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Medical Equipment Maintenance Management optimization for hospitals performance improvement

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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.

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Declaration

I, Angelique NIYONAGIZE, declare that this dissertation entitled "**Medical Equipment Maintenance Management Optimization for hospitals performance improvement**" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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Certification

This is to certify that the project entitled "**Medical Equipment Maintenance Management Optimization for Hospitals Performance Improvement**" is a record of original work done by Angelique NIYONAGIZE (Reference number: 215026640), a MSc degree student in Biomedical Engineering.

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ABSTRACT

Medical equipment makes a significant contribution to the effectiveness and quality of healthcare services. In general, medical equipment malfunctions and is unavailable in healthcare facilities, affecting the delivery of healthcare services to the general public. The problems are frequently caused by the responsible party's failure to manage and maintain the medical equipment's condition. To improve availability, performance, and safety, an assessment of the medical equipment condition was an important activity during the maintenance and management of the equipment life cycle. The goal of this study was to identify gaps in the administration of medical equipment and its maintenance, as well as to provide solutions to such problems. For this analysis, all data were collected from hospitals and the organization's maintenance department. 77 Biomedical personnel from 25 different hospitals or organizations were cross-examined via questionnaires. Equipment condition, inventory, maintenance, education and training, information bank and physical resources are important areas that were focused during the study. It helped clinical engineers in determining the reliability of medical equipment used in healthcare facilities, as well as contributing to providing effective healthcare to the public. At the conclusion of this study, recommendations for further work were offered.

Keywords: Medical equipment; physical resources**;** equipment condition; Value of equipment; inventory; education and training.

LIST OF ACRONYMS

A:	Availability
BMETs:	Biomedical Equipment Technicians
CBM:	Condition Based Maintenance
CM:	Corrective Maintenance
CM:	Corrective Maintenance
CMMS:	Computerized Maintenance Management System
CT:	Computed Tomography
EC:	Equipment condition
ET:	Education and Training
FMEA:	Failure Mode and Effect Analysis
FR:	Failure Rate
FR:	Failure Rate
HSS:	Hospital Support Services
HTM:	Healthcare technology management
I:	represents the Inventory
IPM:	Integrated pest management
MRI:	Magnetic Resonance Imaging
MTBF:	Mean Time Between Failures
MTBF:	Mean Time Between Failure
MTTR:	Mean Time to Repair
MTTR:	Mean Time to Repair
OEM:	Original Equipment Manufacturers
PHM:	Proportional Hazards Model
PM:	Preventive maintenance
Pr. M:	Predictive Maintenance
PR:	Physical resources
RBC:	Rwanda Biomedical Center

RCM: Reliability-Centered Maintenance

SPSS: Statistical Package for Social Sciences

TPM: Total Productive Maintenance

VE: Values of equipment

WHO: World Health Organization

β: Beta coefficient

ε: Error Margin

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CHAPTER 1. GENERAL INTRODUCTION

1.1. Introduction

Modern medical technology is growing increasingly complex and smart. A lot of support services are made to effectively handle the equipment in a hospital to ensure reliability and safety of medical equipment. One of these services is the maintenance service**.** A maintenance plan is one method of carrying out a maintenance strategy that keeps medical equipment in a healthcare facility reliable, safe, and usable. Preventive maintenance (PM) of medical equipment is performed at predetermined intervals (Time-based maintenance) or when a condition variable crosses a certain limit (Condition-based maintenance). The goal of preventive maintenance interventions is to reduce the likelihood of equipment becoming non-operational and to achieve maximum availability**.** According to the findings, the most serious issue in developing countries is not a shortage of medical equipment, but rather the fact that more than half of the equipment are non- operational due to lack of spare parts, Lack of medical equipment Consumables and Lack of trained technical staff**.** Therefore, it is vital to arrange maintenance activities by assuring proper equipment functioning (e.g., availability, dependability, and patient satisfaction), as well as maintaining maintenance cost efficiency and resource utilization (staffing and tools) (Ameriyoon, 2006).

According to Campbel, (2019), there are three main service and support options for medical equipment maintenance: in-house biomedical maintenance, Original Equipment Manufacturers (OEM), and independent third-party service provider (with or without contracts). The decision makers decide whether maintenance tasks should be performed in-house or outsourced, with or without a service contract, based on the criticality of the equipment and the maintenance department's available budget. Different countries have different forms of contracts for hospitals (Tong, 2020).

The type of medical equipment used in any hospital can be generally classified into biomedical, laboratory, ward; service support, utilities and hospital furniture. This study will focus on the maintenance strategy of selected critical-high risk bio-medical equipment: specifically, the kidney dialysis machine, anesthesia machine, defibrillator, diathermy and cardiac catheterization machine. Elements of Reliability-Centered Maintenance will be used to analyze the current maintenance strategies used on the selected critical medical equipment. These elements include quantitative and qualitative reliability analysis, both of which affect the operation of the equipment (Wang *et al.* 2014). The quantitative analysis of reliability will be established through

the calculation of the equipment's availability, Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Failure Rate (FR) (Nasiripour *et al.* 2019). Qualitative analysis is used to examine the various 'modes and causes' of failure and unreliability (Murthy *et al.* 2002; Tsantis and Apostolakis 2014).

This study intends to assess medical equipment maintenance management optimization towards hospital performance improvement, It sought to identify challenges and to propose solutions for medical equipment maintenance may bring Hospital effectiveness and efficiency.

1.2. Background of the study

Maintenance is an important aspect of medical equipment's life cycle. It is made up of two categories of activities: ordinary (i.e., scheduled maintenance) and extra-ordinary, both included in the medical equipment maintenance activities of all hospitals. The first consists of operations carried out at specified intervals in order to reduce the likelihood of a function failing or degrading (preventive maintenance), as well as to check compliance with the manufacturer's essential safety criteria and performance specifications. Repairs, or restoring equipment to a needed function (corrective maintenance, CM), or replacements, when fixing is not practicable or cost-effective. Maintenance is also an important element of a Biomedical Engineering department's activities because it requires a lot of resources, both human and financial (Painter, 2010).

The purpose of medical equipment is to be of assistance in the diagnosis, monitoring and even the treatment of patients' medical conditions (Kumar and Srinivas 2014; Polisena *et al.* 2014). Medical equipment can be classified according to its use: critical, important or necessary, and also the risk its unavailability poses to patient outcomes: high, medium or low (Khalaf *et al.* 2013; Wang 2007; Wang and Levenson 2000).

Maxwell (1985) has established that in an organization, improving maintenance performance leads to increasing productivity, quality, safety and improving the environment. It has been shown that effectiveness and efficiency are the elements used to evaluate and improve processes or productivity Jamshidi *et al.* 2014; Halbwachs *et al.* 2012), and reduce unnecessary expenses that affect the total ownership costs for capital equipment (Downe and Kintner 2014).

Although progress has been made in Africa, medical equipment shortages continue to be a major issue in hospitals. Medical Equipment Unavailability in Africa is primarily caused by high capital costs, a lack of financing option, and poor service support (lack of expert biomed, spare

parts, and training). Furthermore, the great majority of African health institutions lack access to high-quality life-saving medical devices[4].

In Rwanda, findings show that the health sector was of poor quality in general, including biomedical engineering and HTM, but that this has improved dramatically in recent decades. Rwanda has a universal health-care system and is considered to have one of the best health-care systems in Africa[5].

The Rwanda Biomedical Center (RBC) is tasked by the Ministry of Health with ensuring that health institutions have working equipment and that infrastructure is maintained and extended to improve geographical accessibility and quality health care services for the people. However, there have been some issues with equipment management. Various assessments and audit reports undertaken in health facilities and at the Ministry of Health have expressed concerns about poor medical equipment management.

1.3. Statement of the problem

Research shows that in developing countries the absence of spare parts, lack of medical equipment consumables, dearth of trained technical staff is remaining challenges and obstacles that keep 50% of medical equipment from not working (Dyro, 2018).

In fact, Lack of medical equipment Consumables like liquids or supplies required for the use of equipment causes some equipment to fail to perform as expected. Lack of trained technical staff is the most difficult factor that causes medical equipment to remain in downtime for so long. Modern medical equipment often requires highly skilled technicians to operate and maintain them but in developing countries we still lack trained technical personnel capable of maintaining medical equipment. Therefore, this study assessed the medical equipment maintenance management optimization for hospital performance improvement.

1.4. Study Objectives

The objectives of this study are as follows:

1.4.1. General Objective

The general objective of this study is to find out how and to which extend medical equipment maintenance management optimization may improve hospital performance.

1.4.2. Specific Objectives

(i) To assess factors of medical equipment management optimization

(ii) To identify challenges during equipment maintenance and mitigation

(iii) To analyze the level of hospital performance improvement

(iv) To find out relationship between constructs of this study.

1.5. Hypothesis development

This project will be based on optimization of medical equipment maintenance.

Research questions of this project are the following:

- What is the performance level of selected hospitals in Rwanda?
- What are the factors to consider when performing maintenance**?**
- Is there any correlation between medical equipment maintenance management optimization and Hospital performance improvement?

Based on above research questions, the following hypothesis were formulated:

Medical equipment should be maintained at a higher safety level than other types of equipment. Most of sophisticated and complicated machines found in the intensive care unit, have their electrical connection existing between the equipment and patient. The equipment may be used on the patients who are not able to respond to hazardous conditions or pain while other types of medical equipment function as life support and their failure may result in the patient's death when the machine is in use.

H_1: Education and training have a positive effect on medical equipment maintenance management towards medical performance.

H_2: Equipment condition factor has a positive effect on medical equipment maintenance management just before medical performance

Indeed, equipment may be used until repairs are no longer possible. It is important, therefore, that original parts are available so that the facilities maintenance organization can use the correct parts when repairing devices (Ameriyoon et al, 2007). The number of overdue patients and length of waiting time represent measures of hospital performance in the provision of health care services. Better management of hospital services could help patients avoid the experience of an excessive wait for booked treatment. Improved quality of life may be achieved more quickly, as well as gaining patient satisfaction and community confidence in the health system

H_3: Inventory factor has a positive effect on medical equipment maintenance management.

In the field of medical equipment maintenance management, there is no single and standard checklist that includes all hospitals in the country. The only available checklists include accreditation measures that generally assess the tasks and activities of the medical engineering

unit. Since the issue of maintenance management includes a wide variety of topics, and in the low- and middle-income countries, there is major weakness in this regard, so we decided to design a checklist for uniformity and accurate and comprehensive assessment using Iranian context. The Departments of Medical Equipment of some provinces in Iran have designed a checklist natively for its affiliated hospitals, the dimension and method of which are different. For example, the maintenance management evaluation checklist of Tabriz Medical Equipment Office includes 15 indicators (technical force, medical engineering unit, medical equipment ID, quality control tests, PM, training, medical equipment and spare parts storage, service and maintenance contract, the existence of purchase process, the existence of decommissioning process, the existence of recall system and reporting of adverse events, ensuring sound electricity, implementing a continuous maintenance improvement process, familiarizing with the general administration's rules and website, management and allocating a separate budget for maintenance).

H_4: Physical resources factor has a positive effect on medical equipment maintenance management.

The facility maintenance managers should ensure that the equipment is safe to use and complies with all required standards. Equipment should meet the specified performance criteria and should not be damaged. They should also match with the order and arrive complete with specified accessories. Equipment should be placed on a routine maintenance program and the maintenance personnel must be trained and conversant with its use and servicing arrangements.

H_5: Value of equipment has a positive effect on medical equipment maintenance management.

Knowing the value of equipment is a key to maintenance management, the maintenance and its management constitute a checklist that ensures the equipment performance. There exist four criteria in which the hospitals coincide that they should improve, even though each of them in different measure and sub-criterion. These criteria are an organization of maintenance; human resources; planning, programming and control of the maintenance and corrective maintenance. These criteria are among the sub-categories of maintenance management assessment checklists.

1.6. Study Scope

The study was conducted in 2022 to optimize medical equipment maintenance management in Rwanda. A survey was carried out in 2 months to collect data from 20 hospitals across the country and 4private companies that supply and maintain medical equipment in Rwanda.

1.7. Significance of the study

The significance of this research can be summarized as follows:

- This study provides dimensions which can support selected hospitals and organizations to optimal maintenance policies for the use of critical medical equipment currently in use by detecting the gaps in the performance of maintenance activities. Importantly, it will determine the factors that lead to an increased incidence of failure and the time spent on repairs.
- Reliability-Centered Maintenance will be investigated to succor hospital administration to make a decision on whether to either adopt the proposed maintenance strategy or maintain the current one. It provides a scientific standard to enable the hospital to make an informed choice between repairing or replacing the critical medical equipment
- The maintenance strategy proposed in this study will show how a hospital can rely on its own staff to repair critical medical equipment rather than rely on external maintenance companies. This work will consider whether an area of maintenance strategy known as RCM which involves equipment operators and owners optimizing availability and the reliability may be the best approach.

1.8. Contribution of the study

This study contributes to the development of appropriate maintenance strategies by conducting an analytical study that examines recognized factors of measurement and linking them to hospital performance using appropriate statistical methods. The findings will provide hospitals with information about how the quality of maintenance strategies used impacts on their competitive advantage and ability to achieve strategic objectives.

1.9. Organization of the Study

This study is divided into of five chapters; Chapter1 is General introduction it covers background of the study, statement of the problem, objectives of the study, research question and Hypothesis development scope and organization of the study. Chapter 2 named literature review encompasses definition of key concepts, overview of medical equipment maintenance management optimization, overview of hospital performance, related literature of this study and research gap. Chapter 3 entitled Research Methodology, it comprises population and sampling technique, data collection instruments, method of data analysis, and research model. Chapter 4 is Results and Analysis, it consists of findings from data collected and analyzed. Chapter 5 termed conclusion and recommendation, it provides conclusion and recommendations based on discussion made in chapter 4, and so far, suggestion for further research.

1.10. Summary

General introduction provides the background of the study and its main contribution, lack of trained technicians and biomedical engineering, Lack of medical equipment Consumables like liquids or supplies required for the use of equipment causes some equipment to fail to perform as expected have been identified as main statement of the problem that caused the researcher to conduct this study. Specific objectives like assessment of factors of medical equipment management optimization, identification of challenges during equipment maintenance and mitigation, analysis of the level of hospital performance improvement and to find out relationship between constructs of this study followed by research question and Hypothesis development, the academic, time and geographical scope of the study have been stated and finally this chapter provided the entire organization of the study

CHAPTER 2. RELATED LITERATURE

The second chapter developed for related literature, it comprises definition of key concepts, overview of medical equipment maintenance management optimization, overview of hospital performance, related literature of this study and research gap.

2.1. Definitions of key concepts

This part provides description of crucial conception such as medical equipment; physical resources**;** equipment condition; Value of equipment; inventory; education and training.

2.1.1. Medical equipment

Medical equipment also known as “Armamentarium” and is designed to help in the diagnosis, monitoring or treatment of medical conditions. Instinctively, medical equipment is a common diagnostic equipment used in Hospital and clinics such as Imaging Machines like X-ray, MRI Scans, CT scans, and medical instruments like Stethoscopes and Thermometers (Ameriyoon, 2014).

2.1.2. Physical resources

Maintenance management relies on physical resources. These include workspace, tools and test equipment, supplies, replacement parts, and operation and service manuals needed to perform maintenance mechanisms. Workspace is one of the main factors in MEMM. The participants harbored these notions that lack of workspace for repair and maintenance of medical equipment is a great issue. Moreover, they stated that providing a safe and healthy work environment for staff and patients is required (Bracale, 1994).

Various tools and test equipment are required to perform maintenance activities, depending on the type of equipment in service. Some participants expressed that the existence of some facilities such as computers, printers and types of software are essential for the unit of biomedical engineering.

A maintenance program depends on a number of physical resources. These include the workspace, tools and test equipment, supplies, replacement parts, and operation and service manuals needed to perform maintenance. Each of these should be taken into account separately when developing a maintenance program, as follows:

a. Workspace

The site where maintenance will be performed should be taken into account when organizing the program. A tidy and well-organized workspace is a good workspace. It gives access to utility systems that the equipment needs as well as sufficient lighting (electricity and medical gases, for example). It includes work benches and storage space for tools and test equipment, repair parts and supplies, and equipment awaiting repair. It also includes space for records and documentation, service and operator manuals, and access to whatever computer resources are required.

Inclusion of computer resources in the workspace is also important to consider. Basic documentation may be maintained with paper records but the use of a computer spreadsheet, database programme, or computerized maintenance management system (CMMS) supports good record-keeping, performance monitoring and performance improvement. Additionally, when internet access is available, it can be a valuable resource. Many technical resources are available online at little or no cost, and online educational programmes may be an option to further technical knowledge and facilitate training.1 Furthermore, inexpensive voice communication and e-mail communication enable effective collaboration across wide distances. However, where internet communication is unreliable, keeping in touch by mobile phone can be an effective alternative. The clinical engineering workshop is typically found within the facility itself, but if the programme includes multiple facilities, it may be more economical to establish a centralized repair depot (Bracale, 1994).

b. Tools and test equipment

Without the proper tools and test equipment, the productivity of biomedical equipment technicians (BMETs) will be constrained. It should be highlighted that investing in tools and testing equipment leads to lower maintenance expenses when purchases are scheduled**.** In addition, having the right equipment will greatly increase the reliability of the readings, the accuracy of the calibrations, and the margin of safety for the patients and staff, as well as the efficiency of the staff doing the maintenance (Duffuaa, 2012).

c. Supplies

These primarily consist of cleaning and lubricating supplies, and need to be acquired in sufficient quantities. The manufacturers' service manuals give cautions about using the wrong cleaning agents, which can damage labelling and the plastic surfaces of some equipment.

d. Replacement parts

When planning an IPM programme, it is possible to forecast in advance what parts need to be replaced and how often, by referring to the manufacturer's guidelines.

e. Operation and service manuals

Maintenance programme will have an operation (user) manual and a service manual for each model of medical equipment. The operation manual is valuable not only for equipment users but also for equipment technicians who need to understand in detail how the equipment is used in clinical practice. The service manual is essential for inspection, preventive maintenance, repair, and calibration.

2.1.3. Equipment condition

The world health organization defines medical equipment as a piece of equipment that requires maintenance, repair, user training, and decommissioning. Regulation 15 of the health and social care Act 2008 ensures that Equipment used to deliver care and treatment is used only for its intended purpose and that it is maintained, stored, and cleaned appropriately. Failure to adhere to the legislation can result in substandard material that can lead to poor surgical outcomes **(**Halbwachs,2018**)**.

It is also a legal requirement that employers must ensure employees are trained and competent in the use of an equipment that they may use. To support the training of employees, manufacturers often provide national and local training, as well as updates on their equipment and demonstration of new equipment (Hsieh, 2005).

All practitioners rely on medical equipment to be in good working order to ensure a safe and effective service to the patient. Equipment should be checked for functionality and safety before and after use, following manufacturer guidance (Kinley, 2012).

Equipment should have a planned, regular maintenance contract, with each piece of equipment recorded on an asset register which documents service history and planned replacement dates. Within healthcare organizations, the Biomedical engineering department is responsible for scheduling maintenance and servicing of all medical equipment (Mahady, 2019).

2.1.4. Value of equipment

Medical devices are considered a fundamental component of healthy systems, the benefits they can provide continue to increase as they are essential to prevent, diagnose, treat and rehabilitate illnesses and diseases in a safe and effective way (Wang, 2000).

2.1.5. Inventory

A medical equipment inventory list is a mechanism that provide more control over assets. It includes information related to the equipment, such as purchase date, dimensions, serial numbers, and much more. A completed and finished equipment inventory list is one of the best hospital's assets (Wang et. Al, 2018).

2.1.6. Education and training.

For the safety of the patient and the user, proper training is critical for both the user and the technical staff. The technical staff and the maintenance department manager have dual responsibility for ensuring that the technical personnel as well as the clinical users are informed, trained and versed on their specific responsibilities. Training and education are not a one-time activity but a continual process (Remmelzwaal, 2017).

2.2. Overview of medical equipment maintenance management optimization

An efficient health care technology management (HTM) system must include an inventory of the equipment. The inventory needs to be updated regularly in order to accurately reflect the status of the medical equipment in the healthcare facility at any given time and be successful in supporting various HTM operations. Initial data collection, as information is updated, for example, when a new piece of equipment is delivered or retired, as well as annual inventory audits, are all update points. The inventory of medical equipment is utilized in conjunction with inventories of various supporting assets, such as consumables, replacement parts, and testing and safety instruments and equipment. In order to ensure proper time and resource allocation, as well as to cut down on superfluous effort, inclusion of equipment in an inventory is selected through a risk-based analysis. The medical facility chooses the level of informational detail to be included in its inventory based on its own requirements and capabilities. Depending on the resources available, inventory management is done using a paper-based or computer-based approach.

Once established, the inventory acts as the cornerstone for developing the HTM system and guaranteeing secure and efficient medical equipment. The inventory can be used to build and support an effective clinical engineering department, allowing for workshop planning, hiring and training of technical support staff, and establishing and maintaining service contracts. It can also

be used to support an effective medical equipment management program, such as planning preventive maintenance activities and tracking work orders, and plan the stock of spare parts and consumables. The inventory may also be used to track the acquisition, receipt, retirement, and disposal of equipment as well as to support assessments of the health care facility's equipment needs. An inventory also supports facility risk analysis and mitigation, as well as emergency and disaster planning (Sandelowski, 1995).

The ability to diagnose, monitor, and treat patients in a contemporary hospital today depends heavily on many forms of medical equipment. To save expenses, decrease patient dissatisfaction, treat the patient quickly, and lower mortality and dangers during patient care, it is crucial to maintain medical equipment. In order to avoid medical equipment failures, hospitals must have well-planned and implemented maintenance management plans.

Since medical equipment is crucial to the functioning of the hospital system, it is essential that hospitals invest in it, maintain it, and replace it (Stiefe, 2009). This will help ensure that the delivery of healthcare services is successful. Hospitals must create checklists that indicate the performance status of maintenance on medical equipment in order to accomplish these objectives. It is crucial for clinical managers and engineers to forecast the risks of unexpected failure in addition to expanding the hospital's capacity.

Research on strategic management of technology in public health sector was conducted in Kenya and South Africa. The main objective was to investigate factors contributing to health care equipment problems and associated technological investments in public hospitals (Cheng and Dyro, 2004). The research reviewed the processes of equipment planning, procurement and management in ten public equipment maintenance institutions. Fifty-six questionnaires were mailed to target technology managers, clinical/medical engineers and technicians in public hospitals in Kenya and South Africa. Thirty-eight equipment maintenance experts participated in the survey where majority of them were drawn from teaching hospitals. After the research it was evident that the way health technology is managed in health care institutions directly affects the quality of treatment patients receive (Krippendorff, 2004). Despite the strategic importance of technology in health care being documented widely in scientific literature; equipment planning, procurement and management have not received the attention they deserve in the transformation of health care service in the two countries under the survey (Cheng and Dyro, 2004).

2.2.1. Maintenance Management optimization

In general, a maintenance management strategy has number of goals (Palesh *et al.* 2001; Pope 2000; Walsh 1995; WHO 2011; Wang 2012; Dargahi, 2014). These include:

(i) Extending equipment lifetime by replacement, repair, the mean time to the next failure whose may be too costly;

(ii) Reducing the frequency of service interruptions and the many undesirable consequences of such interruptions;

(iii) Improving component and system reliability;

(iv) Enhancing equipment capability quantitatively and qualitatively;

(v) Improving safety, health and environmental factors in the expectation that such improvements will contribute to better quality and higher profits and

(vi) Reducing maintenance costs by increasing system capacity, reinforcing redundancy and employing more reliable components.

Benefits include:

(i) Improving the utilization of medical equipment;

(ii) Ensuring that medical equipment is always in the best technical condition;

(iii) Ensuring the integrity rate of equipment usage;

(iv) Improving equipment reliability;

(v) Improving the economic benefits to the hospital;

(vi) Reducing hospital operating costs, optimizing the financial structure and improving the ongoing costs of medical equipment; Reducing hospital dependence on sub-contractors, which is the main factor in increasing maintenance costs and low maintenance performance and

(vii) Reducing the cost of maintenance by having an effective spare part inventory.

2.2.2. Factors Affecting Maintenance Performance optimization

Maintenance performance impacts on all departments of an organization and comprehends a number of factors. Aghaei (2019) highlights seven main criteria for the measurement of maintenance performance. These are: (1) process-related maintenance, (2) maintenance costs, (3) maintenance activities, (4) customer satisfaction, (5) quality maintenance, competitive growth, training and innovation, (6) health, safety and environmental issues, and (7) staff satisfaction. Kumar *(*2006*)* divides maintenance performance into two categories, Internal and External.

Internal effectiveness factors gauge maintenance activities, based on their performance during the manufacturing process.

External effectiveness factors concern the issues after a product is sold as shown in Figure 2.1 below, which illustrates the divisions of total maintenance effectiveness and common factors affecting it. Internal effectiveness factors include productivity, costs and profit and are therefore directly related to maintenance operations. As maintenance is undertaken by people, it needs to be measured so as to eliminate unnecessary maintenance mistakes. The reliability and efficiency of Resource-Utilization is also a major factor for consideration (Boisvert *et al.* 1998). External effectiveness covers customer satisfaction, and needs to be measured to counter inadequate internal factors. Service quality, timeliness of delivery, health, safety and environmental issues are highlighted. The monitoring of the long-term effects of maintenance also ensures effective manufacturing, which results in reliable products (Boisvert *et al.* 1998). Successful maintenance management is dependent on a number of important factors, as summarized by Kumar (2006) in Figure below.

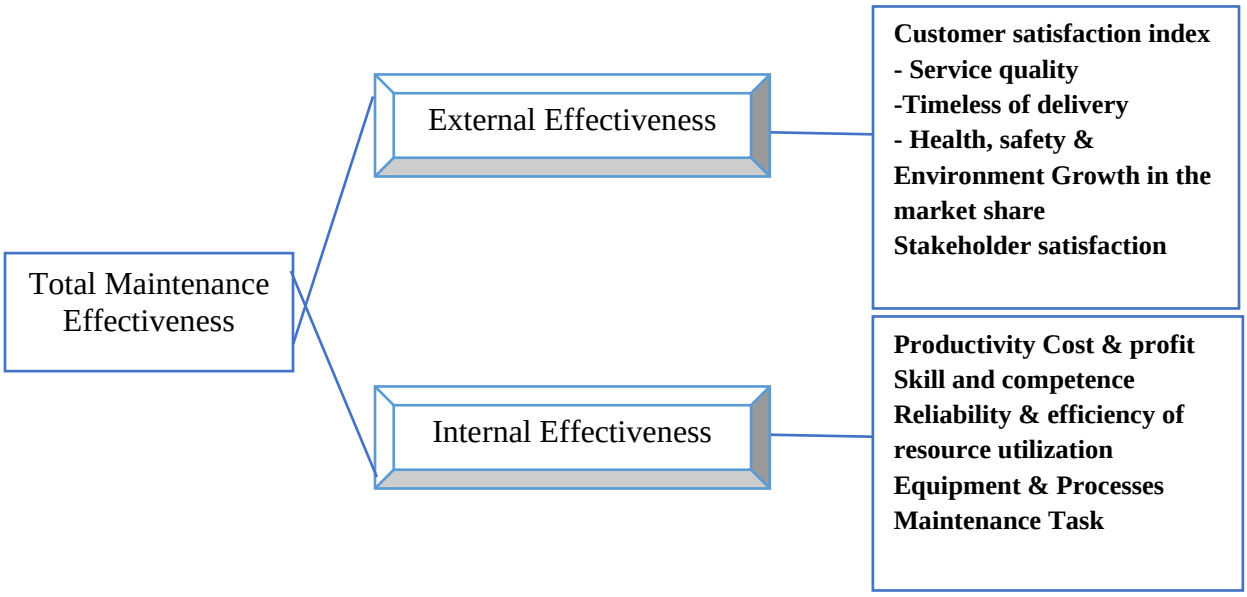

Figure 2. 1: Total maintenance effectiveness based on an organizational effectiveness model (Kumar, 2006)

In the above figure, the main goal of successful maintenance in industrial organizations is the maximization of profit. In contrast, healthcare organizations are concerned more with improving patient outcomes and reducing total costs.

2.2.3. Maintenance Management Strategies

Maintenance management strategies fall into two categories. The first involves unplanned activities such as repair and replacement. The second involves planned activities which include proactive and reactive strategies. Proactive activities include scheduled replacement, predictive (or on-condition) maintenance and scheduled discard. Reactive activities include failure-finding tasks, recalibration, and redesign (Augustýnek *et al.* 2018). The type of maintenance management selected by any organization will depend on its operational system, its resources and the skill of its employees. To develop an appropriate maintenance strategy, it is necessary to identify and apply 'effective ways of managing unavailability of the hospital equipment' (Noori 2020). There are, however, many types of maintenance strategies: Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM) and Mixed Maintenance Management Strategies.

The majority of organizations that apply TPM or RCM gain the benefit of a reduction in machinery failure. This is because technical infrastructure is maintained in a proper condition which promotes production continuity. There is also a sizeable reduction in machine maintenance costs (Stadnicka and Antosz 2013). TPM is directly aligned to a lean manufacturing philosophy, which is considered to substantially improve productivity in enterprises, by the integration of processes not

considered to be value-adding to the product (Shahanaghi and Yazdian 2012; Stadnicka and Antosz 2013). But RCM authored by engineers; Tom et. Al (2013) working for United Airlines argued that actions recommended, in particular to Technical Machines Park Supervision, have resulted in a reduced failure rate, and an automatic boosting of equipment capacity because of the significantly reduced down-time. 71% of companies studied chose to implement TPM because 41% experienced low machine capacity and 34% reported high failure rates. Thus, TPM appears to be an advanced maintenance strategy involving equipment users in day-to-day maintenance of that equipment. This is a rather foreign concept in hospital equipment maintenance but it may have potential in terms of productivity, economics reliability and ultimately patient outcomes.

2.2.3.1. Preventive Maintenance (PM)

Preventive maintenance can be defined as all these actions carried out on a planned, periodic, and specific schedule to keep equipment in its original working condition through the process of checking and reconditioning (Dhillon and Liu 2006; Wang *et al.* 2018) in order to prevent or minimize breakdowns and depreciation rates (Halbwachs 2018). PM was first developed at General Electric in the 1950s (Stadnicka and Antosz 2013), and currently adopted by most organizations to achieve their objectives, which include: maintaining the condition and reliability of operating equipment; minimize interruptions to production and major breakdown; and keep production continuously running (Shahanaghi and Yazdian 2012; Stadnicka and Antosz 2013). PM is also referred to as scheduled maintenance or planned maintenance (Boisvert *et al.* 1998).

Despite the fact that PM is widely used in organizations, there is significant variation in the activities it is used for and there are competing ideas about its effectiveness. Lo (2004) argues that unified PM strategies can provide an optimum maintenance strategy for managing equipment failure and the associated risks of unavailability of medical equipment. However, Wang *et al.* (2006) suggests that the PM of equipment may not only reduce its reliability, but can also 'introduce failure'. Noori, (2020). argue that planning maintenance (routines) might be ineffective because it is expensive in the long term and may not extend component lifetime as required. This suggests that despite the popularity of PM, its use should be related to the condition

of the equipment.

The PM of medical equipment includes more than safety and performance inspection activities, Wang *et al.,* (2006). It also includes risk analysis and other criteria that reflect the needs and reality of the healthcare organization. Examples of other criteria that should be considered are: mission criticality or operational impact; the ability to detect failure, "hidden failures" and their respective severity; equipment hazards and recall history that occur outside the healthcare organization; reliability including failure patterns and statistics and availability of medical equipment and

spare parts (Wang *et al.,* 2006).

In relation to the relative importance of PM and medical equipment issues Augustýnek (2018) noted that US hospitals continued to allocate approximately US$300 million per year to PM when there was still no collaborative consensus on the definition of PM, no identification of equipment maintenance activities, no rational process for the definition of a non-critical item of equipment and no efficient method for the justification of the regularity of PM intervals. It is

indicated that PM does not prevent all facets of equipment failure, but only addresses failures resulting from the degeneration in a device's non-durable parts which cause failure. Furthermore, Augustýnek (2018) discusses the extent to which PM improves the reliability of equipment in consideration of downtime and safety. He discovered that PM does have an impact on the reliability of some equipment items, and has a beneficial impact on the equipment's uptime. Ridgway argued that a properly executed PM program brings to an organization increased safety, reduced downtime and fewer expensive repairs. However, as medical equipment becomes more complex, it is argued by Stadnicka and Antosz, (2013) that PM activities become less relevant.
This is because PM, in their review, is only concerned with inspection and scheduled maintenance activities, which do not take into consideration age-related failure. For this reason, PM is of limited use in improving the reliability of complex items.

2.2.3.2. Corrective Maintenance (CM)

Corrective Maintenance can be defined as unscheduled repairs on reported failures, or replacement of parts to restore equipment to working condition (Wang *et al.* 2010). CM is also known as Repair and Replacement (R&M), (Endrenyi *et al.* 2001), Run-to-Failure, Failure-Based Maintenance, Fire-Fighting Maintenance or Breakdown Maintenance activities are carried out only after an equipment breakdown (Dhillon and Liu 2006; Wang *et al.* 2018). The reason, according to the authors, is that it is complicated and difficult to predict stochastic and unforeseen equipment failures and breakdowns.
CM involves the repair of stalled motors, repairs to ruptured pipelines or even the replacement of a failed light bulb. In 1957 the system called CM was developed, to include all measurements to improve the reliability of equipment (Dhillon and Liu 2006; Wang *et al.* 2018). This method is used particularly where the failure of equipment and appliances does not result in undue risk, does not violate the rules of work safety and does increase investment costs. CM may be a good strategy where the failure rate is normal and the cost of breakdown is low (Halbwachs 2018). In the long term however, it is more expensive than Preventive Maintenance (PM) because, for example, a sudden breakdown in the case of medical equipment creates idle time waiting for spares parts, haphazard troubleshooting scenarios and unplanned interruptions of services operations. In US manufacturing industries, over US$300 billion is spent each year on the maintenance of manufacturing operations. Of this amount, about 80 percent is spent in the correction of chronic equipment failure, production operations and workers' wages (Halbwachs 2018). Therefore, while CM can be useful, it is usually an expensive option if used in isolation.

2.2.3.3. Predictive Maintenance

Predictive Maintenance (Pr. M) can be defined as the application of mathematical models to diagnose the condition of operating equipment (Stiefe, 2009). It can be applied to improve outage scheduling, operating flexibility, equipment performance efficiency, better fuel use and more efficient spare part management (Cheng and Dyro, 2004). Predictive Maintenance activities are performed as needed, and inspections should be carried out frequently to initiate maintenance before equipment break-down. These maintenance activities are included in the healthcare organization's medical equipment management plan and should be performed even if it takes place beyond the established inspection time.

For example, a quarterly inspection period may possibly have a one-month grace period while an annual inspection period may possibly have a two-month grace period (Wang *et al.,* 2006). Predictive maintenance routines also involve a group of programs called Reliability-centered Maintenance (RCM) (Krippendorff, 2004). In contrast to preventative and corrective maintenance strategies, predictive maintenance actively utilizes diagnostic methods in order to avoid the risk of breakdown Palesh *et al.* (2001). Diagnostic methods include visual and optical inspections; temperature, vibration, neutron, lubricant and magnetic flux leakage analysis; radiography; ultrasonic and eddy current testing and acoustic emission monitoring. Each of these methods has advantages and limitations. By using continuous inspection, or condition monitoring, of operating equipment, the detection of abnormalities indicative of future failure can be identified. Condition monitoring is preferable where it is not possible to expect wear-out trends through periodic inspections with reasonable accuracy, for cost effectiveness, where off-line inspections are not desirable and where the criticality of a failure justifies keeping a constant vigil on medical equipment or services process.

When applying predictive maintenance to medical equipment, it is important to be flexible in the planning and scheduling of maintenance activities. This is because it is often difficult to perform planned maintenance activities at a suitable time due to its use on patients and other external control factors. For this reason, Wang *et al.* (2006) suggest use of a grace period (or slippage) for determining when an item of medical equipment must be considered overdue for a planning inspection or maintenance action.

It is argued that predictive maintenance is more advanced than other maintenance strategies because it focuses on inspection, condition and risk-based techniques (Boisvert *et al.* 1998). Predictive maintenance was, and currently still is, limited to those applications where it is both technically practicable and cost-effective. Encouraging this trend was that condition monitoring equipment became more accessible and cheaper. In the past, these techniques were reserved for

high-risk applications only, such as aircraft or nuclear power plants. Health organizations, however, should consider applying this strategy to their operations.

2.2.3.4. Condition Based Maintenance (CBM)

Condition Based Maintenance (CBM) is undertaken as a result of periodic monitoring of equipment by the use of non-invasive checking. It is performed at a critical time when the equipment requires overhaul, and includes diagnostic information and the making of effective maintenance decisions (Augustýnek *et al.* 2018). These maintenance activities are concerned with the condition of a machine component that may be found during observation and analysis rather than by occurrence of failure "Corrective Maintenance" or by following a strict maintenance time schedule "Preventive Maintenance" (Stadnicka and Antosz 2013). CBM assists in identifying incipient faults before they become critical, which enables more accurate planning of preventive maintenance. For this reason, CBM is also known as Predictive Maintenance (Krippendorff, 2004). "CBM strategy reduces the probability of sudden random failures with the aid of diagnostics and timely intervention. In order to achieve an effective implementation of "zero-failure" strategy the condition control helps to discover causes of failure, potential failures and mechanisms of failure. For instance, spectral analysis, one of the most useful fault diagnostic tools, provides a basis for identification of failure mechanisms, causes of failure and failure modes in mechanical systems, such as rotating and reciprocating machines" (Krippendorff, 2004).

The main advantage of CBM is that it promotes cost-effective production because it can be performed without stopping equipment or processes (Slack *et al.* 2005). CBM also reduces the number or extent of maintenance activities and false alarms, eliminates scheduled inspections, predicts useful remaining life, detects incipient faults, enables autonomic logistics and diagnostics, enables information management, enhances reliability, and consequently reduces life cycle costs. For these reasons, it is considered an effective strategy for asset maintenance, and is becoming more commonly used by US manufacturers and the US military. There are many factors contributing to the incremental use of CBM, including the need for improved equipment availability; protection against failure of critical equipment and reduced maintenance and logistics costs (Cheng and Dyro, 2004).

The use of CBM in asset management is not a new strategy. In fact, condition monitoring and analysis has been used for the last seventy years to improve technology, equipment and practices (Palesh *et al.* 2001). However, over the last two decades there has been a quickening in the pace of technological development and this has had an impact on the relevance and usefulness of

maintenance strategies (Dargahi, 2014). The technological development that has occurred over the past two decades involve many advantages; it has made data collecting and analysis hardware much more compact, stronger and less expensive, enabling improved reliability of critical machinery like military rotorcraft, civilian vehicles, medical equipment, energy electronics, automotive and oil and gas production industries.

However, because of the high cost of CBM, the more traditional maintenance strategies of Corrective and Preventive Maintenance are often used at the same time as CBM. Because CBM is concerned with monitoring and replacing parts and equipment before the end of their operation lifetime, WHO (2011) tried to find a model for an optimal replacement policy and observation interval. They applied several models, including the Proportional Hazards Model (PHM) which models a system's failure rate. PHM is used to calculate the optimal replacement policy and long-run average cost for a system which lacks information but is used extensively in medical studies. Augustýnek, (2018) found that CBM can assist in finding the optimal observation interval of an operation process based on the total long-run average cost, as well as the corresponding replacement policy that optimizes the total long-run average cost of the replacement observations. Noori, (2020) found in their survey that one company used the strategy based on failure rate. 65 percent of companies surveyed showed the most common maintenance strategies utilized were planned inspections. 63 percent of companies implemented a technical condition assessment by an operator prior to work commencement.

Overview of hospitals performance improvement

Measurement is central to the concept of hospital quality improvement; it provides a means to define what hospitals actually do, and to compare that with the original targets in order to identify opportunities for improvement. The principal methods of measuring hospital performance are regulatory inspection, public satisfaction surveys, third-party assessment, and statistical indicators, most of which have never been tested rigorously (Wang, 2018).

At the system level, improvement in such areas as health priority setting, system planning, financing and resource allocation, professional recognition and overall quality management often become important aims of health reforms.

Hospital performance may be defined according to the achievement of specified targets, either clinical or administrative (10). Ultimately, the goal of health care is better health, but there are many intermediate measures of both process and outcome. Targets may relate to traditional hospital functions, such as diagnosis, treatment, care and rehabilitation as well as to teaching and research. However, both the definition and the functions of hospitals are changing, as emphasis

shifts from inpatient care to ambulatory care, community outreach programmes and health care networks (11). Hospital performance may thus be expected to include elements of community care and public health, as well as social and employment functions. These dimensions of hospital performance have been analysed in the European context (12).

Measurement is Hospitals need positive incentives to provide timely, accurate and complete data to external assessment programmes. If such programmes are perceived to have intrinsic value to the organization (for example, in staff motivation, team building; clinical and professional development or risk management), hospitals have less need for financial or market incentives to participate. Conversely, neither individuals nor hospitals are keen to provide information which might lead to public blame, litigation, and loss of staff, authority and trade. Many performance measurement systems assume a common culture of transparency, professionalism and accountability that motivates cooperation.

According to the research Internal process, Finance, Mission, Customer, Training and development staff perspectives are factors that affect hospital performance.

Mission factor: The relationship between an entity's mission and its decision-making and implementation processes is reflected by this factor. The execution of the mission will be perceived as having priority over the vision, the value strategy, and the viability of the approach.

Customer factor: Including indicators that show how well services met customers' needs and expectations in terms of quantity and quality.

Internal process factor: Indicators that are included show how well an organization is able to provide a range of services. The process and service activities offered in accordance with specified quality standards are also included in this variable.

Training and development staff factor: Employee contentment, job satisfaction, employee impression of work, level of training to satisfy job needs, and staff skill level are all indications of the training and development of the workforce.

Finance factor: Measurements of indicators of income, expenses, and resource management are included in the financial factor.

2.3.1Method of performance measurement

The methods used for performance measurement and quality improvement have not been rigorously evaluated within or across countries, largely because they are complex interventions which are not easily isolated and measured. The evidence to support these strategies is mostly based on descriptive studies or expert reports and on respected authority. There are in principle five different types of measurement of hospital performance, of which the first four will be dealt with here:

- Regulatory inspection
- Surveys of consumers' experiences
- Third-party assessments
- Statistical indicators
- Internal assessments.

Hospital performance is dependent variable: It is determined by an indicator that assesses the unit's growth and development in relation to broad, synthetic indicators that take into account both the organization's financial and non-financial activities from all angles (Wang, 2018)

Medical equipment maintenance management and hospital performance improvement

Today's modern hospital is highly dependent on various types of medical equipment to assist in the diagnosis, monitoring and treatment of patients. It is impractical to provide health services without them. Good maintenance management in hospitals can minimize breakdowns or failures of the medical device. This is particularly critical in developing countries for providing good healthcare services and saving scarce resources and alternatives. The equipment maintenance management of the hospital not only makes them easily accessible when needed but also increases their reliability and reduces their failure rate. The maintenance of medical equipment is also important for reducing dispatch costs, reducing patient dissatisfaction, timely patient treatment, and reducing mortality and risks during patient's care. Good medical equipment maintenance management improves customer satisfaction and help hospitals to reach to their mission as some of the factors that affect hospitals performance.

2.3. Empirical research

In 1997, an audit assessment of the facilities maintenance management in a public hospital in Malaysia was carried out. The purpose of the research was to assess the existing facilities maintenance management practices and processes in public hospital, in accordance with the concession agreement, in order to identify the performance status. The government of Malaysia took the initiative to implement this major privatization project for the provision, maintenance and management of hospital support services (HSS) of public hospital throughout the country (Stadnicka and Antosz 2013). Three concession companies were selected to initially take responsibility on a total of 123 hospitals and four health institutions throughout the entire country making a total of 127 hospitals, on a fixed price and period basis. The questionnaire constructed was based on the following:

- Standards and guidelines in managing the environment of care as stipulated in Juran Institute (1998) Management of environment of care standards;
- Concession Agreement, hospital support services (HSS) privatization project;
- Requisites, determined as necessary from the experience of the assessors, in order to

provide effective management of facility engineering maintenance.

The data was collected through questionnaires, guided interviews, documentation review and archival records. Reviews were conducted to assess five key elements: Leadership policies, service performance, supervision, training and orientation.

2.4. Research Gap

The findings of the research described the status of facilities maintenance management in the hospitals under study to be having a good planning and management with all essential requirements and compliance with regulation. However, the audit assessment was not able to develop and implement comprehensive and systematic policies, plan and procedures of facilities management through a maintenance management program. This is because the main objective of the research was only to identify the maturity level of the maintenance organization in specific hospitals with regard to the effectiveness of their management of facility engineering maintenance services. The result from the research suggested that the maintenance organization in the case study hospitals had still not realized the importance and effective maintenance management. It was apparent from the research findings that the maintenance organization had not made much effort to accomplish their roles and responsibilities towards successful implementation of facility engineering maintenance services

According to reviewed literature, significant progress has been made in Rwanda; some guidelines and frameworks have been established, and a database of information has been established; however, it’s so hard to find studies or papers that talk about medical equipment management in Rwanda. So, more studies are needed to know all the existing challenges and the way of mitigation.

Summary

Literature review encompasses definition of key concepts, overview of medical equipment maintenance management optimization, overview of hospital performance, related literature of this study and research gap. Based on the finding, conclusion and recommendations by some researchers in the related literature in this study reveals that the ability to diagnose, monitor, and treat patients in a contemporary hospital today depends heavily on many forms of medical equipment. To save expenses, decrease patient dissatisfaction, treat the patient quickly, and lower mortality and dangers during patient care, it is crucial to maintain medical equipment. In order to avoid medical equipment failures, hospitals must have well-planned and implemented maintenance management plans. Since medical equipment is crucial to the functioning of the hospital system, it is essential that hospitals invest in it, maintain it, and replace it. This will help ensure that the delivery of healthcare services is successful.

CHAPTER 3. RESEARCH METHODOLOGY

This chapter represents sources of data and research methodology used to analyze collected data.

3.1. Population and sample size

This part is mainly focused on showing the number of staff in maintenance department per each hospital/ organization and sample size, the table below showing the Population, sample size and sampling method from 25 Hospitals in Rwanda.

Table 3. 1: Population, sample size and sampling method.

hospitals/ organizations	Biomedical Engineers	Biomedical technicians	Population	Sample size	Sampling method
King Faisal Hospital	2	6	8	8	Purposive
CHUK	2	6	8	8	Purposive
NYARUGENGE DISTRICT HOSPITAL	2	2	4	4	Purposive
Muhima hospital	1	1	2	2	Purposive
CHUB	1	3	4	4	Purposive
Kabgayi DH	0	2	2	2	Purposive
Gitwe Hospital	1	1	2	2	Purposive
Nyabikenke District hospital	0	1	1	1	Purposive
Remera Rukoma District Hospital	0	1	1	1	Purposive
Ruhengeri Referral hospital	2	3	5	5	Purposive
RUTONGO HOSPITAL	0	1	1	1	Purposive
KINIHIRA	1	1	2	2	Purposive

Byumba level 2 teaching hospital	1	2	3	3	Purposive
Rwinkwavu hospital	0	1	1	1	Purposive
KIZIGURO D.H	2	2	4	4	Purposive
NYAMATA LEVEL II TEACHING HISPITAL	2	2	4	4	Purposive
Gatunda District Hospital	0	1	1	1	Purposive
Bushenge Provincial Hospital	1	1	2	2	Purposive
Shyira hospital	0	1	1	1	Purposive
GIHUNDWE DH	0	2	2	2	Purposive
AMS	3	5	8	8	Purposive
Rugomero ltd	0	1	1	1	Purposive
AFRICA MEDICAL SUPPLIER	2	2	4	4	Purposive
CROWN HEALTHCARE CARE RWANDA	0	1	1	1	Purposive
Merite equipment ltd	0	5	5	5	Purposive
Total	**23**	**54**	**77**	**77**	**Purposive**

3.2. Research process

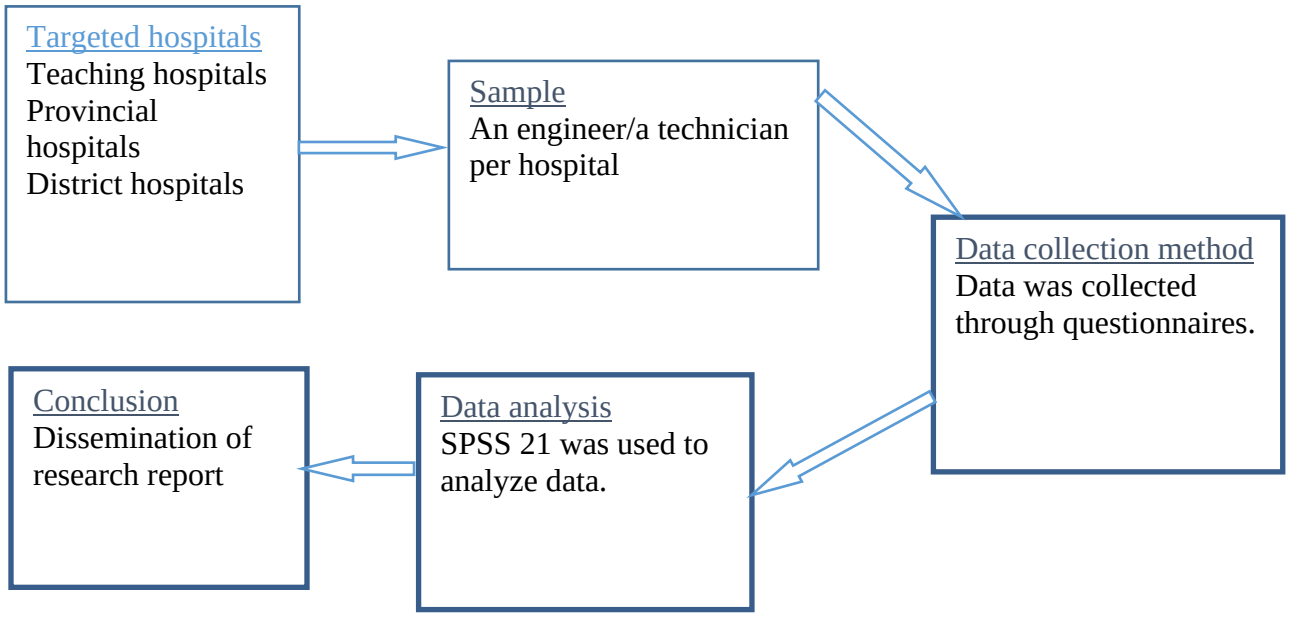

Figure 3. 1: Research process

Teaching, provincial hospitals and district hospitals were selected because are the ones that have a big number of medical equipment and some of them are the class 4 equipment and class 4 presents a greater potential risk and is subject to in-depth scrutiny.

An engineer or a technician per targeted hospitals across the country was interviewed through questionnaire. Questionnaire was used as method of data collection. SPSS software was used for data analysis as one of software which is very user-friendly, understandable and it also displays data in a spreadsheet.

Purposive sampling method were also embraced, as selective sampling which is a form of non-probability sampling in which researcher rely on their own judgement when choosing respondents from population to participate in the survey.

3.3. Data collection method

Data was collected from 20 public hospital's maintenance department and 5 private companies that supply and maintain medical equipment in Rwanda, biomedical personnel were interviewed via questionnaires. The questionnaire had two main parts; Section A and Section B. In section A, the questionnaire defines the goal of the research and outlines main parameters to be interviewed on. In section B, each main parameter had several questions in which respondents is required to answer.

A model of 77 plaintiffs was nominated to answer the prepared questionnaire. The questionnaire was administered to the target sample size during the full-scale survey through an online survey. Plaintiffs were friendly and invited to bung up the questionnaire based on their understanding of logistic service companies. Out of the 77 that were distributed, 70 were collected back and took into consideration, this was making the comeback ratio 90.9%. five (5) questionnaires were excluded from the collected questionnaires because respondents did not answer more than 50% of the questions on the questionnaires, and two (2) did not answer any question.

3.4. Research Model

Based on the factors affecting the medical equipment maintenance management we design the research model as shown below:

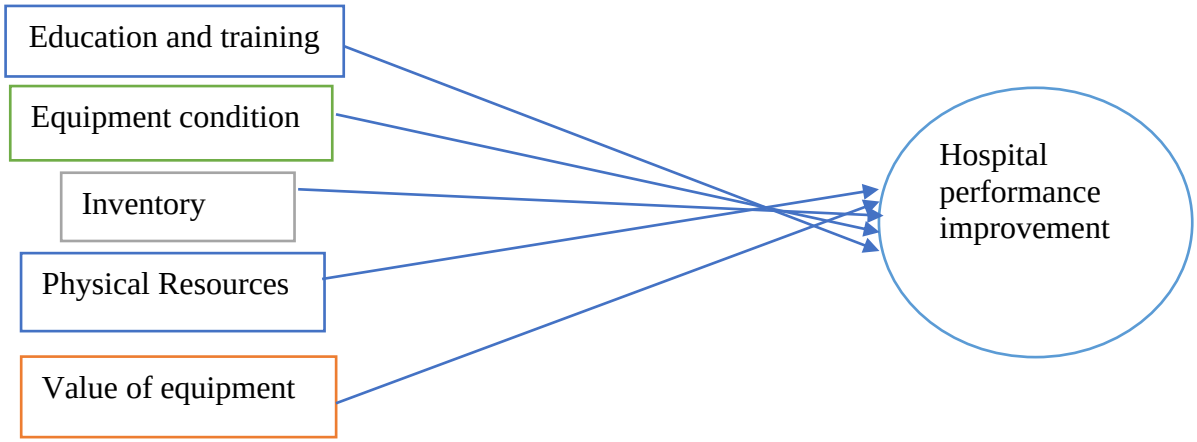

Figure 3. 2: Research model

The figure 3.2 reveals the interconnection between factors affection medical maintenance management towards hospital performance improvement. In fact, relevant coefficient shown in the next chapter represents the contribution of each factor.

3.5 Regression model

$HPI = \beta 0 + \beta ET + \beta EC + \beta I + \beta PR + \beta VE + \varepsilon$

Where:

β: is coefficient

ET: stands for Education and Training

EC: is Equipment condition

I: represents the Inventory

PR: stands for Physical resources, and

VE: is Values of equipment

While ε is the error margin

3.6 Data analysis method

Collected data were analyzed by SPSS Software, and Chi-square test was used for correlation matrix, constructs of this study were analyzed. Validity and reliability test were calculated and founded to be above 70%.

This study used Reliability-centered Maintenance as a methodology to measure the status of equipment that have a high-risk level. Reliability-centered maintenance is the application of quantitative measures appropriate to the nature of the data collected. It is also providing data on the probability of failure of equipment through the adoption of Failure Mode and Effect Analysis (FMEA). The measures available that can be relied upon in the analysis of results include; Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), Failure Rate (FR), and Availability (A).

3.7 Summary

Research Methodology comprises population and sampling technique, here the total respondents are 77 but only 70 respondents were considered due to the status of their responding, questionnaire have been used as data collection instrument, SPSS was used as data analysis tool to make descriptive analysis, regression and chi-square test were used as method of data analysis in order to find the reliable and valid results, and research model was formulated to make a structure of hypothesis summary and to enable good performance of regression analysis, for this linear regression equation model was provided.

CHAPTER 4 RESULT AND DISCUSSION

In the full consistency check, the matters under each of the maintenance management optimization measurements were too verified to check if they can measure the same aspect. All dimensions' reliability test effect was acceptable, meaning greater than 0.7. Therefore, the reliability measures of all dimensions are adequate.

Table 4. 1: Validity and reliability

Variables	Cronbach's alpha	Deleted items	Remaining items	No. of items
Cons	.853			
ET	.792	NO ONE	ET1-ET4	4
EC	.796	NO ONE	EC1-EC3	3
I	.782	NO ONE	I1-I4	4
PR	.832	NO ONE	PR1-PR2	2
VE	.835	NO ONE	VE1-VE2	2

Source: Survey Result (2022)

The table above reveals that all constructs of this this study provides reliable information as their Cronbach's Alpha of all are higher than 0.70. This shows that this study is trustable and the information provided is consistent. Meaning that the consistency of a measure i.e whether the results can be reproduced under the same conditions and the accuracy of a measure i.e whether the results really do represent what they are supposed to measure as it is also represented the following chart:

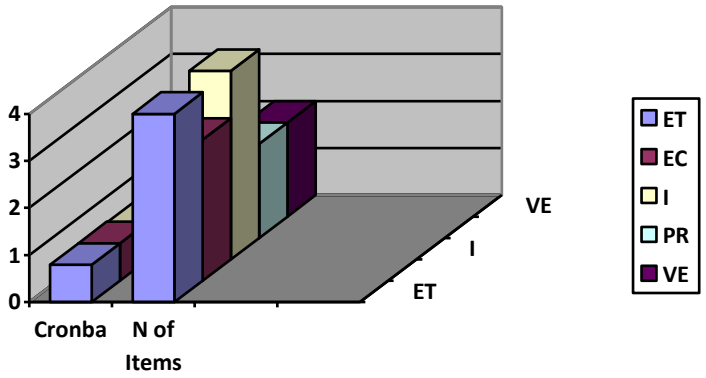

Figure 4. 1: Validity and reliability

4.1. Medical equipment management optimization

Table 4. 2: Equipment inventory period

Inventory period	N	Mean	St. Dev
Monthly	32	5.23	.187
Quarterly	20	3.24	.213
Annual	8	2. 43	.314
Total	**70**	**5. 77**	**.684**

Source: Survey Result (2022)

The table above reveals that based on the findings from the studied hospitals, the equipment inventory period is made monthly, as it is shown by the mean of 5.23 and standard deviation of 0.187; This equipment inventory is done quarterly at the mean score level of 3.24 and standard deviation of 0.213, but other hospitals made this inventory annually as presented by the mean of 2.43 and standard deviation of 0.314. The above results showing that the equipment inventory is done in the hospital and equipment information is collected during inventory, even if some hospitals delayed to make inventory, it is better to do so at least not later that quarterly. The clinical engineering department should identify and select the devices to be included in the inventory, and which of those to include in the maintenance programme. While some may prefer to record all equipment in the facility (and some government agencies may require this), studies have shown that not all equipment needs to be tracked in an inventory, inspected or maintained, and very few hospitals or health-care organizations have the manpower to accomplish this level of effort.

Table 4. 3: Medical equipment maintenance information keeping

Information keeping	N	Mean	St. Dev
Manually	9	3.21	4.76
Computerized information system	4	3.18	.233
Both	57	6. 17	.184
Total	**70**	**5.17**	**2.62**

Source: Survey Result (2022)

The above table reveals that some of equipment information are kept manually as represented by mean score of 3.21 and standard deviation of 4.76; through computerized information system it represented by the mean of 3.18 and standard deviation of 0.233; there are numerous hospitals

that used both manually and computerized information system; Information keeping is one of key role in equipment maintenance. It is an important function of information management to reduce the risk of legal and financial punishments against the organization. It achieves this with a well-defined protocol for recording, storing, disseminating and destroying data. This reduces the chance of breaches and improves compliance with regulations.

Table 4. 4: Equipment downtime period

	N	**Mean**	**St. Dev**
Less than 24 Hours	9	6.00	.265
Between 24 and 48 Hours	65	1.02	.121
Above 48 Hours	1	8.92	3.96
Total	**70**	**4. 97**	**.224**

Source: Survey Result (2022)

As revealed by the table above, Equipment downtime intended to be essentially any period of time that a piece of equipment is not working or producing within 24 and 28 hours. Downtime can either be unplanned because of a breakage or defect or planned in the case of scheduled or intended maintenance activities.

Table 4. 5: Process of getting spare parts for equipment maintenance

	N	**Mean**	**St. Dev**
Planning and purchasing	45	5.00	.265
Requisition on central level	9	3.14	.332
Contactors	2	2.02	.421
All	14	3.92	.396
Total	**70**	**4. 97**	**.324**

Source: Survey Result (2022)

The above table showing that most of hospital and organization assessed uses Requisition on central level method to get spare parts. To be a successful, practical spare part inventory management remains the foundation for dependable plant operation. A supply chain manager, is required to know the process of determining which spare parts needed to make the system productive. It needed to develop a planned approach that follows best organization or hospital practices.

Table 4. 6: Types of medical equipment maintenance

	N	Mean	St. Dev
Preventive maintenance	0	0	0
Corrective maintenance	2	1.04	.834
Both	68	8.14	.112
Total	**70**	**5. 87**	**.584**

Source: Survey Result (2022)

The table 4.7 reveals that both preventive and corrective maintenance are likely to be used as it is represented by 68 respondents. It is essential for any health-care facility, regardless of its size, to implement a maintenance programme for medical equipment. The complexity of the programme depends on the size and type of facility, its location, and the resources required.

Table 4. 7: Responsible for maintenance

	N	Mean	St. Dev
In-house BT	6	2.80	.565
Contractors	1	1.08	.434
Both	63	8.73	.184

Source: Survey Result (2022)

The above table shows that the combined percentages mean ratings for public, private, consultant and contracted maintenance organizations were 8.73 and 0.184 mean and standard deviation respectively. The maintenance organizations from public hospitals do not have excellent procedures to acquire the best equipment in their procurement processes. The institutions managements or hospital boards do not involve the facility maintenance managers in equipment selections or evaluations. This has contributed to acquisition of incorrect equipment by the hospitals or equipment for which there is difficulty in acquiring spares parts for them. The warrants of the equipment do not cover most of the crucial needs which leads to earlier failure of the equipment. The equipment is compromised due to lack of co-operation between hospital

management and facility maintenance managers. The facility maintenance manager from public hospital should develop an up-to-date computerized inventory system. This will aid the maintenance department on identification of the type and amount of the equipment in the system. It will also help in identifying the new technology in the market.

Table 4. 8: Factors considered before decommissioning or disposing equipment

	N	**Mean**	**St. Dev**
Lifetime ended	16	3.72	.365
New version coming	4	2.07	.534
Asset manager sign	2	1.20	.854
Lack of spare parts	4	2.07	.534
Team approved	4	2.07	.534
All	40	5.82	.235
Total	**70**		**.684**

Source: Survey Result (2022)

The table 4.8 make known that lifetime ended is the most factors to be considered before disposing equipment as represented by the mean of 3.72 and standard deviation of 0.365. In addition, the study shows that new version coming, lack of spare parts and team provided are also considered at the mean score of 2.07 and standard deviation of 5.34. Asset manager sign also is used at 1.20 and standard deviation of 0.854. Respondents asserted that most of the time guidelines from WHO should be followed before making this decision.

4.2. Descriptive statistics

Table 4. 9: Descriptive statistics

Maintenance management optimization	N	Mean	St. Dev
ET	70	4.03	.365
EC	70	5.64	.234
I	70	3.90	.459
PR	70	7.02	.159
VE	70	6.87	.284

Source: Survey Result (2022)

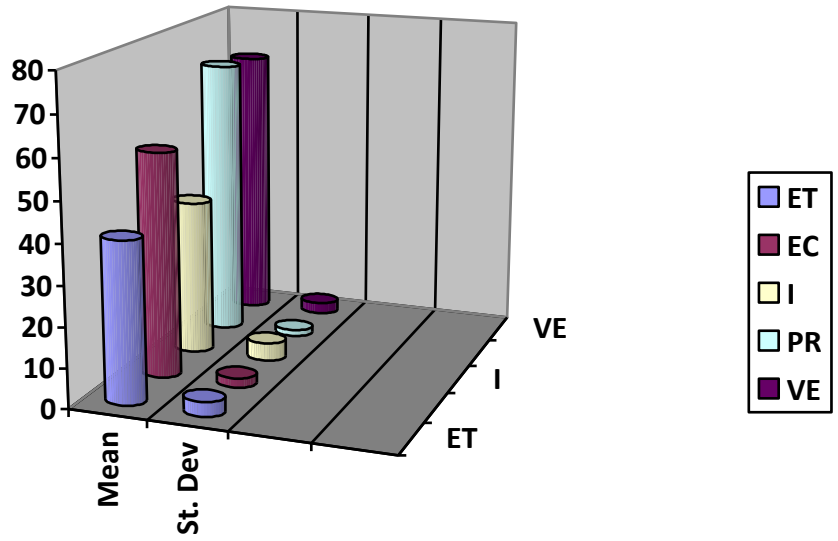

Figure 4. 2:Descriptive statistics

The objective of maintenance optimization is to determine the optimum maintenance tasks that minimize the downtime while providing the most effective use of systems in order to secure the desired results at the lowest possible costs, considering all possible constraints. Referring to the table above, constructs of management maintenance optimization are at good level as represented with their respective mean and standard deviation.

Table 4. 10: Correlation matrix

Variables	VIF	ET	EC	I	PR	VE	MMO	HPI
ET	2.24	1						
EC	2.45	0.741**	1					
I	2.37	0.618**	0.615**	1				
PR	2.13	0.710**	0.569**	0.785**	1			
VE	1.09	0.587**	0.455*	0.586**	0.642**	1		
MMO	2.28	0.671*	0.762**	0.692**	0.746**	0.652**	1	
HPI	2.23	0.615**	0.648**	0.455*	0.662**	0.586**	0.580*	1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

As shown in the correlation matrix table, the performance of scheduled preventive maintenance services on the medical equipment does not take priority over corrective repairs in most of the public hospitals compared to private hospitals. Public hospitals have no quality control system for the repair and preventive maintenance.

Technical manuals are not fully utilized when repairs are made, maintenance on the medical equipment are not done on the stipulated time frame. Deferment of maintenance may be required due to non-availability of manpower or other extenuating circumstance for instance lack of spare parts.

Table 4. 11: Linear regression result

Variable	Hypothesis sign	Model 1 (t-value)	Model 2 (t-value)	Model 3 (t-value)	Model 4 (t-value)
Constant		1.37 (4.12)***	1.13 (3.96)***	1.18 (4.01)***	1.27 (4.13)***
ET	H1 (+)	0.223 (3.21)**	0.125 (3.17)**	0.126 (3.18)**	0.124 (3.61)**
EC	H2 (+)	0.421(3.01)**	0.341 (3.31)**	0.222 (3.21)**	0.013 (2.18)**
I	H3 (+)	0.213 (2.89)*	0.216 (2.43)*	0.214 (2.71)*	0.178 (3.08)**
PR	H4 (+)	0.356 (3.92)***	0.339 (3.77)***	0.234 (3.86)***	0.164 (3.71)***
VE	H5 (+)	0.224 (3.26)**	0.212 (2.13)*	0.276 (3.01)**	0.110 (3.11)**
R^2		.178	.175	.174	.173
Adjusted R^2		.168	.174	.178	.173
-Cons		0.037	0.037	0.43	0.043
N		70	70	70	70

Dependent variables: Customer satisfaction and loyalty

*** indicates significance at p<0.01

** indicates significance at p<0.05

* indicates significance at p<0.1

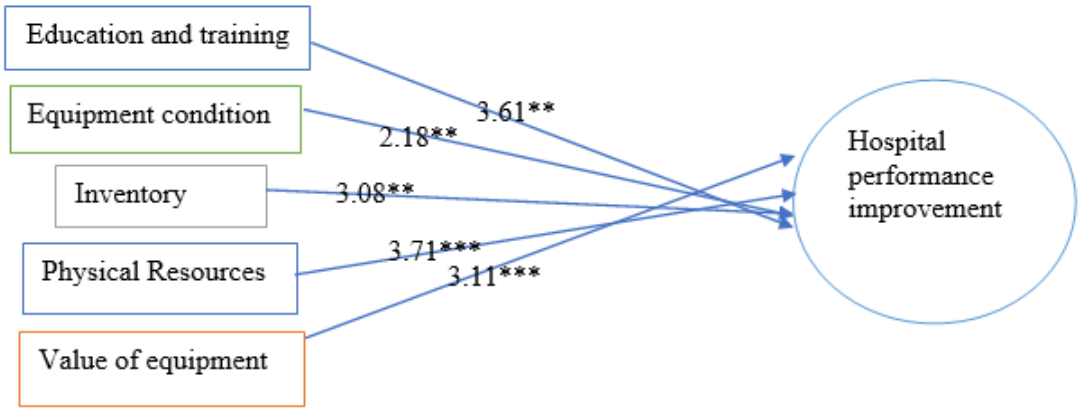

Figure 4. 3 : Hypothesis coefficients for linear regression results

In table and the figure above, all the values are calculated on a 5 Likert Scale and Yes or No questions, to study the effect of medical equipment management optimization on hospital performance. It is revealed that all hypotheses of this study are supported. This is proved by the results of each hypothesis in Table 4.11 of linear regression, which reveals that regression model 4 supports H1 at a significance 0.1 significance level of significance. H2 is accepted based on its

significant level of 0.01; that is, Equipment condition can significantly positively affect hospital performance levels through equipment maintenance. Regression model 4 also supports a significant positive effect of inventory at a 0.1 significance level. This is not surprising as inventory seems to be a critical factor in equipment maintenance management. Survey Result (2022). Similarly, H4 and H5are also supported at a 0.1 significance level.

4.3. Summary of findings

Entirely, dimensions' reliability test effect was acceptable, meaning greater than 0.7. Therefore, the reliability measures of all dimensions are adequate. The results from analyzed data reveals that both general and specific objectives of this study were achieved; factors of medical equipment management optimization were assessed and founded to be significant. Some challenges during equipment maintenance have been identified such as lack of technical trainings, spare parts, etc… the research reveals that these challenges cause confrontation of the equipment maintenance optimization and hospital performance in general, essential recommendations for equipment maintenance optimization and performance improvement were provided in the next chapter. Correlation of this study constructs were founded to be strong. Research hypothesis were supported as represented in the table 10 and 11. The data collected from the Biomedical engineers and technicians determined their effectiveness as they managed the life cycle of the medical equipment. The results offered management the opportunity to appraise the overall maintenance program and sought improvement for increased efficiency and more effective utilization of available resources. The challenges encountered in this research included hospital's policy, Trainings and the low salary of biomedical engineers and technicians.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

Quality medical equipment maintenance ensures a strong and consistent workflow. Delays in essential procedures can have serious significances. An equipment that breaks down or works inaccurately can be a matter of life and death. Well maintained equipment also streamlines hospital functioning and improve productivity.

5.1. Conclusion

Proper management of medical equipment which includes selection, purchase, installation and maintenance are important for ensuring continued readiness of the service, positive impact on the safety and effectiveness of health services. It increases the lifetime of the equipment and provides information essential for equipment management. The findings from the data collected and analyzed revealed that some of the public maintenance organization does not have proper management of the medical equipment. Private, consultant and contractor maintenance organization have excellent procedures to coordinate and oversee the safe, secure and environmentally sound operations. They also maintain the hospital assets in a cost-effective manner which is aimed at long-term preservation of the asset value.

The public hospital maintenance managers are operating in 'a fair standard' as per their combined mean on seven parameters in the questionnaire. The organization fails to assess the new technology when selecting new equipment, thus compromising the healthcare and patient safety. Lack of proper involvement of the organizations on procurement of the medical equipment has contributed to acquisition of incorrect equipment by the hospitals or equipment which have difficulties in acquiring their spares parts. The technicians are not well trained and most of them do not proceed for specialized training especially on medical equipment training. The institutions do not provide job training to their staff at national and international level. They lack proper training and are therefore unable to repair most of the modernized equipment.

The performance of scheduled preventive maintenance services on the medical equipment does not take priority over corrective repairs in most of the public hospitals compared to private hospitals. Public hospitals have no quality control system for the repair and preventive maintenance. Technical manuals are not fully utilized when repairs are made, maintenance on the medical equipment are not done on the stipulated time frame. Deferment of maintenance may be required due to non-availability of manpower or other extenuating circumstance for instance

lack of spare parts. Based on the findings from analysis of this study, it is revealed that specific objectives were achieved and all hypothesis of this study were supported.

5.2. Challenges

- Based on respondent's perception the following Challenges have been mentioned:
- There is a need of more specifications training (neo & maternity equipment, laboratory equipment, oxygen &air medical equipment, imaging medical equipment.....)
- Lack of spare parts, insufficient of effective biomedical engineers
- Some technicians are supposed to do every technical duty which are not related to biomedical engineering
- Lack of skills on special equipment.

Solution on the above challenges were formulated through recommendation of this study

5.3. Recommendations

On basis of research results, following recommendations are proposed:

- To continue updating knowledge of new equipment
- Improving the standard of biomedical field
- Increase the number of staff, buy spare parts and tools, Construction of workshop and increase trainings
- To specify the duties of Biomedical technician
- Central level to provide capacity building on hospital
- To provide testing tools
- To increase the number of technicians in every field
- Hospitals need equipment assets management systems for monitoring equipment life-cycle costs, maintenance costs and management of equipment replacement.
- There is need to strengthen and streamline management of technical infrastructure for health care equipment selection, procurement and maintenance management.

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APPENDICES

QUESTIONNAIRE

Medical equipment maintenance management survey

The survey will take approximately 7 minutes to complete. Dear respondent, I'm Angelique NIYONAGIZE, a master's student in biomedical engineering, I'm doing a research on how maintenance is being done in Rwanda that's why We would like you to dedicate a few minutes to fill out this survey. It will help us to get information we want to be able to optimize Medical equipment maintenance management in Rwanda. This questionnaire is composed of 2 sections. **section1** is about personal identification of respondent. **Section2** covers Medical equipment management system, availability of physical resources, services and management process to extend life of equipment, Staff and education and Information bank.

Identification of respondent

1. Organization/Hospital's name

2. Position of the respondent

3. If yes on Q4, what is the interval to which inventory is conducted?

- ☐ Monthly
- ☐ Quarterly
- ☐ Yearly
- ☐ Other (Specify)

4. Do you do an inventory of medical equipment at your organization/Hospital?

   ◯ Yes

   ◯ No

5. Do you have medical equipment maintenance Policies and procedures at your organization?

   ◯ Yes

   ◯ No

6. If yes on Q6, Who is responsible for producing policy and procedures related to medical equipment in your organization?

7. Do policy makers consult Biomedical engineers / technicians of the organization/hospital?

   ◯ Yes

   ◯ No

8. Do you have a workspace or workshop?

   ◯ Yes

   ◯ No

9. If yes on Q10, Is it comfortable at which level**?**

   ☐ Low level

   ☐ Medium level

   ☐ High level

10. Do you have general tools for maintaining the equipment?

- ◯ Yes
- ◯ No

11. Do you have Testing equipment?

- ◯ Yes
- ◯ No

12. Do you do calibration of the equipment at your organization?

- ◯ Yes
- ◯ No

13. Do you have tools for calibration?

- ◯ Yes
- ◯ No

14. Dou you get spare parts easily?

- ◯ Yes
- ◯ No

15. What's the process do you go through to get spare parts?

- ◯ Planning and purchasing
- ◯ Requisition on central level
- ◯ Contractors
- ◯ All
- ◯ Other (Specify)

16. Do have operation and service manual?

- ◯ Yes
- ◯ No

17. What types of medical equipment maintenance done at your work place?

- ☐ Preventive
- ☐ Corrective
- ☐ Both

18. Preventive maintenance is being done based on what?

- ◯ Who guidance
- ◯ Manufacture guidance
- ◯ Organization/hospital schedule
- ◯ All the above

19. Who is involved in the preventive maintenance?

- ☐ Contractors
- ☐ In house biomedical technicians/engineers
- ☐ Both

20. Do you perform timely and regular preventive maintenance?

- ◯ Yes
- ◯ No

21. How long does a medical equipment/device stay in out of use state or downtime?

- ◯ <24hours
- ◯ <48hours
- ◯ >48hours

22. What do you think causes the equipment to stay so long in downtime?

- ◯ Lack of enough skills
- ◯ Lack of spare parts
- ◯ low number of technicians/ engineers
- ◯ Others (Specify)

23. Does the hospital/organization have a way of measuring results and knowing how well maintainers do their work?

24. If yes, how do you measure it?

- ◯ Yes
- ◯ No

25. If yes, how do you measure it?

26. Does the hospital/organization do decommissioning of equipment

- ◯ Yes
- ◯ No

27. Does the hospital/organization do disposal of equipment?

- ◯ Lifetime ended
- ◯ New version coming
- ◯ Asset manager sign
- ◯ Lack of spare parts
- ◯ Team approved
- ◯ All
- ◯ Others (Specify)

28. How many biomedical engineers does the hospital/organization employ?

- [ ] None
- [ ] 1
- [ ] 2
- [ ] >3

29. How many biomedical technicians does the hospital/organization have?

- [ ] None
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] >4

30. At your work place, Do Biomedical Engineers/ technicians focus on medical equipment only or they maintain every equipment?

- ◯ Yes
- ◯ No

31. How many hours a biomedical engineer/technician works per day at your hospital/organization?

- ◯ <8Hours
- ◯ >Hours

32. Do you work overtime?

- ◯ Yes
- ◯ No

33. If yes on Q32, Do you get paid for it?

- ◯ Yes
- ◯ No

34. Does the hospital/organization plan for maintenance training?

- ◯ Yes
- ◯ No

35. If yes on Q32, Who pays for maintenance training fees

- ◯ Hospital/ Organization
- ◯ Maintenor
- ◯ Manufacture/ Contractors

36. How do you keep the information of medical equipment maintenance?

- ◯ Manually
- ◯ Computerized management system
- ◯ Both
- ◯ Other (Specify)

37. Does Maintenance department have direct telephone line to communicate with nurses or Doctors easily?

- ◯ Yes
- ◯ No

38. If no on Q32, how do nurses report incidents that happen when they need help from Maintenance department?

- ☐ Fixed Telephone
- ☐ Personal mobile
- ☐ Writing a letter asking and submit it to the Maintenance department

39. What are challenges are you facing as biomedical Engineers/technicians

40. What advice can you give to improve the management of medical equipment maintenance?