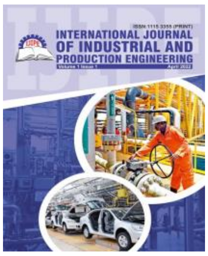

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Assessment of Industrial Maintenance Management Strategies on Productivity.

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ABSTRACT

The effectiveness of industrial operations is closely linked to the success of maintenance management techniques, which are crucial for preventing operational disruptions, minimizing equipment downtime, and preserving ideal production levels. This research examines the effects of various maintenance management strategies, including preventive, corrective, and predictive maintenance, on the productivity of industrial systems. By examining both theoretical models and practical applications, the study assesses each strategy's impact on equipment performance, cost-effectiveness, and overall production output. A quantitative approach was applied by carefully analyzing secondary data from the three-year 2019 Plant Engineering Maintenance and 2020 State of Industrial Maintenance surveys (2018-2020). Descriptive statistics, ranking analysis, comparative analysis, and correlation approaches were deployed to investigate the effectiveness of predictive, preventive, and reliability-centered maintenance processes together with as their relationship to significant productivity measures. The findings of the ANOVA and post-hoc analysis showed that, although maintenance strategies were not different between sectors, they were significantly different throughout the course of the three years that were studied. Chi-square analysis supports the significant switch in maintenance tactics between 2018 and 2020. The research's ranking analysis identifies the top maintenance techniques, difficulties, and technology as being preventive maintenance, financial restrictions, and computerized maintenance management systems, respectively. Technology's contribution to maintenance is becoming more widely acknowledged. As per the polls, the deployement of IoT and CMMS has increased from 60% in 2019 to 65% in 2020. Additionally, predictive analytics increased, suggesting a tendency toward using digital technologies to maximize productivity and efficiency. The study's findings emphasize the importance of a comprehensive strategy to management of maintenance, whereby well-considered maintenance expenditures lead to enhanced equipment reliability, longer machinery lifespans, and better overall productivity. This research provides industry practitioners with useful insights on how to develop and implement maintenance programs that support productivity targets.

Keywords: Assessment, Industrial, Maintenance, Management, Productivity.

1.0 Introduction

Sustaining high levels of productivity is important for organizational success in the fiercely competitive industrial landscape of today. Profitability and Industry lead are directly impacted by productivity, which is commonly expressed as output per unit of input (Handoyo et al., 2023). The efficiency of maintenance management is one important element that can affect output. By keeping machinery and equipment in top operating condition and minimizing downtime, effective maintenance management raises overall operational efficiency (Hamasha et al., 2023). Preventive, predictive, and corrective maintenance are just a few of the tasks that go under the umbrella of maintenance management, which aims to keep assets in good operating condition. To stop equipment breakdowns, preventive maintenance entails routine, planned inspections and servicing. Instead of following a set plan, Product Data Management (PdM) use of data to forecast when maintenance should be done depending on the equipment's actual state. Conversely, corrective maintenance means fixing equipment following a failure.

One important element that has a direct effect on productivity is downtime, or the period the equipment not in use. Sudden failures can cause major downtime, which can cause production schedule disruptions and financial losses. On the other hand, by making sure that equipment is routinely inspected, serviced, and repaired on schedule, good maintenance management can reduce downtime. Another crucial component of productivity is throughput, or the rate at which goods are produced. By guaranteeing that equipment operates at optimum performance levels and reducing bottlenecks and production delays, effective maintenance management techniques can increase throughput. Furthermore, a thorough statistic that assesses how well equipment is used is called Overall Equipment Effectiveness (OEE). OEE provides a perspective of equipment productivity by taking into account variables including product quality, performance efficiency, and equipment availability.

Even though maintenance management is acknowledged, many organizations find it so hard to put efficient maintenance plans into practice. Therefore, for firms looking to improve their efficiency and competitiveness, it is therefore important to comprehend the relationship that between maintenance and productivity. This study examines how maintenance management affects productivity by examining important variables like throughput, Overall Equipment Effectiveness (OEE), and downtime. Through the application of questionnaires, case studies, literature reviews, and data analysis, this work aims to shed light on the linkage between productivity and efficient maintenance management techniques. The results of this work will add to the corpus of knowledge already available on maintenance management and provide useful suggestions for businesses looking to improve productivity and optimize their maintenance plans.

The research emphasizes the important of maintenance management and its effect output. The goal of this work is to better understand how businesses may use efficient maintenance management in increasing efficiency and productivity by examining the link between maintenance schemes and productivity metrics.

2. Review of Literature

Industrial maintenance management ensures that physical assets perform reliably, and safely Therefore, this entails a set of activities, like planning, tracking, and performing a whole scope of maintenance works to assure the most efficient performance with minimum losses. In its development, maintenance strategies moved from pure reactive to forward-thinking and predictive solutions.

Reactive maintenance, sometimes known to as a "run-to-failure" strategy, was more or less applied at onset of industrial development. While simple, this method frequently resulted in extended downtimes and repair costs. CBM and PdM have become particularly critical in industries like energy and aviation, where unplanned shutdowns have severe financial losses and safety risks (Kumar et al., 2020).

The onset of digitalization brought a different dimension to maintenance management. Artificial Intelligence, ML, and the IoTs allowed developing smart maintenance systems. These systems analyze data patterns, predict failures, schedules through advanced analytics. For example, digital twins enable the simulation of asset performance in virtual environments to assess and provide insights to inform decision-making. Predictive analytics has now been widely applied in the monitoring of critical assets Like pipelines and rotating equipment to ensure uninterruptible operations with minimal downtime (Kumar et al., 2020).

Effective maintenance aims to enhance company's profitability and competitiveness through continuous cost-effective improvement of production process efficiency, effectiveness and productivity, which can be achieved via maintaining and improving the quality of all the elements contribute in the production process continuously and cost-effectively. Optimize maintenance activities, and ensure the reliability and longevity of their machinery, ultimately leading to enhanced operational efficiency and competitiveness (Buhr & Schicktanz, 2022). Unanticipated pump failures can lead to serious disruptions, monetary losses, and safety risks (Yang, et al., 2022). In order to proactively identify anomalies and potential pump failures, it is crucial to adopt effective machine condition monitoring systems.

Pramesh et al. (2019) investigated the development of a method to assess the level of implementation of best productivity practices in the petrochemical industry. The approach involved the verification of best productivity practices and the development of an assessment method designed to fit the characteristics of petrochemical projects. The assessment points out productivity practices with low implementation levels and provides recommendations to increase their usage. The results showed that the level of implementation of productivity practices in the petrochemical projects investigated was 68.42%, out of a maximum score of 100%. Practices related to Material Management and Equipment Logistics received the lowest scores and recommendations on how to bridge this productivity practice implementation gap were provided. The adoption of the Best Productivity

Practices Implementation Index (BPPII) as a Productivity management tool will help the petrochemical plants to improve productivity in their projects and to be resilient during the pre-planning phase.

With more industries embracing digital technologies the challenge will be toward building robust, efficient, and eco-friendly maintenance frameworks that will cope with an ever-evolving industrial environment. Hence, this research investigates the assessment of industrial maintenance strategies on productivity.

3. Methodology

3.1 Research Design

3.1.1 Selection of Case Studies

The "Plant Engineering 2019 Maintenance Report" and the "State of Industrial Maintenance Report 2020," two respected industry sources, conducted in-depth surveys that served as the premise for these studies.

3.2.1 2019 Plant Engineering Maintenance Report

3.2.1.1 Survey Objectives

The Plant Engineering Maintenance -2019 Report's major goal was to understand more about manufacturing facilities' maintenance procedures and the way it affect equipment reliability, , productivity, and safety. The survey's specific objectives were to: Know the commonly used maintenance techniques and procedures employed in manufacturing plants.

i. Evaluate how well these tactics work to increase equipment readiness and decrease downtime.
ii. Analyze how maintenance management contributes to both quality and operational effectiveness.
iii. To assist firms in comparing their maintenance procedures with industry norms, provide benchmarking data.

3.2.1.2 Data Collection Method

The organization provided secondary data for the report (plant engineering). A targeted sample of Plant Engineering subscribers, including maintenance managers, facility managers, Engineers and other professionals in charge of facility integrity maintenance, received the survey. The poll was conducted between 2018 and 2019. Respondents were asked a series of questions covering various aspects of maintenance, including maintenance philosophy, challenges, technologies used, and outcomes. Effective data collection was made possible by the online survey structure, which also made sure that respondents could finish the survey whenever it was convenient for them.

3.2.1.3 Sample Characteristics

This is a survey of 199 respondents from various manufacturing industries that was conducted for Plant Engineering Maintenance Report -2019. In ensuring provision of a detailed grasp of maintenance practices across various organizational sizes and sectors, the sample comprised maintenance experts from small, medium, and large facilities. The sample's salient features were as follows

- Responses from different industries, like the automobile, food and beverage, and chemical processing sectors, provided a diverse viewpoint on maintenance procedures.
- Role and Responsibility: The data was gathered from people who had direct control over maintenance tasks because the many of respondents were in roles like maintenance managers, plant managers, and engineers.
- Facility Size: Various facility sizes were included in the sample, from tiny plants with under 50 employees to large plants with over 500 people

3.2.2.2 Data Collection Method

The group provided the information for the State of Industrial Maintenance Report 2020. In
Partnership with Advanced Technology Services (ATS), the survey was created and disseminated to a specific group of maintenance professionals from a range of sectors. In order to guarantee a large and pertinent sample, respondents were invited to participate via email and industry networks. A multiple-choice and open-ended question were part of the survey to gather comprehensive data regarding maintenance procedures, technologies utilized, difficulties faced, and results attained. Respondents were able to submit detailed answers whenever it was convenient for them, and the online approach made data collecting more efficient.

3.2.2.3 Sample Characteristics

171 respondents from a wide range of industrial sectors participated in the State of Industrial Maintenance Report survey 2020. A thorough picture of maintenance practices in the industry was provided by the sample, which comprised maintenance specialists from various organizational positions and facility sizes.

3.3 Data Analysis

3.3.1 Data Processing and Cleaning

The main goal was to obtain vital information and make sure it was appropriate for secondary analysis because the surveys utilized in this research study already contained processed and analyzed data. Among the actions taken were: Data verification and reorganization.

3.3.2 Analytical Techniques

In order to arrive at results that were particular to the research aims, the analytical procedures used in this study involved interpreting and building upon the analyses already conducted in the original surveys.

3.3.2.1 Descriptive Statistics

To arrive at results that were good to the research aims, the analytical procedures used in this work involved interpreting and building upon the analyses already conducted in the original surveys.

3.3.2.2 Comparative Analysis

Comparative study entailed looking at variations and parallels among different survey data segments: Group comparisons.

3.3.2.3 Chi square test for independence

A statistical technique for figuring out whether two categorical variables in a contingency table have a significant relationship is the Chi-square Test of Independence. The test determines if any observed differences are the outcome of chance by comparing the observed frequencies in each category to the predicted frequencies, which are determined assuming that the variables are independent. The total sum of the squared differences between the obtained and predicted values, divided by the expected values, yields the test statistic, χ^2. The null hypothesis of independence is rejected if the computed χ^2 value is greater than a crucial threshold, suggesting a substantial link between the variables. This test is frequently employed in research to investigate correlations in categorical data obtained from a various disciplines. The governing equations for this test can be seen in Equation (1) and (2)

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

$$df = \text{Number of Categories} - 1 \qquad (2)$$

where:

- χ^2 is the Chi-square statistic.
- O_i represents the observed frequency in each category.
- E_i represents the expected frequency in each category, which is calculated under the assumption of independence.
- df degree of freedom.

The association between various factors in the survey data was investigated in this research using the Chi-square Test of Independence. Specifically, the effect of maintenance methods on productivity across different industrial sectors, facility sizes, and geographic locations was examined. To gain a better understanding of the link between particular maintenance techniques and variations in productivity, the study used the test to see whether there were significant connections between these categorical variables. The Chi-square analysis's findings added significantly to the research's overall conclusions by shedding light on the link between maintenance tactics and their results.

3.3.2.4 Ranking Analysis

Similar to the approach outlined by Yu et al., ranking analysis was used in this study to assess the relative relevance of several maintenance management strategies using survey data (2019). The analysis emphasized which behaviors were continuously prioritized and which witnessed changes in relevance by ranking the elements within each category for both years. This cross-temporal comparison highlighted on changing maintenance priorities and helped pinpoint places where strategy emphasis has changed or where new possibilities and problems have surfaced.

To know the efficiency of various maintenance tasks in boosting productivity, a structured ranking methodology was utilized. To measure and compare the effects of various methods on KPIs related to industrial productivity, this methodology comprised some steps. Key performance indicators (KPIs) were selected according to their relevance to maintenance and productivity. These KPIs offer quantifiable results that show how well a maintenance plan affects operational effectiveness. In this research work, the following KPIs were employed:

1. The periodicity of equipment malfunctions or breakdowns is referred as equipment reliability.
2. Reduction of Downtime: The amount of time that machines are not in use as a result of maintenance.
3. Maintenance Costs: The price value of personnel, supplies, and equipment needed to complete maintenance operations.
4. Production Output: The amount of items produced in relation to the pre maintenance baseline.
5. Safety and Compliance: The length to which maintenance procedures lower hazards and adhere to safety standards.

Weight Assignment

Because not every KPI is important in every industrial context, a weighting mechanism was deployed to document for each KPI's relative value. Surveys of the industries and professional opinions from maintenance specialists were utilized to calculate the weights. For example: Equipment efficiency and downtime reduction were given higher weights (40 percent and 30 percent, respectively) due to their direct impact on productivity

Maintenance cost: were given moderate weight (20 percent) since cost efficiency is critical but often secondary to uptime in highly competitive manufacturing environments. Production outcome, safety and compliance received reduced weights (5 percent each), reflecting their indirect but nonetheless essential influence on general productivity.

Calculation of Weighted Scores

The corresponding weights given to each KPI were then multiplied by the raw results. For instance, the weighted score for that KPI would be as follows if preventative maintenance received an 8 for equipment reliability:

$$Weighterrd\ score = raw\ score * weight \tag{3}$$

A weighted outcome for each strategy in each KPI category was produced by doing this computation for every KPI under every maintenance approach. An overall score was calculated by adding the weighted scores for each KPI for each strategy.

Ranking and Interpretation

The maintenance solutions were graded from most to least successful in accordance to the total scores. The maintenance objectives, maintenance issues, and technology used by the several organizations were all replicated.

3.3.2.5 ANOVA and Post Hoc Analysis Using Tukey's HSD

A statistical method called analysis of variance - ANOVA is utilized to ascertain if the means of three or more independent groups differ in ways that are statistically significant. This helps in determining if data variances are the outcome of random chance or differing amounts of a categorical independent variable. The post hoc test, such Tukey's Honestly Significant Difference (HSD) test, is utilized to pinpoint the precise groups that are different from one to another after an ANOVA shows that there are significant differences.

- **ANOVA (Analysis of Variance)**

ANOVA analyzes the means of distinct groups by examining the variance within each group and the variation across groups. The following are crucial steps in doing an ANOVA:

Developing Hypotheses:

- All groups Means are equal, according to the null hypothesis (H0).
- At least one group mean differs from the others, according to the alternative hypothesis (Ha).

- **Calculation of F-Statistic**:
  - The F-statistic is calculated by dividing the variance between groups by the variance within groups.
  - The F-value is then compared with critical a value from the F-distribution table using degrees of freedom of the denominator and numerator (between groups) (within groups).

$$F = \frac{\text{Variance Between Groups}}{\text{Variance Within Groups}} \quad (4)$$

- **Decision Making**

The null hypothesis is rejected if the computed F-value is greater than the critical value, signifying that the group means differ significantly.

The means of various groups pertaining maintenance management techniques, like productivity across different industry sectors, facility sizes, and geographic locations, were compared in this research using ANOVA. The purpose was to ascertain whether these various circumstances had a substantial influence on the efficacy of maintenance measures.

- **Post Hoc Analysis Using Tukey's HSD**

Tukey's Honestly Significant Difference (HSD) test is used as post Hoc analysis to identify which particular groups vary after an ANOVA reveals significant differences between group means. Tukey's HSD is very helpful since it helps the whole error rate stays at the intended level by controlling for type1 error across numerous comparisons.

- **Calculation of the Tukey HSD**:
  - Each pair of group means' difference is computed and compared to critical value called the HSD in the Tukey HSD test.
  - The amount of groups within-group variance determine the HSD value, which is obtained from studentized range of distribution.

$$\text{HSD} = q \cdot \sqrt{\frac{\text{MS}_{\text{within}}}{n}} \quad (5)$$

Where:

- q is the critical value from the studied range of distribution.
- $\text{MS}_{\text{within}}$ is the mean square within groups (i.e., the pooled variance).
- n is the amount of observations per group.

Pairwise Comparisons:
- For each pair of group means, the difference is compared to the HSD value.
- If the absolute difference between a pair of means exceeds the HSD value, the difference is considered statistically significant.

- **Interpretation of Results**
  - The Tukey HSD test results highlight which of the specific groups differ significantly from each other, providing deeper insights into where the variations lie.

Tukey's HSD test was used in this research work, after the ANOVA to pinpoint particular variations in productivity or other outcome measures across different industries, facility sizes, and geographical areas. A more understanding of how the maintenance processes affected different situations was possible by this post hoc analysis, which led to more focused suggestions for improving maintenance tactics.

ANOVA and Tukey's HSD together offered a strong framework for investigating and analyzing the distinctions in maintenance management techniques among various groups, guaranteeing that the outcomes were both practically significant and statistically sound.

4. Results/Discussion

Statistical Analysis of Maintenance Strategy Shifts: Chi-Squared Test Application

A statistical technique for assessing significant discrepancy between the predicted and observed frequencies in one or more categories is the chi-squared test. To determine the distribution of maintenance techniques reported in 2020 differs significantly from those reported in 2019, the Chi-squared test was utilized in this analysis. The test enables us to find the movements seen in 2020 are statistically significant or result of chance variation by using the 2019 data as the predicted baseline. Since major shifts in strategy adoption may be a reflection of larger business trends that affect operational efficiency, this is especially pertinent to comprehending how changing maintenance management schemes affect productivity.

Table 1. Comparison of Maintenance strategies: Expected vs. Observed Counts Based on 2019 and 2020 Survey Data

Category	2019 Percentages	2019 Expected Count (Out of 199)	2020 Percentages	2020 Observed Count (Out of 171)
Reactive Maintenance	20%	39.8	15%	25.65
Preventive Maintenance	80%	159.2	70%	119.7
Predictive Maintenance	35%	69.65	40%	68.4
Reliability-Centered Maintenance	25%	49.75	30%	51.3

Table 1 presents the percentages and the corresponding counts for maintenance strategies in 2019 and 2020, which were deployed to execute the Chi-squared test.

4.3.1 Chi squared component

$$\text{Chi-Squared Component } = \frac{(\text{ Observed } - \text{ Expected })^2}{\text{Expected}}$$

- **Reactive Maintenance**

$$\text{Chi-squared } = \frac{(25.65 - 39.8)^2}{39.8} = \frac{200.8225}{39.8} \approx 5.05$$

- Preventive Maintenance

$$\text{Chi-squared } = \frac{(119.7 - 159.2)^2}{159.2} = \frac{1554.25}{159.2} \approx 9.76$$

- Predictive Maintenance

$$\text{Chi-squared } = \frac{(68.4 - 69.65)^2}{69.65} = \frac{1.5625}{69.65} \approx 0.02$$

- Reliability-Centered Maintenance

$$\text{Chi-squared } = \frac{(51.3 - 49.75)^2}{49.75} = \frac{2.4025}{49.75} \approx 0.048$$

Table 2 Chi-Squared Test Results for Maintenance Strategies: Comparison of 2019 Expected and 2020 Observed Counts

Maintenance Strategy	2019 Expected Count	2020 Observed Count	Chi-Squared Component
Reactive Maintenance	39.8	25.65	5.05
Preventive Maintenance	159.2	119.7	9.76
Predictive Maintenance	69.65	68.4	0.02
Reliability-Centered Maintenance	49.75	51.3	0.048
Total			**14.878**

- Degrees of Freedom (df): 3
- Critical Value at 0.05 Significance Level: 7.815
- Total Chi-Squared Statistic: 14.878

The difference between the total Chi-squared statistic (14.878) and the critical value is significant (7.815). This implies that the spread of maintenance philosophy has changed between 2019 and 2020 in ways that are statistically significant. These changes reflect the evolving objectives of maintenance as companies adopt more predictive and reliability-focused strategies. A change like this can directly impact productivity and overall efficiency by reducing downtime, improving equipment dependability, and optimizing maintenance costs.

4.4 Ranking Analysis

This section, ranking analysis is deployed to rank the various maintenance schemes, challenges, technology, and goals spotted in the 2019 and 2020 surveys. By ranking each category based on its purported importance, we can quickly ascertain which components are most crucial in each year and monitor how their significance has changed over time. Providing a stark contrast, this study aids in noting areas for strategic attention and enhancement in maintenance management procedures.

4.4.1 Summary of Ranks

Information on ranking analyses about different maintenance strategies, problems, technologies, and goals has been provided according to data from questionnaires for both 2019 and 2020, have been summarized in Table 4.5 below. The priorities at both points in time can be compared since, in the table, it highlights the relative importance of each area at each period under review. We may find trends and areas of attention that have either become more or less important by looking at these rankings, which will give us important information for enhancing maintenance procedures

Table 3. Rank Summary

Category	**2019 Rank**	**2020 Rank**
Primary Maintenance Strategy		
Reactive Maintenance	4	4
Preventive Maintenance (PM)	1	2
Predictive Maintenance (PdM)	3	3
Reliability-Centered Maintenance (RCM)	2	1
Main Challenges		
Budget Constraints	1	1
Aging Equipment	2	2
Lack of Skilled Staff	3	3
Increasing Complexity of Equipment	4	4
Use of Technology		
CMMS	1	1
IIoT	3	3
Predictive Analytics	4	4
Mobile Devices	2	2
Maintenance Goals		
Reduce Downtime	1	1
Improve Equipment Reliability	2	2

4.4.2 Analysis and Insights on Ranking

Primary Maintenance Strategy:

- It is known that in both years, preventive maintenance constantly comes in first is still the most popular approach.
- A move toward more forward-thinking maintenance techniques is presented in the fact that reactive maintenance is routinely ranked lowest.

Maintenance Budget Increase:

- Majority of respondents in both years reported a budget increase, with a slight rise in 2020. This suggests an increasing focus on maintenance funding.

Main Challenges:

- The biggest obstacle is budgetary constraints, which are followed by aging equipment. This implies that the necessity to maintain aging machinery and financial constraints are the vital issues.

- Although they score lower, the shortfall of skilled personnel and the intricacy of equipment are equally significant, indicating persistent problems with workforce competence and technological integration.

Use of Technology:

- Most popular technology: CMMS, followed by mobile devices. This stresses how central the role of technologies is in maintenance.
- Predictive analytics and IIoT-while gaining more popularity-are less common, possibly due to issues with integration, cost, or complexity.

Maintenance Goals:

- The objective is to lessen downtime, with improving reliability coming in second. This reflects a target on sustaining operating efficiency and minimizing disruptions.

4.5 Analysis of Variance (ANOVA) and Post-Hoc Analysis

This section highlights the outcome of the ANOVA analysis conducted on data regarding main maintenance tactics, major problems, and technology use. The means of three or more groups can be compared statistically to see their differences. ANOVA was deployed to compare the data from 2019 and 2020 to assess any significant differences in the categories listed above.

Below show details of the ANOVA analysis results for individual group

4.5.1 Primary Maintenance Strategy

Summary of Data:

- **Group 1 (2019):** Count = 4, Sum = 160, Average = 40, Variance = 750
- **Group 2 (2020):** Count = 4, Sum = 155, Average = 38.75, Variance = 539.58

Table 4 ANOVA 1 Results

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	3.125	1	3.125	0.0048	0.947	5.987
Within Groups	3868.75	6	644.792			
Total	3871.875	**7**				

The key maintenance processes employed in 2019 and 2020 do not differ statistically significantly, F-value of 0.0048 and the P-value of 0.947 (higher than 0.05). Rather than reflecting a major difference in strategy efficacy, the observed variations are probably the outcome of random chance.

Post-Hoc Analysis: The post-hoc pairwise comparisons utilizing Tukey's HSD (Honestly Significant Difference) test revealed no major significant distinctions between the years 2019 and 2020 for any of the primary maintenance strategies, considering the non-significant ANOVA outcome. This supports the finding that there haven't been many changes in the deployment of strategies over these years.

4.5.2 Main Challenges

Summary of Data:

- **Group 1 (2019):** Count = 4, Sum = 150, Average = 37.5, Variance = 41.67
- **Group 2 (2020):** Count = 4, Sum = 170, Average = 42.5, Variance = 41.67

Table 5: ANOVA 2, Results:

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	50	1	50	1.2	0.315	5.987
Within Groups	250	6	41.667			
Total	300	**7**				

The research reveals no statistically significant distinction between the primary obstacles encountered in 2019 and 2020, with an F-value of 1.2 and a P-value of 0.315. The variation between the years is not substantial enough to imply that the respondents' difficulties have changed significantly.

Post-Hoc Analysis: Despite the ANOVA's P-value of 0.315, a post-hoc Tukey's HSD test was used, however. The findings verified no notable variations between the two years in any of the challenges for instance financial limitations, outdated equipment, etc.). This shows that the industry's problems stayed the same and that any variations in the stated percentages are not statistically significant.

4.5.3 Use of Technology
Summary of Data:

- **Group 1 (2019):** Count = 4, Sum = 145, Average = 36.25, Variance = 322.92
- **Group 2 (2020):** Count = 4, Sum = 165, Average = 41.25, Variance = 322.92

Table 6 ANOVA Results 3,

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	50	1	50	0.1548	0.708	5.987
Within Groups	1937.5	6	322.917			
Total	1987.5	**7**				

As depicted, the F-value of 0.1548 and the P-value of 0.708, no statistically significant difference in the proportion of technology used in 2019 and 2020. In accordance to the data, there were no major variations in the usage of technology for years under review.

Post-Hoc Analysis: Despite the ANOVA P-value of 0.708 for technology use, a post-hoc analysis was conducted using Tukey's HSD. In line with the test, there were no appreciable variations in the uptake of technologies like mobile devices, IIoT, CMMS, or predictive analytics between 2019 and 2020. This demonstrates that during this period, there was no notable variation to the technology environment in the industry.

There are no statistically significant differences between 2019 and 2020 in the three categories of primary maintenance techniques, key problems, and technology utilization, in respect to the ANOVA and post-hoc tests. This indicates that there haven't been any distinctive changes in maintenance processes or difficulties for the years. The stability and consistency of maintenance tactics during this time period are further supported the differences shown are probably the result of random fluctuations rather than significant changes in industry practices.

4.5 Maintenance Management Strategies

4.5.1 Prevalence of Maintenance Strategies

The surveys offered comprehensive information on the periodicity of diverse maintenance techniques applied at different industries. Reactive maintenance, PdM, and CBN were the main tactics that were found.

1. Reactive Maintenance: Known as "run-to-failure," this approach entails doing repairs after equipment has malfunctioned. As presented by 2019 Plant Engineering Maintenance Report, this philosophy is still used in some industries when immediate maintenance is practical, despite being less popular because of its disruptive nature.
2. Preventive maintenance-PM is a tactic used to stop failures by doing routine, planned maintenance tasks. Preventive maintenance was the most generally used method, as per the State of Industrial Maintenance Report 2020, with a sizable majority of respondents citing its use to increase equipment lifecycle and reliability.
3. Predictive Maintenance- PdM**:** Uses data and cutting-edge technologies to envision breakdowns prior to failures. According to both studies, PdM is becoming more popular because of its ability to drastically lower maintenance expenses and downtime.
4. RCM stands for Reliability-Centered Maintenance. This methodical approach guarantees the efficient maintenance of vital assets to enhance general performance and dependability. Pursuant to the reports, RCM is becoming gradually popular, especially in sectors with intricate and vital gear.

4.5.2 Adoption of Predictive vs. Preventive Maintenance-PM

Surveys revealed an interesting trend in the usage of predictive versus preventive maintenance:

1. PM was embraced by more than 80% of respondents, as per the 2019 Plant Engineering Maintenance Report. Its easy setup and the capacity to carry out maintenance activities during scheduled downtime, which minimizes interruption, were the fundamental factors in its broad adoption.

2. Predictive maintenance has been increasing popularity, although being less common than preventative maintenance, as indicated in the State of Industrial Maintenance Report 2020. Roughly 40% of those surveyed said they used PdM methods. Improvements in sensor technologies, data analytics, and the Industrial IoTs are driving the adoption since they offer live tracking data for more precise maintenance forecasts.

PdM is steadily becoming popular because of its benefits in lowering overall maintenance costs, improving maintenance, and limiting unplanned downtime. However, its wider adoption may be hampered by the greater setup cost and the requirement for technical know-how.

Conclusion

This study, which compares data from the 2020 State of Industrial Maintenance Report and the 2019 Plant Engineering Maintenance Report, reveals notable shifts in the uptake of maintenance strategies, especially the persistence of PM and the growth of PdM across industrial sectors. The deployment of the Chi-squared test to determine the statistical significance of these changes is the major achievements, providing a sound methodological framework for comprehending how maintenance management is changing. Technology's contribution to maintenance is becoming more widely acknowledged. As per the polls, the deployemnt of IIoT and CMMS has increased from 60% in 2019 to 65% in 2020. (from 25 percent to 30 percent). Additionally, predictive analytics increased, suggesting a tendency toward using digital technologies to maximize productivity and efficiency. The results highlight the Relevant of technologically sophisticated approaches, such PdM, in raising equipment reliability, decreasing failures, and increasing operating efficiency. All things considered, this study adds significantly to the body of knowledge on the influence of maintenance output and operational effectiveness, and to the field's practical applications.

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