Formation of Mathematical Model for Heijunka To Improve the Process Effectiveness Measure

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1. ABSTRACT

In situations where the customer defines the delivery sequence, however, scheduling production to maximize utilization becomes more challenging. Production leveling is widely used by many industries now days, so as to improve their productivity and delivery compliance. This paper highlights the Japanese methodology 'Heijunka' for leveled production planning. It also provides an example of actual application and generation of a leveling pattern. In Indian scenario, where the majority of medium and low volume production is still unorganized which needs to be focused and develop a mathematical relation which simulates the real input and output data directly from the machining field where the work is actually being executed. Experiments were conducted on three machines for the duration of three months and equations were formed so as to optimize the production and overall equipment efficiency in the terms of quantity produced, operator used and time loss. 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.

Keywords: Production leveling, Heijunka, Overall equipment efficiency, production efficiency, productivity, delivery compliance, field database mathematical simulation.

2. INTRODUCTION

Product demand will always vary with the newly emerging market situations. [1] A typical large manufacturing business engaging in production planning will aim to maximize profit while maintaining a satisfied consumer base. Five years ago all the people in manufacturing only talked about production but today they realize that it is much beyond production-even shop floor is not only about production it is about aligning yourself with the global changes, it is aligning yourself with your supplier and your customer and it is aligning your manufacturing practices to your upstream and downstream partners.[2] Production leveling also referred to as production smoothing or Heijunka[11]. It aims at balancing production volume as well as production mix and enhancing production efficiency by means of reducing waste, unevenness, and overburden of people or equipment [6,14]. When using standard methods, leveling is only implementable in repetitive production environments with limited product diversity, i.e. large scale production [20].

VSME (Visionary Small and Medium Enterprises**)** program was launched with assistance from the Government of Japan through Japan International Co-operation Agency (JICA)[15]. As a part of this association two Japanese Scientist Prof. Shoji Shiba[16] and Prof. Furuhashi[17] were sent to India to introduce VSME to industries. VSME is a program to improve all aspects of manufacturing. This program is yielding breakthrough results in shop floor and manufacturing practices. The biggest change is being brought about in the mind sets of senior managers. The program is focused on creating a win-win relationship between the tiers. There are 8 modules in VSME program. One of the module is Heijunka.[2]

HEIJUNKA is a Japanese technique of achieving **Even Output Flow** by coordinated sequencing of very small production batches throughout the manufacturing line. Leveling the production in manufacturing industry is the need of the hour. Production systems must always balance inventory, capacity utilization and system variability.

The figures below briefly explain the concept of Heijunka.[19]

Consider A's, B's and C's are to be manufactured, small batch quantity for A, medium batch quantity for B and large batch quantity for C.

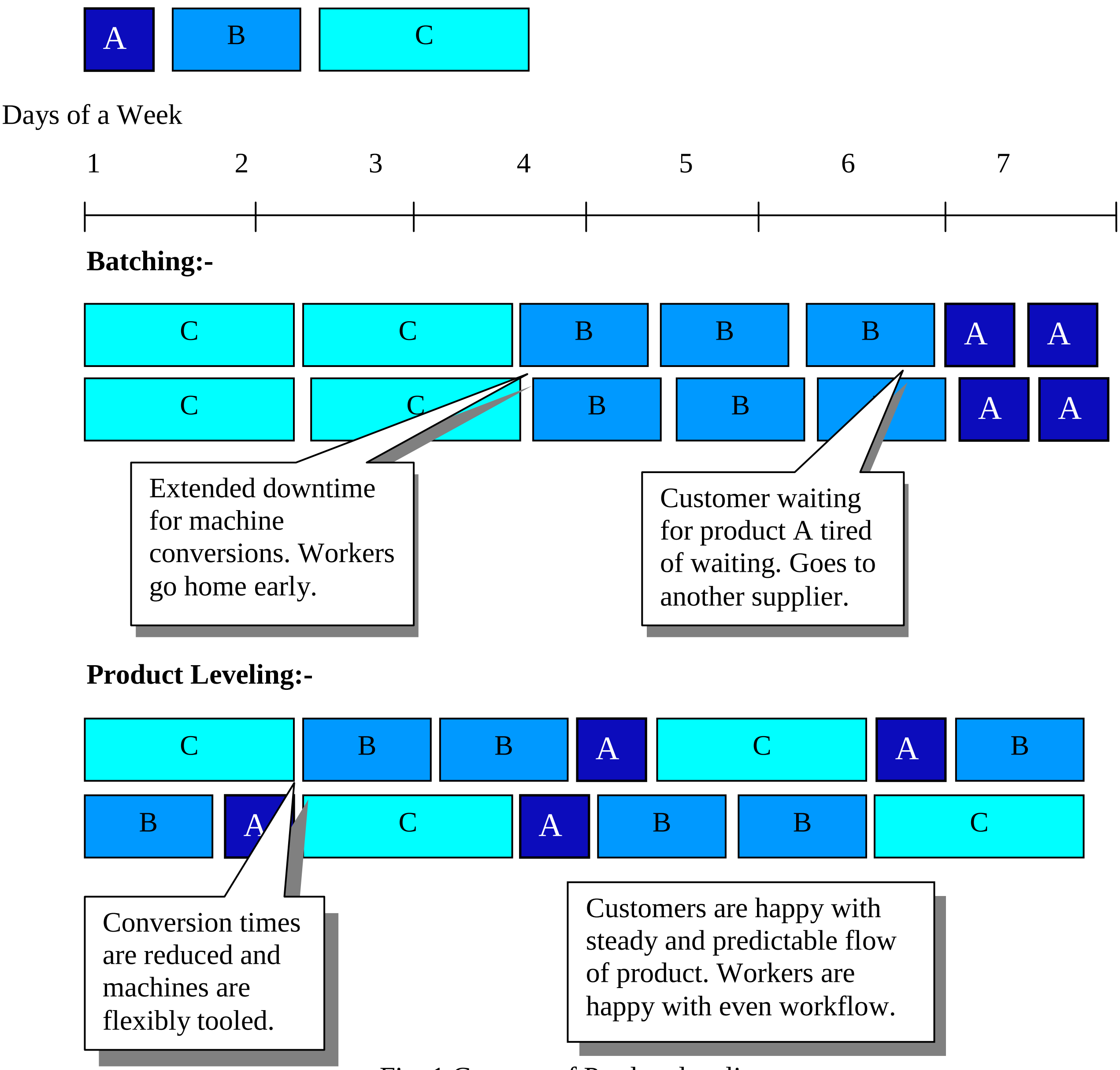

Fig. 1 Concept of Product leveling

The objective of Heijunka is to avoid peaks and valleys in the production schedule. It calls for distributing the jobs requiring more labor input throughout the production schedule to permit higher average utilization assuming that the cycle time is held constant overtime. Heijunka was created primarily to address the issues of manufacturing and how to handle the shift in demand by sheltering the production line from the fluctuations becomes a reality with this unique concept. Constant output without having any unwanted delay is the ultimate goal of Heijunka. Thus, Heijunka is an advance technique that will help a company to achieve its goals that are based on the demand pattern for a specific product. It will also ensure proper and schedules utilization of resources making the company profitable and the end customers happy.[1]
The flowchart below gives the idea about steps in Heijunka planning.

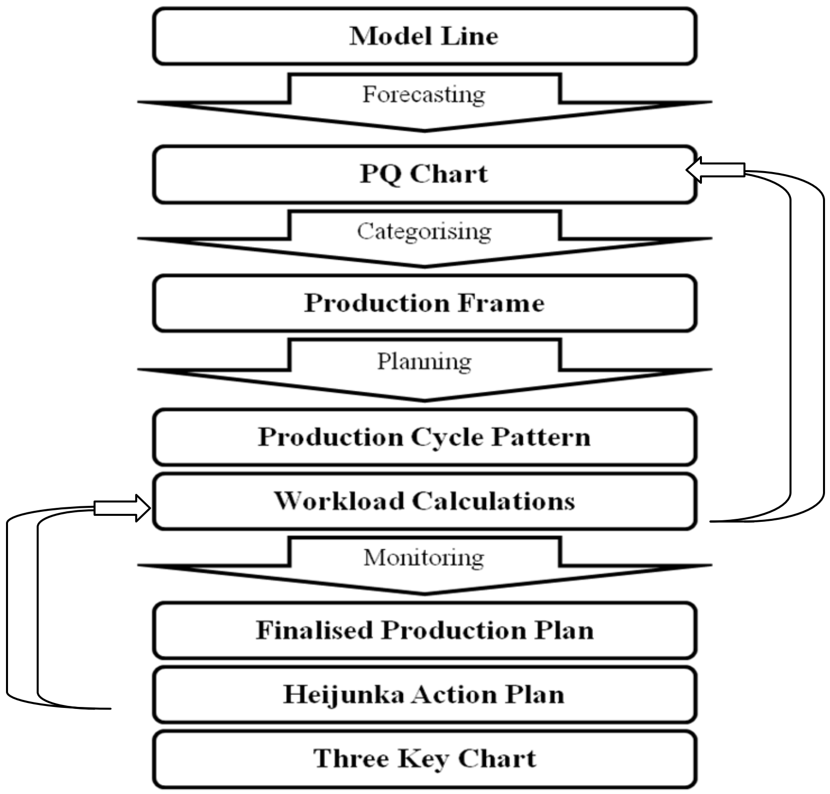

Fig. 2 Heijunka Flowchart

2.1 FORMULATION OF MATHEMATICAL MODEL FOR HEIJUNKA:

Mathematical model represents the essential aspects of an existing system which presents knowledge of that system in usable form [23]. Model updating is time consuming task, so it is important to rigorously evaluate the quality of the model with respect to its end use the decision which rely upon the module. Mathematical modeling of complex system assist the analyst in making decisions for design, control, structural interfacing, **reliability** and safety analysis and so on.[5] It is used to analyze a system that is to be controlled, in analysis a descriptive model of the system as a hypothesis of how the system could work, or try to estimate how an unforeseeable event could affect the system was built.[4]. In this paper, process effectiveness is measured by using Heijunka tool. OEE, HP & MP are the focused indicators of the Heijunka tool which are being formulated.

3. EXPERIMENTAL DETAILS:

Fig. 3 VMC and Lathe machines under experimentation

Initially this study was carried for the components operating on three machines VMC1, VMC2 and LATHE. For each component among the various processes carried out on that particular machine the process requiring maximum cycle time (bottle neck time) was considered. By using the bottle neck time and the number of components produced per day on that machine processing time was calculated. Available time for processing was calculated excluding the scheduled losses. The difference between the available time and processing time was calculated to give the losses on each machine.

Table1: Details of components

Components	Machine used	Cycle time(min)
Bearing cap	VMC1	1
	VMC2	3
	Lathe	0.25
Bonnet100NB	VMC1	1.5
	VMC2	15
	Lathe	4
Bonnet80NB	VMC1	5
Axel stop	VMC1	4.5
	Lathe	15
Adapter plate	VMC1	4.5
	VMC2	4

3.1 Work Load Calculations:

Table 2: Workload Calculation

Part Name	**CT**	**1 Jan**	**2 Jan**	**3 Jan**	**4 Jan**	**5 Jan**	**6 Jan**
Bearing Cap	1min	584	Nil	Nil	376	Nil	Nil
Axle Stop	4.5min	Nil	77	109	25	110	80
Bonnet 100NB	1.5min	23	23	6	Nil	Nil	Nil
Bonnet 80NB	5min	Nil	Nil	Nil	Nil	Nil	27
Daily Production Qty.		607	100	115	401	110	107
Actual Rejection		2	3	1	1	10	20
Daily Planned Qty.		440	440	440	440	440	440
Heijunka Qty Adh score		1	1	1	1	1	1
Heijunka Sequence Adh Score		1	2	2	1	1	2
Total Processing time (2)		618.5	381	499.5	488.5	495	495
Actual Total Set up Time(min) (3)		60	90	90	30	30	60
Actual Unscheduled Losses (4)		642	849	731	802	795	765
Regular Operating (min) (5)		1320	1320	1320	1320	1320	1320
Actual OEE (2/5)		47%	29%	38%	37%	38%	38%
Human Productivity (Qty/Man-Hrs)		13.795	2.272	2.613	9.113	2.5	2.431
M/c Productivity (Qty/Mc-hrs)		27.59	4.545	5.227	18.22	5	4.863
Breakdown Loss(min)		600	30	30	51	95	63
External Mat. Shortage		14	800	700	750	700	700

The work load plan gives the visibility of work load against regular working hours. The sheet reveals the components, their cycle time & quantity produced for the whole month and operating time. Also it lays down the calculations regarding OEE (Overall Equipment efficiency) which provides us the efficiency of each machine working for specific period of time. Also Human productivity and Machine productivity are calculated. The following table indicates the work load calculations on VMC1 for the month of January (contents indicate only for a week). Similar tables and calculations are made for VMC2 and LATHE. This table reveals that in the month of January the production level was much unorganized and there were immense losses. So there was a need for highly organized production which was later done by adopting **HEIJUNKA TOOL.**

4. EXPERIMENTAL APPROCH

A theoretical approach can be adopted in a case. If known logic can be applied correlating the various dependent and independent parameters of the system. Though qualitatively, the relationships between the dependent and independent parameters are known, based on the available literature, the generalized quantitative relationships are not known sometimes. Hence formulating the quantitative relationship based on the logic is not possible in the case of complex phenomenon. Because of no possibility of formulation of theoretical model (logic based), one is left with the Only alternative of formulating experimental data based model. Hence, it is proposed to formulate such a model in the present investigation.

4.1 FORMULATION OF MATHEMATICAL MODELLING:

The process variables selected are dimensionless quantities. It is necessary to correlate quantitatively various independent and dependent terms involved in this very complex phenomenon. This correlation is nothing but a mathematical model as a design tool for such situation.

Table 3: Independent variables

Parameters selected	Notations used	Formulae
Quantity produced	X1	
Operator Ratio	X2	= (Age/Expirence)*Skill Rating
Loss Time Ratio	X3	=Time Loss/Operating (in min)

Table 4: Dependent variables

Parameters selected	Notations used	Formulae
Overall Equipment Efficiency (OEE)	Y1	= Processing time/Operating time
Human Productivity (HP)	Y2	= Qty produced/(Man*Hrs)
Machine Productivity (MP)	Y3	= Qty produced/(Machine*Hrs)

Table5: Experimentation

	Input parameters			**Output parameters**			**Calculated Values**		
Experiment No.	X1-Quantity produced	X2-Operator ratio	X-3 Loss time Ratio	Y1-OEE (%)	Y2-HP	Y3-MP	Y1CAL	Y2CAL	Y3CAL
1	96	9.6667	0.5931	36.13	2.1818	4.3636	27.9734	3.8819	7.2590
2	92	9.6667	0.6636	31.36	2.0909	4.1818	26.3592	3.7374	6.9705
3	240	6.4	1	30	8.9999	17.9999	37.8491	7.1943	14.4796
4	283	6.4	0.3562	56.87	10.612	21.2249	58.6178	8.9872	18.2061
5	240	10.0767	0.1	90	8.9999	17.9999	80.3171	7.9610	15.8350
6	245	10.0767	0.081	91.87	9.1874	18.3749	87.1774	8.2676	16.4499

As in this study the output parameters are the functions of the input parameters such that each input is related exactly to one output.

$$y=f(x)$$

General form can be defined as

$$y=f(x1, x2, x3)$$

With the help of mathematical modeling, it can be understood how typical value of dependent variable changes when any one of the independent variables is varied. For estimating the relationships among the variables a statistical, best known and the most powerful technique for achieving our goal is **Regression Analysis**[7].

$$X = \begin{pmatrix} n & \sum x1 & \sum x2 & \sum x3 \\ \sum x1 & \sum x1*x1 & \sum x1*x2 & \sum x1*x3 \\ \sum x2 & \sum x1*x2 & \sum x2*x2 & \sum x2*x3 \\ \sum x3 & \sum x1*x3 & \sum x2*x3 & \sum x3*x3 \end{pmatrix}$$

$$Y = inv\ (X)$$

$$Z = \begin{pmatrix} \sum z \\ \sum x1*z \\ \sum x2*z \\ \sum x3*z \end{pmatrix}$$

K = Y*Z

$$K = \begin{pmatrix} \text{Log k} \\ a \\ b \\ c \end{pmatrix}$$

$$\mathbf{Y = f(x) = K * X1^{(a)} * X2^{(b)} * X3^{(c)}} \qquad (1)$$

This equation gives the relation between input and output values. It is the General Solution used to evaluate calculated values for the output variables .The calculated output values were evaluated in the terms of considered input parameters. The values of exponents a, b, c are established independently at the time, on the basis of data collected through experimentation. There are four unknown terms in the equation (1) curve fitting constant k and indices a, b, c. To get the values of these unknowns a set of three dimensionless parameters was used.

In the above set of equations the values of the indices k, a, b and c are substituted to compute the set of equations. After substituting these values in the equations (1) one will get a set of three equations. The above equations can be verified in the matrix form and further values of K, a, b, c can be obtained by using matrix analysis.

Solving these equations using 'MATLAB' we get,

1. For the first output(OEE)
   Log k = -0.2124
   a = -0.0466
   b = -0.1451
   c = -0.3893

2. For the second output(HP)
   Log k = -0.8561
   a = 0.0285
   b = -0.4625
   c = -0.1691

3. For the third output (MP)
   Log k = -0.7468
   a = 0.1080
   b = -0.4560
   c = -0.1627

Hence the final Model is

1. Overall Equipment Efficiency

$$\mathbf{Y = f(x) = 0.6131 * X1^{(-0.0466)} * X2^{(-0.1451)} * X3^{(-0.3893)}}$$

Correlation: 0.709972
Reliability: 85.76419%

2. Human Productivity

$$Y = f(x) = 10^{(-0.8561)} * X1^{(0.0285)} * X2^{(-0.4625)} * X3^{(-0.1691)}$$

Correlation: 0.50446905
Reliability: 97.74266%

3. Machine Productivity

$$Y = f(x) = 10^{(-0.7468)} * X1^{(0.1080)} * X2^{(-0.4560)} * X3^{(-0.1627)}$$

Correlation: 0.585372
Reliability: 95.7767%

5. RESULT

5.1 MODEL SENSITIVITY ANALYSIS

Table 6: Sensitivity analysis and Indices of model:

	Indices of model for Y1	Indices of model for Y2	Indices of model for Y3
X1	-0.0466	0.0285	0.108
X2	-0.1451	-0.04625	-0.456
X3	-0.3893	-0.01691	-0.1627

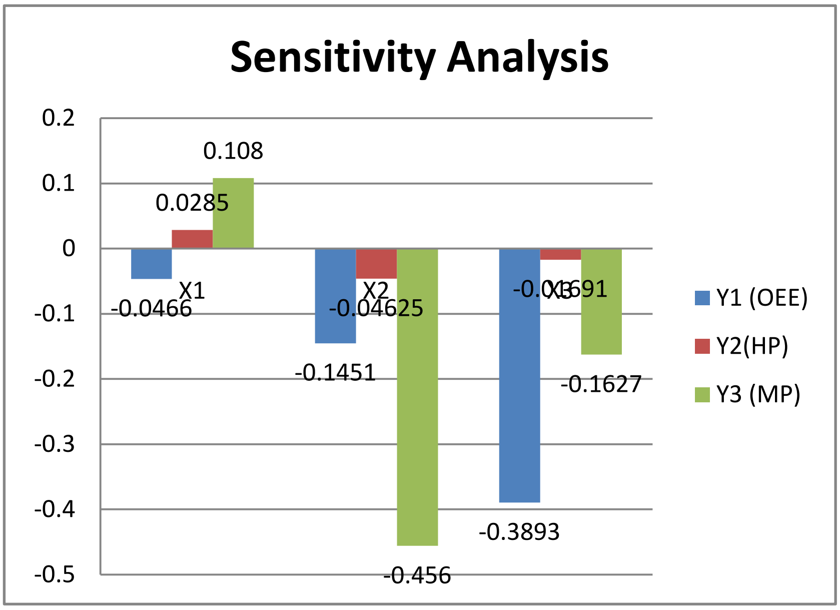

Fig:4 Graph for sensitivity

The influence of the various independent terms has been studied by analyzing the indices of the various output terms in the models. Through the technique of sensitivity analysis, the change in the value of a dependent term caused due to an introduced change in the value of

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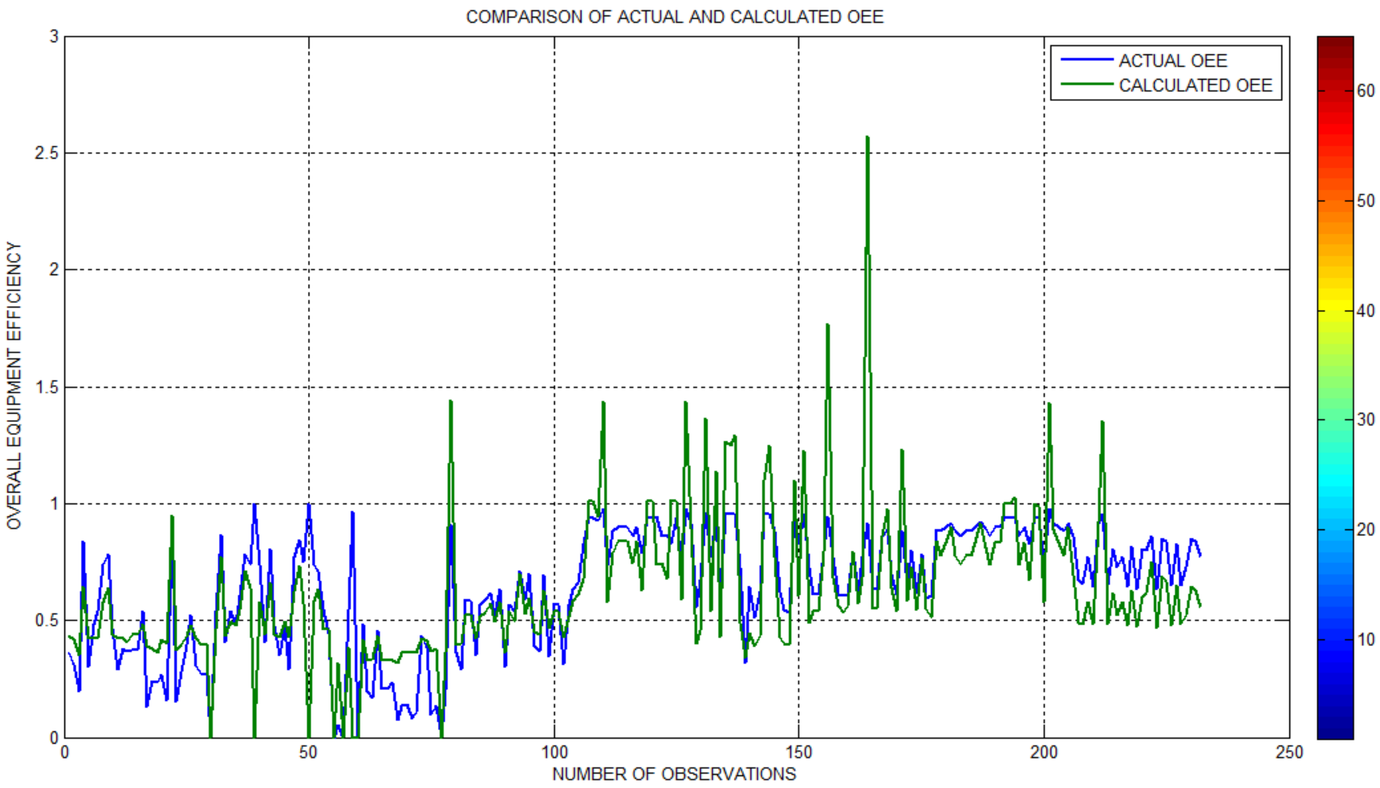
individual term is evaluated. The effect of this introduced change on the change in the value of the dependent term is evaluated.

5.2 VALIDATION OF FORMULATED FIELD DATA BASE MODEL

The validity of the formulated model can be checked by comparing the actual experimental values of th input parameters and the simulated value obtained from the formulated mathematical model. The graphs below show the variation of the actual and the simulated result. The errors may occur due to error in measurements.

Graph 1: Overall Equipment Efficiency V/s Number Of Observations

Fig. 5



The initial stage of the graph depicts the OEE of the month January from which we can see that the OEE is not only less but also highly fluctuating. In the succeeding months with the application of Heijunka, the OEE is increased and also the fluctuations & errors are reduced to a considerable extent.

Graph 2: Human Productivity Vs Number of Observation

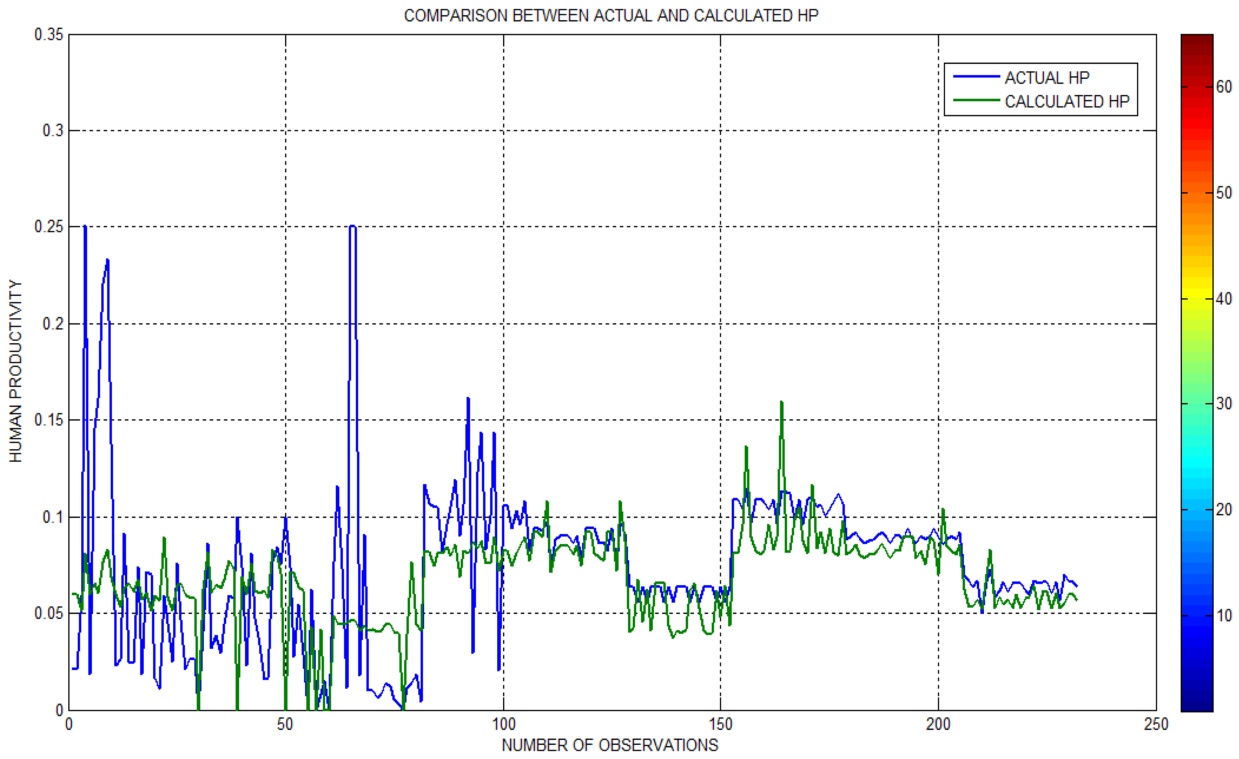


Fig. 6

Graph 3: Machine Productivity Vs Number of Observations

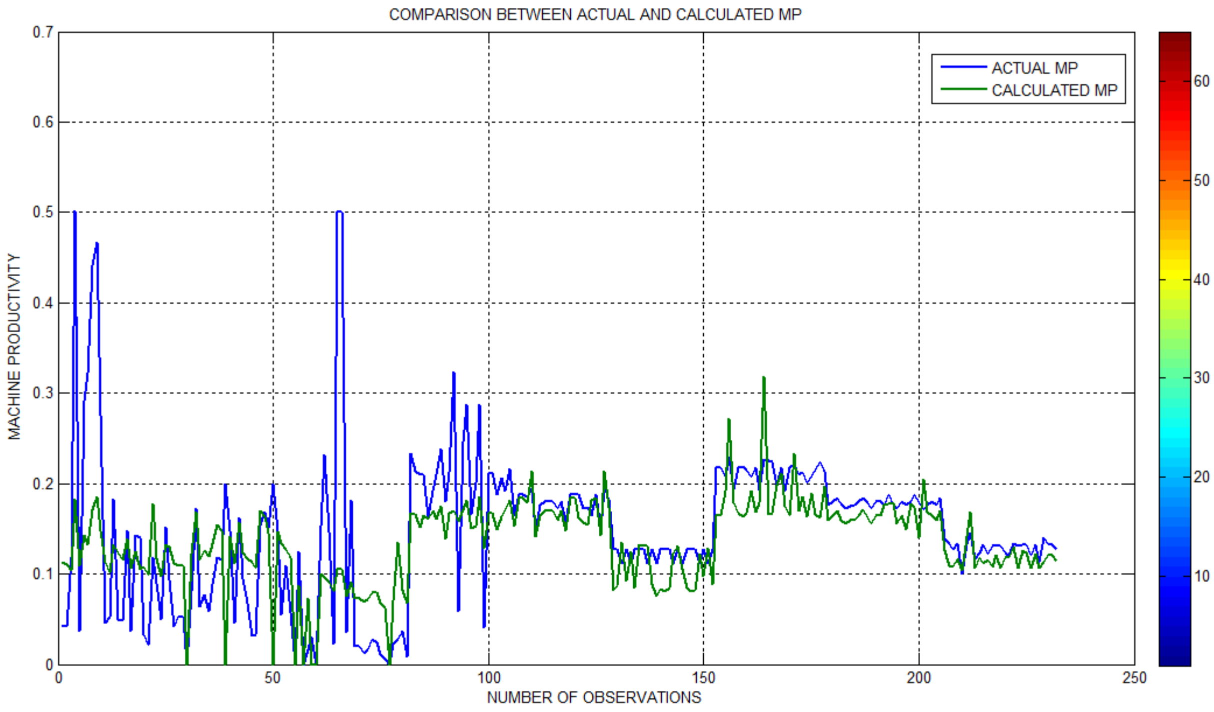


Fig. 7

The initial stage of the above two graphs (shown in fig.6 & fig.7) depicts the Human Productivity (HP) & Machine Productivity (MP) of the month January from which we can see that the MP & HP are not only less but also highly fluctuating. In the succeeding months with the application of Heijunka, the both of them are increased and also the fluctuations & errors are reduced to a considerable extent.

6. CONCLUSION:

In this study, a generalized field data based model was developed to simulate the application of Heijunka tool for the leveled production planning. The approach of generalized & formulation model provided an excellent and simple way to analyze the engineering complex process where the impact of field data is dominating the performance.

The following primary conclusions appear to be justified from the above model

Model 1: Overall Equipment Efficiency Model

- The absolute index of X1 is the highest viz.-0.0466. Thus in X1, the terms are related to quantity produced which is the most influencing factor in this phenomenon. The value of this index is negative indicating Y1 (OEE) is inversely varying with respect to X1.
- The index of X3 is lowest viz. -0.3893, hence X3 related to time loss parameter is the least influencing term in the model.
- The sequence of influence of the other independent input terms is X1, X2, X3 having absolute indices (-0.0466,-0.1451,-0.3893) respectively. The indices are negative indicating that input parameters are inversely proportional to Y1 i.e. OEE.

Model 2: Human Productivity Model

- The absolute index of X1 is the highest viz.0.0285. Thus in X1, the terms are related to quantity produced which is the most influencing factor in this phenomenon. The value of this index is positive indicating Y2 (HP) is directly varying with respect to X1.
- The index of X2 is lowest viz. -0.4625, hence X2 related to operator ratio is the least influencing term in the model.
- The sequence of influence of the other independent input terms is X1, X3, X2 having absolute indices (0.0285,-0.1691,-0.4625) respectively. The indices X2 and X3 are negative indicating that these parameters are inversely proportional to Y2 i.e. HP.

Model 3: Machine Productivity Model

- The absolute index of X1 is the highest viz.0.1080. Thus in X1, the terms are related to quantity produced which is the most influencing factor in this phenomenon. The value of this index is positive indicating Y3 (MP) is directly varying with respect to X1.
- The index of X2 is lowest viz. -0.4560, hence X2 related to operator ratio is the least influencing term in the model.
- The sequence of influence of the other independent input terms is X1, X3, X2 having absolute indices (0.1080, -0.1627, -0.4560) respectively. The indices of X2 and X3 are negative indicating that these input parameters are inversely proportional to Y3 i.e. MP.

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