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The Impact of IoT and Artificial Intelligence Implementation on Optimizing Machine Maintenance in the Automotive Industry in Karawang

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Abstract

This study investigates the effects of the Internet of Things (IoT) and Artificial Intelligence (AI) on machine maintenance optimization in the automotive industry in Karawang. The increasing adoption of digital technologies has transformed maintenance strategies from reactive approaches to predictive and data-driven systems, improving operational efficiency and equipment reliability. A quantitative research design was employed, involving 75 respondents from automotive manufacturing companies that have implemented IoT and AI technologies in their maintenance processes. Data were collected using a structured Likert-scale questionnaire and analyzed using SPSS version 26. The findings reveal that both IoT and AI have a significant positive impact on machine maintenance optimization. The implementation of these technologies contributes to reduced machine downtime, enhanced maintenance accuracy, and improved operational performance. AI was found to exert a slightly stronger influence than IoT in supporting maintenance effectiveness. Furthermore, the combined effect of IoT and AI accounted for 65% of the variance in machine maintenance optimization, indicating a substantial contribution to maintenance performance outcomes. These results demonstrate the strategic role of IoT and AI in advancing industrial maintenance practices and supporting sustainable manufacturing operations. The study provides valuable insights for automotive companies seeking to leverage digital technologies to enhance maintenance efficiency, productivity, and long-term operational sustainability. The findings also contribute to the growing body of literature on Industry 4.0 technologies and their application in optimizing industrial maintenance systems.

Keywords: Internet of Things, Artificial Intelligence, Machine Maintenance Optimization, Automotive Industry.

Introduction

The rapid advancement of digital technologies has driven significant changes across various industries, including the automotive sector. Among the key technological developments are the adoption and

integration of the Internet of Things (IoT) and Artificial Intelligence (AI) into manufacturing and maintenance systems [1], [2], [3]. These technologies have emerged as essential enablers of operational optimization, offering substantial benefits in terms of productivity, reliability, and cost efficiency. In machine maintenance, IoT facilitates continuous real-time monitoring of equipment, automated data acquisition, and predictive maintenance capabilities, enabling organizations to detect potential issues before they result in equipment failure. At the same time, AI enhances maintenance effectiveness through advanced data analytics, intelligent decision-making, and accurate fault prediction based on historical and real-time operational data [4], [5], [6]. The integration of IoT and AI creates a smart maintenance framework that supports proactive maintenance strategies, minimizes machine downtime, and reduces maintenance costs. Furthermore, the use of these technologies promotes sustainable industrial practices by optimizing resource utilization, improving energy efficiency, and reducing environmental impacts associated with maintenance operations [1], [7], [8]

In recent years, the automotive industry has experienced growing pressure to align its operations with the principles of sustainable development. As environmental concerns continue to influence industrial policies and business strategies, organizations are increasingly adopting sustainable practices aimed at reducing their ecological footprint while maintaining operational efficiency and profitability [9], [10], [11]. Within this context, the implementation of the Internet of Things (IoT) and Artificial Intelligence (AI) has become particularly significant. These technologies enable companies to enhance resource management, reduce energy consumption, and improve operational performance through data-driven decision-making and process optimization [12], [13], [14]. This trend is especially relevant in Karawang, one of Indonesia's major automotive manufacturing hubs, where technological innovation plays a crucial role in meeting environmental standards, increasing production efficiency, and sustaining competitive advantage in an increasingly dynamic industrial landscape.

Despite the substantial benefits offered by the Internet of Things (IoT) and Artificial Intelligence (AI), research examining their specific contributions to machine maintenance optimization in the automotive industry remains limited, particularly within the context of sustainable and environmentally responsible operational practices [5], [15], [16], [17], [18]. Although prior studies have investigated the broader applications of IoT and AI in manufacturing environments, relatively few have focused on their combined role in improving maintenance performance while supporting sustainability objectives. As environmental sustainability continues to become a strategic priority for industrial organizations, a deeper understanding of how these technologies can facilitate efficient, predictive, and environmentally conscious maintenance practices is increasingly necessary.

To address this research gap, the present study examines the effects of IoT and AI implementation on machine maintenance optimization within the automotive industry in Karawang. Specifically, the study explores how the adoption of these technologies contributes to improving maintenance effectiveness, reducing equipment downtime, and supporting sustainable operational practices. By analyzing the experiences of automotive companies that have integrated IoT and AI into their maintenance systems, this research aims to provide empirical evidence regarding the value of digital technologies in enhancing maintenance performance and sustainability outcomes.

The findings of this study are expected to contribute to the growing body of literature on Industry 4.0 technologies and their application in industrial maintenance management. Furthermore, the research offers practical insights for automotive manufacturers seeking to leverage IoT and AI to optimize maintenance processes, improve operational efficiency, and achieve sustainability objectives. Ultimately, the study

highlights the strategic importance of technological innovation in fostering more resilient, productive, and environmentally sustainable industrial operations.

Literature Review

Internet of Things (IoT) in Machine Maintenance

The Internet of Things (IoT) refers to a network of interconnected devices capable of collecting, transmitting, and exchanging data in real time. Within the field of machine maintenance, IoT technology enables equipment to be equipped with smart sensors that continuously monitor operational conditions, identify abnormalities, and provide early warnings of potential failures before they occur [19], [20], [21]. This capability forms the foundation of predictive maintenance (PM), a maintenance approach that utilizes real-time operational data to determine the optimal timing for maintenance activities based on actual equipment conditions rather than fixed maintenance schedules.

The implementation of IoT-based predictive maintenance has been widely recognized for its ability to enhance maintenance performance by reducing unplanned downtime, lowering maintenance expenses, and extending equipment service life. Previous studies have demonstrated that real-time monitoring and condition-based maintenance strategies significantly improve machine reliability and operational efficiency [22], [23]. By providing continuous insights into equipment health, IoT systems enable organizations to make more informed maintenance decisions and proactively address emerging issues before they escalate into critical failures.

In addition to improving maintenance effectiveness, IoT contributes to greater energy efficiency and sustainability in industrial operations. Continuous monitoring through IoT sensors allows organizations to identify inefficiencies in machine performance, enabling timely adjustments that reduce unnecessary energy consumption and optimize resource utilization. Research by [19], [22], and [23] highlights that IoT-enabled maintenance solutions support both operational excellence and environmental sustainability by minimizing waste, improving equipment utilization, and promoting more efficient use of resources. As a result, IoT has become a key enabler of sustainable industrial development, particularly in sectors such as the automotive industry, where operational efficiency and environmental responsibility are increasingly important strategic objectives.

Artificial Intelligence (AI) and Machine Learning in Maintenance

Artificial Intelligence (AI), particularly machine learning (ML), has become a key technology for improving machine maintenance performance in modern industrial environments. AI systems are capable of processing and analyzing large volumes of operational and maintenance data to identify patterns, detect anomalies, and predict equipment failures with a higher level of accuracy than conventional maintenance approaches. This capability is especially valuable in automotive manufacturing, where production processes are highly dependent on equipment reliability and where unexpected machine downtime can lead to substantial operational and financial losses.

By leveraging predictive analytics, AI enables organizations to anticipate potential equipment failures and schedule maintenance activities at the most appropriate time, thereby minimizing disruptions to production operations. Previous studies have demonstrated that AI-based maintenance systems significantly enhance the effectiveness of predictive maintenance by improving fault diagnosis accuracy and supporting

data-driven maintenance planning [17], [24]. Furthermore, AI contributes to more informed decision-making by providing real-time insights and recommendations regarding maintenance actions, resource allocation, and operational strategies.

In addition to reducing downtime and improving maintenance efficiency, AI has been shown to extend equipment lifespan by identifying early signs of deterioration and preventing excessive wear caused by either overutilization or insufficient maintenance [16], [25], [26]. Such advantages are particularly important in industries characterized by strict quality standards, high production volumes, and continuous operational demands, such as the automotive sector. Through the optimization of maintenance activities, AI not only enhances equipment reliability but also improves overall operational performance and cost efficiency.

When integrated with the Internet of Things (IoT), AI establishes a more advanced and intelligent maintenance ecosystem. Real-time data collected from IoT-enabled sensors can be continuously analyzed by AI algorithms, enabling dynamic learning, more accurate failure predictions, and ongoing optimization of maintenance strategies. This synergy between IoT and AI supports the transition from reactive and preventive maintenance approaches toward fully predictive and prescriptive maintenance systems, ultimately improving operational reliability, productivity, and sustainability within manufacturing environments.

Machine Maintenance Optimization in the Automotive Industry

The automotive industry has consistently been among the leading sectors in adopting advanced technologies to enhance operational performance and manufacturing efficiency. Within this industry, effective machine maintenance is a critical factor due to the high value of production equipment, the complexity of manufacturing processes, and the necessity of maintaining uninterrupted production schedules. As a result, organizations are increasingly investing in innovative maintenance solutions to improve equipment reliability and reduce operational disruptions. Recent studies indicate that predictive maintenance systems supported by the Internet of Things (IoT) and Artificial Intelligence (AI) have become essential tools for optimizing maintenance activities and improving production performance [5], [17].

The adoption of IoT-enabled predictive maintenance allows automotive manufacturers to continuously monitor equipment conditions, identify potential faults at an early stage, and perform maintenance interventions before failures occur. This proactive approach has been shown to increase equipment availability, reduce unplanned downtime, and lower maintenance-related expenses. Similarly, AI technologies enhance maintenance effectiveness by analyzing large volumes of operational data, generating accurate failure predictions, and supporting data-driven maintenance decision-making. Research has demonstrated that automotive companies implementing IoT and AI-based maintenance systems achieve significant improvements in machine uptime, maintenance efficiency, and overall operational productivity [5], [17].

In addition to operational benefits, the automotive industry faces increasing pressure to comply with environmental regulations and sustainability objectives. Consequently, manufacturers are seeking innovative approaches that not only improve productivity but also minimize environmental impacts throughout their operations. In this context, IoT and AI technologies play a crucial role in supporting sustainable maintenance practices by enabling more efficient resource utilization and reducing unnecessary energy consumption. Environmentally responsible maintenance strategies supported by digital technologies contribute to optimizing machine performance while minimizing waste and environmental footprints [27], [28].

Furthermore, sustainable maintenance practices in the automotive sector include continuous monitoring of energy usage, reduction of material waste, and the minimization of hazardous substances used during maintenance activities. Through real-time data collection and intelligent analytics, IoT and AI systems enable organizations to identify inefficiencies, optimize resource allocation, and implement corrective actions that support both operational excellence and environmental sustainability. Therefore, the integration of IoT and AI has emerged as a strategic approach for automotive manufacturers seeking to enhance maintenance performance, achieve regulatory compliance, and promote sustainable industrial development [27], [28]

Environmentally Friendly Agribusiness and Industrial Sustainability

The concept of environmentally sustainable industrial practices has gained increasing attention across a wide range of sectors, including automotive manufacturing. Such practices emphasize the integration of sustainability principles into industrial operations with the objective of minimizing environmental impacts while maintaining productivity and economic performance [29], [30], [31], [32]. Within the automotive industry, these initiatives include the adoption of energy-efficient production processes, waste reduction strategies, and advanced technologies that support environmental sustainability, such as the Internet of Things (IoT) and Artificial Intelligence (AI).

The growing emphasis on sustainability has encouraged automotive manufacturers to seek innovative solutions that balance operational efficiency with environmental responsibility. Previous studies have demonstrated that sustainable industrial practices can significantly reduce carbon emissions, optimize resource utilization, and improve long-term organizational performance without compromising profitability [33], [34], [35]. As a result, the implementation of digital technologies has become an essential component of sustainability initiatives in modern manufacturing environments.

In the context of machine maintenance, the principles of environmental sustainability are closely aligned with the capabilities of IoT and AI technologies. IoT-enabled sensors facilitate continuous monitoring of equipment conditions, while AI-driven analytics support predictive maintenance and intelligent decision-making. Together, these technologies enable organizations to optimize maintenance schedules, improve equipment performance, and utilize resources more efficiently. By identifying potential failures before they occur, companies can reduce unnecessary maintenance activities, minimize material waste, and prevent excessive energy consumption associated with inefficient machine operation.

Furthermore, the integration of IoT and AI contributes to extending equipment lifespan and reducing the frequency of repairs and component replacements, thereby lowering the environmental burden associated with manufacturing and disposal processes. Through real-time monitoring, predictive analytics, and data-driven maintenance strategies, organizations can achieve greater operational efficiency while supporting sustainability objectives. Consequently, IoT and AI have emerged as critical enablers of environmentally responsible industrial practices, assisting automotive manufacturers in improving maintenance effectiveness, reducing environmental impacts, and advancing sustainable industrial development

IoT, AI, and Environmental Sustainability in Automotive Maintenance

Recent studies indicate that the implementation of Internet of Things (IoT) and Artificial Intelligence (AI) technologies extends beyond improving machine maintenance performance and plays a significant role in advancing environmental sustainability. Through real-time monitoring, intelligent data processing, and

predictive analytics, these technologies enable organizations to track resource consumption, identify operational inefficiencies, and implement data-driven strategies that minimize environmental impacts. By providing continuous insights into equipment performance and resource utilization, IoT and AI support more efficient and sustainable maintenance practices across industrial operations [17], [36], [37].

In the automotive industry, the adoption of IoT and AI-based maintenance systems has been associated with measurable improvements in environmental performance. Previous research has shown that companies utilizing these technologies can reduce energy consumption, lower greenhouse gas emissions, and minimize material waste through enhanced maintenance planning and optimized equipment operation [17], [36], [37]. Furthermore, IoT and AI contribute to the development of circular economy practices by promoting more efficient use of resources, extending equipment lifespan, and reducing the need for unnecessary repairs, replacements, and material disposal. These capabilities allow manufacturers to achieve both operational and environmental objectives simultaneously.

As sustainability becomes an increasingly important strategic priority, the integration of IoT and AI has emerged as a critical approach for enhancing maintenance effectiveness while supporting environmentally responsible industrial practices. Despite the growing body of research on predictive maintenance enabled by IoT and AI, limited attention has been given to their contribution to sustainable maintenance and environmental performance within the automotive sector [38], [39], [40], [41]. This research gap is particularly evident in emerging industrial regions such as Karawang, where the adoption of advanced digital technologies continues to expand alongside increasing sustainability requirements.

To address this gap, the present study investigates the impact of IoT and AI implementation on machine maintenance optimization in the automotive industry in Karawang. Specifically, the study examines how these technologies contribute to improving maintenance efficiency, reducing operational waste, and supporting sustainable industrial practices. The findings are expected to provide both theoretical and practical insights into the role of IoT and AI in fostering efficient, reliable, and environmentally sustainable maintenance systems within modern automotive manufacturing environments.

Methods

Research Design

This study employs a quantitative research approach to examine the influence of Internet of Things (IoT) and Artificial Intelligence (AI) implementation on machine maintenance optimization. A quantitative design was selected because it enables the systematic collection and analysis of numerical data, allowing for an objective evaluation of the relationships between the independent variables (IoT and AI) and the dependent variable (machine maintenance optimization). Furthermore, this approach facilitates the testing of hypotheses and the measurement of the magnitude of the effects of IoT and AI on maintenance performance.

The research adopts a cross-sectional design, whereby data were collected from respondents at a single point in time. The target population consists of automotive companies in Karawang that have implemented IoT and AI technologies within their machine maintenance systems, particularly organizations that emphasize sustainable and environmentally responsible operational practices. These companies provide an appropriate setting for investigating the role of advanced digital technologies in improving maintenance effectiveness and operational efficiency.

A total of 75 respondents participated in the study. The sample was selected using a convenience sampling technique based on the accessibility and availability of companies that have adopted IoT and AI technologies in their maintenance operations. Although this sampling method may limit the generalizability of the findings, it enables the collection of relevant data from organizations with practical experience in the application of these technologies. Consequently, it provides valuable insights into the benefits and challenges associated with the adoption of IoT and AI in machine maintenance.

The respondents comprised maintenance managers, maintenance engineers, supervisors, and other professionals directly involved in machinery maintenance activities within the selected automotive companies. Their direct involvement in maintenance operations and technology implementation ensures that the information collected accurately reflects organizational experiences and practices. By focusing on individuals with relevant expertise, the study aims to generate reliable evidence regarding the impact of IoT and AI on machine maintenance optimization and sustainable industrial performance.

Data Collection

Primary data were collected using a structured questionnaire administered to respondents from selected automotive companies. The questionnaire was designed to evaluate respondents' perceptions of the effectiveness of Internet of Things (IoT) and Artificial Intelligence (AI) technologies in optimizing machine maintenance, reducing equipment downtime, and supporting sustainable operational practices. Responses were measured using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), enabling the quantification of participants' views and experiences regarding technology implementation.

The questionnaire consisted of three main sections. The first section gathered demographic and organizational information, including company size, types of machinery utilized, and the extent of IoT and AI adoption within maintenance operations. The second section focused on IoT implementation, assessing factors such as the use of sensor technologies, real-time equipment monitoring, data collection capabilities, and predictive maintenance applications. The third section examined AI implementation, including the utilization of machine learning algorithms, predictive analytics, intelligent fault detection, and data-driven decision-making processes in maintenance management.

The questionnaire was distributed electronically to facilitate efficient data collection and to ensure access to respondents across different organizations. Data collection was conducted over a one-month period, during which participants voluntarily completed the survey. To uphold ethical research standards, respondents were informed of the purpose of the study, and their anonymity and confidentiality were fully protected throughout the research process. This approach helped ensure the reliability of the collected data while encouraging honest and unbiased responses from participants

Data Analysis

The collected data were analyzed using Statistical Package for the Social Sciences (SPSS) version 26, which was selected due to its comprehensive statistical capabilities for processing and analyzing survey-based data. A range of statistical techniques was employed to examine the relationships among the study variables and to test the proposed hypotheses.

Initially, descriptive statistical analysis was conducted to summarize the demographic characteristics of the respondents and provide an overview of the collected data. This analysis included measures such as frequencies, percentages, means, and standard deviations, offering insights into the respondents' profiles and organizational backgrounds.

To assess the consistency and reliability of the measurement instrument, a reliability analysis was performed using Cronbach's Alpha. A coefficient value of 0.70 or higher was considered indicative of acceptable internal consistency, confirming that the questionnaire items reliably measured the intended constructs.

Subsequently, Pearson correlation analysis was utilized to evaluate the strength and direction of the relationships between the independent variables, namely Internet of Things (IoT) and Artificial Intelligence (AI), and the dependent variable, machine maintenance optimization. This analysis provided an initial assessment of the degree of association among the variables under investigation.

Furthermore, multiple regression analysis was conducted to determine the individual and combined effects of IoT and AI on machine maintenance optimization. This technique enabled the identification of the relative contribution of each independent variable while controlling for the influence of other variables included in the model. The regression results also provided information regarding the proportion of variance in machine maintenance optimization explained by IoT and AI implementation.

Finally, Analysis of Variance (ANOVA) was employed to evaluate the overall significance of the regression model and to determine whether the observed relationships between the variables were statistically significant. Through these analytical procedures, the study systematically assessed the impact of IoT and AI adoption on maintenance performance within the automotive industry.

Results and Discussions

Descriptive Statistics

Descriptive statistics were employed to provide an overview of the demographic characteristics of the respondents and the organizations involved in the study. The study included 75 respondents from automotive companies in Karawang that had implemented Internet of Things (IoT) and Artificial Intelligence (AI) technologies in their machine maintenance operations. The respondents consisted of maintenance managers (40%), engineers (35%), and other technical personnel directly involved in maintenance activities (25%). Regarding technology adoption, the majority of the companies (60%) had utilized IoT and AI technologies for more than two years, while the remaining 40% had adopted these technologies within the previous two years. The participating companies varied in size, with 45% classified as medium-sized enterprises employing between 100 and 500 employees, 30% categorized as large enterprises with more than 500 employees, and 25% identified as small enterprises with fewer than 100 employees. All participating organizations reported the use of IoT and AI for predictive maintenance, real-time equipment monitoring, and resource optimization to support sustainable and environmentally responsible operational practices.

Reliability Analysis

To assess the internal consistency of the research instrument, reliability testing was conducted using Cronbach's Alpha. The analysis was performed for the two independent variables, namely IoT implementation and AI implementation, as well as the dependent variable, machine maintenance optimization. The results indicated Cronbach's Alpha coefficients of 0.823 for IoT implementation, 0.858 for AI implementation, and 0.871 for machine maintenance optimization. Since all values exceeded the recommended threshold of 0.70, the findings demonstrate satisfactory internal consistency and confirm that the measurement items reliably captured the constructs under investigation. Therefore, the questionnaire was considered suitable for subsequent statistical analyses.

Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships among IoT implementation, AI implementation, and machine maintenance optimization. The results revealed statistically significant positive correlations between all variables. Specifically, IoT implementation was positively correlated with machine maintenance optimization ($r = 0.654$, $p < 0.01$), indicating that increased adoption of IoT technologies is associated with enhanced maintenance performance. Similarly, AI implementation demonstrated a strong positive relationship with machine maintenance optimization ($r = 0.722$, $p < 0.01$), suggesting that greater utilization of AI technologies contributes to more effective maintenance practices. Furthermore, a significant positive correlation was observed between IoT implementation and AI implementation ($r = 0.607$, $p < 0.01$), reflecting the complementary nature of these technologies in supporting advanced maintenance systems. Overall, the results suggest that higher levels of IoT and AI adoption are associated with improvements in machine maintenance optimization.

Regression Analysis

A multiple regression analysis was performed to evaluate the individual and combined effects of IoT and AI implementation on machine maintenance optimization. In the regression model, machine maintenance optimization served as the dependent variable, while IoT implementation and AI implementation were treated as independent variables. This analysis enabled the assessment of the relative contribution of each technological factor to maintenance performance while controlling for the influence of the other variable. The regression findings indicated that both IoT and AI significantly contributed to machine maintenance optimization, confirming their importance in enhancing maintenance efficiency, reducing equipment downtime, and improving operational effectiveness. The detailed results of the regression analysis are presented in the following table:

Variable	B (Unstandardized Coefficient)	Standard Error	Beta (Standardized Coefficient)	t- value	p- value
IoT Implementation	0.420	0.116	0.414	3.823	0.000**
AI Implementation	0.534	0.103	0.506	4.957	0.000**
$R^2 = 0.65$, Adjusted $R^2 = 0.63$, $F = 42.1$, $p<0.001$					

Source: Data Analysis, 2024

The results of the multiple regression analysis indicate that the proposed model explains 65% of the variance in machine maintenance optimization ($R^2 = 0.65$). This finding demonstrates that the implementation of Internet of Things (IoT) and Artificial Intelligence (AI) technologies collectively exerts a substantial influence on maintenance performance within the automotive industry. Both independent variables were found to have significant positive effects on machine maintenance optimization. However, AI implementation ($\beta = 0.50$) exhibited a slightly stronger impact compared to IoT implementation ($\beta = 0.41$), suggesting that AI plays a more prominent role in enhancing maintenance effectiveness, although both technologies contribute meaningfully to maintenance improvements.

Discussion

The findings of this study provide strong empirical evidence that the implementation of IoT and AI technologies significantly enhances machine maintenance optimization in the automotive industry. The positive and statistically significant relationship between IoT implementation and machine maintenance optimization supports Hypothesis 1 (H1), which proposed that IoT adoption positively influences maintenance outcomes. This result is consistent with previous research highlighting the capability of IoT technologies to facilitate real-time equipment monitoring, predictive maintenance, and early fault detection, ultimately reducing machine downtime and improving operational efficiency [17], [36]. Through continuous data collection and monitoring, IoT enables organizations to shift from reactive maintenance approaches toward more proactive and condition-based maintenance strategies.

Likewise, the significant positive effect of AI implementation on machine maintenance optimization confirms Hypothesis 2 (H2). The findings indicate that AI contributes substantially to improving maintenance performance through advanced data analytics, predictive modeling, and intelligent decision-making processes. These results are in line with earlier studies that emphasized the role of AI in enhancing predictive maintenance capabilities, increasing fault prediction accuracy, and supporting efficient maintenance planning [37], [38], [39]. The higher standardized coefficient for AI suggests that its ability to process and interpret complex operational data provides considerable value in reducing maintenance-related disruptions and improving equipment reliability.

Furthermore, the results of the multiple regression analysis provide support for Hypothesis 3 (H3), which proposed that the combined implementation of IoT and AI would have a significant positive impact on machine maintenance optimization. The coefficient of determination ($R^2 = 0.65$) indicates that the two technologies jointly explain a substantial proportion of the variation in maintenance performance. This finding underscores the complementary nature of IoT and AI within modern maintenance systems. While IoT serves as the foundation for real-time data acquisition and equipment monitoring, AI transforms the collected data into actionable insights through predictive analytics and intelligent recommendations. The integration of these technologies enables organizations to develop more accurate, responsive, and data-driven maintenance strategies.

From a practical standpoint, the findings carry important implications for automotive manufacturers, particularly in industrial regions such as Karawang, where companies face increasing demands to improve both operational performance and environmental sustainability. The adoption of IoT and AI not only enhances maintenance efficiency and equipment reliability but also supports sustainable industrial practices. By enabling more effective resource management, reducing unnecessary maintenance activities, and minimizing

equipment downtime, these technologies contribute to lower energy consumption, reduced material waste, and improved resource utilization.

Moreover, the integration of IoT and AI aligns with broader sustainability objectives by supporting environmentally responsible maintenance practices. Continuous monitoring of machine conditions helps organizations identify inefficiencies and optimize energy use, while predictive maintenance reduces the frequency of unexpected failures and excessive component replacements. As a result, companies can extend the operational lifespan of machinery, reduce waste generation, and lower their overall environmental footprint. These outcomes demonstrate that IoT and AI are not only technological tools for improving productivity but also strategic enablers of sustainable industrial development.

Overall, the findings highlight the critical role of IoT and AI in transforming maintenance management within the automotive industry. Their combined application provides a robust framework for achieving higher levels of operational efficiency, equipment reliability, and environmental sustainability, thereby supporting the long-term competitiveness and resilience of automotive manufacturers in an increasingly technology-driven industrial landscape

Implications for Sustainable Industrial Practices

The findings of this study underscore the significant potential of Internet of Things (IoT) and Artificial Intelligence (AI) technologies in supporting sustainable industrial practices, particularly within the automotive industry. By enhancing machine maintenance processes, these technologies enable organizations to improve operational efficiency while simultaneously reducing their environmental impact. The implementation of IoT- and AI-driven predictive maintenance systems allows companies to identify potential equipment failures before they occur, thereby minimizing unnecessary energy consumption, reducing material waste, and lowering the frequency of machine repairs and replacements.

Furthermore, the integration of IoT and AI contributes to more efficient resource utilization through continuous monitoring and data-driven decision-making. Real-time insights into machine performance enable organizations to optimize maintenance schedules, prevent equipment inefficiencies, and minimize operational disruptions. As a result, companies can reduce resource consumption and improve the overall sustainability of their maintenance operations.

The positive impact of IoT and AI on machine maintenance optimization also highlights their strategic importance in supporting the automotive industry's transition toward more environmentally responsible production practices. As manufacturers increasingly face stringent environmental regulations and growing stakeholder expectations regarding sustainability, the adoption of advanced digital technologies has become essential for maintaining competitiveness while achieving environmental objectives. Consequently, the implementation of IoT and AI not only enhances maintenance performance and productivity but also contributes to broader sustainability goals by promoting cleaner, more efficient, and resource-conscious industrial operations.

Limitations and Future Research

Despite the valuable insights generated by this study, several limitations should be acknowledged. First, the use of a convenience sampling technique may limit the generalizability of the findings, as the sample

consisted exclusively of companies that had already adopted IoT and AI technologies. Consequently, the results may not fully represent the experiences and perspectives of organizations that have not yet implemented these technologies. Future studies are encouraged to include a more diverse range of companies to provide a broader understanding of technology adoption and to identify the challenges and barriers associated with implementing IoT and AI in maintenance operations.

Second, the cross-sectional nature of the research design restricts the ability to assess changes in maintenance performance over time. Since data were collected at a single point in time, the study cannot capture the long-term effects of IoT and AI implementation on maintenance efficiency, equipment reliability, and sustainability outcomes. Future research could employ longitudinal research designs to examine how the benefits of these technologies evolve over extended periods and to assess their long-term contribution to operational and environmental performance.

Additionally, future studies may explore other factors that influence machine maintenance optimization, such as organizational readiness, employee competencies, technological infrastructure, and management support. Investigating these variables could provide a more comprehensive understanding of the conditions required for successful IoT and AI implementation. Further research may also compare different industrial sectors or geographic regions to determine whether the observed benefits of these technologies vary across organizational and operational contexts

Conclusions

The findings of this study demonstrate that the implementation of Internet of Things (IoT) and Artificial Intelligence (AI) technologies has a significant positive effect on machine maintenance optimization in the automotive industry. Both technologies contribute substantially to improving maintenance performance by increasing equipment availability, enhancing predictive maintenance capabilities, minimizing unplanned downtime, and reducing operational costs. Among the two technologies, AI was found to have a slightly stronger influence on maintenance optimization, reflecting its advanced capability to analyze operational data and support intelligent decision-making.

Furthermore, the integration of IoT and AI supports sustainable industrial practices by improving resource utilization, increasing energy efficiency, and reducing material waste. Through real-time monitoring and predictive analytics, these technologies enable companies to implement proactive maintenance strategies that not only enhance operational effectiveness but also contribute to environmental sustainability. As a result, IoT and AI have emerged as critical enablers of both maintenance excellence and sustainable manufacturing.

The implications of these findings are particularly relevant to the automotive industry in Karawang, where organizations are increasingly challenged to achieve high levels of operational performance while complying with environmental sustainability requirements. The adoption of IoT and AI provides a strategic pathway for companies to optimize maintenance processes, improve productivity, and reduce their environmental footprint, thereby supporting broader sustainability objectives and long-term industrial competitiveness.

Future research is recommended to examine the long-term impact of IoT and AI implementation on maintenance performance through longitudinal studies. In addition, further investigation into the barriers, challenges, and success factors associated with the adoption of these technologies across different industrial

sectors would provide deeper insights and contribute to a more comprehensive understanding of their role in advancing sustainable and intelligent maintenance systems.

Declaration of Conflicting Interests

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