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Evaluation of Overall Equipment Effectiveness (OEE), its Optimization and analysis through Design of Experiment (DOE)

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Abstract- *For any industry, continuous availability of the equipment is needed, to stay in the competitive market. Overall Equipment Effectiveness (OEE) is an important performance measure which indicates the current status of production with least calculation to measure the losses and corrective actions to be taken to reduce it. An attempt has been done to evaluate and analyse the existing overall equipment effectiveness of the critical machinesof company producingginning machine parts. Grading system is of scale of five points which is used to identify the critical machine. Overall Equipment Effectiveness of the identified critical machines is evaluated to get the reference value for design of experiment. By using MiniTab16 software experimentationis performed on three factors and two levels of OEE. Main effect plots provide the information regarding the most influencing factor for OEE and regression analysis gives the classic relationship among availability, performance rate, quality rate and overall equipment effectiveness (OEE). Significance of each factor is indicated by P-value in the given analysis. Finally contour plot and surface plot results into optimized values of the three factors of OEE. This simulated value of OEE would be the useful information to the industry.*

Keywords *– Overall Equipment Effectiveness (OEE), Design of Experiment (DOE), MiniTab16, Regression analysis, Response surface optimization.*

I. INTRODUCTION

Efficiency and effectiveness are playing vital role for any organization to stay in the competitive environment. Higher the value of efficiency and effectiveness, higher will be the productivity of the organization. Overall Equipment Effectiveness (OEE) is such a key performance indicator, which shows current status of the production with least calculations. It also aids to determine the losses and corrective actions can be taken to reduce it. Overall equipment effectiveness is a measure of total equipment performance – the degree to which the asset is doing what it is supposed to do. OEE is also a three part analysis tool for equipment performance based on actual availability, performance efficiency and quality of the product or output.

Overall equipment effectiveness is the product of three important parameters viz. availability, performance rate and quality rate. For higher productivity, the machine tool which is converting the raw material into finished product should be reliable. Reliability includes availability of machine with least downtime. If the mean time between failure (MTBF) is more, it indicates that the machine is available for its desired performance. Attempt must be made to reduce mean time to repair (MTTR) and improve MTBF. It involves failure data analysis and root cause analysis. The failure data collected will help us to calculate availability (A) of the equipment.

The data collected of the Ideal cycle time and actual cycle time with the set up and adjustments, results into performance rate (P). Quality rate (Q) can be obtained by subtracting the defective components from the total components produced. Product of availability, performance rate and quality rate will result into machine Overall Equipment Effectiveness (OEE). Therefore,

$$OEE = A \times P \times Q$$

Where A = Availability,
P = Performance rate and
Q = Quality rate

$$\text{Availability (A)} = \frac{\text{Operating time}}{\text{Planned operating time}}$$

$$\text{Performance rate (P)} = \frac{\text{Ideal cycle time}}{\text{Actual cycle time}}$$

$$\text{Quality rate (Q)} = \frac{\text{Good products produced}}{\text{Total products produced}}$$

Overall equipment effectiveness is used to identify a single asset (machine or equipment) and or single stream process related losses for the purpose of improving total asset performance and reliability. It is also a measure of machine capability which indicates where the scope of improvement is. Statistical data collected from manufacturing plant results into useful information for improvement area.

Nakajima (1998) introduces OEE in Total Productive Maintenance. Researchers have noted that this definition varies with different process. A.J. de Ron and J.E. Roda modified OEE by introducing operational efficiency (OE) and rate efficiency (RE) in performance rate. Tom Pomorski defines OEE in terms consistent with SEMI E-10-96. OEE as one element of which measures the performance of the equipment, but can OEE measures the performance of the entire

manufacturing process. The productivity metric standard proposal defines variations of OEE as production OEE, demand OEE, simple OEE and cluster tool OEE. P.Muchiri and L. Pintelon evolve OEE as a tool to track improvement and enlarge this tool with different technologies. Such as at equipment level – production equipment effectiveness (PEE) and total equipment effectiveness performance (TEEP) at factory level, overall factory effectiveness (OFE) and overall plant effectiveness (OPE).

It is observed that various parameters of OEE, contributes to overall OEE in a different manner, has significant effect on improving the performance. Use of Design of Experiment (DOE) is explored in this paper. Obtained values are used as an input to simulation model. Observed values are plotted in the form of counter plots. Response surface method is used to determine optimized value.

II. METHODOLOGY USED

Review of literature related to overall equipment effectiveness indicates the strong need of performance measurement system. It shows reduction in down time losses, speed losses for performance improvement. Grading system is used for grading the various machines of the plant on the scale of five points to get the critical machines of the study industry. For identified critical machines Overall Equipment Effectiveness are evaluated. For the critical machine having the least value of Overall Equipment Effectiveness, optimization is done using DOE (Design of Experiments). Finally recommendations are provided to improve the Overall Equipment Effectiveness.

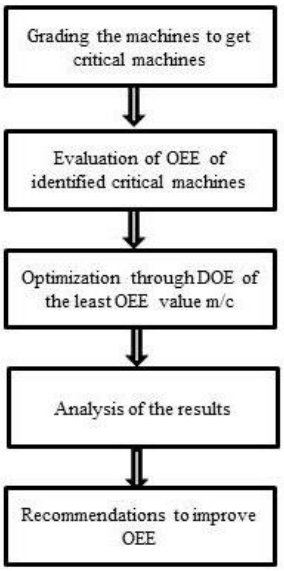


Fig. 1 Methodology used

2.1 Grading of machines

Study plant has sixty number of various machine, production manager of the plant is asked to grade the machines on the scale of five points considering failure, quality, age factor, cycle time, safety and set-up time, to get the critical machines. Following table 1 shows number of machines in different categories found in the study company.

After grading eight machines are found to be critical machines, table 2 shows the eight machines found critical in the study company.

Table 1: Categories of Machines

S.No.	Type	Points	Number of machines
1	Critical Machines	24 and above	8
2	Rank 2 Machines	21-23	9
3	Rank 3 Machines	18-20	25
4	Rank 4 Machines	15-17	10
5	Rank 5 machines	Below 14	8

Table 2: Critical Machines

S.No.	Machines	Failure	Quality	Age	Cycle Time	Safety	Set-up Time	Total
1	PM-1	4	4	4	5	4	5	26
2	PMM-1	5	4	3	5	3	5	25
3	PMM-3	5	4	5	4	4	5	27
4	MM-2	4	4	5	5	4	5	27
5	MM-3	5	4	3	4	5	4	25
6	HM	4	5	3	4	5	3	24
7	RDM-1	5	4	3	4	4	5	25
8	RMD-2	5	4	4	5	4	5	27

2.2 Data collection:

The study company manages production sheet every day which consists of number of information like department name, date, machine number, shift, worker name, helper name, operation number, problem statement, machine down time, setup time, and cycle time. These data are entered after end of every shift. This is the only reliable data for calculating Overall Equipment Effectiveness (OEE). Data of thirty days have been taken. Company is having the shift length of 540 minutes, out of which two short breaks of 15 minutes and one meal break of 60 minutes are provided. So Planned production time for one day is 450 minutes and for thirty days it is 13500 minutes which is same for all machines. Table 3, table 4, table 5 and table 6give the information about availability, performance rate, quality rate and OEE of identified critical machines respectively.

Table 3: AvailabilityCalculations

Machine	Planned Production time(min)	Down Time (min)	Operating Time (min)	Availability (%)
PM-1	13500	270	13230	98.00
PMM-1	13500	990	12510	92.67
PMM-3	13500	960	12540	92.89
MM-2	13500	1440	12060	89.33
MM-3	13500	1560	11940	88.44
HM	13500	300	13200	97.78
RDM-1	13500	630	12870	95.33
RDM-2	13500	720	12780	94.67

Table 4: Performance Rate Calculations

Machine	Ideal cycle Time (min)	Actual Cycle Time (min)	Performance Rate (%)
PM-1	30	36.05	83.22
PMM-1	12.5	15	83.33
PMM-3	21	25.03	83.89
MM-2	3.5	4.5	77.78
MM-3	7	8.49	82.37
HM	1.4	1.81	77.43
RDM-1	17.3	20.76	83.34
RDM-2	8.8	10.58	83.11

Table 5: Quality Rate Calculations

Machine	Total Products produced	Good Products	Quality Rate (%)
PM-1	367	356	97.00
PMM-1	834	803	96.28
PMM-3	501	489	97.60
MM-2	2680	2619	97.72
MM-3	1405	1345	95.72
HM	7300	7154	98.00
RDM-1	620	605	97.58
RDM-2	1207	1165	96.52

Table 6: OEE Calculations

Machine	Availability (%)	Performance Quality (%)	Quality Rate (%)	OEE (%)
PM-1	98.00	83.22	97.00	79.11
PMM-1	92.67	83.33	96.28	74.35
PMM-3	92.89	83.89	97.60	76.06
MM-2	89.33	77.78	97.72	67.90
MM-3	88.44	82.37	95.72	69.74
HM	97.78	77.43	98.00	74.18
RDM-1	95.33	83.34	97.58	77.52
RDM-2	94.67	83.11	96.52	75.94

III. DESIGN OF EXPERIMENT (DOE)

It is a systematic approach to analyse any process by changing some of the input variable purposefully to determine its effect on the output of the process. The objective in many cases may be to develop a robust process, that is, a process affected minimally by external source of variability.

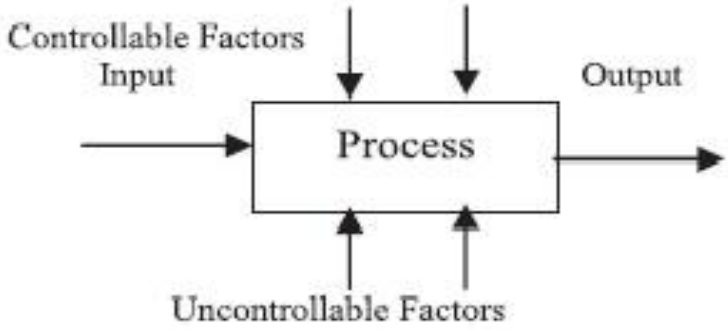


Figure 2: General Model of process or system

Overall Equipment Effectiveness (OEE) system or process is studied under this model as in figure 2. Input variables are mean time between failure (MTBF) and mean time to repair (MTTR), setup and adjustment for Availability (A), actual cycle time, ideal cycle time, small stops, reduced speed for Performance Rate (P) and start-up rejects, production rejects for Quality Rate (Q). Output of the process is OEE. Uncontrolled factor in this process are ideal cycle time, unscheduled breakdown and operator.

From above data collection and calculation for availability, performance rate, quality rate and Overall Equipment Effectiveness (OEE), MM-2 (Milling Machine-2) is found to be low performing machine with availability 89.33%, performance rate 77.78%, quality rate 97.72 and OEE 67.90.

Design of Experiment is used to analyse, which factor of MM-2 (Milling Machine-2) affects output significantly and at what rate. Three variables Availability (A), Performance Rate (P) and Quality Rate (Q) are taken with variation of two levels. Reference values are Availability 89% and 94%, Performance rate 77% and 82%, Quality rate 97% and 99%.

A full factorial design has following details by using MiniTab16 software. Experiment has designed for three factors and two levels.

Factors: 3 Base Design: 3, 8
Runs: 8 Replicates: 1
Blocks: 1 Center Point (total): 0

Table 7: Experimental Setup for OEE

Availability (%)	Performance Rate (%)	Quality Rate (%)	OEE (%)
89	82	99	72.2502
89	77	97	66.4741
94	82	99	76.3092
94	77	99	71.6562
94	82	97	74.7676
94	77	97	70.2086
89	77	99	67.8447
89	82	97	70.7906

Table 7: Estimated Effects and Coefficients for OEE (coded units)

Term	Effect	Coef
Constant		71.2876
A	3.8955	1.9477
P	4.4835	2.2417
Q	1.4549	0.7274
A*P	0.1225	0.0613
A*Q	0.0397	0.0199
P*Q	0.0458	0.0229
A*P*Q	0.0012	0.0006

Table 8: Analysis of Variance for OEE (coded units)

Source	DF	SeqSS	AdjSS	AdjMS
Main Effects	3	74.7866	74.7866	24.9289
2-Way Interaction	3	0.0374	0.0374	0.0125
3-Way Interaction	1	0.0000	0.0000	0.0000
Residual Error	0	*	*	*
Total	7	74.8239		

Table 9: Estimated Coefficient for OEE using data in uncoded units

Term	Coef
Constant	4.20783E-11
A	-3.73257E-13
P	-5.80772E-13
Q	-4.09702E-13
A*P	5.24568E-15
A*Q	3.61121E-15
P*Q	5.67981E-15
A*P*Q	0.000100000

IV. Regression Analysis: OEE versus A, P, Q

The regression equation is

OEE = -143 + 0.779A + 0.897 P + 0.727 Q

Table 10: Variables and its Significance value (P)

Predictor	Coef	SE Coef	T	P
Constant	-142.575	3.736	-38.16	0.000
A	0.77910	0.01367	57.00	0.000
P	0.89670	0.01367	65.61	0.000
Q	0.72743	0.03417	21.29	0.000

S = 0.0966461 R-Sq = 100.0% R-Sq (adj) = 99.9%

Table 11: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	74.787	24.929	2668.91	0.000
Residual Error	4	0.037	0.009		
Total	7	74.824			

Table 12: Ranking most Significant factor with SeqSS as P

Source	DF	SeqSS
A	1	30.350
P	1	40.204
Q	1	4.233

Figure 3: Contour Plot of OEE vs P, A

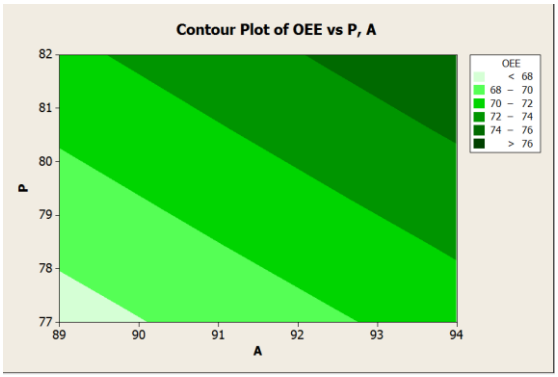
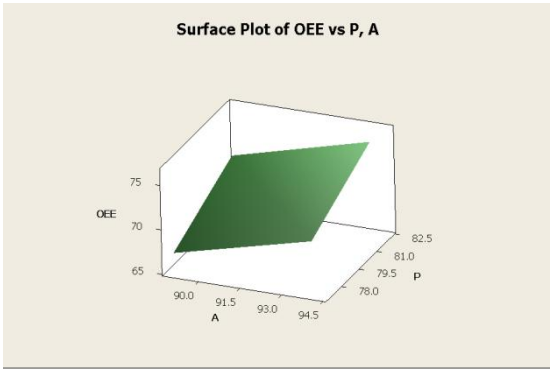


Figure 4: Surface Plot of OEE vs P, A



MiniTab16 is uded to plot a contour and surface plot of experimental values. Variation of OEE with respect to availability and performance rate can be observed in the surface plot.

V. CONCLUSION

As Overall Equipment Effectiveness (OEE) is a important KPI (Key Performance Indicator), which provides the performance measure with least calculations for effectiveness of any equipment, thorough analysis is required to know the effect of various components. Regression analysis gives the classic eqution of OEE with availability, performance rate and quality rate as predictor and OEE as response. In this study an an attempt has been done to predict the OEE by using Design Of Experiment (DOE). This study indicates that OEE will be significantly improved if focus is given on performance rate improvement. To achieve OEE of 76.31%, optimized values are Availability 94%, Performance Rate 82%, and Quality Rate 99%. Simulated values of the above scenario will add more valuable information to company.

VI. FUTURE RECOMMENDATIONS

a) As the study industry carries out breakdown maintenance, means whenever machine gets breakdown maintenance is performed to restore the machine to its initial operating conditions. This leads to increase in the unexpected down time. Instead of this Total Productive Maintenance is recommended, which would reduce the unexpected down time and increase the availability of machine.
b) It has been observed that, for the machine having least value of OEE, workstation is not properly designed for example bin for the storage of raw material is far away from the machine, so there is unnecessary wastage of time in material handling. So, it is recommended to keep the bin for raw material nearer to the machine which would reduce the unnecessary time involved for material handling.
c) It has been observed that, set up time is comparitively more, so it recommended to design proper jigs and fixture so that set up time can be reduce to get the improved performance rate.

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