & CH & DH & EH & FH & GH & H^2 & IH & JH & KH \\ I & AI & BI & CI & DI & EI & FI & GI & HI & I^2 & JI & KI \\ J & AJ & BJ & CJ & DJ & EJ & FJ & GJ & IJ & J^2 & KJ \\ K & AK & BK & CK & DK & EK & FK & GK & HK & IK & JK & K^2 \end{matrix} \begin{matrix} K_1 \\ a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ f_1 \\ g_1 \\ h_1 \\ i_1 \\ j_1 \\ k_1 \end{matrix}$$

Calculate the values of independent pi terms for corresponding dependent pi term by using MATLAB software this process of model formulation precise, quickest and least cumbersome, the values of constant and different indices of the proposed model have been found out for dependent variable [11].

**4.2 Model developed for the dependent variable for crank shaft**

$$(Z_1) = 1.7198 * [(\pi_1)^{0.0873} (\pi_2)^{0.1026} (\pi_3)^{0.6137} (\pi_4)^{0.2115} (\pi_5)^{-0.2101} (\pi_6)^{-0.0025} (\pi_7)^{1.54} (\pi_8)^{-0.4451} (\pi_9)^{-0.125} (\pi_{10})^{-0.0609} (\pi_{11})^{0.1131}] \tag{3}$$

$$(Z_2) = 1.2203 * [(\pi_1)^{0.2769} (\pi_2)^{0.018} (\pi_3)^{-0.2583} (\pi_4)^{3.3045} (\pi_5)^{0.0597} (\pi_6)^{-0.0314} (\pi_7)^{1.3341} (\pi_8)^{0.0415} (\pi_9)^{-0.0103} (\pi_{10})^{0.002} (\pi_{11})^{-0.3935}] \tag{4}$$

$$(Z_3) = 1.6837 * [(\pi_1)^{-0.0873} (\pi_2)^{-0.1026} (\pi_3)^{-0.1837} (\pi_4)^{-1.2275} (\pi_5)^{0.2101} (\pi_6)^{0.0025} (\pi_7)^{0.9916} (\pi_8)^{0.4451} (\pi_9)^{0.125} (\pi_{10})^{0.0609} (\pi_{11})^{-0.1131}] \tag{5}$$

In the above equations  $Z_1$  is related to response variable time,  $Z_2$  is related to response variable human energy and  $Z_3$  is related to response variable productivity of crankshaft activity.

**5. CONCLUSIONS**

The analysis of the mathematical model using different dependent pi terms of crankshaft maintenance activity presented as follows

**5.1 Analysis of the model for dependent pi term Z1 (Time):**

The equation (4) represents the mathematical model of  $Z_1$  related to response variable time of crankshaft maintenance activity. The conclusions drawn from the equation are

1. The absolute index of  $\pi_7$  is the highest viz. 1.54. Thus this term related to workstation used for crankshaft activity which is the most influencing  $\pi$  term in this equation. The value of this index is positive indicating that time of crankshaft maintenance activity is directly proportional to work station of crankshaft activity
2. The absolute index of  $\pi_8$  is the lowest viz. -0.4451. Thus this term is related to the tools which is least influencing  $\pi$  term in this equation. The value of this index is negative indicating that time of crankshaft maintenance activity is inversely proportional to tools used for crankshaft overhauling
3. The other moderate influencing independent  $\pi$  terms are  $\pi_3, \pi_4, \pi_{11}, \pi_2, \pi_1, \pi_6, \pi_{10}, \pi_9$  and  $\pi_5$  having absolute indices as 0.6137, 0.2115, 0.1131, 0.1026, 0.0873, -0.0025, -0.0609, -0.125 and -0.2101. The time of crankshaft activity is directly proportional on crankshaft data, tools, noise, workers data, and anthropometric data and inversely proportional to axial clearance, light, humidity and solvents.

The equation (5) represents the mathematical model of  $Z_2$  related to response variable human energy of crankshaft maintenance activity. The conclusions drawn from the equation are

**5.2 Analysis of the model for dependent pi term Z2 (Human Energy):**

The equation (5) represents the mathematical model of  $Z_2$  related to response variable human energy of crankshaft maintenance activity. The conclusions drawn from the equation are

1. The absolute index of  $\pi_4$  is the highest viz. 3.3045 .thus this term related to tools of used for crankshaft activity which is the most influencing  $\pi$  term in this equation. The value of this index is positive indicating that time of crankshaft maintenance activity is directly proportional to tools of crankshaft activity
2. The absolute index of  $\pi_{11}$  is the lowest viz. -0.3935. Thus this term is related to noise which is the least influencing  $\pi$  term in this equation. The value of this index is negative indicating that time of crankshaft maintenance activity is inversely proportional to work station
3. The other moderate influencing independent  $\pi$  terms are  $\pi_7, \pi_1, \pi_5, \pi_8, \pi_2, \pi_{10}, \pi_9, \pi_6$  and  $\pi_3$  having absolute indices as 1.3341, 0.2709, 0.0597, 0.0415, 0.018, 0.002, -0.0103-0.0314 and -0.2583 The human energy of crankshaft activity is directly proportional on workstation data, anthropometric data, solvents, temperature, workers data and light and inversely proportional to humidity, axial clearance and specification of crankshaft

**5.3 Analysis of the model for dependent pi term Z3 (Productivity):**

The equation (6) represents the mathematical model of  $Z_3$  related to response variable productivity of crankshaft maintenance activity. The conclusions drawn from the equation are

1. The absolute index of  $\pi_7$  is the highest viz. 0.9916 .thus this term is related to workstation used for crankshaft activity which is the most influencing  $\pi$  term in this equation. The value of this index is positive indicating that time of crank shaft maintenance activity is directly proportional to work station of crank shaft activity

2. The absolute index of  $\pi_4$  is the lowest viz. -2.5291. Thus this term is related to tools which is the least influencing  $\pi$  term in this equation. The value of this index is negative indicating that time of crank shaft maintenance activity is inversely proportional to tools used for crank shaft overhauling

3. The other moderate influencing independent  $\pi$  terms are  $\pi_8$ ,  $\pi_5$ ,  $\pi_9$ ,  $\pi_{10}$ ,  $\pi_6$ ,  $\pi_1$ ,  $\pi_2$ ,  $\pi_{11}$  and,  $\pi_3$  having absolute indices as 0.4451, 0.2101, 0.125, 0.0609, 0.0025, -0.0873, -0.1026,-0.1131, and -0.1837, The productivity of crank shaft activity is directly proportional on temperature, solvents, humidity, light and axial clearance and inversely proportional to anthropometric data, workers data, noise and specification of crankshaft

**5.4 Interpretation of curve fitting constant (K) for Crankshaft:** The value of curve fitting constant in Z1 is 1.7198, Z2 is 1.2203 and Z3 is 1.6837. This collectively represents the combined effect of all extraneous variables. Further as it is positive, this indicates that there are good numbers of causes influencing on increasing effect. The relationship between various inputs such as anthropometry of workers, specifications of maintenance tools, surrounding environmental conditions and their responses such as time to complete maintenance, human energy and productivity of maintenance activity is not known to them quantitatively. Thus from these mathematical models “Intensity of interaction of inputs on deciding response” can be predicted which will help to control the variable for the desired results.

#### REFERENCES

- [1] Barnes, R.M., “Motion and Time study Design and Measurement of work John wiley & Sons,”1980.
- [2] Belkhode, P.N., “Mathematical Modelling Maintenance Activity to Minimize Overhauling Time and Human Energy Consumption”, Series C Springer Publication: 2017,1-9.
- [3] Kartalopoulos, V., “Understanding Neural Networks and Fuzzy Logic, 2014.
- [4] Marmaras, N., G. Poulakakis, and V. Papakostopoulos, “Ergonomic design in ancient Greece”, Applied Ergonomics,1999.

[5] Narkhede B. E. ,”The Implications of Manufacturing Strategy Practices on Manufacturing and Business Performance”, Industrial Engineering Journal, Vol. 7 (3), 2014.

[6] Kulkarni SD, Dhake RJ, Raut RD, Narkhede BE, “Achieving Operational Excellence through Integrated Approach of Lean Manufacturing and TPM Methodology in Mechanical Cluster Line: A Case Study”, International Journal of Global Business and Competitiveness, Vol .9 (1), 2014, 15-31

[7] Mittal, A., Nicholson, and M. M. Ayoub..”A guide to Manual Material Handling”, 2<sup>nd</sup> Edition: Taylor and Francis,1997.

[8] Rao, S.S., “Optimization Theory and Application, 1994

[9] Schenck, H, “Theories of Engineering Experimentation”, 1961.

[10] Belkhode P. N. and Vidyasagar V., “Mathematical Model for Face Drilling in underground mining operation”, IJERST International Journal of Engineering Research and Science Technology, 3(2), 2014.

[11] Belkhode P.N., Borkar K., “Optimization of Models of Liner Piston Maintenance Activity Of Loco Shed”, International Journal of Applied Engineering and Technology Vol. 6 (1), 2016.

#### AUTHORS

**Dr. Pramod N Belkhode**, Assistant Professor, Department of General Engineering, Laxminarayan Institute of Technology, Amravati Road, Ram Nagar, Nagpur – 440 033 (Maharashtra), India  
Email: pramodb@rediffmail.com

**Dr. Kanchan V Borkar**, Assistant Engineer, Military Engineering Services, (MES), Vayusena, AFI Building, Katol Road, Nehru Marg, Sadar, Nagpur – 440 013 (Maharashtra), India  
Email: kanchan.borkar@rediffmail.com

**Dr. Manish S Giripunje**, Assistant Professor, Priyadarshini College of Engineering, (PCE), No.2, Hingna Road, Hingna Naka, Hingna, Nagpur – 440 016 (Maharashtra), India  
Email: manishgiripunje@gmail.com