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Assessment of Conveyor Telemetry System in a Manufacturing Firm: A Case Study of a Brewery in Eastern Nigeria

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Abstract

Unplanned downtimes in conveyor systems present significant operational and financial challenges in manufacturing environments. This study assesses and enhances a telemetry-based predictive maintenance system for the conveyor lines of an international brewery in Eastern Nigeria. The modified system integrates vibration, speed, temperature, and current sensors, supported by Programmable Logic Controllers (PLC), Variable Frequency Drives (VFD), and a Grafana dashboard for real-time visualization. Data collected under real operational conditions revealed early warning signs of faults: electric motor current rose from an optimal 0–1A to a critical 3A before automatic shutdown; bearing vibration levels escalated from 0.5 mm/s to 4.6 mm/s, indicating failure; and conveyor belt speed dropped from 7 cm/s to 2 cm/s, signaling slippage. These anomalies were detected and corrected before resulting in major downtime. The system also enabled condition-based maintenance, avoiding the inefficiencies of reactive and preventive strategies. Benchmarking against ISO 17359, ISO 55000, and IEC 61508 confirmed alignment with industrial best practices. Financial analysis showed a 60% reduction in monthly maintenance costs, from ₦20 million to ₦6.2 million, yielding estimated savings of ₦13.8 million per month. Over a six-month period, cumulative savings totaled ₦82.8 million, affirming the system's economic viability. These results validate the role of integrated telemetry in reducing downtime, extending equipment lifespan, and improving manufacturing efficiency. The study encourages broader industry adoption and recommends future integration with machine learning for automated fault prediction.

1. Introduction

Industries worldwide are undergoing a transformative shift from traditional operational processes to advanced technologies, aiming to optimize business operations and gain competitive advantages [1]. This paradigm shift, often referred to as Industry 4.0, encompasses digitalization within manufacturing industries, fostering smarter and more efficient operations [2]. Among the forefront technologies, telemetry plays a pivotal role, offering significant support through data collection and remote monitoring across diverse sectors, including production facilities, energy management, and logistics [3].

Belt conveyor systems are integral to manufacturing industries, facilitating the transport of semi-finished and finished products across various stages of production. These systems are widely used in industries such as manufacturing, mining, and logistics for their ability to save labor and time while ensuring efficient material handling [4, 5]. However, these systems face performance challenges, including wear and tear, which can lead to operational disruptions, financial losses, and safety risks [6]. Predictive maintenance has emerged as a critical solution to these challenges, enabling the proactive identification of potential failures and minimizing downtime.

Telemetry systems have become indispensable in modern industrial automation, particularly in conveyor belt operations. Through sensors and data acquisition systems, telemetry enables the real-time monitoring of parameters such as temperature, vibration, and speed. This facilitates predictive maintenance, ensuring the reliability, safety, and efficiency of conveyor belt systems [7]. Studies reveal that unscheduled downtime costs global manufacturing industries over $50 billion annually, underscoring the importance of implementing proactive maintenance strategies [8]. The integration of telemetry into conveyor belt systems enhances their operational effectiveness by providing real-time insights and enabling data-driven decision-making. This, in turn, reduces unplanned downtime, improves system performance, and extends the lifespan of critical components [3].

Despite these benefits, existing telemetry-based predictive maintenance approaches still face limitations. Many studies have primarily focused on monitoring isolated parameters such as belt misalignment or motor current without integrating a comprehensive, multi-sensor approach for holistic condition-based monitoring. Furthermore, limited research has explored the real-world impact of predictive telemetry systems in reducing downtime and operational costs in manufacturing environments. Previous works have also not benchmarked telemetry-based maintenance against industrial standards such as ISO 17359 (Condition Monitoring and Diagnostics of Machines), making it difficult to assess its scalability and applicability across diverse industries. Addressing these gaps, this study enhances traditional telemetry-based maintenance by integrating additional sensors (current, temperature, vibration, and speed), deploying a real-time visualization dashboard (Grafana), and systematically evaluating its impact on downtime reduction and cost savings [9, 10].

Given these considerations, this study focuses on assessing and developing a prototype telemetry process tailored to a belt conveyor system in a manufacturing setting. Specifically, the research leverages the case study of an International Brewery in Eastern Nigeria to address the challenges and limitations of existing conveyor systems. By implementing advanced telemetry technologies, the study aims to improve condition monitoring, predictive maintenance, and overall system efficiency. The objective of this research is to assess and develop a comprehensive telemetry system applicable to belt conveyor systems in manufacturing industries, with a specific focus on International Breweries in Eastern Nigeria.

2. Review of Related Works

A substantial body of research has explored telemetry in manufacturing systems, demonstrating various methodologies, outcomes, and limitations. [11] conducted a study on the multipoint monitoring of beer fermentation processes using optoelectronic detectors, integrating biosensors to track equipment performance. While this research demonstrated how such technologies could streamline the operational control of pumps and valves, it primarily focused on the fermentation process rather than transportation systems, leaving a gap in applying telemetry to conveyor belt monitoring. Similarly, [12] examined the use of secondary data and PRISMA protocols in beer production plants, emphasizing the role of nanotechnologies and electronic systems in predictive maintenance. Despite demonstrating the potential for advanced sensing technologies in industrial applications, the study did not extend its scope to real-time telemetry applications for conveyor belt systems, thereby overlooking a crucial aspect of industrial automation.

Further contributions to the field have focused on improving efficiency in specific areas of production. [13] analyzed pulse electric fields, ultrasound, thermosonication, high-pressure processing, and ohmic heating in beer manufacturing. However, their study remained confined to assessing production efficiency rather than extending telemetry applications to transportation and material handling. Additionally, [14] optimized a pallet roller conveyor system by redesigning critical components, which significantly reduced material usage while maintaining structural integrity. Despite these improvements, their research was limited to structural optimization, with little attention given to real-time monitoring and predictive maintenance.

Other studies have attempted to incorporate telemetry into conveyor system monitoring, but with limitations. [5] designed a telemetry system using magnetic sensors to monitor the condition of steel cord conveyor belts, demonstrating its effectiveness in real-time condition monitoring and fault prediction. However, the research focused solely on belt condition and did not account for other critical system components such as electric motors and bearings. Similarly, [15] developed a telemetry-based fault detection system to identify belt misalignments, which improved production consistency and reduced sudden failures. While effective for alignment issues, this system did not incorporate additional parameters such as vibration and speed, which are essential for comprehensive condition monitoring.

Another study by [16] contributed to industrial automation by synchronizing conveyor line speeds, improving bottle inspection and liquor level monitoring. However, this system was narrowly designed for bottle conveyor applications, limiting its adaptability to broader manufacturing environments. While these studies demonstrate the potential of telemetry for industrial systems, their focus remains largely fragmented, addressing only isolated aspects of conveyor system health rather than a comprehensive, multi-sensor approach to predictive maintenance.

Despite the advancements in telemetry, existing research has not fully integrated multiple parameters such as vibration, speed, temperature, and current into a single, real-time predictive maintenance framework. Furthermore, no prior studies have benchmarked telemetry-based predictive maintenance systems against industrial standards such as ISO 17359, making it difficult to evaluate scalability and applicability across diverse industries. Additionally, the economic benefits of telemetry adoption have not been quantified, leaving gaps in understanding its cost-effectiveness compared to traditional maintenance strategies.

This research addresses these gaps by developing a comprehensive telemetry-based predictive maintenance system for belt conveyor systems in manufacturing environments. The study integrates advanced sensors (current, temperature, vibration, and speed) with a real-time monitoring dashboard (Grafana), ensuring a more robust and holistic approach to condition-based monitoring. Additionally, this research conducts a quantitative comparison of predictive maintenance against traditional methods, benchmarks its effectiveness against industry standards, and evaluates its economic viability for industrial adoption. By bridging these research gaps, the study contributes to the broader application of telemetry in industrial automation, offering a scalable and cost-effective solution for predictive maintenance.

3. Materials and Methods

3.1 Research Design

This study was designed to evaluate the existing telemetry framework of a belt conveyor system and implement modifications to enhance predictive maintenance capabilities. The research was conducted at the packaging department of an International Brewery in eastern Nigeria. The department comprises three conveyor lines, and the crate conveyor system on Line 2 was selected for analysis. This unit was chosen due to its critical role in production and the access granted to the researcher. The study involved an initial assessment of the existing telemetry setup, integration of additional sensors, modification of the data acquisition process, and testing the performance of the enhanced system under real-world operational conditions. The belt Conveyor system layout is shown in Figure 1.

3.2 Materials

The study utilized a range of materials and technologies to achieve its objectives. These included vibration sensors (Ultra II) to measure displacement and unusual noise levels, thermistors to monitor temperature changes, and current sensors to track variations in electrical load. Control systems such as Programmable Logic Controllers (PLC) and Variable Frequency Drives (VFD) were integral for system operation and data acquisition. Additionally, a Human Machine Interface (HMI) was employed using the Grafana dashboard to visualize real-time data. The Historian database was used to store historical data for trend analysis, while Archestra software facilitated the integration and processing of telemetry data.

3.3 Existing System Assessment

An assessment of the existing belt conveyor telemetry system was conducted to identify its operational limitations and opportunities for improvement. The existing system monitored parameters such as current, temperature, and torque through sensors embedded in the electric motors. These parameters were displayed on the HMI and logged into the Historian database. Faults detected during operations were recorded and shared with the maintenance team to address issues during scheduled maintenance, which occurred bi-monthly. Observations revealed that the system primarily relied on reactive maintenance practices, leading to unplanned downtimes and inefficiencies. The assessment findings highlighted the need for a more robust telemetry system to enable condition-based monitoring and predictive maintenance.

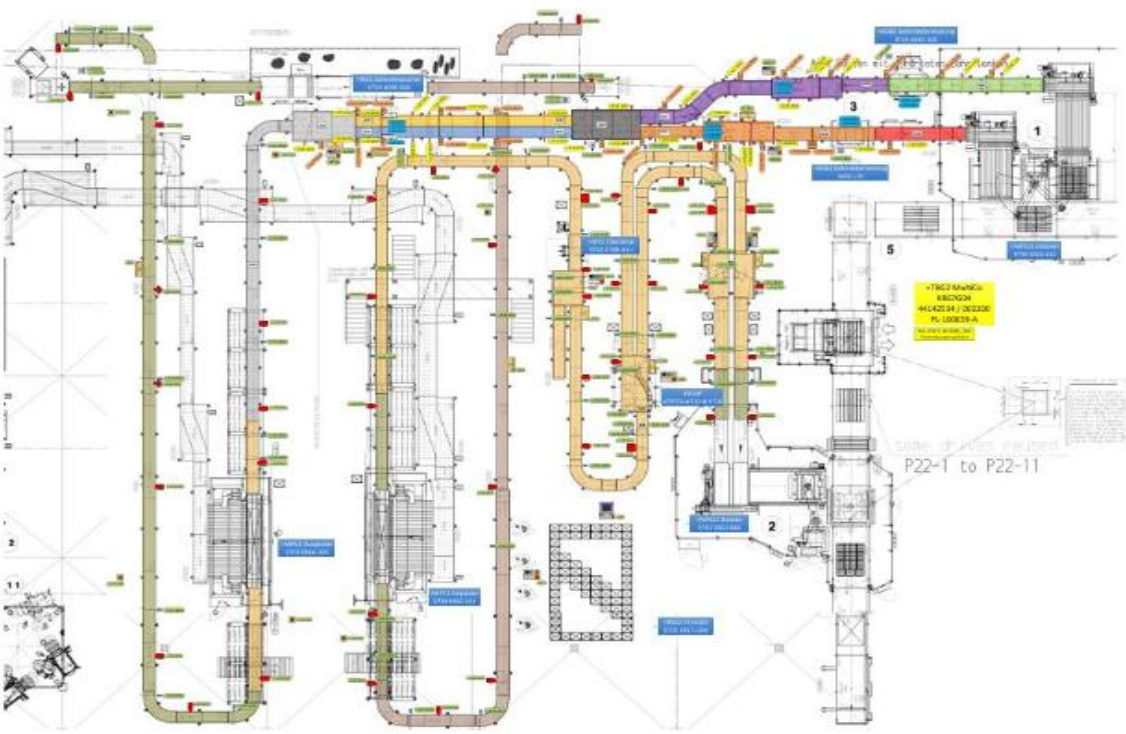

Fig 1: Belt conveyor system Layout

3.4 Data Acquisition and Monitoring

The data acquisition process in the existing system involved communication between the electric motor, VFD, PLC, and HMI. The electric motor was connected to a power source through thermal protection relays to safeguard against overload conditions. A thermistor embedded in the motor monitored temperature, while the VFD tracked current draw. The VFD communicated with the PLC using the Profibus protocol, which converted analog signals into digital data for interpretation. The PLC controlled the movement of the conveyor belt by adjusting the motor speed based on the load and torque requirements. Real-time data collected from the sensors was logged into the Historian database, while operational parameters and fault alerts were displayed on the Grafana dashboard for monitoring. Figure 2 shows the Existing Data Acquisition Process Flow.

3.5 Telemetry System Modification

To address the limitations of the existing system, several modifications were made to the telemetry setup. Additional sensors were installed to monitor key parameters more effectively. Vibration sensors were placed on the bearings of the electric motors to detect unusual noise and displacement, which could indicate potential failures. Speed sensors were installed along the conveyor to monitor belt slippage and ensure precise movement. The modified system also included enhanced data acquisition processes, where sensors were configured to trigger alerts when parameters exceeded predefined thresholds. These alerts were displayed on the HMI and used to guide maintenance interventions. The redesigned system was integrated with existing components to ensure compatibility and ease of use. Figure 3 ahows the modified Data Acquisition Process Flow.

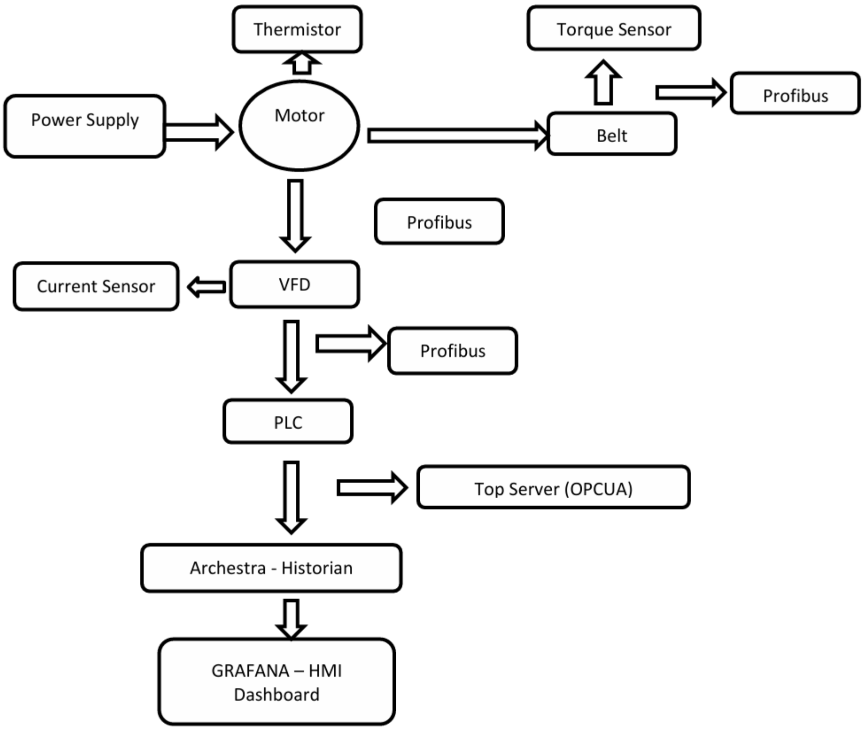

Fig 2: Existing Data Acquisition Process Flow

3.6 System Testing and Data Analysis

After deploying the modified telemetry system, its performance was tested under operational conditions. Key parameters such as current, temperature, vibration, and speed were monitored to evaluate the system's effectiveness. Data collected from the sensors were analyzed to identify anomalies and trends, with a focus on detecting early warning signs of potential faults and addressing them proactively.

4. Results and Discussion

The results presented in this study were derived from the analysis of telemetry data collected during the monitoring and assessment of the conveyor belt system at an International Brewery in eastern Nigeria. The results illustrate how predictive maintenance, enabled by condition-based monitoring, enhances system performance and reduces unplanned downtime. Key parameters, including electric motor condition, bearing condition, and belt condition, were monitored and analyzed to evaluate the health of the conveyor system.

4.1 Electric Motor Condition Analysis

The performance of the electric motor was evaluated based on current readings over time, which provided critical information on the motor's load handling capability, friction levels, and overall health. The classification of conditions based on current thresholds offers a structured approach to understanding system performance under different operational states.

The electric motor operated **o**ptimally when the current remained between 0 and 1A**,** as shown in Figure 4, indicating efficient performance with minimal load and no mechanical resistance**.** The system exhibited stable energy consumption, smooth conveyor movement, and proper alignment of bearings, pulleys, and belt tensioners**.** No excessive vibration, overheating, or force fluctuations were detected, ensuring seamless operation without requiring immediate maintenance actions**.** However**,** continuous monitoring was necessary to detect early anomalies**.**

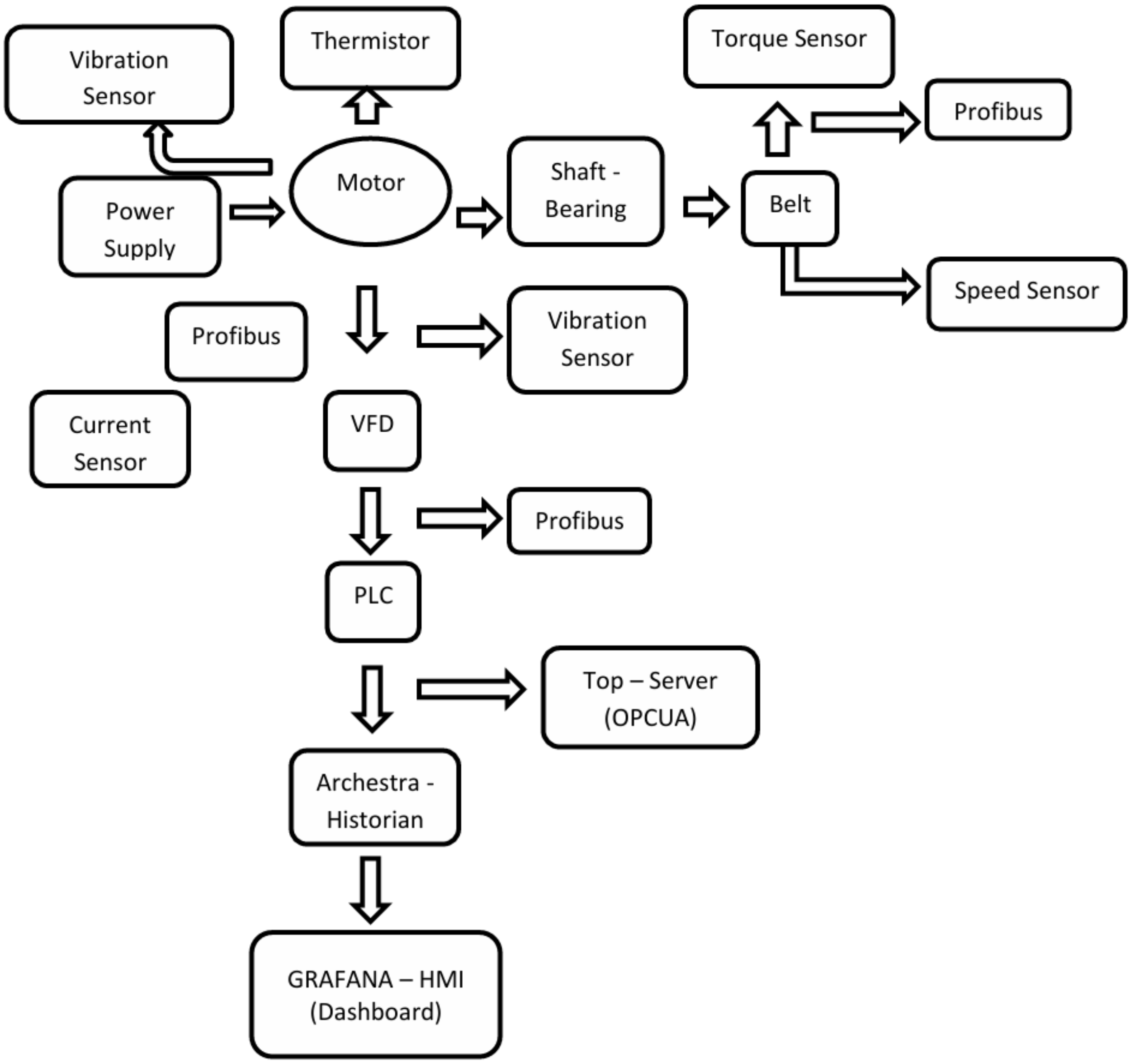

Fig 3: Modified Data Acquisition Process Flow

Fig 4: Display of Current against Time for Electric Motor Operating with Normal Current

As the current exceeded 1A, mechanical resistance emerged, marking the warning condition also shown in Figure 4. The motor compensated for slight misalignment or increased belt tension, leading to torque fluctuations and moderate vibration spikes. Though still within operational limits, progressive stress could escalate into thermal overload and potential system failure if left unchecked. To prevent escalation, the maintenance team conducted inspections, applied lubrication, and adjusted system tension, restoring efficiency and preventing further deterioration.

The telemetry data showed a sharp rise in current above 1.8A, reaching 3A, indicating severe operational stress, as seen in Figure 5. This spike suggested high mechanical resistance, excessive friction, and increased thermal load on the motor windings.

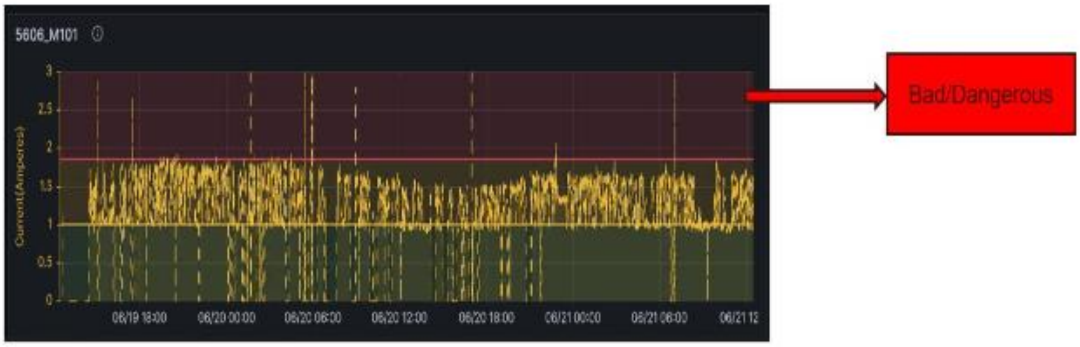

Fig 5: Display of Current against Time for Electric Motor Operating with High Current

At this stage, vibration levels, torque, and conveyor speed fluctuations intensified, signaling critical system strain. The excessive current draw reflected severe inefficiencies, forcing the Variable Frequency Drive (VFD) to shut down the motor beyond 2.5A to prevent overheating, winding damage, and potential burnout.

A post-shutdown inspection identified bearing wear, excessive belt tension, and poor lubrication as root causes. Corrective actions, including bearing lubrication, tension adjustments, and conveyor realignment, successfully restored the system. Figure 6 underscores the importance of real-time monitoring, as early detection allowed intervention before catastrophic failure and costly downtime.

4.1.1 Electric Motor Condition

The electric motor's performance was evaluated by analyzing current, temperature, and vibration data captured during operations. Data for a specific motor (M121) were extracted and trended to ascertain its health. Table 1 presents the extracted data, showing variations in current, temperature, and vibration levels over a 24-hour period.

Table 1: Data Extract on Electric Motor (Current, Temperature and Vibration)

DATE	25/08/2024		
Time (hr)	Current (A)	Temperature (°C)	Vibration (mm/s)
0:00	3.5	42	5
1:00	3.5	42	3.2
2:00	3.6	44	4.5
3:00	3.6	45	5.1
4:00	3.6	43	1.2
5:00	3.4	43	20
6:00	3.5	44	6.7
7:00	3.6	42	3
8:00	3.4	41	1.1
9:00	3.6	41	1.8
10:00	3.9	43	2.5

11:00	3.6	42	4.3
12:00	3.6	42	1.9
13:00	3.7	41	1.2
14:00	3.5	42	1.3
15:00	3.8	42	1.4
16:00	3.6	43	1.3
17:00	4.6	62	5.6
18:00	4.9	63	7.2
19:00	6.1	71	7.3
20:00	6.3	73	7.3
21:00	6.6	73	7.4
22:00	-	53	0
23:00	-	34	0

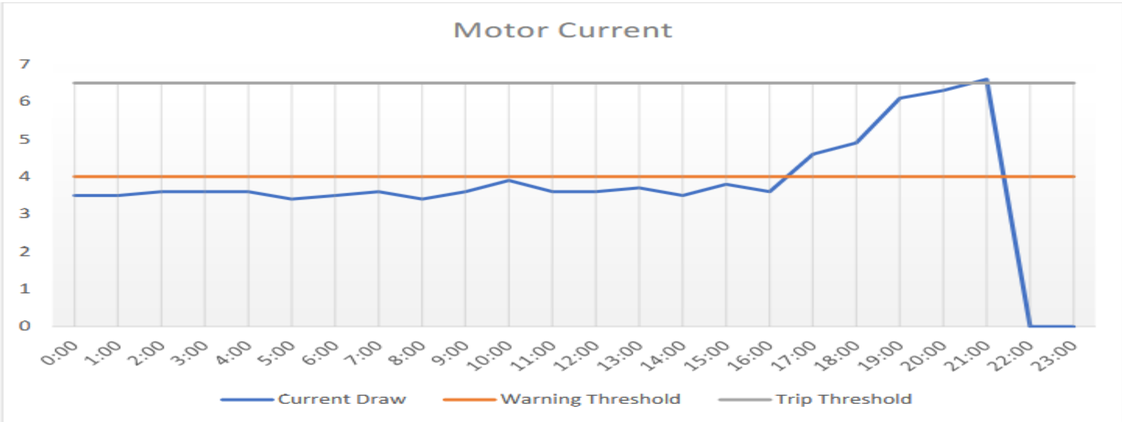

Fig 6: Plot of Current Against Time

From Figure 6 the current drawn by the M121 electric motor remained steady between 0:00 and 16:00, operating within the safe threshold of 3.6A. A spike in current from 3.6A to 4.6A was observed after 16:00, indicating increased friction on the conveyor belt, as the load remained unchanged. The motor's warning threshold was set at 4.0A, with a trip threshold at 4.5A. The motor tripped at 4.5A to prevent further damage. Further analysis of temperature and vibration data was necessary to pinpoint the exact fault causing the increased friction.

Figure 7 highlights a correlation between the rise in motor current, temperature, and vibration levels, indicating excessive friction on the conveyor line. The temperature of the motor windings increased steadily, reflecting the additional workload required to overcome friction. Simultaneously, a spike in vibration levels confirmed the friction-related issue and prompted inspection and maintenance interventions to restore normal operation. Notably, while the vibration spike pointed to friction on the conveyor line, a steady rise in vibration levels could have indicated bearing failure in the motor. This analysis demonstrates the critical role of monitoring multiple parameters for accurate fault diagnosis and timely resolution.

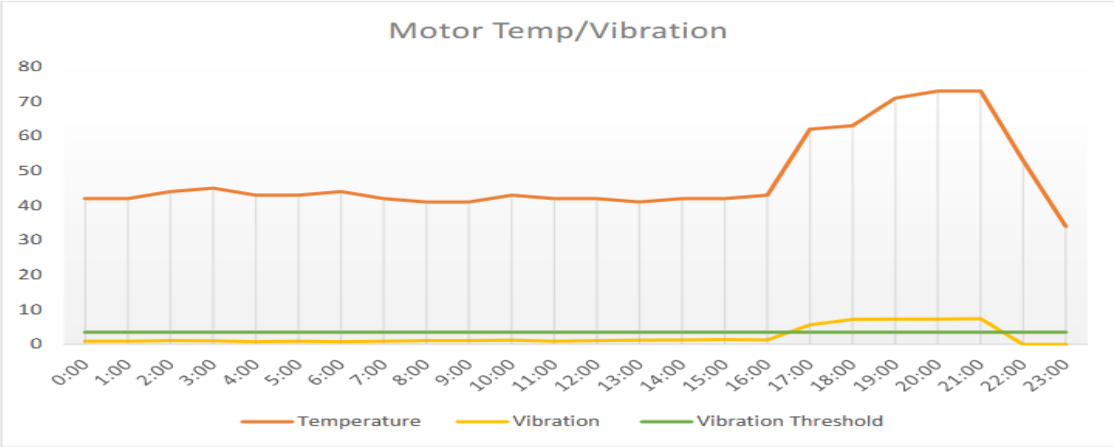

Figure 7: Plot of Temperature and Vibration Against Time

4.1.2 Bearing Condition

The health of the conveyor bearings was assessed using vibration data captured by surface-mounted sensors. Table 2 shows the vibration data collected over a 24-hour period, while Figure 8 presents a plot of vibration levels against time. Initially, the vibration levels were stable at 0.5 mm/s. A significant increase beyond the threshold of 1.2 mm/s was observed after 09:00, peaking at 4.6 mm/s by 23:00. This indicated progressive bearing failure, necessitating immediate replacement. The defective bearing was identified and replaced during scheduled maintenance, preventing further system degradation.

Table 2: Data Extract on Bearing (Vibration) and Belt Speed

Time (hr)	Vibration-Bearing (mm/s)	Speed-Belt (cm/s)
0:00	0.5	7
1:00	0.4	7
2:00	0.4	7
3:00	0.5	7
4:00	0.4	7
5:00	0.4	7
6:00	0.3	6.9
7:00	0.4	6.8
8:00	0.4	6.5
9:00	0.5	6.2
10:00	2.4	5.9
11:00	2.5	5.6
12:00	2.6	5.3
13:00	3.2	5
14:00	3.4	4.7
15:00	3.5	4.3
16:00	3.9	3.9
17:00	4.2	3.6
18:00	4.4	3.2
19:00	4.5	2.9
20:00	4.4	2.5
21:00	4.6	2.2
22:00	4.6	2
23:00	4.6	2

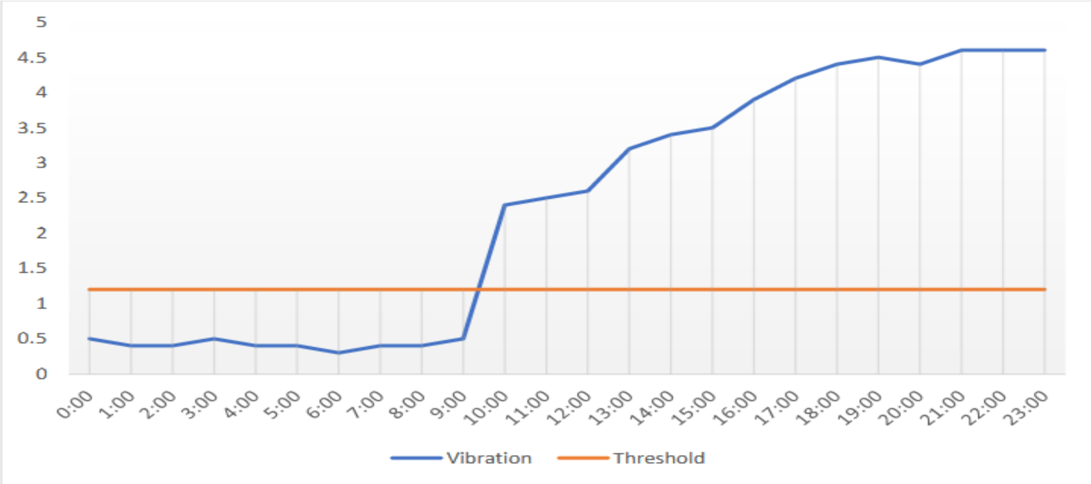

Fig 8: Plot of Vibration Against Time

The conveyor belt's performance was monitored through speed data also in Table 2 and represented in Figure 9.

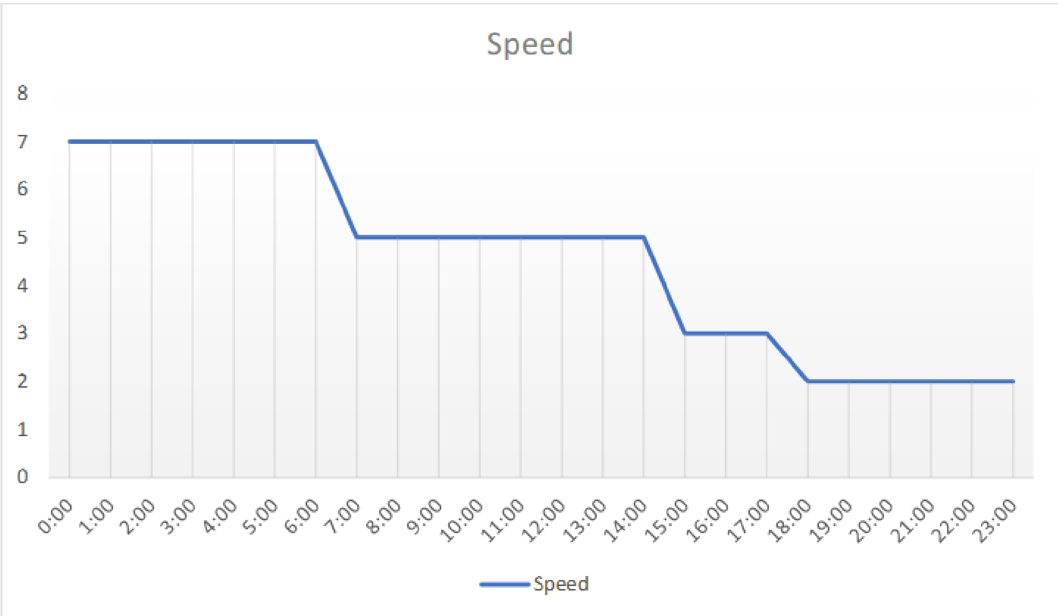

Figure 9: Plot of Speed Against Time

The belt maintained a steady speed of 7 cm/s but began to decline from 07:00, reaching 2 cm/s by 20:00, indicating belt slippage due to reduced traction between rollers and the pulley mechanism. The slippage caused production delays and package misses, despite packaging operations continuing with proximity sensors. A trouble memo prompted the mechanical team to tighten loosened connectors and fasteners. To prevent recurrence, regular belt tension checks were incorporated into the maintenance schedule.

4.2 Discussion

The results demonstrate the effectiveness of the modified telemetry system in detecting and addressing faults in the conveyor system at an International Breweries in Eastern Nigeria. By integrating additional sensors and implementing a predictive maintenance framework, significant improvements in fault detection, system reliability, and operational efficiency were achieved. The findings emphasize the importance of real-time monitoring in preventing unexpected failures and optimizing system performance.

The analysis of electric motor performance was based on current, temperature, and vibration data, allowing for the early detection of friction-related faults. As depicted in Figure 4, the M121 electric motor initially operated within a safe current range of 0 – 1A, ensuring efficient power consumption and smooth conveyor operation. During this phase, the motor experienced minimal mechanical resistance, leading to stable operation with no significant energy losses. However, as time progressed, the current increased beyond 1A, moving into the warning condition, indicating the onset of mechanical stress along the conveyor system. By Figure 5, the motor current had risen between 1A and 1.8A, signaling increased friction or load imbalance within the system. The telemetry system detected torque fluctuations, confirming that the motor was compensating for mechanical resistance, possibly due to misalignment, debris accumulation, or belt tension issues. This warning condition suggested that while the system was still functional, it required preventive maintenance to prevent a transition into severe failure conditions.

The most critical stage, represented in Figure 6, captured the motor current exceeding 1.8A and reaching 3A, indicating severe operational stress. This drastic escalation in current suggested excessive mechanical resistance, extreme friction on the belt conveyor, and increased thermal load on the motor windings. At this stage, the motor torque peaked, vibration intensified, and conveyor belt speed fluctuated, making it increasingly difficult for the motor to sustain continuous operation. To protect the system from irreversible damage, the Variable Frequency Drive (VFD) initiated an automatic shutdown when the current exceeded 2.5A, thereby preventing overheating, motor winding burnout, and mechanical breakdown. If the motor had continued operating under these extreme conditions, it could have resulted in a total system failure, requiring expensive repairs and prolonged downtime. A post-shutdown inspection revealed that bearing degradation, excessive belt tension, and insufficient lubrication were contributing factors to the escalation in motor stress. Corrective measures, including bearing lubrication, tension adjustments, and conveyor realignment, were implemented to restore the system to optimal operation. This demonstrates the importance of real-time monitoring, as early fault detection allowed for timely intervention, preventing production losses and extending motor lifespan.

The health of the conveyor bearings was analyzed using vibration data collected from surface-mounted sensors, with findings illustrated in Table 2 and Figure 6/ Figure 7. During the initial phase of operation, vibration levels remained stable at 0.5 mm/s until 09:00, indicating healthy bearing function with no abnormal wear. However, by 10:00, vibration levels exceeded the 1.2 mm/s threshold, signaling the onset of progressive bearing wear. The telemetry data showed that vibration levels continued increasing, peaking at 4.6 mm/s by 23:00, confirming severe bearing degradation. The primary cause of this degradation was attributed to inadequate lubrication and prolonged operation under high friction conditions. If this condition had not been detected in time, it could have led to bearing seizure, increased motor load, and conveyor misalignment. With early detection, the maintenance team scheduled and executed a timely replacement of the defective bearings, preventing further mechanical deterioration and production stoppages. This reinforces the value of real-time telemetry systems, as continuous vibration monitoring enabled proactive maintenance, extending bearing lifespan and optimizing conveyor system performance.

The conveyor belt's operational efficiency was evaluated through speed data, as presented in Table 3 and Figure 8/ Figure 9. Initially, the belt maintained a consistent speed of 7 cm/s, ensuring seamless material flow and packaging efficiency. However, from 07:00 onwards, the belt speed began to decline, reaching 2 cm/s by 20:00, indicating significant slippage due to traction loss between rollers and pulley connectors. This decline in speed led to production delays and misaligned packaging, despite the presence of proximity sensors designed to regulate conveyor movement. The reduction in traction was linked to loosened connectors and worn-out fasteners, which compromised the belt's ability to maintain steady motion. Upon receiving telemetry alerts, a trouble memo was issued, prompting the mechanical team to conduct a thorough inspection and tighten all loosened connectors and fasteners. To mitigate future occurrences, the maintenance schedule was updated to include routine belt tension checks, ensuring consistent belt traction and reducing the risk of unexpected slippage.

4.2.1 Comparative Analysis of Maintenance Strategies

To further validate the effectiveness of telemetry-based predictive maintenance**,** it is essential to compare it with traditional maintenance approaches, including reactive and preventive maintenance**.** Reactive maintenance (also known as "run-to-failure") involves fixing equipment only after a failure occurs, leading to higher downtime, unexpected costs, and potential operational risks**.** Preventive maintenance**,** on the other hand, follows a fixed schedule for maintenance activities regardless of the actual condition of the system, which may lead to unnecessary part replacements and increased labor costs**.** Predictive maintenance, facilitated by telemetry, offers a data-driven approach, enabling real-time condition monitoring and early fault detection, minimizing downtime while optimizing cost efficiency**.**

Table 3 presents a comparative analysis of these three maintenance strategies, focusing on key factors affecting industrial efficiency.

Table 3: Comparison of Maintenance Strategies

Factor	Reactive Maintenance	Preventive Maintenance	Predictive Maintenance (Telemetry-Based)
Approach	Fix only after failure occurs	Scheduled at regular intervals	Real-time monitoring & data-driven fault prediction
Downtime Impact	High, since breakdowns are unplanned	Moderate, as maintenance may not always be necessary	Low, as faults are detected early and addressed before failure
Cost Efficiency	Expensive due to emergency repairs and unexpected failures	Moderate, with some unnecessary servicing costs	Highly cost-effective, reducing both repair costs and downtime
System Reliability	Low, frequent unexpected failures	Moderate, avoids major failures but may replace components prematurely	High, prevents failures while maximizing component lifespan
Labor & Maintenance Effort	High, requires emergency interventions	Moderate, scheduled maintenance requires routine labor	Low, only necessary repairs are conducted based on real-time data
Scalability	Poor, not adaptable for high-efficiency industries	Moderate, requires a fixed maintenance schedule for each system	High, scalable across industries with condition-based adaptation
Application in Study	Not applicable due to high risk of downtime in production	Inefficient, as scheduled maintenance may not align with real-time machine conditions	Implemented, leveraging telemetry to detect faults early, reduce downtime, and optimize operational efficiency

As demonstrated in table 3, telemetry-based predictive maintenance significantly outperforms both reactive and preventive maintenance by minimizing downtime, improving cost efficiency, and enhancing system reliability. The real-time monitoring capability of telemetry allows for early fault detection, ensuring that maintenance is performed only when necessary, rather than on a fixed schedule or after a failure occurs. In this study, the implementation of predictive maintenance via telemetry successfully reduced the risk of unplanned equipment failures by continuously monitoring current, temperature, vibration, and speed parameters. This proactive approach enabled timely interventions, minimizing operational disruptions and maximizing system uptime and efficiency.

4.2.2 Benchmarking Against Industrial Standards

To ensure the effectiveness and scalability of the proposed telemetry-based predictive maintenance system, it is essential to compare it with established industry standards. One of the most widely recognized frameworks for condition-based monitoring is ISO 17359: Condition Monitoring and Diagnostics of Machines, which outlines a structured approach for predictive maintenance, including fault detection, diagnosis, prognosis, and maintenance decision support. The telemetry system developed in this study aligns with ISO 17359 by incorporating multi-sensor monitoring (current, temperature, vibration, and speed), automated fault alerts, and real-time visualization via the Grafana dashboard. This ensures proactive maintenance strategies rather than reactive interventions, reducing unplanned downtime and optimizing system efficiency.

Additionally, the study aligns with ISO 55000 (Asset Management), which emphasizes maximizing asset lifespan and operational efficiency. By integrating condition-based maintenance strategies, the telemetry system reduces unnecessary wear and enhances equipment longevity, ensuring cost-effective maintenance scheduling.

Furthermore, the study incorporates principles from IEC 61508 (Functional Safety of Electrical/Electronic Systems), particularly through the implementation of Programmable Logic Controllers (PLC) and Variable Frequency Drives (VFDs). These components ensure automated responses to critical motor stress conditions, triggering shutdowns when operational limits are exceeded. This enhances system safety, preventing catastrophic failures that could lead to prolonged downtime and high repair costs. By adhering to these internationally recognized standards, the developed telemetry system is not only effective for predictive maintenance but also scalable across different industrial applications. The alignment with ISO 17359, ISO 55000, and IEC 61508 reinforces the system's viability for broader manufacturing adoption, ensuring compliance with best practices in condition monitoring, asset management, and industrial safety.

4.2.3 Adaptability to Other Manufacturing Environments

While this study was conducted in the brewery industry, the proposed telemetry-based predictive maintenance framework is highly adaptable to other manufacturing environments. Many industries, including food processing, pharmaceuticals, automotive assembly, and mining, utilize conveyor systems for material transport, and implementing a similar telemetry system could enhance reliability and efficiency across these sectors. However, specific modifications may be required depending on industry demands. For instance, the food processing industry necessitates compliance with hygiene and safety regulations, requiring the integration of moisture-resistant sensors and stainless-steel enclosures to withstand frequent washdowns. In mining and metallurgy, where systems operate in high-temperature and dust-prone conditions, durable vibration and thermal sensors must be employed to ensure operational accuracy. In pharmaceutical manufacturing, conveyor systems must maintain precise speed control for dosage accuracy, necessitating the incorporation of precision speed sensors and automated calibration tools**.** By making these necessary adjustments, the telemetry-based predictive maintenance system developed in this study can be successfully implemented in a variety of industrial applications**,** enhancing system efficiency, reducing downtime, and optimizing resource utilization across different sectors.

4.2.4 Cost-Benefit and ROI Evaluation of the Telemetry System

To further assess the real-world impact of the implemented telemetry system, a high-level cost-benefit and Return on Investment (ROI) evaluation was carried out based on organizational data. Prior to the integration of the telemetry-based predictive maintenance framework, the brewery incurred an average of ₦20 million per month in conveyor maintenance costs. These expenses were tracked through the organization's Zero-Based Budgeting (ZBB) system, which records accumulated maintenance costs on a daily basis and summarizes them weekly, monthly, and annually.

Following the deployment of the telemetry system, which featured real-time monitoring of current, vibration, temperature, and belt speed parameters, there was a notable cost reduction of nearly 60% in monthly maintenance expenditures. This translates to a financial saving of approximately ₦13.8 million per month across the plant. The cost savings primarily stem from reduced unplanned downtime, early fault detection, timely interventions, and optimized maintenance scheduling, eliminating the need for reactive or premature preventive maintenance.

While specific individual hardware or software component costs were not disclosed by the technology provider, the return on investment was estimated using consolidated figures. Assuming a conservative implementation cost of ₦20 million, the following ROI calculation illustrates the system's cost-effectiveness:

$$\mathrm{ROI}_{\text{First month}} = \frac{13.8-20}{20} \times 100 = -31\%$$

Although the initial investment results in a short-term loss in the first month, the telemetry infrastructure is a one-time cost. In subsequent months, with recurring savings of ₦13.8 million, the ROI improves significantly:

$$\mathrm{ROI}_{\text{second month onward}} = \frac{13.8}{20} \times 100 = 69\%$$

By the end of the second month, the system moves into a positive return territory. Over a 6-month period, cumulative savings reach approximately ₦82.8 million, strongly justifying the economic viability of the telemetry-based predictive maintenance system. This evaluation not only highlights the operational benefits but also substantiates the financial feasibility and long-term sustainability of adopting telemetry solutions in industrial environments.

5. Conclusion

This study successfully developed and implemented a modified telemetry system for predictive maintenance in a belt conveyor system at an International Brewery in Eastern Nigeria. The results demonstrated that real-time monitoring of current, temperature, vibration, and speed parameters significantly improved fault detection and system reliability, allowing for timely interventions that minimized unplanned downtime and enhanced operational efficiency.

The study also highlighted key challenges in conveyor systems, such as belt slippage, energy inefficiency, and unexpected equipment failures. By integrating predictive maintenance strategies using telemetry, these challenges were effectively mitigated, resulting in improved reliability, reduced maintenance costs, and enhanced productivity. Additionally, the deployment of the Grafana dashboard for real-time visualization enabled better monitoring and data-driven decision-making, reducing the risks associated with reactive maintenance approaches.

Beyond the brewery industry, this study demonstrated that the developed telemetry system can be adapted for various manufacturing environments, including food processing, pharmaceuticals, automotive assembly, and mining. By implementing industry-specific modifications, such as moisture-resistant sensors for food processing or high-temperature-resistant components for mining applications, the system can enhance reliability and operational efficiency across diverse industrial sectors.

Furthermore, the telemetry-based predictive maintenance system aligns with established industrial standards, including ISO 17359 (Condition Monitoring), ISO 55000 (Asset Management), and IEC 61508 (Functional Safety). By integrating real-time condition monitoring, automated fault detection, and preventive maintenance strategies, the system meets best-practice guidelines for industrial automation and predictive maintenance. This alignment enhances the system's scalability and applicability to other industries requiring optimized condition-based monitoring.

In conclusion, the study validates the effectiveness of telemetry-based predictive maintenance in reducing operational inefficiencies, extending equipment lifespan, and improving overall manufacturing productivity. The findings support the broader adoption of telemetry systems across various industries to enhance reliability, efficiency, and sustainability in industrial operations.

It is recommended that future research explore the integration of machine learning algorithms for enhanced fault prediction and maintenance optimization. Additionally, regular training for maintenance personnel on telemetry system operation and fault diagnosis is essential to maximize the system's benefits and ensure timely and accurate fault resolution.

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