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Preventive Maintenance Strategies to Increase Industrial Machine Life

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ABSTRACT

In modern industries that increasingly rely on machines and automation systems, efficient maintenance is key to maintaining production continuity and avoiding losses due to unscheduled downtime. Preventive maintenance has emerged as a more effective solution compared to the corrective maintenance approach, which is reactive. This study discusses the urgency of implementing preventive maintenance in improving machine reliability, extending equipment life, and reducing long-term costs. The use of advanced technologies such as the Internet of Things (IoT), Computerized Maintenance Management Systems (CMMS), and predictive analytics can optimize preventive maintenance by detecting potential failures early, thereby minimizing downtime by up to 50%. However, the effectiveness of this strategy is highly dependent on the readiness of the digital infrastructure and the competence of the human resources (HR) who manage the technology. Without the integration of historical data, real-time monitoring systems, and adequate training, the implementation of preventive maintenance is at risk of being less than optimal. Therefore, the development of a technology-based preventive maintenance strategy must be accompanied by increased technical and managerial capacity, as well as organizational readiness to adapt to digital change. This research shows that a structured, data-driven preventive approach can support operational efficiency, strengthen competitiveness, and support industry sustainability.

Keywords: Machine Reliability; Preventive Maintenance; Industry 4.0 Technology

INTRODUCTION

In the increasingly competitive modern industrial environment, machine reliability is a major determinant in maintaining production continuity and operational efficiency. High dependence on machines and automation systems makes any damage a potential serious threat to company productivity. According to Yaqin et al (2020), around 70% of machine failures occur suddenly and can be avoided if the right maintenance strategy is implemented. This shows that the conventional approach that only relies on maintenance after damage (corrective maintenance) is no longer relevant, especially in industries with high pressure on production time and product quality. In this context, machine reliability is not only a technical aspect, but also an indicator of the company's overall performance.

Furthermore, machine disruptions not only have a direct impact on decreasing production output, but also trigger chain effects such as late deliveries, energy waste, and product damage due to process disruptions. A study by Markulik et al (2021) states that losses due to unscheduled downtime can increase the annual revenue of the manufacturing industry. Therefore, a strategic approach is needed in machine maintenance that is not only reactive, but also predictive and preventive. This kind of strategy allows companies to identify potential failures early, optimize the machine life cycle, and minimize the risk of unwanted production disruptions.

On the other hand, preventive maintenance is present as a more proactive and systematic solution in facing the challenges of industrial machine maintenance. This approach emphasizes periodic maintenance actions before damage occurs, such as routine replacement of spare parts, lubrication, and system calibration. According to Situngkir (2019), preventive strategies can reduce the risk of machine failure by up to 50% compared to corrective approaches. In addition, the implementation of planned preventive maintenance allows companies to control costs more consistently, because maintenance is carried out under controlled conditions, not in stressful emergency situations. This provides space for companies to design a more stable and sustainable maintenance budget.

However, the implementation of preventive maintenance strategies cannot be done carelessly. Many companies fail to maximize the benefits of this approach due to the lack of historical data integration, real-time monitoring systems, and lack of technical training for operational personnel. As explained by Sopianti (2020) using the Reliability-Centered Maintenance (RCM) concept, maintenance effectiveness depends on a deep understanding of the critical functions of the machine, failure modes, and the impact of each damage on the entire production system. Without a data-based approach and risk analysis, preventive strategies can actually become a disproportionate cost burden to the results achieved. Therefore, it is important for the industry to develop a preventive maintenance framework that is structured, technology-based, and aligned with the company's operational needs.

Along with the advancement of industrial technology 4.0, preventive maintenance strategies are increasingly strengthened by the implementation of digital systems such as Computerized Maintenance Management System (CMMS), Internet of Things (IoT)-based sensors, and predictive analytics. This technology allows real-time monitoring of machine conditions, so that companies can identify declines in machine performance before more serious damage occurs. According to Judijanto et al (2024), the integration of smart sensors in the maintenance system can increase efficiency by up to 25% and reduce downtime by 35–45%. This shows that technology-based preventive maintenance not only extends the life of the machine but also strengthens the company's competitiveness through higher operational efficiency and data-based decision making.

However, the adoption of technology in preventive maintenance strategies also poses its own challenges, especially related to the readiness of human resources and digital infrastructure. Many industries, especially medium and small scale, still face obstacles in terms of initial investment, data security, and lack of digital literacy among technicians and maintenance managers. Without careful implementation planning, maintenance digitalization can actually create new complexities and risks of system failure. Therefore, a transformative approach is needed that does not only focus on hardware and software, but also on improving technical competence and organizational change management (Arifin et al., 2023). Thus, preventive maintenance can truly become a sustainable long-term strategy and provide maximum added value to the industry.

Implementing a proper preventive maintenance strategy requires comprehensive planning that not only focuses on technical aspects, but also considers organizational factors and resource management. One crucial element is maintenance scheduling based on the condition and historical performance of the machine, not just a fixed time interval. As stated by Sembiring & Elvira (2018), maintenance effectiveness is highly dependent on selecting a schedule that is in accordance with the component failure profile. Without a systematic and accurate recording system, companies will have difficulty analyzing damage trends and evaluating the effectiveness of preventive actions that have been taken. Therefore, recording maintenance history is the main foundation in data-based decision making, as well as in developing maintenance strategies that are adaptive to changes in operational conditions.

In addition, an effective preventive maintenance strategy must also be supported by adequate technician competency and a continuous training system. Many maintenance failures occur not because of ignorance of technical methods, but due to a lack of thorough understanding of system functions and diagnostic capabilities. According to Harianja et al (2025), investment in technician training has a direct correlation to increased equipment reliability and reduced maintenance costs. Therefore, companies must make human capacity development an integral part of their maintenance strategy. This approach that combines technical, managerial, and HR development aspects will result in a preventive maintenance system that is not only reactive to problems, but also adaptive to new challenges in an ever-evolving industrial environment

METHOD

This study uses a qualitative approach with a literature review method to analyze preventive maintenance strategies in increasing the service life of industrial machines. This approach was chosen because it aims to explore concepts, principles, and best practices that have been studied in various scientific and technical sources, without conducting direct experiments in the field. Qualitative research allows researchers to deeply understand the context, dynamics, and relationships between variables related to maintenance strategies in industrial settings.

The data sources in this study come from relevant secondary literature, such as indexed scientific journals (Scopus, Google Scholar, ScienceDirect), technical books, industry reports, and international standards related to machine maintenance such as ISO 55000 and Reliability-Centered Maintenance (RCM) guidelines taken from the last 10 years (2015-2025). The data collection procedure was carried out by tracing and selecting documents containing studies on the effectiveness of preventive maintenance, the use of technology in maintenance, and its effect on the service life and reliability of industrial machines. The data obtained were then analyzed thematically using content analysis techniques, to identify key patterns, implementation challenges, and strategic recommendations that can be applied in an industrial context. Thus, the results of this study are expected to provide theoretical and practical contributions to the development of technology-based maintenance strategies that can only be successful if supported by human resources who have adequate competence and readiness.

RESULT AND DISCUSSION

The Urgency of Preventive Maintenance Strategy in Modern Industry

1. Weaknesses of Corrective Maintenance Approach in Conventional Industries

The corrective maintenance approach, which is a maintenance strategy that is only carried out after a tool or machine is damaged, is still widely applied in conventional industries, especially in companies with low levels of digitalization and automation. This strategy is considered simpler and more cost-effective at the start because it does not require sophisticated monitoring systems or resources to carry out routine maintenance. However, in the context of long-term operations, this approach tends to cause serious problems, both technically, operationally, and financially. One of the most obvious impacts is the emergence of unexpected downtime, which can suddenly stop the production process. This not only disrupts the continuity of operations, but also has a direct impact on delivery delays, loss of potential revenue, and even damage to the company's reputation in the eyes of customers.

In addition to disrupting the production process, corrective maintenance also accelerates machine degradation and reduces the technical life of the equipment. Because maintenance is not carried out regularly and predictively, important components in the machine wear out undetected, until they finally fail completely. According to Baru et al (2024), systems that are allowed to operate until they fail completely tend to experience more extensive damage, which includes not only the main components but also the surrounding support systems. This worsens the overall condition of the machine and has an impact on decreasing energy efficiency and output stability. Even in the long term, the increasing frequency of damage increases the risk of major overhauls that drain the budget and production time.

Financially, corrective maintenance incurs much higher operational costs than preventive or predictive maintenance. Costs come not only from the purchase of spare parts that are often urgent and expensive, but also from the need for emergency technicians, overtime, and additional logistics such as fast delivery and supporting equipment. The cost of repairs due to sudden failures can be three to four times greater than routine maintenance (Arfan et al., 2025; Lubis, 2017). In addition, sudden damage often requires companies to stop the entire production line, so that indirect costs such as lost productivity, potential income, and opportunity costs become very significant. If this happens repeatedly, the total cost of ownership (TCO) of the machine will exceed its investment value.

From an asset management and industrial risk management perspective, reliance on corrective approaches indicates a weak technical risk planning and mitigation system. A study by the European Federation of National Maintenance Societies (EFNMS) found that companies that rely on predictive maintenance can increase machine reliability by up to 25% and reduce maintenance costs by up to 30%. This proves that data-driven and predictive maintenance approaches are much more efficient in ensuring the continuity of modern industrial operations. Therefore, although corrective maintenance is still common in conventional industries, this approach is increasingly seen as obsolete in the modern management framework that emphasizes efficiency, reliability and sustainability. The transformation towards a predictive or preventive maintenance system supported by digital technology is an important step to avoid long-term losses caused by such reactive patterns.

2. Preventive Maintenance as a Strategy for Operational Efficiency and Reliability

Preventive maintenance is a scheduled maintenance strategy carried out to prevent damage or disruption to industrial equipment before system failure occurs. This approach emphasizes proactive actions in the form of routine inspections, lubrication, replacement of worn components, and scheduled technical testing. This strategy is fundamentally different from corrective maintenance which is reactive and generally more expensive because it is carried out after damage occurs. In the context of modern operational management, preventive maintenance is considered a form of quality control and efficiency that is integral to the production system. According to Romadhon (2024), this approach can reduce machine downtime by 30-50%, while significantly increasing production efficiency. This reduction in downtime is crucial, considering that irregularities in production can have an impact on disrupting the supply chain and causing financial losses.

Furthermore, preventive maintenance contributes greatly to extending the service life of industrial assets. By maintaining equipment in optimal working condition, potential technical degradation and major damage can be avoided. This is in line with the concept of reliability-centered maintenance (RCM), which emphasizes the importance of maintaining equipment function to avoid major and expensive damage consequences. A study by Utomo (2018) shows that a preventive maintenance strategy can reduce annual maintenance costs and reduce the frequency of major unit replacements. Thus, companies not only gain short-term efficiency in the form of repair cost savings, but also long-term efficiency through reducing the need for heavy equipment replacement investments. In addition, optimal temperature, vibration, and lubrication control also play a role in avoiding micro-damage that is difficult to detect but has a major impact in the long term.

From a managerial and strategic perspective, preventive maintenance can be viewed as an investment in operational excellence and company competitiveness. With a more reliable and predictive production system, companies can respond to market demand more flexibly and quickly. This supports the lean manufacturing and just-in-time production approaches, which rely heavily on process stability and minimal production disruptions. According to Defriyanti & Ernawati (2021), companies that adopt a structured maintenance system have advantages in terms of operational risk management and capacity planning. In the midst of competitive market dynamics, the reliability of the production system is a significant added value in maintaining reputation and customer satisfaction.

In addition to supporting efficiency and reliability, preventive maintenance is also in line with the principles of sustainable manufacturing. By reducing major breakdowns and energy waste due to suboptimal machine operation, this approach helps companies reduce their carbon footprint and industrial waste. This is becoming increasingly important in the context of stringent environmental regulations and increasing public awareness of environmentally friendly industrial practices. In a study by Manalu (2020), it was found that companies implementing preventive maintenance experienced a 10-15% reduction in energy consumption compared to companies that only relied on corrective maintenance. Therefore, this strategy is not only a technical tool, but also an important component in the industrial transformation towards sustainable efficiency and social responsibility.

Integration of Technology and HR Competence in Preventive Maintenance Strategy

1. The Role of Digital Technology in Optimizing Preventive Maintenance

The digital transformation in the manufacturing industry has shifted the paradigm of preventive maintenance from traditional methods that rely on time or certain intervals to a condition-based and predictive approach. In this regard, the Internet of Things (IoT) plays a central role, enabling real-time monitoring of machinery and equipment. Sensors installed on machines can measure various parameters, such as temperature, vibration, pressure, and energy consumption, providing a comprehensive picture of the machine's operational condition. According to research by Aryza & Novelan (2025), IoT technology can detect small changes in machine conditions that would not be visible through manual inspection, enabling prediction of failures before they occur. This is crucial in preventing larger damage that can lead to costly production downtime and significant financial losses.

In addition to IoT, the implementation of a Computerized Maintenance Management System (CMMS) provides additional benefits in preventive maintenance management. This system not only facilitates maintenance scheduling based on historical data, but also stores a complete history of maintenance, component replacement, and damage that occurs to the equipment. Research by Mursidi & Sarjito (2025) shows that the use of CMMS is directly related to increased operational efficiency, as it allows companies to plan and manage maintenance more precisely and in a structured manner. With CMMS, companies can avoid late or forgotten maintenance, which is often the main cause of machine failure. It also helps in managing spare part inventory and speeds up response to repair needs, which in turn increases productivity and reduces unexpected costs.

One of the technologies that is increasingly developing and has a significant impact on preventive maintenance is predictive analytics. This technology uses machine learning-based algorithms to analyze historical and real-time data to predict the possibility of failure or damage to equipment. For example, the use of predictive models in industrial machines makes it possible to project when certain components, such as pumps or motors, are likely to fail based on patterns detected from previous operational data. According to Zaenudin & Riyan (2024), the application of predictive maintenance can reduce downtime by up to 50% and save costs by up to 30% compared to traditional maintenance methods. In addition, this technology also helps in maximizing machine life and extending component replacement cycles, which reduces the frequency of large expenditures for urgent repairs.

However, although the potential of digital technology in preventive maintenance is enormous, there are several challenges that must be overcome for the adoption of this technology to be successful. First, the readiness of the company's digital infrastructure is the main key. The implementation of IoT, CMMS, and predictive analytics requires a stable internet network, reliable sensor devices, and a sophisticated data management system. In addition, companies need to prepare a workforce that has skills in data management and digital technology. According to Amanda et al (2024), the success of implementing digital technology in maintenance is highly dependent on the organization's ability to manage and analyze the very large volume of data generated by IoT devices. In addition, although this technology can provide long-term savings, the high initial investment costs and changes in work culture and internal company policies can be obstacles to adopting this system comprehensively. Therefore, success in implementing digital technology depends not only on choosing the right tools, but also on the organization's readiness to adapt to rapid and complex technological changes.

2. The Importance of HR Competence and Readiness in Maintenance Transformation

In the modern world of maintenance, technology does play an important role in optimizing operations and reducing downtime. Technology-based preventive maintenance systems, such as condition-based maintenance and reliability-based maintenance, provide a more accurate picture of equipment status. However, even though technology has developed rapidly, its implementation will not be successful without the full support of competent human resources. This is because technology will only be effective if it can be operated properly by technicians who have sufficient understanding. Technicians not only need to know how to use devices and tools, but also how to interpret the data generated and make decisions based on that information. Without a deep understanding, technology can actually be a hindrance rather than a solution.

Reflecting on a study conducted by Herwantono & Nugraha (2022), they stated that HR development, both technically and managerially, is one of the key factors in implementing reliability-based maintenance. HR who are not only skilled in carrying out maintenance procedures but also have managerial skills in managing assets and making data-based decisions, will be better able to utilize technology optimally. In addition, low digital literacy among technicians is a significant barrier to integrating new technologies.

Technicians who are accustomed to traditional mechanical equipment may find it difficult to switch to digital systems that require an understanding of sensors, software, and complex data analytics. Therefore, HR training and skills development are a priority so that they can adapt to rapid technological changes.

Not only technical skills, effective communication between management and field teams also plays an important role in the success of implementing a technology-based maintenance system. Often, the lack of clear communication between management who designs the system and the field team who implements it causes a gap in understanding and implementation. According to research conducted by Bokrantz et al (2020), a successful maintenance system requires close collaboration between various levels of the organization, from managers to technicians in the field. Without good collaboration, data generated by the monitoring system can be misinterpreted or not used optimally, which ultimately reduces the effectiveness of preventive maintenance.

To that end, companies need to invest in continuous training and development for their human resources. This includes not only technical training, but also the development of a data-driven work culture and cross-functional collaboration. According to Sharma et al. (2021), companies that succeed in digital transformation and preventive maintenance are those that successfully integrate technology with human resource development simultaneously. Building a work culture that prioritizes data in decision-making, as well as training that combines technical and analytical skills, will enable technicians and managers to work more effectively. In this way, technology and human resources work synergistically, resulting in more efficient maintenance, reduced costs, and increased reliability and asset life. This all shows that technology-based maintenance can only be successful if supported by human resources who have adequate competence and readiness

CONCLUSION

Preventive maintenance is superior to reactive corrective maintenance because it can reduce downtime, extend machine life, and reduce long-term maintenance costs. Although more expensive up front, this approach is more operationally and financially efficient. The use of technologies such as IoT, CMMS, and predictive analytics can optimize preventive maintenance strategies by predicting failures early, reducing downtime by up to 50%. However, the success of preventive maintenance depends on the readiness of digital infrastructure and the competence of human resources (HR) who are skilled in managing the technology. Continuous training and HR development are essential so that technology can be utilized optimally. Overall, preventive maintenance supports operational efficiency, competitiveness, and industry sustainability.

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