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RESEARCH ARTICLE

An IoT-based Downtime Data Tracking and Alert System to Support OEE Monitoring in Production Lines

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ABSTRACT - This project presents the development of a Downtime Data Tracking and Alert System (DDTAS) to enhance the efficiency of technical support teams and machine operators in monitoring and recording production line downtimes, thereby supporting improved monitoring of Overall Equipment Effectiveness (OEE). The project was conducted in collaboration with an industry partner through a Work-Based Learning (WBL) programme. Previously, machine downtimes were recorded manually using note cards, and breakdowns were signaled using emergency lights. This manual approach led to inaccuracies due to inconsistent time logging and reliance on human input. Additionally, repair times were logged separately through online forms, complicating data integration for performance analysis. To address these limitations, DDTAS was developed using the ESP32 microcontroller, RDM6300 RFID reader, PHPMyAdmin, and custom software. The system automates the capture and storage of downtime data, transmitting it to a centralized database and displaying it through an HTML-based web interface. The interface includes a graphical user interface (GUI) that indicates machine status—such as down, under repair, or operational—along with a Gantt chart visualizing downtime duration, repair time, and idle periods. This real-time dashboard, deployed in the technical team's workspace, enables faster response and more accurate downtime tracking. By replacing manual recording with automated data acquisition and visualization, DDTAS improves the reliability of downtime data, which is critical for calculating OEE metrics. The system ultimately contributes to enhanced operational visibility, more informed decision-making, and continuous improvement in production efficiency.

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1.0 INTRODUCTION

In today's highly competitive industrial landscape, optimizing manufacturing performance is crucial to ensure product quality, delivery reliability, and operational cost-effectiveness. Among the widely adopted performance indicators in production environments is Overall Equipment Effectiveness (OEE), which serves as a benchmark for identifying and minimizing losses in equipment utilization [1], [2]. Accurate downtime tracking is fundamental to OEE calculation, which integrates three core metrics: availability, performance, and quality [3].

This study was conducted in collaboration with a host company through a Work-Based Learning (WBL) initiative. The company operates globally, providing design-led electronics and advanced manufacturing services for Original Equipment Manufacturers (OEMs) in critical sectors such as healthcare, aerospace, and industrial automation [4]. The company's local facility consists of two floors comprising several departments, with the Production and Technical Support Departments being the focus of this project.

The production area is segmented into multiple sections, with Precision Manufacturing and Aerospace & Defence operations located on the lower floor, while Power Magnetics is housed on the upper floor. The technical support team, distributed between upper and lower rooms, is responsible for the repair and maintenance of all production machinery. When a machine breakdown occurs, operators trigger an emergency switch, installed at both ends of the production line, to signal a fault. However, the process of identifying the affected machine involves manual verification with the line leader, followed by response actions from the technical team.

This traditional method introduces several inefficiencies. First, the emergency lights remain active until the technician physically completes the repair and the operator deactivates the switch. This results in ambiguous signals, as technicians cannot differentiate between newly reported and already addressed breakdowns [5], [6]. Second, operators manually record downtime on printed tables, which the technical support team later refers to when filling in Google Forms for

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reporting. Unfortunately, operators frequently forget to log the exact start and end times of downtimes, leading to significant discrepancies in recorded downtime, repair time, and idle time—three metrics critical to OEE analysis [7], [8].

In manufacturing systems, downtime refers to the total period a machine is non-operational due to faults or failures; repair time indicates the duration required by technicians to resolve the issue; and idle time captures the delay between the moment a machine stops and when a technician responds to it [9], [10]. These metrics are not only vital for maintenance decision-making but also directly influence productivity analytics and continuous improvement frameworks like TPM (Total Productive Maintenance) and Lean Manufacturing [11], [12].

Manual recording methods are widely acknowledged to be prone to human error, subjectivity, and time lag [13]. Studies have shown that reliance on handwritten logs and verbal communication leads to incomplete or inaccurate maintenance records, undermining the reliability of any subsequent data analytics process [14], [15]. Consequently, there is a growing trend towards IoT-based downtime tracking systems that utilize microcontrollers, cloud databases, and real-time dashboards to enhance operational visibility and enable informed decision-making [16], [17], [18].

Motivated by these challenges, this project proposes the Downtime Data Tracking and Alert System (DDTAS), an integrated solution leveraging IoT technologies to automate downtime recording, alert generation, and data visualization. The implementation aims to improve real-time monitoring capabilities, reduce response time, and ensure the integrity of downtime-related data, ultimately supporting OEE monitoring and process optimization.

2.0 SYSTEM ARCHITECTURE

The design of the Downtime Data Tracking and Alert System (DDTAS) is centered on providing an automated and reliable method for capturing and monitoring machine downtime events on a production floor. The system architecture integrates hardware and software components to streamline data acquisition, processing, storage, and visualization. This section outlines the key elements of the system, beginning with an overview of the block diagram followed by detailed descriptions of the main components.

2.1 System Block Diagram

A block diagram is a simplified graphical representation used to model the structure and function of a system. It illustrates how different modules interact and transfer data to achieve the system's operational goals. As shown in Figure 1, the DDTAS architecture consists of interconnected hardware modules, database integration, and a real-time web dashboard.

At the core of the system is the ESP32-S3 microcontroller (model ESP32-4827S043), which includes a 4.3-inch TN color screen capable of displaying 65K RGB colors. This controller communicates with a RDM6300 RFID module for user identification via RFID cards and is programmed to transmit data to a centralized MySQL database (managed through PHPMyAdmin). The web dashboard, built using HTML and PHP, retrieves and visualizes data in real time, presenting machine status, repair activity, and downtime history to the technical support team.

The ESP32 device collects machine status signals and operator RFID data, processes them locally, and uploads the information to the database through a Wi-Fi network. The dashboard displays real-time system status with indicators and a Gantt chart, enabling responsive decision-making and timely technical intervention.

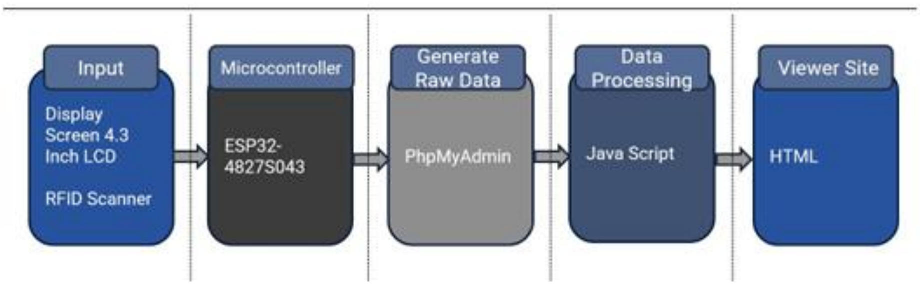

Figure 1. System Block Diagram of DDTAS

2.2 Downtime Data Tracking and Alert System (DDTAS) Objectives

The objective of DDTAS is to improve the efficiency of downtime monitoring by replacing the existing manual reporting processes with a fully automated system. Under the manual approach, machine operators recorded breakdown events on note cards and later transferred repair information via Google Forms. This method was prone to human error, inconsistencies in time logging, and delayed data entry, limiting its effectiveness for performance monitoring and analysis.

By deploying DDTAS, the process is digitized and streamlined. The system automatically captures downtime triggers, associates events with operator IDs through RFID cards, and records accurate timestamps for downtime, repair, and idle periods. This data is then visualized on a centralized dashboard, which provides the technical support team with real-time insights, enabling faster fault response and improved operational decision-making. The integration of these features also supports the broader goal of improving Overall Equipment Effectiveness (OEE) tracking.

2.3 DDTAS Device Configuration

The main hardware component of DDTAS is the ESP32-S3 microcontroller, equipped with a touch-enabled 4.3-inch screen. This device is configured to interface with the RDM6300 RFID reader, which scans operator RFID cards to capture Pass ID data. Upon detection, the ESP32 processes the information and updates the corresponding records in the MySQL database.

Key features of the DDTAS device include:

- Real-time status updates displayed on the built-in screen (e.g., "Machine Down," "Under Repair," "Repaired").
- RFID-based authentication, ensuring each downtime event is tied to a specific user or technician.
- Automated data upload via Wi-Fi to eliminate manual reporting delays.
- Visual confirmation of actions on the screen to enhance user feedback and accuracy.

This device replaces manual paperwork with digital tracking, reduces operator workload, and ensures higher data reliability for continuous improvement and OEE analysis.

3.0 RESULTS AND DISCUSSION

This section presents the implementation results and performance validation of the Downtime Data Tracking and Alert System (DDTAS), developed to automate machine downtime monitoring and reporting in a production environment. The objective is to demonstrate the system's functional effectiveness in replacing manual downtime tracking methods, enhancing data accuracy, and streamlining workflows for both operators and technical support personnel. This section also provides discussion on the implemented system.

3.1 Results and System Validation

3.1.1 System Deployment and User Roles

The DDTAS device was successfully deployed on two production lines within the host company, namely, Line 1 and Line 2. The system, developed using the Arduino IDE, is designed to serve two main user groups: operators and technical support personnel as presented by the user interface shown in Figure 2. Each group interacts with a dedicated interface tailored to their respective tasks, allowing them to record downtime and repair-related events through intuitive touch-screen commands. The logic behind these interface displays is illustrated in Figure 3, which outlines the flow of user interactions, from RFID authentication to event logging and screen transitions. This structured interface ensures that users follow a consistent process when entering data, reducing input errors and improving timestamp accuracy. Operators are responsible for logging the start and end of machine downtimes, while technical support personnel input the start time of repair activities, creating a complete event trail for each downtime incident. Figure 4 shows the operator interface screen to report machine downtime events.

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Figure 2. DDTAS device user interface

3.1.2 Data Logging and Visualization

All event data including machine downtime, repair time, and idle time are captured by the ESP32 microcontroller and stored in a MySQL database via PHPMyAdmin. The database is hosted using the AMPPS platform, ensuring reliable performance and integration. The system enables accurate tracking of the following key parameters:

- Downtime duration (from operator report to repair start)
- Repair time (from technician start to completion)
- Idle time (delay between downtime report and technician response)

Figure 5 presents the web-based dashboard, developed using HTML and PHP, which displays the captured data through an intuitive and user-friendly graphical interface. The dashboard features both tabular logs and a Gantt chart, enabling clear visualization of event timelines such as machine downtime, repair duration, and idle periods. This interface supports real-time monitoring while also facilitating retrospective analysis, thereby enhancing decision-making and operational insight.

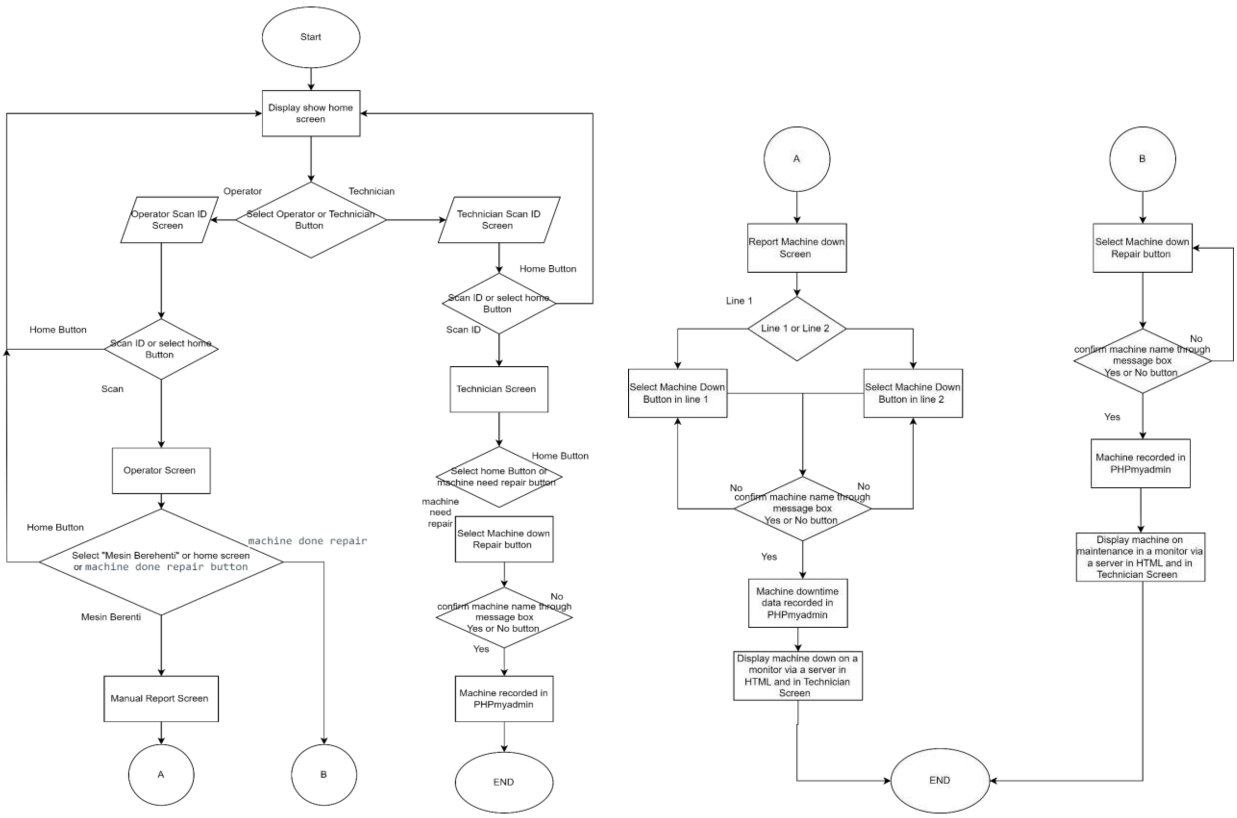

Figure 3. Flowchart for interface display

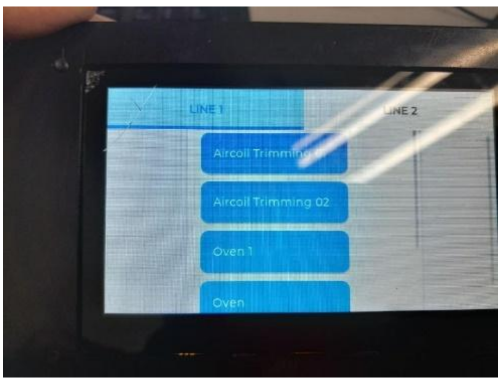

Figure 4. Operator interface screen to report machine downtime events

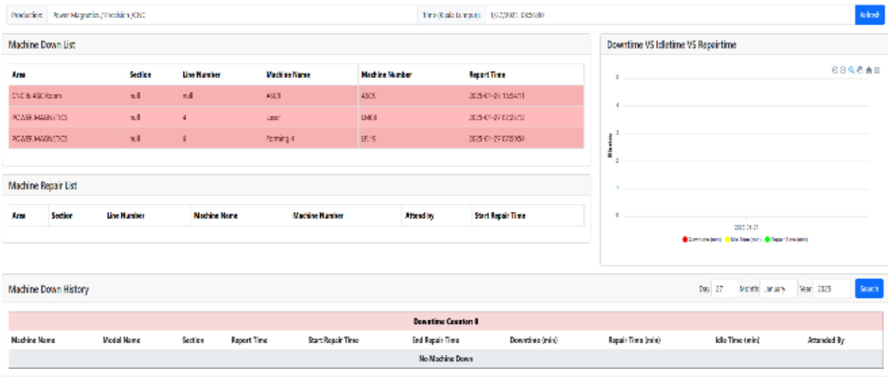

Figure 5. Web dashboard showing machine status, downtime records, and historical data

3.1.3 Technical Implementation Tools

The software environment for DDTAS includes both programming and debugging tools. Arduino’s Serial Monitor was used for low-level debugging and HTTP data transmission monitoring during development. Visual Studio Code was employed to simulate and visualize the technical support room layout, assisting in UI/UX design.

Despite minor challenges during database integration and HTTP communication tuning, the system demonstrated stable performance across both pilot lines. It maintained consistent real-time updates and seamless data synchronization between the device and dashboard.

The system successfully addressed several limitations inherent in the previous manual recording method. Most notably, it eliminated the need for manual data entry, thereby reducing the risk of human error and inconsistencies in event logging. This transition to automation also improved the accuracy of recorded data, particularly in terms of timestamp precision, which is critical for meaningful downtime analysis. In addition, the availability of a real-time dashboard enhanced operational transparency and enabled more proactive and informed decision-making. Workflow efficiency was also improved, especially within the technical support team, as the system streamlined the process of responding to and resolving machine downtime events.

Although the current deployment is limited to Line 1 and Line 2, the system architecture and codebase were developed with scalability in mind. The modular design allows for seamless expansion to other production lines with minimal configuration, making the system a viable solution for broader implementation across the factory floor.

3.1.4 Hardware and Software Components

The list below summarizes the key hardware and software elements used in the development of DDTAS:

Table 1. Key hardware and software elements used in the development of DDTAS

Component type	Element
Hardware	• ESP32-4827S043C (Microcontroller with 4.3” display) • RDM6300 (RFID module) • ABS Plastic Enclosure (Black Box)
Software	• Arduino IDE (Firmware development) • PHPMyAdmin (Database management) • HTML & PHP (Dashboard interface) • AMPPS (Local server environment) • Visual Studio Code (UI layout visualization)

Figure 6. DDTAS hardware prototype

3.2 Discussion

The implementation of the Downtime Data Tracking and Alert System (DDTAS) demonstrates a significant improvement in how machine downtime is tracked, recorded, and analyzed within a production line environment. This discussion highlights the practical implications, system performance, challenges encountered, and the potential scalability of the system, particularly in the context of improving Overall Equipment Effectiveness (OEE).

3.2.1 Practical Implications

The DDTAS system effectively addresses longstanding inefficiencies in traditional downtime tracking practices, which relied heavily on handwritten logs and delayed manual reporting. By introducing real-time automated logging through the ESP32 microcontroller and RFID-based user identification, the system eliminates latency in data capture and ensures accurate recording of key operational metrics such as downtime, repair duration, and idle time.

In practice, this transformation has resulted in several operational benefits. Operator accountability has improved, as each downtime event is now associated with a specific RFID Pass ID, allowing traceability and responsibility attribution. Additionally, the system provides immediate visual feedback through both the device's built-in screen and the web-based dashboard, enhancing situational awareness on the production floor. Centralized access to performance data further empowers engineers, technical support staff, and managers to make timely and coordinated decisions.

These improvements align well with the principles of Lean Manufacturing and Total Productive Maintenance (TPM), where accurate and real-time data are essential for identifying inefficiencies, reducing production losses, and driving continuous improvement initiatives [1][2].

During the system deployment on Line 1 and Line 2, the accuracy of recorded event timestamps showed significant improvement compared to manual logs. This directly contributes to more reliable OEE calculations by eliminating estimation or memory-based entries. The automated process also ensures that:

- Downtime duration is not underestimated due to delayed reporting.
- Repair time is logged from the actual technician start time, rather than being approximated post-repair.
- Idle time can be minimized through real-time alerts and technician readiness.

With such granularity, production bottlenecks and high-failure machines can be identified and addressed through preventive action planning.

3.2.2 System Challenges and Future Improvements

Although the system demonstrated effective performance, several challenges were encountered during its development and deployment. One of the primary issues was database synchronization. During the initial testing phase, delayed updates were observed due to intermittent network instability. This challenge was addressed by optimizing the HTTP data transmission intervals and refining the error-handling routines within the ESP32 firmware, which helped stabilize the communication between the device and the database.

Another challenge involved user training, particularly among operators who were initially unfamiliar with RFID-based logging and touchscreen interactions. This issue was relatively minor and was resolved through short, focused training sessions, after which the users adapted to the system with minimal difficulty.

Lastly, the scope of implementation was initially limited to just two production lines. While the pilot deployment successfully validated the system's functionality, expanding it to a factory-wide scale would require careful network planning, sufficient hardware provisioning, and potentially, integration with more complex systems such as SCADA (Supervisory Control and Data Acquisition) or MES (Manufacturing Execution Systems) platforms to ensure seamless operation [3][4].

The modular and open-source nature of the system architecture enables easy scalability. New ESP32 units can be added to other production lines with minimal configuration, using the same database and dashboard framework. Additionally, several improvements can be explored in future iterations:

- Integration of wireless sensors to automatically detect machine stoppages without operator intervention.
- Deployment of mobile dashboards for supervisors and technicians to receive alerts and status updates via smartphones or tablets.
- Linking DDTAS data with predictive maintenance algorithms, allowing deeper insights into recurring fault patterns.

3.2.3 Contribution to OEE Monitoring

One of the main motivations behind this project was to support OEE monitoring through precise and timely data acquisition. The three primary components of OEE—Availability, Performance, and Quality—can now be more accurately quantified:

- Availability is directly influenced by the accurate tracking of downtime and repair duration.
- Performance losses (e.g., frequent stops or slow cycles) can be analyzed using the downtime trends.
- Quality losses could be correlated by integrating defect reporting in future system upgrades.

Overall, DDTAS provides a low-cost, high-impact solution for real-time monitoring that aligns with smart manufacturing and Industry 4.0 goals.

4.0 CONCLUSION

This paper presented the development and implementation of the Downtime Data Tracking and Alert System (DDTAS), an IoT-based solution designed to automate machine downtime monitoring in a production line environment. The system, which was developed as part of a WBL initiative in collaboration with an industry partner, successfully replaced manual downtime reporting methods with a digital system that leverages an ESP32 microcontroller, RFID technology, and a real-time web-based dashboard.

The implementation on two production lines demonstrated the system's capability to capture key operational metrics: downtime, repair duration, and idle time, with improved accuracy and reliability. The integration of RFID authentication enabled operator-specific logging, while the use of a centralized database and visual dashboard facilitated real-time monitoring and faster technical response. As a result, the system significantly improved workflow efficiency, data accuracy, and decision-making processes within the technical support and operations teams.

Furthermore, DDTAS supports the broader objective of enhancing Overall Equipment Effectiveness (OEE) monitoring by providing precise and timely data for Availability-related analysis. Although the current deployment was limited to two lines, the system's modular architecture and low-cost design make it highly scalable for broader factory-wide implementation.

Future enhancements may include the integration of automatic machine status detection, mobile notification systems, and predictive analytics to support proactive maintenance strategies. These improvements would further align the system with Industry 4.0 principles and smart manufacturing objectives.

In conclusion, DDTAS offers a practical and scalable solution to modernize downtime tracking in industrial settings, contributing to continuous improvement efforts and laying a strong foundation for data-driven manufacturing performance management.

5.0 AUTHORS CONTRIBUTION

A. Nasharudin Kamal Zaim (Writing - original draft; Methodology; Validation; Formal analysis; Data curation; Investigation; Validation; Visualisation)

Idris Syafie Khajar (Validation; Resources; Software; Data curation; Visualisation)

Amran Abdul Hadi (Writing - review & editing; Validation; Funding acquisition; Resources; Software; Supervision)

Mohd Zamri Ibrahim (Writing - review & editing; Methodology; Validation; Supervision)

Mohamad Rahimi M. Rodzi (Writing - review & editing; Validation; Resources; Software; Project administration)

R.M.T. Raja Ismail (Writing - review & editing; Conceptualisation; Methodology; Validation; Visualisation)

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