Statistical Analysis and Reliability Estimation of Total Productive Maintenance

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Total Quality Management (TQM) and Total Productive Maintenance (TPM) systems are considered as the key operational activities of the quality management system. Implementing TQM and TPM together results in synergy. They act as two drives to improve the business performance excellence in a typical industry. One of the main objectives of TPM is to increase the productivity of plant and equipment with a modest investment in maintenance. After implementing TPM, it is necessary to measure the effectiveness of TPM. Overall Equipment Effectiveness (OEE) is an indicator that measures the effectiveness of TPM. The number of defective products produced by the machine indicates the condition of the machine and also reduces the rate of quality and affects the OEE. In this paper, an attempt is made to measure the effectiveness of TPM by performing a statistical analysis. The assessment of TPM on a continual basis is an essential activity of OEE validation. This activity involves large computations and analytical skills. The estimation of TPM is a time-consuming and costly process. It is not possible to conduct the study very often. If the behavioral pattern of TPM is determined analytically, it helps the maintenance engineer to predict the OEE over a specific period of time. In view of the above, reliability-based TPM estimation is proposed in the paper.

Introduction

Total Productive Maintenance (TPM) is a system of maintaining and improving the integrity of production and quality systems through the machines, equipments, processes and employees that add business value to the organization (Ahuja and Khamba, 2008). TPM, when implemented fully, dramatically improves productivity and quality, and reduces the cost. Thus, it is an innovative approach to the maintenance system which optimizes the Overall Equipment Effectiveness (OEE), eliminates breakdowns and promotes the autonomous maintenance through day-to-day activities

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involving the total workforce. The goal of the TPM program is to enhance the volume of the production, employee morale and job satisfaction.

In any organization, adding additional best practices, such as TPM approach, to operations management is most useful in the development of extra capabilities (McAdam and McGeough, 2000). The TPM is a proactive and cost-effective approach to the equipment maintenance. It maximizes the equipment effectiveness by establishing a comprehensive productive-maintenance system covering the life of the equipment and spanning all equipment-related fields. The philosophies behind TPM are principles of teamwork and empowerment in the form of autonomous maintenance to the productive maintenance techniques (Al-Hassan *et al.*, 2000).

TPM is carried out by all the employees through well-planned small-group activities (Brahy and Chongy, 2004). The maximum utilization of the equipment during its productive life with minimum investment is the serious goal of a business. TPM acts as one of the tools to achieve this. It is a new paradigm in production and operations management philosophy and has been widely recognized as a strategic weapon for improving the manufacturing performance. TPM improves many aspects such as operational performance, safety, cleanliness, employee morale and customer satisfaction to achieve excellence in business performance (Miyake and Enkawa, 1999).

In simple terms, TPM has twin goals of 'zero breakdowns' and 'zero defects', which would help organizations meet their promises made to the customers and stakeholders. The elimination or greatly reducing breakdowns and defects would lead to reduction in the equipment downtime together with its associated cost. Thus, TPM helps in minimizing the work-in-progress inventory and increasing the productivity. It also helps in preventing the unscheduled breakdown. The evaluation of TPM efficiency can assist the industry in improving its operations across a variety of dimensions (Wang, 2006).

Objectives of TPM

The key objectives of TPM are to:

- Focus and improve people management to minimize the targeted losses.
- Develop the policy, strategy and early management activities to ensure easy maintenance of the equipment.
- Develop the autonomous maintenance system to empower the production operators to take care of the conditions and effectiveness of the equipment.
- Develop a planned maintenance of the machine and equipments.
- Provide training and education to the operators and maintenance personnel to upgrade their equipment-related knowledge and skills.
- Establish safety practices and also prevent adverse environmental effects.
- Reduce the wastage of organizational resources.

Implementation of TPM

Following are the steps involved in the implementation of TPM in an organization.

- Initial evaluation of TPM level.
- Introductory Education and Propaganda (IEP) for TPM.
- Formation of TPM committee.
- Development of master plan for TPM implementation.
- Stage by stage training to the employees and stakeholders on all eight pillars of TPM.
- Implementation preparation process.
- Establishing the TPM policies and goals.
- Development of a road map for TPM implementation.

The Common Barriers to Implementing TPM

The main barriers to implementing TPM are lack of top management commitment, lack of middle management support and employee resistance to change. The employee resistance to change is usually due to the increased workload without appropriate reward and recognition (McAdam and McGeough, 2000).

Changing the environment to suit TPM is a challenging task in the public sector undertakings, where apart from normal business constraints, managers deal with stiffer government control, large and unwieldy operations, wary unions and bleeding bottom lines. The status-conscious and hierarchy-bound middle level executives lacking initiatives are also bottlenecks in the improvement process (Seth and Tripathi, 2006).

Factors That Reduce the Equipment Effectiveness

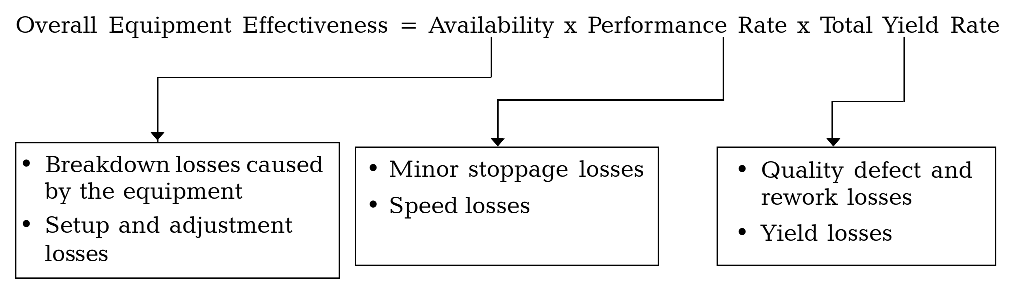
In TPM, the relationship between losses and equipment effectiveness is defined in terms of both quality of the product and equipment availability. On the basis of a thorough examination, six major factors that reduce the equipment effectiveness are found to be:

1. Breakdown losses caused by the equipment.
2. Setup and adjustment losses.
3. Minor stoppage losses.
4. Speed losses.
5. Quality defect and rework losses.
6. Yield losses.

These six losses can be presented using three indices, i.e., availability, performance rate, and total yield rate. Their multiplicative effect is shown in Figure 1.

The gap between the equipment's actual effectiveness and its optimal value is referred to as chronic loss. When the chronic loss increases, the equipment effectiveness decreases to a great extent. This kind of loss is referred to as sporadic loss. These

Figure 1: Overall Equipment Effectiveness and Its Multiplicative Dependent Factors



losses are usually due to the variability in raw materials, operating conditions, jigs, tools, electric current, voltage, atmospheric temperature, humidity, airflow, etc.

Validation of OEE

Measuring and/or evaluating the effectiveness of TPM is an essential activity of TPM steering committee. OEE is an indicator that shows the effectiveness of TPM. The OEE may be measured using statistical techniques which help the organization and maintenance individuals to know the status of the operational effectiveness. The assessment of TPM on a continual basis is an essential activity of OEE validation. This involves large computations and analytical skills. Added to this, estimation of TPM is a time-consuming and costly process. It is not possible to conduct the study very often. If the behavioral pattern of TPM is determined analytically, it helps the maintenance engineer to predict the OEE over a specific period of time. In view of the above, reliability-based TPM estimation is proposed in this paper.

Statistical Analysis of TPM

Hypothesis testing is carried out using OEE as a measuring parameter of TPM effectiveness.

H_0: *There is no significant difference in the percentage of defectives produced before and after the implementation of TPM (TPM implementation has no positive effect)*.

H_a: *There is a significant difference in the percentage of defectives produced before and after the implementation of TPM (TPM implementation has positive effect)*.

Mathematically,

$H_0: \mu_B - \mu_A = 0$ i.e., $H_0: \mu_d = 0$

$H_a: \mu_B - \mu_A > 0$ i.e., $H_a: \mu_d \neq 0$

Data regarding defectives is collected before TPM and after implementation of TPM. The number of parts produced and the number of defectives are noted for different shifts before and after TPM. The differences between the defectives are computed for

Table 1: Data for Hypothesis Testing								
S. No.	**Number of Parts Produced**	**Number of Defectives**	**% of Defectives Before TPM**	**Number of Parts Produced**	**Number of Defectives**	**% of Defectives After TPM**	**Deviation (d)**	**d^2**
1	50	2	4.0	60	1	1.7	2.3	5.29
2	50	3	6.0	60	0	0	6.0	36.00
3	50	2	4.0	60	1	1.7	2.3	5.29
4	50	3	6.0	60	0	0	6.0	36.00
5	50	4	8.0	60	0	0	8.0	64.00
6	50	3	6.0	60	1	1.7	4.3	18.49
7	50	2	4.0	60	0	0	4.0	16.00
8	50	3	6.0	60	0	0	6.0	36.00
9	50	4	8.0	60	0	0	8.0	64.00
10	50	3	6.0	60	1	1.7	4.3	18.49
11	50	4	8.0	60	1	1.7	6.3	39.69
12	50	3	6.0	60	1	1.7	4.3	18.49
13	50	4	8.0	60	0	0	8.0	64.00
14	50	3	6.0	60	1	1.7	4.3	18.49
15	50	4	8.0	60	1	1.7	6.3	39.69
16	50	4	8.0	60	0	0	8.0	64.00
17	50	3	6.0	60	1	1.7	4.3	18.49
18	50	4	8.0	60	0	0	8.0	64.00
19	50	3	6.0	60	0	0	6.0	36.00
20	50	4	8.0	60	1	1.7	6.3	39.69
21	70	4	5.7	80	2	2.5	3.2	10.24
22	70	4	5.7	80	2	2.5	3.2	10.24
23	70	4	5.7	80	1	1.3	4.4	19.36
24	70	3	4.3	80	2	2.5	1.8	3.24
25	70	4	5.7	80	1	1.3	4.4	19.36
26	70	3	4.3	80	2	2.5	1.8	3.24
27	70	4	5.7	80	1	1.3	4.4	19.36
28	70	3	4.3	80	1	1.3	3.0	9.00
29	70	4	5.7	80	2	2.5	3.2	10.24
30	70	4	5.7	80	1	1.3	4.4	19.36
						Σ =	146.8	825.74

hypothesis testing (Table 1). Statistically, 95% of confidence level and 5% significance level are considered to find the critical t-value.

Computation of Test Statistics

Student's t-value is calculated using the average of deviations and standard deviation.

Average of Deviations = 4.893; Standard Deviation S = 1.9244; Standard Error = 0.35135; and Student's t-value = 13.927.

The table value for 29 degrees of freedom at 5% significance is 2.756, which is less than 13.927. Hence, the null hypothesis is rejected.

Result: From the above computation, null hypothesis (H_0), i.e., there is no change after implementation of TPM, is rejected. Hence, it may be concluded that TPM implementation brings positive change to the process development.

Reliability-Based Estimation of TPM

TPM improves the maintenance system in the context of operations management. To succeed in a demanding market, manufacturing companies have to fulfill several requirements. One such crucial aspect is reliability of the maintenance system. TPM has the potential to increase the process efficiency. The quality of the process, product and hence the reliability are important factors to gain competitive advantage of the operations management (Srinath, 2005). Further, reliable production and maintenance are necessary to meet the quality specifications of the product and process. To enhance high process capability, maintenance performance must be systematic and reliable. Reliability estimation helps in quantifying OEE and assists manufacturing in reducing the machine downtime due to breakdowns.

The reliability estimation helps in determining the behavioral pattern of TPM over a period of time. A method is proposed to estimate the reliability of TPM over a period of time. The process parameters are generated using the simulation technique for a large number of production months and the corresponding OEE is estimated.

The Proposed Approach

OEE values are obtained using random numbers. OEE is computed for a large number of production months. Using these computations and considering the threshold value of OEE as 80%, reliability of TPM is estimated.

One year data for availability, performance efficiency and rate of quality is collected and OEE for the given period is estimated (Table 2). The Monte Carlo simulation procedure is adopted to simulate the random numbers for the next five years' OEE values.

The simulated values for availability, performance efficiency and rate of quality are computed (Tables 3, 4 and 5). The random numbers are obtained from the standard random table.

Table 2: OEE Value for One Year

(in %)

Month	Availability	Performance Efficiency	Rate of Quality	OEE
Jan.	92	90	88	73
Feb.	89	93	92	76
Mar.	89	92	97	79
Apr.	91	92	98	82
May	92	90	97	80
June	94	95	100	90
Jul.	98	80	100	78
Aug.	98	85	99	82
Sept.	98	89	99	86
Oct.	98	92	99	89
Nov.	98	93	99	90
Dec.	98	94	99	91

Table 3: Random Number Interval for Availability

Availability (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
89	2	0.17	0.17	0-16
91	1	0.08	0.25	17-24
92	2	0.17	0.42	25-41
94	1	0.08	0.50	42-49
98	6	0.50	1.00	50-99

Table 4: Random Number Interval for Performance Efficiency

Performance Efficiency (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
80	1	0.0833	0.08	0-07
85	1	0.0833	0.17	08-16
89	1	0.0833	0.25	17-24
90	2	0.1667	0.42	25-41
92	3	0.2500	0.67	42-66
93	2	0.1667	0.83	67-82
94	1	0.0833	0.92	83-91
95	1	0.0833	1.00	92-99

Table 5: Random Number Interval for Rate of Quality				
Rate of Quality (%)	Frequency	Probability	Cumulative Probability	Random Number Interval
88	1	0.0833	0.08	0-07
92	1	0.0833	0.17	08-16
97	2	0.1667	0.33	17-32
98	1	0.0833	0.42	33-41
99	5	0.4167	0.83	42-82
100	2	0.1667	1.00	83-99

The availability, performance efficiency and rate of quality are recorded (Table 6). Based on the random numbers, OEE has been computed for five years (Table 7).

Table 6: Random Numbers for Availability, Performance Efficiency and Rate of Quality						
Months	Random Numbers	Availability (%)	Random Numbers	Performance Efficiency (%)	Random Numbers	Rate of Quality (%)
1	22	91	68	93	61	99
2	19	91	13	85	85	99
3	16	89	09	85	16	92
4	78	98	20	89	46	99
5	3	89	73	93	88	100
6	93	98	07	80	08	92
7	78	98	92	95	82	99
8	23	91	99	95	56	99
9	93	98	93	95	22	97
10	78	98	18	89	49	99
11	23	91	24	89	44	99
12	15	89	22	89	33	98
13	58	98	07	80	77	99
14	57	98	29	90	87	100
15	48	94	57	92	54	99
16	61	98	33	90	08	92
17	36	92	49	92	64	99
18	18	91	65	92	24	97

Table 6 (Cont.)

Months	Random Numbers	Availability (%)	Random Numbers	Performance Efficiency (%)	Random Numbers	Rate of Quality (%)
19	88	98	92	95	29	97
20	9	89	98	95	40	98
21	12	89	00	80	35	98
22	85	98	57	92	37	98
23	38	92	12	85	28	97
24	53	98	31	90	56	99
25	40	92	96	95	33	98
26	2	89	85	94	82	99
27	95	98	72	93	89	100
28	35	92	91	94	78	99
29	26	92	77	93	24	97
30	77	98	37	90	53	99
31	46	94	34	90	61	99
32	37	92	11	85	18	97
33	61	98	27	90	45	99
34	93	98	10	85	04	88
35	21	91	59	92	23	97
36	95	98	33	90	53	99
37	97	98	87	94	45	99
38	69	98	72	93	23	97
39	4	89	73	93	25	97
40	61	98	79	93	45	99
41	85	98	20	89	11	92
42	21	91	85	94	89	100
43	15	89	59	92	87	100
44	2	89	72	93	59	99
45	87	98	88	94	66	99
46	98	98	49	92	50	99
47	10	89	12	85	77	99
48	47	94	79	93	27	97

Table 6 (Cont.)

Months	Random Numbers	Availability (%)	Random Numbers	Performance Efficiency (%)	Random Numbers	Rate of Quality (%)
49	22	91	38	90	54	99
50	67	98	47	92	10	92
51	27	92	71	93	04	88
52	33	92	64	92	39	98
53	13	89	59	92	05	88
54	10	89	82	93	44	99
55	28	92	16	85	14	92
56	34	92	95	95	9	92
57	61	98	79	93	52	99
58	61	98	61	92	71	99
59	17	91	44	92	38	98
60	36	92	37	90	69	99

Table 7: OEE Computation for Five Years (Simulated Values)

Months	Availability (%)	Performance Efficiency (%)	Rate of Quality (%)	OEE (%)
1	91	93	99	84
2	91	85	99	77
3	89	85	92	70
4	98	89	99	89
5	89	93	100	83
6	98	80	92	72
7	98	95	99	92
8	91	95	99	86
9	98	95	97	90
10	98	89	99	86
11	91	89	99	80
12	89	89	98	78
13	98	80	99	78
14	98	90	100	88
15	94	92	99	86
16	98	90	92	81

Table 7 (Cont.)

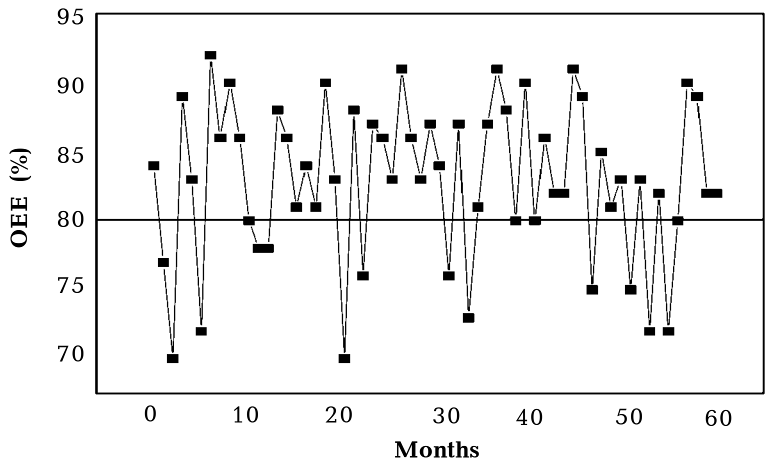
Months	Availability (%)	Performance Efficiency (%)	Rate of Quality (%)	OEE (%)
17	92	92	99	84
18	91	92	97	81
19	98	95	97	90
20	89	95	98	83
21	89	80	98	70
22	98	92	98	88
23	92	85	97	76
24	98	90	99	87
25	92	95	98	86
26	89	94	99	83
27	98	93	100	91
28	92	94	99	86
29	92	93	97	83
30	98	90	99	87
31	94	90	99	84
32	92	85	97	76
33	98	90	99	87
34	98	85	88	73
35	91	92	97	81
36	98	90	99	87
37	98	94	99	91
38	98	93	97	88
39	89	93	97	80
40	98	93	99	90
41	98	89	92	80
42	91	94	100	86
43	89	92	100	82
44	89	93	99	82
45	98	94	99	91
46	98	92	99	89
47	89	85	99	75
48	94	93	97	85

Table 7 (Cont.)

Months	Availability (%)	Performance Efficiency (%)	Rate of Quality (%)	OEE (%)
49	91	90	99	81
50	98	92	92	83
51	92	93	88	75
52	92	92	98	83
53	89	92	88	72
54	89	93	99	82
55	92	85	92	72
56	92	95	92	80
57	98	93	99	90
58	98	92	99	89
59	91	92	98	82
60	92	90	99	82

Since 80% is the standard expected value, the OEE observations above 80% are noted down. The reliability of TPM is estimated by considering the ratio of observations above the threshold value to the total number of observations. The graphical representation of this procedure is presented in Figure 2. The number of observations above 80% are 47. The total number of observations is 60.

Figure 2: OEE Status Over 60 Months



Reliability = Number of observations above the threshold value / Total number of observations

= 47 / 60 = 0.78

Hence, the reliability of TPM is 0.78.

Conclusion

The TPM is an innovative approach of the maintenance system, which optimizes the equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by the operators through day-to-day activities involving the total workforce (Tajiri and Fumio, 1992). Thus, TPM is not a specific maintenance policy but a culture, a philosophy and a new attitude towards the maintenance. The salient features of TPM are the involvement of operators, carrying out autonomous maintenance by participating in cleaning, lubrication, housekeeping, minor-repairs, adjustments, etc. In addition to the tangible benefits, TPM also offers various intangible benefits such as fostering of teamwork, increased morale, safety and nurturing the workforce with increased intellectual capabilities to meet the desired level of competition and challenges (Nakajima, 1988; Brown, 1993; Grantt and Leaven Worth, 1996; Ross, 1998; Andersen and Henrik, 2001; Yang and El-Haik, 2003; and Chary, 2005). The key dimensions of TPM are maximizing the equipment effectiveness, autonomous maintenance and small-group activities.

Though the product meets the specification limits and the process is in the state of control, actions may be initiated to quantify and further reduce the process variability to gain marvelous advantages (Prabhuswamy, 2004; and Prabhuswamy, 2007). Considering this view, statistical analysis thus adopted in this paper shall help the maintenance individuals to measure the effectiveness of TPM.

Hypothesis testing can be performed to know whether TPM meets or exceeds the target reliability value. Also, the method of reliability estimation of TPM over the number of production months has been developed. The approach adopted helps in determining the reliability of OEE over the number of production months. This prediction helps maintenance engineers to further study the variability of the OEE. Thus, the proposed approach helps the maintenance plan and administers the activities necessary to achieve a high level of performance and identifies the opportunities to improve quality and performance. ❖

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Reference # 07J-2013-02-01-01