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RESEARCH ARTICLE

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THE IMPACT OF OPTIMUM MAINTENANCE POLICY AND LIFE CYCLE COST ON SYSTEM PERFORMANCE

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ABSTRACT

The need for an optimum maintenance policy cannot be over-emphasized as it offers a pro-active and all encompassing approach to maintenance towards creating additional value in maintenance system. The system to be maintained is subject to stochastic degradations and assumed to be continuously monitored, and the condition to perform a preventive maintenance corresponds to a system failure rate, reliability threshold and maintenance cost. Thus, the maintenance optimization problem to be solved consists on finding the optimal cumulative breakdowns and life cycle cost together with the optimal number of preventive maintenance actions to maximize the average system performance, reliability and availability over a system's service life. Analysis of findings from the research work throughout the period of assessment and evaluation between the two types of preventive maintenance policy approach- varying maintenance policy and fixed maintenance policy reveals a significant difference in the following parameters: cumulative breakdown-CBD equipment downtime hours, reliability threshold-R_{th} with respect to the number of preventive maintenance actions and the maintenance cost -LCC over a given period of time at SEDI-Enugu. Therefore, the evaluation being considered in this research work is that there is a difference between fixed and varying preventive maintenance policy, in terms of its impact on the system life-cycle cost and operational effectiveness.

Keywords: Preventive Maintenance Actions, Cumulative Breakdowns, Life Cycle Cost, Mathlab Graphing, Trend line graph.

1. INTRODUCTION

In this study, an increasing effort is made to encourage the usage of a specific type of preventive maintenance policy approach known as varying (sequential) preventive maintenance policy or fixed (periodic) preventive maintenance policy which consists on monitoring either continuously or according to a regular time intervals the condition of a system so as to prevent its failure and to determine appropriate number of preventive maintenance actions to be performed. In this maintenance policy approach, system conditions are obtained via observations, collections and analysis of data such as breakdown pattern, failure rate, maintenance cost, and so on. According to a level of system performance, maintenance actions are then scheduled to reduce system failures while reducing total operation costs.

The organization interested in this research has many complex mechanical systems that need to be maintained. They are also interested in reducing the costs involved in keeping the effectiveness of the systems at their present level. Parts of the mechanical systems to be maintained are the Lathe Machines which were used as a case study to analyze the average system performance within a given period of time and determine the optimization values, factoring the aging effect throughout the system's service life. The preventive maintenance policy was initially set with the support of the supplier or manufacturer. But over the lathe machine's life cycle, it was discovered that the rate of degradation was becoming stochastic and thus became advisable to change the preventive maintenance policy to account for deterioration of the system with time.

In order to figure out the problem of breakdowns, failures, efficient utilization of maintenance resources and maintain smooth flow of production without interruption in an industry, an optimum maintenance policy needs to be developed to provide a strategic approach to maintenance management across assessment, planning, scheduling, methods selection, performance monitoring, evaluation and forecasting of maintenance functions.

Therefore, the need for an optimum maintenance policy cannot be over-emphasized as it offers a pro-active and all encompassing approach to maintenance towards creating additional value in maintenance system for improved maintenance productivity, ensuring the plant functions (i.e. availability, reliability, etc), ensuring the plant reaches its design life, ensuring the efficient use of resources (energy and raw materials) and cost effectiveness in maintenance.

Hence, the overall goal is to build an optimum maintenance capacity needed to sustain the attainment of the planned production objectives with respect to availability, reliability, predetermined time and pre-established cost.

2.0 Materials and Methods of evaluation

2.1 Design of the Study

The research methodology of this thesis was designed to use preventive maintenance actions, cumulative breakdowns and life-cycle cost along with opportunity loss (loss due to breakdown) as the metrics that determine optimum maintenance policy for any system by evaluation and comparison method.

The analytical and case study research is based on the annual system performance and maintenance data obtained from January – December 2013 from records of the maintenance unit and other information collected through direct observation and interviews with maintenance personnel of Scientific Equipment Development Institute SEDI Enugu.

Due to aging, most of the mechanical systems with an expected service life of about 20-25 years have been identified to record an increase of about 50% cumulative breakdowns after some years of installation and usage, and the cost of maintenance has also increased beyond maximum tolerable life cycle cost.

2.2 Source of Data

Based on the information gathered and the historical data obtained from the mechanical maintenance unit and records with regard to the performance of the lathe machines over the previous years due to aging, two (2) of the multipurpose Lathe Machines (YUCY 6240B model) of same capacity each with an expected service life of 25 years situated at the machine shop of the institute's factory were set and monitored for fixed maintenance policy and varying maintenance policy concurrently. These two machines were allowed to undergo the same task schedule and operation from January – December 2013 as a strategic approach towards development of an optimum maintenance policy for the mechanical systems of the institute.

2.3 Method of Data Collection

2.3.1 Maintenance Performance Metrics

These are indicators for determining the performance level of the implemented maintenance activities. Thus, it provides the key performance indicators for evaluating the strength and the weakness of the maintenance policy for possible effective system performance.

Some maintenance performance models were established and used for monitoring and evaluating maintenance effectiveness namely:

A. Availability Model

Availability is the fraction of time a plant facility is capable of being used for production during the period it is needed. Depending upon the data available in terms of the details, such as, repair times, mean times, logistics delay time and administrative delay time, the following metric could be used.

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (2.1)$$

Where, A is for Availability of the machines

$$MTBF(\text{Mean Time Between Failure}) = \frac{\text{Number of Operatin time (NOT)}}{\text{Number of Breakdown (NOB)}} \quad (2.2)$$

$$MTTR(\text{Mean Time To Repair}) = \frac{\text{Total Repair Time (TRT)}}{\text{Number of Breakdown (NOB)}} \quad (2.3)$$

B. Reliability Model

System reliability is the ability of a production system to perform its intended functions under stated operating conditions in a given period of time.

System reliability is given by the function:

$$R(t) = e^{-\lambda t} \quad (2.4)$$

$$\lambda = f/T$$

Where R = System Reliability, λ = failure rate, which is expressed in terms of failure per unit time, T = Total production time

C. Maintenance cost index

The maintenance cost index gives the ratio of maintenance cost to capital cost.

$$\text{Maintenance Cost Index}(MCI) = \frac{\text{Total Maintenance Cost(TMC)}}{\text{Total production Cost(TPC)}} \times 100 \quad (2.5)$$

$$\text{Maintenance Breakdown Severity}(MBS) = \frac{\text{Cost of Breakdown Repair (CBR)}}{\text{Number of Breakdown (NOB)}} \quad 2.6)$$

D. Downtime index

This is the amount of idle time due to equipment breakdown which makes machines and workers idle resulting in loss of production, delay in schedules and expensive emergency repairs.

$$\text{Down Time Index} = \frac{\text{Down Time hours}}{\text{Production hours}} X\ 100 \quad (2.7)$$

E. Total annual cost (Tc)

Tc(t) = lab cost + repl cost + service cost + safety cost + downtime cost . (2.8)

F. Life Cycle Cost (LCC)

LCC(t) = lcc(t-1) + Tc(t) + disposal interest factor (2.9)

2.4 Method of Data Analysis

The data and results generated were computed and analyzed using equations (2.1- 2.9) of the Maintenance Performance Metrics together with the Mathlab Graphing Calculator and 3-D Surface Contour Modeling in finding the optimized values and the impact of different policies on the lathe machine's performance.

3.0 Results and Discussion

The analytical results were generated and computed using the equations of the maintenance performance metrics stated in equations (2.1- 2.9) encompassing the Mean Time Before Failure, Maintenance Breakdown Severity, Down Time Index, Reliability, Availability, Preventive Maintenance Actions, Cumulative Breakdowns, Life Cycle Cost (production cost, maintenance cost, opportunity loss, etc) and thereafter, presented with 3-D surface chart and Mathlab graphical representations.

3.1 Analysis of the Maintenance Performance Results with Mathlab Graphing Approach – PMA vs MTBF and PMA vs DTI

MTBF- mean time before failure.

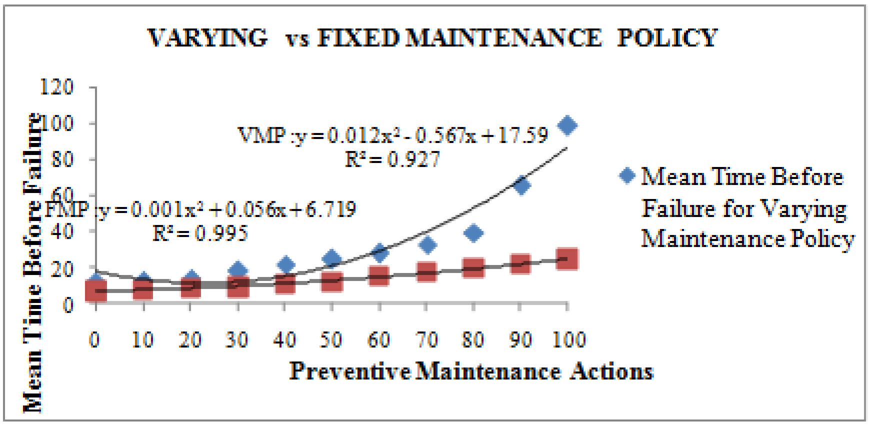

Figure 3.1 Trend Line Graph of the Fixed and Varying Preventive Maintenance Polices showing Mean Time before Failure with Polynomial Equations.

Figure 3.1 shows the Trend line graph and regression line for varying policy and fixed policy with the regression equations as follows:

$y = 0.012x^2 - 0.567x + 17.59$-Varying Maintenance Policy

$y = 0.001x^2 - 0.056x + 6.719$-Fixed Maintenance Policy

The trend equation gives a good statistical fit as shown for R^2 which indicates that preventive maintenance actions affects mean time before failure.

Applying the above equations from the trend line graph of the varying and fixed policy to the Mathlab graphing calculator for optimized values, gives the below

Optimum values of VMP and FMP for MTBF and PMA

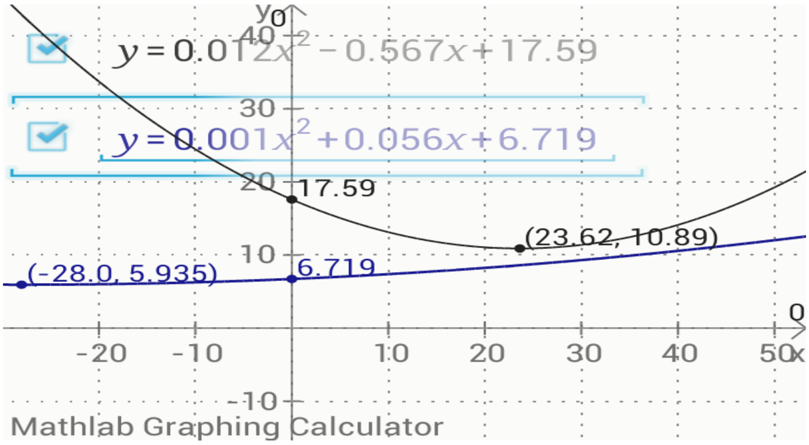

Figure 3.2: Mathlab Graphing of varying and fixed preventive maintenance policy showing MTBF in a polynomial equation; $y=0.012x^2 - 0.567x + 17.59$ & $y=0.001x^2 - 0.056x + 6.719$

As seen from Figure 3.2 of the Mathlab Graphing, at preventive maintenance actions ranging above 20 which is the minimum optimized value, the performance efficiency of the machine achieved in a year for VMP was 10.89 and for FMP was 5.93 indicating that any point below this value, the machine is prone to failure.

The value of the intercept on the y-axis 17.59 for VMP and 6.71 for FMP is equal to the mean time before failure when no preventive maintenance actions are carried out (i.e. PMA= 0) in the machine for the preceding year.

DTI – Down Time Index

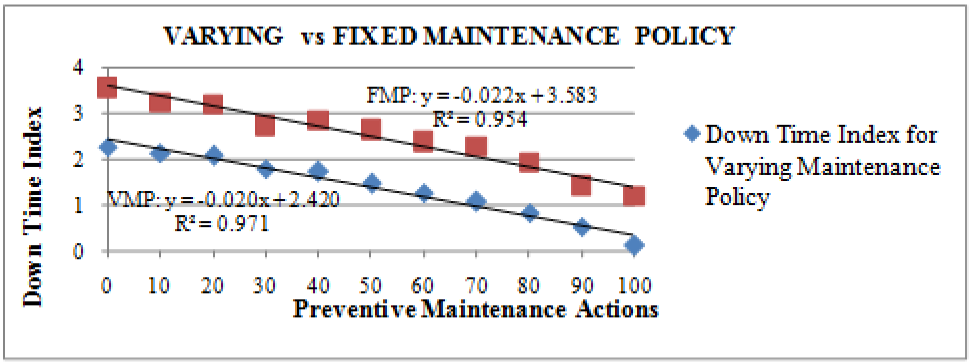

Figure 3.3: Trend Line Graph of the Fixed and Varying Preventive Maintenance Polices showing Down Time Index with Linear Equations.

Figure 3.3 shows the Trend line graph and regression line for varying policy and fixed policy with the regression equations as follows:

$y = -0.020x + 2.420$-Varying Maintenance Policy

$y = -0.022x + 3.583$-Fixed Maintenance Policy

The trend equation gives a good statistical fit as shown for R^2 which indicates that preventive maintenance actions affects rate of down time index.

Applying the above equations from the trend line graph of the varying and fixed policy to the Mathlab graphing calculator for optimized values, gives the below:

Optimum values of VMP and FMP for DTI and PMA

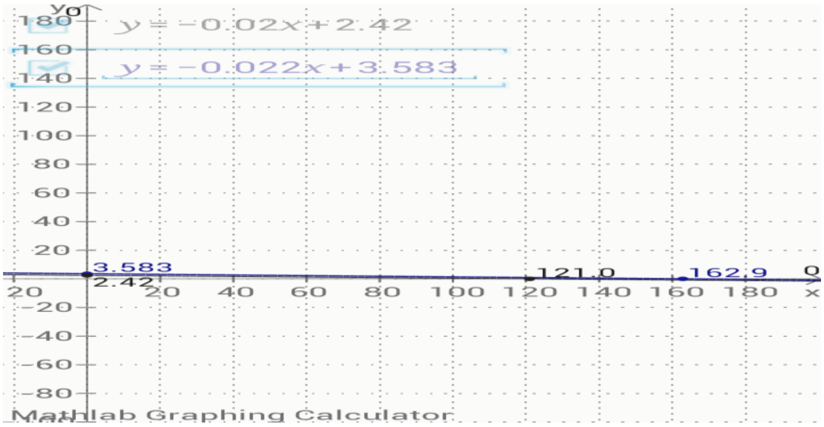

Figure 3.4: Mathlab Graphing of varying and fixed preventive maintenance policy showing Down Time Index (DTI) in a linear equation; y=– 0.02x + 2.42 & y=– 0.022x + 3.583

As seen from Figure 3.4 of the Mathlab Graphing, for the machine to maintain no down time (i.e. zero DTI) for a given period, the optimum preventive maintenance actions to undertake must be up to 120 for VMP and 160 for FMP in a year.

The value of the intercept on the y-axis 2.42 is equal to the down time index when no preventive maintenance actions are carried out (i.e. PMA= 0) in the machine for the preceding year.

3.2 Analysis of Optimized values for VMP and FMP with Mathlab Graphing Approach – PMA vs CBD

CBD– Cumulative Breakdowns

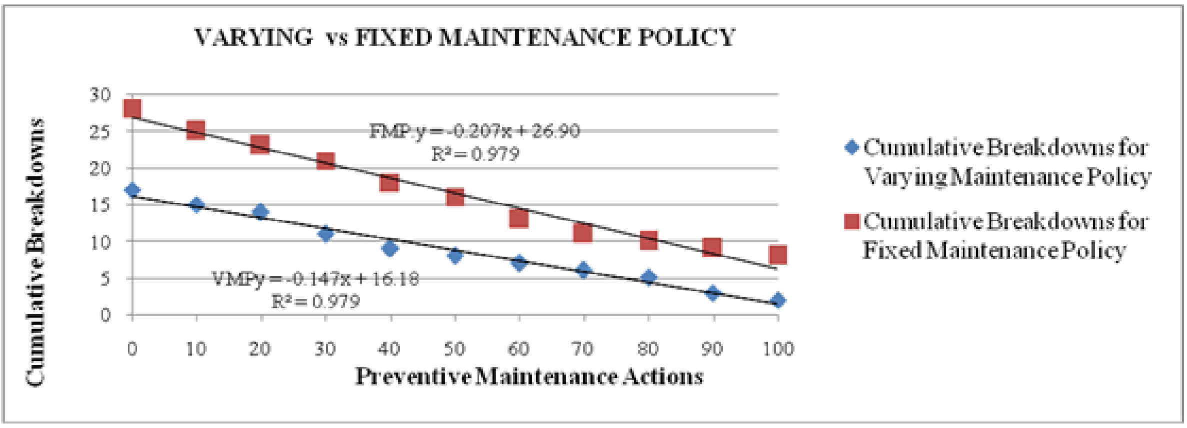

Figure 3.5: Trend Line Graph of the Fixed and Varying Preventive Maintenance Polices showing Cumulative Breakdowns with Linear equations.

Figure 3.5 shows the Trend line graph and regression line for varying policy and fixed policy with the regression equations as follows:

y= -0.147x + 16.18-Varying Maintenance Policy

y= -0.207x + 26.90-Fixed Maintenance Policy

The trend equation gives a good statistical fit as shown for R^2 which indicates that preventive maintenance actions reduce breakdowns.

Applying the above equations from the trend line graph of the varying and fixed policy to the Mathlab graphing calculator for optimized values, gives the below:

Optimum values of VMP and FMP for CBD and PMA

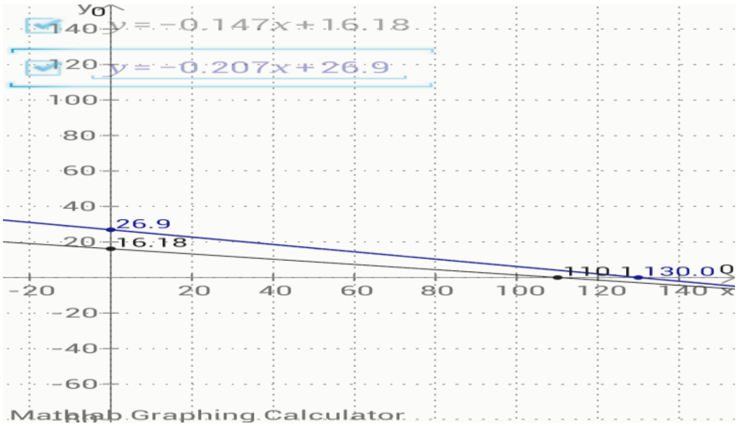

Figure 3.6: Mathlab Graphing of varying and fixed maintenance policy showing Cumulative Breakdowns in a linear representation. y=-0.147x + 16.18 & y=-0.207x + 26.90

As seen from Figure 3.6 of the Mathlab Graphing, at 110 and 130 PMAs, zero (0) cumulative breakdowns can be achieved in a year for VMP and FMP respectively. The value of the intercept on the y-axis 16 and 27 is equal to the number of breakdowns when no Preventive Maintenance Actions are carried out (i.e. PMA= 0) in the system for the preceding year for VMP and FMP respectively.

3 Analysis of Optimized values for VMP and FMP with Mathlab Graphing Approach – PMA vs LCC

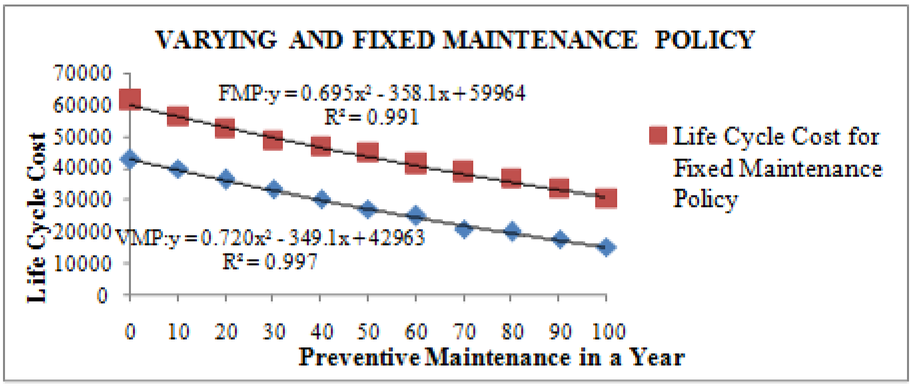

Figure 3.7: Trend Line Graph of the Fixed and Varying Preventive Maintenance Polices showing Life Cycle Cost with Polynomial Equations.

The regression equations of the trend line for the variation are:

y = 0.702x^2 + 349.1x + 42963 -Varying maintenance Policy

y = 0.695x^2 – 358.1x + 59964-Fixed Maintenance Policy

The trend equation gives a good statistical fit as shown for R^2 which indicates that preventive maintenance actions reduce life cycle cost.

Applying the above equations from the trend line graph of the varying and fixed policy to the Mathlab graphing calculator for optimized values, gives the below **Optimum values of VMP and FMP for LCC and PMA**

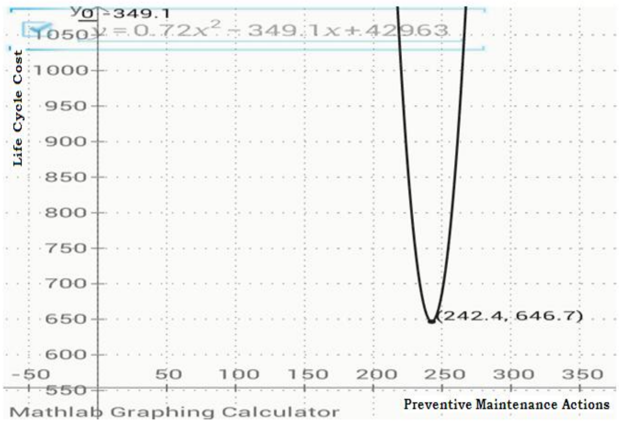

Figure 3.8: Mathlab Graphing of varying and fixed preventive maintenance policy showing LCC in a polynomial; y=0.720x^2 +349.1x +42963 & y=-0.695x^2 + 358.1x + 59964

As seen from Figure 3.8, at 242 PMA, the minimum cost that can be achieved in the system in a year is given at 646 for VMP while at 258 PMA; the minimum cost that can be achieved is given at 13,836 for FMP.

The value of the intercept on the y-axis 42,963 and 59,964 are equal to the life cycle cost when no preventive maintenance actions are carried out (i.e. PMA = 0) for VMP and FMP respectively in a system for the preceding year.

Table 3.1 Maintenance Performance Measurement Chart/Results.

Maintenance Performance Measurement Chart/Results for Fixed Policy.

Planned Production Time(hrs)	Total Machine Downtime (hrs)	Number of Operating Time (hrs)	Number of Break-downs	MTBF (hrs)	MBS naira/ bd	MTTR (hrs)	Down Time Index %
198	7.0	191	28	6.82	448.21	73.93	3.54
198	6.4	191.6	25	7.66	454.00	82.80	3.23
198	6.3	191.7	23	8.33	452.17	90.00	3.18
198	5.4	192.6	21	9.17	512.14	98.57	2.72
198	5.6	192.4	18	10.69	530.00	115.00	2.83
198	5.2	192.8	16	12.05	540.63	129.38	2.63
198	4.7	193.3	13	14.87	583.08	159.23	2.37
198	4.5	193.5	11	17.59	573.18	188.18	2.27
198	3.8	194.2	10	19.42	600.00	207.00	1.92
198	2.8	195.2	9	21.68	627.78	230.00	1.41
198	2.3	195.7	8	24.46	650.00	258.75	1.16

Maintenance Performance Measurement Chart/Results for Varying Policy.

Planned Production Time(hrs)	Total Machine Downtime (hrs)	Number of Operating Time (hrs)	Number of Breakdowns	MTBF (hrs)	MBS (naira/ breakdown)	MTTR (hrs)	Down Time Index %
198	4.5	193.5	17	11.38	517.05	124.59	2.27
198	4.2	193.8	15	12.92	543.33	141.20	2.12
198	4.1	193.9	14	13.85	516.43	151.29	2.07
198	3.5	194.5	11	17.68	637.73	192.55	1.77
198	3.4	194.6	9	21.62	700.00	235.33	1.72
198	2.9	195.1	8	24.39	638.75	264.75	1.46
198	2.5	195.5	7	27.93	618.57	302.57	1.26
198	2.1	195.9	6	32.65	455.83	353.00	1.06
198	1.6	196.4	5	39.28	534.00	423.60	0.81
198	1.0	197.0	3	65.67	850.00	706.00	0.51
198	0.2	197.8	2	98.90	1085.0	1059.0	0.10

Table 3.2 - Maintenance Performance Measurement Chart/Results

Maintenance Performance Results of Variables for Fixed Maintenance Policy

Preventive Maintenance Actions	Cumulative Breakdowns	Life-cycle Cost
0	28	61390
10	25	55880
20	23	52180
30	21	48540
40	18	46460
50	16	44770
60	13	41170
70	11	38860
80	10	36580
90	9	33390
100	8	30180

Maintenance Performance Result of Variables for Varying Maintenance Policy

Preventive Maintenance Actions	Cumulative Breakdowns	Life-cycle Cost
0	17	42590
10	15	39910
20	14	36330
30	11	33300
40	9	30260
50	8	27070
60	7	24930
70	6	21010
80	5	19960
90	3	17890
100	2	15050
	Σ = 97	Σ = 392,300

4.0 Conclusion

Based on the above analysis, it can be seen that the maintenance performance efficiency of the lathe machines was best with the varying maintenance policy when compared with fixed maintenance policy.

The financial (cost) resources spent on maintenance services on the lathe machines with the varying maintenance policy was lower when compared with the fixed maintenance policy which was as a result of planned interventions done on unequal times thereby reducing failure rate.

The number of breakdowns which is a function of the downtime index for the machines was much lower with the varying maintenance policy than that of the fixed maintenance policy which also led to reduced opportunity loss (loss due to breakdowns).

If management decides to have conservative preventive maintenance policies, it would be a good option to adopt the varying preventive maintenance policy on the basis of a lower life-cycle cost and cumulative breakdowns.

Also, from the results, as the factor by which time (age) affects breakdowns increases, the varying policy helps achieve a reduction in both life cycle cost and cumulative breakdowns.

The basis of this preventive maintenance policy evaluation process is that the preventive maintenance required for a system is directly proportional to its past records or the breakdowns (or opportunity loss) expected in the next period.

However, it may not be suitable to have a fixed preventive maintenance policy in case of systems with long service periods due to aging.

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