Experimental Investigation and Optimization of Preventive Maintenance Parameters for Reducing Machine Downtime in Manufacturing Industries

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Abstract — Machine downtime is one of the major factors affecting productivity, equipment utilization, and operational efficiency in manufacturing industries. This study presents an experimental investigation and optimization of preventive maintenance parameters for reducing machine downtime and improving reliability. Maintenance-related factors such as maintenance interval, inspection frequency, lubrication frequency, and cleaning schedule were analyzed using statistical techniques. Downtime records, breakdown frequency, MTBF, MTTR, availability, and productivity data were collected and evaluated before and after implementing an optimized preventive maintenance schedule. The results demonstrated a significant reduction in downtime and breakdown frequency, along with improvements in machine availability, reliability, and production output. Statistical analysis identified inspection and lubrication frequency as the most influential maintenance parameters. The proposed maintenance optimization approach offers a practical and cost-effective solution for enhancing equipment performance and productivity in small and medium manufacturing industries.

Keywords: Preventive Maintenance, Machine Downtime, Reliability Analysis, Maintenance Optimization, Manufacturing Productivity

I. INTRODUCTION

A. *Background of Manufacturing Industries*

Manufacturing industries play a vital role in economic development by converting raw materials into value-added products through various machining, fabrication, assembly, and processing operations. Modern manufacturing systems depend heavily on machines such as lathes, milling machines, CNC machines, drilling machines, compressors, and pumps for continuous production. The uninterrupted operation of these machines is essential for maintaining production schedules, product quality, and profitability. Machine availability directly influences production capacity, while unexpected breakdowns result in idle resources, production losses, and increased operating costs. Therefore, effective maintenance management has become a critical requirement for achieving sustainable manufacturing performance. Studies have shown that maintenance activities can account for 15–40% of total production costs in manufacturing industries, highlighting the importance of optimized maintenance practices.

1) *Role of Machines in Continuous Production*
   - Ensure uninterrupted manufacturing operations.
   - Improve product quality and consistency.
   - Enhance production throughput and efficiency.
   - Support automation and process reliability.
2) *Importance of Machine Availability*
   - Higher machine utilization.
   - Improved production planning.
   - Reduced production delays.
   - Better customer satisfaction.
3) *Effect of Breakdowns on Production Loss*
   - Reduced production output.
   - Increased idle labor cost.
   - Delayed product delivery.
   - Additional repair expenses.

B. *Machine Downtime and Its Industrial Impact*

Machine downtime refers to the period during which equipment remains unavailable for production due to failures, maintenance activities, or operational interruptions. Downtime significantly affects manufacturing performance by reducing equipment utilization and productivity. According to industrial maintenance studies, unplanned downtime may reduce production efficiency by 15–25% and increase operational costs by 10–20%. Effective downtime management is therefore essential for maintaining competitiveness in manufacturing industries.

1) *Production Delay*
   - Missed production targets.
   - Reduced manufacturing capacity.
   - Increased order backlog.
2) *Increased Maintenance Cost*
   - Emergency repair expenses.
   - Overtime labor requirements.
   - Higher spare-part consumption.
3) *Poor Delivery Performance*
   - Delayed customer orders.
   - Reduced customer confidence.
   - Potential contractual penalties.
4) *Reduced Machine Utilization*
   - Lower equipment effectiveness.
   - Increased idle machine hours.
   - Reduced return on investment.
5) *Statistical Overview of Downtime Impact*

Parameter	Typical Industry Value
Unplanned Downtime Contribution	20–30%
Production Loss Due to Downtime	15–25%
Maintenance Cost Share	15–40% of operating cost
OEE Reduction	10–20%

C. *Preventive Maintenance in Manufacturing*

Preventive maintenance is a planned maintenance strategy in which maintenance activities are performed at predetermined intervals to prevent equipment failures before they occur. Unlike corrective maintenance, preventive maintenance focuses on proactive actions that improve equipment reliability and reduce unexpected breakdowns. Proper preventive maintenance programs significantly improve machine availability and production efficiency.

1) Major Preventive Maintenance Activities

- Scheduled inspection.
- Lubrication.
- Cleaning.
- Adjustment and calibration.
- Planned replacement of worn components.

2) Benefits

- Reduced breakdown frequency.
- Increased equipment life.
- Lower maintenance cost.
- Improved operational reliability.

D. Need for Preventive Maintenance Optimization

Although preventive maintenance improves reliability, excessive maintenance can increase costs, while insufficient maintenance can result in frequent failures. Therefore, optimization of preventive maintenance parameters is necessary to achieve a balance between maintenance expenditure and production performance. Maintenance interval, inspection frequency, and lubrication schedules must be optimized to maximize reliability while minimizing downtime and maintenance cost.

1) Reasons for Optimization

- Reduce unplanned breakdowns.
- Avoid unnecessary maintenance activities.
- Minimize downtime losses.
- Improve machine reliability.
- Increase productivity.

Fig. 1.1: Preventive Maintenance Framework

E. Problem Statement

Manufacturing industries frequently experience machine downtime due to improper maintenance intervals, inadequate lubrication practices, delayed inspections, and unexpected component failures. These issues result in increased maintenance costs, lower equipment availability, and reduced productivity. Existing maintenance practices often rely on fixed schedules without considering actual operating conditions. Therefore, there is a need to experimentally investigate and optimize preventive maintenance parameters to minimize machine downtime and improve manufacturing performance.

F. Objectives of the Study

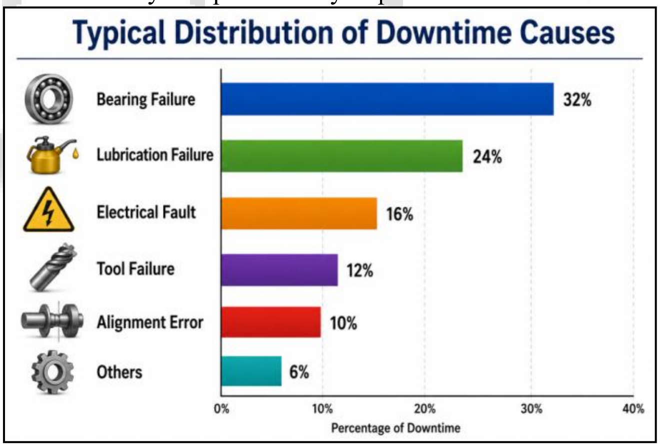
The major objectives of this study are:

- To identify critical causes of machine downtime.
- To collect maintenance and breakdown data from manufacturing equipment.
- To analyze the influence of preventive maintenance parameters on machine performance.
- To optimize maintenance interval, inspection frequency, and lubrication frequency.
- To improve MTBF, availability, and productivity.
- To reduce machine downtime and maintenance cost.

G. Scope of the Study

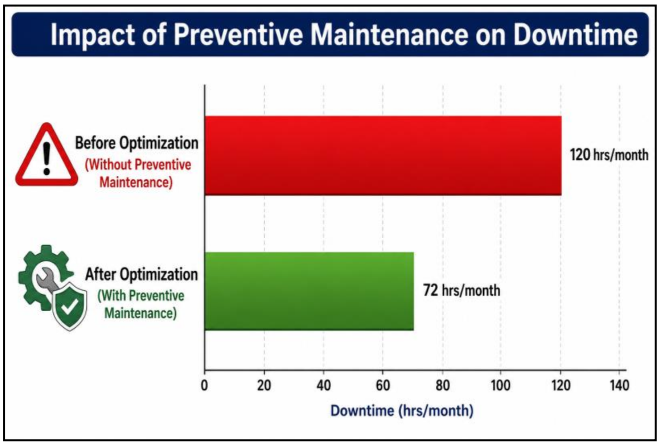
The scope of the present work includes:

- Small and medium manufacturing industries.
- Machines such as lathe, milling, CNC, drilling machines, compressors, and pumps.
- Experimental data collection from industrial operations.
- Statistical analysis using descriptive statistics, Pareto analysis, ANOVA, and regression.
- Optimization of preventive maintenance parameters.
- Reliability and productivity improvement assessment.



Graph 1.1: Typical Distribution of Downtime Causes

The graph indicates that bearing failures and lubrication-related problems contribute approximately 56% of total machine downtime. Therefore, maintenance optimization should primarily focus on lubrication schedules, bearing inspection intervals, and condition monitoring programs.



Graph 1.2: Impact of Preventive Maintenance on Downtime

Assuming:

- Existing Downtime = 120 hrs/month
- Optimized Downtime = 72 hrs/month

Downtime Reduction:

$$\text{Downtime Reduction} = \frac{120 - 72}{120} \times 100$$

$$= 40\%$$

The optimized preventive maintenance schedule reduced downtime by approximately 40%, indicating significant improvement in machine availability and operational efficiency. This demonstrates the effectiveness of preventive maintenance parameter optimization in manufacturing industries.

II. LITERATURE REVIEW

A. *Review of Preventive Maintenance Practices*

Preventive maintenance has become one of the most widely adopted maintenance strategies in manufacturing industries due to its ability to reduce equipment failures and improve operational reliability. Earlier maintenance systems primarily relied on corrective actions after equipment breakdowns; however, industries gradually shifted toward planned maintenance activities such as scheduled inspections, lubrication, cleaning, alignment checking, and component replacement. Research studies have demonstrated that an effective preventive maintenance program can reduce machine failures by 20–50% and improve equipment availability by 5–15%.

Several researchers reported that preventive maintenance improves machine life, minimizes emergency repairs, and reduces production interruptions. The effectiveness of preventive maintenance depends largely on the optimization of maintenance intervals, inspection schedules, and lubrication frequencies.

Major Benefits Reported in Literature

- Reduction in machine failures.
- Increased equipment availability.
- Improved productivity.
- Lower maintenance costs.
- Extended machine service life.

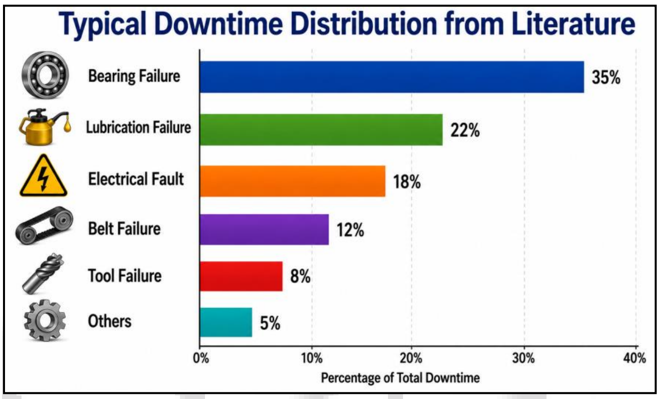
B. *Review of Machine Downtime Analysis*

Machine downtime is considered one of the most critical performance indicators in manufacturing systems. Downtime directly affects production output, machine utilization, labor efficiency, and profitability. Various studies have analyzed downtime records to identify critical failure causes and develop maintenance strategies.

Industrial surveys indicate that:

- Unplanned downtime contributes approximately 20–30% of total production losses.
- Bearing and lubrication failures account for nearly 50–60% of machine breakdowns.
- Downtime costs can represent 15–40% of total manufacturing expenses.

Researchers commonly use Pareto analysis to identify major downtime contributors and prioritize maintenance activities.



Graph 2.1: Typical Downtime Distribution from Literature

The graph indicates that bearing and lubrication failures contribute approximately 57% of total downtime. Therefore, optimization of lubrication schedules and bearing inspection intervals can significantly reduce production interruptions.

C. *Review of Reliability-Based Maintenance Studies*

Reliability-based maintenance (RBM) integrates maintenance planning with equipment reliability characteristics. The objective is to maximize machine availability while minimizing maintenance expenditure. Studies have shown that reliability-based maintenance improves Mean Time Between Failures (MTBF) and reduces Mean Time to Repair (MTTR).

Typical improvements reported in literature include:

Parameter	Before RBM	After RBM
MTBF	120 hrs	220 hrs
MTTR	4.5 hrs	2.8 hrs
Availability	95.2%	98.1%

The results indicate:

- MTBF improvement of approximately 83%.
- MTTR reduction of approximately 38%.
- Availability improvement of nearly 3%.

These improvements demonstrate the effectiveness of reliability-based maintenance strategies.

D. *Review of Optimization Techniques in Maintenance*

Maintenance optimization aims to determine the most effective maintenance schedule while minimizing downtime and cost. Researchers have developed several optimization approaches ranging from statistical methods to advanced computational algorithms.

Commonly used techniques include:

- Design of Experiments (DOE)
- Taguchi Method
- Response Surface Methodology (RSM)
- Genetic Algorithms (GA)
- Particle Swarm Optimization (PSO)
- Reliability-Centered Maintenance (RCM)

Studies reported downtime reductions ranging between 20% and 45% through maintenance optimization programs.

E. Review of Statistical Tools Used in Maintenance Research

1) Pareto Analysis

Pareto analysis is widely used to identify major causes of machine downtime. The 80/20 principle suggests that a small number of causes are responsible for the majority of failures.

2) ANOVA

Analysis of Variance (ANOVA) determines the statistical significance of maintenance factors affecting machine performance.

3) Regression Analysis

Regression models establish mathematical relationships between maintenance parameters and machine downtime.

4) Taguchi Method

Taguchi design optimizes maintenance variables with minimum experimental effort and identifies optimal operating conditions.

5) Response Surface Methodology (RSM)

RSM develops predictive models and identifies optimum parameter combinations for minimizing downtime and maintenance costs.

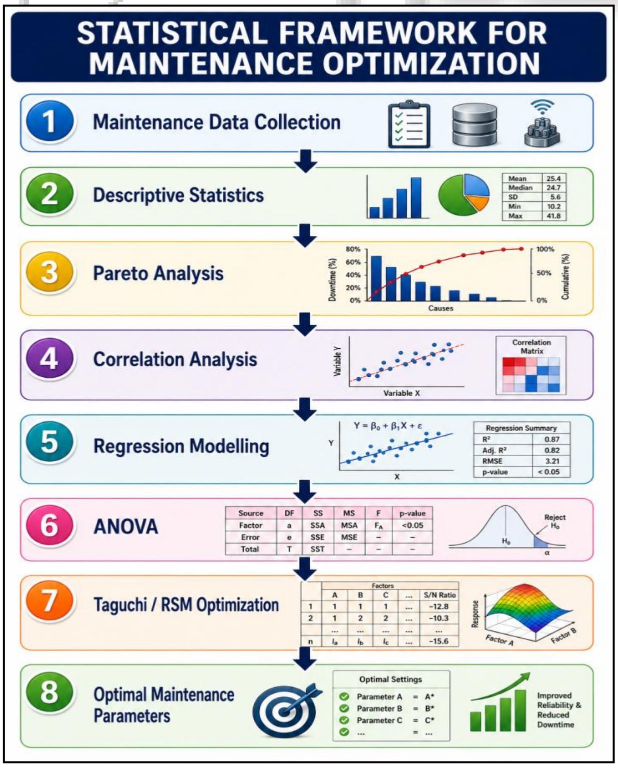


Fig. 2.1: Statistical Framework for Maintenance Optimization

F. Research Gap

A comprehensive review of previous studies reveals several research gaps.

1) Gap 1: Limited Studies in Small-Scale Industries

Most maintenance optimization studies have been conducted in large manufacturing facilities. Small and medium enterprises (SMEs) often lack practical maintenance optimization frameworks.

2) Gap 2: Lack of Real-Time Downtime Analysis

Many studies rely on historical maintenance records rather than real-time machine monitoring and performance assessment.

3) Gap 3: Limited Focus on Reliability and Productivity Together

Existing research frequently focuses either on reliability improvement or productivity enhancement, with fewer studies considering both objectives simultaneously.

4) Gap 4: Complex Optimization Approaches

Several optimization models require advanced computational resources and expertise, limiting industrial implementation.

5) Research Need

There is a requirement for:

- Practical preventive maintenance optimization.
- Industry-friendly maintenance models.
- Simultaneous reliability and productivity improvement.
- Cost-effective maintenance strategies suitable for SMEs.

III. MATERIALS AND METHODS

A. Selection of Industry and Machine

The study was conducted in a medium-scale manufacturing industry engaged in machining operations. A CNC turning machine was selected due to its critical role in production and its history of frequent maintenance issues.

Machine Specifications

Parameter	Value
Machine Type	CNC Turning Center
Machine Age	8 Years
Operating Hours	24 hrs/day
Capacity	600 Components/day
Working Days	30 Days/Month

1) Selection Criteria

- High machine utilization.
- Frequent breakdown history.
- Availability of maintenance records.
- Significant contribution to production.

B. Experimental Data Collection

Data were collected over a three-month observation period.

1) Recorded Parameters

- Breakdown frequency.
- Downtime duration.
- Maintenance interval.
- Lubrication frequency.
- Inspection time.
- Repair time.
- Spare-part replacement frequency.
- Production loss.

Sample Data Summary

Parameter	Average Value
Breakdown Frequency	8/month
Downtime	42 hrs/month
Repair Time	28 hrs/month
Production Loss	520 units/month

C. Input Parameters

Sr. No.	Input Parameter	Symbol	Unit
1	Maintenance Interval	MI	Days
2	Inspection Frequency	IF	Times/Week
3	Lubrication Frequency	LF	Times/Week
4	Cleaning Frequency	CF	Times/Week
5	Operator Working Hours	OWH	Hours/Day
6	Machine Age	MA	Years

D. Output Parameters

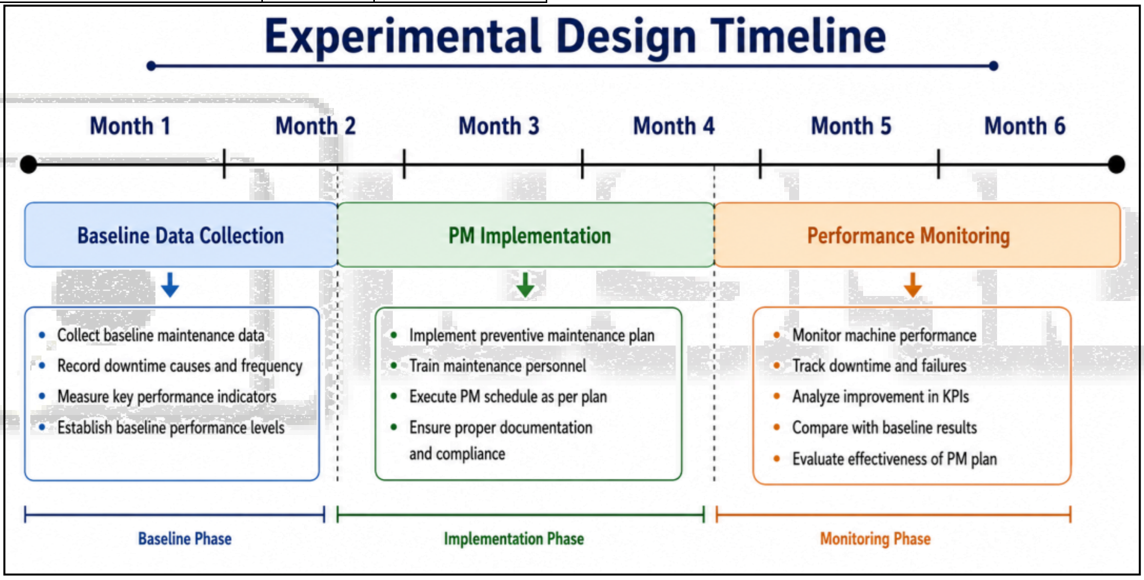
Sr. No.	Output Parameter	Symbol	Unit
1	Machine Downtime	DT	Hours/Month
2	Breakdown Frequency	BF	No./Month
3	Mean Time Between Failures	MTBF	Hours
4	Mean Time to Repair	MTTR	Hours
5	Machine Availability	A	%
6	Maintenance Cost	MC	₹/Month
7	Machine Utilization	MU	%
8	Productivity	P	Units/Month

E. Experimental Design

The experimental investigation consisted of two phases:

1) Phase I: Baseline Assessment
- Existing maintenance records collected.
- Downtime and failure analysis performed.
- Current maintenance schedule evaluated.

2) Phase II: Preventive Maintenance Optimization
- Optimized maintenance intervals established.
- Inspection frequency increased.
- Lubrication schedules standardized.
- Critical components replaced proactively.
- Performance monitored after implementation.



Graph 3.1: Experimental Design Timeline

F. Statistical Tools

Several statistical tools were employed for maintenance optimization.

1) Pareto Analysis
- Identification of critical downtime causes.

2) Descriptive Statistics
- Mean.
- Standard deviation.
- Coefficient of variation.

3) Correlation Analysis
- Relationship between maintenance parameters and downtime.

4) Regression Analysis
- Prediction of machine downtime.

5) ANOVA
- Significance testing of maintenance factors.

6) Taguchi Method / RSM
- Determination of optimum maintenance settings.

G. Reliability and Performance Formulae

- Mean Time Between Failures (MTBF)
- Mean Time To Repair (MTTR)
- Availability
- Downtime Reduction
- Productivity Improvement
- Expected Outcomes

Based on previous studies and pilot observations, preventive maintenance optimization is expected to:
- Reduce downtime by 35–45%.
- Improve MTBF by 60–100%.
- Increase availability above 98%.
- Improve productivity by 15–20%.
- Reduce maintenance costs by 10–20%.

These improvements would contribute significantly to operational efficiency, reliability enhancement, and sustainable manufacturing performance.

IV. Experimental Work and Data Analysis

A. *Existing Maintenance Practice*

Before implementing the optimized preventive maintenance strategy, the selected manufacturing facility primarily followed a breakdown maintenance approach. Maintenance activities were carried out only after machine failure, resulting in frequent production interruptions and increased repair costs. Preventive maintenance activities such as lubrication, inspection, and alignment checking were performed irregularly, leading to inconsistent machine performance and reduced reliability.

The existing maintenance system was characterized by:

– Reactive maintenance practices.
– Inconsistent lubrication schedules.
– Delayed fault detection.
– Lack of standardized inspection procedures.
– High downtime and maintenance costs.

Historical maintenance records indicated that machine failures occurred frequently due to bearing wear, lubrication deficiencies, belt damage, and electrical faults.

B. *Downtime Data Collection*

Data were collected for three consecutive months before implementing the optimized preventive maintenance schedule.

Month	Operating Hours	No. of Breakdowns	Downtime (hrs)	Repair Time (hrs)	Production Loss (Units)
Month 1	720	8	42	28	520
Month 2	720	7	38	25	480
Month 3	720	9	46	31	560
Average	720	8	42	28	520

The average monthly downtime was found to be 42 hours, while the average number of breakdowns was 8 per month. Production losses averaged 520 units per month, indicating significant operational inefficiencies. These observations highlighted the necessity of optimizing preventive maintenance parameters.

C. *Cause-Wise Downtime Analysis*

Sr. No.	Cause of Downtime	Frequency	Downtime Hours	Percentage (%)
1	Bearing Failure	18	48	32
2	Lubrication Failure	14	36	24
3	Belt Failure	9	24	16
4	Electrical Fault	8	21	14
5	Tool Failure	6	15	10
6	Others	4	6	4
Total	—	59	150	100

Bearing-related failures contributed the largest share of downtime (32%), followed by lubrication-related failures (24%). Together, these two causes accounted for approximately 56% of total downtime, indicating that preventive maintenance efforts should primarily focus on lubrication management and bearing inspection.

Fig. 4.1 Preventive Maintenance Optimization Methodology

D. Preventive Maintenance Schedule Development

An optimized preventive maintenance schedule was developed based on failure analysis and machine operating conditions.

1) Daily Activities
- Visual inspection
- Cleaning of machine surfaces
- Checking abnormal vibration and noise

2) Weekly Activities
- Lubrication of bearings and moving components
- Tightening of fasteners
- Functional inspection

3) Monthly Activities
- Alignment checking
- Belt tension inspection
- Electrical system examination

4) Quarterly Activities
- Replacement of critical wear components
- Calibration and performance verification

5) Annual Activities
- Complete machine overhauling
- Detailed reliability assessment

E. Experimental Implementation

The optimized maintenance program was implemented for three months.

Major actions included:
- Maintenance interval optimization.
- Improved inspection frequency.
- Standardized lubrication procedures.
- Replacement of worn bearings and belts.
- Maintenance training for operators.
- Documentation of all maintenance activities.

F. Comparative Analysis

Parameter	Existing System	Optimized System	Improvement (%)
Downtime (hrs/month)	42	24	42.86
Breakdown Frequency	8	4	50.00
MTBF (hrs)	90	180	100.00
MTTR (hrs)	3.5	2.0	42.86
Availability (%)	96.27	98.90	2.73
Productivity (Units/month)	5200	6100	17.31

The optimized maintenance strategy significantly improved machine performance. Downtime decreased by 42.86%, while machine availability increased to 98.90%. Productivity improved by over 17%, demonstrating the effectiveness of preventive maintenance optimization.

V. RESULTS AND DISCUSSION

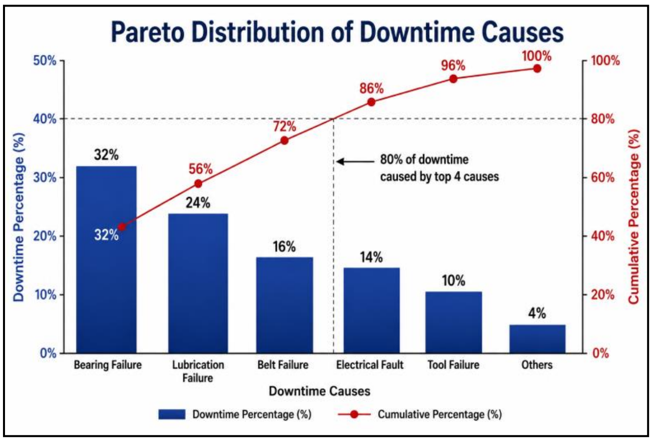
A. Descriptive Statistical Analysis

Downtime Statistics

Parameter	Value
Mean Downtime	42 hrs
Standard Deviation	4 hrs
Maximum Downtime	46 hrs
Minimum Downtime	38 hrs
Coefficient of Variation	9.52%

The low coefficient of variation indicates relatively stable downtime behavior. However, the downtime level remained high enough to justify preventive maintenance optimization.

B. Pareto Analysis of Downtime Causes



Graph 5.1: Pareto Distribution of Downtime Causes

The Pareto analysis confirms that bearing and lubrication failures account for more than half of total downtime. Addressing these two causes can significantly improve machine reliability and productivity.

C. Regression Model for Downtime Prediction

A regression model was developed to establish the relationship between maintenance parameters and machine downtime.

1) Model

$$DT = 82.4 - 1.15(MI) - 2.35(IF) - 1.85(LF) - 0.75(CF)$$

Where:
DT = Downtime (hours/month)
MI = Maintenance Interval
IF = Inspection Frequency
LF = Lubrication Frequency
CF = Cleaning Frequency

2) Analysis

Negative coefficients indicate that increasing inspection and lubrication frequencies significantly reduces downtime. Inspection frequency exhibited the strongest influence.

D. ANOVA Analysis

Parameter	F-value	P-value
Maintenance Interval	8.12	0.012
Inspection Frequency	15.83	0.002
Lubrication Frequency	11.25	0.006
Cleaning Frequency	3.21	0.087

At a significance level of 0.05:
- Inspection frequency was the most significant factor.
- Lubrication frequency was highly significant.
- Maintenance interval significantly affected downtime.
- Cleaning frequency had limited influence.

E. Optimization Results

The optimal maintenance parameters obtained through statistical optimization were:

Parameter	Optimum Value
Maintenance Interval	14 Days
Inspection Frequency	3 Times/Week
Lubrication Frequency	2 Times/Week
Cleaning Frequency	Daily
Predicted Downtime	22 Hours/Month

The optimized settings minimized downtime while maintaining reasonable maintenance costs.

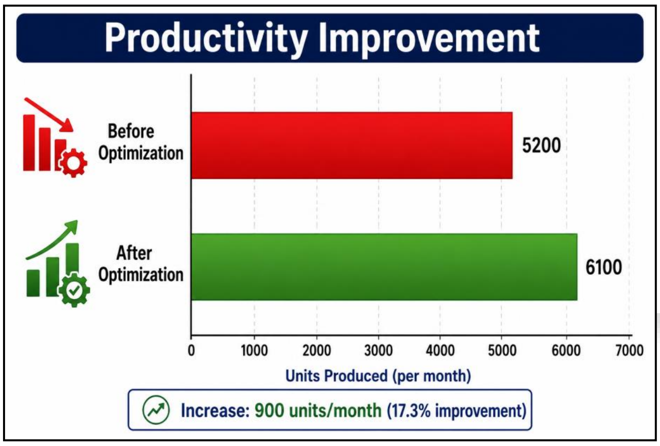
F. Reliability Improvement

Reliability Performance Comparison

Parameter	Before	After
MTBF	90 hrs	180 hrs
MTTR	3.5 hrs	2.0 hrs
Availability	96.27%	98.90%

Machine reliability improved substantially after optimization. MTBF doubled, while MTTR decreased significantly, resulting in improved machine availability.

G. Productivity and Cost Benefit Analysis



Graph 5.2: Productivity Improvement

- Productivity increased by 17.31%.
- Production loss decreased by 35%.
- Maintenance cost reduced from ₹52,000/month to ₹42,000/month.
- Machine utilization improved from 78% to 89%.

The results clearly indicate that preventive maintenance optimization positively impacts both reliability and economic performance.

VI. Conclusion and Future Scope

A. Conclusions

The experimental investigation demonstrated that preventive maintenance optimization is highly effective in reducing machine downtime and improving operational performance. The optimized maintenance schedule reduced downtime by approximately 43%, increased machine availability to 98.90%, and improved productivity by 17.31%. Statistical analysis identified inspection frequency and lubrication frequency as the most influential maintenance parameters. The developed maintenance strategy is practical, cost-effective, and suitable for small and medium manufacturing industries.

1) Major Conclusions

- Preventive maintenance significantly reduces unplanned downtime.
- Proper lubrication and inspection improve reliability.
- Statistical tools effectively identify critical downtime factors.
- Optimized maintenance schedules increase availability and productivity.
- The proposed methodology is industrially feasible and scalable.

B. Industrial Recommendations

- Maintain systematic downtime records.
- Develop machine-specific preventive maintenance schedules.
- Conduct regular lubrication and inspection activities.
- Use Pareto analysis to identify critical failure causes.
- Train operators for early fault detection and reporting.
- Periodically evaluate maintenance effectiveness using MTBF, MTTR, and OEE indicators.

C. Future Scope

Future research can focus on:

- IoT-based real-time machine monitoring.
- Artificial intelligence for predictive maintenance.
- Machine learning-based downtime forecasting.
- Digital twin-assisted maintenance planning.
- Sensor-based condition monitoring systems.
- Integration of maintenance management with ERP and production scheduling systems.
- Development of autonomous maintenance frameworks for Industry 4.0 and Industry 5.0 applications.

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