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IoT-Integrated Computerized Maintenance Management System (CMMS) for Optimizing Maintenance Efficiency in Smart Manufacturing

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Abstract.
Purpose: The manufacturing industry continues to face persistent challenges in maintaining equipment reliability and maintenance efficiency, particularly in scheduling, spare parts control, and real-time monitoring of machine conditions. This study aims to develop an Internet of Things (IoT)-based Computerized Maintenance Management System (CMMS) to improve maintenance effectiveness, minimize equipment downtime, and support the realization of smart manufacturing in the automotive sector.
Methods: The system was developed using the ADDIE model, consisting of analysis, design, development, Implementation, and Evaluation. and was integrated with IoT sensors to acquire real-time machine temperature and operational status data. and integrated with IoT sensors to collect real-time data on machine temperature and operational status. The collected data were processed in a centralized database and presented through a web-based CMMS application comprising work order management, preventive and corrective maintenance, inventory control, and analytical reporting modules. System functionality was validated using black-box testing, while performance evaluation was conducted by comparing Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and maintenance efficiency before and after system implementation.
Result: The results indicate that all evaluated equipment experienced performance improvements following CMMS implementation, characterized by increased MTBF and reduced MTTR. On average, overall maintenance efficiency increased by approximately 368%, demonstrating significant reductions in downtime and improvements in maintenance responsiveness supported by real-time condition data.
Novelty: The novelty of this study lies in the integration of IoT technology into CMMS that emphasizes the utilization of real-time machine condition data not only for monitoring purposes but also to support maintenance planning, work order management, and data-driven decision-making within a single application. The findings provide empirical evidence that effective data utilization strategies within CMMS implementations can significantly enhance maintenance efficiency and support smart maintenance practices aligned with Industry 4.0 principles.

Keywords: Maintenance management, IoT integration, CMMS, Smart manufacturing
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INTRODUCTION

The manufacturing industry plays central role in the global economy by providing essential products and supporting various industrial sectors [1], [2]. In modern production environments, ensuring the availability and optimal performance of equipment and machinery is crucial for maintaining smooth and efficient operations [3]. However, in practice, many manufacturing companies encounter persistent challenges in managing maintenance effectively [4]. These challenges include the lack of structured planning and scheduling, inefficiencies in spare parts inventory management, and limited real-time monitoring capabilities for machine conditions [5], [6]. Furthermore, increasing demands for higher productivity, cost reduction, and enhanced equipment reliability have intensified the complexity of maintenance management within industrial operations [7], [8]. Therefore, addressing maintenance management issues is essential to improving operational efficiency, minimizing downtime, and maximizing equipment utilization [9], [10], [11].

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To address these challenges, the implementation of Computerized Maintenance Management System (CMMS) has been widely recognized as a strategic solution in industrial maintenance management [12], [13]. CMMS is an information technology-based platform that integrates maintenance data, automates maintenance processes, and supports analytical decision-making, including preventive maintenance scheduling, repair history tracking, spare parts management, and maintenance performance analysis [14],[15]. Several studies have examined the implementation of Computerized Maintenance Management Systems (CMMS) as an effective approach to enhancing maintenance efficiency, optimizing maintenance scheduling, and reducing equipment downtime in industrial environments [16], [17], [18]. These studies indicate that CMMS facilitates systematic maintenance planning, structured work order management, and reliable maintenance data recording. Moreover, the integration of Internet of Things (IoT) technologies has increasingly been adopted to enable automated data acquisition, real-time equipment condition monitoring, and early fault detection in manufacturing systems [19], [20], [21].

However, a significant portion of previous research remains focused on partial or fragmented system implementations, in which CMMS functionalities and IoT-based monitoring systems are developed independently. This separation results in limited data interoperability and continued reliance on manual data input during maintenance execution [22], [23]. Other studies have developed IoT-enabled monitoring platforms that provide real-time visualization of machine conditions [24]. However, these systems often lack direct integration with core maintenance management functions, including work order execution, preventive and corrective maintenance scheduling, spare parts inventory control, and maintenance performance evaluation. As a result, real-time monitoring data are not fully utilized to support integrated maintenance decision-making and continuous performance improvement.

Therefore, this research improves upon previous studies by developing a fully integrated IoT-based Computerized Maintenance Management System (CMMS), in which real-time data acquisition from production equipment is directly linked to preventive and corrective maintenance processes, inventory management, and intelligent monitoring within a unified system architecture. Furthermore, the developed system incorporates maintenance performance evaluation using reliability indicators such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) to quantitatively assess maintenance effectiveness and support data-driven maintenance optimization [25], [26]. The objectives of this research are to identify CMMS requirements within manufacturing environments, design an efficient and secure system architecture, and validate the developed system through functional testing to ensure its reliability and applicability in smart maintenance operations aligned with Industry 4.0 principles.

METHODS

This study employs a descriptive and experimental research approach focusing on the development of an Internet of Things (IoT)-based Computerized Maintenance Management System (CMMS) to optimize maintenance management within a smart manufacturing environment. The research adopted the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) [27], [28]. as shown in Figure 1. which provides a systematic and adaptive framework for technology-based system development. The descriptive approach was utilized to analyze existing maintenance workflows, while the experimental approach was applied during system implementation and testing to validate the proposed solution [28], [29].

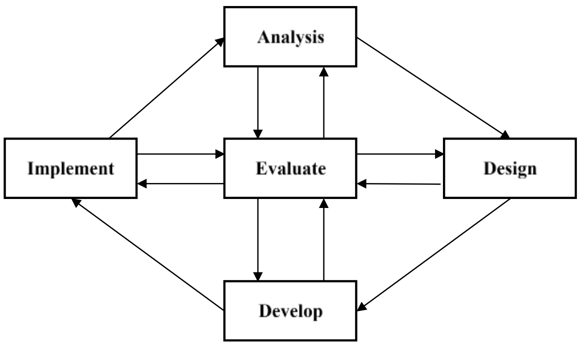

Figure 1. ADDIE development method

Analysis phase involved identifying functional and non-functional system requirements through direct field observations, semi-structured interviews with maintenance engineers, and examination of existing maintenance logs and standard operating procedures. The results informed the design phase, where the system architecture, maintenance workflows, database schema, and user interface layouts were developed [30]. The proposed architecture comprises three primary layers as shown in figure 2: IoT layer, responsible for acquiring real-time data from sensors and Programmable Logic Controllers (PLC); data management layer, which handles data processing, storage, and communication between IoT devices and the server; and application layer, which provides visualization dashboards and maintenance management functionalities.

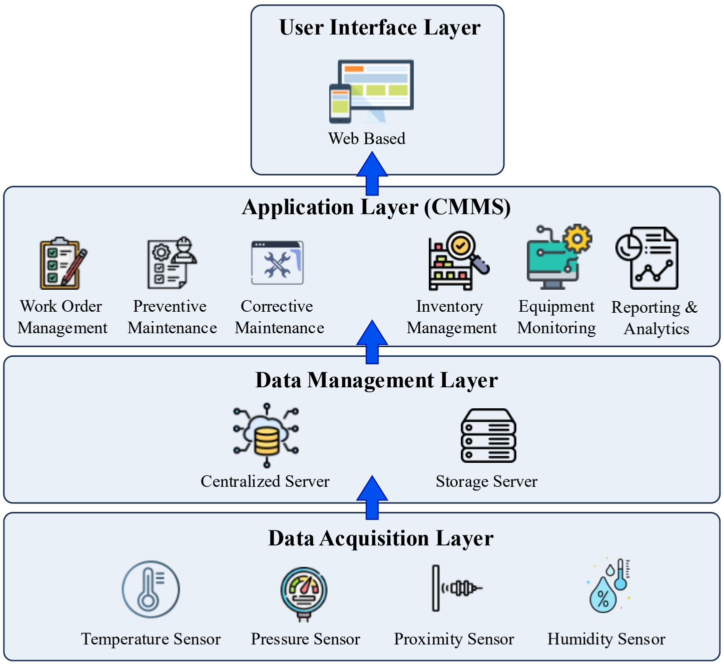

Figure 2. System architecture design

In development phase, CMMS was implemented as a web-based system using the Laravel PHP framework and MySQL database [31], [32]. IoT integration was achieved through TCP/IP communication protocols, enabling data exchange between sensors and the web server [33], [34]. Core modules developed include work order management, preventive and corrective maintenance scheduling, equipment condition monitoring, spare parts inventory control, and analytical reporting. Security mechanisms such as role-based authentication and AES data encryption were incorporated to ensure system integrity, reliability, and data protection [35]. Implementation phase involved pilot testing in a manufacturing facility to verify system connectivity, real-time data acquisition, and operational stability. IoT devices, including pressure, humidity, proximity, and temperature sensors connected through Allen-Bradley PLCs CompactLogix, were deployed to validate the system's performance in a live environment.

The evaluation phase consisted of two complementary approaches: functional testing and performance assessment. Black-box testing was employed to ensure each CMMS module operated according to defined functional requirements [36], [37]. System's performance effectiveness was evaluated using two standard reliability indicators: Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) [38], [39]. These indicators provide quantitative measures of system reliability and maintenance responsiveness, calculated using the following equations [40]:

$$\text{MTBF} = \frac{\text{Total Operation Time}}{\text{Number of Failures}} \tag{1}$$

$$\text{MTTR} = \frac{\text{Total Downtime}}{\text{Number of Failures}} \tag{2}$$

Maintenance efficiency was then determined by comparing the ratio of MTBF to MTTR before and after CMMS implementation [41], as expressed in Equation:

$$\text{Maintenance Efficiency } (\%) = \frac{\left(\frac{MTBF_{after}}{MTTR_{after}}\right) - \left(\frac{MTBF_{before}}{MTTR_{before}}\right)}{\left(\frac{MTBF_{before}}{MTTR_{before}}\right)} \times 100 \quad (3)$$

A higher MTBF-to-MTTR ratio indicates enhanced maintenance efficiency and improved equipment reliability. Statistical comparisons between pre and post implementation datasets were conducted to validate the significance of performance improvements achieved through CMMS deployment.

RESULTS AND DISCUSSIONS

Computerized Maintenance Management System (CMMS) aims to optimize maintenance operations through integrated real-time monitoring, automated scheduling, and data-driven decision-making. This section presents the results of system design, interface implementation, functional testing, and maintenance performance evaluation.

System design

Workflow of Computerized Maintenance Management System (CMMS) in this study was designed to optimize maintenance processes and improve equipment reliability. Integration of IoT sensors, technician inputs, and preventive as well as corrective maintenance modules results in a structured and responsive system for managing real-time maintenance data. This design facilitates automated data acquisition, efficient work order tracking, and enhanced decision-making in maintenance scheduling. The flow of maintenance management activities using CMMS as shown in figure 3, which shows the process from equipment monitoring to maintenance execution and performance feedback.

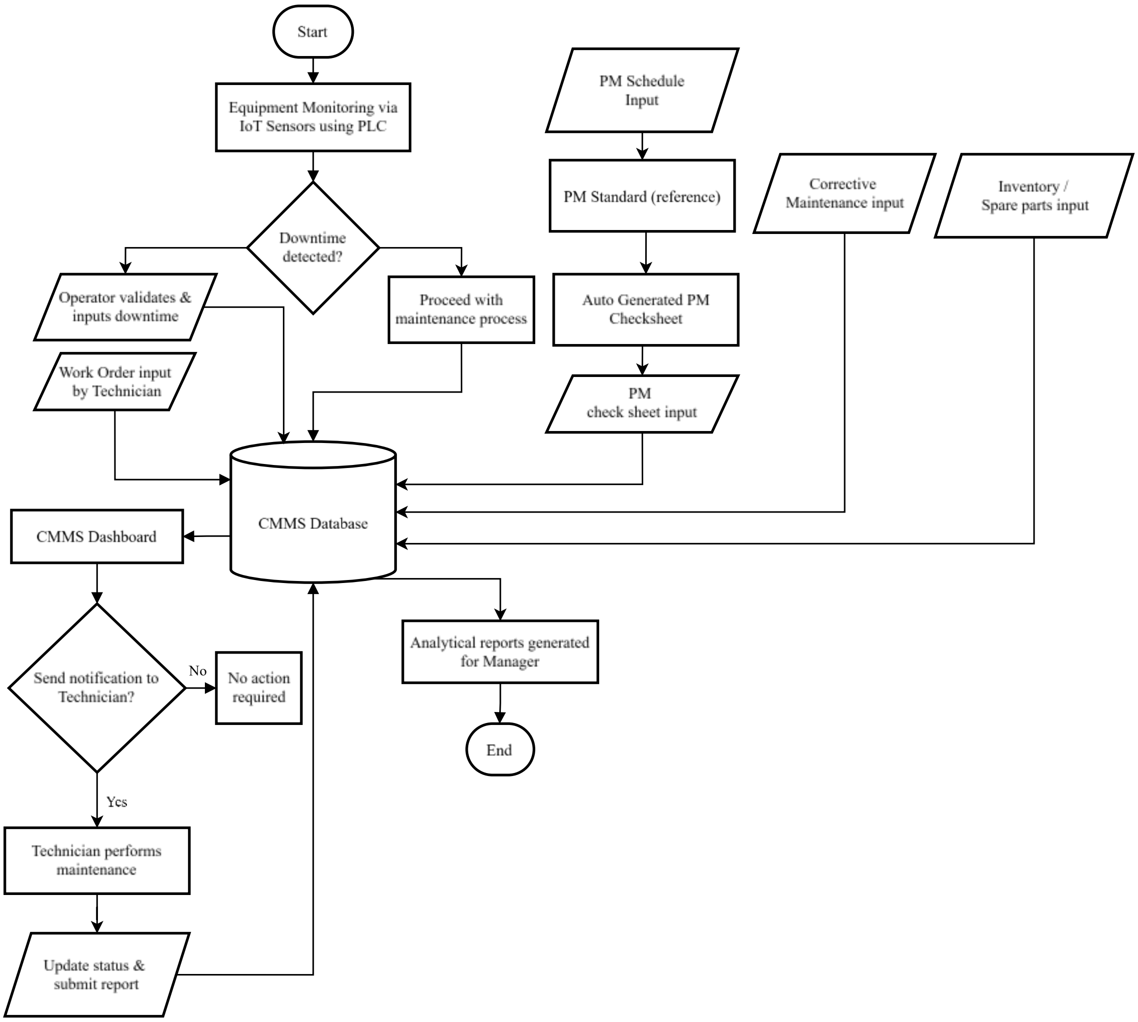

Figure 3. System flowchart of CMMS

IoT-integrated CMMS was designed to establish interconnections between machines, controllers, and PC server for real-time data acquisition and monitoring. Each unit such as Injection Molding, Oven, Robot Pick and Place, Robot Painting, and Robot Laser Cutting utilizes sensors connected to PLCs, which transmit data to PC server hosting web and database servers. This setup enables automatic data collection and integration into CMMS dashboard for maintenance monitoring and decision-making. Figure 4 shows the block diagram of CMMS data acquisition system, illustrating sensor, PLC, and server interconnections.

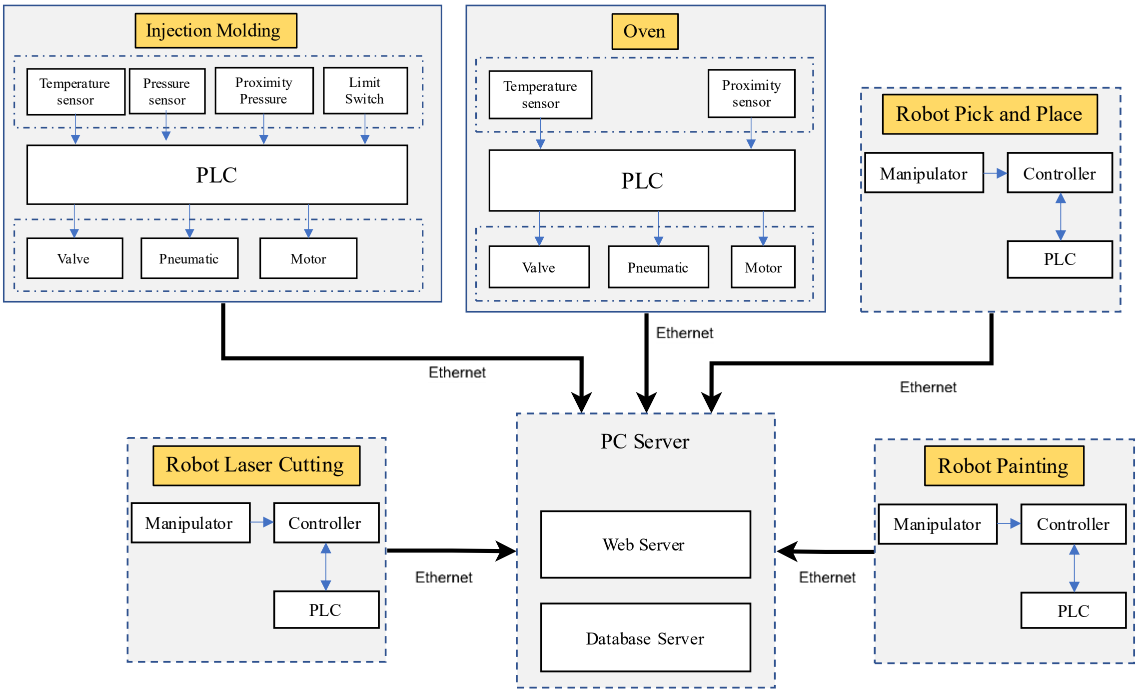

Figure 4. Block diagram of CMMS

Real-time data monitoring implementation

Data acquisition flow in system begins with production sensors, including temperature, pressure, proximity, and limit switch sensors installed on various manufacturing equipment. These sensors transmit signals to PLC, which functions as main controller and processes signals into digital data. PLC then sends data to server using industrial communication protocols. At this stage, RS Link OPC Server serves as middleware to bridge communication between PLC and application system, enabling monitoring software to access data. Data received by the server are stored in a database and displayed via a web-based dashboard. The system retrieves data either through database queries or direct API access for real-time monitoring. Dashboard presents machine condition status, downtime, and key parameters, allowing timely and data-driven maintenance decisions as shown in figure 5.

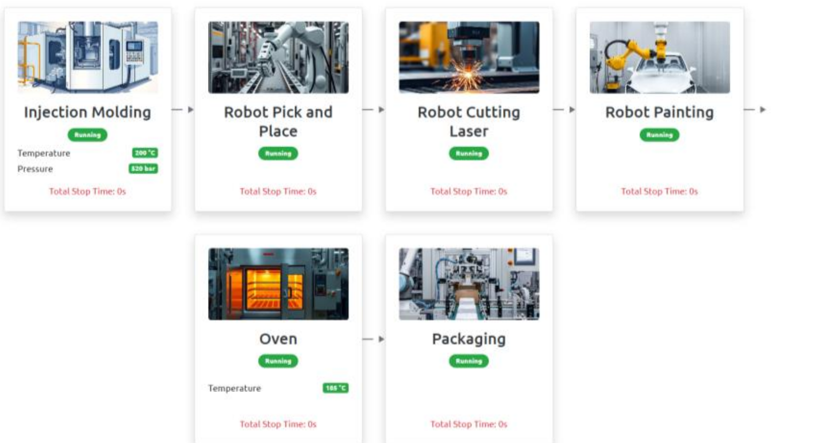

Figure 5. Real-time monitoring visualization in CMMS

Downtime history is visualized to support performance analysis and identify recurring issues as shown in figure 6 presents downtime trends on an hourly, daily, and monthly basis for evaluating maintenance strategy effectiveness.

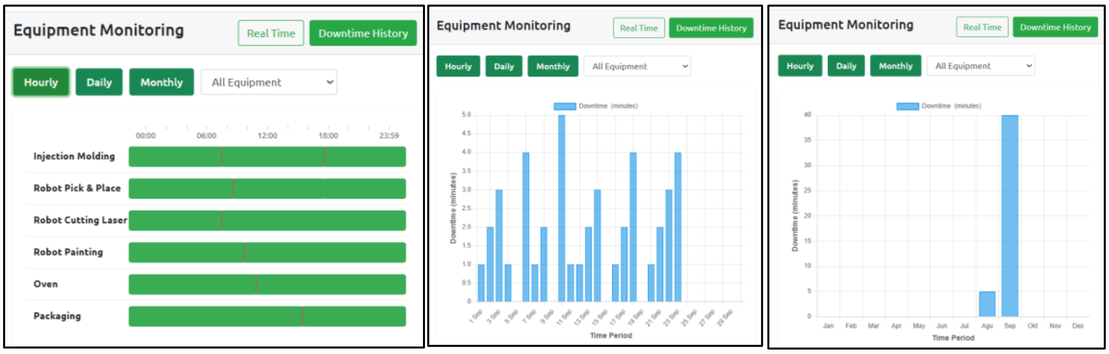

Figure 6. Visualization history trend of downtime in CMMS

Maintenance process implementation

Maintenance process in CMMS is managed through three main modules: Work Order, Preventive Maintenance, and Corrective Maintenance. Work Order module structures all maintenance activities by recording job details. Through web interface, users can create, monitor, and filter work orders in real time, ensuring transparency and efficiency in task execution, as shown in Figure 7.

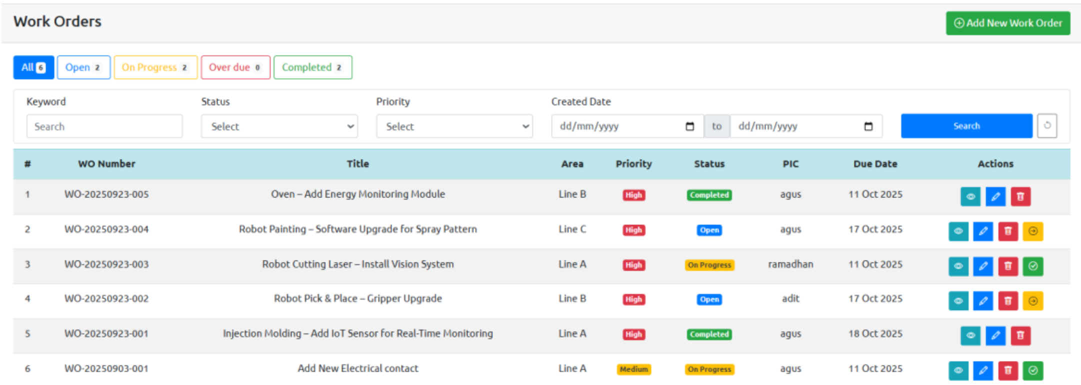

Figure 7. Work order management interface in CMMS

Preventive Maintenance (PM) module operates through a systematic workflow beginning with the creation of maintenance standards that define equipment, part, maintenance cycles, and approved as shown in figure 8. Based on these standards, the system automatically generates a PM schedule as shown in figure 9 that visualizes annual, quarterly, and monthly plans while tracking job progress.

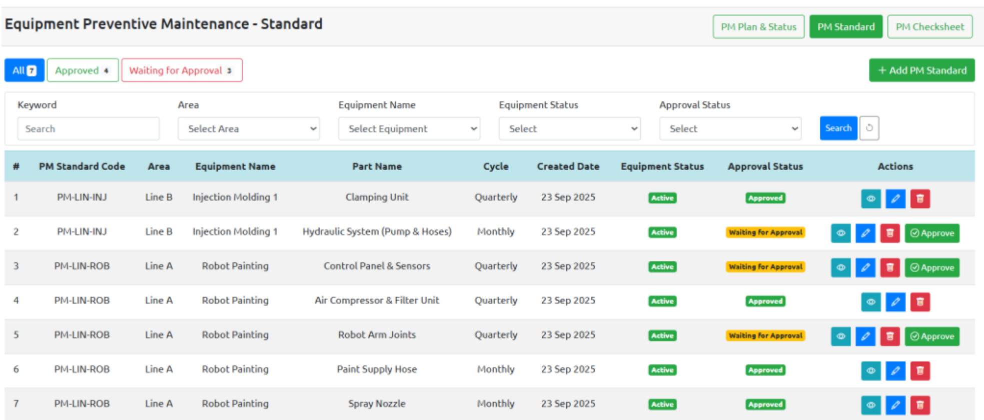

Figure 8. Preventive maintenance standard interface in CMMS

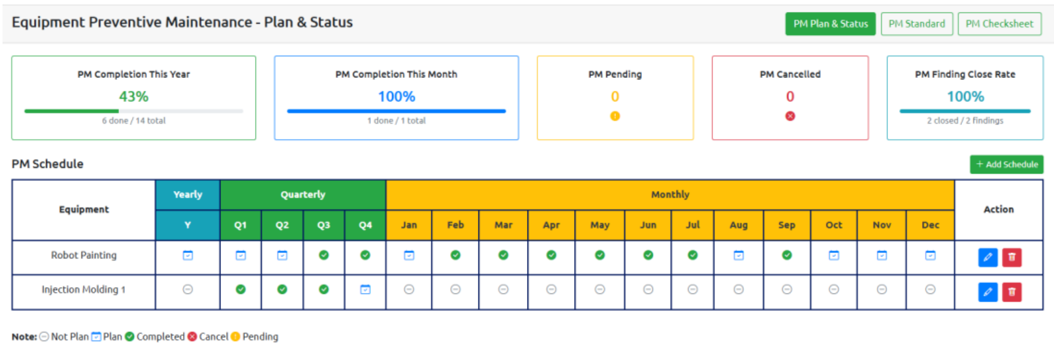

Figure 9. Preventive maintenance schedule interface in CMMS

Technicians execute tasks using a digital PM check sheet as shown in figure 10 that records inspection results, working time, and identified issues. This process ensures consistent documentation and facilitates timely corrective actions. Integrated workflow enhances equipment reliability, minimizes unexpected failures, and supports effective maintenance management.

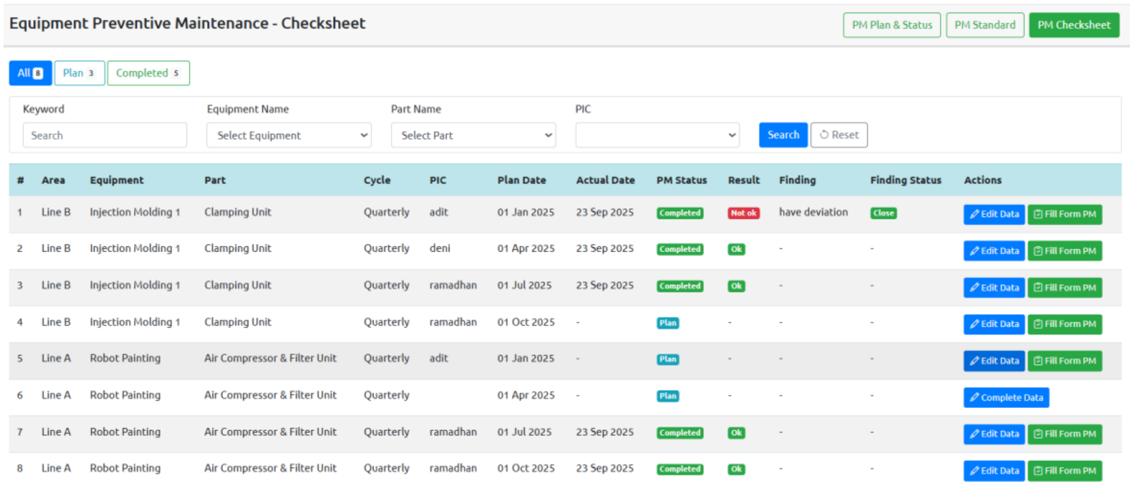

Figure 10. Visualization preventive maintenance check sheet in CMMS

Inventory management implementation

CMMS inventory module ensures material availability through a structured database containing item code, rack address, category, specifications, brand, price, and stock status as shown in figure 11. Stock In and Stock Out transactions are recorded with details such as date, quantity, requester, and supplier as shown in figure 12. All transactions are updated in real time, enabling quick monitoring of material usage and inventory levels. This feature supports transparency, traceability, and effective control of procurement and maintenance costs.

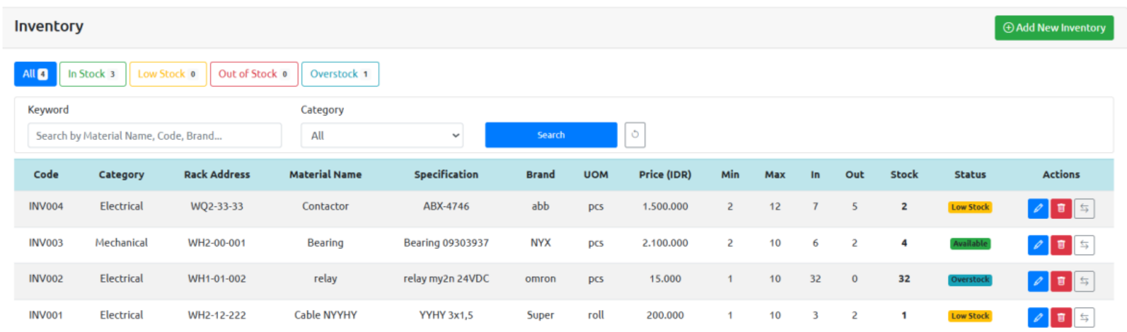

Figure 11. Inventory list interface in CMMS

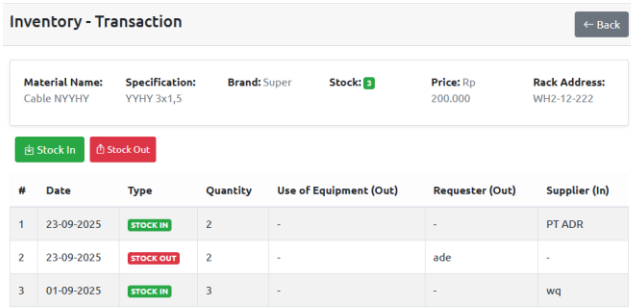

Figure 12. Stock transaction interface in CMMS

Maintenance analytical reports

CMMS analytical reporting module provides key performance indicators (KPIs) to evaluate maintenance effectiveness and equipment reliability. Reports include monthly Work Order Completion Rate, Preventive Maintenance Completion Rate, Corrective Maintenance Completion Rate, Total Downtime per Month, and Material Cost per Month, all generated automatically from historical CMMS data. flow process of report as shown in figure 13.

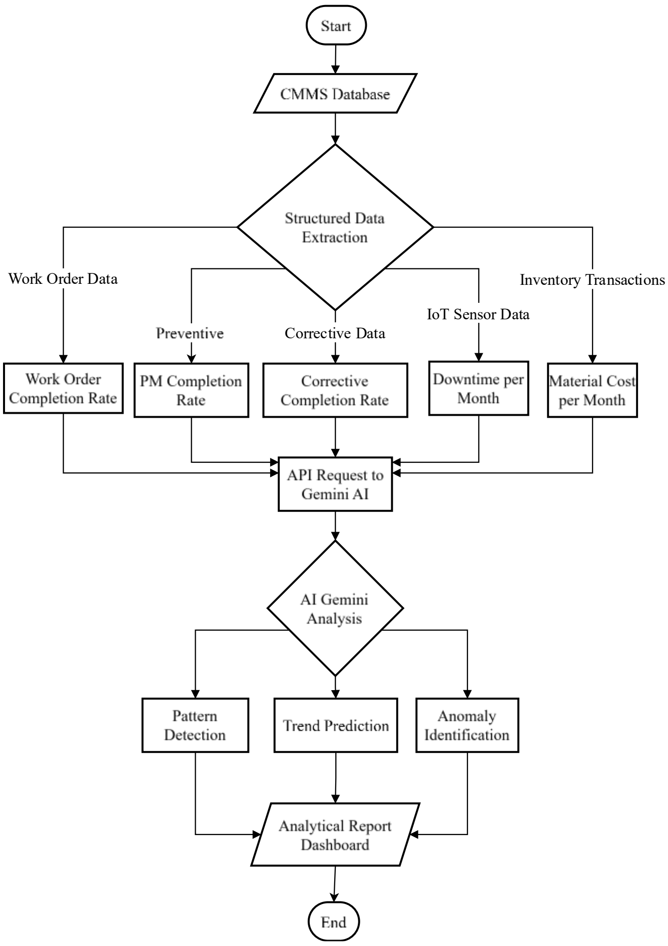

Figure 13. Flow process of maintenance analytical reports in CMMS

Reports are integrated with Gemini AI, which analyzes structured CMMS data through an API to detect patterns, predict performance trends, and identify operational anomalies. This integration transforms raw maintenance data into actionable insights, enabling proactive decision-making for optimizing scheduling, improving preventive maintenance compliance, and reducing maintenance costs. Visualization of Work Order and Preventive Maintenance Completion Rates are shown in Figure 14, Corrective Maintenance Completion Rate and Total Downtime per Month are shown in Figure 15, and Material Cost per Month is shown in Figure 16.

Figure 14. Work order and preventive maintenance completion rates

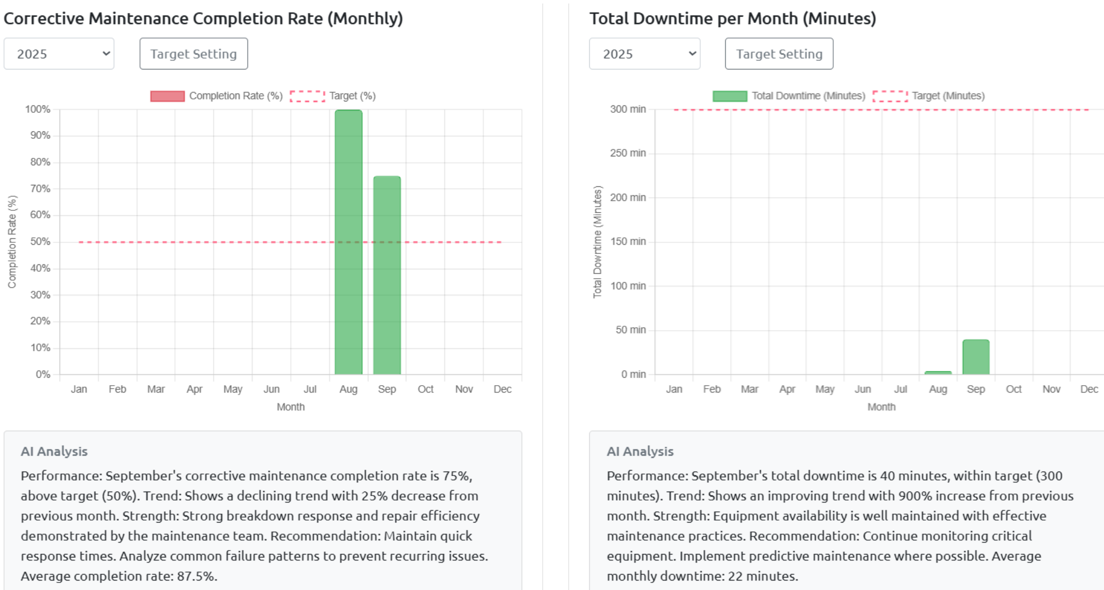

Figure 15. Corrective maintenance completion rate and total downtime trend

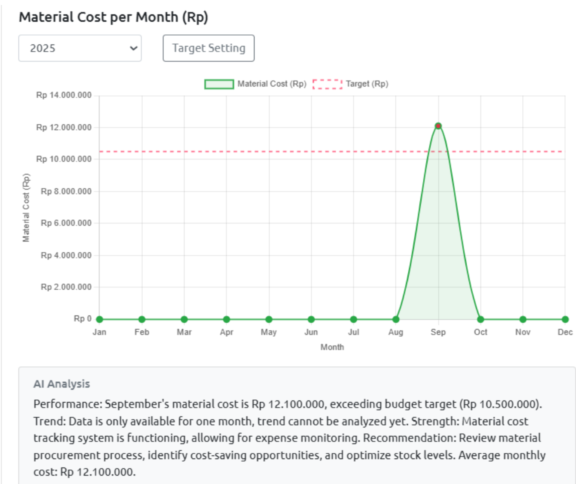

Figure 16. Monthly material cost analysis

Functional testing results

Functional testing was conducted using the black-box method to verify that all CMMS modules met their defined functional requirements. Testing covered system input, process, and output validation for each module. Testing results is shown in Table 1, all major modules including Work Order, Preventive Maintenance, Corrective Maintenance, Machine Monitoring, and Inventory are achieved 100% success rates, confirming that the system operated correctly and reliably under various scenarios.

Table 1. Functional testing results of CMMS

Test Case	Scenario Test	Status
Work order	user can successfully edit and delete a work order.	valid
	user can change status of a work order	valid
Preventive maintenance	system displays correct count on "PM completion this year, and month" card.	valid
	system displays correct number of PM pending and PM cancelled	valid
	system displays correct percentage on "PM finding close rate" card.	valid
	PM schedule correctly shows status of each PM task for respective months.	valid
	user can add a new PM standard and submit it for approval.	valid
	user can update status of a PM check sheet	valid
	system displays an updated list of pm items with correct status.	valid
Corrective maintenance	user can successfully add a new corrective maintenance record.	valid
	user can add, update and close a CM record	valid
Inventory	user can perform a stock in transaction, successfully updating inventory quantity.	valid
	user can perform a stock out transaction, successfully reducing inventory quantity.	valid
Settings	user can successfully add, edit, deactivate, and delete new user account.	valid
	user can successfully add, edit and delete an area and equipment	valid
Equipment monitoring	system displays all equipment in a process flow with status (running or stopped).	valid
	system accurately calculates and displays trend of stop time	valid
KPI report	system displays all KPI graphs	valid
	user can change year filter, and all graphs update accordingly.	valid
	user can change target settings for each KPI graph.	valid
	analysis provides performance summary and recommendation based on data.	valid

Maintenance efficiency evaluation

Effectiveness of CMMS implementation was evaluated based on equipment reliability and maintainability using two key indicators: Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR). Evaluation period spanned four months, from July to October 2025, where July–August represented the pre-implementation phase and September–October represented the post-implementation phase. Both indicators were analyzed across five critical equipment units, including Injection molding, Robot pick and place, robot cutting laser, Robot Painting, and Oven. Figure 17 presents MTBF trend of each equipment. The results show a consistent increase in MTBF values after the CMMS implementation, indicating improved equipment reliability and extended operating cycles between failures.

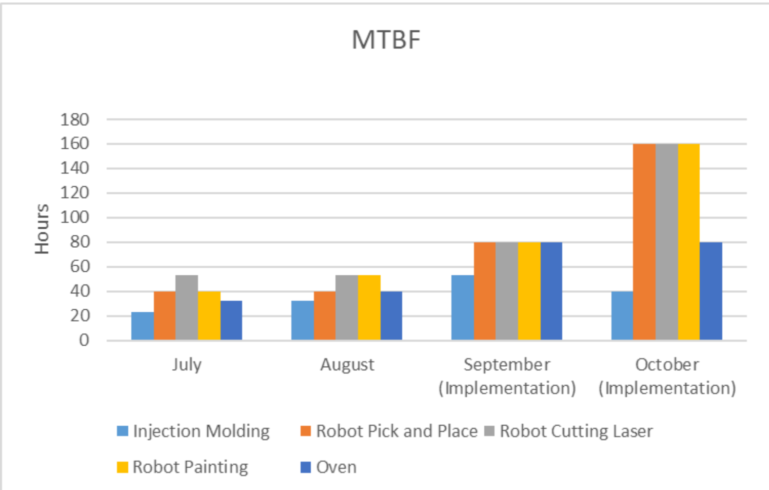

Figure 17. MTBF trends of critical equipment before and after CMMS implementation

Figure 18 presents MTTR trend that representing repair time required to restore equipment functionality after a failure. A significant decrease in MTTR was observed across all equipment types following system implementation, implying more efficient troubleshooting and maintenance execution. Improvement demonstrates the positive effect of CMMS Implementation.

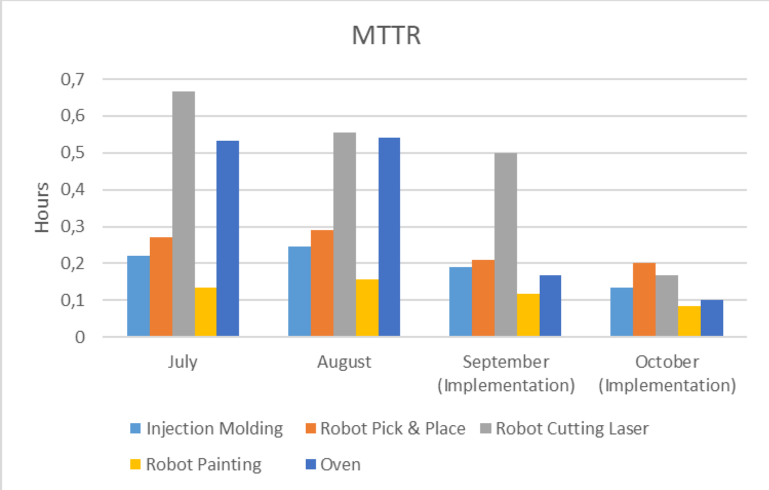

Figure 18. MTTR trends of critical equipment before and after CMMS implementation

The results of maintenance efficiency after CMMS implementation as shown in Table 2, indicate that all equipment demonstrated a substantial improvement in performance following system integration. This improvement was primarily driven by reduced downtime and enhanced technician responsiveness through real-time monitoring features. On average, overall maintenance efficiency increased by approximately 368%, confirming that the CMMS significantly enhanced both the reliability and responsiveness of maintenance operations.

Table 2. Maintenance efficiency after CMMS implementation

Equipment	Average MTBF before Implementation (Hours)	Average MTTR before Implementation (Hours)	Average MTBF After Implementation (Hours)	Average MTTR After Implementation (Hours)	Maintenance Efficiency (%)
Injection Molding	27,43	0,23	46,67	0,16	147,2
Robot Pick and Place	40,00	0,28	120,00	0,20	313,3
Robot Cutting Laser	53,33	0,61	120,00	0,33	312,5
Robot Painting	46,67	0,14	120,00	0,10	271,4
Oven	36,00	0,54	80,00	0,13	795,8
Average					**368,0**

The implementation of an IoT-based CMMS was proven to enhance the maintenance performance of all evaluated equipment, as indicated by an increase in Mean Time Between Failures (MTBF) and a reduction in Mean Time to Repair (MTTR). The improvement in MTBF reflects enhanced equipment reliability, while the decrease in MTTR indicates faster diagnosis and repair processes. These results validate that the integration of IoT-based condition monitoring with preventive maintenance scheduling and work order management effectively reduces unplanned downtime and improves maintenance efficiency.

The average maintenance efficiency improvement of 368% achieved in this study demonstrates superior performance compared to most previous studies, which generally reported improvements in the range of 60% to 98% [42], [43]. This improvement is influenced by the utilization of real-time machine condition data, which are not only used for visualization purposes but are systematically employed as a reference for preventive maintenance scheduling, work order management, and data-driven decision-making through CMMS modules available within a single application. By consolidating equipment condition information and historical failure records within the same system, maintenance activities can be executed in a more structured and consistent manner, leading to a sustained reduction in MTTR and an overall improvement in equipment reliability. These findings indicate that significant improvements in maintenance efficiency can be achieved without the implementation of fully automated decision-making systems, provided that machine condition data are effectively utilized to support maintenance activities. This study provides empirical evidence highlighting the importance of data utilization strategies in the implementation of Computerized Maintenance Management Systems (CMMS) to support smart maintenance initiatives in accordance with Industry 4.0 principles.

CONCLUSION

This study successfully developed and implemented an Internet of Things-based Computerized Maintenance Management System (CMMS) aimed at improving maintenance reliability and operational efficiency in the manufacturing sector. Functional evaluation using black-box testing proved that all CMMS modules operated according to design specifications. Effectiveness evaluation through maintenance indicators, namely Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR), showed a significant improvement in maintenance efficiency of approximately 368% after implementation. These results indicate that the proposed CMMS effectively reduces downtime, improves technical responsiveness through real-time monitoring, and strengthens data-driven decision-making in maintenance management. Overall, this system contributes to the development of smart manufacturing practices by providing a sustainable, data-oriented framework for continuous improvement in industrial maintenance operations.

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