Assessing Maintenance Performance within Manufacturing Entities: A Comprehensive Evaluation and Tangible Guidance

Sanjeev Kumar Khare [1] and Sumati Sidharth [2]

[1,2]Dept of Technology Management, Defence Institute of Advanced Technology, Pune, India

sanjeevkhare46@gmail.com

Abstract: The paper provides a comprehensive literature review and practical recommendations for measuring maintenance performance in manufacturing organizations. The study emphasizes how monitoring maintenance performance has become more important as a result of the changing nature of maintenance and the complexity of manufacturing technology. The primary objective of the research paper is to offer a thorough analysis of the practices employed for monitoring maintenance performance in manufacturing units. The paper delves into the indicators utilized to gauge maintenance performance, putting forth a suggested framework for effectively monitoring the outcomes of maintenance activities. Moreover, it concludes by presenting insights and recommendations. Costs for maintenance have increased as a result of the expanding function that maintenance plays within organizations and the complexity of production technology. The importance of process management in reaching the highest levels of equipment reliability, availability, and cost-effectiveness is emphasized in this paper. The outcome of the paper indicates the need for a more comprehensive approach to selecting important Maintenance Performance Indicators and offer potential directions for further study. The research paper is a useful tool for comprehending the procedures involved in keeping track of maintenance effectiveness. It demonstrates to be especially pertinent in the context of manufacturing policy with regards to the reliability and accessibility of diverse assets.

Keywords: Maintenance Performance Key Indicators, Equipment Reliability and Availability, Predictive and Preventive Maintenance, MTBM, MTBF, MTTR, Enhancing Maintenance Management.

1 Introduction

The efficacy, efficiency, and general performance of maintenance activities within an organization are assessed and evaluated using a set of quantifiable metrics and measures known as Maintenance Performance Key Indicators. With the ultimate goal of improving equipment reliability, lowering downtime and minimizing maintenance costs, these indicators are crucial for monitoring, managing, and optimizing maintenance activities. The useful insights that maintenance KPIs offer enable organizations to take data-

M. Rani Nimmagadda et al. (eds.), *Proceedings of the 3rd International Conference on Reinventing Business Practices, Start-ups and Sustainability (ICRBSS 2023)*, Advances in Economics, Business and Management Research 277,
https://doi.org/10.2991/978-94-6463-374-0_71

driven choices, put preventive measures in place, and continuously enhance their maintenance plans. The importance of monitoring maintenance performance within manufacturing organizations has significantly increased in recent years. The evolution is brought about by the changing maintenance function and the increasingly complicated production technology. This paper delves into a literature review that not only offers a conceptual framework but also guides future research in the realm of maintenance performance measurement.

2 Frame Work for Maintenance Performance Indicators (MPI): A Starting Point

The degradation of manufacturing systems begins soon after commissioning, with normal wear, deterioration, and potential failures due to factors like exceeding design limits or operational errors These challenges lead to quality issues, speed losses, environmental contamination, safety hazards, and equipment downtime. Operating expenses, profitability, customer satisfaction, and productivity may all suffer as a result of such results. Maintenance management must decide wisely on maintenance goals and tactics in order to maintain optimal plant operation and meet output targets at the lowest possible cost. The goals of maintenance are related to meeting production targets (through high availability) while upholding safety regulations, system conditions, and quality standards [1] [2]. In addition, maintenance funds are allotted to guarantee that production machinery is operating at peak efficiency, the plant reaches its intended lifespan, safety regulations are respected, and aspects like energy and raw material use are optimized [3].

Evaluating performance is a foundational managerial concept. Similar to other facets of manufacturing, the assessment of performance holds significance in overseeing maintenance operations. Clearly defined performance indicators have the potential to aid in recognizing discrepancies between current and desired performance, offering insights into the progress made in bridging these gaps. Moreover, performance measures serve as a crucial connection between overarching strategies and managerial actions, thereby facilitating the implementation and execution of initiatives for improvement [4]. Furthermore, these measures can help maintenance managers focus resources and attention on specific areas of the production system that can affect manufacturing performance. Measuring and quantifying the maintenance process's input and output provides challenges. This challenge stems from the complex interrelationship between manufacturing and maintenance [5]. Most academics concur that a thorough performance measurement is required to assess how the maintenance function contributes to manufacturing and more general business strategic goals [6].

In the literature, various approaches for assessing maintenance performance have been proposed. Value-based performance measurement is a system audit approach that researchers have developed to measure how much the maintenance system contributes to organizational success [7]. This approach emphasizes the lag time between actions and results and takes into account how maintenance efforts will affect the organization's future value. Researchers have also supported composite metrics like the maintenance productivity index, which determines the proportion of maintenance input to maintenance output [8]. Nevertheless, this method has drawbacks, offering a limited viewpoint on maintenance performance and posing difficulties in measuring a variety of maintenance inputs. Researchers have suggested employing the well-known balanced scorecard as part of a strategic approach for managing maintenance performance [6]. The effectiveness of this approach depends on how strongly and favorably strategy affects the total performance of the firm. There is a dearth of research that has attempted to define and measure how maintenance affects a company's primary competitive objectives, which are cost, quality, and production [9]. This model provides strategic decision help in selecting different improvement plans and evaluates the cost-effectiveness of maintenance investments.

Various maintenance measures are found in the literature, with classifications based on different criteria. Three layers (strategic, tactical, and operational) of maintenance control and performance indicators have been identified by some authors using the time horizon [10]. Maintenance strategies that are in line with each level are then created to facilitate efficient control [11]. The authors have also presented a three-dimensional hierarchical framework of maintenance performance indicators namely production expenses, Overall Equipment Effectiveness (OEE), and production quality [12]. The goal of this system is to clarify the function and importance of distinct indicators across many hierarchies.

A study was carried out by employing a business process approach to examine the maintenance function [13]. This approach, grounded in process management principles, operates under the belief that the process itself generates the desired outcomes. Consequently, managing and measuring the process becomes imperative. By adopting this approach, we can effectively oversee the maintenance process, striving for optimal equipment reliability, availability, and cost- effectiveness. Maintenance is a multifaceted process encompassing various aspects, phases, and domains. To assess maintenance strengths and weaknesses, it is crucial to divide the maintenance process into distinct areas, each requiring its performance evaluation. Examples of these areas includes preventive maintenance, material management, planning and scheduling, maintenance budgeting and work control. To lay the foundation for a maintenance performance monitoring framework, the initial step involves defining the concept of maintenance monitoring. In this context, it is expected that the manufacturing plant implements a maintenance monitoring system to promote maintenance excellence by addressing current or foreseeable flaws. Figure 1 shows the suggested approach for tracking maintenance performance. The suggested system for monitoring maintenance includes a combination of leading and lagging indicators. In the context of maintenance, leading indicators assess how effective the maintenance process is, while lagging indicators measure the outcomes achieved. The reason for tracking maintenance performance indicators beyond equipment reliability and availability is to identify the sources of negative trends (leading indicators). The end goal of maintenance, on the other hand, is the availability and dependability of systems and parts that satisfy operational and general plant needs.

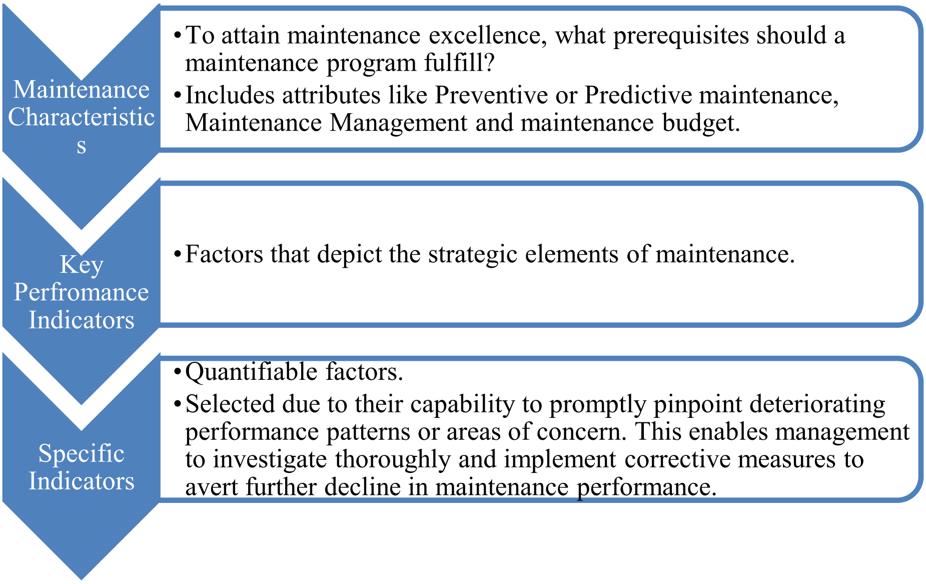

Fig. 1. A method for overseeing maintenance performance.

For measuring maintenance performance on this broader scale, we rely on lagging performance indicators like failure frequency or Mean Time Between Failure (MTBF), downtime due to maintenance and the number of unresolved backlogs. It is crucial to grasp that performance indicators are not merely a way to showcase success but they also serve as a tool for successfully managing the maintenance process. Organizations should utilize these indicators to uncover possibilities for enhancement rather than treating them as measures of success or failure. Some of the Maintenance Performance Indicators are shown in figure 2 below.

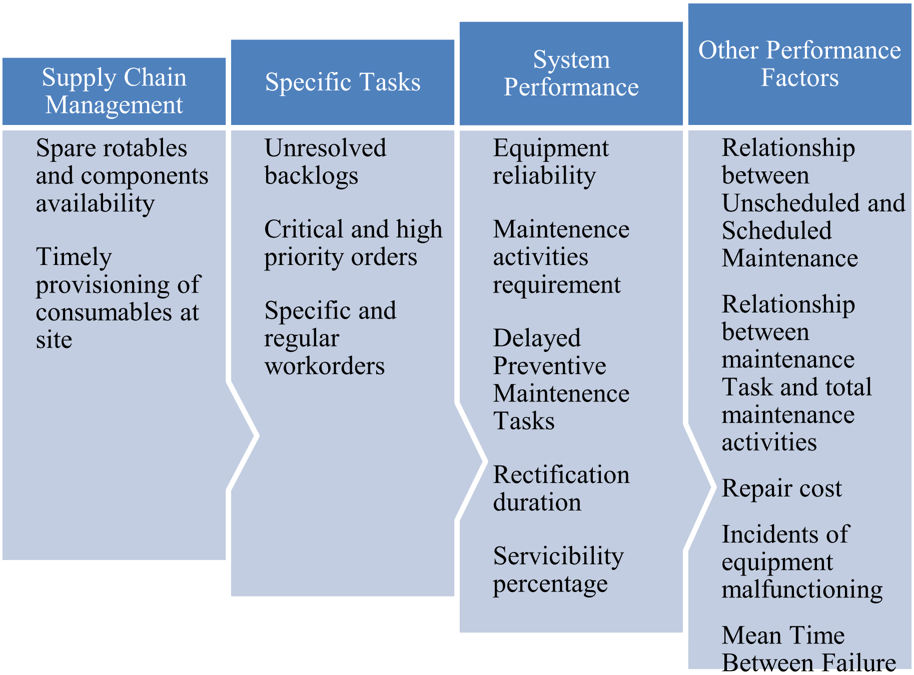

Fig. 2. Key Maintenance Performance Indicators

3 Role of Maintenance Performance Indicators in Enhancing System Reliability and Availability.

The ultimate goal of maintenance activities is to ensure the reliability and availability of systems and equipment. Assessing the quality of this outcome relies on a crucial component within the system that measures maintenance performance [14]. Many manufacturing facilities implement preventive maintenance programs to uphold equipment performance within design parameters and extend equipment lifespan. In tandem with predictive maintenance measures, preventive maintenance proactively addresses potential issues before they gets materialize. This approach enables equipment repairs to occur at times that do not disrupt production schedules, which ultimately reduces the downtime costs and boost profitability. Keeping this in mind, some of the critical attributes associated with key maintenance performance indicators in enhancing System reliability and availability has been redefined. These indicators are mentioned below.

3.1 Quantifying Maintenance Rework. This metric serves as a tool for tracking rework levels, but it falls short in uncovering the underlying reasons behind deviations from the maintenance schedule.

3.2 Adherence to Planned Schedules. This indicator is defined as the percentage of scheduled work completed in relation to the total available work time for scheduling. However, it should be noted that this metric is not suitable for assessing issues related to maintenance diligence or negligence.

3.3 Spare Parts and Materials Management. This metric stands as a crucial component for bolstering efficient maintenance planning and scheduling, while upholding the maintenance process's quality and effectiveness. Enhancing the management of materials and spare parts has the potential to create additional time for maintenance planners, supervisors, and hourly maintenance staff.

3.4 Budget Allocation for Maintenance. This metric holds growing significance within the evolving economic landscape of the energy market. In this competitive manufacturing environment, curtailing production expenses, with a special focus on maintenance costs, is imperative for long-term viability. Cost-effective maintenance ought to serve as a pivotal performance indicator for manufacturing plants.

3.5 Availability or Unavailability for System or Equipment. The concept of "availability" concerning a system or equipment refers to the likelihood that the system or equipment is operational when required. It can also be described as the portion of time that the service is accessible. Conversely, "unavailability" is defined as the probability that a system or equipment is not accessible when needed, or as the portion of time when the service is unavailable.

3.6 Reliability of System or Equipment. The concept of reliability for a system or equipment is articulated as the probability that the system or equipment will execute its designated function without experiencing any failures within a specified timeframe.

3.7 Mean Time Between Failures (MTBF). A frequently employed gauge of reliability is referred to as Mean Time Between Failures (MTBF), which represents the average duration expected between instances of failure [14]. MTBF signifies the average operational period (typically in hours), during which a component operates without encountering a failure. It also denotes the duration for which a user can reasonably anticipate a device or system to function before a debilitating fault arises. It is calculated as the total hours under observation divided by the number of failures. Another interpretation presents MTBF as a measure of anticipated system reliability, derived statistically from the known failure rates of different system components.

3.8 Mean Time to Repair (MTTR). A maintenance service interruption resulting from a failure is quantified as MTTR [14]. MTTR encompasses the time required for detecting the failure, diagnosing the fault and completing the actual repair process. The ability to predict the duration during which a system or component will be unavailable due to maintenance activities is of utmost significance in reliability and availability assessments. Employing a maintenance prediction approach enables the identification of areas with suboptimal maintainability, ultimately leading to decreased system availability. Subsequent modifications in maintenance protocols may be recommended to enhance system availability. MTTR plays a crucial role in evaluating the availability of repairable systems and is typically computed as the total repair time expended within a defined period (in hours) divided by the number of repair events occurring in that specific timeframe.

3.9 Mean Time Between Maintenance (MTBM). Another indicator closely linked to equipment or system availability is MTBM. MTBM is defined as the average duration between two successive maintenance actions for a specific piece of equipment or component [14]. This metric is specifically applicable to maintenance actions that necessitate or result in a disruption of functionality. Unlike MTBF, which accounts solely for failures, MTBM encompasses both corrective and preventive maintenance actions. MTBM is computed by dividing the total operational time by the number of maintenance actions conducted within the same timeframe. This metric proves valuable for evaluating maintenance effectiveness, as it quantifies how often maintenance tasks interrupt the functioning of the equipment or system. The primary goal of this indicator is to minimize the frequency of function interruptions by establishing an appropriate maintenance strategy and implementing the correct maintenance procedures.

4 Role of Maintenance Performance Indicators in Enhancing Maintenance Management.

Effective coordination of maintenance activities is vital to prevent any potential disruption to the regular operation of the manufacturing unit, exemplifying a hallmark of sound maintenance management. A notable increase in such interferences indicates deficiencies in planning and coordinating maintenance activities. With this in mind, some of the critical attributes associated with key maintenance performance indicators in Enhancing maintenance management has been redefined. These indicators are mentioned below.

4.1 Strategic Planning and Timely Scheduling. Maintenance planning and scheduling are often regarded as the central facets of maintenance management, as they serve as a foundation for other processes like preventive maintenance and materials management. The planning and scheduling of maintenance activities within manufacturing systems [14] rely on several distinct indicators, such as planning adherence, schedule adherence, and the count of unresolved backlogs.

4.2 Management of Work Processes. The most widely adopted indicators in this category encompass maintenance rework volume, overtime maintenance hours, response time to service requests, and Wrench Time. Response time to service requests is particularly valuable in assessing the quality of services provided by contractors or Original Equipment Manufacturers (OEMs). A commitment to resolving system or equipment malfunctions within a specified timeframe necessitates effective management and strong collaboration between operations and contractors/ OEMs. This indicator also integrates improved inventory management to ensure the timely availability of spare parts, when needed. The service call-to-repair time indicator signifies the preparedness level of the contracted or OEM maintenance organization to address urgent operational requirements. A low call-to-repair time suggests a high level of efficiency within the maintenance organization, encompassing planning, coordination, resource allocation, and material management, among other factors. The Wrench Time indicator is a common metric used in various industries to gauge the efficiency of maintenance services. This metric allows for the assessment of productivity within the maintenance processes, encompassing planning, scheduling, supervision, and overall maintenance management. It serves as a tool to identify opportunities for increasing productive work time. Wrench time is expressed as the percentage of time an employee dedicates to physically operating tools, equipment, or materials in the execution of assigned tasks. It aids in evaluating how effectively the manufacturing plant plans, schedules, and executes its work.

4.3 Material Management. Effective material management is essential to the financial health of production facilities in today’s highly competitive manufacturing environment [3]. Material management encompasses several critical facets, including the management of stock items that are available but not yet utilized, maintaining inventory accuracy, addressing spare parts and material obsolescence, and evaluating vendor performance.

5 Role of Maintenance Performance Indicators in Enhancing Preventive and Predictive Maintenance.

5.1 Predictive Maintenance (PdM). PdM is a precisely timed maintenance strategy that relies on a process requiring both technology and human expertise. It entails using a variety of diagnostic and performance data, maintenance records, operator logs, and design information to quickly determine the important equipment's maintenance requirements. The integration of various data, information, and processes is crucial for a PdM programme to be successful [15]. This approach entails scrutinizing the trends in measured physical parameters in comparison to established engineering thresholds with the aim of identifying, analyzing, and rectifying issues before they escalate into failures. Maintenance plans are devised based on prediction outcomes derived from condition-based monitoring. While implementing a predictive maintenance program entails an initial investment in monitoring hardware and software, staffing, tools, and training, it ultimately yields improved equipment reliability and provides advanced insights for better planning. This results in a reduction in unexpected downtime and operating costs, a critical advantage for the manufacturing industry.

5.2 Preventive Maintenance (PM). PM can be characterized as a structured regimen of planned and scheduled activities aimed at averting equipment, system, or facility failures. To create a more comprehensive approach, PM should be complemented with PdM. PM encompasses actions such as lubrication programs, routine inspections, and adjustments. In conjunction with PdM measures, PM plays a crucial role in preemptively resolving potential issues before they materialize. One of its significant advantages is the ability to conduct equipment repairs without disrupting production schedules, thus mitigating one of the major contributors to downtime costs and enhancing profitability. An elevated level of PM, in fact, helps reduce the backlog of pending orders. This is because PM activities can be meticulously planned in advance, facilitating control over backlog levels within reasonable bounds. It is essential to prioritize PM for equipment, whose failure could compromise safety, reliability, or result in forced shutdowns. Key indicators for the preventive aspects of maintenance include the availability of systems and equipment, the dependability of systems and components, and the success of PM programs.

While PM is typically seen as an alternative to corrective maintenance, its effectiveness can vary significantly. In many instances, relying solely on PM may not be sufficient to enhance equipment reliability, ensure availability, and prevent recurring breakdowns. When a PM program is strictly time-based and solely follows the manufacturer's recommendations, its outcomes may not align with expectations. Diverse perspectives exist regarding the relationship between PM and PdM, with one view suggesting that PdM is a subset of PM [16]. According to this approach, a comprehensive PM program should incorporate predictive elements. It should encompass predictive activities aimed at inspecting equipment, components, or systems to predict potential failures before the next scheduled inspection cycle. In this interpretation of PM, a pivotal aspect of the program definition revolves around the ability to detect critical wear and impending failure in equipment.

6 Modified List of Maintenance Performance Indicators.

The development of the maintenance monitoring system discussed in [14] was founded on the concept of process management, which operates on the premise that the process inherently generates the desired outcomes. This methodology is instrumental in effectively overseeing the maintenance process, with the ultimate goal of attaining optimal levels of equipment reliability, availability and cost-effectiveness. In light of the preceding discussions, the key Maintenance Performance Indicators to specifically address the reliability and availability of both systems and equipment, as mentioned in figure 2, has been amended and same is placed at table below (Table 1).

Table 1. Modified List of Maintenance Performance Indicators

Sl No	Maintenance Key Performance Indicator	Associated parameters
1	Accessing Equipment Dependability (Reliability)	• Total count of corrective Work order Administered. • Number of incidents involving sensor and safety system malfunctions. • MTBF

Sl No	Maintenance Key Performance Indicator	Associated parameters
2	Management of Work Process	• Component repair duration according to technical specifications. • Wrench Time.
3	Assessing the efficiency of Preventive Maintenance	• Conformity with Preventive Maintenance Protocols. • Proportion of Corrective Work arising from Preventive Maintenance initiatives. • Trend analysis of backlogged Preventive Maintenance Work Orders. • Proportion of deficiencies unearthed through surveillance, testing, and inspections. • Proportion of Preventive Maintenance task to Total Maintenance Activities. • Delayed Preventive Maintenance tasks. • Count of planned tasks which are not executed. • Count of tasks not started on time, as planned. • Comparison of actual versus scheduled Man-Hours.
4	Operational status of systems and equipment	• Availability of system and equipment. • Planned Operational Interruptions. • Unplanned Operational Interruptions. • Production disruptions attributed to maintenance-induced reductions or outages. • MTBM • MTTR
5	Strategic Planning and Timely Scheduling	• Proportion of unplanned to scheduled Work Orders. • Adherence to planning guidelines. • Adherence to scheduled activities. • Proportion of completed Corrective Work Orders to Programmed Work Orders. • Unresolved backlogs.
6	Spare Parts and Material Management	• Inventory Maintenance Performance (Store Level) • Pending Maintenance Tasks requiring spare parts. • Inventory Turnover Rate. • Unused inventory items on hand. • Precision of inventory records.

Sl No	Maintenance Key Performance Indicator	Associated parameters
		• Obsolete Spare Parts and Materials. • Supplier Evaluation.

7 Prospects for Future Research

The approach attempts to clarify the function and importance of distinct indicators in various hierarchies. However, the literature primarily presents lists of Key Performance Indicators (KPIs) without offering a methodological approach for their selection or derivation. As a result, customers frequently have to decide which KPIs are pertinent to their particular circumstances. Determining an operational level-based maintenance measurement model that clearly connects maintenance goals, the maintenance procedure, and outcomes is a critical requirement for the growth of an organization. A model proposed in the present paper could be used as a basis to determine what performance indicators are suitable for a maintenance function in a given setting.

8 Conclusion.

Effective maintenance performance monitoring is an essential component of the comprehensive maintenance management system in place across all production units. The range and comprehensiveness of these monitoring systems can vary significantly, from those relying on single maintenance key performance indicators to more advanced systems integrated into the plant's asset management framework, encompassing various groups and categories of maintenance performance metrics. The creation of the maintenance monitoring system approach ensures effective maintenance process management, which eventually results in the achievement of the highest levels of equipment dependability, availability, and cost effectiveness. As a proactive measure, preventive maintenance programs should be implemented within manufacturing facilities to uphold equipment under design operating conditions and prolong its lifespan. The paper provides a comprehensive review and practical recommendations for measuring maintenance performance in manufacturing organizations. The research emphasizes how monitoring maintenance performance has become more important as a result of the changing nature of maintenance and the complexity of manufacturing technology. The study highlights the need for a more thorough approach by identifying key issues linked to maintenance performance measurement. The paper suggests that maintenance is a multifaceted process encompassing various aspects, phases, and domains, and to assess maintenance strengths and weaknesses, it is crucial to divide the maintenance process into distinct areas, each requiring its performance evaluation.

Overall, this paper contributes to the existing pool of knowledge concerning maintenance performance measurement, while also extending practical recommendations for manufacturing organizations to bolster their measurement practices in the domain of maintenance performance. By adopting a more comprehensive approach to measuring maintenance performance, organizations can strive for optimal equipment reliability, availability and cost-effectiveness, ultimately leading to improved overall equipment and performance.

References

1. A. H. C. Tsang, A. K. S. Jardine, and H. Kolodny, "Measuring maintenance performance: a holistic approach," *Int. J. Oper. Prod. Manag.*, vol. 19, no. 7, pp. 691–715, Jan. 1999, doi: 10.1108/01443579910271674.
2. J. K. Visser and M. W. Pretorius, "The development of a performance measurement system for maintenance," *South Afr. J. Ind. Eng.*, vol. 14, no. 1, pp. 83–98, May 2003, doi: 10.10520/EJC46050.
3. R. Dekker, "Applications of maintenance optimization models: a review and analysis," *Reliab. Eng. Syst. Saf.*, vol. 51, no. 3, pp. 229–240, Mar. 1996, doi: 10.1016/0951-8320(95)00076-3.
4. A. Neely, M. Gregory, and K. Platts, "Performance measurement system design: A literature review and research agenda," *Int. J. Oper. Prod. Manag.*, vol. 15, no. 4, pp. 80–116, Jan. 1995, doi: 10.1108/01443579510083622.
5. B. Al-Najjar, "Impact of real-time measurements of operating conditions on effectiveness and accuracy of vibration-based maintenance policy - A case study in paper mill," *J. Qual. Maint. Eng.*, vol. 6, no. 4, pp. 275–287, Jan. 2000, doi: 10.1108/13552510010346815.
6. A. H. C. Tsang, "A strategic approach to managing maintenance performance," *J. Qual. Maint. Eng.*, vol. 4, no. 2, pp. 87–94, Jan. 1998, doi: 10.1108/13552519810213581.
7. R. Dwight, "Frameworks for measuring the performance of the maintenance system in a capital-intensive organisation," *Univ. Wollongong Thesis Collect. 1954-2016*, Jan. 1999. Available: https://ro.uow.edu.au/theses/1582
8. H. Löfsten, "Measuring maintenance performance – in search for a maintenance productivity index," *Int. J. Prod. Econ.*, vol. 63, no. 1, pp. 47–58, Jan. 2000, doi: 10.1016/S0925-5273(98)00245-X.
9. B. Al-Najjar, "The lack of maintenance and not maintenance which costs: A model to describe and quantify the impact of vibration-based maintenance on company's business," *Int. J. Prod. Econ.*, vol. 107, no. 1, pp. 260–273, May 2007, doi: 10.1016/j.ijpe.2006.09.005.
10. R. H. P. M. Arts, G. M. Knapp, and L. Mann, "Some aspects of measuring maintenance performance in the process industry," *J. Qual. Maint. Eng.*, vol. 4, no. 1, pp. 6–11, Jan. 1998, doi: 10.1108/13552519810201520.
11. A. Parida and G. Chattopadhyay, "Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)," *J. Qual. Maint. Eng.*, vol. 13, no. 3, pp. 241–258, Jan. 2007, doi: 10.1108/13552510710780276.
12. K. Komonen, "A cost model of industrial maintenance for profitability analysis and benchmarking," *Int. J. Prod. Econ.*, vol. 79, no. 1, pp. 15–31, Sep. 2002, doi: 10.1016/S0925-5273(00)00187-0.
13. J. M. Simões, C. F. Gomes, and M. M. Yasin, "A literature review of maintenance performance measurement: A conceptual framework and directions for future research," *J. Qual. Maint. Eng.*, vol. 17, no. 2, pp. 116–137, Jan. 2011, doi: 10.1108/13552511111134565.

14. P. Vaisnys and P. Contri, "Monitoring the Effectiveness of Maintenance Programmes Through Use of Performance Indicators," JRC Publications Repository. Available: https://publications.jrc.ec.europa.eu/repository/handle/111111111/6150
15. "Near-zero downtime: Overview and trends." Available: https://www.reliable-plant.com/Read/6971/downtime-trends
16. J. Levitt, *Complete Guide to Preventive and Predictive Maintenance*. Industrial Press Inc., 2003.