

IoT and OEE Integration for Improving Rewinder Performance in Paper Industry: A Systematic Review

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ABSTRACT

The rewinder is a critical unit in the paper production process because it determines operational stability, final product quality, and the overall effectiveness of production flow. However, this unit frequently experiences operational disturbances such as downtime, speed loss, and quality deviations, which directly contribute to reductions in Overall Equipment Effectiveness (OEE). With the advancement of Industry 4.0 technologies, the integration of the Internet of Things (IoT) with OEE monitoring systems offers new opportunities to improve machine efficiency through real-time monitoring, early fault detection, and data-driven performance analysis. This study conducts a systematic literature review of 37 scientific publications related to IoT implementation, predictive maintenance, and OEE improvement in manufacturing environments. The reviewed literature was analyzed using the PRISMA framework and categorized into four major themes: IoT–OEE integration, OEE improvement strategies, predictive maintenance and smart manufacturing, and downtime reduction and availability improvement. The findings indicate that IoT-based predictive maintenance systems can increase equipment availability by approximately 25–30%, reduce downtime by 30–40%, and improve fault detection accuracy through machine learning models reaching up to 92%. In addition, IoT-enabled monitoring systems enhance data visibility and improve the accuracy of OEE measurement by approximately 15%, thereby strengthening operational decision-making. Future research should validate IoT–OEE integration through industrial case studies, given its potential to improve rewinder performance and reliability in paper machines.

KEYWORDS: *IoT, OEE, Paper Machine, Paper Industry, Rewinder.*

1. INTRODUCTION

The paper manufacturing industry operates as a continuous-process production system in which operational stability across all machine units is essential for maintaining productivity, product quality, and cost efficiency. Among the key processing units, the rewinder plays a critical role in the final stage of paper production by converting jumbo rolls into smaller rolls according to customer specifications. Because the rewinder functions as a conversion unit, disturbances occurring at this stage can directly influence downstream production performance. Operational issues such as web breaks, tension instability, cutter blade malfunction, and delays in material supply frequently disrupt the rewinding process and may significantly reduce Overall Equipment Effectiveness (OEE). These disturbances affect the three core components of OEE—availability, performance, and quality, thereby decreasing overall machine productivity.

In many industrial environments, monitoring of machine performance and evaluation of OEE are still conducted through manual data recording systems. Manual monitoring often leads to delays in detecting operational problems, inaccurate classification of production losses, and limited capability for comprehensive data analysis. Consequently, decision-making related to maintenance planning, machine utilization, and process optimization is frequently based on incomplete or delayed information.

The rapid development of Industry 4.0 technologies has created new opportunities to improve machine monitoring and performance evaluation in manufacturing systems. One of the key enabling technologies is the Internet of Things (IoT), which allows machines to be equipped with interconnected sensors capable of collecting operational data in real time. Through IoT-based monitoring systems, machine conditions, production performance, and operational disturbances can be continuously observed and analyzed. Integration of IoT technologies with machine monitoring systems also enables the development of predictive maintenance strategies and digital dashboards that provide real-time visualization of performance indicators such as OEE.

Numerous studies have explored the implementation of IoT technologies in smart manufacturing, predictive maintenance, and industrial monitoring systems. However, most of these studies focus on general manufacturing environments,

assembly lines, or smart factory architectures. Research specifically examining the integration of IoT technologies with OEE-based performance evaluation for individual machine units remains relatively limited. This limitation is particularly evident in the paper manufacturing industry, where conversion equipment such as rewinder machines plays a crucial role in determining overall production efficiency. In paper manufacturing plants, Paper Machine 1 (PM1) refers to a continuous production line responsible for forming and processing paper sheets before the conversion stage, where the rewinder unit operates as the final processing equipment.

Existing literature often examines predictive maintenance systems, industrial monitoring platforms, and production efficiency indicators as separate research topics. Studies that comprehensively integrate IoT-based monitoring systems with OEE performance analysis for specific industrial equipment are still relatively scarce. In addition, limited research has investigated how real-time operational data generated through IoT systems can directly support operational decision-making and performance optimization for conversion machines within the paper industry.

Several research gaps can therefore be identified. First, there is a lack of studies that specifically examine the implementation of IoT-OEE integration for rewinder units in the paper manufacturing sector. Second, existing literature

lacks a systematic synthesis explaining how IoT technologies contribute to improving OEE performance in conversion machines, particularly rewinder systems. Third, the utilization of real-time operational data to support data-driven decision-making in rewinder operations remains insufficiently explored. Addressing these gaps is particularly important for industries that rely on continuous production processes, where machine downtime and operational inefficiencies can significantly affect productivity and operational costs. A structured understanding of how IoT technologies can support OEE monitoring and performance improvement is therefore required to enhance the reliability and efficiency of industrial production systems.

Accordingly, this study aims to conduct a systematic literature review on the integration of Internet of Things (IoT) technologies and Overall Equipment Effectiveness (OEE) in manufacturing environments. The objective of this review is to synthesize existing research, identify technological approaches and implementation strategies, and highlight research opportunities related to IoT-based monitoring systems for improving machine performance. Particular emphasis is placed on understanding the potential role of IoT-OEE integration in enhancing the operational performance of rewinder units within Paper Machine 1 production systems in the paper manufacturing industry.

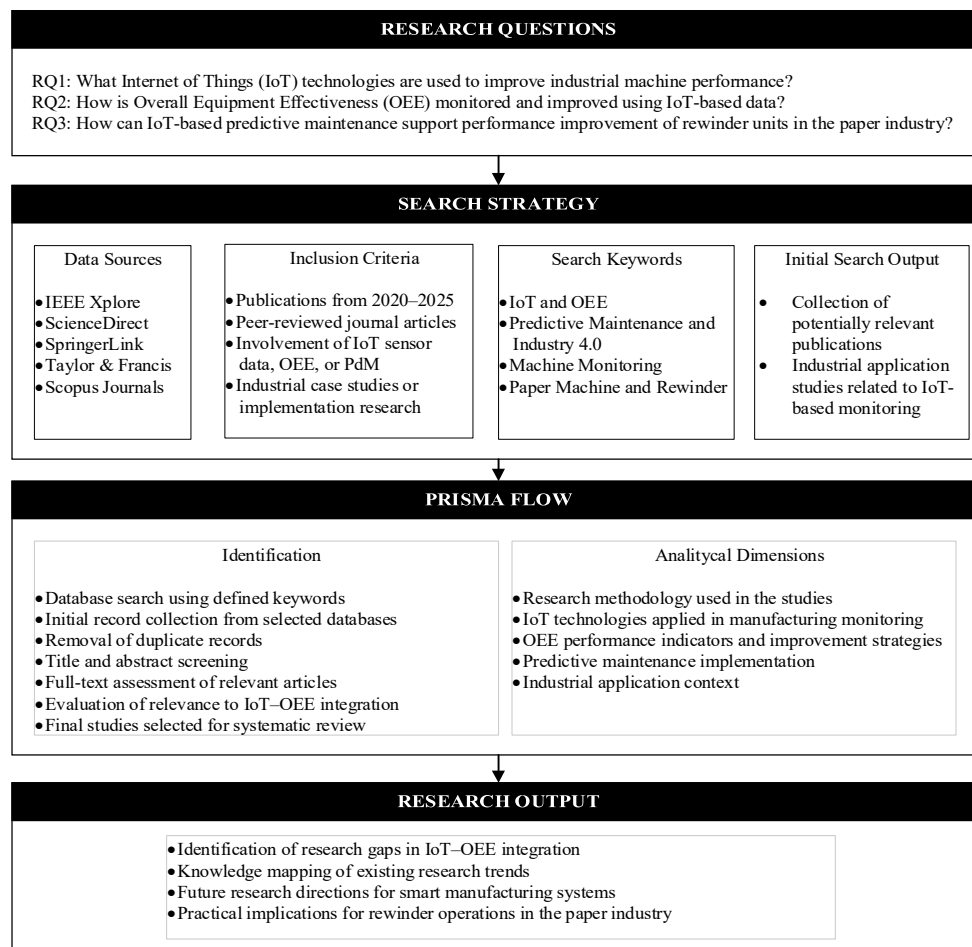


Figure 1: Systematic literature review framework for IoT-OEE integration in rewinder systems

2. RESEARCH METHODOLOGY

A Systematic Literature Review (SLR) approach was employed to synthesize and critically analyze previous studies related to the integration of Internet of Things (IoT) technologies and Overall Equipment Effectiveness (OEE) within manufacturing environments. Particular attention was given to studies addressing machine performance monitoring, predictive maintenance strategies, and digital transformation initiatives relevant to industrial production systems. Relevance to the paper manufacturing industry, especially conversion equipment such as rewinder units, was considered an important aspect in identifying literature aligned with the objectives of this study. Implementation of a structured review framework ensured that the identification, screening, and evaluation of literature were conducted in a transparent and reproducible manner.

Relevant publications were identified through several widely recognized scientific databases, including Scopus,

Science Direct, IEEE Xplore, Taylor & Francis, Springer Link and Google Scholar, which provide extensive coverage of peer-reviewed research in industrial engineering, smart manufacturing, maintenance engineering, and Industry 4.0 technologies. Development of the search strategy involved combinations of keywords associated with the research scope, including "Internet of Things", "IoT", "Overall Equipment Effectiveness", "OEE", "predictive maintenance", "machine monitoring", "smart manufacturing", "paper industry", and "rewinder". Boolean operators such as AND and OR were applied to structure the search queries and refine the retrieval of relevant publications. A representative search query used during the literature search process was ("Internet of Things" OR "IoT") AND ("Overall Equipment Effectiveness" OR "OEE") AND ("predictive maintenance" OR "machine monitoring") AND ("manufacturing" OR "paper industry" OR "rewinder").

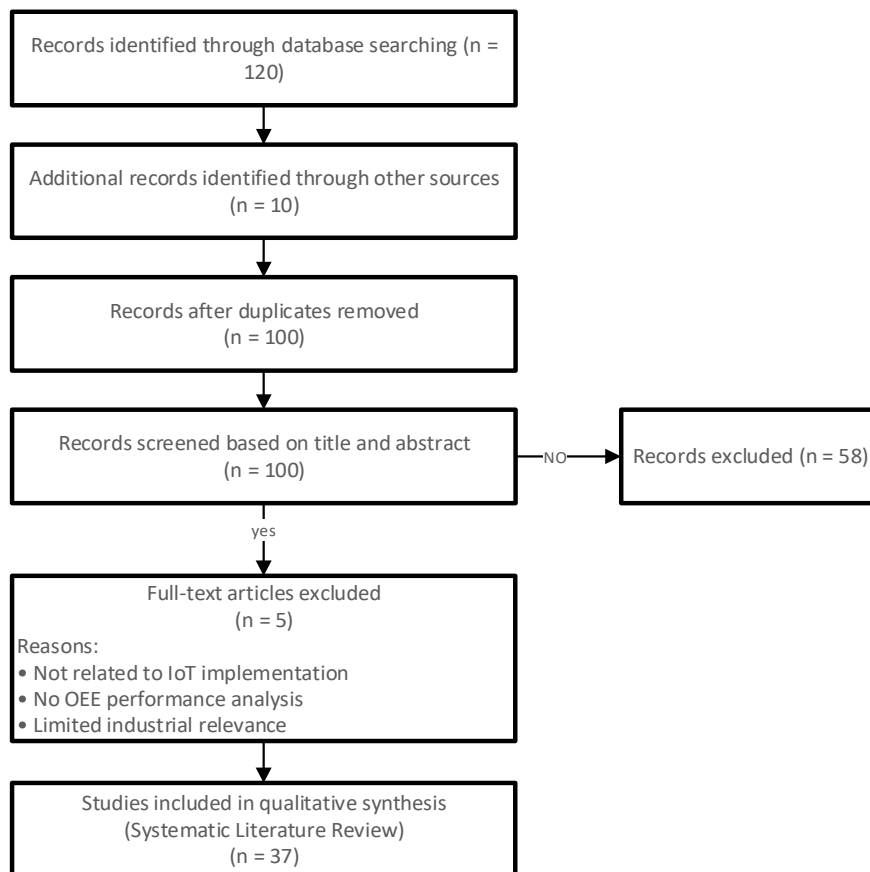


Figure 2: PRISMA Diagram

Records retrieved from the selected databases were compiled and organized prior to the screening stage. Duplicate records identified across multiple databases were removed to ensure that each publication was evaluated only once during the review process.

The selection of relevant studies followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides a systematic procedure for filtering and selecting literature in review-based research.

The selection process consisted of four main stages: identification of relevant records, screening based on titles and abstracts, eligibility assessment through full-text evaluation, and final inclusion of studies considered relevant to the objectives of the review. Initial screening was conducted to remove studies that were clearly unrelated to IoT implementation, equipment performance measurement, or industrial maintenance systems. Full-text evaluation was subsequently carried out to determine the eligibility of the

remaining publications for inclusion in the final dataset.

Inclusion and exclusion criteria were defined to ensure that the selected literature maintained strong relevance to the objectives of the study. Inclusion criteria covered peer-reviewed journal articles written in English that discuss the application of Internet of Things technologies, Overall Equipment Effectiveness measurement, predictive maintenance systems, machine monitoring, or smart manufacturing approaches within industrial environments. Publications addressing equipment performance improvement, production efficiency optimization, machine reliability enhancement, or digital maintenance strategies were considered particularly relevant to the scope of this review. Emphasis was placed on literature published within the period 2020–2025, reflecting the rapid development of Industry 4.0 technologies and industrial digitalization in recent years. Studies presenting empirical investigations, implementation frameworks, case studies, or technological evaluations related to IoT or equipment performance monitoring were prioritized in the final dataset.

Exclusion criteria were applied to remove publications that did not align with the scope of the review. Documents such as conference abstracts without full manuscripts, editorial notes, duplicated records, book chapters, and non-English publications were excluded during the screening process. Studies focusing on topics unrelated to IoT implementation, equipment effectiveness evaluation, predictive maintenance, or manufacturing system performance were also removed. Literature lacking methodological clarity or failing to provide meaningful discussion regarding machine performance monitoring or industrial maintenance strategies was excluded as well.

Application of these criteria ensured that the final set of selected studies remained directly relevant to the integration of IoT-based monitoring systems and OEE performance evaluation in manufacturing environments, while also enabling identification of existing research gaps concerning the implementation of IoT-OEE integration for conversion machines, particularly rewinder units in the paper manufacturing industry.

The methodological framework adopted in this study provides a transparent overview of the literature identification and selection process and supports systematic analysis of the reviewed studies. The overall methodological framework and the PRISMA flow diagram illustrating the literature selection process are presented in Figure 1 and Figure 2, respectively.

3. RESULTS AND DISCUSSION

The analysis of the selected studies was organized into four main thematic categories: IoT-OEE integration, OEE improvement strategies, predictive maintenance and smart manufacturing, and downtime reduction and availability improvement. These themes reflect the dominant research directions identified in the reviewed literature and highlight the technological approaches used to enhance machine performance in manufacturing environments.

3.1 IoT-OEE Integration

A review of nine studies demonstrates that IoT integration has been proven to enhance operational effectiveness by improving data accuracy, reducing bottlenecks, and enabling real-time monitoring. Previous studies highlight improvements in data accuracy and acquisition speed, which are highly relevant for calculating OEE in rewinder units that are sensitive to minor downtime events [10], [11]. Other studies emphasize the importance of material flow mapping and bottleneck detection to ensure that the rewinder does not become a limiting point in the production line [9], [12]. Additional research further highlights the importance of edge-cloud architectures, sensor integration, and IoT-based traceability to ensure that the rewinding process operates in a stable, responsive, and easily diagnosable manner [13], [14], [16]. Overall, these findings indicate that IoT adoption can serve as a strong foundation for optimizing rewinder OEE. Table 1 presents research findings on IoT-OEE integration.

Table 1: Research findings on IoT-OEE integration

No.	Author (Year)	IoT-OEE Method	Key Findings (Impact)	Relevance to Rewinder
1	Zhou et al. (2020), [1]	OPC-UA + MQTT + MUDAQ	OEE data accuracy increased by 15%	Supports digitalization of rewinder OEE (PM1)
2	Vlachos et al. (2022), [2]	IoT + AGV positioning	Idle time & blockage reduced by 12%	Stabilizes material flow to the rewinder
3	Llopis et al. (2024), [3]	IoT sub-bottleneck detection	Line efficiency improved; bottlenecks more easily identified	Helps determine whether the rewinder is a bottleneck in PM1
4	Becker & Sanders (2016), [4]	IoT manufacturing review	IoT increases process visibility	Theoretical foundation of IoT for rewinder OEE
5	Mikhailov et al. (2021), [5]	IIoT monitoring system	More accurate real-time process monitoring	Supports real-time monitoring of the rewinder
6	Ooi et al. (2021), [6]	Real-time IoT tracking	Faster process tracking	Useful for tracking jumbo roll flow toward rewinder
7	Cabrini et al. (2021), [7]	IIoT-cloud continuum	More efficient edge-cloud data pipeline	Relevant for designing the rewinder's IoT architecture
8	Sharma et al. (2020), [8]	Industrial IoT	Sensor-cloud integration improves control	Supports design of rewinder data architecture
9	Sama et al. (2023), [9]	Automated data acquisition	Improved identification of machine data patterns	Basis for rewinder data acquisition architecture

3.2 OEE Improvement

This group of studies demonstrates that integrating OEE methodologies with IoT technologies provides a consistently positive impact on machine performance and overall production lines. Previous studies confirm that IoT-based predictive maintenance systems can significantly reduce downtime and improve machine availability through real-time monitoring and data-driven maintenance strategies [15], [16]. IoT-enabled monitoring platforms also enhance production visibility and facilitate more accurate OEE measurement in complex manufacturing environments [10]. In addition, the integration of SMED, TPM, and IoT technologies has been shown to significantly improve OEE performance in

production systems, particularly in conversion processes similar to rewinder operations [17]. Earlier research also provides a strong methodological foundation for evaluating production line performance through the Overall Equipment Effectiveness of Manufacturing Lines (OEEML) framework, which can be used as a reference for assessing rewinder performance within the broader Paper Machine 1 production system [4]. Overall, these findings strengthen the argument that integrating IoT technologies, lean practices, and OEE methodologies represents an effective approach for improving the reliability and operational stability of rewinder systems. Table 2 summarizes research findings on OEE improvement.

Table 2: Research findings on OEE improvement

No.	Author (Year)	Method	Key Findings (Impact)	Relevance to Rewinder
1	Zhou et al. (2020) [1]	OEE integration	OEE baseline measured at 61.51%	Serves as a benchmark for rewinder OEE in PM1
2	Ayvaz & Alpay (2021), [15]	IoT-based predictive maintenance	Availability increased by 25%; downtime reduced by 40%	Highly relevant for improving PM1 rewinder performance
3	Compare et al. (2019), [18]	IoT predictive maintenance (4-layer analytics)	Downtime reduced by 30%	Direct contribution to improving rewinder performance
4	Zhang & Wang (2022), [19]	DSS and OEE dashboard	Availability improved by 25%	Supports real-time visualization of OEE for PM1
5	Gonzales-Vera et al. (2025), [14]	SMED + TPM + IoT	OEE increased significantly	Applicable to conversion machines similar to rewinder
6	Braglia et al. (2009), [20]	OEEML model	Better performance evaluation across production lines	Reference model for rewinder OEE assessment
7	Nor Aziana et al. (2025), [21]	Lean + Industry 4.0	Lean-IoT synergy improves OEE	Supports continuous improvement in PM1
8	Peko et al. (2022), [22]	Digital quality metrics	Quality KPIs improved	Additional quality indicators applicable to rewinder
9	Novochadlo et al. (2024), [23]	Real-time OEE indicator (IoT, Big Data, Cloud Computing)	Average efficiency improved by 12.3% in 7 months; increased performance and availability	Supports real-time monitoring and improvement of rewinder OEE and availability
10	Fakinafiddin et al. (2025), [12]	IoT-based monitoring	OEE of mixer machine at 77.5%; IoT crucial for monitoring downtime and OEE	Directly applicable for improving PM1 rewinder OEE and reducing downtime

3.3 Predictive Maintenance and Smart Manufacturing

This group of studies highlights that predictive maintenance, enabled through the integration of Internet of Things (IoT) technologies and machine learning, provides significant improvements in industrial machine reliability. Several studies report that IoT-based predictive maintenance systems can significantly reduce downtime while improving equipment availability through continuous monitoring and data-driven maintenance strategies [18], [27]. Sensor-based monitoring approaches, including vibration and temperature analysis, further enhance early fault detection and improve prediction accuracy for critical machine components such as bearings, motors, and gearboxes [20], [28]. In addition, the integration of Industry 4.0 technologies into maintenance management systems strengthens real-time diagnostics and improves maintenance responsiveness in industrial environments [16]. Overall, these findings provide a strong foundation for developing predictive maintenance strategies to support the operational stability and reliability of the PM1 rewinder. Research findings on predictive maintenance and smart manufacturing can be seen in Table 3.

3.4 Downtime Reduction and Availability Improvement

This group of studies reinforces the finding that the integration of Internet of Things (IoT), predictive maintenance (PdM), and Overall Equipment Effectiveness (OEE) has a direct impact on improving machine reliability and reducing downtime in industrial equipment, including rewinder units and Paper Machine 1. Several studies report that IoT-based predictive maintenance platforms can significantly reduce downtime and improve machine availability through real-time monitoring and data-driven maintenance strategies [18], [27]. Sensor-based monitoring and real-time machine tracking systems further enhance early fault detection and troubleshooting capabilities, thereby reducing operational stoppages in industrial production systems [14], [3]. In addition, advanced IoT architectures such as Industrial Internet of Things (IIoT) platforms have demonstrated the ability to identify sub-bottlenecks within production lines, ensuring that critical units such as rewinders do not become operational constraints [12]. Furthermore, the implementation of OEE measurement and related performance evaluation frameworks provides an essential

basis for identifying production losses and improving equipment availability across manufacturing processes [4], [23]. Collectively, these studies establish a strong foundation for optimizing rewinder performance through the integration

of IoT technologies, predictive maintenance strategies, and OEE-based performance monitoring. Research findings on downtime reduction and availability improvement, it can be seen in Table 4.

Table 3: Research findings on predictive maintenance and smart manufacturing

No.	Author (Year)	PdM Method	Key Findings (Impact)	Relevance
1	Ayvaz & Alpay (2021), [15]	IoT-based PdM + Machine Learning	Availability increased by 25%; downtime reduced by 40%	Supports PdM implementation for the rewinder
2	Civerchia et al. (2017), [24]	IoT vibration/temperature monitoring	Early failures reduced by 25%	Relevant for rewinder bearing monitoring
3	Christou et al. (2020), [25]	QARMA ML + IIoT	Prediction accuracy improved by 30%	Enhances fault prediction for rewinder components
4	Teoh et al. (2021), [26]	Fog-computing PdM	False alarms reduced by 20%	Improves early detection for PMI motors
5	Kamgba (2024), [27]	SVM & DNN	Accuracy >92%	Useful for gearbox fault prediction in the rewinder
6	Compare et al. (2019), [18]	4-layer IoT PdM architecture	Downtime reduced by 30%	Framework applicable to PMI maintenance
7	Zhang & Wang (2022), [19]	IoT-based DSS for PdM	Availability improved by 25%	Supports HMI and PdM visualization for rewinder
8	Mendes et al. (2023), [28]	Lean + Industry 4.0 real-time maintenance	Diagnostic response time significantly faster	Relevant for conveyor-to-roll feed process in rewinder
9	Ginting et al. (2025), [11]	IoT-enabled maintenance	Reliability improved	Supports reliability improvement of rewinder maintenance

Table 4: Research findings on downtime reduction and availability improvement

No.	Author (Year)	Method	Key Findings (Impact)	Relevance
1	Ayvaz & Alpay (2021), [15]	IoT-based PdM	Downtime reduced by 40%	Addresses breakdown issues in PMI
2	Compare et al. (2019), [18]	4-layer PdM architecture	Downtime reduced by 30%	Supports downtime reduction in PMI
3	Civerchia et al. (2017), [24]	IoT vibration sensing	Early failures reduced by 25%	Relevant for rewinder bearing monitoring
4	Zhang & Wang (2022), [19]	DSS alarm system	Troubleshooting time reduced by 20%	Reduces stoppages in PMI
5	Llopis et al. (2024), [3]	I3oT architecture	Sub-bottlenecks detected, losses reduced.	Detects potential bottlenecks in the rewinder
6	Ooi et al. (2021), [6]	IoT machine monitoring	Real-time machine status visibility	Supports rewinder monitoring
7	Fakinafidin et al. (2025), [12]	IoT downtime analytics	More precise identification of downtime events	Improves classification of rewinder downtime
8	Setiawan et al. (2025), [29]	OEE implementation	Breakdown and losses clearly identified	Baseline OEE mapping for rewinder
9	Badiea et al. (2023), [30]	TPM	Reliability improved	Supports availability improvement in PMI

3.5 IoT-OEE Framework

The IoT-OEE framework is presented in Figure 3. It illustrates a four-layer framework that represents the flow of data within the IoT-OEE system for the rewinder machine. At the lowest level, the Physical Resources Layer includes IoT devices (such as vibration, temperature, and current sensors, as well as meter counters), the rewinder machine itself, and smart terminals, all of which serve as primary sources of production data. The collected data is then transmitted through the Network Layer, consisting of cellular, wired, and wireless networks that ensure stable and real-time

communication. Subsequently, the data is processed and stored in the Cloud Layer, where cloud services, servers, and databases perform analytical functions such as OEE calculations, downtime detection, and predictive maintenance. The processed information is visualized in the Application Layer through dashboards, performance displays, and machine condition alarms, enabling operators and management to make data-driven decisions. Overall, the framework illustrates how data moves from sensors to applications to support comprehensive monitoring, diagnostics, and performance optimization of the rewinder.

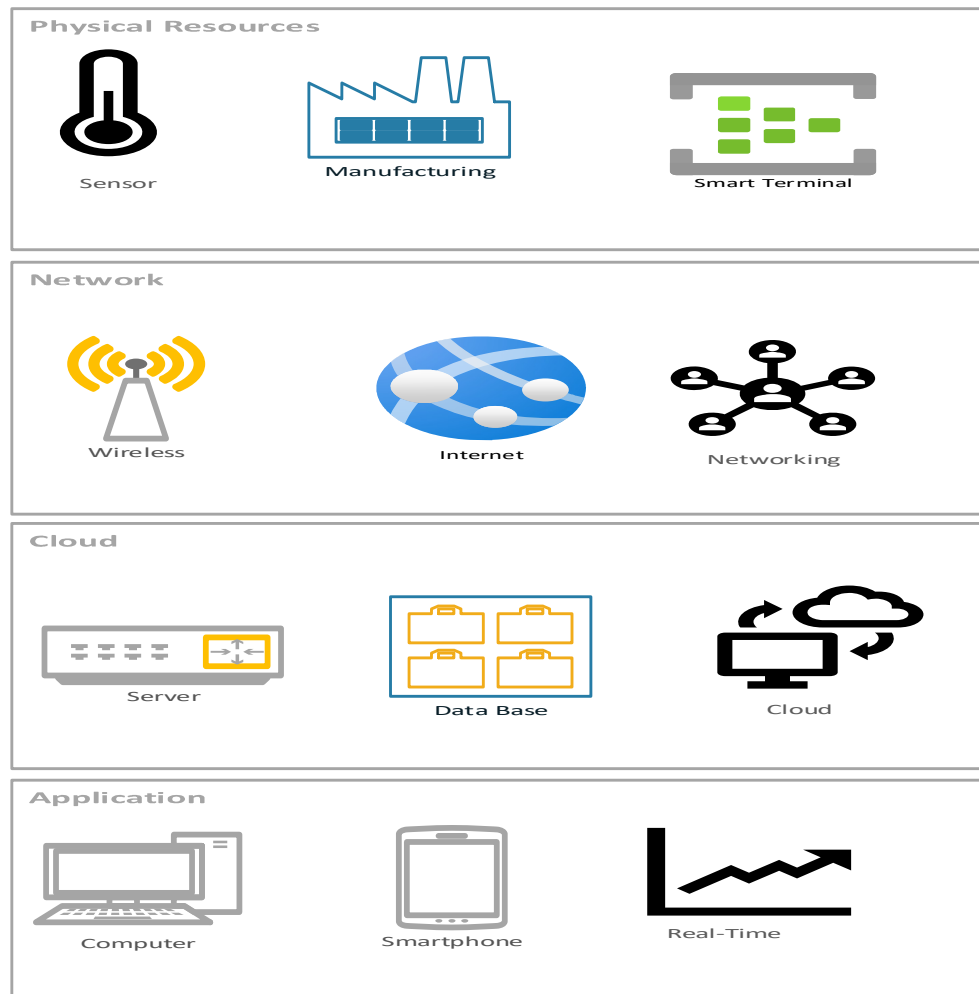


Figure 3: IoT-OEE Framework

4. CONCLUSIONS

This study synthesizes previous research related to the integration of Internet of Things (IoT) technologies, Overall Equipment Effectiveness (OEE), and Predictive Maintenance (PdM) within industrial production environments. The reviewed literature indicates that IoT-based monitoring systems can contribute to improvements in machine reliability, operational visibility, and maintenance efficiency. Several studies report that the implementation of IoT sensors, real-time monitoring platforms, and machine learning-based analytics can reduce downtime by approximately 30–40%, improve early fault detection capability, and enhance troubleshooting processes.

Integration of IoT technologies with OEE measurement also enables more accurate identification of production losses related to availability, performance, and quality. In addition, complementary approaches such as Lean manufacturing, Total Productive Maintenance (TPM), and digital quality monitoring further support continuous improvement initiatives in industrial production systems. Collectively, the reviewed findings suggest that the integration of IoT, OEE, and predictive maintenance provides a promising

technological foundation for improving the operational performance and reliability of rewinder machines within Paper Machine 1 production systems.

Nevertheless, the reviewed literature also highlights several limitations. Empirical studies specifically focusing on rewinder machines in the paper manufacturing industry remain relatively limited, and most existing research is conducted in general manufacturing environments. Future research should therefore focus on empirical validation of IoT-OEE monitoring frameworks in real industrial settings, particularly in paper production systems where rewinder units play a critical role in determining overall production efficiency.

Recommendations

To maximize the potential benefits of IoT-OEE-PdM integration in rewinder systems, several strategic initiatives can be considered. First, a pilot implementation of an IoT-OEE monitoring system on the rewinder unit is recommended to evaluate system performance, quantify its impact on downtime reduction, and assess the readiness of existing infrastructure within the production line. Such pilot studies would provide practical insights into the feasibility of

integrating real-time monitoring technologies into paper manufacturing operations.

Second, the development of a rewinder digital twin can support advanced performance simulation, predictive diagnostics, and failure analysis without interrupting ongoing production processes. Digital twin technology enables engineers and operators to test maintenance strategies, evaluate machine behavior under different operating conditions, and improve predictive maintenance planning.

Third, integration of IoT monitoring platforms with Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) systems should be further explored. This integration would allow operational data generated from rewinder machines to support both technical-level monitoring and higher-level managerial decision-making, including production scheduling, maintenance planning, and resource allocation. Implementation of these strategies is expected to improve the reliability, operational stability, and overall efficiency of Paper Machine 1 production lines, while also supporting the broader digital transformation of the paper manufacturing industry.

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