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COLLEGE OF SCIENCE AND TECHNOLOGY

Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

OPTIMAL UTILIZATION OF CMMS: A CASE STUDY ON RWANDA's MEDICAL EQUIPMENT MANAGEMENT AND MAINTENANCE SYSTEM (MEMMS).

By: **Mick Ganza**

Reference Number: 220000105

A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by: Prof. Celestin Twizere and Prof. Abdelbaset Khalaf

DECLARATION

I, Mick Ganza, hereby declare that I am the sole author of this document entitled "Optimal Utilisation of CMMS: A Case Study on Rwanda's Medical Equipment Management Maintenance System (MEMMS)." This document is submitted in partial fulfilment of the requirements for the Master's Degree.

I declare that the content of this document is original and has not been taken from any other source, except where due acknowledgment has been made in the text. Any ideas, data, or information obtained from other sources have been fully referenced in accordance with the appropriate referencing style.

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Mick Ganza

Date: **October 7, 2024**

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CERTIFICATE

This is to certify that the project entitled "**Optimal Utilisation of CMMS: A Case Study on Rwanda's Medical Equipment Management and Maintenance System (MEMMS).**" is a record of original work done by Mick Ganza (Reference number: 220000105), an MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Prof. TWIZERE Celestin and Prof. Abdelbaset Khalaf

Main Supervisor:

Prof. TWIZERE Celestin

Co-Supervisor:

Prof. Abdelbaset Khalaf

Biomedical Engineering Master's Program Coordinator

Dr. Gerard Rushingabigwi

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ABSTRACT

In the rapidly evolving landscape of healthcare facilities and the medical industry, the effective management and maintenance of medical equipment and technology have become paramount. The utilisation of Medical Equipment Maintenance Management Systems (MEMMS) offers a strategic solution for healthcare organisations to monitor, prevent equipment failures, optimise operational efficiency, and ensure the seamless functioning of critical medical equipment. The purpose of this study is to assess the impact of MEMMS on medical equipment maintenance and repair practices in Rwanda's healthcare system. The study used a comprehensive research methodology to examine existing maintenance practices, identify operational challenges, and collect insights via a structured questionnaire. The data analysis, which was carried out using the R programming language, provided a solid foundation for reaching meaningful conclusions. The study's findings in Rwanda's healthcare institutions revealed a concerning trend regarding the use of MEMMS. Only 4.4% of participants reported daily usage, while a slightly larger group, 8.9%, used MEMMS on a weekly basis. Approximately 35.6% indicated monthly usage. However, a substantial majority, 51.1%, had not used MEMMS at all. This data highlights the underutilisation of MEMMS in Rwanda's healthcare institutions, despite its availability. The study emphasises the critical importance of taking action to increase MEMMS adoption in Rwandan healthcare settings. This will increase the efficiency of medical device management by closing the technology gap, resulting in better maintenance practices, streamlined operations, and better patient care outcomes. In conclusion, this study shows there is inadequacy of MEMMS utilisation in Rwanda's healthcare landscape and advocates for proactive measures to increase its integration, enabling healthcare institutions to elevate their maintenance practices, improve equipment management, and enhance the quality of healthcare delivery.

Keywords: healthcare technology management, maintenance practices, CMMS, effectiveness.

LIST OF ACRONYMS

CMMS: Computer Maintenance Management System.

MEMMS: Medical Equipment Management and Maintenance System.

WHO: World Health Organisation.

HTM: Health-care Technologies Management.

GIHT: Global Initiative on Health Technologies

MOH: Ministry of Health

RBC: Rwanda Biomedical Centre

MTI: Medical Technology Infrastructure

LMIC: Low- and Middle-Income Countries

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CHAPTER 1. INTRODUCTION

1.1 GENERAL INTRODUCTION

The healthcare sector in Rwanda has experienced significant progress in recent years, thanks to the government's efforts to improve infrastructure, implement policies, and invest in modern medical equipment [1]. These developments align with the standards set by the World Health Organization (WHO) to evaluate the effectiveness of health systems [2]. To ensure the successful implementation of these plans, the government has established institutions like the Center of Excellence for Biomedical Engineering and E-Health [3].

As healthcare facilities continue to expand and the number of medical devices increases, the importance of effective healthcare technology management has become more pronounced. The use of technology is critical in providing quality healthcare services, and Health-care Technology Management (HTM) programs play a crucial role in selecting and maintaining the appropriate medical equipment systems. The department of Clinical Engineering or Medical Equipment oversees HTM programs, which includes testing, maintaining, and repairing medical equipment to ensure optimal performance.

Biomedical operations in healthcare settings, including hospitals, clinics, and outsourced maintenance organizations, play a crucial role in ensuring the smooth functioning of critical equipment and machinery. To meet regulatory compliance standards and maintain a high level of operational efficiency, these operations require a robust Computerized Maintenance Management System (CMMS).

Effective maintenance management plays a vital role in biomedical operations due to several reasons. Firstly, the implementation of preventive maintenance schedules is crucial to ensure a hygienic and safe environment, enabling uninterrupted patient treatment. Secondly, it is necessary to respond promptly and efficiently to service requests in order to minimize downtime and prevent disruptions in healthcare services. Lastly, capturing and organizing maintenance-related data in a logical manner is essential, as this data serves as valuable information for auditors and regulatory bodies.

To address these requirements, Maintenance Connection provides a web-based biomedical equipment and facilities management application tailored to meet these specific needs. This application empowers organisations to maintain accurate maintenance records, exercise greater control over maintenance schedules and routines, and meet the strict standards and requirements for biomedical maintenance. Notably, it incorporates features like risk analysis, life safety tracking, and equipment calibration monitoring, which contribute to achieving regulatory compliance.

Implementing maintenance procedures and preventive maintenance schedules is crucial within biomedical facilities and clinics as it enables efficient management of various critical equipment and facilities, including imaging systems, surgical equipment, rehabilitation equipment, water treatment equipment, dialysis machines, respiratory equipment, hospital beds, sterilising equipment, and radiation machines.

The selection and maintenance of medical equipment can be challenging due to the technical complexity of these devices. Therefore, the role of HTM programs and Clinical Engineering or Medical Equipment departments in ensuring that medical devices are used efficiently, effectively, and safely cannot be overstated. These departments also provide training and support to healthcare staff on how to use the equipment properly [4].

To streamline the maintenance of medical equipment and track associated costs, computerised maintenance management systems (CMMS) have been developed. These systems assist HTM managers in automating the maintenance process, thereby improving the efficiency and effectiveness of healthcare technology management. The problem statement of this study is to address the growing need for effective healthcare technology management in Rwanda, which has become increasingly important with the expansion of healthcare facilities and the increasing use of medical devices [2].

1.2. Problem Statement

The overarching problem addressed in this study is the suboptimal management of medical equipment in public hospitals, which is primarily due to underutilization of the Medical Equipment Management and Maintenance System (MEMMS), also known as the Computerised Maintenance Management System (CMMS). This problem is exacerbated by the CMMS's low adoption rate, which makes medical equipment management difficult. The study aims to investigate the consequences of these deficiencies and to clarify the potential benefits and consequences of effectively implementing MEMMS. By delving into the dynamics of CMMS utilisation and exploring the role of CMMS adoption, the research endeavours to provide insights and recommendations for improving the management of medical equipment in public healthcare settings.

1.3. Research Questions

- To what degree is the use of CMMS implemented in Rwanda?
- What are the factors that influence the adoption and utilisation of MEMMS in Rwanda?
- What strategies can be implemented to increase the optimal utilisation of MEMMS in Rwanda?

1.4. Study Objectives

1.4.1. General Objective:

The primary objective of this research is to comprehensively study the impact of MEMMS/CMMS (Medical Equipment Management and Maintenance Computerised Maintenance Management System) usage in Rwanda's healthcare sector.

1.4.2. Specific Objectives:

1. Assess the current adoption and utilisation of MEMMS/CMMS in Rwanda:
    - Examine the extent to which MEMMS/CMMS is currently adopted and utilised within healthcare institutions in Rwanda.
    - Investigate the implementation processes, system functionalities, and utilisation patterns of MEMMS/CMMS in managing medical equipment and technology.

2. Evaluate the Impact of MEMMS/CMMS on Medical Equipment Management:
    - Analyse the effects of MEMMS/CMMS implementation on various aspects of medical equipment management, such as asset tracking, maintenance scheduling, cost control, and overall operational efficiency.
    - Measure the quantitative and qualitative impact of MEMMS/CMMS usage on healthcare service delivery, patient care, and resource utilisation.
3. Identify challenges and limitations of MEMMS/CMMS Implementation:
    - Identify and analyse the challenges and limitations faced during the implementation and utilisation of MEMMS/CMMS in the Rwandan healthcare system.
    - Understand the perspectives of stakeholders, including healthcare professionals, administrators, and system users, regarding the obstacles and limitations.

1.5. Study Scope:

This research aims to comprehensively examine the utilisation and impact of computerised maintenance management systems (CMMS) or medical equipment maintenance management systems (MEMMS) in the context of healthcare institutions in Rwanda. The study will focus on assessing the level of adoption, effectiveness, challenges, and limitations associated with these systems in managing medical equipment and technology within healthcare facilities.

1.5.1. Target Population:

The research will target a diverse range of participants from key healthcare organisations in Rwanda. These include staff members from the Ministry of Health, the Rwanda Biomedical Centre, hospitals, and health centres that currently have access to or utilise CMMS and MEMMS within their operations.

1.6. Significance of the Study and Contribution:

1.6.1. Significance of the Study

This research contributes significantly to healthcare management and technology in Rwanda by rigorously examining Medical Equipment Maintenance Management Systems (MEMMS) and their impact on healthcare operations.

It enhances operational efficiency by preventing equipment failures and ensuring seamless functionality of critical medical equipment, potentially leading to streamlined operations and improved patient care outcomes. Tailored insights specific to Rwanda's healthcare system enable targeted recommendations, addressing the country's unique infrastructure and needs. The development of a mobile application to support MEMMS usage represents a practical solution to underutilization, promoting better maintenance practices and streamlined operations. Methodological rigor, including comprehensive research methodology and data analysis using the R programming language, ensures robust findings. The study's recommendations for increased MEMMS adoption advocate for proactive measures, aiming to elevate maintenance practices, enhance equipment management, and improve healthcare delivery quality. Overall, the research advances healthcare management and technology in Rwanda through its holistic approach and actionable recommendations tailored to the country's context.

1.7. Organization of the Study

The study report is structured into five cohesive chapters, commencing with an abstract summarizing the research. The introductory chapter provides a comprehensive overview, including the background, motivation, problem statement, objectives, hypothesis, and scope of the study, concluding with a justification for its relevance. Chapter two offers an extensive literature review on medical equipment maintenance, examining it globally and within an African context, while also incorporating international standards and best practices. In chapter three, the study methods are detailed, covering setting, design, data collection tools and procedures, as well as data management and analysis methodologies, alongside addressing challenges and limitations. Chapter four presents the results of data analysis, supported by graphical representations, followed by a discussion highlighting major findings. Finally, chapter five offers conclusions drawn from the study and provides actionable recommendations to address identified issues, while also suggesting opportunities for further research, thus ensuring a comprehensive and structured approach to the study's organization.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

The importance of the maintenance function in medical equipment life cycle management cannot be overstated. It is vital to ensure that medical devices and equipment are properly maintained and managed in order to minimise costs and prevent equipment failures and malfunctions that can have a significant impact on healthcare service delivery [5]. The maintenance function involves a range of activities that are designed to ensure that medical equipment is functioning at its optimal level. These activities include routine inspections, repairs, upgrades, and replacements of worn out or damaged parts. Proper maintenance can help to extend the lifespan of medical equipment, reduce the risk of breakdowns, and ensure that the equipment is always in good working order

To effectively handle maintenance tasks in healthcare facilities, it involves the strategic planning and scheduling of preventive measures, as well as the proper management of spare parts, and the analysis of data to reduce failures and enhance maintenance efficiency. As a means to achieve this goal, the World Health Organisation suggests the implementation of computerised maintenance management systems (CMMS) to ensure the prompt and precise dissemination of information [2].

Maintenance has been acknowledged as a function with a significant impact on the overall results of healthcare institutions, and its efficiency is often seen as having a high potential for improvement. In the past, maintenance was viewed as a "necessary evil" and was overlooked in favour of more visible organisational functions such as production or logistics. However, some institutions have begun to understand the importance of investing in maintenance due to its impact on overall business performance [6]. In modern times, maintenance is perceived as a multifaceted management procedure that involves a range of organisational operations, including but not limited to production, quality control, environmental management, risk assessment, and safety protocols [7].

In order to effectively manage maintenance, one of the most important resources for developing the maintenance function is information, which is essential for better operability and coordination within the organisation. To support the maintenance function, organisations often use computerised maintenance management systems (CMMS).

These systems provide the organisation with the ability to define the information that must be recorded and provided to support the maintenance strategy. The implementation of a CMMS can bring many benefits, such as improved planning and scheduling, easy access to historical data and report generation, and cost reductions associated with spare parts and maintenance activities. A CMMS is a tool for supporting maintenance strategies that is built on an information system and a collection of operations that analyse data to provide indications to assist maintenance actions [8]. To ensure an operational healthcare system, the presence of a CMMS is crucial. The CMMS selected must provide the necessary access required for managing medical equipment, as well as promoting teamwork and real-time information sharing among team members, thereby enhancing their overall efficiency and effectiveness.

Effective utilization of medical devices and Computerized Maintenance Management Systems (CMMS) is significantly influenced by comprehensive user training and support systems. According to Hwang (2016), the importance of training healthcare personnel cannot be overstated, as it directly impacts the safety and efficiency of medical device operation. Proper training not only ensures that staff can effectively use medical devices but also equips them with the necessary skills to navigate and utilize the associated CMMS. This dual focus is essential for promoting optimal equipment performance and maintenance management.

The training process should encompass several critical components. Hands-on training sessions allow healthcare professionals to engage with medical devices under supervised conditions, fostering confidence and competence in their usage. Additionally, simulation-based training can enhance learning outcomes by enabling staff to practice various scenarios without jeopardizing patient safety [18]. Clear, accessible training materials and documentation further empower personnel by providing resources they can reference when needed.

Ongoing education is also vital. Continuous training programs ensure that healthcare personnel remain informed about the latest features of medical devices and CMMS, thereby maintaining high levels of proficiency and adherence to best practices. Regular updates to training content based on technological advancements and user feedback are essential for keeping the workforce engaged and knowledgeable.

In conjunction with training, effective support systems play a crucial role in sustaining user competence. Hwang (2016) emphasizes that having a robust support network for troubleshooting and addressing maintenance-related inquiries is essential for minimizing equipment downtime. When healthcare personnel are well-supported, they are more likely to adhere to maintenance schedules, which enhances the reliability and performance of medical equipment.

Feedback mechanisms are also critical. Establishing channels for users to report their experiences with medical devices and CMMS allows for continuous improvement of training programs and support systems. Incorporating user feedback into training materials ensures that they remain relevant and effective, ultimately enhancing the overall user experience.

The integration of comprehensive training programs and effective support systems is paramount for the optimal utilization of medical devices and CMMS in healthcare settings. By prioritizing user training and support, healthcare facilities can significantly improve equipment maintenance practices, reduce downtime, and enhance the quality of care provided to patients. Hwang's insights highlight the need for a cohesive approach that combines education, technical support, and user feedback to foster an environment of continuous improvement in healthcare technology management.

Medical technologies have greatly improved healthcare outcomes globally over the past two decades, but Low- and Middle-Income Countries (LMICs) still face challenges in fully utilizing these technologies. Approximately 40% of medical equipment in LMIC health facilities is out of service due to barriers such as lack of spare parts, consumables, reliable power, user training, and technical personnel. Studies indicate that a significant portion of equipment failures (80%) can be prevented through user training and routine maintenance. For example, user training can address 20% of equipment failures, while regular preventive maintenance can prevent an additional 60%. Furthermore, research has shown that 70% of broken medical equipment in LMICs can be repaired using locally available spare parts.

Capacity-building approaches, such as training users and biomedical technicians (BMETs), are crucial for improving the utilization of medical equipment in LMICs. The charity "Knowledge for Change" (K4C) implemented a model in Uganda that demonstrated the effectiveness of user training and preventive maintenance.

K4C placed volunteers and a biomedical engineer in Ugandan hospitals and supported training and mentorship programs, leading to enhanced medical equipment use. This intervention highlights the potential for capacity-building programs to improve healthcare delivery in low-resource settings.

2.2 Computerised Maintenance Management System Modules

Assets Management: that consists of recording all assets (or equipment) and a historical record of repairs and equipment parts lists [8]:

- Work Orders Management: This allows setting and releasing of work orders to the maintenance technicians.
- Preventive Maintenance Management: that supports the planning, scheduling and control of activities;
- Inventory control: giving access to spare parts availability.
- Report Management: CMMS processes large amounts of data and produces performance indicators.

2.3 International standard on CMMS on Medical Equipment.

The World Health Assembly adopted a resolution in May 2007 recognising the importance of health technologies, specifically medical devices, in the prevention, diagnosis, and treatment of illness and disease, as well as patient rehabilitation [2]. The resolution addresses issues related to the inappropriate deployment and use of health technologies, and calls for the establishment of priorities in the selection and management of these technologies. It also calls for the expansion of expertise in the field of health technologies and requests that the World Health Organisation (WHO) take specific actions to support Member States in this regard.

The Global Initiative on Health Technologies (GIHT) was established by the World Health Organisation (WHO) as part of the WHO's strategic objective to "ensure improved access, quality, and use of medical products and technologies.

The GIHT aims to make core health technologies available at an affordable price, particularly to communities in resource-limited settings, in order to effectively control important health problems with these objectives [2]:

- To identify and prioritise essential health technologies that are most needed in resource-limited settings, and
- To support the development and implementation of policies and strategies that will help increase access to these technologies in these settings.
- To challenge the international community to establish a framework for the development of national essential health technology programmes that will have a positive impact on the burden of disease and ensure effective use of resources.
- To challenge the business and scientific communities to identify and adapt innovative technologies that can have a significant impact on public health. The main goal is to increase access to essential health technologies, particularly in resource-limited settings, to improve health outcomes and reduce the burden of disease.

To achieve the objectives of the Global Initiative on Health Technologies (GIHT), WHO and its partners have been working to develop an agenda, an action plan, tools, and guidelines to increase access to appropriate medical devices. This effort includes the development of a series of reference documents that can be used at the country level. These documents are meant to provide guidance and support to governments, health care providers, and other stakeholders in the selection, procurement, and management of medical devices. They aim to ensure that the medical devices used in a country are safe, effective, and appropriate for the population's needs, and that they are used in a way that maximises their benefits and minimises any potential harms. It includes topics such as:

- policy framework for health technology
- medical device regulations
- health technology assessment
- health technology management
- medical device data
- medical device innovation, research and development.

Health-care technology management (HTM) programs play a key role in the effective delivery of healthcare by ensuring that the medical technology used in a facility is appropriate, safe, and effective. The selection, maintenance, and repair of medical devices are often the responsibility of the clinical engineering or medical equipment department. Computerized maintenance management systems (CMMS) have emerged as a tool to support HTM managers in maintaining medical equipment and monitoring their associated costs. A CMMS is a software package that contains a computer database of information about an organization's maintenance operations. It is used to automate the documentation of all activities related to medical devices, including equipment planning, inventory management, corrective and preventive maintenance procedures, spare parts control, service contracts, and medical device recalls and alerts. The collected data can be analysed and used for technology management, quality assurance, work order control, and budgeting of medical devices.

The decision to automate an HTM system or replace an existing CMMS depends on the individual circumstances of the health facility, including working procedures, information technology infrastructure, and available budget [9]. While major vendors strive to develop a system that universally meets the needs of all HTM managers, no available system presents a complete solution. Most systems can be customized to meet the specific needs of the health facility or an IT firm can be contracted to develop a CMMS package tailored to local requirements. Customized CMMS package is generally more expensive but if well-designed and maintained will often produce a more satisfactory solution that meets local needs. According the WHO the CMMS can be used to:

- Standardize and harmonize information within a HTM programme;
- Assist in the planning and monitoring of inspection and preventive maintenance, and schedule and track repairs;
- Monitor equipment performance indicators such as mean time between failures, down time and maintenance costs for individual or equipment groups of the same model, type or manufacturer;
- Monitor clinical engineering staff performance indicators such as repeated repairs by the same staff member for the same problem, average down time associated with individuals, and productive work time for individuals or groups;

- Generate reports that can be used to plan user training programs based on equipment failure trends in certain departments or health facilities;
- Host libraries of regulatory requirements and safety information;
- Generate the appropriate documentation for accreditation by regulatory and standard organisations.

A computerised maintenance management system (CMMS) can be a valuable tool for clinical engineers to manage and maintain medical equipment. Clinical engineers play a crucial role in the management of medical equipment. They are responsible for ensuring that devices are functioning correctly, safely, and efficiently. To help them in their work, computerised maintenance management systems (CMMS) can be used to keep track of equipment inventory, schedule preventative maintenance, and document repairs. This allows clinical engineers to monitor the health of medical equipment proactively, reducing the risk of unexpected downtime or failures. By ensuring that medical equipment is functioning reliably and safely, patient care can be improved. Additionally, CMMS can help healthcare facilities comply with regulatory requirements and reduce equipment-related costs. Additionally, a CMMS can also help clinical engineers manage equipment budgets, track equipment usage, and generate reports on equipment performance [10]. By using a CMMS, clinical engineers can improve the efficiency of their healthcare technology management (HTM) programme and better achieve their department's objectives.

2.3 Computerised Maintenance Management System of medical equipment in developing countries.

2.3.1. Overview

The World Health Organisation (WHO) emphasises the critical role of accurate and updated documentation in healthcare settings, which can be effectively achieved through the implementation of a computerised maintenance management system (CMMS). CMMS serves as a sophisticated software tool employed by clinical engineering (CE) departments to streamline the management and maintenance of medical equipment (ME). This includes functions such as overseeing equipment inventory, scheduling service appointments, recording repairs, maintaining service histories, tracking expenditures, and generating comprehensive reports [2].

Ideally, a well-implemented CMMS not only enhances operational efficiency but also enables users and CE staff to access essential information promptly and produce detailed reports. This capability is vital for assisting hospitals in aligning with regulatory requirements, industry codes, and established standards [13].

Despite the undeniable benefits of CMMS, its widespread adoption faces notable challenges in developing countries. These challenges encompass a shortage of specialized healthcare staff and personnel dedicated to ME maintenance, logistical issues in the supply chain, a lack of robust local regulations and control functions, and the fact that CMMS solutions are often designed by international companies, potentially following different standards. Additionally, the prevalence of donated medical equipment contributes to a reduced sense of responsibility for maintenance. Limited internet access and unreliable Local Area Networks (LANs) further hinder the successful implementation of CMMS in these settings [12].

Beyond these challenges, various factors influencing medical equipment maintenance are intricately tied to quality management and control standards. A comprehensive study examining medical equipment management systems in Low- and Middle-Income Countries (LMICs) revealed that 60% of medical equipment becomes unusable for various reasons (11). This underscores the profound impact of these factors on maintenance practices and, consequently, on the overall functionality of healthcare systems in these regions [17]. Addressing these multifaceted challenges is crucial not only for cost reduction but also for minimising amortisation, preventing equipment failures, and ensuring the seamless delivery of patient care services.

By implementing a good equipment management system, healthcare facilities can ensure that their medical equipment is functioning reliably and safely, which can improve patient care and reduce costs associated with equipment downtime and replacements. Inappropriate technology transfer can lead to many problems in the work environment and productivity. The transfer of technology, including healthcare equipment management systems, to developing countries should be carefully evaluated to ensure that it is appropriate for the specific context and will meet the needs of the healthcare facility.

Mahady et al. - (2023) designed an evaluation protocol that can be used as a selection tool for the transfer of medical technology to developing countries. This protocol can help assess the suitability of different equipment management systems based on factors such as cost, ease of use, maintenance requirements, and compatibility with existing systems. The protocol can be applied to various types of equipment management systems, such as user-based systems, paper-based filing systems, in-house developed computer-based systems, and off-the-shelf systems. This can help to ensure that the equipment management system selected is appropriate for the specific context and will meet the needs of the healthcare facility in a developing country [12].

Inadequate management of biomedical equipment and healthcare infrastructure is a prevalent challenge within healthcare systems in low-income countries. This issue can be attributed to several key factors, with the foremost being the absence of precise information. Few Ministries of Health (MoH) maintain accurate asset inventories at various administrative levels, including the national, sub-national, and healthcare facility levels. These inventories encompass a wide range of resources, such as diagnostic equipment, medical transportation, buildings, grounds, and IT equipment. In obtaining current information pertaining to the operational condition, maintenance history, and maintenance scheduling of equipment and infrastructure, there is a pronounced challenge. This dearth of essential data significantly impedes the effective planning, administration, and oversight of substantial public investments in healthcare equipment and facilities. As a consequence, numerous structures deteriorate due to inadequate maintenance practices, and scrap yards accumulate non-functional yet potentially repairable medical equipment. Furthermore, the distribution of biomedical equipment may lack rationality, and some items remain non-operational due to a basic absence of electricity or the requisite technical expertise for installation and configuration.

2.3.2. Important criteria for selecting CMMS for medical equipment in developing countries.

It is important for a healthcare equipment management system to be robust, easy to maintain, and adapted to the environmental conditions of the specific location where it will be used. This is to ensure that the system will work effectively and efficiently and that it will be able to meet basic safety requirements. For example, a computer-based system will require a dependable electricity supply to function properly.

In areas where a dependable electricity supply is not available, a paper-based system may be a more appropriate option. This is because it does not rely on electricity, and can still function effectively in the absence of a reliable power supply. It's important to note that the system should be chosen based on the specific needs and limitations of the facility and the location where it will be used [12].

According to Wang, et al., it is not uncommon for companies to provide poor back-up services for healthcare equipment management systems. Therefore, they recommend selecting a system from a company that provides a comprehensive range of user support. This is to ensure that the system will receive adequate support and maintenance in case of any issues. In a similar vein, Taylor, et al. suggest that users should develop in-house support for their systems if possible. They believe that this is more feasible when using systems designed specifically for use in developing countries. This is because such systems are often more basic and simpler to use, making it easier for users to develop the necessary skills to maintain and support the system. It's important to note that the choice of the system should be based on the specific needs and limitations of the facility and the location where it will be used [13].

In general, medical equipment tends to become underutilised when there is a lack of trained operators or support personnel. Taylor observed that a significant cause of under-usage of equipment in developing countries is a lack of competent users [11]. This can be caused by a number of factors, such as poor training opportunities or a drain of trained personnel for more lucrative positions in developed countries. It is important to have a proper training programme in place to ensure that the operators and support personnel are well-trained in the use and maintenance of the equipment. This will help to ensure that the equipment is used to its full potential and that it is properly maintained to ensure it functions reliably. Additionally, it is important to have a system in place to track and schedule maintenance, to ensure that the equipment is properly serviced and maintained on a regular basis. This can be done through an in-house system or a commercial CMMS (computerised maintenance management system).

It is important to consider the financial implications of purchasing, operating, and maintaining healthcare equipment management systems in developing countries, as hospitals often operate on limited funds. This evaluation should include the costs of the initial purchase, operation, and maintenance of the system, as well as any additional costs that may arise over time.

It is important to keep in mind that a lack of funds may leave a system redundant, and it is important to choose a system that is affordable and sustainable in the long run [14]. It is also important to consider the cost-effectiveness of the system, and whether the benefits of the system outweigh the costs. This can be done by considering factors such as the potential increase in patient care and the overall efficiency of the equipment management process.

In addition, it is important to consider the scalability of the system, as the hospital may grow in size and need to expand the system to accommodate more equipment and users [15]. It is important to have a proper budgeting and cost management plan in place to ensure that the system is financially sustainable in the long term and does not put undue stress on the hospital's finances.

2.4 CMMS in Rwanda

In Rwanda under the Ministry of Health (MoH), there is Rwanda Biomedical Centre (RBC) the nation's central health implementation agency. RBC is a government-funded organization established in 2011 through the merger of 14 key health institutions. Its mission is to improve the health of the Rwandan population by providing high-quality, affordable, and sustainable health care services through preventative, rehabilitative, and curative interventions. RBC also conducts scientific research, provides diagnostic services, and implements innovative health interventions to protect the nation against diseases and other health threats. RBC's **mission** is to promotes high quality, affordable, and sustainable health care services to the population through evidence-based interventions and practices guided by ethics and professionalism and the **vision** is to become a Center of Excellence for the prosperity of the country, ensuring quality health service delivery, education and research.

RBC has a division in charge of the Medical Technology and Infrastructure (MTI) and is responsible for Healthcare Technology Management (HTM) as well as supervision and assistance in engineering of healthcare infrastructure with a **Vision** to ensure sustainable and equitable access to quality health equipment and infrastructure to improve health service delivery and a **Mission** to provide efficient management of healthcare equipment and infrastructure through qualified and sufficient human resources, state-of-art guidelines, standards and processes, and high-standard quality control.

The MTI division provides efficient management and coordination of healthcare equipment and infrastructure in all public healthcare facilities in the country.

- The division also coordinates the planning activities related to medical equipment for government health facilities determined by a Prime Minister's Order.

- The Planning unit provides assessment of new infrastructure and medical equipment, budgeting and financing, procurement support and logistics, monitoring of activities for ongoing projects, and replacement/extension assessment.

- The Healthcare Technology Management unit provides technology assessment and selection, installation and commissioning, training and skill development, operation and safety (use), monitoring of maintenance and repairs, decommissioning and disposal, and verification of invoice prior to submission for payment.

- The Infrastructure Projects Management unit provides healthcare infrastructure project design, participates in tender and contract negotiations, monitors activities of ongoing projects, and healthcare facility maintenance planning and financing.

The Government of Rwanda started implementing CMMS known as Medical Equipment Management and Maintenance System (MEMMS). MEMMS is a web-based portal designed to improve the efficiency of maintenance staff at public health facilities in Rwanda, and to provide visibility for Ministry of Health managers over the management and maintenance of medical equipment. MEMMS is being implemented at Provincial and District Hospitals, Health Centers, and some Referral Hospitals. Its purpose is to help in tracking the inventory, scheduling, and reporting of maintenance activities on medical equipment, thus improving the overall management of medical equipment in the public healthcare facilities in Rwanda [16].

However, by analysing the currently available systems in the Rwandan hospitals, some weaknesses and limitations were identified:

- Condition monitoring data analysis;
- Equipment failure diagnosis;
- Limited support for resource allocation;
- Decision analysis support
- Reporting

2.5 Summary

Based on the limitations outlined above, the current Medical Equipment Management and Maintenance System (MEMMS) may not fully satisfy the requirements of the biomedical engineering department, medical equipment users, and hospital management. To address this issue, this research aims to conduct a comprehensive analysis of the adoption rate of MEMMS in healthcare facilities in Rwanda. The study will also identify any challenges encountered by hospitals and other institutions during the implementation and use of MEMMS, as well as propose solutions to improve its efficiency and performance. By addressing the limitations of MEMMS and enhancing its capabilities, healthcare facilities can optimize the use of medical equipment, resulting in better patient outcomes and a more efficient healthcare system.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Introduction

This research methodology provided a structured and organised foundation for the whole investigation. It involved developing and structuring research questions, selecting the most effective data collection methods, and evaluating and interpreting the research's findings.

This chapter outlines the systematic approach employed in the study, detailing the processes, tools, and techniques utilised for data collection, management, and analysis. Specifically, qualitative research methods were applied to investigate the research questions. Additionally, this chapter addresses the encountered limitations throughout the study, providing transparency about the constraints and challenges faced in the research process

3.2. Research Process

The questionnaire was created and used to conduct interviews with MEMMS users in order to understand the current state of CMMS (MEMMS) adoption and usage, identify the challenges hospitals and other institutions in Rwanda face when implementing and using MEMMS, and comprehend the overall effects that MEMMS have on the maintenance operations in Rwanda, including improvements in efficiency and performance. People who were expected to have access to MEMMS were the participants:

- Hospital administrators are responsible for planning, organising, directing, and controlling all resource departments and services of the centre, including personnel, finances, facilities, equipment, and supplies.
- Biomedical engineers and technicians who maintain and repair medical, biomedical, diagnostic imaging, and electronic equipment and systems.
- Medical equipment users are the primary users of MOH medical devices.
- RBC and MOH are the personnel and staff who participate in policy-making process as policy-makers.

Following the interviews, data was gathered using a specially developed Microsoft form and analysed using R and R Studio.

3.3. Method of Data Collection

To gather data from the study participants, a survey was developed using the Microsoft Forms platform. The survey was carefully designed to align with the research objectives of the project. The survey questions were customised to address specific aspects of the study and ensure that the data collected was relevant and informative. The questions were structured to include a range of response options, such as multiple-choice, Likert scales, and open-ended questions. By offering participants different response options, the survey allowed them to provide their input in a manner that was convenient and straightforward, enhancing the chances of obtaining accurate and complete data. The accuracy and comprehensiveness of the data are crucial for the success of the study, and by using a well-designed survey, they were able to collect valuable insights to inform their study findings.

3.4. Method of Data Analysis

To analyse the data collected through the survey, R programming language was employed in this study, leveraging its powerful capabilities for statistical analysis. R Studio served as our primary tool, facilitating robust data manipulation, visualization, and statistical modelling. In addition to employing a variety of analytical techniques, a significant aspect of this analysis involved t-test analysis.

T-test analysis was utilized to compare the means of different groups within the dataset. This method enabled us to assess the significance of differences between groups, identify patterns, and explore relationships between variables. By conducting t-test analysis, we gained insights into the differences in responses across different groups and survey questions.

The integration of t-test analysis within R Studio enhanced our analytical workflow by providing seamless access to a plethora of statistical functions and visualization tools. Through R's extensive library of packages, we implemented t-test techniques tailored to the characteristics of our dataset, ensuring accurate and comprehensive exploration of the data.

The results of the t-test analysis were visually represented using R's data visualization capabilities. Graphs, charts, and plots were generated to illustrate the differences in means of key variables, facilitating clear and concise communication of findings.

These visual representations served as valuable aids in interpreting the results and communicating them effectively to stakeholders.

The use of t-test analysis within the R environment contributed to the validity and reliability of our study results. By employing established statistical methods supported by a reputable software platform, we ensured the accuracy and integrity of our data analysis process.

Incorporating t-test analysis alongside other analytical techniques within the R programming language allowed for a comprehensive exploration of the survey data. The combination of advanced statistical tools and visualization capabilities provided by R Studio enabled us to uncover meaningful insights, ultimately enhancing the quality and depth of our research findings.

3.5. Mobile application development

To complement the existing web-based Maintenance, Equipment, and Materials Management System (MEMMS) used in the organisation, I developed a mobile application that provides a more convenient and efficient way for users to access and manage maintenance-related tasks and information. The key objectives were to reduce the need for double data entry, offer a comprehensive set of maintenance management functionalities, and improve overall accessibility and visibility of maintenance operations.

The mobile application includes the following core modules:

- **Preventive Maintenance:** This module allows users to schedule, track, and manage preventive maintenance activities for equipment and assets. It provides features for creating and assigning maintenance tasks, setting reminders, and logging completed work.

- **Corrective Maintenance:** The corrective maintenance module enables users to report and manage reactive maintenance issues, such as equipment breakdowns or malfunctions. It includes functionalities for logging maintenance requests, assigning technicians, and monitoring the status of corrective actions.

- **Inventory Management:** The inventory management module helps users keep track of spare parts, consumables, and other maintenance-related inventory. It allows for inventory tracking, stock level monitoring, and reordering of supplies.

- **Spare Parts Management:** This module integrates with the inventory management functionality to provide a dedicated interface for managing spare parts. Users can view part details, check availability, and request new or replacement parts.

A key feature of the mobile application is its ability to integrate with the organization's existing MEMMS web application. This integration allows users to access the same data and functionality across both the mobile and web platforms, avoiding the need for double data entry. Information entered in the mobile app is automatically synchronised with the web application, enabling seamless transitions between the two interfaces depending on user location and device preferences.

The development of this mobile application has brought several benefits to the organisation, including:

- Improved accessibility and convenience for maintenance personnel, who can now access and manage maintenance tasks on-the-go.
- Increased efficiency and reduced errors by eliminating the need for duplicate data entry.
- Enhanced visibility and control over maintenance operations with real-time updates and centralised data management.
- Improved collaboration and communication among maintenance teams, as the mobile app facilitates information sharing and task coordination.

By integrating this mobile application with the existing MEMMS system, the organisation has been able to streamline its maintenance management processes and improve overall operational efficiency.

3.6. Research Design Method

The initial phase involved conducting a comprehensive assessment of the current CMMS and medical equipment management systems (MEMMS) infrastructure in Rwanda. This assessment entailed reviewing relevant documentation, engaging with stakeholders through interviews, and evaluating the existing capabilities and limitations of the systems in place.

Subsequently, relevant data was gathered using a variety of methods, including surveys, interviews, and observations. This data underwent systematic analysis to extract insights into the present state of CMMS/MEMMS utilisation and pinpoint areas for enhancement.

A meticulous review of academic and industry literature was undertaken to gain a deeper understanding of best practices, case studies, and emerging trends in the application of CMMS for medical equipment management. This literature review served to provide a contextual framework for the findings derived from the data collection phase.

The research process involved collaboration with subject matter experts such as CMMS/MEMMS vendors, maintenance professionals, and healthcare administrators. This engagement facilitated the acquisition of additional insights and served to validate the research findings.

Building upon the acquired insights, there was a potential for the development of a prototype or model application to showcase the optimal utilisation of CMMS for medical equipment management within the Rwandan context.

The final stage of the research design entailed synthesising all collected data, analysis outcomes, and expert input to present key findings and actionable recommendations aimed at enhancing the utilisation of CMMS for medical equipment management in Rwanda.

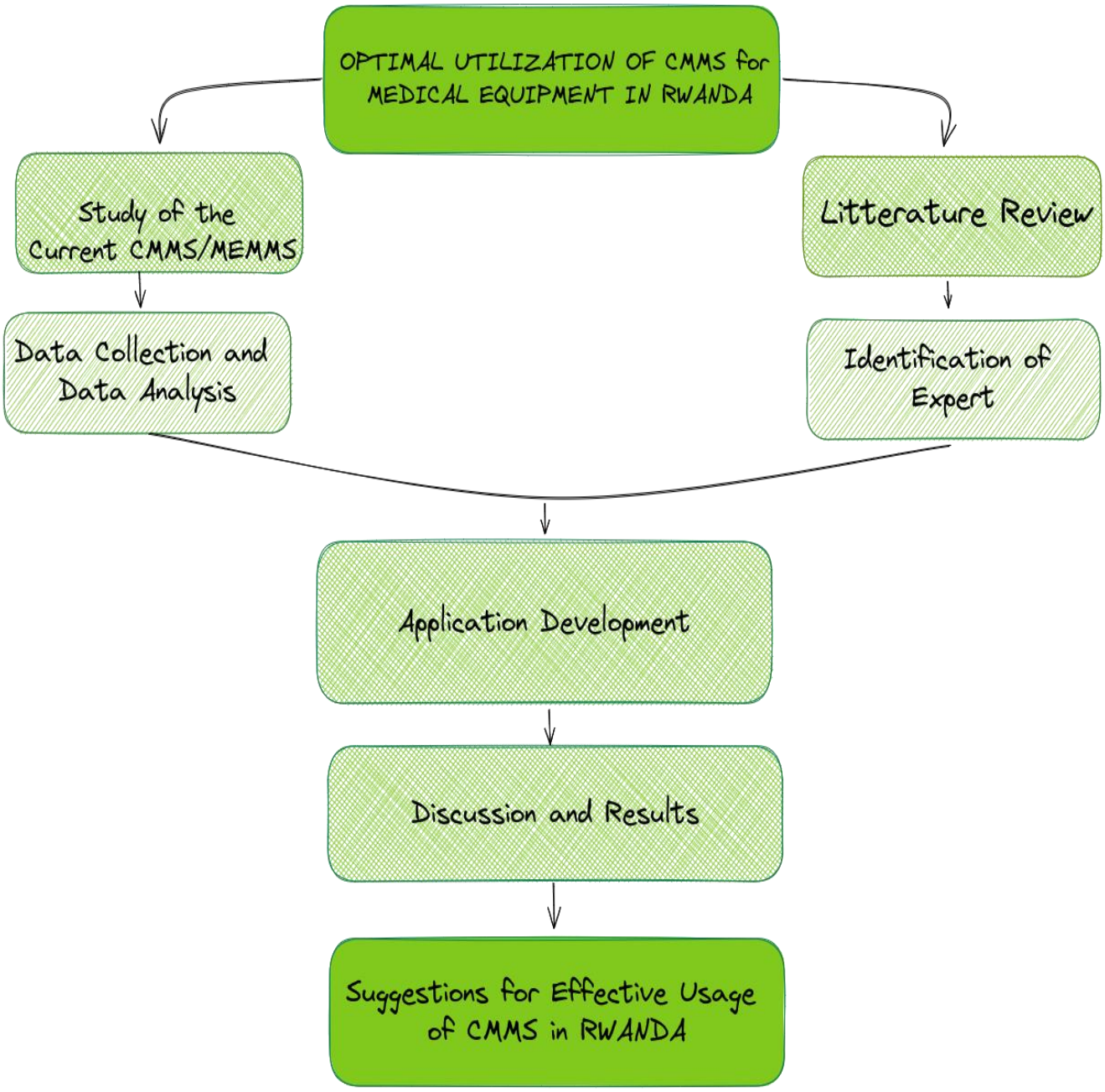

Figure 3.1: Research Design

Diagram 3.1. illustrates the method used in this research to optimise the utilisation of the Computerised Maintenance Management System (CMMS) for medical equipment in Rwanda. Firstly, the current status of CMMS in healthcare settings was examined. Through data collection and analysis, we gained insights into its current usage, identified challenges, and evaluated its overall performance.

In the second part, existing literature was reviewed to extract insights and best practices. This involved exploring expert knowledge globally to identify effective strategies for optimising CMMS usage in managing medical equipment.

The final step involved integrating the findings from both parts. By combining insights from current practices and best practices identified in the literature, practical suggestions were formulated. These suggestions aim to guide Rwanda in making the most effective use of CMMS in medical equipment management, offering tailored recommendations for improved efficiency and effectiveness in healthcare operations. The diagram visually represents this process of studying, learning from experts, and providing actionable recommendations.

3.7. Limitation

One notable limitation of this study was the unavailability of an open API (Application Programming Interface) for integrating the developed mobile application with existing Computerized Maintenance Management Systems (CMMS). Despite the acknowledged benefits of synchronizing the mobile application with established CMMS platforms, the absence of an accessible API posed a significant constraint in achieving seamless connectivity.

The inability to leverage an open API restricted the scope of data exchange and interoperability between the mobile application and prevalent CMMS systems. Consequently, the full potential of the mobile application in enhancing maintenance operations and facilitating efficient asset management within organizational frameworks was hindered.

Although efforts were made to explore potential integration solutions and collaborate with CMMS providers, the absence of an accessible API remained a persistent challenge throughout the research process. As a result, the mobile application's functionality and utility were somewhat limited by its inability to seamlessly sync with existing CMMS infrastructures.

While this limitation impacted the comprehensiveness of the study's findings and the practical implementation of the developed mobile application within real-world maintenance environments, it also highlights a significant area for future research and development. Addressing the need for standardized, open APIs in CMMS systems could unlock greater opportunities for innovation and interoperability in the realm of maintenance management software.

3.8. Summary

The study aimed to examine the utilisation of CMMS or MEMMS among the health institutions in Rwanda, targeting staff members from the Ministry of Health, RBC, hospitals, and health centres in Rwanda who have access to CMMS or MEMMS. A survey was created using the Microsoft Forms platform, and the obtained data were analysed using R Studio, a tool for the R programming language, to identify patterns, trends, and correlations. The use of R Studio was critical in ensuring that the data collected was properly analysed and that the results of the study were accurate and reliable. In summary, a questionnaire was used to gather data, and R was used as a tool for statistical computing and graphics.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Results

Based on the analysis of the collected data, this study provides valuable insights into the usage patterns and challenges of MEMMs in healthcare entities and highlights potential areas for improvement and future research.

4.1.1. Data Collection and Findings

The purpose of this research was to investigate the usage of Medical Equipment Maintenance Management Systems (MEMMS) in various healthcare entities by collecting data through user surveys and observations. Research questions were formulated based on the problem statement presented in Chapter 1.

For the data-gathering process in this study, questionnaires were used as a statistical method of collecting information. Respondents were selected through random sampling from various healthcare entities such as hospitals, health centres, RBC, and the Ministry of Health. The research population consisted of 45 participants, which was also the total number of participants in the study.

The study population was stratified based on profession, consisting of the following categories:

- biomedical engineers,
- biomedical technicians,
- hospital administrators,
- medical equipment users,
- Ministry of Health (MOH) staff, and
- Rwanda Biomedical Center (RBC) staff.

The collected data were analysed using the R programming language, known for its powerful statistical computing and visualisation capabilities. R is a modern language used for data analysis due to its advanced packages and flexibility, making it a superior choice over other software such as Stata.

In addition to the data analysis, I developed a mobile app that integrates with MEMMS, providing a web view functionality that enhances the user experience and facilitates the management of medical equipment maintenance. This mobile app was designed to support the use of MEMMS, making it easier for healthcare professionals to access and manage medical equipment maintenance information.

Based on the analysis of the collected data, this study provides valuable insights into the usage patterns and challenges of MEMMS in healthcare entities and highlights potential areas for improvement and future research. The study's findings are expected to contribute to the development of more effective MEMMS and improve the overall management of medical equipment in healthcare settings.

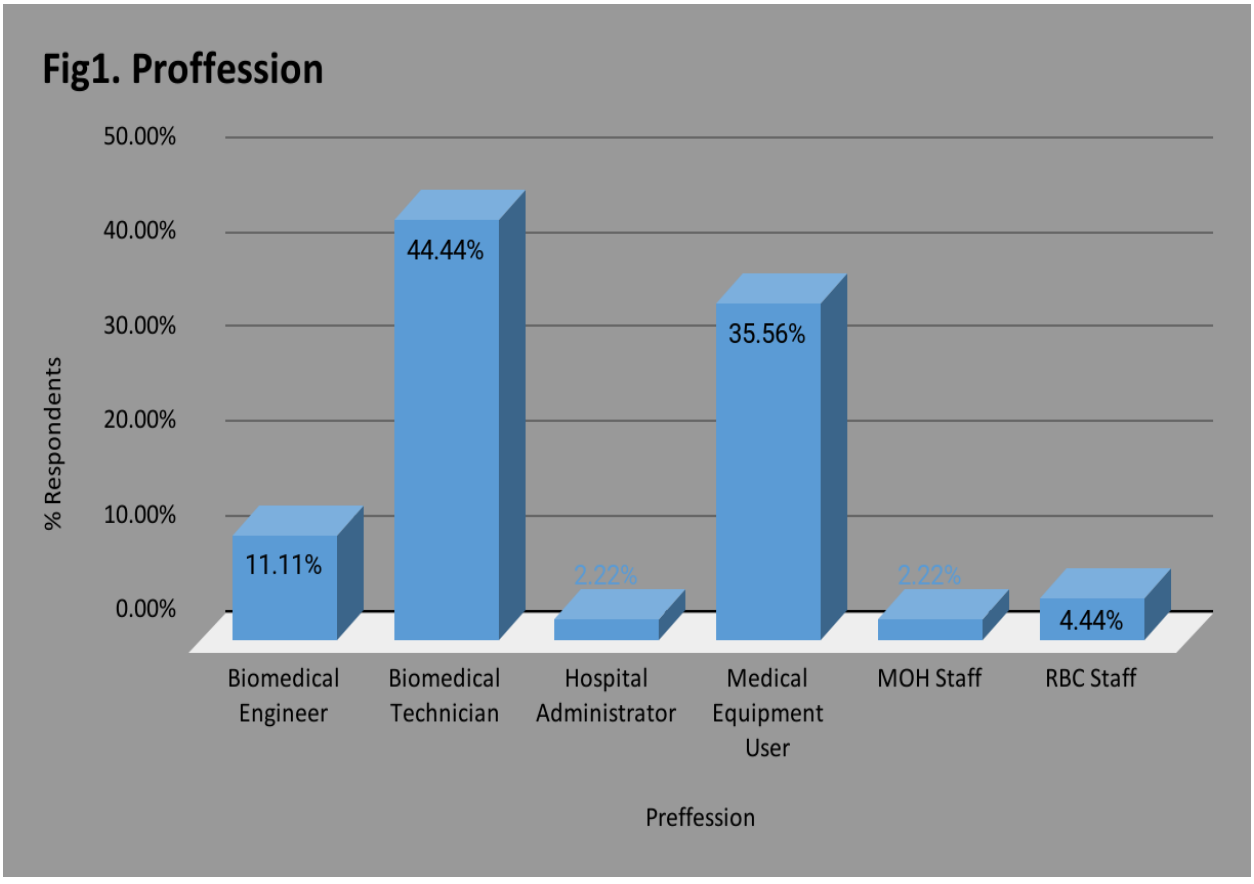

Figure 4.2: Professional background of respondents

The figure 4.2. displays the distribution of respondents according to their profession. Biomedical technicians represented the largest group, accounting for 44% of the total respondents, followed by medical equipment users at 36%. Biomedical engineers constituted 11% of the sample, while RBC staff, hospital administrators, and MOH staff accounted for 4% and 2%, respectively.

As the figure above shows, the results are summarised in the chart, where participants identify their profession. According to the chart, the most significant group of respondents were biomedical technicians, constituting 44.44% of the total. Medical equipment users followed, with 35.56% representation. Biomedical engineers made up 11.11% of the participants, while hospital administrators, and Ministry of Health staff each accounted for 2.22%, and Rwanda Biomedical Centre staff had 4.44% of the respondents.

To summarise, the chart indicates that the majority of the survey participants were either biomedical technicians or medical equipment users, while the other categories comprised a smaller portion of the total.

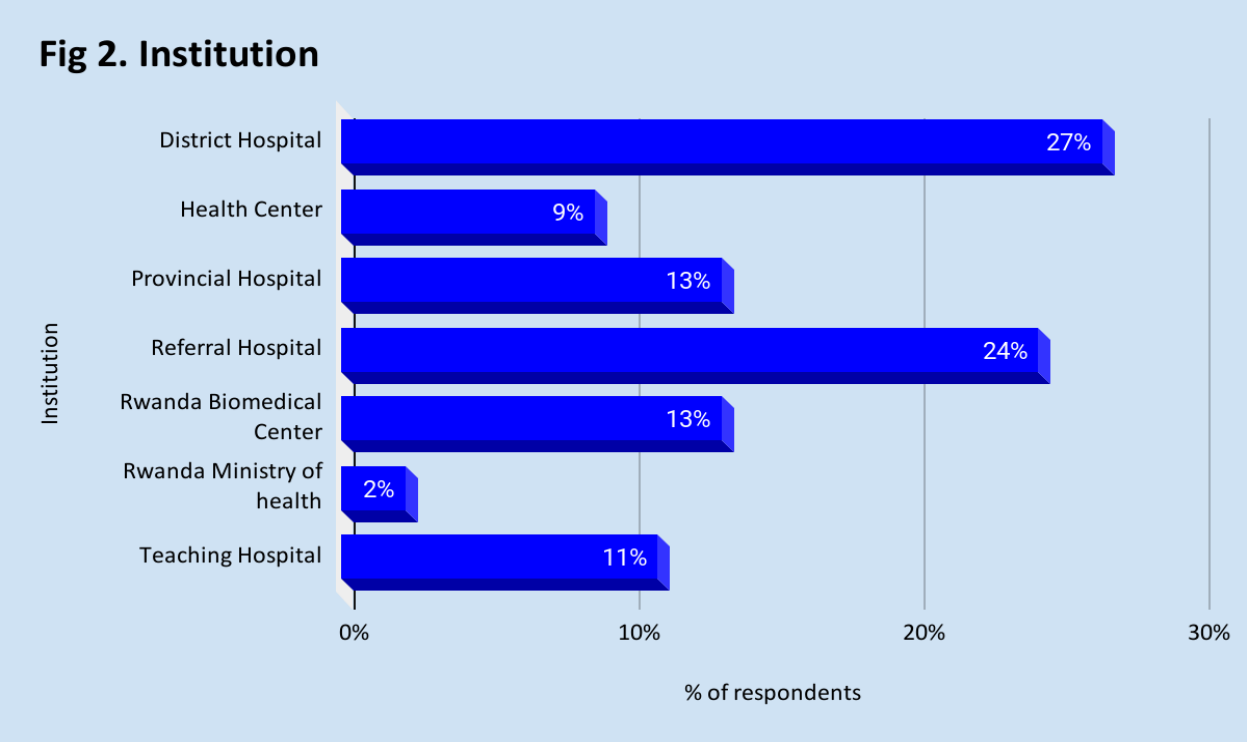

Figure 4.3: Health Institutions

According to the information provided in this study, questionnaires were sent out to a variety of healthcare organisations, including hospitals and health clinics. The institutions that made up the study sample on the use of MEMMs were chosen at random. Twenty-seven percent of respondents worked at district hospitals, twenty-four percent in referral hospitals, thirteen percent in provincial hospitals, and eleven percent in teaching hospitals. 9%, 2%, and 13% of the respondents, respectively, were from health centers, the Rwanda Ministry of Health, and RBC. 27% of my respondents are from district hospitals, followed by referral hospitals with 24% of attendance.

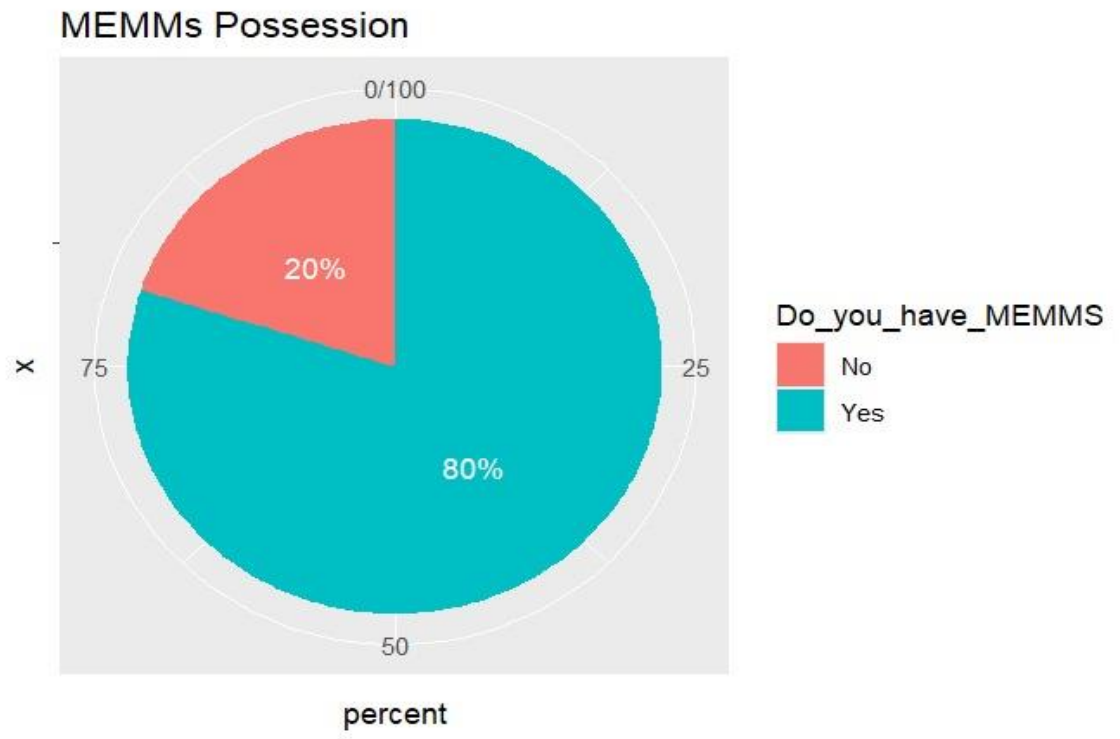

Figure 4.4: MEMMS Usage

According to the figure above, 39 out of 45 respondents from various health institutions reported having MEMMs in their facilities, representing 80% of the sample. However, it is important to note that the mere presence of MEMMs does not necessarily indicate their usage. The subsequent figures will provide further insights into the frequency of MEMMs usage among the respondents. 80% (39 out of 45) of the respondents have MEMMs in their health institutions.

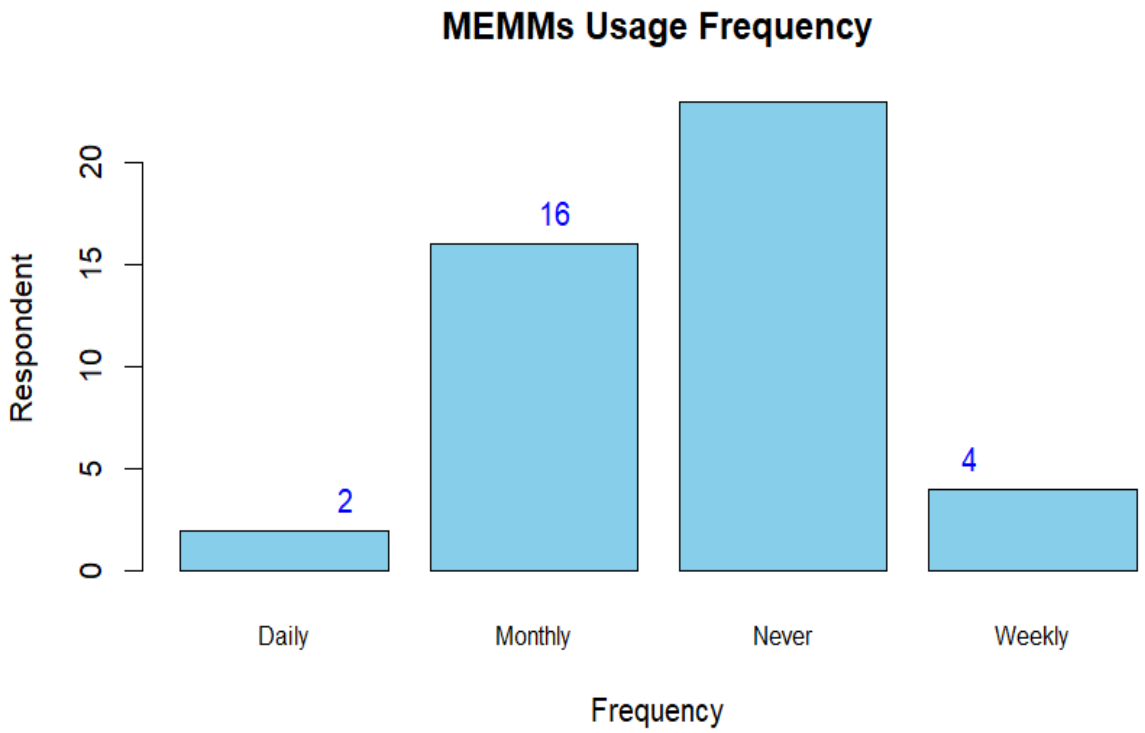

Figure 4.5: MEMMS usage frequency

The Figure 4.5 depicts the frequency of usage of MEMMS among a group of people. The data suggests that the majority of people, 51.1%, have never used MEMMS. A significant number of respondents, 35.6%, reported using MEMMS monthly, while only a small portion, 8.9%, reported using it weekly. The smallest group, 4.4%, reported using MEMMS daily.

The results indicate that the adoption of MEMMS technology is limited among the surveyed group, with the majority of people having never used it. This suggests that either the technology is not widely adopted or that it is not a commonly used technology.

In our research, we examined the professions of the respondents and inquired whether they utilize MEMMs or not.

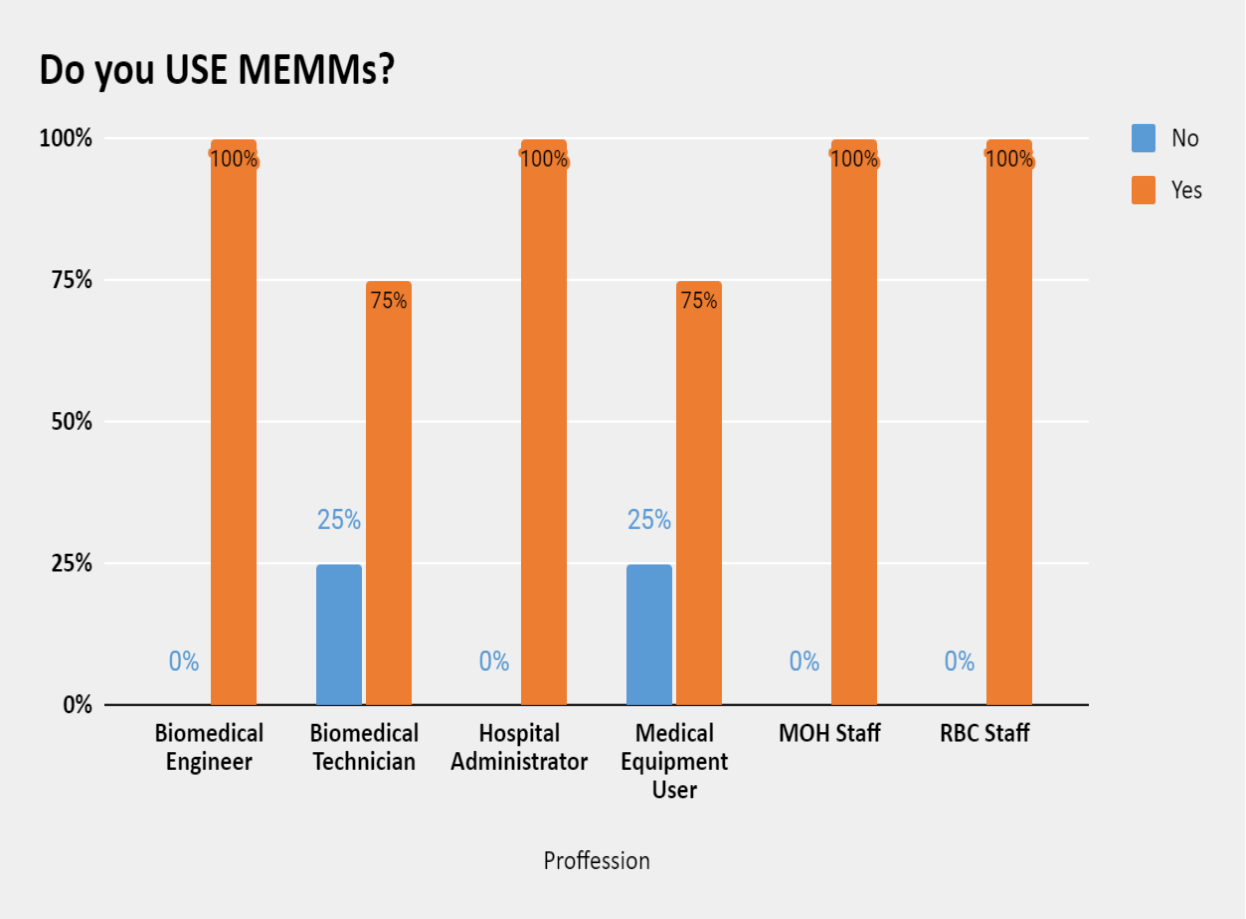

Figure 4.6: MEMMS usage by Profession

The data presented in Figure 4.6 illuminates the predominant utilization of MEMMS across various professions. This visual representation elucidates the profession that extensively relies on MEMMS technology. By analysing the insights provided in Figure 4.5, we can discern the profession that stands out for its significant use of MEMMS compared to others. This information provides valuable insights into the diverse applications and impact of MEMMS within specific professional domains.

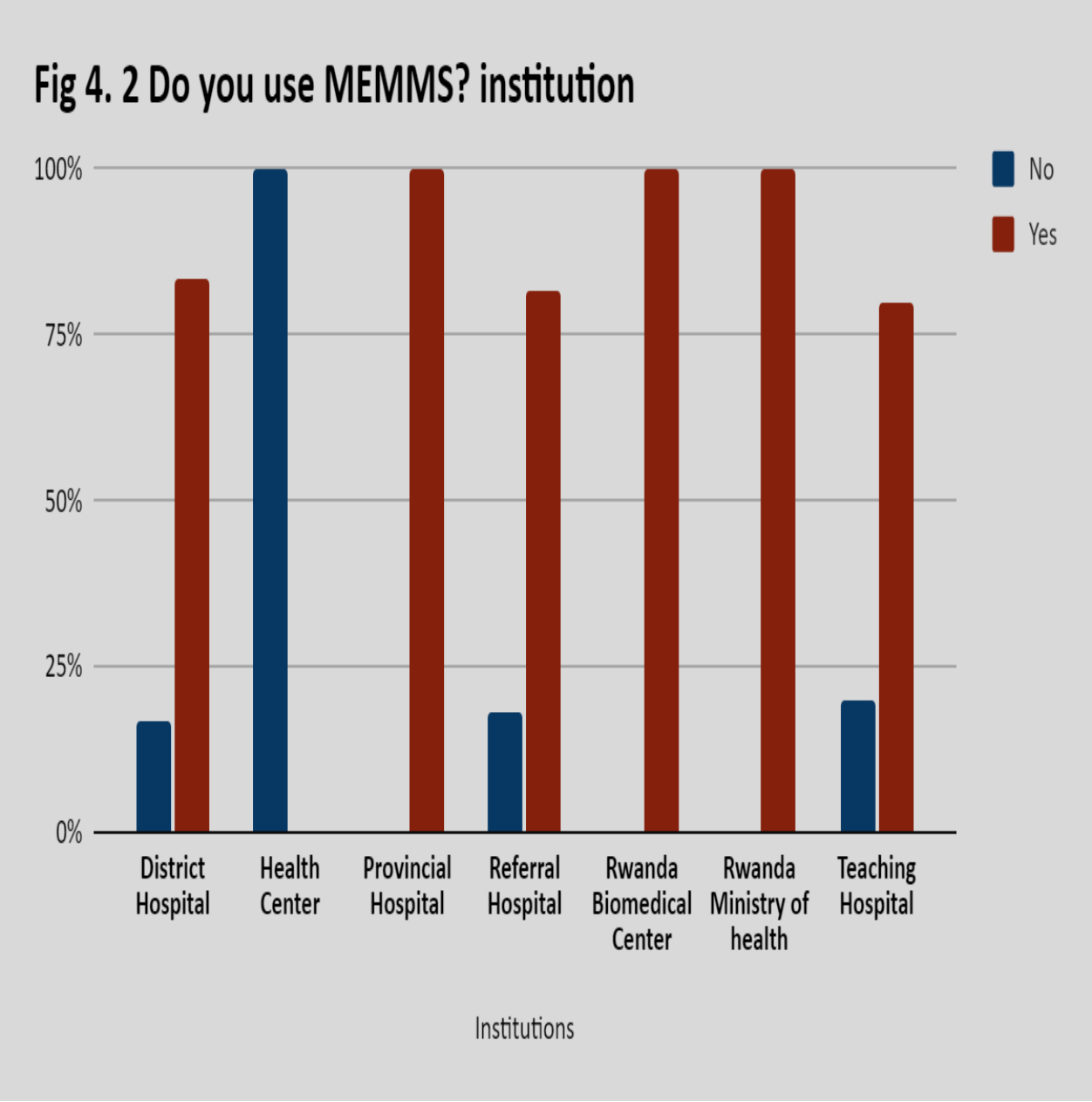

Figure 4.7: MEMMS usage by Health Institution

The figure above shows that MEMMS are more used in district hospitals, Provincial hospitals, Referral hospitals, and Teaching hospitals. Health centers have a huge lack of MEMMS.

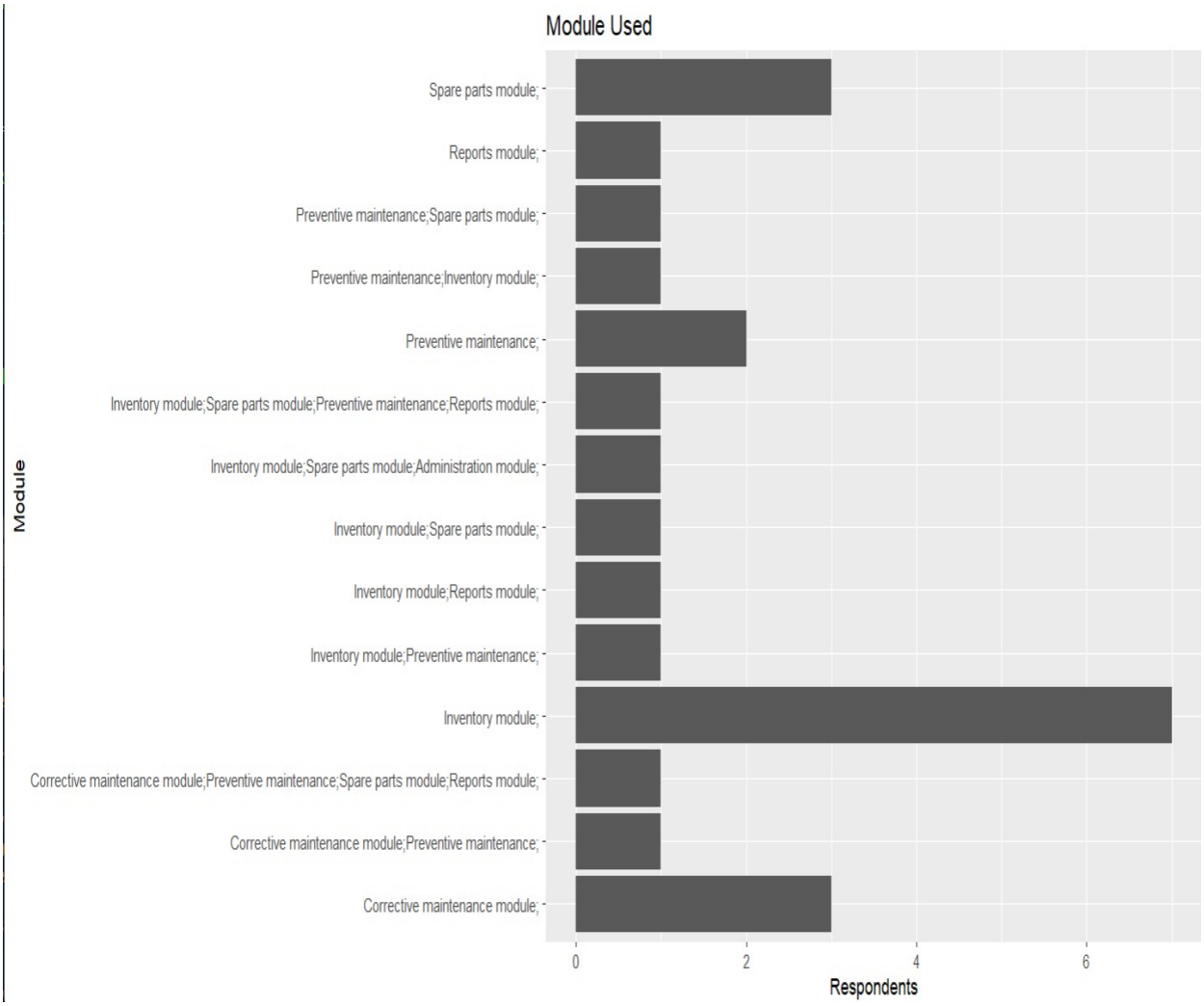

Figure 4.8: MEMMS module used

This figure focuses on the MEMMS module and its utilization across respondents. By highlighting the respondent most frequently interfacing with this module, the figure underscores the prominent role of CMMS within our research framework. This illustration provides a concise snapshot.

4.2. Discussion

This discussion is based on the research question, and the literature review of this research. The question was formulated to understand the adoption rate of the computerized maintenance management system (CMMS) in case of Medical Equipment Maintenance management system (MEMMS) and the factors affecting the usage of the system. This section correlates the results with the research questions and objectives.

4.2.1. Degree of usage of CMMS in Rwanda (MEMMS)

In order to address the research question regarding the extent of CMMS implementation in Rwanda, an assessment of its implementation was conducted, and the results revealed that CMMS, is widely present across various healthcare institutions, with 80% of respondents indicating the presence of MEMMS in their facilities. However, our analysis also revealed that the degree of utilization varies significantly, with a majority of respondents reporting infrequent usage. This suggests that while MEMMS implementation is widespread, its actual utilization remains suboptimal. MEMMS is available to health institutions but the degree of usage of the system is very low. Considering the WHO recommendations, the computerized management maintenance system should be used on daily basis, to achieve efficiency and should be used in support processes, asset management, financial, workload management, unfortunately the results shows that the degree of usage is at low level.

MEMMS should be accessible to all stakeholders who participates in the management of the medical equipment to achieve the optimal usage of medical devices because the results shows that it is mostly accessed by biomedical technicians and it does not help the achieve its full potentiality.

Table 1: Summary of the survey

Category	Details	Responses
Respondent Roles	• Hospital Administrators, • Medical Equipment Users, • RBC Staff, • Biomedical Engineers	• -Hospital Administrator • Biomedical Engineer
Institutions Represented	• Referral Hospitals, • Rwanda Biomedical Center (RBC), • Ministry of Health, • District Hospitals	• - Referral Hospital • RBC

Category	Details	Responses
MEMMS Availability	Most respondents have access to MEMMS	• Yes: Majority
MEMMS Usage Frequency	Varies from never, monthly to daily use	• - Daily: RBC Staff - Never: Many
Challenges of Using MEMMS	Lack of knowledge, lack of skills, system issues	• "I don't know how to use i" • "No skills"
Modules Used in MEMMS	Preventive Maintenance, Inventory, Corrective Maintenance	• Preventive Maintenance • Inventory Module
Effectiveness of MEMMS (1-5)	Varies, most responses are low (1 or 2) with a few higher ratings	• 1: Majority • 4: RBC Staff
Cost Savings	Majority believe MEMMS does not save on maintenance or equipment costs	• No: Majority
Suggestions for Improvement	More training, use of updated tools, improve modules, add automation	• Increase training Use updated tools

Table: Summary of the Findings presents an overview of the key data collected from respondents regarding their experiences and perceptions of the Medical Equipment Management and Maintenance System (MEMMS). The table categorizes the findings into several important aspects:

Respondent Roles: This section outlines the various professional roles of participants, including Hospital Administrators, Medical Equipment Users, Rwanda Biomedical Center (RBC) Staff, and Biomedical Engineers. Understanding the diverse backgrounds of respondents provides context for their perspectives on MEMMS.

Institutions Represented: The table lists the institutions where respondents work, such as Referral Hospitals and the Rwanda Biomedical Center (RBC). This information is crucial for understanding the operational environments and challenges unique to each institution.

MEMMS Availability: It highlights that most respondents reported having access to MEMMS, indicating a generally positive accessibility landscape for the system.

MEMMS Usage Frequency: The table shows varying usage frequencies, from daily use by some RBC staff to infrequent use by others, illustrating the diverse engagement levels with the system.

Challenges of Using MEMMS: Respondents identified significant challenges, such as a lack of knowledge, skills, and system-related issues, which may hinder effective usage of MEMMS.

Modules Used in MEMMS: This section indicates the various modules that users engage with, such as Preventive Maintenance and Inventory, which are critical for effective medical equipment management.

Effectiveness of MEMMS (1-5): The table presents a range of effectiveness ratings from respondents, with most ratings falling on the lower end of the scale, suggesting concerns about the system's performance.

Cost Savings: It indicates that the majority of respondents believe MEMMS does not contribute to savings on maintenance or equipment costs, signalling a potential area for improvement.

Suggestions for Improvement: Finally, respondents provided constructive feedback on enhancing MEMMS, emphasizing the need for increased training, updated tools, improved modules, and greater automation.

4.2.2. Factors that influence the adoption and utilization of CMMS in Rwanda (MEMMS

This research study identified a variety of challenges in implementing Maintenance and Engineering Management Systems (MEMMS) within healthcare facilities in Rwanda, many of which are commonly observed across developing countries. Issues such as staffing shortages, the absence of sufficient training on how to utilize the tool is the primary cause of individuals' lack of proficiency in using it, the utilization of MEMMs is not mandatory and is not seen as a critical component of the procedure. The individuals involved in the process have the freedom to choose whether or not they want to use MEMMs, based on their own discretion. This highlights the fact that while MEMMs may be helpful, it is not considered a necessary step in the process and individuals are not obligated to use it if they do not feel comfortable or confident in doing so. all these challenges present formidable obstacles to sustainable CMMS adoption.

Comparing MEMMS implementation in Rwandan healthcare facilities with international standards and guidelines highlighted both alignment and divergence. While initiatives such as the Global Initiative on Health Technologies (GIHT) underscore the importance of ensuring access to appropriate medical devices and technologies, our findings suggest that MEMMS implementation in Rwanda may not fully meet recommended standards [2].

4.2.3. Strategies to increase the optimal utilisation of CMMS in Rwanda.

A ground-breaking mobile application has been developed to address the unique challenges faced in enhancing the optimal utilization of CMMS within Rwanda's healthcare facilities. In response to identified challenges and the urgent need for improvement, a novel strategy was devised, recognizing the pivotal role of technology in facilitating adoption.

The mobile app serves as a pivotal solution in this strategy, designed to streamline and augment the adoption process of CMMS within Rwandan healthcare facilities. By providing a user-friendly interface and seamless integration with existing CMMS platforms, the innovative mobile application developed in this thesis, has the capacity to revolutionizes maintenance management practices in Rwanda.

Tailored specifically for Rwandan healthcare contexts, the mobile app acts as a user-friendly and intuitive tool, facilitating the adoption and utilization of CMMS within healthcare facilities across the country. This innovative app offers a comprehensive suite of features meticulously crafted to streamline maintenance management processes and enhance operational efficiency.

Key features of the mobile application includes:

- **Seamless Integration:** seamlessly integrates with existing CMMS platforms, ensuring a smooth transition and compatibility with current systems. This ensures that healthcare facilities can leverage their existing infrastructure while benefitting from our advanced features.

- **Mobile Record of Preventive Maintenance Data:** enables users to conveniently record preventive maintenance data on the go. With our mobile solution, healthcare professionals can easily schedule, track, and manage preventive maintenance tasks, enhancing equipment reliability and prolonging lifespan.

- **User-Friendly Interface:** With an intuitive interface, mobile app simplifies the process of data recording, inventory management, and maintenance scheduling, empowering users with efficient tools at their fingertips.
- **Mobile Record of Corrective Maintenance Data:** Streamline corrective maintenance processes the mobile app provides a mobile platform for recording and managing corrective maintenance data, enabling swift identification and resolution of issues to minimize downtime and optimize operational efficiency.
- **Inventory and Spare Part Module**: Keep track of medical equipment records effortlessly with the mobile application's dedicated inventory and spare part module. Our intuitive interface allows users to manage inventory levels, track usage, and maintain accurate records of spare parts, ensuring uninterrupted healthcare services.

Figure 4.9: Initial user interaction

Figure 4.9 illustrates the initial user interaction, specifically the entry or login process, within the mobile application.

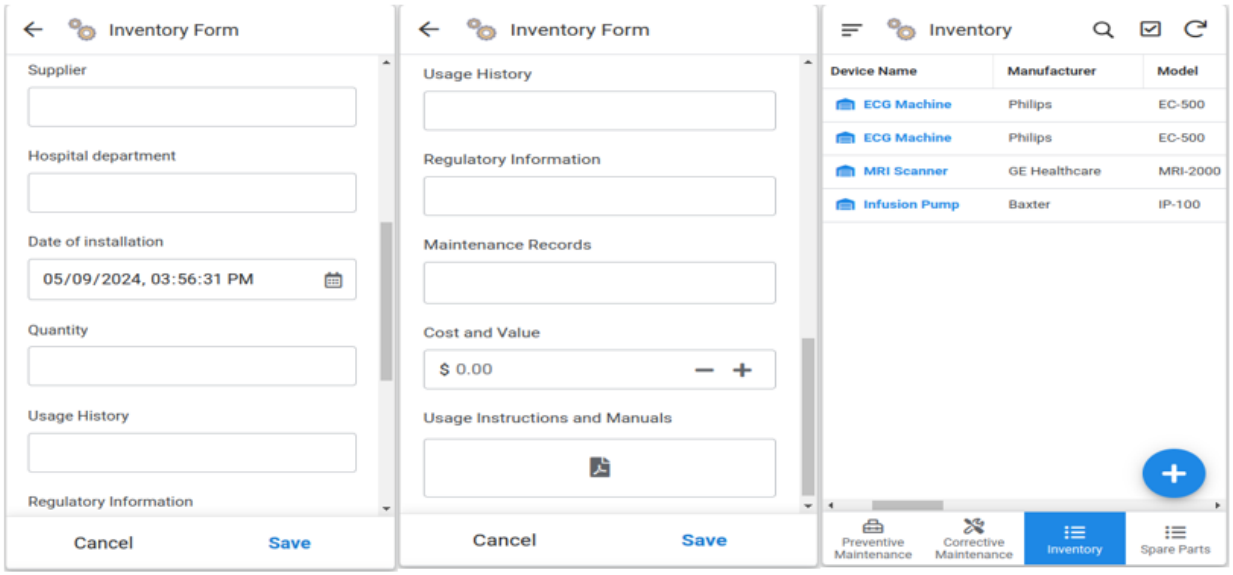

Figure 4.10: Inventory module

The Figure 4.10 illustrates the inventory module within the module application developed as part of this research endeavour. The depicted screenshots present a comprehensive inventory listing, showcasing the available items within the system. Furthermore, the images demonstrate the process of recording new items, highlighting the functionality and user interface design of the inventory management component within the application.

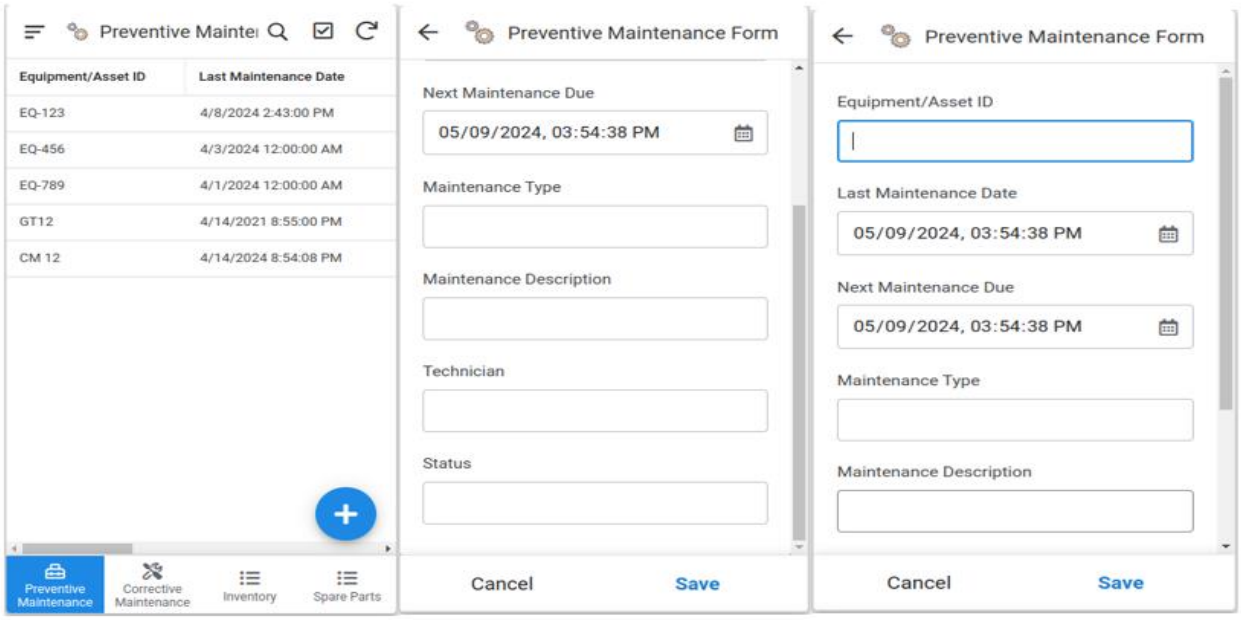

Figure 4.11: Preventive Maintenance Module

The figure 4.11 presents the preventive module screenshots, depicting the recording of detailed preventive maintenance information. The images also display a historical log of completed preventive maintenance tasks, indicating the schedule for future maintenance activities.

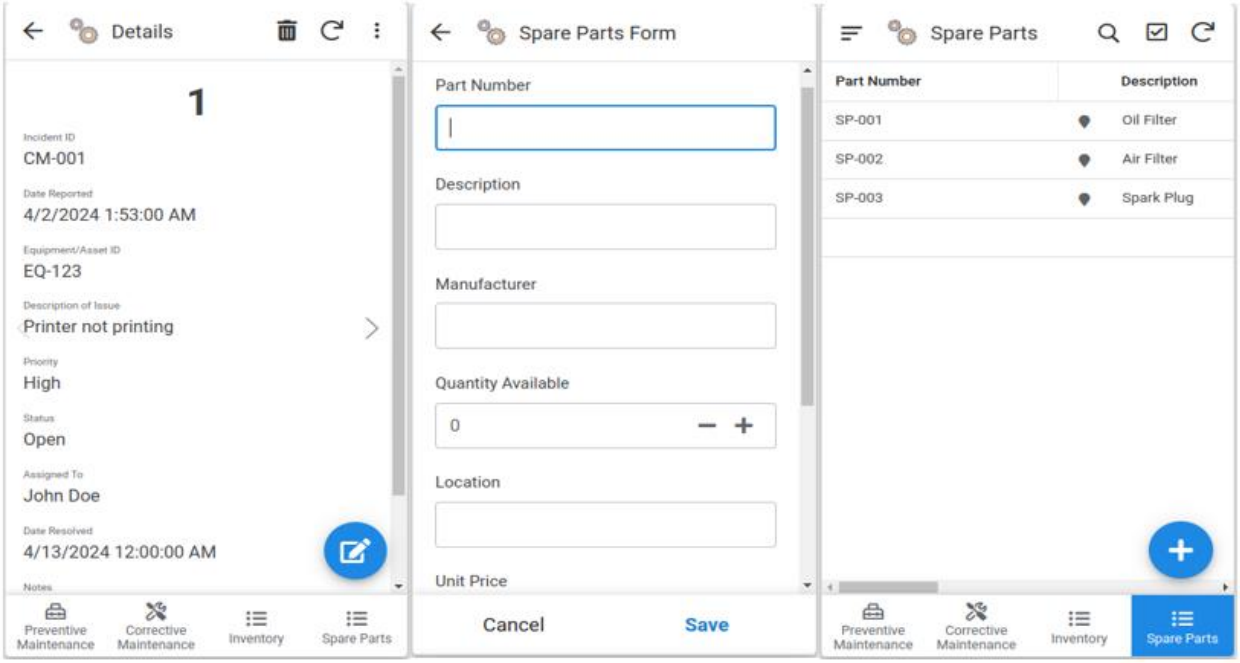

Figure 4.12: Spare Parts Module

The figure 4.12 displays the spare parts module, providing a comprehensive view of the spare parts inventory management system. This module allows users to record and access essential information related to spare parts.

The mobile application developed in this thesis serves as a pivotal solution in the strategy to streamline and augment the adoption of Computerized Maintenance Management Systems (CMMS) within Rwandan healthcare facilities. Designed to provide a user-friendly interface and seamless integration with existing CMMS platforms, particularly the Medical Equipment Management and Maintenance System (MEMMS), this app has the potential to revolutionize maintenance management practices in Rwanda. By enabling healthcare professionals to easily access and manage maintenance workflows, the app addresses key challenges in healthcare infrastructure management; ensuring facilities remain operational and efficient.

The primary goal behind the development of this mobile application was to create a tool that facilitates the adoption of CMMS systems, specifically within the context of Rwandan healthcare facilities. By integrating directly with the existing MEMMS web application, the app allows healthcare staff to manage maintenance tasks in a streamlined and user-friendly manner. This approach simplifies the process of monitoring equipment, scheduling maintenance tasks, and ensuring that all critical equipment is serviced in a timely manner, thereby enhancing operational efficiency.

In addition to native mobile functionality, the app incorporates a **web view option** to provide access to the **MEMMS web platform** directly from within the mobile application. This feature enables:

- **Real-Time Data Synchronization**: Users can view up-to-date reports, equipment status, and maintenance tasks from MEMMS, ensuring they have access to the latest information.
- **Flexibility and Adaptability**: The web view integration ensures that any updates made to the MEMMS web platform are immediately reflected in the mobile app without requiring users to update the app itself.

By combining native mobile functionality with the existing MEMMS web platform through a web view, the app provides a hybrid solution that meets the needs of healthcare facilities while allowing for continuous updates to web-based services without disrupting mobile functionality.

This mobile app is specifically designed to meet the unique needs of **Rwandan healthcare facilities**, ensuring that it acts as a **user-friendly and intuitive tool** for the **adoption and utilization of MEMMS**. The app provides a **comprehensive suite of features** that are tailored to improve **maintenance management processes** and ensure operational efficiency within healthcare environments.

The integration with MEMMS is a key component of this app's success. By bridging the gap between a fully functional mobile tool and a well-established web platform, the app ensures that **healthcare staff, biomedical engineers and technician can manage tasks on the go**, contributing to the overall **improvement of healthcare services** in Rwanda.

The mobile app uses a **hybrid architecture** combining native mobile components with a **web view-based integration with MEMMS**. This allows for:

- **Native Features**: Managing tasks such as authentication, notifications, and offline access to locally stored data.
- **Web view for MEMMS**: Real-time synchronization with the MEMMS web application for tasks like equipment management and maintenance schedules.

This architecture ensures that the app not only leverages the strengths of native mobile capabilities but also fully integrates with the **existing MEMMS platform**, offering healthcare professionals a **comprehensive maintenance management tool**.

By integrating with the **MEMMS web application**, the mobile app greatly enhances the ability of healthcare facilities to **digitize and streamline their maintenance processes**. The app's integration with MEMMS ensures:

- **Improved Real-Time Management**: Users can access and update equipment maintenance tasks in real-time, resulting in faster response times for equipment repairs and maintenance.
- **Reduced Downtime**: The app helps minimize equipment downtime by ensuring that maintenance is tracked, scheduled, and completed efficiently.

This integration ensures that the mobile app is not only a stand-alone tool but a vital part of the broader **Rwandan medical maintenance management ecosystem**.

The mobile application developed in this thesis plays a vital role in facilitating the adoption and implementation of CMMS within Rwandan healthcare facilities. By providing a user-friendly interface and intuitive design, the app empowers healthcare workers to manage maintenance tasks more effectively, positioning it as a transformative tool for ensuring optimal maintenance of healthcare infrastructure in Rwanda. Although the mobile app has not yet been integrated with the MEMMS web platform, there is significant potential for a hybrid solution that streamlines maintenance management processes and enhances operational efficiency.

Looking ahead, future improvements will focus on enhancing the app's offline capabilities, ensuring uninterrupted access to key functionalities even without internet connectivity. Additionally, an open API will be developed to facilitate seamless integration between the mobile application and MEMMS, allowing for better data exchange and a more scalable integration. Plans also include extending the app's availability to iOS users, broadening its accessibility and impact across different mobile platforms.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this study aimed to evaluate the usage of MEMMs in Rwanda. Through the data collection and analysis process, it was found that the primary reason for individuals not being able to effectively use MEMMs was due to a lack of proper training. This highlights the importance of investing in training and development for new technologies to be utilized effectively.

While the use of MEMMs is not currently mandatory, the study recommends that opportunities for training be increased and that the use of MEMMs be made mandatory, along with adding more modules. This will help ensure that everyone can effectively use the tool and realize its benefits. The use of MEMMs has the potential to streamline processes and improve efficiency and accuracy in various industries and sectors, including the health system.

Additionally, the endorsement of international organizations such as the World Health Organization (WHO) for the use of MEMMs further highlights its potential impact. By following such recommendations and investing in proper training and development, Rwanda can fully leverage the benefits of MEMMs and enhance the efficiency and effectiveness of its health system. The conclusion of this study emphasizes the importance of investing in proper training and development for new technologies to be utilized effectively and to enhance the overall efficiency and effectiveness of various industries and sectors.

It is crucial for organizations to invest in the training and development of new technologies in order to stay competitive and to effectively utilize these tools to achieve their goals. The conclusion of this study highlights the importance of investing in proper training and development for MEMMs usage in Rwanda, and it is recommended that organizations take this into consideration when implementing new technologies. By doing so, they will be able to fully leverage the benefits and make a positive impact on their operations and the industry as a whole.

5.2 Recommendation

In recent years, the use of technology has become increasingly important in various industries and sectors, including the health system.

One such technology is MEMMs (Medical Equipment Management and Maintenance System), which has been evaluated in Rwanda through the findings of this study. The study aimed to understand the usage of MEMMs in Rwanda and the challenges faced by individuals in effectively utilising the tool.

The study found that the lack of proper training was the primary reason for individuals not being able to effectively use MEMMs. This highlights the importance of investing in training and development for new technologies to be utilised effectively. The study recommends that opportunities for training be increased and that the use of MEMMs be made mandatory, along with adding more modules. This will help ensure that everyone can effectively use the tool and realise its benefits.

Additionally, the recommendation can be further enhanced by emphasising the role of mobile applications, such as the "Easy Access" app developed by Dr. Horatius Munyampundu in Rwanda, in improving and increasing the usage of MEMMs. This innovative mobile app allows patients to book appointments with doctors quickly and efficiently through SMS, reducing the time and cost associated with securing appointments. The success of this mobile application showcases the potential for user-friendly and accessible technologies to facilitate the adoption and utilization of healthcare technologies like MEMMs.

By incorporating the mobile app's success story into the recommendation, it can be highlighted that user-friendly and accessible technologies, like mobile apps, play a crucial role in overcoming barriers to adoption, such as lack of training. The ease of use and convenience offered by mobile applications can complement the implementation of tools like MEMMs by providing a user-friendly interface and improving overall engagement with the technology.

It is recommended that organizations take this study's conclusion into consideration when implementing new technologies. Investing in proper training and development, as well as integrating user-friendly mobile applications, is crucial for organizations to stay competitive and effectively utilize new technologies to achieve their goals. By doing so, they will be able to fully leverage the benefits of MEMMs and make a positive impact on their operations and the industry as a whole.

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APPENDICES

Appendix 1: Questionnaire used in data collection

Optimal Utilization of CMMS for Medical Equipment in Rwanda, case of MEMMS

Dear Sir/Madam,

I am Mick Ganza, a final year student in University of Rwanda in Center of Excellence in Biomedical Engineering and E-Health, and I am conducting a research entitled **Optimal Utilization of CMMS for Medical Equipment in Rwanda, case of MEMMS.** For me to understand the current usage and impact of computerized maintenance management systems (CMMS) in Rwanda by conducting an in-depth analysis of the current MEMMS adoption rate, the specific CMMS solutions being used, the challenges faced by organizations in implementing and utilizing CMMS, and the overall impact of CMMS on the efficiency and performance of maintenance operations in our country, you are selected as a person to participate in this research and the filling of the questionnaire will take you maximum five minutes.

1. **What is your professional role?**
   - Hospital Administrator
   - Biomedical Engineer
   - Biomedical Technician
   - Medical Equipment User
   - RBC Staff
   - MoH Staff
   - Other
2. **Which institution do you work for?**
   - Rwanda Ministry of Health
   - Rwanda Biomedical Center
   - Referral hospital
   - Provincial Hospital
   - District Hospital
   - Health Center
   - Teaching Hospital

3. **Do you have MEMMS (Medical Equipment Maintenance Management System)?**
   - No
   - Yes
4. **If you have MEMMS, how often do you use it?**
   - Daily
   - Weekly
   - Monthly
   - Never
5. **Which module do you use? (Multiple selections allowed)**
   - ❖ Inventory module
   - ❖ Corrective maintenance module
   - ❖ Preventive maintenance module
   - ❖ Spare parts module
   - ❖ Reports module
   - ❖ Administration module
6. **What are the challenges of using MEMMS?**
   - I don’t know how to use it
   - I don’t have internet
   - I don’t have a computer
   - I don’t have electricity
   - Other
7. **At which level MEMMS helps you at work? (1 is the lowest and 5 is the highest)**

1	**2**	**3**	**4**	**5**

8. **In which activity do you use MEMMS? (Multiple selections allowed)**
   - ❖ Planning (inspection)
   - ❖ Maintenance (CM & PM)
   - ❖ Healthcare Technology Assessment
   - ❖ Generate Reports
   - ❖ Spare parts database
   - ❖ Monitor medical Equipment Performance

- ❖ Monitoring Clinical Engineer Performance
- ❖ Documentation (Library)
- ❖ Contract Management
- ❖ Getting Notification
- ❖ Other

9. Does MEMMS save maintenance, equipment costs?

- o Yes
- o No

10. How MEMMS can be improved to be effective?

Enter your answer:

Appendix 2: R programming IDEA, R studio.