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Procedia Engineering 38 (2012) 2973 – 2980

Procedia Engineering

www.elsevier.com/locate/procedia

ICMOC-2012

Optimizing & Analysing Overall Equipment Effectiveness (OEE) Through Design of Experiments (DOE)

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Abstract

Continuous availability of reliable sophisticated equipment with precision is need of the competitive market. Overall equipment effectiveness (OEE) is important performance measure metric for equipment effectiveness. An attempt has been done to measure and analyze existing overall equipment effectiveness of critical machinery producing important automobile components like serration cap, Dowel rod and sequence rod. Which are used by leading automobile company. By measuring the performance of existing system, reference values are obtained for design of experiments. By using MiniTab15 software an experimentation has been done on three factors and two level of OEE. Main effect plots and regression analysis provides information about which is most influencing factor and classic relationship between availability, performance rate and quality rate. Significance of each factor is indicated by P- value in the given analysis. Finally counter plots and response surface method results in to optimized values of three factors of OEE. Simulated values of the output will be useful information to industry.

Keywords:- Overall equipment effectiveness (OEE), Design of Experiments (DOE), Minitab15, Regression analysis, Response surface optimization.

1. Introduction:

Efficiency and effectiveness are buzzwords words in today's competitive market. Greater the efficiency and effectiveness, more productive is the organization. Overall equipment effectiveness is such a performance measure, which indicates current status of production with least calculations. It also helps

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doi:10.1016/j.proeng.2012.06.347

to measure losses and corrective actions can be taken to reduce it. Effective utilization of Men, Machines, Material and Methods will result into higher productivity.

Overall equipment effectiveness (OEE) is a product of three important parameters, Availability (A), Performance Rate (PR) and Quality Rate (QR) .When higher productivity is expected the machine tool which are converting raw state of the product into finish goods, must be reliable. Reliability includes availability of machines with least down time. If mean time between failure (MTBF) is more, it indicates machines are available for its desired performance . Attempt must be made to reduce mean time to repair (MTTR) and improve MTBF. It requires failure data analysis and root cause analysis. The failure data collected will help us to calculate availability (A) of equipment.

The data collected of Ideal cycle time and actual cycle time with set up and adjustment, results into performance rate(QR) . Quality rate (QR) can be obtained by subtracting rejected components from total number produced. The product of above mentioned three measures, will results into machine Overall Equipment Effectiveness (OEE). [1]Thus,

$$OEE = A \times PR \times QR \tag{1}$$

$$Availability\ (A) = \frac{(Loading\ time - Down\ time)}{Loading\ time} \tag{2}$$

$$Performance\ rate = operating\ speed\ rate \times net\ operating\ rate$$

$$Performance\ rate\ (PR) = \left\{\frac{ideal\ cycle\ time}{actual\ cycle\ time}\right\} \times \left\{\frac{actual\ cycle\ time \times output}{operating\ time}\right\} \times 100 \tag{3}$$

$$Quality\ rate(QR) = \frac{(Processed\ amount\ time - defect\ \ amount\ time)}{Processed\ amount\ time} \tag{4}$$

Nomenclature

A	Availability
PR	Performance Rate
QR	Quality Rate
OEE	Over all Equipment Effectiveness

OEE is a measure of machine capability. It indicates where is scope of improvement. Statistical data collected from shop floor results into useful information for improvement area.

Nakajima (1988) introduces OEE in Total Productive Maintenance. Researchers have noted that this definition varies with different processes. A.J. de Ron and J.E. Roda modified OEE by introducing operational efficiency (OE) and rate efficiency (RE) in performance rate.[2] Tom Pomorski[8] of semiconductor industry, USA defines OEE in terms consistent with SEMI E-10-96. OEE as one element of which measures the performance of 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[3] evolve OEE as tool to track improvement and enlarge this tool with different terminologies. 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).[2][3]

It is observed that various parameters of OEE, contribute 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.

2. Methodology Used:

Literature review in the field of overall equipment effectiveness shows that there is strong need of performance measurement system. It indicates to reduce down time losses, speed losses for performance improvement.

A survey of 50 automobile ancillary companies has been conducted. It has been observed that there is no or little idea to maintenance crew about mean time to failure (MTTF) and mean time to repair (MTTR). These are most important parameters for availability of machine. It indicate that accuracy level of failure data recorded, is very less. Skill level of maintenance crew is not upgraded. Real time data collection is a need of hour for applying corrective action.

From the above survey, an attempt has been done to model a manufacturing scenario of leading automobile company by simulation. Where focus is to improve capacity of manufacturing facility.

2.1 Model Development & Experimentation: A model has been developed for a company, which supplies dowel rod, serration cap etc.to a multinational automobile company. [4][5]

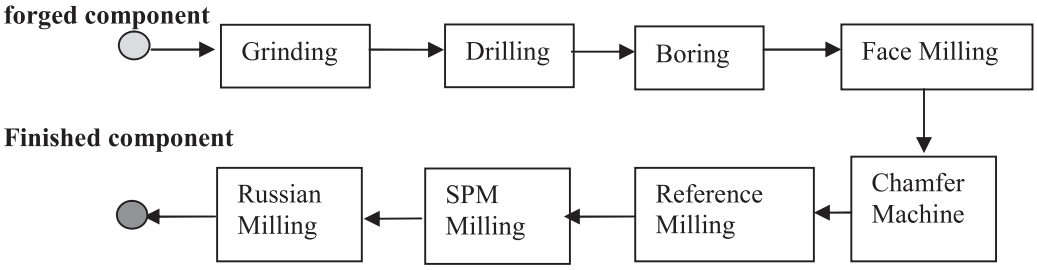

Fig.1 Model of a Manufacturing Line

Table 1: Actual Cycle time of manufacturing machines

Name Of Machine	Actual Cycle Time (min.)
Grinding	1.28 (Batch of 20)
Drilling	0.35
Boring	0.22
Face milling	0.51(Batch of 2)
Chamfer	0.07
Reference Milling	0.32 (Batch of 3)
SPM Milling	1.18 (Batch of 3)
Russian Milling	0.25 (Batch of 3)

Being 12 hrs. Shift company had 2 tea breaks of 15 min. each and 2 break for food of 30 min each.

2.2 Data Col lection by Excel Sheet:

A systematic approach of collecting true data is given in the table as below. Excel tool is used to collect data of all the manufacturing machines. Daily calculation of OEE is possible if given format is used to record (or input) data. Following table shows specific format of true data collection required to calculate OEE.

Table 2 :Excel Sheet format for Availability Calculations

Name of Machine	S.L. (min)	S.D. (min)	US.D. (min)	G.T. (min)	A.T. (min)	Availability (%)
Grinding	660	90	15	570	555	97%
Drilling	660	90	10	570	560	98%
Boring	660	90	20	570	550	96%
Face Milling	660	90	15	570	555	97%
Chamfer	660	90	30	570	540	95%
Ref.Milling	660	90	15	570	555	97%
SPM Milling	660	90	10	570	560	98%
Russian Milling	660	90	15	570	555	97%

S.L.- Shift length; Scheduled downtime; Unscheduled downtime; Gross time; Actual time; Availability.

Table 2: Excel Sheet format for Performance Rate Calculations

Machine Name	I.C.T. (min)	A.C.T. (min)	Performance	P.R. (%)
Grinding	1.2	1.28	0.9375	93.75
Drilling	0.266	0.35	0.76	76.00
Boring	0.2	0.233	0.858369	85.83
Face Milling	0.466	0.533	0.874296	87.42
Chamfer	0.06	0.0833	0.720288	72.02
Ref. Milling	0.3	0.333	0.900901	90.09
SPM Milling	0.233	0.266	0.87594	87.59
Russian Milling	0.96	1.033	0.929332	92.93

I.C.T.: Ideal Cycle Time **;** A.C.T**.:** Actual cycle time; P.R.: Performance rate

Quality is not a problem for this industry as rejection rate is very low. As machine are new and in good condition. Quality rate found to be 97% to 100%.

3. Design of Experiments (DOE):

It is a systematic approach to analyze any process by changing some of input variable purposefully to determine its effect on output of the process. The objective in many cases may be to develop a robust process, that is, a process affected minimally by external sources of variability. [6] [7]

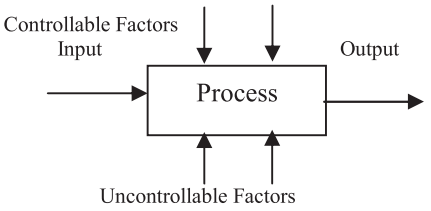

Fig.2: General model of a Process or System

OEE system or process is studied under this model as indicated in fig.2.Input variables are mean time between failure (MTBF) and mean time to repair (MTTR), Setup and adjustment for Availability rate (A), Actual cycle time , ideal cycle time, small stops, reduced speed for performance rate (PR) and startup rejects, production rejects for Quality rate (QR). Out put of the process is OEE. Uncontrolled factors in this process are ideal cycle time, unscheduled breakdown and operator.

From above data collection and calculation for availability and performance measurement, chamfer machine is found to be low performing machine with availability 95% and performance rate 72.02%.

Design of experiment is used to analyze, which factor of Chamfer machine affects output significantly and at what rate. Three variables such as Availability, Performance rate and quality rate are taken with variation of two level. Reference values are **Availability90%& 95%;Performance rate 72%&77%;Quality Rate 97% &99%.**

A full factorial Design has following details by using MiniTab14 software. Experiment has designed for 3 factors and 2 levels.

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

Table3: Experimental setup for OEE.

Availability (%)	Performance Rate (%)	Quality Rate (%)	OEE (%)
95	77	97	70.9555
90	72	97	62.856
95	72	97	66.348
90	72	99	64.152
95	**77**	**99**	**72.4185**
95	72	99	67.716
90	77	97	67.221

Table 4: Estimated Effects and Coefficients for OEE (coded units)

Term	Effect	Coef
Constant	67.5343	
A	3.6505	1.8252
B	**4.5325**	**2.2663**
C	1.3782	0.6891
A*B	0.1225	0.0613
A*C	0.0372	0.0186
B*C	0.0462	0.0231
A*B*C	0.0013	0.0006

Table 5: Analysis of Variance for OEE (coded units)

Source	DF	Seq SS	Adj SS	Adj MS
Main Effects	3	71.5386	71.5386	23.8462
2-Way Interactions	3	0.0371	0.0371	0.0124
3-Way Interactions	1	0.0000	0.0000	0.0000
Residual Error	0	*	*	*
Total	7	71.5756		

Table 6: Estimated Coefficients for OEE using data in un coded units

Term	Coef
Constant	-5.95861E-11
A	6.26343E-13
B	7.68980E-13
C	6.15375E-13
A*B	-8.05143E-15
A*C	-6.47271E-15
B*C	-7.93485E-15
A*B*C	0.000100000

4. Regression Analysis: OEE versus A, PR, QR

The regression equation is

OEE = - 135 + 0.730 A + 0.906 B + 0.689 C (5)

Table 7: Variables and its significance value (P)

Predictor	Coef	SE Coef	T	P
Constant	-135.068	3.707	-36.44	0.000
A	0.73010	0.01361	53.63	0.000
B	0.90650	0.01361	66.59	0.000
C	0.68912	0.03404	20.25	0.000

S = 0.0962664 R-Sq = 99.9% R-Sq(adj) = 99.9%

Table 8: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	71.539	23.846	2573.18	0.000
Residual Error	4	0.037	0.009		
Total	7	71.576			

Table 9: Ranking most Significant factor with SeqSS as B

Source	DF	Seq SS
A	1	26.652
B	**1**	**41.087**
C	1	3.799

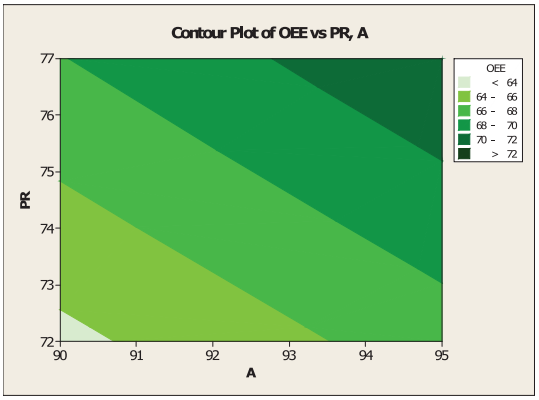

Fig. 3: Contour Plots of OEE Vs A and PR

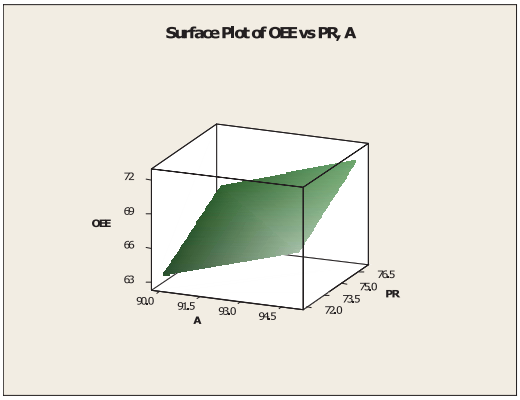

Fig. 4: Surface Plots of OEE Vs A and PR

Minitab15 is used to plot a contour & surface plot of experimented values. Variation of OEE with respect to availability and performance rate can be observed in surface plot.

5. CONCLUSION:

As OEE is an important performance measure for effectiveness of any equipment, careful analysis is required to know the effect of various components. A excel sheet can be used as simplest tool to measure and monitor true data collection. A regression analysis gives classic equation of OEE. An attempt has been done in this study to predict the OEE by using Design of Experiments (DOE). This study indicates that OEE will be significantly improved if focus is given on performance rate improvement. To achieve OEE of 72.41%, optimized values are Availability 95%, Performance rate77% , and Quality Rate 99%. Simulated values of above scenario will add more valuable information to industry.

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