

Digitalization of Maintenance Management for TPM Implementation in a Medical Imaging Department: A Tunisian Hospital Case Study

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Abstract

The maintenance of medical equipment has traditionally been based on a corrective approach, focused on repairing failures after they occur rather than preventing them. However, the increasing complexity of medical devices and the need to ensure patient safety have made this approach insufficient. As a result, healthcare systems have adopted more structured and engineering based methods to improve equipment reliability. Nevertheless, maintenance management in many public hospitals still relies on reactive and paper-based practices, which limit equipment traceability, delay interventions, and prevent effective monitoring of maintenance performance indicators. In such environments, the implementation of advanced maintenance strategies such as Total Productive Maintenance (TPM) remains difficult due to the absence of reliable and structured maintenance data. This study proposes a digital maintenance management framework to support the future implementation of Total Productive Maintenance (TPM) in the medical imaging department of a Tunisian public hospital referred to, for confidentiality reasons, as Hospital AZ. The proposed approach focuses on the digitalization and structuring of maintenance information. A low-cost no-code application, named AppAZ is developed using AppSheet and Google Sheets technologies, was implemented to centralize equipment data, digitize breakdown reporting, improve intervention traceability, and automates the calculation of maintenance Key Performance Indicators (KPIs), including Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and equipment availability. The originality of this study lies in positioning maintenance digitalization as a foundational step toward data-driven maintenance and TPM-oriented management in hospitals. For Hospital AZ, the developed AppAZ provides a practical alternative to conventional Computerized Maintenance Management Systems (CMMS), which are often difficult to deploy in healthcare systems with limited financial resources.

Keywords

Healthcare maintenance, Medical Imaging Equipment, Total Productive Maintenance (TPM), Maintenance Digitalization, AppSheet.

1. Introduction

Medical imaging services play a central and strategic role in modern healthcare systems. They provide essential information for diagnosis, treatment planning and patient monitoring (Smith-Bindman et al., 2008). Through technologies such as CT scanners, MRI machines, ultrasound devices, mammography units, and conventional radiography tables, they deliver accurate anatomical and functional data that support clinical decision making. These devices must be continuously available and reliable. In a hospital environment characterized by high patient flow, any equipment failure or unexpected downtime can lead to delays in diagnostic, disrupt the continuity of care and negatively impact patient outcomes.

The organization surrounding medical devices is equally important for ensuring their effective and safe use. Key factors include collaboration between multidisciplinary staff (Simoes, 2012), effective communication between departments (Matinheikki et al., 2024), strict maintenance protocols (Sezdi, 2019), and efficient biomedical information systems (S. Kumar et al., 2025). These systems improve operational efficiency and ensure high standards of medical services by providing continuous monitoring and reducing downtime.

In this context, maintenance plays a critical role in ensuring equipment performance and reliability. According to the World Health Organization (WHO), an effective maintenance program is necessary to guarantee the safety, reliability and availability of medical devices throughout their lifecycle (WHO, 2011). However, in many hospitals, maintenance practices remain largely reactive and paper based practices. Such practices limit equipment traceability, delay maintenance interventions and prevent effective monitoring of maintenance performance indicators. The absence of comprehensive and reliable data on equipment performance and failure patterns limits the ability to implement proactive maintenance strategies. Therefore, hospitals need to integrate information technology, social networking technologies, digitization and management of medical devices, and the use of big data technologies and Machine Learning (ML) techniques to improve healthcare services (Manchadi et al., 2023).

Despite the growing interest in maintenance digitalization and Total Productive Maintenance (TPM), there is still a significant gap in the literature regarding their integration in healthcare systems. Most existing studies present TPM and digital maintenance tools separately. TPM aims to maximize equipment availability and efficiency through proactive and preventive maintenance, operator involvement, and continuous improvement, making it suitable for complex and high-demand environments such as medical imaging services. In addition, healthcare systems can benefit from proactive maintenance strategies that enable failure prediction, optimization of maintenance schedules, and reduction of unplanned downtime especially for critical medical devices (Manchadi et al., 2023). Furthermore, the adoption of Industry 4.0 technologies such as the Internet of Things (IoT), big data analytics, and digital platforms provides new opportunities for real-time monitoring and predictive maintenance of medical equipment. These approaches can save hospitals a lot of money and support more effective maintenance strategies (Li et al., 2023).

However, TPM implementation requires reliable, structured, and accessible maintenance data, which are often unavailable in hospitals using manual maintenance systems. Therefore, maintenance digitalization should be considered a necessary first step toward TPM-oriented maintenance management.

1.1 Objectives

This study proposes a digital maintenance management framework to support the future implementation of Total Productive Maintenance (TPM) in the medical imaging department of a Tunisian public hospital referred to as Hospital AZ. The proposed approach focuses on the digitalization of maintenance information in order to improve equipment traceability, centralize maintenance data and automate the calculation of maintenance Key Performance Indicators (KPIs), including Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and equipment availability.

The main contribution of this paper is to present maintenance digitalization as a necessary first step toward data-driven maintenance and TPM-oriented management in the medical imaging department. The proposed solution supports the transition from reactive and paper-based maintenance practices to a more structured and data-driven maintenance approach in a healthcare context.

2. Literature Review

Hospital maintenance plays a critical role in ensuring safety and continuity of care. Effective maintenance helps prevent unexpected breakdowns that can delay medical examinations or treatments, allowing healthcare professionals to focus on patient care without technical interruptions. In this sense, maintaining equipment properly contributes indirectly to better clinical outcomes by improving diagnostic accuracy and procedural safety.

Hospital maintenance improves operational efficiency by reducing equipment downtime, extending equipment lifespan, and lowering costs related to emergency repairs and service interruptions. For this reason, maintenance management is considered an essential part of risk management and continuous quality improvement in healthcare systems.

To better position this study within the international context, several studies conducted in different countries were reviewed. These studies highlight common technical and organizational challenges related to medical equipment maintenance in hospital, as well as the different strategies proposed to improve maintenance performance. Table 1 summarizes the main research findings from literature.

Table 1. Summary of technical issues and maintenance strategies in hospital

<i>Article</i>	<i>Year</i>	<i>Hospital/ Country</i>	<i>Technical problem</i>	<i>Proposed maintenance strategy</i>	<i>Source</i>
Medical Equipment Maintenance Programme Overview	2011	Developing countries, WHO reference	50% of equipment is out of service due to the lack of a national maintenance program.	National maintenance program, mandatory inventory, training of biomedical technicians	(WHO, 2011)
Maintenance Management of Medical Equipment in Hospitals	2012	Kenyatta National Hospital, Kenya	Radiotherapy machine out of service for 4 years due to a lack of spare parts, IT tools, and qualified personnel	Computerized tool for fault diagnosis, digital inventory, and systematic technician training.	(Mutia et al., 2012)
Preventive Maintenance of Medical Equipment in Alzahra Hospital	2013	Alzahra Hospital, Iran	Ventilators and cardiac monitors repeatedly breaking down, with no scheduled maintenance visits	Semi-annual preventive maintenance schedule for standard equipment, and quarterly for critical equipment.	(Vesal et al., 2013)
Maintenance Practice, Causes of Failure and Risk Assessment	2017	Diagnostic hospitals, Ghana	Premature wear due to improper storage, poor handling, and repairs carried out without proper methodology.	Regular preventive maintenance, risk assessment for each piece of equipment, and user training.	(Kwaku Kutor et al., 2017)
Assessment of Medical Equipment Maintenance	2021	Hospital Al-Zahra, Saudi Arabia	Absence of checklists; maintenance is purely reactive and does not	Validated management checklist and regular audits to ensure	(Arab-Zozani et al., 2021)

			comply with safety standards.	compliance with ISO and WHO standards.	
Maintenance versus Replacement of Medical Equipment	2022	District hospitals, Nepal	Equipment replaced instead of repaired, resulting in costs 39% higher.	Outsourcing of preventive and corrective maintenance, with a digital MMIS tracking system.	(Hillebrecht et al., 2022)
Medical Equipment Management in General Hospital	2023	Tulu Bolo General Hospital, Rural Ethiopia	Lack of local technicians; reliance on costly external service providers for every breakdown.	Training of first-level local technicians; service contracts negotiated at the time of purchase.	(Kabeta et al., 2023)
Practices and Factors Affecting On site Medical Equipment Maintenance	2024	WauTeaching Hospital, South Sudan	No biomedical engineer; donated equipment remains unused due to a lack of trained personnel.	Recruitment of biomedical engineers, preventive maintenance program, and a monitoring database.	(Massimino Ucin et al., 2024)
Medical Equipment Management and Failure Factors in Ethiopian Teaching Hospitals	2025	Jimma University Hospital, Ethiopia	Spare parts are not available locally; repeated power outages damage equipment.	Installation of uninterruptible power supplies (UPS) for sensitive equipment, and inclusion of a maintenance budget from the time of purchase.	(Yihunie et al., 2025)

These studies presented in Table 1 highlight several common points, independently on the country. Medical equipment failures are generally caused by a combination of factors, including the absence of a preventive maintenance programs, a lack of qualified personnel and insufficient financial resources allocated to maintenance activities. Most of the proposed strategies are based on the similar principle: preventing failures is more effective than repairing equipment after breakdowns occur. This requires structured maintenance organization and reliable monitoring tools. However, implementing a maintenance strategy alone is not sufficient to ensure long-term effectiveness without proper data management and maintenance traceability.

Medical equipment management in healthcare systems has been based on a reactive approach focused on repairing failures rather than preventing them. As patient safety and service continuity have become major priorities, this approach is no longer sufficient. Healthcare systems have therefore progressively adopted more structured and engineering-based maintenance methods. Table 2 describes the evolution of hospital maintenance through four main generations from reactive maintenance to digital and TPM oriented maintenance approaches:

Table 2. Evolution from reactive to digital and TPM-oriented maintenance models in Hospitals

Model	Period	Characteristics and Limitations	Typical Results
Corrective Maintenance	Before the 1990s	Operated in a strictly reactive mode: no preventive action. The absence of preventive maintenance led to unexpected equipment failures. This model was found to be disastrous for patient safety and economic performance (Nasser & Abdulghafour, 2025).	Availability < 70% Failure rate > 20% High repair costs
Systematic Preventive Maintenance	1990-2000	Preventive maintenance schedules were based on manufacturers' recommendations. This approach aims to reduce unexpected failures. This approach remained costly and sometimes excessive. Parts were replaced regardless of their actual wear condition, increasing the biomedical budget up to 3% of the total budget (Shamayleh et al., 2019)	Availability: 75–85% Maintenance budget up to 3% of the total budget
Early TPM approaches in	2000-2010	Key aspects of TPM implementation include staff training and the use of digital tools such as CMMS	Availability: 85–92% Failure reduction: 30–

hospitals (maintenance + CMMS)		(Computerized Maintenance Management Systems). A gradual shift from a paper-based system to CMMS occurred. Lean methods and the 5S approach were also applied (Dalal & Cudney, 2025)	40%
Advanced TPM combined with IoT and Artificial Intelligence	Since 2015	Real-time monitoring of equipment using connected sensors. Predictive maintenance based on Machine Learning and Digital Twin technologies enables simulation of equipment behavior and anticipation of failures before they occur (Pabitha et al., 2025)	Availability > 96% Cost maintenance reduction by 42% Increase lifespan 28% Return On Investment (ROI) > 250%

Recent studies have shown that many healthcare maintenance systems remain fragmented and insufficiently digitalized, limiting the implementation of advanced maintenance strategies. Although Computerized Maintenance Management Systems (CMMS) are widely used, many systems still lack real-time monitoring, structured reliability data, and predictive maintenance capabilities due to lack of training, and insufficient integration with other technologies (J. N. Kumar et al., 2021). In many hospitals, maintenance decisions are still based on fixed preventive schedules rather than on dynamic equipment performance indicators such as Mean Time Between Failures (MTBF) and equipment utilization history (Alburaiesi, 2020). These limitations reduce the effectiveness of preventive maintenance and make the implementation of data-driven maintenance strategies, including Total Productive Maintenance (TPM), more difficult.

Several studies have focused either on TPM methodologies or on digital maintenance systems separately. A limited number of studies consider maintenance digitalization as a necessary step for successful TPM implementation in resource-constrained hospital. Moufid et al. (2025) showed that fragmented datasets and low levels of digitalization create important challenges for the implementation of advanced maintenance strategies in healthcare systems. They developed a structured data preparation process using real biomedical maintenance records collected from a public hospital. The process included data cleaning, semantic harmonization, category standardization and classification of critical medical equipment. The developed model confirmed that structured and digitalized maintenance data can support advanced maintenance analytics and future data-driven maintenance strategies.

3. Methods

This study presents a case study approach conducted in the medical imaging department of Hospital AZ. The objective is to analyze the current maintenance management practices and identify the main limitations affecting medical equipment traceability and maintenance decision making. A SWOT analysis was used to identify internal strengths (S) and weaknesses (W), as well as the external opportunities (O) and threats (T) related to maintenance management in the imaging department maintenance. This analysis is based on field observations, maintenance document analysis and discussions with biomedical technicians and healthcare staff. The SWOT analysis is summarized in Table 3.

Table 3. SWOT Analysis of the maintenance management for medical imaging service

Internal Factors	
Strengths (S)	Weaknesses (W)
✓ Acquisition of modern medical equipment through institutional donations ✓ Qualified staff who are open to training and skill development ✓ Use of specialized suppliers for maintenance activities ✓ Existence of planned preventive maintenance programs ✓ Availability of maintenance tracking sheets for each equipment ✓ Public funding of the hospital ensuring a certain level of budget stability	✓ Incomplete and non-systematic traceability system ✓ Intervention delays not adapted to the urgency of imaging equipment ✓ Mainly corrective maintenance with no root cause analysis ✓ Lack of formalized and monitored performance indicators ✓ No digital link between the imaging department and the maintenance department ✓ Poor document and physical organization within the service

External Factors	
Opportunities (O)	Threats (T)
✓ Availability of proven methodologies adaptable to the hospital context (TPM) ✓ Potential for digitalization of maintenance tracking through dedicated applications ✓ Existing and exploitable partnerships with equipment suppliers ✓ Availability of specialized training programs in biomedical maintenance ✓ Partnerships with engineering schools and research institutions ✓ Emergence of connected health technologies	✓ Clinical risk related to unexpected equipment failures ✓ Budget constraints in the public healthcare sector ✓ Progressive obsolescence of medical equipment ✓ Risk of prolonged unavailability of critical equipment ✓ Risk of permanent loss of historical data stored on paper ✓ Resistance of staff to change when introducing new maintenance practices

The SWOT analysis shows several organizational and technical limitations in the current maintenance system, including incomplete maintenance traceability, intervention delays, fragmented maintenance records, lack of performance monitoring indicators and the absence of digital communication between the medical imaging and maintenance departments. The analysis also shows that the hospital still operates according to the first generation reactive maintenance model rather than the more advanced third or fourth generation maintenance approaches. Therefore, before moving toward advanced maintenance strategies such as TPM-oriented maintenance, an intermediate stage focused on maintenance digitalization and traceability is necessary. The main needs include maintenance data centralization, real-time access to maintenance information, improved equipment traceability, automatic KPI calculation, and better monitoring of maintenance activities.

A digital maintenance management framework was proposed to support the transition from reactive maintenance toward more structured and data driven maintenance practices. The objective is to improve preventive maintenance actions, ensure traceability, provide real-time information and support better maintenance decision making. In addition, the proposed framework provides the digital foundation necessary for the future implementation of TPM at Hospital AZ. It also addresses several key strategic challenges in the healthcare sector. Equipment failures may directly affect patient safety and continuity of care, particularly in medical imaging services where unexpected downtime of critical equipment such as CT scanners can lead to the postponement of a large number of medical examinations. This situation was observed during a previous 134-day period of unavailability, as documented in equipment performance reports in Hospital AZ. Also, corrective maintenance after an unplanned failure costs 3 to 5 times more than planned preventive maintenance. Added to that, maintenance traceability and structured maintenance management support regulatory compliance and contribute to extending the operational lifespan of medical devices.

The hospital is currently at Level 1 corresponding to reactive maintenance practices. The transition toward advanced maintenance approaches such as condition based maintenance and TPM oriented management (Level 3) requires first moving to Level 2, focused on maintenance digitalization and traceability. The proposed framework aims to improve maintenance information management and establish the digital foundation necessary for future TPM-oriented maintenance management.

4. Data Collection

In this study, the dataset was collected from the medical imaging department of the Hospital AZ. This department plays a crucial role in the patient diagnostic process. Major clinical decisions, such as emergency diagnostic, thoracic surgery planning and cancer follow up depend on the medical imaging service. The availability and performance imaging equipment directly affect the quality of patient care across all hospital units. The temporary unavailability of the CT scanner or MRI machine has immediate consequences on the healthcare system, including medical examination delays, postponed diagnosis, and deterioration in the quality of patient care.

4.1. Patient Flow

The patient process starts with a medical prescription. The patient then schedules an appointment with the department. The waiting time depends on the availability of the imaging equipment. After arrival, the patient is registered and directed to the appropriate examination room. The examination is performed by a radiology

technician, and the medical images are transferred to the RIS/PACS system for analysis by the radiologist. A diagnostic report is then prepared and sent to the prescribing physician or to the patient, completing the patient care process. Figure 1 illustrates the patient flow in the medical imaging department:

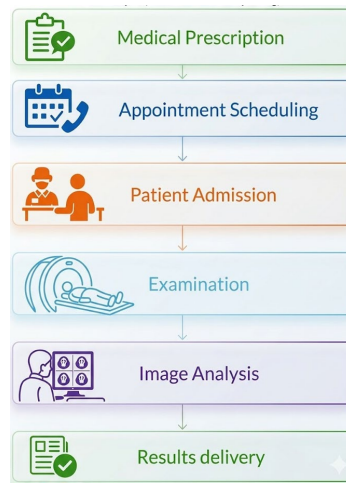


Figure 1. Patient flow in the medical imaging department

4.2. Equipment inventory

The imaging department is equipped with a large technical platform made up of 12 main units, covering all diagnostic medical imaging modalities needed for hospital activity.

The hospital has three fully digital radiography rooms designed for a high number of standard examinations, mainly for chest and bone imaging. These systems include robotic positioning tools, modern high-voltage generators, and high-sensitivity digital detectors. They provide good image quality while reducing radiation dose to patients. The radiology equipment inventory is summarized in Table 4.

Table 4. Radiology table inventory

Designation	Model	Supplier
Radiology table n°1	Shimadzu	Continental
Radiology table n°2	DRGEM	Rimpex
Radiology table n°3	GMM	Tiamed

The department has two ultrasound units used for imaging with sound waves. These portable and non-radiating devices are used for many types of examinations, such as vascular Doppler studies, abdominal and pelvic imaging, cardiac exams, and interventional guidance. Their availability is very important in a respiratory hospital, where conditions such as pleural effusion and lung masses require fast ultrasound evaluation for treatment decisions.

The department has one CT scanner provided through an institutional donation. This equipment produces high-resolution cross-sectional images of the human body using X-rays. It is essential for diagnosing complex lung diseases such as pulmonary embolism, tumors, and severe infections like bilateral pneumonia. It is also used for surgical planning and treatment follow-up. In this specialized pulmonary and thoracic surgery hospital, the CT scanner is one of the most used and most critical devices for care continuity.

MRI is the most advanced and expensive equipment in the department. It uses a strong magnetic field and radiofrequency waves to produce high-resolution images of internal body structures without ionizing radiation, which is important for repeated exams and sensitive patients. Due to its technical complexity, MRI is highly sensitive to failure. Breakdowns can last several days and cause significant financial losses, estimated at around 15,000 € per day of downtime according to WHO (2023).

In this study, after analysing the current situation in the medical imaging department, we identified three main categories of dysfunction that reduce the effectiveness of the maintenance function.

4.3. Lack of Traceability and Data- Driven Monitoring

The maintenance information flow in Hospital AZ is entirely manual and follows a five steps process, where each step introduces potential data loss and uncertainty:

- ✓ Failure detection: Equipment failures are usually detected randomly by radiology technicians or biomedical staff during use. There is no automatic alert system for early detection of faults.
- ✓ Failure reporting: The information is communicated informally through phone calls or handwritten notes, without consistent recording of the exact date and time. This leads to delays, missing information, and lack of clarity.
- ✓ Maintenance intervention: The biomedical technician attempts to diagnose and repair the failure. For major equipment, external suppliers must be contacted, which increases delays and reduces control over the process.
- ✓ Intervention recording: Details such as failure cause, downtime, actions performed, and spare parts used are manually recorded on paper forms. These records are often incomplete or inconsistent.
- ✓ Archiving: All information is stored as paper documents in the service without structured organization or indexing, making later analysis very difficult.

Without an organized database, key indicators such as MTBF and MTTR and equipment availability cannot be calculated, which prevents proper monitoring of equipment performance and limits any data-driven improvement of the system.

4.4. Reactive Maintenance Problems

The imaging service mainly reacts to equipment failures during normal operation. It focuses on fixing visible problems without investigating the root causes of repeated malfunctions. For example, the remote radiology table experienced three similar breakdowns within one year due to a communication problem with the VIP/OPERA software. Each time, the only solution applied was to restart the system, without addressing the underlying cause. The lack of a tracking system also made it difficult to recognize that the same problem was repeating.

4.5. Administrative Delays

The imaging department does not present a systematic classification of equipment based on criticality when managing procurement requests. The example of the CareStream sensor illustrates this issue: the device remained out of service for 42 days, not because of technical difficulty, but due to the delay in obtaining a replacement battery. The approval of the purchase order by the administration was slower than expected, which extended the downtime. This situation shows a gap between clinical urgency and administrative procedures, directly affecting patient care.

The data collection shows poor traceability, a mainly reactive maintenance approach and administrative delays that affect equipment availability and patient care. The absence of structured data also means that maintenance performance cannot be properly measured or analyzed. Without indicators or reliable records, it is difficult to identify recurring problems or improve maintenance actions in a systematic way.

5. Results and Discussion

The analysis of the existing maintenance system identified several organizational and structural limitations. Equipment breakdowns were recorded manually on paper, maintenance traceability was uncompleted, coordination between the medical imaging department and the maintenance service was not formalized, and the calculation of key performance indicators (KPIs) was difficult. The objective of the proposed digitalization is not only to replace paper-based records, but also to structure maintenance information in order to support data-driven maintenance management based on measurable and usable indicators.

Several alternatives were considered, including using a traditional Computerized Maintenance Management System (CMMS). However, these systems are not considered suitable for public hospitals, as they are expensive and difficult to deploy, particularly in an environment with limited resources.

The final choice selected was AppSheet, a no-code platform based on Google Sheets. It allows the quick development of a customized maintenance application adapted to the real needs of the hospital services. It requires no licensing cost, can be deployed immediately on desktop computers, smartphones and tablets, and provides a flexible interface that does not require any programming skills.

5.3 Graphical Results

The proposed AppAZ application was designed based on four main interconnected tables, as illustrated in Figure 2:

- **Machine Table:** Contains all equipment information, including technical characteristics and operational parameters required to calculate performance indicators.
- **Breakdown Table:** Records each reported failure with date, time, and description, linked to a specific machine. In line with TPM principles and operator empowerment, the interface was designed to maximize adoption by healthcare staff. The Breakdown Table records each reported failure by linking it to a specific machine, with the exact date, time, and description of the malfunction.
- **Interventions Table:** Stores all maintenance actions, including start and end dates, intervention type (corrective or preventive), and downtime duration.
- **Planning Table:** Organizes future preventive maintenance tasks and ensures their follow-up. The actual downtime duration is automatically calculated from the entered dates and pauses, without requiring any additional input from the user.

The application structure distinguishes between two types of interventions: corrective interventions related to a reported breakdown and preventive interventions planned separately. This distinction allows a more accurate analysis of equipment performance and supports the calculation of indicators such as MTBF.

The figure displays four distinct user interface screens of the AppAZ application, designed for medical imaging department maintenance management.

- Top Screen (Table: Machines):** This screen shows a data table with columns: NAME, TYPE, KEY?, LABEL?, and FORMULA. It lists various medical equipment such as 'CareStream Scanner', 'Scanner', 'ECHOGRAPHER', 'Resona RP', 'Mammograph', and 'Telecommand Table' with their respective IDs and formulas.
- Bottom-Left Screen (Interventions Form):** This form is used to report a breakdown. It includes fields for 'Intervention ID *' (INT-2026-001), 'Machine' (CareStream Detector - RADIOLOGY 2), 'Technician' (Mohamed Ali), and 'Status' (In progress).
- Bottom-Middle-Left Screen (Intervention Details):** This form provides details for a specific intervention. It includes 'Start Date' (03/04/2026 04:00), 'End Date' (06/04/2026 00:00), 'Intervention Type' (Preventive), and 'Duration (hours)' (4.50).
- Bottom-Middle-Right Screen (Planning Form):** This form is used to schedule preventive maintenance. It includes 'Planning ID *' (PLN-2026-001), 'Machine' (ECHOGRAPHER - S/N: S18VM3HN200013Y), 'Intervention Type' (Preventive), and 'Scheduled Date' (13/04/2026).
- Bottom-Right Screen (Planning Details):** This form provides details for a planned maintenance task. It includes 'Scheduled Date' (13/04/2026 08:00), 'Actual Date' (13/04/2026 12:30), 'Technician' (Mohamed Ali), 'Findings' (No anomaly detected), and 'Status' (Completed).

Figure 2. Different Interfaces of the proposed AppAZ Application

5.4 Proposed Improvements

The proposed framework allows calculating maintenance performance indicators automatically. Figure 3.b shows the virtual columns that are automatically generated by AppAZ from the maintenance data entered into the system. These indicators are updated in real time whenever an equipment record is accessed as illustrated in Figure 3.a.

When a healthcare operator reports a breakdown or a when a biomedical technician records an intervention, all maintenance indicators are recalculated automatically without any manual computation. This process reduces the risk of calculation error. Before the implementation of this application, it was necessary search through paper records and estimate downtime durations in order to calculate the equipment availability rate. In practice, this process was rarely performed because it was time consuming and difficult to manage.

Total Operating Time :

$$(\text{HOUR}(\text{TODAY}()) - \text{DATE}([\text{Service_Date_Start}])) / 24 / 7 \\ \times \text{Operating_Days_per_Week} \times \text{Operating_hours_per_day}$$

MTBF :

$$\text{Actual_operating_Time} / \\ \text{COUNT}(\text{SELECT}(\text{Interventions}[\text{Id_Intervention}], \\ [\text{Id_Machine}] = [\text{_THISROW}].[\text{Id_Machine}])))$$

MTTR :

$$\text{SUM}(\text{SELECT}(\text{Interventions}[\text{Corrective_Downtime}], \\ \text{AND}([\text{Machine}] = [\text{_THISROW}].[\text{Id_Machine}], \\ [\text{Statut}] = \text{"Corrective"}))) \\ / \text{COUNT}(\text{SELECT}(\text{Interventions}[\text{Id_Intervention}], \\ \text{AND}([\text{Machine}] = [\text{_THISROW}].[\text{Id_Machine}], \\ [\text{Statut}] = \text{"Corrective"})))$$

Availability :

$$([\text{MTBF}] / ([\text{MTBF}] + [\text{MTTR}])) \times 100$$

Figure 3. a. Mechanism for Maintenance Performance Evaluation

Figure 3. b. Virtual Columns in the Machine Table

Figure 3. Digitalization of Maintenance Performance Indicator Calculation

5.5 Validation

To validate the functionality of the proposed framework, a failure was recorded on the CareStream Sensor on 30/01/2025 at 12:00. A corrective maintenance intervention was then scheduled and completed on 13/03/2025 and recorded between 08:00 and 16:00 (8 hours). Based on the entered maintenance data, the application automatically calculated the following indicators (see Figure 4):

- **Total Operating Time:** 78 936 hours (equipment operating continuously since 09/04/2017, operating 24/7)
- **Total Downtime:** 102.84 hours (Corresponding to two recorded interventions: 94.84h+8h)
- **Actual Operating Time :** 78833.16 hours (Corresponding to Total Operating Time – Total Downtime)
- **MTBF:** 39 417 hours (approximately 1642 days between two failures)

$$\text{MTBF: } \frac{\text{Actual Operating Time}}{\text{Number of Interventions}} \quad (1)$$

$$\text{MTBF: } \frac{78833.16}{2} = 39416.58 \text{ hours} \approx 39417 \text{ hours}$$

- **MTTR:** 51.42 hours

$$\text{MTTR: } \frac{\text{Total Downtime}}{\text{Number of Interventions}} \quad (2)$$

$$\text{MTTR: } \frac{102.84}{2} = 51.42 \text{ hours}$$

- **Availability:** 99.87%

$$\text{Availability (\%): } \frac{MTBF}{MTBF+MTTR} \times 100 \quad (3)$$

$$\text{Availability (\%): } \frac{39416.58}{39416.58+51.42} \times 100 \approx 99.87\%$$

These results demonstrate the reliability of the CareStream Sensor, with only two recorded failures since 2017. They also confirm the ability of the proposed application to automatically generate accurate and real time maintenance performance indicators, which was not possible with the previous paper based maintenance system.

Figure 4. CareStream Sensor Equipment Sheet after Data Entry

6. Conclusion

This study proposed a digital maintenance management framework designed to support the future implementation of TPM oriented maintenance management in the medical imaging department of Hospital AZ. The proposed approach focused on the digitalization of maintenance information to improve equipment traceability, maintenance monitoring and maintenance decision-making.

The results showed significant improvements in maintenance information management, including better equipment traceability, reduction of information loss associated with paper-based records, and improved support for preventive maintenance activities. The design and development of the AppAZ application enabled the automatic calculation of maintenance performance indicators such as MTBF, MTTR and equipment availability. These indicators provide maintenance managers with real-time information to better monitor equipment reliability and maintenance performance.

The proposed framework also improved coordination between the medical imaging department, biomedical technicians and external maintenance providers through a centralized and connected maintenance database. In addition, our study demonstrated that maintenance digitalization represents an essential intermediate step before

implementing advanced maintenance approaches such as TPM oriented and data driven maintenance management in hospitals.

This study contributes by developing maintenance digitalization with an accessible low-cost no code solution adapted to public hospitals operating under limited financial resources. Unlike conventional Computerized Maintenance Management Systems (CMMS), which are often expensive and difficult to deploy, the proposed approach provides a flexible, practical and easily implementable alternative in public healthcare systems.

Despite the improvements provided by the proposed approach, several limitations remain. First, the reliability of the calculated indicators depends on the accuracy of manual data entry by operators and technicians. Therefore, staff training and change management are essential to ensure proper use of the system and long-term adoption. Second, the current application is based on manually entered data and does not yet include IoT sensors. Real-time monitoring of physical parameters such as temperature, vibrations, or equipment performance still needs to be implemented in order to move toward predictive maintenance. In addition, some organizational and administrative constraints remain unresolved. For example, delays in administrative approval for spare parts purchasing, such as the 42 days delay observed for the CareStream Sensor battery replacement, cannot be directly solved by the digital tool alone and require improvement of administrative procedures.

Future work will focus on integrating IoT sensors on critical medical equipment such as MRI and CT scanners, predictive maintenance models based on artificial intelligence and advanced maintenance analysis tools in order to further improve equipment reliability and maintenance decision making in hospitals. Future developments may also include extending the proposed framework to other technical hospital departments such as sterilization services, operating rooms, and medical laboratories.

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