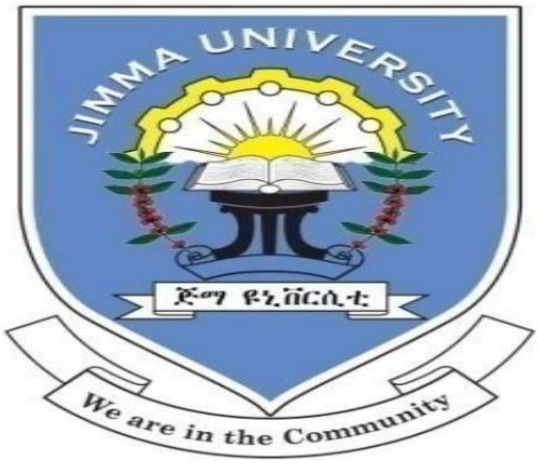


Jimma University School of Graduate Studies

Jimma Institute of Technology

School of Biomedical Engineering Bioinstrumentation Stream

Development, Implementation and Evaluation of Evidence-based Training Model and Computerized Maintenance Management System for Improved HTM: Case Study at Selected Jimma Zone Hospitals, Southwest Ethiopia

A Thesis Final Document Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Biomedical Engineering (Bioinstrumentation Stream)

By: Tessema Tameru (RM0209/10)

February, 2021

Jimma, Ethiopia

Jimma University School of Graduate Studies

Jimma Institute of Technology

School of Biomedical Engineering Bioinstrumentation Stream

Development, Implementation and Evaluation of Evidence-based Training Model and Computerized Maintenance Management System for Improved HTM: Case Study at Selected Jimma Zone Hospitals, Southwest Ethiopia

A Thesis Final Document Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Biomedical Engineering (Bioinstrumentation Stream)

Main Advisor: Dr. Timothy Kwa (PhD)

Co-advisor: Mr. Gelan Ayana (PhD Candidate)

February, 2021

Jimma, Ethiopia

DECLARATION

I declared that this final research project document is my original work and has not been presented for a degree in any other university and I assure it with my signature.

Name: Tessema Tameru

Signature:_____ Date: Feb. 16, 2021

On behalf of the School of Biomedical Engineering at Jimma University, Jimma Institute of Technology, we the advisors of this research with the title of **"Development, Implementation and Evaluation of Evidence-based Training Model and Computerized Maintenance Management System for Improved HTM: Case Study at Selected Jimma Zone Hospitals, Southwest Ethiopia"** and I, the evaluator, confirm that this research report is approved as M.Sc. in Bioinstrumentation thesis work for the student.

Main adviser: Dr. Timothy Kwa (PhD)

Signature _____ Date: Sept. 23, 2020

Co-advisor: Mr. Gelan Ayana (PhD Candidate)

Signature _____ Date: Sept.25, 2020

External Examiner Name: Masreshaw Demelash

Signature:_____ Date: March 19, 2021

Internal Examiner Name: Wasihun Alemayehu

Signature:_____Date:_____

ABSTRACT

In resource-poor environments, the shortage of usable medical equipment has a detrimental impact on healthcare. More than 50% of innovations in developing countries and over 40% in Ethiopia are projected not to be in use, not to be used correctly and optimally, and not to be maintained invariably. The shortage of spare parts and highly trained technicians are the most widely cited factors. There is little information, however, to support these theories and to produce evidence-based solutions. This study determined and discussed the unique barriers that block the successful development and utilization of healthcare technology at 6 Jimma zone hospitals. To identify the need for changes, data was gathered and examined on the general characteristics of the hospitals, type and status of all available equipment, and major causes of failures and knowledge required to restore 11 most available types of equipment as well as the systems which provides utilization, maintenance, and repair of biomedical equipment. Afterwards, a unique model of evidence-based intervention solution incorporating technicians' capacity building was designed and implemented by considering all major and directly contributing factors. In addition, a computerized maintenance management system (CMMS) package with a remote access feature, that best suits the needs in the hospitals was locally developed and implemented. After 4 months, a matched cohort study was conducted to determine the impact of the intervention program on healthcare infrastructure and technicians' productivity.

The condition of the hospitals is largely dependent on infrastructure and finances, management problems, and needs for training. All hospitals lacked a proper program scope, effectiveness, and efficiency for utilization, coupled with the maintenance and repair. A total of 161 repair conditions (88 out-of-service at the time of analysis and 73 completed) were examined. Among the 73 completed repairs, 34 were adequately recorded on paper, and among 39 cases registered from technician's memory, only the 32 sufficiently described cases were selected to identify the required skills. Power fluctuation for problems related to power supply and other electrical components as well as aging, and lack of proper handling and PM operations for the mechanical and plumbing related problems, were among the main factors for equipment being out-of-service. After reviewing repair needs, we found that 82% of them involved electrical, mechanical, plumbing, and user training areas of knowledge. These variables have therefore become key elements of the established systematic intervention approach and customized CMMS package. With a 2.11 odds ratio (17% vs. 36%), hospitals with technicians in the program have substantially fewer out-of-service equipment. 70% of broken equipment is due to missing parts and consumables in intervention hospitals, compared with 36% in control hospitals (95% increase). Intervention hospitals have large quantities of repairs recorded on paper (73.5% vs. 25.5%) and report significant differences in all informal equipment interactions, including participation in the procurement process. In Ethiopia, they seek assistance twice as often and outside of Ethiopia, 4 times higher. Overall, by actively using and exchanging taught skills, the unique training curriculum greatly enhanced healthcare. Policy-based guidelines for the Federal Ministry of Health, regional and zonal health departments, Ministry of Science and Higher Education, and medical equipment managing staff and CEOs of the respective hospitals were recommended by the findings review and evaluation.

Key words: Medical devices, Availability, Utilization, Functionality, Management, Evidence-based, Jimma zone hospitals, CMMS, Intervention, Control.

ACKNOWLEDGMENTS

First and foremost, glory be to Almighty God for helping me all the way through the whole endeavor and owing me strength with health and power to complete this work.

Secondly, I would like to express that I am privileged for JiT, School of BME for providing me opportunity to upgrade my academic career and attend the MSc program. I am humbly grateful for Jimma zone health bureau, hospitals administrators, and BMEs and BMETs who participated in the research project. Most sincerely, I would like to express my deepest gratitude to my advisor Dr. Timothy Kwa and co-advisor Gelan Ayana for their highly valuable guidance on working my graduate research project and to all my instructors who have taught me at Jimma Institute of Technology.

Thirdly, I would like to say thanks a lot to all my friends who shared their continuous unlimited help and kind support. Specially, my gratitude goes to my friends Mr. Hailu, Mr. Alexander, and Ms. Lielt for supporting, inspiring and guiding me in each and every of my activities.

Finally, my special thanks go to my parents, brothers and sisters who are always been there in times of difficulties and giving me moral support to complete this research work.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AAiT - Addis Ababa Institute of Technology,

AgGH - Agaro General Hospital

AwPH - Awaitu Primary Hospital

BME - Biomedical Engineering

BMET - Biomedical Engineering Technicians

BTA - Biomedical Technician Assistant

CDC - Center for Disease Control

CEO - Chief Executive Officer

CM - Corrective Maintenance

CMMS - Computerized Maintenance Management System

EBDM - Evidence Based Decision Making

EHNRI - Ethiopian Health and Nutrition Research Institute

EPSA – Ethiopian Pharmaceutical Supply Agency

ERA - Ethiopian Ray Authority

FFS - Fee for Service

FDRE - Federal Democratic Republic of Ethiopia

FMoH - Federal Ministry of Health

FMoI - Ministry of Industry

FTE - Full Time Equivalents

GO - Government Organizations

HIV - Human Immune Virus

HTM - Healthcare Technology Management

ICAP - International Center for AIDS Care and Treatment Programs

ICU - Intensive Care Unit

IDE - Integrated Development Environment

IPM - Inspection and Preventive Maintenance

IT - Information Technology

JiT - Jimma Institute of Technology

JUMC - Jimma University Medical Center

JVM - Java Virtual Machine

KOFIH - Korea Foundation for International Healthcare

Koica - Korea International Cooperation Agency

LGGH - Limu Genet General Hospital

MD - Medical Director

MoSHE – Ministry of Science and Higher Education

NGO - Non Governmental Organizations

OHB - Oromia Heath Bureau

PHC - Primary Health Care

PHP - Hypertext Preprocessor

PM - Preventive Maintenance

RHB - Regional Health Bureau

SEA - Situation Evidence Action

SGGH - Shenen Gibe General Hospital

SPH - Seka Primary Hospital

SPSS - Statistical Product and Service Solutions

TAGHT - Technical Advisory Group on Health Technology

TVET - Technical and Vocational Education and Training

USAID - United States Aid for International Development

WHO - World Health Organization

DEFINITIONS

Health technology: Usage of coordinated knowledge and skills in the form of instruments, medications, vaccines, processes and systems designed to resolve health issues and to improve the quality of life. It is used with health-care technology interchangeably.

Medical device: An object, tool, apparatus or machine used for the preventing, diagnosis or therapy of disease or illness, or for the purpose of investigating, testing, preserving, correcting or manipulating the structure or function of the body for a specific purpose of health. The purpose of a medical device is usually not accomplished by pharmacological, immunological or metabolic means.

Medical equipment: It include medical devices needing calibration, servicing, repair, user training and disposal which activities normally handled by clinical engineers. Medical equipment may be used either alone or in conjunction with any accessory, consumable or other medical equipment for the specific purposes of diagnosis and treatment of disease or therapy after injury or illness. Medical equipment includes various diagnostic, laboratory, surgery and dental medical instruments excluding medical devices that are implantable, disposable or single-use.

Acceptance testing: The preliminary checkup made on a piece of medical equipment before putting into medical service. It is the process of inspecting a medical equipment when it first reaches in the healthcare facility. It is checked to make sure that it is the same with the purchase order, functionality specification as well as proper installation and user training arrangement.

Calibration: Making periodical adjustment or correction on the output level of some medical equipment, mainly those with therapeutic energy output, for instance, ESUs, defibrillators, physical therapy stimulators, as well as other laboratory and vital sign measuring equipment that needs high degree of output accuracy which include ECG, pulmonary function analyzers, patient scales, and others. It is performed by measuring the output energy levels or other values and comparing them with the manufacturers specifications or other known standard to make sure there is no difference from the indicated levels.

Clinical engineering department: One of the working departments of a healthcare facility with a staff of engineers/technicians who are responsible for the maintenance and management of medical equipment. Some alternative names used to refer this department depending on country or some context include: ‘biomedical engineering department’, ‘medical equipment management unit’, ‘medical equipment maintenance department’ and other. We used ‘clinical engineering department’ most often in this document.

Corrective maintenance (CM): A process of work performed on a device after a failure, which is used to return the physical reliability, safety and/or other performance. It is regarded equivalent with the terms unscheduled maintenance and repair. In this document**,** we referred CM interchangeably with repair.

Failure: The situation of an equipment not meeting the required performance or safety measures, and/or a lack of physical integrity. A failure is fixed by repair and/or calibration.

Inspection: A necessary scheduled activity that performed to make sure a piece of medical equipment is working correctly. It involves both safety inspections and performance inspections. It is performed in combination with PM, CM, or calibration but it can also be done as a separate work scheduled at specific intervals.

Inspection and preventive maintenance (IPM): All the necessary scheduled interval activity that worked to make sure a piece of medical equipment is working correctly and is well maintained. IPM therefore includes both inspection and preventive maintenance (PM).

Performance inspections: Testing activities performed to assess current condition and check the functional status of a medical device. The performance test results are compared with the technical specifications determined by the manufacturers' maintenance or service manual. It sometimes referred as 'performance assurance inspections'.

Preventive maintenance (PM): PM includes maintenance activities performed to prolong the life of a device and prevent failure. It is usually scheduled at particular intervals and includes specific maintenance activity procedures established by the manufacturer. Such activities include cleaning (e.g. filters), lubrication, replacing parts that are likely to wear (e.g. bearings) or which have a limited life (e.g. tubing). PM is sometimes referred to as 'planned maintenance' or 'scheduled maintenance'. This document referred these terms interchangeably.

Safety inspections Activities performed to make sure about electrical and mechanical safety of a device. Such inspection activities may also include safety checks for radiation, dangerous gas, and chemical pollutants. While inspections are performed, the results are compared with manufacturer's specifications and country or regional standards as well. The safety inspections frequency are usually determined based on regulatory requirements and they may be different from IPM and performance inspections.

CHAPTER ONE
INTRODUCTION

1.1 Background

Although medical devices are essential for all aspects of healthcare, the availability of adequate and functional medical devices in low and middle income countries remains a significant barrier to improving health outcomes [1]. Essential medical products must be accessible at the appropriate level within the health care system at all times [2]. The increased ability to anticipate, avoid, diagnose and cure many diseases and to mitigate functional disorders by the use of medications and technologies is correlated with improved health changes for a vast majority of the population [3]. A well-functioning health system ensures fair access, along with scientifically sound and cost-effective use, to appropriate vaccines, medical products, and healthcare technologies of assured quality, safety, and efficacy [4].

An extraordinary range of properly balanced and controlled resource inputs is needed for the provision of equitable, quality and sustainable healthcare [5]. The primary types of these inputs include physical resources such as fixed assets and consumables, also defined as healthcare technology. Health technology is the medium on which healthcare delivery is structured and serves as the foundation for the provision of all interventions related to health. Generating, acquiring and using health technology requires massive investment, so relevant decisions need to be taken carefully to ensure the best match between the availability of technology and the needs of the health system, an acceptable balance between capital and ongoing costs, and the ability to maintain health technology throughout its lifetime [5].

Healthcare technology has grown to be an increasingly noticeable policy issue, and in recent years, strategies for HTM have repeatedly come under the spotlight [6]. Although numerous international forums have long recognized and addressed the need for improved HTM practice, health facilities are still burdened with a multitude of problems in many countries, including non-functioning medical equipment due to factors such as insufficient preparation, inappropriate procurement, poorly coordinated and controlled professional health care services, and a shortage of skilled personnel [6]. Other physical assets in the healthcare sector, such as buildings, plants and machinery, furniture and appliances, communication and information systems, catering and laundry facilities, waste management facilities and vehicles, are similar [5].

The lack of physical asset management affects the quality, productivity and sustainability of health services at all levels, whether in a tertiary hospital setting with advanced life-support facilities or at the primary healthcare level, where basic facilities are required for patients to be effectively diagnosed and treated safely. A critical mass of inexpensive, sufficient, and properly operating equipment used and deployed correctly by trained staff, with minimal risk to patients and to themselves, is vital at all levels and at all times [5]. Specific policy, technological guidelines, realistic tools and, most importantly, evidence-based solutions are required to ensure that healthcare technology is effectively and efficiently managed in order to have an impact on priority health challenges and the capacity of the healthcare system respond appropriately to healthcare needs and expectations.

On the other hand, sadly, designing healthcare technology for the developing world market poses specific problems not seen elsewhere. Present failures are the clearest proof of these challenges; the 'HealthCare for Everyone by 2000' project [8] is one example. To carry out major health improvements, several proven, inexpensive technologies were chosen. The campaign was largely a failure, despite some early success [8]. Many other writers have also dramatically claimed that in the developing world, much of the medical equipment is broken. Certain claims were ambiguous. Bracale and Pepino, for instance, only stated that "a great deal of equipment in most health structures in developing countries is out of order" [10]. Some have been more specific, such as Frize and Cheng [11], reporting that more than 60% of medical equipment is out of use in developing countries. The other paper on the Brazilian case stated that up to 96% of medical devices were out of service [17].

Studies worked on the issues of medical equipment in Ethiopia indicated that more than 40% of medical equipment found in public hospitals and other health facilities is estimated to be not usable [12, 19], whereas the WHO reports that about 50% of medical equipment in developing countries is not operational, is not being used properly, is not being used optimally and is not being maintained invariably [3]. Irrational usage, unavailability of spare parts, lack of inspection, preventive maintenance and contractual repair arrangements with suppliers are some of the recorded explanations for recurrent dysfunction.

Such large quantities of damaged equipment are alarming, triggering delays or cancellation of surgery, restricting opportunities for treatment; accurate and timely diagnosis remain elusive. However, although the shock factor of healthcare technology statistics in the developing world is

high, the empirical validity is limited because verifiable evidence has rarely been supported in the studies. With sustainability measures, there is a need to address this issue.

1.1.1 The Healthcare Institutions Landscape in Ethiopia

Over the last decade, Ethiopia has made great progress in improving the health status of the community through the Health Extension Program and expansion of Primary Health Care (PHC). It is reported that this could be achieved mostly due to a well-established coordination, high effort and intensive investment among the government, partners and the community at large in PHC to strengthen the health system and improve the quality of health care in public facilities [14].

The annual medical devices and drugs market in Ethiopia is estimated to be worth $400 -$500 million and growing at an impressive rate of 25% per annum [15]. There are approximately 200 importers of drugs and medical devices. In Ethiopia, the local manufacturing numbers for medical products is about 15 manufacturers [40]. Most manufacturers operate below their capacities and only supply about 20% of the local market. The average annual medical device procurement conducted by PFSA is estimated to be 2.8 billion birr [15].

Medical devices are resources that need to be controlled because they generally require significant investment, have a direct effect on human lives, are highly sensitive, often have high maintenance costs, and some have relatively limited lifetimes. Charities, governments and multilateral organizations are contributing medical equipment in response to this disturbing need. The WHO reports, however, that about 95% of medical devices are imported into developing countries, most of which do not meet the needs of national health care systems and are not used effectively and efficiently [7]. This has far-reaching effects for the delivery of health care and represents a tremendous misuse of scarce resources.

1.1.2 Clinical Engineering Departments in Jimma Zone Hospitals

The ultimate responsibility for the repair and maintenance program for medical equipment rests with the hospitals' biomedical department. The planning, direction, and coordination of the technical aspects of the program should be given through guidelines and instructions prepared by Jimma Zone Health Bureau. The bureau is supposed to create and sustain an efficient program in hospitals in the Jimma zone - to provide optimal maintenance and repair of medical equipment; to ensure adequate preparation for modernization programs for equipment; and to build, train and maintain a workforce to achieve the goals.

The achievement of the goals is intended to further establish and sustain an efficient program that

ensures optimum readiness of the equipment with FMoH support to maintain productivity and economy in the performance of the mission. It is planned to run the program using a combination of internal and external support services compatible with the resources available. Jimma zone hospitals are expected to set up a maintenance and repair facility for medical equipment and provide support to all aspects of the healthcare technology. The cost of supplies, equipment, spare parts, and other miscellaneous costs in setting up a medical equipment maintenance and repair facility is handled by hospital management and most of the time borne by FMoH and Oromia Health Bureau.

In the respective hospitals, medical equipment management facilities have the following activities they are responsible for discharging: designing uniform operating procedures to use both maintenance and repair services cost-effectively, introducing a command preventive maintenance and repair program to ensure all equipment is cyclically inspected and serviced, creating a job control and priority framework to ensure equitable service to all elements and units. They are also responsible to assess all medical equipment at least semi-annually for the specific purpose of recommending replacements based on maintenance histories and life expectancies, and condition code all equipment to ensure fair service to all elements and units.

Although the above goals and tasks are the responsibilities of healthcare facilities' biomedical department staff, their functional adequacy, effectiveness and efficiency are in question in carrying out their mission. It is critical that, as biomedical equipment maintenance and repair programs have grown to meet these new requirements and as its budget increases, ensuring that it is properly maintained becomes more relevant. One of the many questions that needs to be answered about challenges to healthcare technology, and existing human resources to medical equipment maintenance and repair HTM systems is: "Are we using the best combination of BME and BMET capacity building and biomedical service constraints in the country?"

To address such a question, a hospital will need to be able to recognize the specific obstacles to the availability and usage of medical devices and technology, and assess current performance to produce evidence-based solutions and examine how improvements in the program will affect that performance. At present, no system has been established by the MoE, MoH, RHBs, and the clinical engineering department of the respective hospitals to properly assess the above issue. This research was therefore intended to address the issue of identifying problems in existing resource-poor settings, and to generate and introduce evidence-based solutions to current barriers to healthcare technology in Ethiopia by conducting a case study at six hospitals in the Jimma zone.

1.1.3 Computerized Maintenance Management System

A Computerized Maintenance Management System (CMMS) is a package of software containing a computer database of information on the maintenance operations of an organization. It is a method which can enhance the overall management of medical equipment at the level of the facility [16]. Biomedical engineering departments use it to capture, store, and evaluate information on the repair and maintenance carried out on medical devices and other equipment. CMMS in HTM is used to automate the recording of all activities of medical devices, including stock planning, inventory control, corrective and preventive maintenance operations, replacement parts tracking, service contracts, and medical device recall. It is possible to evaluate and use the collected data for technology management, department management, quality assurance, work order monitoring and medical device budgeting.

The decision to automate or replace an existing HTM system to a new CMMS depends on the health facility's specific circumstances, including working practices, IT infrastructure and available budget [16]. In order to assist effectively in the management and repair of medical equipment, the CMMS must consistently address the client's needs, but no approach available offers a full solution [16]. Alternatively, to design a CMMS that best suited to local requirements, an IT company can be employed. In general, if a customized CMMS solution is well designed and implemented, a more satisfactory solution is often created that meets local needs [16].

There is undoubtedly a significant barrier to healthcare technology management in resource-poor hospitals in Ethiopia, especially in the Jimma zone. Most hospitals do not have a proper maintenance management system and some only have a paper-based management system. This was one of the reasons why we were inspired to focus on locally developing a software package along with producing evidence-based solutions to provide an effective platform for health facilities and their clinical engineering departments to complement their existing systems and strengthen overall technology management, while also contributing more efficiently to the delivery of health care. In order to minimize the operating complexity of the application, and to make the clinical engineers get access to the system remotely, we used a Remote Method Invocation (RMI) mechanism to build distributed applications that allows our software to reside in different computers and able to access/invoke the database running on another computer using a Local Area Network (LAN).

Figure 1.1 shows a CMMS feature flow chart that was developed based on a study of several commercial CMMSs and combines several different systems' best practices. The CMMS can be used as a tool by clinical engineers to supplement their current HTM program and help them reach

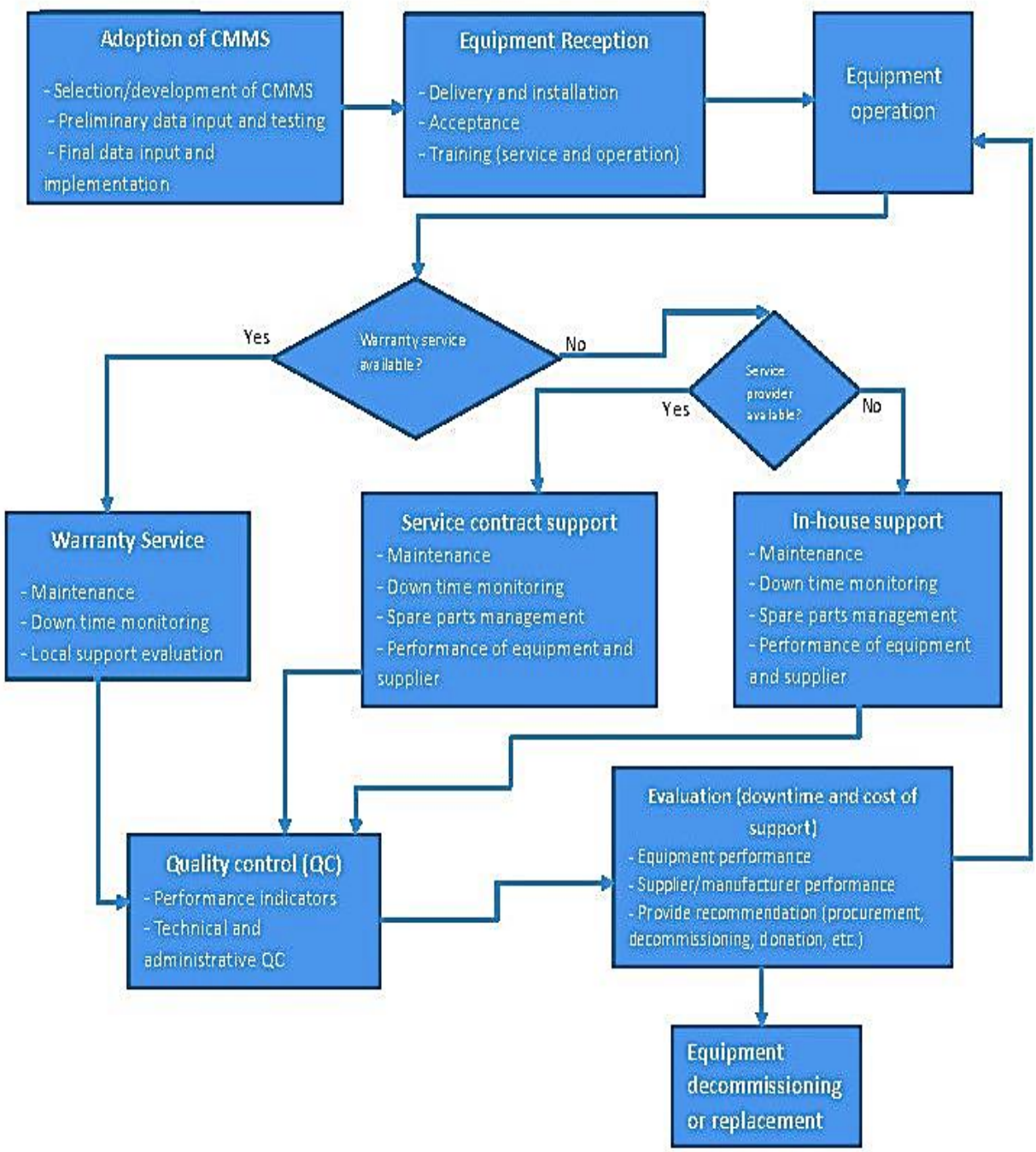


Figure 1. 1 CMMS functionality flowchart.

clear goals for their departments. Implementing a successful CMMS would enhance patient safety by handling and maintaining medical equipment effectively to ensure that it works consistently [16].

1.2 Literature Review

In the literature, the diversification of approaches to medical equipment problems in resource-poor environments is not well documented. There are, however, several studies reviewing specific barriers to the effective design and dissemination of medical devices in the developing world. In essence, few of them worked on quantifying the amount of out-of-service medical equipment, along with explaining the key cause of the issues, and the skills and expertise required to repair the failures.

On the other hand, the various approaches for performing medical equipment maintenance and repair have been well recorded in the literature over the years. The Journal of Clinical Engineering is published four times a year, with at least one article on a specific hospital's approach to medical equipment maintenance and repair in almost every issue. The articles essentially describe the hospital's infrastructure, the need for a medical equipment maintenance and repair program, and the effectiveness of the program that was implemented. What's missing is that none of the papers describe the decision-making process that led to the selection of the medical equipment maintenance and repair program.

A good example of the different studies on causes of non-functional medical equipment in resource-poor hospitals of developing countries and approaches needed to fix back the failures was identified by Engineering World Health (www.ewh.org, an NGO that works to build and provide appropriate healthcare technology to the poorest hospitals in the world), published in 2010. They wanted to find out the degree to which out-of-service medical devices could be put back into service without the use of imported spare parts being required [18]. From 60 resource-poor hospitals in 11 countries in Africa, Europe, Asia, and Central America, they analyzed 2,849 medical equipment-repair requests (which 2,529 equipment were out-of-service). An engineer or an engineering student examined each piece of equipment and a repair was undertaken using only locally available materials [18]. They concluded that the engineer's problem analysis was accurate if the piece was put back into operation.

A total of 1,821 medical equipment pieces, or 72%, were put back into operation without the use of imported spare parts being needed. Of those repaired items, 1,704 were properly reported to assess what skills was needed to bring the equipment back into operation. They discovered that 99 percent of repairs required six areas of knowledge: “electrical (18%), mechanical (18%), power supply (14%), plumbing (19%), motors (5%), and installation or user training (25%)” [18].

Their further review of the domains reveals that 66% of the out-of-service facilities were put back into service using only 107 basic knowledge skills in each domain; much less knowledge than that needed by a BME or BMET [18]. They conclude that, without importing replacement parts and using only basic knowledge, a vast majority of laboratory and medical equipment can be placed back into operation. The main concern with these findings, however, was that the distinctive characteristics of the research hospitals (infrastructure and technical skills available) and their associated effect on the conclusion are obviously one component that is discussed very little. In addition, their method of acquiring data was too general and did not include Ethiopian hospitals as a research area.

Lora Perry and Robert Malkin from Duke University, Department of Biomedical Engineering, Research Laboratory for Developing World Medical Technology, demonstrated another study of medical equipment issues in the developing world. The article was titled "Effectiveness of donations of medical equipment to improve health systems: How much medical equipment in the developing world is broken?" [19]. They quantified the magnitude of out-of-service medical equipment and categorized the various factors determining the condition of the equipment outside the equipment itself.

Over the years 1986-2010, they analyzed original inventory data from fifteen nations covering the Americas, Africa, and Southeast Asia [12, 21-26]. They only had inventories that indicated that they were inventorying medical equipment exclusively, or that the non-medical equipment could be excluded. They collected data for 112,040 pieces in total, in which 93% was from the developing world. The literature stated that, among those, they analyzed data for more than 100,000 pieces of medical equipment [19]. Their data does not support the most drastic assertions. They concluded that, on average, just about 40 percent of medical equipment is out of use in resource-poor settings [19]. They did not find any documentation to support the reporting of more than 50 percent (rounding up) of out-of-service medical equipment.

Analyzing the introduction to the inventory details, they found that the widely cited reasons for out-of-service equipment included the absence of spare parts, the absence of disposables, and the absence of accessories required [12, 22, 23]. Also popular were HTM issues. Users have also refused to report equipment issues to technicians or administrators, regardless of fault [12]. Standard preventive maintenance schedules [12, 22, 23, 25, 26] have seldom been followed, leading to early breakdowns and problems escalating. Administrators or donors were left to make procurement decisions without technical advice in most systems [12, 25, 26].

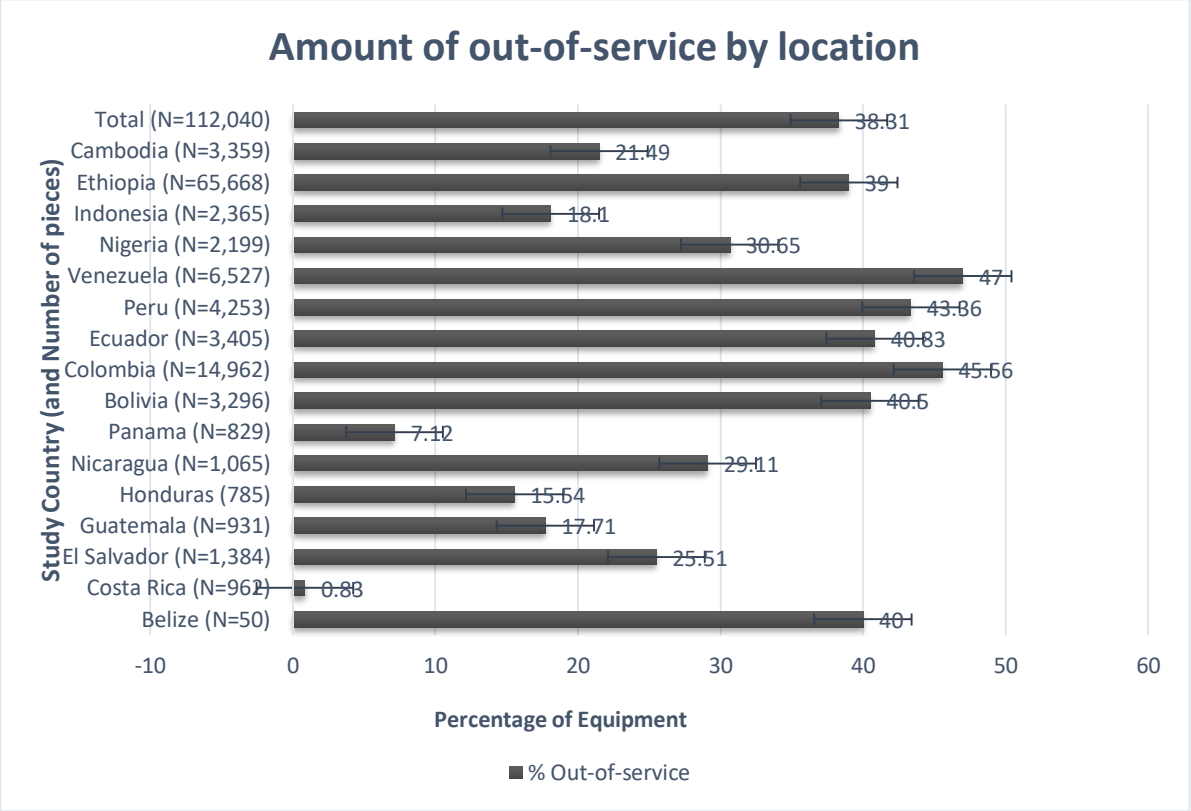


Figure 1. 2 Data showing the amount of medical equipment pieces out-of-service by the location from 16 countries. The study conducted; in 1986 for Belize, Guatemala, Costa Rica, El Salvador, Honduras, Nicaragua and Panama; in 1987 for Bolivia, Colombia, Ecuador, Peru, and Venezuela; in 1991 for Nigeria; in 2005 for Indonesia; in 2008 for **Ethiopia**; and in 2010 for Cambodia.

In the medical ranks, capacity building is frequently considered, but it is also a medical equipment problem. Technicians, however, are not the only ones who need to consider their technology. A basic level of knowledge is important for users, administrators, and donors. Users have not been educated in the proper use or handling of equipment in many systems, leading to avoidable break-downs [12, 22, 23]. There was always a disparity between their expertise and the level of technology when technicians were available to attempt repairs or maintenance [23, 26]. Sadly, it has been documented that technicians with even basic training are scarce. Lora Perry and Robert Malkin also stated that in some regions, more than half of the technicians, and even the heads of maintenance departments, were not formally trained biomedical technicians [12, 26].

The study may, however, underestimate the number of pieces that are out of service. To build the study, they relied on recorded equipment status reports from hospitals. Hospitals may neglect some equipment that has never entered their inventory, missing inventory of equipment, or may lack technicians to perform a detailed inventory for the management team. It is expected, in any case, that many hospitals are underreporting their broken equipment. In addition, they relied on the

introduction of inventory data, which may not have sufficient details on the equipment under study. Moreover, this approach provided the only quantity and possible factors of out-of-service equipment. There is no review found in the literature to base a decision on what kind of solutions should be introduced and what kind of strategies should be pursued for the maintenance and repair program to resolve the identified challenges and burdens associated with the healthcare infrastructure.

In most literature studies, the issue of availability of medical equipment in resource settings was just a cause of problems. However, some have recorded the entire process, from the procurement process to the usability at respective hospitals, by analyzing issues with the provision of medical equipment systems to identify opportunities for improving healthcare systems. Research conducted by Dane Emmerling, Alexander Dahinten, and Robert A. Malkin [20] is a good example. The number of donated, purchased and loaned out-of-service medical equipment was assessed and the obstacles to their return to hospital service in Honduras, Rwanda and Cambodia were recorded.

A cross-sectional analysis of 3421 of medical equipment pieces in five departments of 64 hospitals was conducted from 2010 to 2012 [20]. The period after arrival, source (donated, bought or lent), status of the service contract, and functionality have been determined. The obstacles to bringing the unit back into operation have been recorded for any partial or non-functional equipment. Donated equipment was substantially more subjected to be out-of-service than purchased and loaned equipment added, they reported in the first year. But, 5 to 6 years after arrival, purchased equipment was more prone to be out-of-service compared to donated equipment, and loaned equipment had the highest in-service rates [20]. They also found that, except for high-complexity equipment, service contracts did not substantially decrease out-of-service rates [20].

According to their study technicians, the main hurdle to bringing equipment back into operation was access to spare parts, components and consumables. They recommended that the training of local technicians and the leasing (rather than donating or buying) of equipment, in order to boost the availability of medical equipment and thereby increase access to medical procedures, may be the most sustainable and efficient points of intervention, given the considerable out-of-service rates [20]. Their report, however, only classified the obstacles to getting the equipment back into operation with its source of provision. What is missing is an appraisal of the current in-house biomedical maintenance and repair program that could produce further evidence of the challenges found. In addition, they indicated that training could be an effective method of intervention despite

not having defined any form of information about a training domain that should be introduced to resolve the problems.

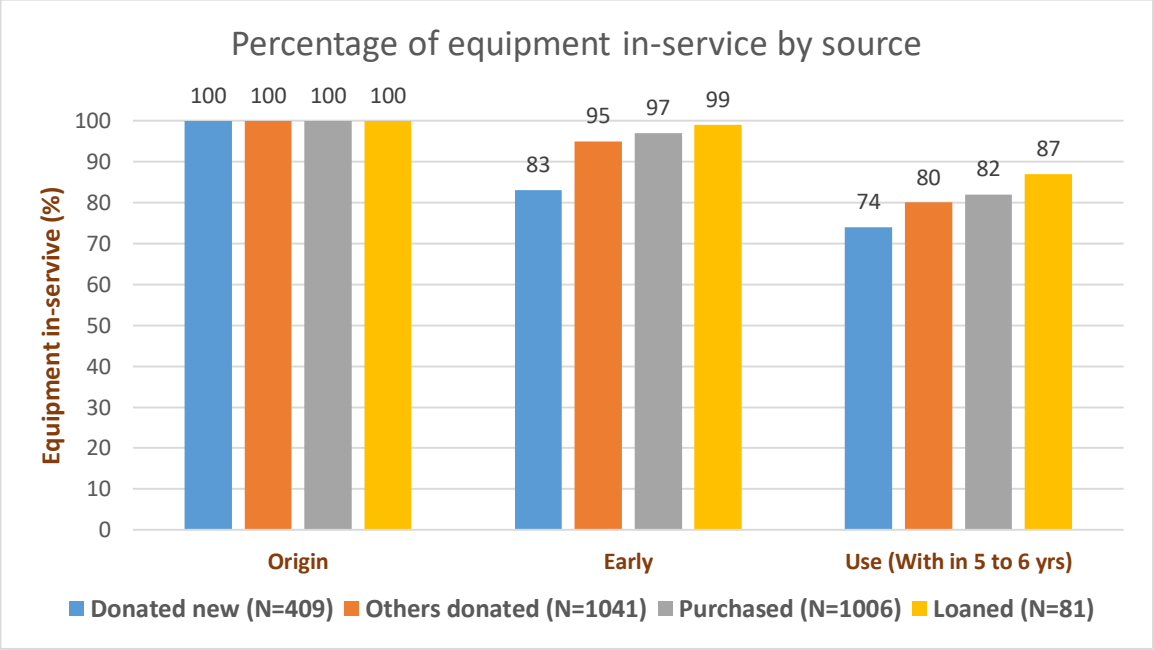


Figure 1. 3 Amount of in-service equipment at origin, early use and during use in 5 to 6 years period. The N's show the total number of pieces under each category. One bar 'Origin' is based on the assumption that before shipping, 100% of all equipment was working.

There are also other literatures that describe the numerous healthcare technology related issues encountered in the developing world in general. There is, however, very little published literature on the specific barriers to the development and introduction of healthcare technology for healthcare facilities found in Ethiopia, especially in the current context of Jimma zone hospitals. After rogueries review, we found one literature worked in Jimma zone hospitals on the availability and usage of medical devices, which was published by Beyene Wondafrash and others in 2013[29].

The main objective of this article was to study the availability and use of medical devices and to identify reported reasons related to medical device problems in three Jimma Zone hospitals [29]. Data were collected by observing the equipment, interviewing selected practitioners and reviewing health care services. According to the observation and checklist interview, 299 pieces of medical equipment were available in the three hospitals in August 2013 [29]. 196 (65.6%) were available at Jimma University Specialized Hospital (now Jimma University Medical Center), while the remaining 57 (19.0%) and 46 (15.4%) were from Limu Genet and Shenen Gibe hospitals, respectively.

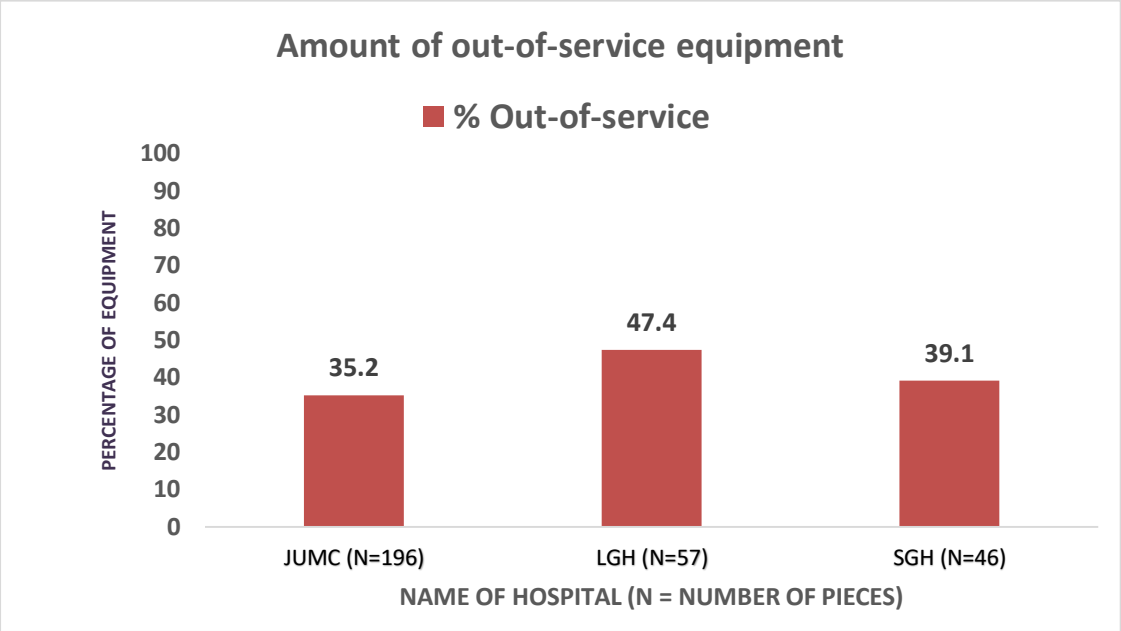


Figure 1. 4 Functional status of equipment in three Jimma zone hospitals in August, 2013

Among the 196 medical equipment in JUSH, 127 (64.8 %) were functional and the remaining; 63 (32.1%) and 6 (3.1%) were out-of-service and not-in-use respectively. Correspondingly, 28 (60.9%) and 30 (52.6%) of the equipment in Shenen Gibe hospital and Limu Genet Hospital respectively was functional [29].

In the three research hospitals, more than a third of the medical devices were not working. Buying medical devices with bids and a preference for low prices were listed as factors affecting their availability and usage, as were a lack of training on how to operate them, a lack of sense of duty, power outages, staff job overload and a lack of maintenance experts, and an inadequate referral system [29]. Nevertheless, like the other research, they have not done evaluation of the current in-house biomedical maintenance and repair program, and they have not suggested any appropriate method of intervention and unique kind of knowledge training area that should be introduced to address the challenges.

1.3 Identified Gaps and Proposed Solution

All study, in general, was common in nature and went a long way to quantifying the sum of out-of-service equipment and recognizing the obstacles to healthcare technology in the developing world. The majority of the literature contained guidelines and supportive ideas about how to consider the problems found in pursuing a well-functioning health system to ensure equal access to critical quality, reliability, efficiency, and scientifically sound and cost-effective medical products and technologies. None, however, included either performance metrics and expectations or a decision

model as part of the study to help the role or to further analyze the program following the implementation of guidelines. In addition, we found no paper that specifically explained the utilization problems and created evidence-based solutions to the barriers found in the healthcare technology facilities of the Ethiopian Hospital in general or the specific context of Jimma Zone Hospitals.

Therefore, the focus of this project was development, implementation and evaluation of a new and unique evidence-based model of BMET continuing training curriculum and CMMS for improved HTM and healthcare in resource - poor settings of Ethiopia by performing case study at six Jimma Zone Hospitals. The project had three different stages. First, we identified the problems and provided evidence on the reason behind why there is a lack of working medical equipment access, and the barriers which inhibit the equipment from returning to function. A comprehensive evaluation of the present system which provides maintenance and repair for biomedical equipment at the six study hospitals is also performed.

Second, every piece of out-of-service equipment was analyzed and categorized according to the equipment type, problem type and repair method based on the equipment failure to identify what knowledge and skill was required to complete the repair, and HTM and professional development skills needed for technicians' capacity building are identified by considering all major components and directly contributing factors for the healthcare technology problems found in Jimma Zone Hospitals. And then a new evidence-based solution of the training curriculum and maintenance model was designed. A CMMS that best suits the needs for Jimma Zone Hospitals HTM problems was also locally developed and implemented.

Finally, the new approach was implemented at the hospitals and evaluation study was performed at the clinical level to determine if the program was an effective way to reduce the number of out-of-service medical equipment, and improve HTM and healthcare by assessing its impacts on different variables using control groups matching with the intervention groups.

1.4 Research Questions

The constant dilemmas and questions about medical equipment problems in resource-poor Jimma zone hospitals suggested that a thorough analysis of the situation in terms of specifications, implementation, and results was needed. The following are the key questions addressed by the research project:

1. What percent of medical equipment in Jimma zone hospital settings is not-in-service?

2. What are the possible causes for medical equipment is being out-of-service in Jimma zone hospitals? Who is affected? What do they know, think and act on the problem?
3. What is the most needed domain of knowledge required to complete the repair for medical equipment failures?
4. How do donations strengthen the health system in Jimma zone hospitals?
5. How can technology be ensured to improve rather than damage health? And how should technology be deployed in an equitable, but financially sustainable way?
6. What is the best practice for the introduction of a newly designed training model and CMMS for medical equipment maintenance and repair problems faced in Jimma Zone Hospitals?
7. How can best practice be implemented most effectively to establish an effective, sustainable, accountable and evidence-based model? Which strategy is most effective?
8. How can an evidence-based model outcome be evaluated and determine the factors for success?

1.5 Scope of the Study

To conduct a research on the whole healthcare technology problems at resource poor settings of Ethiopian hospitals by designing, implementing and evaluating a new and unique evidence-based model of BMET continuing training curriculum and maintenance system for improved HTM and healthcare and make it effective it would be comprehensive and it needs a huge amount of budget and long progress. Hence, our research was limited in scope by sample size, time and geographic area. This study is focused on gathering data about the medical equipment availability and utilization with determining the unique barriers exist to the successful healthcare technology development and introduction along with evaluation of current maintenance and repair programs, and design and development of a CMMS that best suits the needs found in six Jimma Zone Hospitals.

Between June 9, 2019 and June 28, 2019, we studied the functional status of the whole devices available in the six hospitals. Then we selected 11 most available type of medical equipment in their settings, and identified the major causes for failures to generate the most needed knowledge and skills to place them back to service. The class of medical devices used for study and experimentation include: Anesthesia Machines, Autoclaves, Centrifuges (including hematocrit), Electrosurgery Machines, Infant Incubators, Infant Warmers, Microscopes, Oxygen Concentrators, Patient Monitors, Suction Machines (rotary, diaphragm, thermotic, venture), and X-ray (fixed – radiographic and/or fluoroscopic unit). They are found in departments that are highly dependent on

functional equipment and where equipment is concentrated in the area. These devices were used to implement a new approach which includes a limited sets of knowledge for equipment-specific repair training held for seven weeks between July 1 to August 26, 2019. The intervention training also included management and professional development skills needed for technicians' capacity building.

Moreover, this study measured the impact of the intervention on the healthcare and infrastructure, medical equipment in particular between December 9-20, 2019 after four months since intervention. It determined effects of the intervention in terms equipment management works, which included about: workflow and related paperwork, procurement and storage, incoming equipment processes, use of an inventory, and information on the related hospital infrastructure. It also measured the equipment life cycle and the technicians' involvement in each of the stages; technician and hospital administrators' relationship; the use of service providers and efforts to seek outside technical assistance; technicians' efforts toward corrective maintenance, PPM, user training, testing, installation and calibration of equipment. At each hospital status of the class of medical equipment which was included in equipment specific training of the program was also surveyed. Finally, the results are compared and analyzed by matching control group with intervention group hospitals.

The developed CMMS software integrates all medical equipment services into a database made up of fields, tables, modules and screens. The basic structure of developed system has 13 screen windows. The first main window allows the user to generate and analyze data from a selection of fields, tables and modules using a user-friendly filtering interface. The rest 12 windows allow the user to add and collect data with also a user-friendly interface. The (table name, and number of related fields) used to develop the system are: (Equipment type, 7), (Equipment model, 8), (Manufacturer, 6), (Seller/vendor, 6), (Spare parts, 13), (User &staff management, 10), (Training, 3), (Service provider, 2), (Maintenance, 10), (Health facility, 7), (Department, 2), and (Building, 2).

CHAPTER TWO

PROBLEM STATEMENT

2.1 Statement of the Problem

In Ethiopia, a large amount of medical equipment is out-of-service and on which access to critical medical procedures is restricted. To clarify the lack of access to functioning medical equipment, multiple reasons have been suggested. In reality, problems such as, lack of spare parts, lack of consumables, lack of reliable power and water sources, lack of public infrastructure, and other problems plague healthcare technology [27]. In addition, there is evidence [28] that, due to the lack of qualified professionals, most of this medical equipment is out-of-service. If the shortage of professionals is the issue, then teaching will be the remedy. But what type of training? In Ethiopia, in the subject of attempts to HTM capacity building for the resource-poor setting hospitals in the country, curricula built in and for resource-rich settings such as the United States or Europe have been adapted. This approach, however, presumes that the challenges faced by technicians in Ethiopia are analogous to those in a resource-rich environment. That they aren't.

Moreover, there is insufficient evidence on the problems of medical devices in Ethiopian hospitals in general, and in Jimma Zone in particular. More importantly, given the significant out-of-service rates, the most sustainable and efficient points of action to enhance the availability and thereby increase access to medical procedures are not well known. This is due to the fact that there is no evidence-based model that worked on identifying the reasons and addressing the most important unique barriers. Considering the limited resources available, determining which techniques should be implemented has become a complex problem that reflects a critical gap in the knowledge needed for proper medical equipment management and control. Consequently, an effective systematic method involving established factors of consideration to determine the most suitable HTM capacity building intervention and how to achieve it, remains undeveloped. As a consequence, the implementation and use of technology in hospitals in Ethiopia and in the Jimma zone poses many concerns that need to be addressed.

Therefore, this study was designed to improve the HTM and healthcare by identifying the unique barriers and implementing evidence-based solution to healthcare technology problems using firsthand data in 6 Jimma zone hospitals. Besides, in order to improve the overall management of the technology, we designed a CMMS to cope up with the fact that most hospitals do not have proper maintenance management systems and some have only paper based management systems.

2.2 Significance of the Study

Our approach offered an evidence-based solution that could serve as a tool for HTM for a range of practical measures, including maintenance, planning, record-keeping, workplace management, inventory management and staff management. These will allow the technicians to take care of their devices and continue to provide health services. In addition, our results have provided a responsible and comprehensive approach to ensuring that cost-effective, reliable and accessible resources are available to meet the demands of quality clinical service.

We believe that our solution could be considered a high priority and effective program that meets the needs of a specific hospital issue in the Jimma zone and possibly in Ethiopia, as it is explicitly designed for resource-poor environments that are especially relevant when resources are scarce. In order to optimize the benefit of health technology services, it will also promote timely and economical maintenance activities as it was intended for those responsible for planning, managing and implementing health technology management and maintenance of medical equipment at the facility, local, regional and national levels in Ethiopia, particularly in selected Jimma zone resource-constrained hospitals where such services not yet be fully established.

Moreover, health facilities and their clinical engineering departments may use CMMS as an important tool to supplement their current systems and enhance overall technology management, while also leading to a more efficient delivery of health care. It has the potential to enhance medical equipment management while also increasing the availability and efficiency of technology that is used to prevent, diagnose, and treat disease. There are more other benefits of using a CMMS. It requires much less staff time for data entry, maintenance tracking, and reporting; it reduces human errors; and it allows for more effective monitoring of performance metrics and employee productivity. It also provides an electronic record of equipment inventories, inspections, repairs, maintenance, and histories.

In addition, the review and evaluation of the study results identified and reported recommendations for specific organizations or health needs. These will provide valuable practical guidance to the BME department heads, human resource managers, matrons, and CEOs of the respective hospitals who are involved in the management of medical equipment programs. Besides, we recommended the major policy issues and implementation strategies that need to be addressed in order to improve the development goals and strategies of the health sector in Ethiopia. The issues and implementation strategies are recommended to FMoH, Oromia Health Bureau, and Jimma Zone Health Bureau on safety and quality of medical devices, standardization of medical device acquisition and

procurement, safe and effective utilization of medical devices, and governance and financing. With the recommendations adopted, they will help to ensure that citizens access safe and quality health services through the provision of the latest technology. They will also promote efficient and effective use of medical devices and ensure the rational use and allocation of resources.

Moreover, this study suggested the required new approach to educational institutions - Universities, TVETs who teaches BME and BMET programs in the country. The findings will also assist BMEs in their efforts to develop efficient designs for the developing world and NGOs in designing innovative healthcare interventions for the availability of equipment to increase medical outcomes and decrease morbidity rates. It will also enable hospital managers and other stakeholders to build awareness through communication as a means of solving challenges and to take informed steps for improved delivery of health care.

In general, our approach has provided a realistic alternative for healthcare organizations that do not have highly skilled technicians or engineers. For resource-poor hospital technicians, our fundamental evidence-based training and CMMS approach is necessary in order for the hospital to become almost self-sufficient and able to maintain its equipment in good working order. Patients can have access to medical equipment only in this way, which will provide them with a reliable diagnosis, successful care or proper recovery.

CHAPTER THREE

GOAL AND OBJECTIVES

3.1 Overview

The lack of explicit studies conducted on the healthcare technology problems found in Jimma Zone Hospitals required an appropriate research in answering the research questions. The methodology developed was based on a review of recent research in the developing world in general, as well as proposed guidelines in the literatures and those listed in publications for medical equipment management in resource-constrained hospitals. In developing the research methodology, besides answering the research questions as the main objective, several consecutive specific objectives were also included in order to present a comprehensive study of the Jimma zone hospitals' technology barriers including programs of medical equipment maintenance and repair. This helped to identify problem areas and generate evidence-based solutions with appropriate recommendations for healthcare improvement.

3.2 General objective

- To develop, implement and evaluate a new and unique evidence-based training model of BMET continuing training, and CMMS for improved HTM and healthcare in resource - poor settings of selected Jimma Zone Hospitals, Southwest Ethiopia.

3.3 Specific objectives

1. To gather data on medical equipment availability and utilization, and examine the present system which provides maintenance and repair for biomedical equipment.

2. To determine and discuss the unique barriers that block the successful development and utilization of healthcare technology along with specifying the major causes of failures for a class of medical devices.

3. To design a unique model of evidence-based training on knowledge and skills needed for technicians' capacity building and to implement intervention program by considering all major and directly contributing factors.

4. To locally develop and implement a CMMS that best suits the needs for Jimma Zone Hospitals HTM problems.

5. To determine and measure the impact of intervention approach on healthcare infrastructure and technicians' productivity using a matched cohort study between the 6 study hospitals.

CHAPTER FOUR

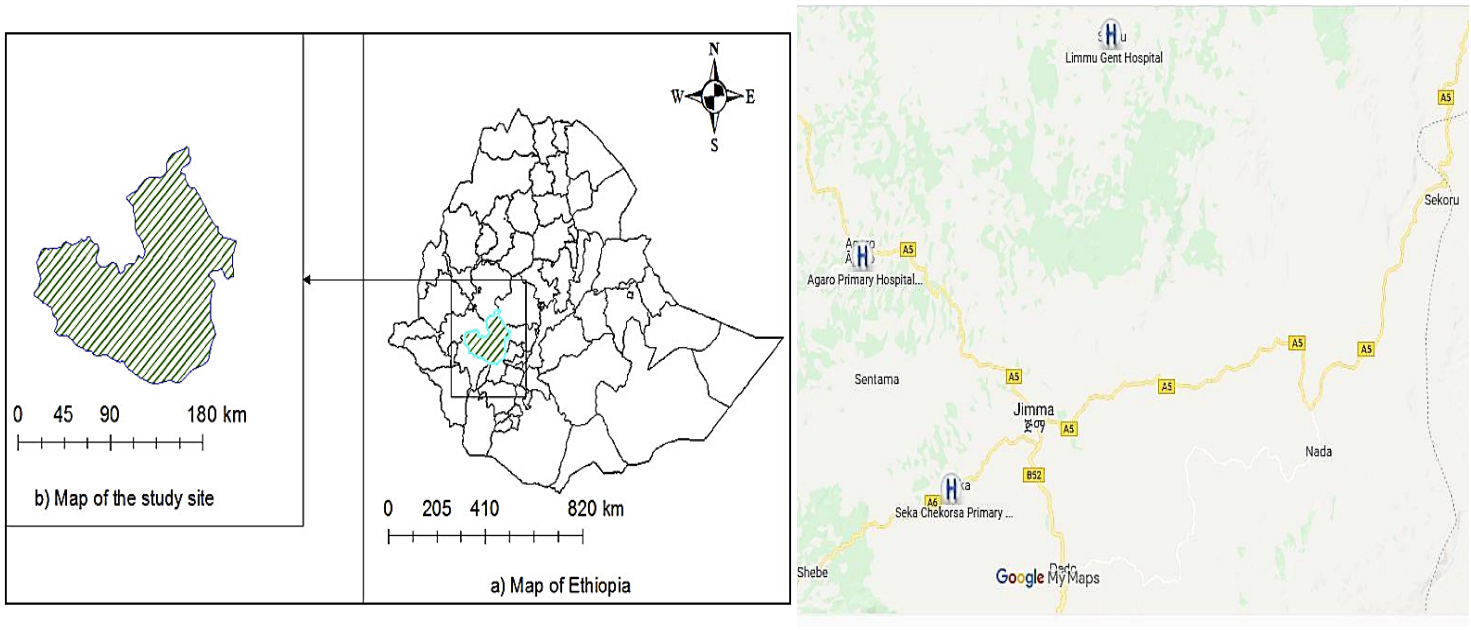
METHODS

4.1 Study Area and Period

The study was conducted from June 9, 2019 to December 20, 2019 at six selected public and private hospitals found in Jimma Zone, Oromia Regional State, Ethiopia. Jimma is the capital town of Jimma zone, which is one of the largest among 20 zonal and 19 special town administrations in Oromia Regional State. It is located in 352 km south-west from Addis Ababa, the capital city of Ethiopia. The zonal administration structure is distributed into 18 woredas (districts) and one town administration. According to the Central Statistics Agency 2007 Census report, Jimma zone has a total of 2,486,155 populations with gender variation of 1,250,527 men and 1,235,628 women; situating with surrounding area of 15,568.58 km^2 [30].

There are 770 health institutions in Jimma one, including health centers (n = 112), health posts (n = 486), private clinics (n = 156), private hospitals (n = 1), NGO clinics (n = 4), diagnostic laboratories (n = 4), and public hospitals (one referral, five district hospitals, and one zonal hospital). Based on access to basic infrastructure six hospitals were selected to conduct the study - government-funded public hospitals namely, Jimma University Medical Center (JUMC), Shenen Gibe General Hospital (SGGH), Limu Genet General Hospital (LGGH), Seka Primary Hospital (SPH), and Agaro General Hospital (AgGH) and one private-funded hospital named Awaitu Primary Hospital (AwPH). The first two public hospitals and the private hospital are situated at Jimma town where as the other are found in zonal and district towns of Jimma zone.

JUMC is one of the oldest public hospitals in Ethiopia. It was established in 1938 GC by Italian invaders and it was intended to give medical service for their soldiers [31]. For decades there was very limited physical infrastructure improvement made. However, after Jimma University had taken over its ownership, it has made a huge effort in extensive renovation and expansion work to make the hospital able to support quality service, teaching and research. To cope up with the fast growing service need and the role of the hospital in teaching, the federal government constructed a new and level-best 660 bedded facilities which started functioning in September 2015. JUMC plays a major role in this zone as it is the only Medical center to deliver with teaching, research and referral service in the southwestern part of the country, and provides specialized service to in-patients and outpatients, coming from the catchment population of about 15 million people.



A) B)

C) D)

Figure 4. 1 A) Geographical map of the study area - Jimma Zone in Ethiopia. B) Google search location of study hospitals. C) and D) represents physical facilities of two of study hospitals AgGH and JUMC respectively.

SGGH is located on other end of the Jimma city and it provides service to Jimma city communities and surrounding areas. AgGH is found in Agaro town located 48 km west of Jimma town. established as a 'primary hospital' in 2014 GC and later became general hospital in 2018. AgGH's catchment area population is estimated to be about 900,000 from six Woreda/ Town named Agaro, Gera, Gomma, Gumay, Setema, and Sigmo. AwPH is the only private hospital found in Jimma

town. It provides better quality service for several inpatient and referral cases and specializing in endoscopic treatments which don't exist in other hospitals. LGGH and SPH are other district hospital found in Jimma zone, which are located in Limu-Genet (80 km south of Jimma town) and Seka Chekorsa (18 km east of Jimma town) respectively. Figure 4.1 indicates the geographical location of study site – map of Jimma zone in Ethiopia, google earth location of the six study hospitals, and photographs of two of the study hospitals JUMC and AgGH.

4.2 Study Design and Population

This study was designed according to the SEA change model for appropriate, effective and sustainable actions needed in health technology problems. First, situation of the medical equipment was studied with contextual consideration and critical reflection of multiple perspectives. Then evidence on situational process is generated to understand the context and acquire new knowledge. Based on the situation evidence data, the question what sort of action and/or change is needed also analyzed and identified. These steps helped to move from context, data, situation, information and finally acquiring new knowledge. The next step was implementing the actions and evaluating their impacts.

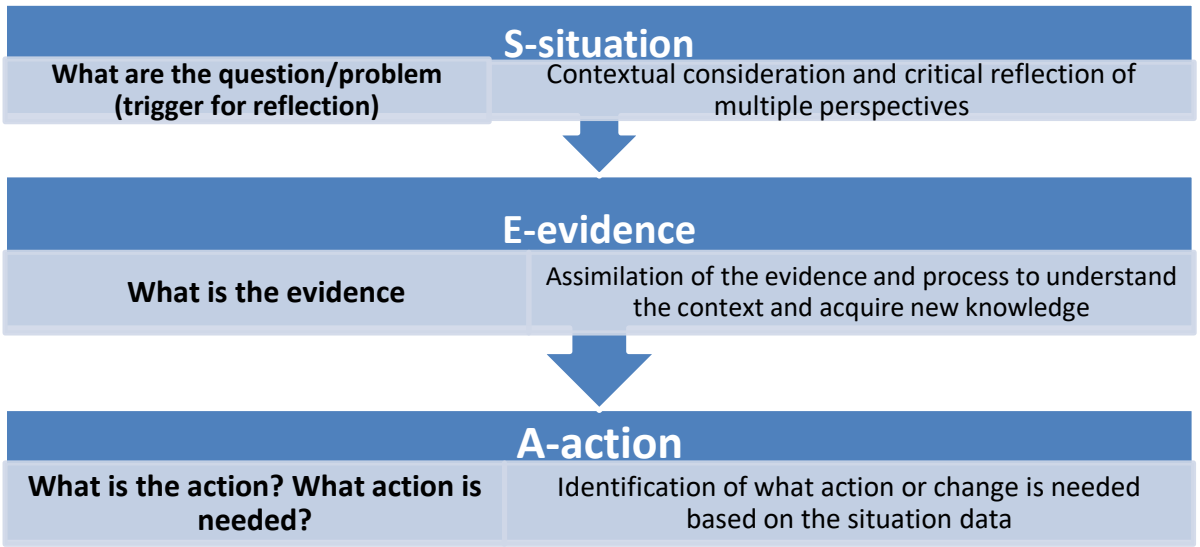


Figure 4. 2 The SEA change model study design.

The study's approach consisted of four main steps: the identification of the need for improvement, the development of a need-meeting proposal, the implementation of the proposal and the evaluation of the magnitude and effect of the change. Each phase was supported by the EBDM practices to ensure that the best evidence obtained from research and local data, the knowledge and expertise of biomedical technicians, managers of healthcare technology, healthcare personnel, and customer values and perspectives were taken into account. Checklists measuring performance attributes,

sustainability variables, and obstacles and enablers were used and implementation strategies were based on these results.

In carrying out the goals of this graduate research project, mixed approaches were used for process and outcome assessment. Initial data collection was carried out using general analytical techniques to include the literature search already presented and inquiry techniques to identify the latest decision-making systems on healthcare technology issues. In order to further delineate this method, questionnaires were used in the investigation methodology to assess the key factors influencing the existing available obstacles and the decision process. The quantitative methods included: the analysis of inventories of healthcare technology, firsthand survey on the status of available medical equipment. Qualitative approaches included observation, out-of-service medical equipment details, assessment of current repair and maintenance programs, in-depth individual and group interviews, and input forms with technical personnel, clinicians, nurses, and administrative staff. In addition, an approach to action research was introduced based on the 'researcher as facilitator of improvement' model, researcher working directly with and for individuals rather than studying them for continual refining of procedures, processes and resources. Throughout, analysis of 'what worked, what did not, why and how it could be changed' was used.

A combination of research designs was used to answer the research questions. The first analytical approach was used to complete the operations research quantitative method for generating evidence based solutions. The steps in this procedure included analyzing and defining the problem, identifying all major contributing factors, developing a model of evidence based solution, and implementing the finished model for intervention. In developing the evidence based solution model, the task was to produce a training curriculum and CMMS which is able to involve the effect of factors crucial to the solution of the problem. Hence, it was based on evidence presented from analysis of barriers for healthcare technology availability and introduction, and shortcomings of maintenance programs. The second experimental study was used in order to assess and measure the extent of intervention impacts by comparing two groups (one group was subject to the intervention, while the other group was not). The final resulting model outputs and their implications are presented along with a statement qualifying how the model should be utilized with recommended suggestions for different stakeholders.

4.2.1 Participants

All six target hospitals explained in study area were involved to perform the work. Besides the other areas of the evidence based training, the intervention was experimented with class of most available

type of medical equipment in resource-poor settings, which includes: Anesthesia Machines, Autoclaves, Centrifuges (including hematocrit), Electrosurgery Machines, Infant Incubators, Infant Warmers, Microscopes, Oxygen Concentrators, Patient Monitors, Suction Machines (rotary, diaphragm, thermotic, venture), and X-ray (fixed – radiographic and/or fluoroscopic unit). This equipment is used in departments that are highly reliant on working equipment which are places where there is a concentration of equipment.

Three stakeholder groups were participated in the design, implementation and evaluation of the new and unique evidence-based training on maintenance program and CMMS.

1. 'Investigation Team' included the researcher, second engineering expert, a third experienced licensed engineer who is with more expertise in technical aspects, and consultants with evidence-based practice.

2. 'Administrators' were biomedical engineering department heads at study hospitals who work on managing the processes related to implementation of new training and maintenance model, hospital departments with specialist staff who provided expertise to assist, monitor and guide in use of evidence and health service utilization, and Jimma zone health bureau departments with expertise in monitoring and controlling medical equipment.

3. 'Applicants' were biomedical technicians and HTM heads or clinical managers who work in respective hospitals, and hospital administrators.

4.3 Data Collection Instruments, Data Processing and Analysis

4.3.1 Identifying the Need for Change

The first stage of the project was to determine and discuss the major factors (unique barriers) exist to the successful healthcare technology development, utilization and introduction at the study hospitals. Hence, to identify the need for changes, the researcher gathered data between June 9, 2019 and June 28, 2019 on the; general characteristics of the hospitals, type and functional status of all available equipment, and major causes of out-of-service medical equipment and knowledge required to place them back to service. The present system which provides utilization, and maintenance and repair of biomedical equipment at each study hospital is also examined and discussed. Structured English format checklists for availability and use of medical devices, as well as an interview guide for in-depth interviews, have been adapted from Duke University's research lab for developing world medical technology document reviews and other related literatures, and

have been updated to suit Jimma zone hospitals. Copies of the questionnaires and checklists are provided as Appendix A.1 – A.7.

The interview-assisted surveys were used to be formally introduced to the hospital administration, gain demographic information and basic description of the hospitals. The first general information surveyed about the study hospitals include; the amount of population the hospital serve, number of beds and their usual occupancy rate? (% of beds filled on average), number of inpatients and outpatients the hospital see in a year, number of operating rooms in use and ICU beds the hospital have. The next survey conducted with hospital administrators for general information was about general equipment information (amount donated and in-service), presence of government organizations (GOs) and NGOs or other aid groups, and the use of outside sources including service contractors (SC) or service providers available. Information about the name of SCs and equipment including who signs the agreement along with the change of fee for service (FFS) over the past four-year period is also gathered. The information is also used to confirm study creation and matching of hospitals.

To verify administrator reports and to identify specific equipment, the type and functional status (functional, non-functional or not-used) of all available equipment at each hospital is recorded. Using the observation checklist, interview guide and record analysis, data was collected from workshops and various departments of the research hospitals. Biomedical technicians and store managers of medical devices have been crucial informants for in-depth interviews. A minimum of one technician was interviewed at each hospital. Often, he was the only technician at most hospitals. Any piece of medical equipment accessible in all departments has been surveyed, except for equipment stored in closets, warehouses, storage units or recycling tanks. While this approach underestimates the total quantity of out-of-service equipment, it provides a clear efficiency benchmark: only in-service equipment should be usable in patient areas.

We subsequently collected extensive information on out-of-service medical equipment, with specific focus on the class of equipment used in the research, specifying the key causes of failures and expertise needed to bring the equipment back into service. To decide why it was out-of-service, every piece of equipment was analyzed. The explanation of the issue by the user and technician, period since last usage and obstacles to putting the equipment back into operation were identified. The barrier categories were:

- Lack of authority: when, due to service contracts, warranty, or other reasons, the technician has been forbidden from working on equipment.

- Communication: when the technician didn't realize that a piece of equipment was broken or mistakenly assumed that the equipment was not needed by the users.
- Component: the absence of a consumable, accessory or spare part required was the main cause of not using the equipment. That the technicians were unable to replace, reuse or obtain locally,
- Limitation of the technician: when the technician lacked the necessary expertise or experience, did not have the necessary tools, was afraid of making the problem worse or had not touched the equipment yet.

In addition, any description of the kind of medical equipment that has been out-of-service and repaired back to service in recent times has been read from work orders or from the memory of the technician. Based on both the explanation and categorization of the equipment, the issue, and the repair, the causes of non-functional equipment failures were reanalyzed. In addition, the documents were also checked to decide what expertise was needed to complete the repair. In addition, it has been established how many pieces of medical equipment have been or can be put back into operation without needing the use of imported replacement parts and what amount of out-of-service equipment includes consumables, including reagent packs, electrodes, and other single-use items. In their workshop, the technicians were also asked about what resources they had. To support communication, a visual aid was used with photographs of the different workshop equipment.

4.3.1.1 Current Maintenance and Repair Programs Evaluation

A proper assessment of the maintenance and repair program demands that a variety of variables be evaluated. Scope, effectiveness, and efficiency quality must be considered for program evaluation. The scope defines whether all the required or needed supports are offered by the program. Effectiveness reflects how well the program meets its objectives, and performance quality offers a comparison to the existing program that can be matched with other ways of achieving the same goal. However, no report on evaluating the efficiency of the maintenance and repair program of their biomedical equipment was found in the study hospitals.

Therefore, the available mechanism that provides the use, maintenance and repair of biomedical equipment at each study hospital has been analyzed and addressed as part of identifying the need for improvement. The study was carried out in order to provide a systematic study to define, quantify and assess the success of existing repair programs. The analysis included organization of

Table 4. 1 Detail information on the nine-part program evaluation methods

Evaluation methods
1. For safety and proper performance, check all biomedical equipment. Provide systems, according to the schedules required by the regulatory agencies, for the efficient recording of the tests. Verify that the test procedures are sufficient, that the test equipment is correctly calibrated and that the testing staff are qualified.
2. Provide all biomedical equipment for timely and professional repair. Document repair costs. Provide a mechanism for tracking repair competency and downtime of equipment.
3. Provide technical assistance and methodology to assess the possible cost-effectiveness of new biomedical equipment. When equipment is bought, have proper legal and fiscal protections. Keep workers informed about recent progress in biomedical equipment.
4. Check the electrical protection of the facility's potentially dangerous areas. Provide structures, in compliance with the schedules required by the regulatory agencies, for the efficient recording of facility testing. Verify that the test procedures are sufficient, that the test equipment is correctly calibrated and that the testing staff are qualified.
5. Provide periodic reports to the administration on the cost and efficacy of the program. To ensure that the balance of in-house and outside resources is optimal, perform management analyses. To help these reports, hold current details on the cost of outside services. Provide any in-house biomedical personnel with professional technical supervision. Review all arrangements about biomedical services..
6. Establish the current legislation and requirements of biomedical safety. Provide an effective system of program documentation, including appropriate policies and procedures for recording the work carried out by both in-house and external service workers.
7. Provide an appropriate structure for the ongoing in-service training of clinical personnel with respect to electrical protection and the safe and proper use of clinical equipment at the hospital.
8. Provide an appropriate framework for managing equipment hazard alerts with written policies and procedures. Distribute danger notices of equipment to the appropriate clinical personnel.
9. Provide the safety committee of the hospital with technical assistance. Provide a framework for investigation of accidents connected with equipment. Provide strategic liaison from the hospital's liability insurance underwriters with the damage management specialists.

the program; implementation and outcomes at the six research hospitals. It performed evaluation of a combination of factors by considering scope, effectiveness, and efficiency. We used a nine-part full-service assessment guideline established by the American Hospital Association's American Society of Hospital Engineering [32], and the findings are presented and discussed. Table 4.1 provides detailed information on each of the nine areas addressed.

Finally, this formal solicitation and compilation of informed judgment was applied to Jimma zone hospitals primarily. The attribute of anonymity was used in factor development and refining rather than a group response. Hence, the evaluation identified the weak points and the major factors (unique barriers) exist in the current programs. They considered necessary to the developed systematic approach of designing the optimal method for intervention. Therefore, these factors became the key elements in designing a new and unique evidence-based training model and CMMS for capacity building at intervention hospitals to maintain a successful healthcare technology development, introduction and management with proper maintenance and repair system. They are also used to understand hospital settings and levels of technical resources to meet specific requirements.

In addition, the opinions of the investigative team and administrators were collected in group and individual discussions in order to recognize the need for change. A literature review of international practice has been conducted to define core concepts for programs of maintenance and repair. Policy papers, reports, WHO journals and academic studies that provide guidance on the implementation of a comprehensive and evidence-based approach were used. Both types of reports discussing processes, techniques, recommendations or suggestions for the adoption of new evidence-based solutions have been used. More importantly, there was a planned critical assessment related to the study design.

4.3.2 Designing and Implementing Evidence-based Training

The researchers drafted and refined proposals for program design, implementation methods and assessment plans on the basis of results from literature, local studies, and stakeholder input. Developing a proposal for change was the next step. Through identified change needs and stakeholder consultation and feedback, all major components and directly contributing factors to the healthcare technology issues found in the selected Jimma Zone Hospitals were created. A Best Practice Guide was collated and tabulated on the values described in the literature and local needs assessment.

In order to measure the possibility of progress and continuity, the investigative team with managers and applicants established obstacles and enablers to the proposed changes in individual discussions. The investigator also used the performance and sustainability checklist and the classification of obstacles and enablers to define additional variables. Barriers and enablers have also been sought in the sense of organizational decision-making. In order to provide baseline data, existing practices were mapped against the established values in the Best Practice Guide. Afterwards, a formal

evaluation plan was developed; a detail evaluation questions for each component, indicators, methods, including sources and timing of data collection.

After initial evaluation period, the researcher designed a new and unique evidence-based model of BMET continuing training on maintenance and repair system, including a limited sets of knowledge for equipment-specific repair training for a class of devices, and management and professional development skills needed for technicians' capacity building by considering all major components and directly contributing factors for the healthcare technology problems. Following the model design, the new and unique evidence-based of BMET continuing training was implemented at the intervention hospitals between July 1 to August 26, 2019 and the next step was determining the effects of the intervention. The researcher collected, analyzed and acted on feedback as ongoing quality improvement activity throughout the four-month period until final measurement of impacts performed.

4.3.3 Methods for Evaluating the Extent and Impact of the Change

We evaluated the magnitude and impact of the change in this final part of the analysis to assess if the intervention strategy was a successful way to minimize the amount of out-of-service equipment and improve medical equipment management. The six hospitals in study area were allocated to two groups: one group was subjected to the intervention whiles the other group not. AwPH, SPH, and SGGH served as a control to observe without intervention (the control group). AgGH, JUMC, and LGGH were used to establish a baseline and determine the effect of intervention (the intervention group).

At the time of this study between December 9 to 20, 2019, it had been four months after implementation of the new and unique evidence-based model of BMET continuing training at the intervention hospitals. The control hospital had not involved in the program, but they were surveyed and reviewed in the first stage of the research on identifying the need for change and evaluation of the current maintenance and repair program. Structured English version checklists and interview guide for in-depth interview for data collection are adapted from Duke university research lab for developing world medical technology document review and other relevant literatures and they are modified to be suited for Jimma zone hospitals. For certain questions, a list of terms or photos from which to choose was shown to the interviewee. The director or technician provided written documentation was photographed or copied. The survey checklists for the study instrument are given in Appendix A.1-A.7.

At the beginning of the visit, a director or other high-level administrator was interviewed at each hospital. Any changes to the basic overview of the hospital, the condition of the equipment, the involvement of NGOs or other support organizations, the protocols for the procurement of medical equipment and supplies, and the use of outside technicians, including service contractors, were asked to the Directors. Directors were also asked about their administrative protocol for the role of technicians in reporting and administrative decisions.

In each hospital, at least one technician was interviewed, or the same technician engaged in a need-identification process where he/she was the only technician in the hospital. Interviews provided questions about workflow and associated documentation, procurement and storage of components, processes of incoming equipment, inventory usage, and related hospital infrastructure information. This included the hospital life cycle of the equipment and the role of the technicians in each of the phases, the relationship between the technician and hospital management, and the use of service providers. A survey of attempts to obtain outside technical assistance was also included in the technician interviews. In addition, each technician was asked about their language skills and their experience in education.

In each hospital, workflow was evaluated through surveys of the efforts of technicians towards CM, PPM, user training, equipment testing, installation, and calibration. Details relating to all work instances from the past 4 months were obtained using a formal interview, either from memory or written record. Ideally, to assess efficiency, a review of work tickets would be sufficient, since a work ticket would have been registered in the previous four months for every piece of equipment repaired or serviced. A work ticket was produced from the technician's memory if there was no work ticket for an event. Hence, the technicians were also asked for all the equipment related works he/she had performed in the previous 4 months.

Each instance of work carried out was reported as a " case." All CM, PM, installation, and user training were included in the cases. All available documentation was collected and checked (work tickets, PM records, etc.). Details regarding the date of repair, the problem addressed, the tools used, the use of external assistance, the use of the Internet, the spare parts used, and whether the device was opened, were collected for each CM case. The technicians were questioned about the issue(s) to every case that had been solved. A list of skills was shown to the technicians and asked which of those skills were implemented. The number of requests for technical assistance, both inside Ethiopia (but outside their hospital) and outside Ethiopia, was recorded for evaluating questions regarding their communication skills.

For PM cases, slightly different questions were used because they are normally conducted several times during the period. Technicians were asked instead of the date how many times PM was scheduled and how many times PM was done for each piece of equipment, their success, and tools and parts used. All cases were listed as (1) fully resolved, (2) partially resolved, (3) retiring the equipment as resolved, or (4) unsolved. One where the user's concern was absolutely handled was a 'fully resolved' work, and the equipment was sent back to the bedside to be used on patients. 'Partially resolved' repairs were for those sent back to be used on patients, but it was not possible to answer all user concerns. It was deemed to be retired if a piece was removed from the inventory. The other incidents were deemed unresolved.

Finally, by frequency and equipment type, instances technician's involvement in installation, user training, testing, and calibration were recorded. User training could be performed for new hires, or as a refresher course, during the installation of the equipment. Questions regarding the provision of a dedicated workspace, manuals access, and all available tools type and number have also been raised to determine the context in which the technicians work. In addition to the interviews, the status of the class of medical equipment that was used in the equipment specific program training was surveyed at each hospital. Each piece was classified as one of the following by both a technician and equipment user, usually nurses.

- In-service: equipment that has been used in the last 4 months by patients and satisfies all clinical specifications.
- Partially functional: equipment that has been used on patients over the past 4 months but cannot be used for at least some of the expected functions.
- Out-of-service (will be repaired): equipment not currently in use or not in use in the last 4 months for patients; repair is desired.
- Out-of-service (will not be repaired): equipment that has not been used or used by patients for the past 4 months. There is no need to fix this equipment. A retired, non-clinically required, not-used, or other status was assigned to equipment to better define this category.

The description of the equipment (type, make, and model), duration of time in the hospital, source (donation or purchase), and SC status were included in the information collected on each piece. Both the technician and users were interviewed to explain the problem with each piece of partially working or out-of-service equipment and how long the problem had existed, and asked to find at least 1 barrier to repair. Users selected from (1) not required for patient treatment, (2) I do not have the requisite user training, (3) I do not have the supplies, (4) I do not have the spare parts or accessories, (5) I have yet to tell the technician about the issue, and (6) I am waiting the technicians to fix it. Technicians selected from (1) I didn't realize it was broken, (2) I know about it but haven't

yet looked at it, (3) I'm afraid to make it worse, (4) it's under service contract, (5) I don't have the authority to fix it, (6) I need tools to repair it, (7) I don't have the supplies or parts to repair it, (8) I don't have the required accessories, and (9) I need training on it.

4.3.4 Methodology for Design and Implementation of the CMMS

The CMMS consists of fields, tables and modules filled with data from the department of clinical engineering or medical equipment of the facility in question. Using CMMS, user-friendly interfaces can be used to access, manipulate and analyze critical data. In order to help policymakers, make decisions about health technologies, reports can be generated from the system. Implementation involves going through a number of stages that will allow the system to be thoroughly planned. The system features for deployment were thoroughly evaluated by completing this multistep process; an appropriate package was designed, installed and customized; and data was entered

The CMMS developed as part of this thesis is a distributed software application with a Remote Method Invocation (RMI) mechanism. Using a Local Area Network (LAN) it allows an object residing in one system Java Virtual Machine (JVM) to access/invoke an object running on another JVM. The RMI feature is used to increase the accessibility of the system as well as minimizing the complexity of the application, and the difference between working with local and remote objects. We used phpMyAdmin tool for the purpose of managing and administering the database application system. The tool contains an uncomplicated graphical user interface that can enable the user with a convenient query editing facility, in order to create, update, delete and manipulate various operations on any SQL query [41]. It also allows the users to copy and paste queries from other systems, to open or import a file containing the query, execution of current or all queries, monitor the run time of each and every query ran in the tool, display to view the output fetched from the queries being run, and others [41].

The distributed CMMS application is coded in Java with NetBeans editor. Java is used to program the frontend and backend application of the CMMS. NetBeans is an open-source integrated development environment (IDE) for working on application development with Java, PHP, C++, and other programming languages [33]. For developing Java desktop applications, NetBeans provides a platform of modular components to be used. It is coded in Java and runs on most operating systems with a Java Virtual Machine (JVM), including Solaris, Mac OS, and Linux. The features and components that can be used to work on and manage the software development platform with NetBeans includes: User settings, Windows (placement, appearance, etc.), NetBeans Visual Library, Storage, Integrated development tools and Framework wizard. NetBeans

framework reusability also simplifies the development of Java Swing desktop application, which provides platform extension capabilities to third-party developers [33].

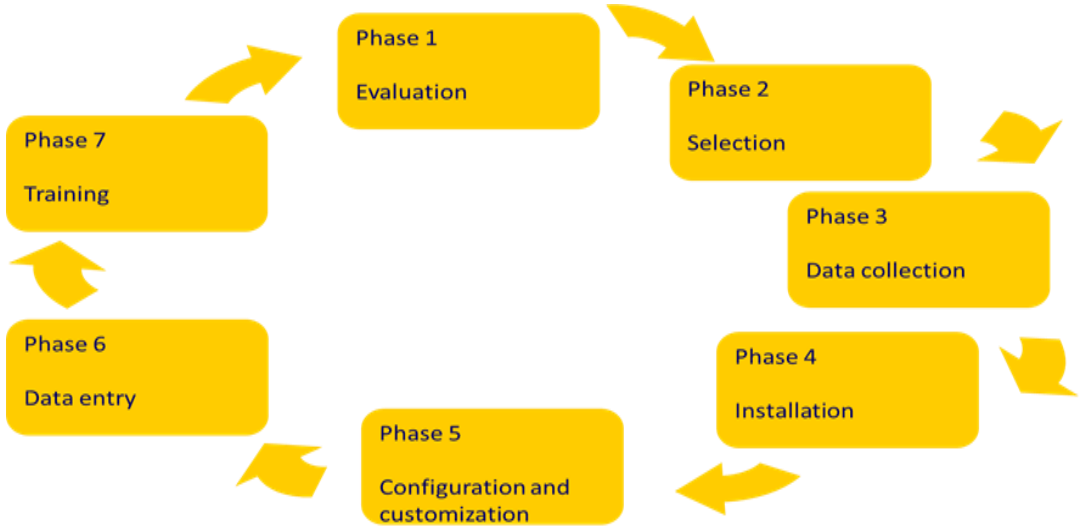


Figure 4. 3 The CMMS implementation flowchart.

The NetBeans IDE components (modules) used to work on the CMMS software development include NetBeans Profiler, a Graphical User Interface (GUI) design tool, and NetBeans JavaScript Editor.

The next section summarizes a basic step process used for implementing the software. Throughout the design and implementation of the CMMS, we used the WHO's medical device technical series document titled "Computerized Maintenance Management Systems" [16] as a reference and guideline. This document is part of the collection of reference documents that are being developed for country-level use specifically to support the establishment or improvement of a medical equipment maintenance program by a health facility or national health ministry. These documents have been written by international experts in their respective fields and have been reviewed by members of the Health Technology Technical Advisory Group (TAGHT) [16]. In addition, before the package was developed locally, a study of the literature on locally and commercially developed CMMS was conducted in order to learn from the experience of others. Figure 4.3 represents the flowchart for implementation of the CMMS.

I. Evaluation:

A complete analysis is carried out during this stage and the scope of the system, a feasibility study to assess and evaluate the need for CMMS, is defined. This analysis is used to develop a clear technical specification covering all compulsory and optional features for the CMMS. The structure

of the existing HTM system, available IT infrastructure, the skill level of staff, the amount of health facilities that will the system used by, and the level of adaptation of technicians are other factors considered at this stage.

II. Selection:

To successfully aid in the operation and repair of medical devices, a CMMS must comprehensively address the needs of the user. An HTM program can be partially paperless or fully automated using a CMMS. The number of features in the CMMS, as well as the features that were chosen, were therefore determined by the requirements of the user who needed to automate the management system. A suitable package design has been selected once specifications for the system have been identified.

The CMMS Software Structure

In a database consisting of fields, tables, modules and screens, the developed CMMS software integrates all medical equipment services. After the initial design was completed for individual modules, the automated procedure was run with test data, and the whole design was modified based on input from system users. This procedure is replicated for all activities; after all activities have been automated, the whole system is put into technical testing until all comments have been taken into account and all issues have been resolved. The sequence of software design phases for the development of the CMMS is presented in Figure 4.4, which was adapted from the WHO 'Medical Device Technical Series Document' [16].

III. Data collection

Before implementing the CMMS, a comprehensive survey and analysis of all available data was done. This information was already available in hospitals, but it was necessary to gather some of it from other sources.

IV. Installation

Before the system is installed, a system administrator is assigned for operational aspects of the system as well as data protection management. Specific modules were collected for the CMMS,

and applied as a complete system. This is a choice made by the clinical engineering department, and it was based on available resources.

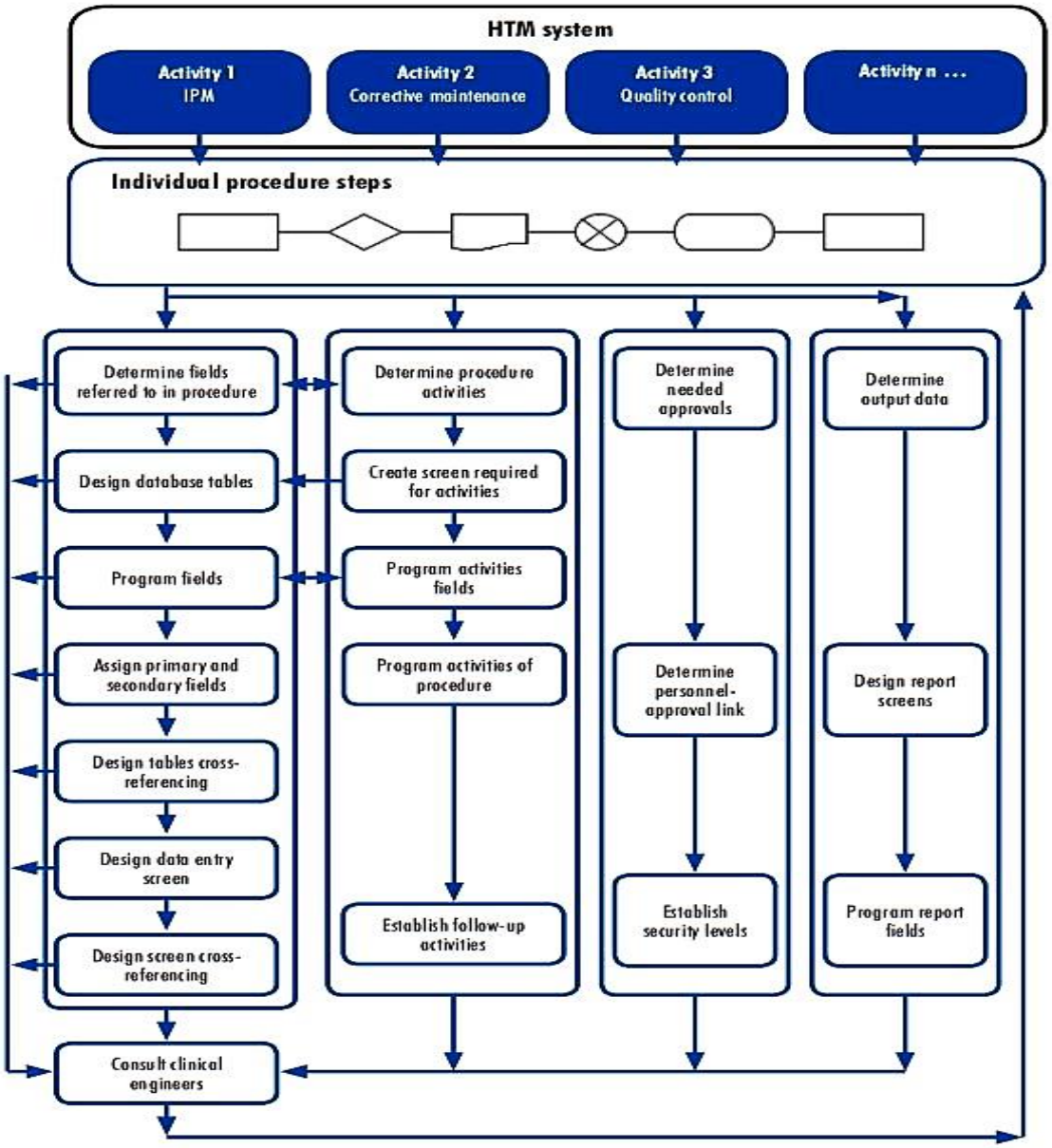


Figure 4. 4 CMMS software design plan adapted from the WHO medical equipment technical series document titled 'Computerized Maintenance Management System [16].

V. Configuration and customization

Before data entry, configuration and customization are carried out with existing mechanisms and processes. Customization refers to the system's technical functional requirements, including custom screens and tables, workflow specific to the facility and additional fields of data.

VI. Data entry

This phase consisted of initial data entry into basic modules of common fields such as equipment types, equipment model, maintenance, manufacturer and seller information, spare part management and others. User security levels and related passwords, access levels and types of access are also set at this stage. Once the initial data entry for all designed modules and fields was accomplished, it helped to put the entire system into additional operational testing to verify that all comments were considered and that all problems were solved.

VII. Training

Complete training on its complete structure, system installation and testing is carried out to ensure that all staff member of the clinical engineering is fully assured and familiar with all utilities of the CMMS.

4.3.4.1 Remote Method Invocation (RMI)

Remote Method Invocation (RMI) is an API which enables an object to invoke a method on another object that exists in another address space [38]. Through RMI, object running in a JVM present on a computer (Client side) can invoke methods on an object present in another JVM (Server side). RMI creates a public remote server object that enables client and server side communications through local area networks using simple method calls on the server object or the invocation address could be on the same computer using a localhost communication.

The communication between client and server is handled by using two intermediate objects: Stub object (on client side) and Skeleton object (on server side) [38]. The stub object on the client machine builds an information block and sends this information to the server. It exists in the client side and represents the remote object which all the outgoing requests are routed through it. The block consists of an identifier of the remote object to be used, method name which is to be invoked, and parameters to the remote JVM. When the caller invokes method on the stub object, it starts a connection, and writes and transmits the parameters to the remote JVM. Then it waits for the result to read the return value or exception, and it finally, forwards return value to the caller [39].

The skeleton object acts as an entry for the server side object through which all the incoming requests are routed. When the skeleton obtains an incoming request, it passes the request from the stub object to the remote object and calls the desired method on the actual object present on the server and then it forwards the parameters received from the stub object to the method which writes

and transmits the result to the caller. The following diagram shows architecture of the RMI application [39].

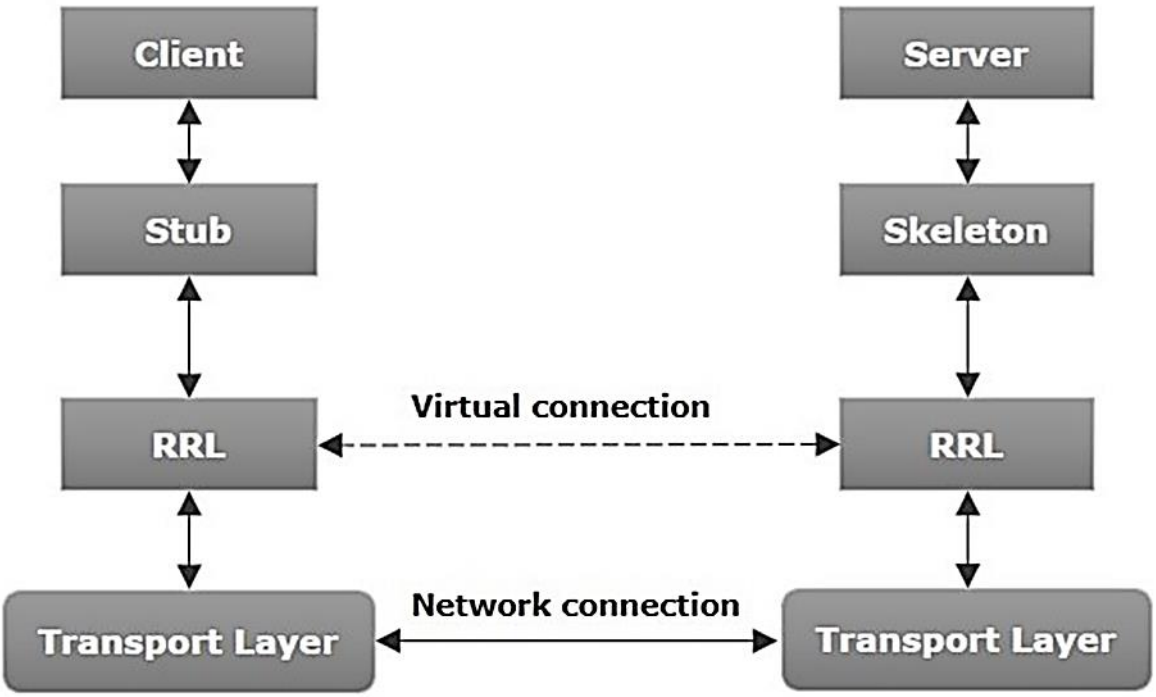


Figure 4. 5 Architecture of the RMI application [39].

- **Transport Layer** − This layer connects the client and the server. It manages the existing connection and also sets up new connections.
- **Stub** − A stub is a representation (proxy) of the remote object at client. It resides in the client system; it acts as a gateway for the client program.
- **Skeleton** − This is the object which resides on the server side which stub communicates with this skeleton to pass request to the remote object.
- **RRL (Remote Reference Layer)** − It is the layer which manages the references made by the client to the remote object.

4.4 Sampling Methods

We used Non-Probability Sampling Technique (Purposive Sampling)**.** The purposive sampling is selected because it is known that it will produce well matched groups. Due to the nature of research design and objectives, it was found to be effective since only limited numbers of hospitals could serve as primary data sources. Personal judgments were used to group study hospitals that helped to answer research questions and achieve research objectives. Purposive sampling was appropriate due to: use of the best available knowledge concerning the sampled study hospitals; the study places

special emphasis upon the control of certain specific variables; intervention and control groups data could be easily matched; and homogeneity of subjected hospitals used in the study.

The approach was to pick out the hospitals in relation to some criterion, which are considered important for this particular study. So they are grouped to control and intervention according to the number of equipment available, functional status, and technical experts available. During 'need for change' study in June, 2019, the six hospitals had in-service percent of study equipment according to the following decreasing order: JUMC, AwPH, SPH, LGGH, AgGH, and SGGH. Besides, JUMC had by far the largest number of equipment, and LGGH and AgGH were two of the last three hospitals which had more out-of-service equipment, so these three were picked to Intervention group. The rest three were listed to Control group.

4.5 Data Analysis

The quantitative data was analyzed using a Software package used for statistical analysis, Statistical Product and Service Solutions (SPSS), which is a powerful statistical analysis and data management system. Descriptive analysis was performed to describe frequency and percentage of the result findings. Matched cohort analysis was done to compare significance of any differences found in statistical tests of all dependent variables. The qualitative data was analyzed after the responses were separately transcribed for every interviewee and then it was thematically categorized and evaluated.

For all measures, significance was specified by $P < 0.05$. The X2 (Chi-square) test for a difference in proportions and the Welch t - tests for a difference in means were statistical tests used for this analysis. Welch's t-test, or unequal variances t-test, is a two-sample location test which was used to test the hypothesis that the two groups (intervention and control) have similar means. It was selected since it provides more accurate results when the two samples have unequal variances and/or unequal sample sizes [37]. Such tests are also referred to as "unpaired" or "independent samples" t-tests, as they are usually implemented when the statistical units underlying the two samples being compared are non-overlapping. A non-parametric (distribution free) method used to evaluate group differences as the dependent variable (intervention vs control) is calculated at a nominal level is the Chi-square statistic. The Chi-square, like all non-parametric statistics, is robust with regard to data distribution. Specifically, equality of variances or homoscedasticity in the data among the study groups is not needed. All cases and study variables were included for analysis unless specifically specified otherwise.

4.6 Ethical Considerations

First, a formal letter was delivered to Jimma Zone Health Bureau and Jimma City Health Bureau from School of Biomedical Engineering, Jimma University to request an ethical clearance and support letter. Then, written formal letter of permission and support was obtained from them explaining the significance, and importance of the study. Using these letters consents were also received from CEOs of each study hospital and verbal consent was asked for each individual study participant. We also learned adequate information about the culture of individuals participated in the study that helped to ensure it is well respected during the data collection process and guarantee the confidentiality of the data obtained.

The work of others, whether published or unpublished and whether it has been written work, an oral presentation or content on a website, has been cited or credited. In order to prevent either a false statement or an omission that distorts the study record, the researcher assumed the primary responsibility. All the reported research results are valid and were observed from firsthand data.

4.7 Data Quality Assurance

Different steps of data quality control have been taken. Research instruments have been adapted from the 'Developing Countries Healthcare Technology Laboratory' of Duke University. To ensure the content quality of the results, they were adapted and revised based on the research goals and context of the study area. The material of the tool was guaranteed to be genuine by the experts. Following the pre-test, the data collection instruments were improved when required. The precision of the data was also assured during data collection by explaining vague terms, checking the completeness and internal consistency of the completed checklist, and conducting exploratory analysis. We had also prepared a work manual to check daily progress and manage the information carefully in order to improve the accuracy of the data. We also tested the data's reliability and accuracy as well. In order to clarify the thoughts, comments and issues faced by biomedical engineers, biomedical technicians, equipment users and hospital managers when reacting to the questions, pre-tests on the questionnaires were carried out. All the study instruments are mentioned in the Appendix.

4.8 Limitations on the Study

In Ethiopia and particularly in Jimma zone hospitals, we believe this to be the first matched, controlled analysis of the effect of evidence-based training and CMMS on healthcare. As such, we consider this study to reflect the best available data on the subject. Nonetheless, this research has limitations. The primary drawback of this analysis is the small scale, which may not statistically

make all of the findings significant. In order to expand the scope of potential solutions and to generate more viable conclusions, a larger study is required. Instead of full hospital inventories, this study used sampled inventories for a class of medical equipment to determine equipment status and assess the effects of intervention. Presumably, in store rooms and closets, there would be a considerable amount of other type non-functional equipment, and therefore the real out-of-service levels for all available devices would be higher than those found in this report. This is possibly the reason why a much larger out-of-service percentage has been recorded by many writers.

The study would be more ideal if the effect on patient wellbeing could be seen by the analysis. Only the impact on health care infrastructure, especially medical equipment management, however, was measured in this analysis. Although there is a clear correlation between medical equipment and patient health, it is not immutable. In addition, while it would have been more objective and accurate to assess hospital equipment maintenance based on paperwork, it was not completely available for this review, mainly at control hospitals. Instead, work cases have been replicated post facto, depending on the memory of the technician, which might not be detailed or reliable because the cases that were effectively resolved can be selectively recalled by technicians. Although the report of equipment problems and obstacles to fix by a technician is not an infallible test, it is considered the best proxy for the diagnosis of equipment problems [19].

In addition, the fact that the technicians are based in the same geographical region and know each other, most likely could have been the technicians talk to each other. This high degree of contact is beneficial and encouraged, but by eliminating a degree of independence between the control and intervention groups, it does complicate the interpretation of the findings. These shortcomings are partially mitigated by the use of matched pairs and the fact that our inference was focused on the discrepancies between trained and untrained cohorts.

Furthermore, there was a lack of coherence in the skills and willingness of technicians, users, and administrators. While all study hospitals had comparable standing in terms of the number of technicians and the quantity of equipment available, in reality, even before the intervention program, JUMC had much higher technical staff and a better management structure. Therefore, if it does not reduce the tested and proven measurements of the program's efficacy, this will also impact the evaluation and analysis of study results. In addition, in several cases, there were contradictions regarding the source, age, and contract status of equipment. Obtaining this information by both the user and the technician is intended to improve validity, but sometimes neither party is certain.

CHAPTER FIVE
RESULTS

5.1 Introduction

Despite the volumes of information, data collection in all parts was successful with only minor problems experienced by the investigator. To encourage a full interpretation of the findings, before any general conclusions were drawn, each objective and variable of the study was examined separately. The most logical format for this segment appeared to be the presentation of results in the same manner. The first part of the next segment presents the general background of the research hospitals and the baseline characteristics of the study population/situation. Consequently, this chapter presents findings and results related to each research objectives and component. Discussion about addressed study questions, comparing study findings to previous works, the provided new addition to knowledge in the field and other interpretations are presented in chapter six of the project. General conclusions and recommendations were explained in the final chapters.

5.2 Characteristics of the Study Population

The first general information surveyed about the study hospitals include; the amount of population the hospital serve, number of beds and their usual occupancy rate? (% of beds filled on average), number of inpatients and outpatients the hospital see in a year, number of operating rooms in use and ICU beds the hospital have. Table 5.1 presents the respecting figures for the findings.

The hospitals varied in size (1–8 operating rooms, 35–659 beds with all occupancy rate higher than 60%, and 570,000-15 mill population served) as shown in Table 5.1. All hospitals are government-funded except AwPH, which is private funded. JUMC has higher frequency of inpatients and outpatients in a year compared to other hospitals with 45,000 and 355,000 in number respectively. In fact, this is due to it is the only specialized and teaching hospital in south-west Ethiopia. AwGH also has relatively higher inpatient number compared to other hospitals except JUMC. We found out it is due to better quality service and specializing in endoscopic treatments which don't exist in other hospitals.

Other hospitals have one-year inpatient and outpatient numbers in a range 886-2000 and 16,321-90,000 respectively. JUMC is the only hospital which has ICU with 24 beds and it has also 8 ORs. AgGH and SGGH have 2 ORs and the rest three hospitals have only 1 OR for delivering medical service. All hospitals except AwPH have NICU with number of beds in the range 10-28.

Table 5. 1 General information of the study hospitals reported by administrators.

Hospital Name	*Population Served*	*# of Beds*	*Beds Occupancy rate*	*#Inpatients in a year*	*#Outpatients in a year*	*# OR*	*# ICU Beds*	*#NICU Beds*	*#Techs*
AgGH	>846,995	75	73%	886	16,321	2	NA	10	1, BME
AwPH	> 1 mill	35	60-65%	3600	10,000	1	Na	NA	2, BMET
JUMC	>15 mill	659	93.5%	45,000	355,000	8	24	28	12 (5 BMET &7 BME (3 active))
LGGH	>570,000	150	60%	2,000	90,000	1	NA	20	1, BMET
SPH	>800,000	90	60-65%	900	70,000	1	NA	12	1, BME
SGGH	1.3 mill	83	80-90%	1,013	29,000	2	NA	15	1, BME

Staffing of biomedical departments at Jimma zone hospitals is primarily achieved with BMEs and BMETs). There are 7 BME and 5 BMET staff at JUMC. AgGH, SGGH and SPH have only 1 BME and No BMET staff each. LGGH and AwPH have 1 and 2 BMET staffs respectively. Ideally, biomedical departments are in charge of maintaining, repairing, and installing electronic, mechanical, electromechanical, and general medical and surgical diagnostic and treatment devices; tracking and executing PM programs; managing repair parts inventories; advising survey and procurement boards, and coordinating medical equipment safety programs with local safety committee; and provide other required technical advice and assistance. Although there were no work performance standards or evaluation criteria to measure the department and their program effectiveness or efficiency at all hospitals, they work to manage tasks within their capability.

The second general information survey questions conducted with hospital administrations were on amount of donated and in-service equipment, and presence of governmental organizations (GOs) and non-governmental organizations or other program which provide/donate medical equipment and trainings. As indicated in table 5.2, they reported 80–95% of the hospital's equipment working (survey average: 85%). However, physical inventories generated and studied by the researcher as presented under 'Availability of medical equipment' section 5.2.1 below suggest that the administration was overestimating the percentage of working equipment.

Table 5. 2 The hospital administrations report on percent of donated and in-service equipment, and GOs and NGOs which provide/donate medical equipment and provide trainings.

Hospital Name	Received & Donated (%)	In-service (%)	Aid org. donate equipment	Aid org. provide training	last year (pieces received by donation)	last 4 years (pieces received by donation)
AGGH	99	85	Biftu Adugna, Koica, ICAP Ethiopia, Koica, USAID, CDC	Oromia Health Bureau, KOFIH	6	>26
AWPH	0	95	Na	Na	0	0
JUMC	25	85	EPSA,, Koica, USAID, CDC	KOFIH. CDC	6	>20
LGGH	90	80	EPSA,, Biftu Adugna, USAID	Oromia Health Bureau, KOFIH,	8	>27
SPH	90	80	Biftu Adugna, USAID, CDC	Oromia Health Bureau, KOFIH	7	>23
SGGH	60	85	EPSA, Biftu Adugna, USAID, Gulf, Koika, CDC	Oromia Health Bureau, CDC, KOFIH	9	>21

The survey reflected that major sources of equipment were from both GOs and NGOs (table 5.2). GOs include EPSA, Regional Health Bureau (Biftu Adugna), and Zonal Health office which provide more than 80% of equipment. NGO donations are from ICAP Ethiopia, Gulf, Koica, USAID, CDC. More than 90% of medical equipment found in AgGH, LGGH and SPH are received from these sources. JUMC made remarkable physical facility improvement in the last 5 years with extensive renovation and expansion work to cope up with the highly growing service demand. Thereby, more than 75% of medical equipment currently found at the hospital is purchased from private companies by the hospital budget with support from different stakeholders. Government funded hospitals received on average 8 and 24 equipment in the last one-year and four-year period respectively. All equipment in private-funded AwPH is purchased by the hospital budget.

Regional Health bureau, Korean government based NGO named KOFIH and CDC provide training on medical equipment. JUMC has a partnership with KOFIH which provides a technical training on different medical equipment annually. The head of biomedical department at the hospital organizes the training and often invites all other Jimma zone hospital technicians to receive the training along with in-house department staffs. LGGH, AgGH, SGGH and SPH technical staffs also receive occasional technical training provided by Oromia Health Bureau.

Table 5. 3 Findings about Service Contractors/ Service Providers available at study hospitals. The respondents selected from Yes (Y), No (N), and Don't know (DK). It provides information about the name of SCs and equipment for, including who signs the agreement. The change of fee for service (FFS) over the past four-year period is also presented.

Hospital Name	Use FMoH SC? Y / N	Use Hospital SC? Y / N	Fee for service? Y / N	SC; Parts: Y / N	Names of SC	Types of equipment.	Who signs SC	FFS Changed (over 4yrs)
AgGH	N	N	Y	-	-		-	Increased
AwPH	N	Y	Y	Y	**Agmase** > Anesthesia and other OR equip. **Afro Germen** > X-ray **WMG** > Chemistry analyzers and other lab equip.		MD and CEO	Increased
JUMC	N	Y	Y	Y	**Infinity** > Chemistry analyzers and other lab equipment., CT scan **Setema** > MRI		BME dept. head & V/P(CEO)	Decreased
LGGH	N	N	Y	-	-		-	Increased
SPH	N	N	Y	-	-		-	Increased
SGGH	N	N	Y	-	-		-	Increased

.

The third general information findings were about service contractors (SCs) and service providers (SPs) available at study hospitals. At all hospitals FMoH doesn't provide SCs for any equipment. However, AwGH and JUMC negotiate SCs with different companies for some equipment. The name of private companies which provide SCs and types of equipment for are described in table 5.3 below. In both hospitals parts, accessories, & consumables included in the contract.

MD and CEO are who negotiates and signs the contract in AwPH whereas at JUMC, SC is signed by BME dept. head and V/P(CEO). All hospitals use occasional fee for service (FFS) / one time providers and the amount of contact for this service increased over four-year period except JUMC due to the item and number of medical equipment increased. The hospital director responded that the number of contact for a fee for service technician decreased at JUMC because of technicians and users' efficiency increased through time.

5.2.1 Availability of Medical Devices

Table 5. 4 Frequency distribution and functional status of all available medical devices in the six hospitals found in Jimma Zone, South-west Ethiopia: June, 2019. Data figures represent frequency (functional, non-functional, not used).

Equipment Type	AwPH	SPH	SGGH	AgGH	JUMC	LGGH
Anesthesia Machines	1 (1,0,0)	5 (2,3,0)	6 (3,1,2)	4 (2,2,0)	10 (8,2,0)	2 (2,0,0)
Autoclaves	5 (2,3,0)	8 (5,3,0)	8 (3,3,2)	10 (6,3,1)	10 (9,0,1)	12 (7,5,0)
Balances (electronic clinical lab)	0	0	0	2 (2,0,0)	3 (3,0,0)	1 (1,0,0)
Blood Pressure Machines (manual, digital & NIBP)	4 (3,1,0)	8 (5,2,1)	6 (5,1,0)	2 (2,0,0)	16 (13.1,2)	7 (4,2,1)
Centrifuges (including hematocrit)	2 (2,0,0)	7 (5,2,0)	4 (3,1,0)	6 (2,4,0)	8 (7,1,0)	2 (2,0,0)
Clinical Laboratory Ovens	2 (2,0,0)	2 (2,0,0)	1 (1,0,0)	2 (2,0,0)	5 (3,2,0)	1 (1,0,0)
Dental chair	1 (1,0,0)	0	1 (1,0,0)	1 (1,0,0)	13 (4,8,1)	2 (2,0,0)
Electrocardiographs	2 (1,1,0)	0	1 (1,0,0)	0	4 (4,0,0)	0
Electrosurgery Machines	2 (1,1,0)	1 (1,0,0)	2 (1,1,0)	1 (1,0,0)	6 (5,1,0)	1 (1,0,0)
Fetal Monitors and Fetal Doppler	3 (2,1,0)	0	3 (2,1,0)	1 (1,0,0)	2 (2,0,0)	0
Fluid Pumps (feeding, IV infusion/syringe, blood etc.)	0	0	1 (0,1,0)	0	6 (4,2,0)	0
Hematology Analyzers (including electrolyte and chemistry analyzers, CD4 counter, gene expert)	4 (3,1,0)	8 (5,2,1)	5 (4,1,0)	6 (4,1,1)	18 (12,4,2)	2 (2,0,0)
Infant Incubators	1 (1,0,0)	3 (3,0,0)	2 (2,0,0)	4 (2,0,2)	6 (6,0,0)	3 (2,0,1)
Infant Warmers	1 (1,0,0)	3 (3,0,0)	6 (6,0,0)	3 (3,0,0)	24 (20.2,2)	4 (3,1,0)
Micropipettes (manual, electronic, not disposable)	0	0	0	0	0	0
Microscopes	3 (3,0,0)	5 (5,0,0)	5 (3,1,1)	6 (5,1,0)	15 (13,2,0)	2 (2,0,0)
Operating Tables	3 (2,0,1)	2 (2,0,0)	1 (1,0,0)	3 (3,0,0)	9 (8,1,0)	2 (2,0,0)
OR Lights and Other Lights	6 (4,1,1)	5 (3,2,1)	7 (5,2,0)	3 (2,1,0)	10 (7,2,1)	4 (3,1,0)
Oxygen Concentrators	3 (3,0,0)	8 (5,3,0)	9 (4,2,2)	7 (4,3,0)	11 (10,0,1)	7 (5,1,1)
Patient Monitors	3 (3,0,0)	1 (1,0,0)	6 (5,1,0)	5 (5,0,0)	22 (20,2,0)	4 (2,1,1)
Phototherapy Lights (including bilirubin meter)	2 (1,1,0)	2 (1,1,0)	5 (3,2,0)	1 (1,0,0)	13 (10,3,0)	1 (1,0,0)
Pulse Oximeters	4 (4,0,0)	6 (4,2,0)	5 (4,1,0)	5 (5,0,0)	5 (5,0,0)	3 (3,0,0)
Refrigerators	5 (4,1,0)	6 (4,1,1)	7 (5,1,1)	7 (4,2,1)	15 (12,2,1)	4 (3,1,0)
Suction Machines (rotary, diaphragm, thermotic, venture)	4 (3,1,0)	8 (6,2,0)	7 (4,2,1)	6 (5,1,0)	27 (21,4,2)	7 (5,2,0)

Slit lamp	2 (1,1,0)	0	1 (1,0,0)	1 (1,0,0)	10 (9,1,0)	2 (1,1,0)
Ultrasounds	2 (2,0,0)	1 (1,0,0)	2 (2,0,0)	3 (2,1,0)	8 (8,0,0)	3 (2,1,0)
Weight and height scales	4 (3,0,1)	13 (9,2,2)	11 (7,3,1)	6 (4,1,1)	19 (15,2,2)	2 (2,0,0)
Water Baths, Stir Plates, and Hot Plates	3 (2,1,0)	4 (3,1,0)	2 (2,0,0)	2 (2,0,0)	6 (5,1,0)	2 (2,0,0)
Water Purifiers (for clinical lab)	0	0	1 (1,0,0)	0	3 (3,0,0)	0
X-ray (fixed – radiographic and/or fluoroscopic unit)	1 (1,0,0)	1 (1,0,0)	1 (1,0,0)	1 (1,0,0)	3 (3,0,0)	1 (1,0,0)
X-ray (portable – such as C-arms)	0	0	0	1 (1,0,0)	4 (4,0,0)	1 (1,0,0)
X-ray (Automatic Film Processor)	1 (1,0,0)	0	0	0	2 (2,0,0)	0
Total per Hospital	74 (57, 14, 3)	108 (76, 26, 6)	116 (80,25,11)	99 (73, 20,6)	382 (320, 47,15)	82 (62,16, 4)
%Status per Hospital	(77,18.9,4.1)	(70.4,24.1,5.6)	(69,21.6,9.5)	(73.7,20.2,6.1)	(83.8,12.3,3.9)	(75.6,19.5,4.9)
%Availability total	8.6	12.5	13.5	11.5	44.4	9.5
Frequency total	861 (668, 148, 45)					
%Status total	100 (77.6, 17.2, 5.2)					
Medical equipment type (#Functional, #Non-Functional) which only found in JUMC: Defibrillators (3,0), Laboratory Incubators (3,0), MRI (1,0), Nebulizer (8,1),Respiration Rate Meters and Apnea Monitors (3,0),Ventilators (14,1),keratometry (4,0), A-scan/Pachymeter (1,0), Auto chart projector (1,0), Computerized tonometer (1,0), CPAP (4,0), Cryo machine (2,1), CT-scan (1,0), Funds camera (1,0), Haesung test vision chart (3,0), Halogen ophthalmoscope (2,0), Hand edger (3,0), Humphrey FDT (1,0), Laserex super Q (1,0), Manual lensometer (1,0), Phaco camera eye (2,0), Phaco machine (2,0), Trinitron color TV (1,0), Victrectomy (3,1)						

During the identification of the need for change in June of 2019, 861 medical devices were available in the six hospitals, with 382 (44.4%) being available at JUMC, 116 (13.5%) at SGGH, 108 (12.5%) at SPH, and 99 (11.5%) at AgGH, as well as 82 (9.5%) and 74 (8.6%) being available in LGGH and AwPH, respectively (Table 5.4). The 668 (77.6%) of the 861 available medical equipment were functional, while the remaining 148 (17.2%) and 45 (5.2%) were not functional and not in use, respectively. JUMC had the highest percentage of functional equipment with 83.8 % followed by AwPH and LGGH with 77% and 75.6% respectively. Whereas, 73.7% and 70.4% of the devices in AgGH and SPH respectively were functional (Table 5.4). In SGGH among 116 available medical devices, only 69 % were functional. As indicated on the last row of table 5.4 above, there were 24 different types of equipment with total number 70 which were only available at JUMC and not anywhere else.

5.3 Structural Review Results of Maintenance and Repair Programs

The study was undertaken to provide a thorough evaluation of the medical equipment maintenance and repair program at the six Jimma zone hospitals. Its results were used to assess and design the

best intervention method for a successful medical equipment maintenance strategy, which included planning, managing, and implementing the medical equipment maintenance. The findings of each thematic area of the full-service assessment program are explained in the following section. It is accompanied by examples of the main primary factors linked to the findings that have been reported.

The first topic examined the existence of a mechanism for ensuring the safety and correct operation of all biomedical instruments, as well as the accurate recording of PM tests in accordance with regulatory agency schedules, the adequacy of test protocols, proper calibration of test equipment, and the expertise of test technicians. Except for AwPH, all hospitals had a kind of inventory of all biomedical devices. Almost all hospitals, on the other hand, lacked a full, up-to-date inventory, and inventories failed to indicate maintenance intervals or who was responsible for each item's scheduled maintenance. There was still no written timetable or any way of generating prompt work orders. There was a written protocol for safety and performance/calibration checks of certain work performed in-house at JUMC and LGGH, but no procedure for work done by outside sources was present at either of the hospitals. Furthermore, no written summaries of test reports for work conducted in-house and from outside sources were given to department heads on a regular basis.

In general, there was insufficient paperwork for all in-house work, including work performed from outside sources, at all hospitals. The hospitals have no evidence on hand that the test equipment they used was calibrated according to the manufacturer's specifications for both in-house and outside operation. They still lacked adequate written documentation of the expertise of the testing staff for each external vendor on paper. In addition, there were no instructions and regulations for the use of equipment and there were no written protocols and no written policy addressing the extent and functioning of the scheduled maintenance programs. The Ethiopian Institute of Health and Nutrition Research (EHNRI), the Oromia Regional Health Bureau (OHB) and the Ethiopian Ray Authority (ERA) are government agencies that track and calibrate such devices at six hospitals, either once or twice a year. Typically, hospitals are judged by the national norm, but the outcome is very poor. As a consequence, no measure was implemented. In regards to occupational hazards such as prolonged exposure to radiation, the amount of rays to which the professionals are exposed is controlled, but no action has been taken. There was no risk management other than infection prevention training reported in this review.

The second thematic area was the existence of a framework for timely and qualified maintenance of all biomedical equipment and recording of the cost of repair for tracking repair skills and

downtime of the equipment. Our findings indicate that, at all hospitals there was a procedure to follow for staff in all departments in order to notify a need for service. However, no written protocols or regulations governing equipment repair services were found at any of the hospitals, nor was there a regulation demanding permission of (estimated) costly repairs before they were completed. Besides, only at JUMC there were individual files in which repair invoices can be kept. Additionally, all hospitals didn't use equipment downtime log sheets to measure downtime performance.

The third thematic area was the availability of methodology and technical assistance to determine the possible cost-effectiveness of new biomedical equipment, appropriate legal and fiscal protections for the procurement of equipment, and keeping personnel aware of recent progress in biomedical equipment. Technicians replied at all hospitals that biomedical engineering departments are alerted whenever new clinical equipment is to be purchased and biomedical engineering routine feedback is available during the procurement of all biomedical equipment items. Prior to being placed into operation for the first time, there is also a standardized acceptance process to check safety and proper performance. All hospitals, however, did not have completed checklists on file and their services did not regularly provide hospital staff with any details on recent developments in biomedical equipment. Furthermore, there were no written guidelines or policies governing the procurement of biomedical equipment, no use of a "order for new equipment" process if new biomedical equipment was required, and no appropriate "General Condition of Purchasing" documentation containing electrical safety, performance, company, and legal specifications for all clinical equipment purchases.

The fourth thematic area was the provision of annual reports on the expense and performance of the program, the presence of a management review methodology to ensure that the combination of in-house and out-of-house resources is optimum, as well as the retention of current information on the cost of out-of-house resources to support these studies, and the professional technical supervision methodology for any in-house biomedical surveillance. At all hospitals, periodic reports were not given to the administration and no periodic evaluations were conducted to assess the appropriate combination of in-house and out-of-house service sources. Furthermore, there was no method for reviewing biomedical service contracts and no study was conducted to keep the costs of different external service sources updated.

On the other side, technical and administrative supervision is provided to the in-house technical staff at all study hospitals though it is not adequate. There are some formal continuing education or

in-service training provided for them. For example, 3 staff members of JUMC are studying their M.Sc. at Jimma Institute of Technology sponsored by the hospital and the hospital has a partnership with Korean government based NGO named KOFIH which provides technical training on different medical equipment annually. LGGH, AgGH, SGGH and SPH technical staff receive occasional technical training provided by Oromia Health Bureau and CDC. On the other hand, the amount of in-house technical staffing in almost all hospitals is lower, due to a complete shortage of technicians and inadequate infrastructure, equipment and support services for in-house technical workers.

The fifth thematic area was the assessment of compliance with existing legislation and requirements for biomedical protection, an effective program documentation system, and the availability of adequate policies and procedures for recording the work carried out by both in-house and out-of-home service staff. There was no full collection of biomedical policies and procedures at all hospitals, and the technical staff did not have an adequate understanding of the biomedical specifications of the existing codes and standards. In addition, there were no sufficient technical libraries (codes, procedures of manufacturers, and so on) and the reporting methods were not fairly accurate.

The sixth thematic area concerned an appropriate framework for the continuing in-service training of clinical personnel on electrical safety and the proper use of medical equipment. All technical personnel provide some routine and/or occasional user instruction, but there were no written curriculum plans detailing the sessions, staff, regular intervals, and persons responsible for preparation and actual training. In addition, the material (electrical safety and the correct use of critical equipment) and the frequency of the sessions were not appropriate. This may not be available due to lack of adequate audiovisual resources, technical books and journals; and a lack of process for evaluating needs for training as they relate to the use and maintenance of in-service clinical equipment.

The last focus area was the adequate framework with written policies and procedures for managing warnings of equipment hazards and the provision of technical assistance to the safety committee of the hospital. A biomedical engineering department delegate is found in the the safety committee at all hospitals. The internal processes for reporting all accidents, incidents or possible hazards associated with equipment were, however, not sufficient. In addition, there were no written guidelines and a written policy on how notifications of equipment hazards are treated and strategies for finding out all existing notifications of equipment hazards. In addition, no simple and effective methods have been developed for recording the required corrective steps taken.

5.3.1 Primary Factors

Generally, program evaluation results on scope, effectiveness, and efficiency indicated that all hospitals didn't have proper programs for utilization, and maintenance and repair of biomedical equipment. All hospitals didn't accomplish important program requirements needed to provide all of the necessary or desired services. There are two key categories of established major factors (unique obstacles) for the lack of proper coordination and implementation of maintenance and repair programs in the study hospitals: 1, lower levels of in-house technical staffing (resident technician staff skills, work load, training needs, and sophistication/complexity of equipment), and 2, lack of adequate infrastructure (lack of quality equipment and spare parts (availability, cost, storage, use rate), lack of necessary equipment for testing/calibration (special tools, service manuals/schematics), history of equipment (age, condition, replacement timeframe, repair history), multiple equipment units, and insufficient budget and contract costs).

Moreover, there is a wide medical device regulation and management related problems in the country. The medical device regulation in the country is very weak as a result poor quality devices are still imported and widely supplied. As a result, medical devices are quickly broken and become malfunctioned without providing the required life cycle service and eventually services disrupted. In addition, multiple brands are being supplied which caused significant burden on the consumables, spare parts, maintenance and training requirements. Procurement lead time, in general, is very long and the contract management capacity is an area that has a critical problem. The long- lead time is majorly caused by poor system and capacities and also due to the poor contract management skill and capacity. Lack of comprehensive medical device regulatory system; poor institutional capacity, lack of medical device testing facilities and lack of qualified staffing are among the core root causes for the weak regulation.

Other factors impacting device use and functionality included the behavior of technical and clinical personnel in caring for the equipment and being reliant on donations. When employees are recruited and human resources is increased, equipment and supply should be changed. When such medical devices are being installed, instruction may be given to one person; however, this person may leave for various reasons, and another person without training may take over the task of running the equipment, affecting the device's function. Dissatisfaction of working staff, incompetence, and less sense of responsibility are also other identified factors affecting availability of medical devices.

5.4 Analyzed Repair Examples and Needed Skills

Data was collected on the 11 classes of devices in the study hospitals, which are the most available type of medical equipment. A total of 161 devices were examined, of which 88 were out-of-service at the time of the analysis and 73 were out-of-service and repaired in recent years (one to two years). The hospitals (and the number of occurrence) were: AgGH (28), AwGH (13), JUMC (37), LGGH (27), SPH (26), SGGH (30). The occurrence of each device type was noted. The devices (and the number of occurrences) were: Anesthesia Machines (16), Autoclaves (31), Centrifuges (including hematocrit) (23), Electrosurgery Machines (9), Infant Incubators (8), Infant Warmers (9), Microscopes (15), Oxygen Concentrators (17), Patient Monitors (7), Suction Machines (rotary, diaphragm, thermotic, venture) (23), and X-ray (fixed – radiographic and/or fluoroscopic unit, digital) (3).

Only 66 of the 73 repaired pieces of medical equipment were sufficiently documented to decide what information was required for the repair to be completed. In order to consider and select these cases with detailed discussion with the technical staff, we used multiple criteria. For example, the 34 equipment were adequately recorded on paper, and among 39 cases registered from technician's memory, only the 32 sufficiently described cases were selected to identify the required skills.

From the recorded examples of repair need problems, among the main factors for equipment being out-of-service are: 'power fluctuation' for the problems related to power supply and other electrical components like contactors, sensors, suction compressors, solenoid valves, switches, transformers, wires, fuses, heating elements, and others. Aging, and lack of proper handling and PM operations causes for the mechanical and plumbing related problems like inlet problems; physical damage and pressure leakage in regulators, vaporizers, and flowmeters, water level indicators; expired soda lime; as well as loose connections and adjustment problems.

After reviewing the repair requirements for the 88 out-of-service equipment and 66 completed repairs, we found that 82 percent of the repairs were needed/used in 4 areas of knowledge: electrical, mechanical, plumbing, and installation or user training. Examples of repair and defined unit skills necessary for the knowledge domain are explained in Table 5.5 below.

We wanted to further establish how deeply each domain should really be mastered. In other sayings, what proportion of repairs needed only fundamental knowledge in a given domain, and what repairs needed extra advanced knowledge or skills. Each area, excluding user training, was therefore further subdivided into units. As a group of related concepts and skills required to diagnose a problem and perform a repair with locally available materials, a unit was identified. Units have been

Table 5. 5 Examples of repairs causes and identified needed skill units with knowledge domain required to repair the out-of-service equipment at 6 Jimma zone hospitals in June, 2019. These six domains of knowledge and unit skills were sufficient to repair 82% of all the out-of-service medical equipment in this study without the use of imported spare parts and without extraordinary financial resources or specialized tools.

TYPE OF EQUIPMENT	REPAIR EXAMPLE CAUSES	IDENTIFIED NEEDED SKILLS
ANESTHESIA MACHINES	Oxygen inlet problem, pressure leakage sound at o2 regulator, expired soda lime, O_2 regulator not working, vaporizer leakage, burned fuse, and AGSS Problems	**Mechanical***:* Attachment, calibration, casing, cleaning, and lubrication **Plumbing**: connections, leaking, seal, and rings **Electrical**: Fuse, and plug/cable **User training**
AUTOCLAVES	Contactor not energizing; door-lock sensor problem; pressure adjustment problem; suction compressor not working; broken pressure gauge; steam and water leakage across water level indicator; burnt wires, fuse, and heating element; dirt blockage; gauze blockage; water sensor problem; solenoid valve problems; broken gasket; failed release valve; failed breaker; locking knob problem.	**Mechanical**: Attachment, calibration, casing, cleaning, and lubrication **Plumbing:** Blockages, connections, filters, leaking, seal, and rings **Electrical**: Connections, connectors, Lighting/ Indicators, Switches and Heating Element**,** Fuse, and Plug/cable **User training**
CENTRIFUGES (INCLUDING HEMATOCRIT)	Carbon brush, motor sounds due to misalignment and dirt.	**Electrical:** Belts/ Gears/ Shafts/ Coupling, Brush Substitution, Cleaning/ Lubrication, and Tightening/ Attachment/ Balance
ELECTROSURGERY MACHINES	Mother board failed due to power fluctuation, mechanical breakdown, and non-functional patient plate cord, loose connection at power board and patient plate cord, broken socket outlet, machine frame, and buttons at front control panel.	**Electrical:** Connections, Switches, connectors, and Lighting/ Indicators, Plug/cable, Regulator, and Fuse **Mechanical**: Attachment, casing, cleaning, and calibration **User training**
INFANT INCUBATORS	Missing temperature probes and access ports, broken control panel, broken ON OFF switch	**Electrical:** Lighting/ Indicator, Connections, connectors, and Heating Element, Fuse, and Plug/cable **User training**
INFANT WARMERS	Temp. sensor alarm continuously and no heat, burnt heating element, burned fuse, and total damage of power supply and PCB.	**Electrical:** Connections, Connectors, Heating Element, and Lighting/ Indicators, Batteries, Fuse, Plug/cable, Regulator, and Transformer
MICROSCOPES	Burnt fuse and bulb, bulb loose connection, fine adjustment problem, Stage adjustment problem (gear part), failed power supply (transformer).	**Electrical: :** Fuse, Plug/cable, Regulator, and Transformer, Connections, Connectors, and Lighting/ Indicators **Mechanical:** Attachment, Calibration, Casing, Cleaning **User training**
OXYGEN CONCENTRATORS	Broken humidifier bottle, low o2 output, broken switch, flow meter problem, leakage on the tubes, Error code.	**Mechanical:** Attachment, Calibration, Casing, and Cleaning **Electrical:** Connections, Switches, and Connectors **Plumbing:** Blockages, Connections, Seal, and Rings
PATIENT MONITORS	Cuff leakage and broken tubes, display problem, Software and BP motor problem.	**Mechanical:** Attachment, and Calibration **Plumbing:** Blockages, Connections, Leaking, and Seal **Electrical**: Plug/cable, Regulator, and Transformer, Connections, Connectors, and Lighting/ Indicators **User training**

SUCTION MACHINES (ROTARY, DIAPHRAGM, THERMOTIC, VENTURE)	Failed 24v step down transformer, broken shaft on suction motor, no negative pressure due to motor problem, backflow to motor.	**Electrical:** Connections, Connectors, and Lighting/ Indicators**,** Plug/cable, Regulator, and Transformer**,** Belts/ Gears/ Shafts/ Coupling, Cleaning/ Lubrication, and Tightening/ Attachment/ Balance **Mechanical**: Attachment, Calibration, Casing, and Cleaning **Plumbing:** Blockages, Connections, Seal, and Rings
X-RAY (FIXED – RADIOGRAPHIC AND/OR FLUOROSCOPIC UNIT, DIGITAL)	Burnt halogen lamp, phase and neutral line short at the main switch and fuse burnt, expose push button not working, broken limit switch, digital printer of the X-ray stopped working, burnt fuse, collimator planes adjustment problem, detached power cable, cassette rig problem due to setting problem.	**Electrical:** Connections, Switches, Connectors, and Lighting/ Indicators, Fuse, Plug/cable, Regulator, Transformer **Mechanical:** Attachment, Casing, and Cleaning

classified as fundamental or advanced. The advanced units which did not come into any of the above four categories were later grouped into one category (called " other "). If the repairs recorded in that unit were performed using skills and tools that we thought an eligible individual should have been taught in 1-2 h, the unit was considered fundamental. An eligible individual was considered to be someone who could read, write, and do mathematics through fractions, but does not necessarily have other previous laboratory or medical equipment experience.

It was possible to further subdivide each unit into unique skills. A skill was described as the steps needed for the repair to be diagnosed and undertaken. If we thought that more than 2 hours would be needed to learn the skill, all skills were divided into multiple skills. There were only fundamental units divided into skills. Our approach varies notably from other approaches to the determination of knowledge domains. We did not presume, for example, any theoretical knowledge of the concepts of machine operation. In fact, in most cases, diagnosis and repairs involving theoretical knowledge of the equipment were omitted from the definitions of domain, unit, and skill. In our coverage of subjects, we have made no effort to be thorough. Instead, we decided to find just the most helpful skills. Therefore, multiple repairs were required for every domain, unit, and skill.

There were a total of 24 basic units listed. From cleaning to calibration or transformers, units varied in complexity. Meanwhile, in a basic unit, we managed to produce 86 fundamental skills recorded in more than one repair. The 86 skills are not listed here, but are available in Appendix B. Since all the results are based on the study of only 11 equipment and the evidence given by the work orders and memory of technicians, the units are not only not detailed, they are not a classically structured, thematically organized body of knowledge. For example, " lubrication " was defined as a simple unit with only four skills in the mechanical domain: greasing/ oiling with thin penetrating oils, unfreezing painted joints, identifying lubricant (type, reservoir), and repack bearings. Skills such as

building/ adapting a charger for rechargeable cells, identification of leaking/corrosive batteries, replacing batteries with a wall transformer, substituting for batteries for primary cells, substituting for batteries for rechargeable cells were included in the electrical domain 'batteries' unit. Those particular skills would be unlikely to be selected by a classical approach to a body of knowledge.

Of the total of 161 items documented, 131 could be placed back into service using one of the skills identified, of which 88 were repaired during the research period and the rest 43 items were repaired in recent period before the research started (with in one to two years). In other words, 82% of the repair specifications required just knowledge of the listed skills to be put back into operation and all those without importing replacement parts. Electrical repairs, where more specialized expertise was needed, were the most frequent repairs that required more than fundamental unit knowledge. Knowledge of circuits or electronics was needed for most of those repairs as well as specialized knowledge or instruments, including some wiring and shaft repair, were required.

5.5 Developed Proposal to Meet the Needs

To meet the specific needs of study hospitals, the evidence-based training was conducted at three intervention hospitals between July 1, 2019 and August 26, 2019. The curriculum was intended for the technical staff who are already BMET or BME. Instead of basic training, continuing education was introduced because they had a higher degree of basic education and more access to previous training programs.

Analyzing the data through the process of evaluating maintenance programs and causes of non-functional equipment, and other situations identified in the 'the need for change', all major components and factors directly contributing to the healthcare technology problems found in research hospitals are developed. Afterwards, these factors became the key elements and considered necessary to the established systemic approach of developing the new and unique evidence-based training model for capacity building at intervention hospitals that helped to sustain a stable healthcare technology development, implementation and management.

As mentioned below, the program complements an equipment-based curriculum with professional development, technology management, and established knowledge of various repair skills by taking into account the settings of the study hospital and technical resource levels to meet specific requirements. The solution also included optimal HTM intervention approaches with training on sample policies and procedures, and an efficient program for the maintenance of medical equipment with planning, management and implementation, along with other parts of the listed curriculum.

5.5.1 The Curriculum

The section below describes the content of the newly designed and implemented evidence based training by topics.

1. **Healthcare technology management:**

It provides topics that will assist technical staff with everyday healthcare technology management. It covered the chain of healthcare technology management operations, from planning and budgeting to procurement, and everyday activity and safety. A variety of practical measures were outlined in the training for: maintenance planning, record-keeping, workplace management, stock management, and personnel management.

2. **Medical equipment maintenance strategy:**

The aim of this training was to provide information on the components of an effective maintenance program for medical equipment. It was intended to assist the intervention hospitals with medical equipment preparation, management and maintenance implementation. It was a suitable curriculum designed to comply with particular specifications. Training was given to those responsible for the preparation, management and implementation of health technology management services at study hospitals where such services were not completely developed, as defined in the section discussing the results of the assessment of existing maintenance programs. This section's content is listed below.

I. **Planning**.

In order to develop a systematic program for HTM, it outlined maintenance program preparation methods. This planning process includes an analysis of essential factors: inventory - the types and numbers of medical devices to be tracked by the hospital and those explicitly included in the program; methodology - identification of the system by which the devices included in the program will be maintained; and resources - the financial, physical, and human resources available to the program. It also discusses how to manage these variables to develop a maintenance program that is optimal and cost-effective for their situation.

II. **Management.**

Once developed, it is necessary to handle the program in an efficient and economical way. Therefore, program management has many aspects that are typically handled concurrently, including financial management; personnel management (service vendors and training required); operational management (development or modification of procedures for IPM, IPM frequency setting, maintenance scheduling, work order prioritization, record keeping, CMMS, tags and labels, communication, and managing use and user error); performance monitoring (completion rate of assigned IPM, equipment location rate, IPM yield, IPM productivity, and CM performance measures); and performance improvement.

III. Implementation.

Training on implementation of a designed program using the correct and appropriate procedures for IPM and problem identification, corrective maintenance (troubleshooting and repair, factors affecting equipment failures, inspection and return to service), reporting, and safety.

IV. **Policies and procedures.**

Training on sample policies and procedures used for the risk-based management program, initial testing and assessment, IPM procedure, CM work order system, PM corrective measures, and infection control. Training also included IPM workload estimation, and examples of inventory and inspection forms (new equipment receive checklist, equipment inspection and work order). Besides, samples of inspection labels (inspection report, inspection record (test) results and defect notification), as well as examples of activities conducted during the creation of maintenance programs were included.

3. **Equipment-specific training**

It included topics: working principle, operation, circuit diagram, assemble and disassemble, troubleshooting, service and repair, and Software upgrade for the 11 study equipment

4. **Non-equipment-specific repair skills**:

It included the 24 units of identified most needed knowledge of essential repair skills: Electrical (11) - Connections, Connectors, Fabrication (cables, electrodes, plates), Heating Element, Lighting/Indicators/Switches, Batteries, Brush Substitution, Fuse, Plug/cable, Regulator, and Transformer; Mechanical (7) - Attachment, Calibration, Casing, Cleaning, Lubrication,

Belts/Gears/Shafts Coupling, and Tightening/Attachment/Balance; Plumbing (6) - Blockages, Connections, Filters, Leaking, Seal, and Rings.

5. **Communications and networking**:

Topics about how to make hospital visits, receive phone mentoring on specific repairs, and imitating the technical forums common clinical engineering works.

6. **Professional development:**

It stressed skills such as how to make user training, how to communicate with director of the hospital, Internet skills (searching and e-mail), and writing basic letters.

7. **Biomedical-specific tools and use:**

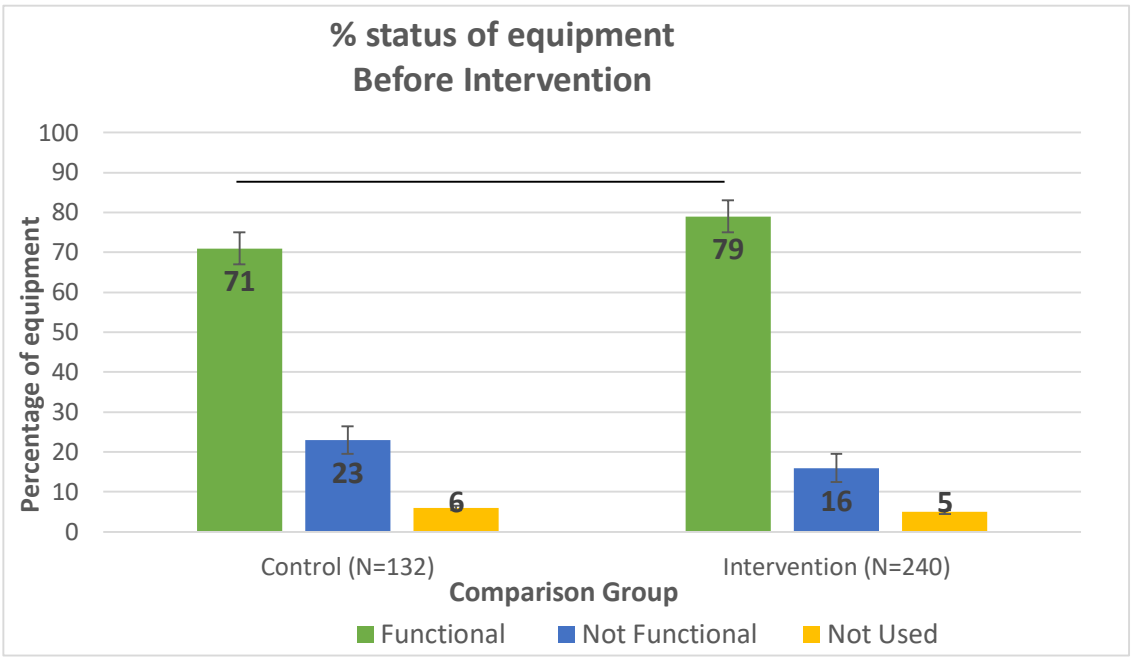
Topics about how to use common electrical tools and equipment analyzers.

5.6 The Extent and Impact of the Change

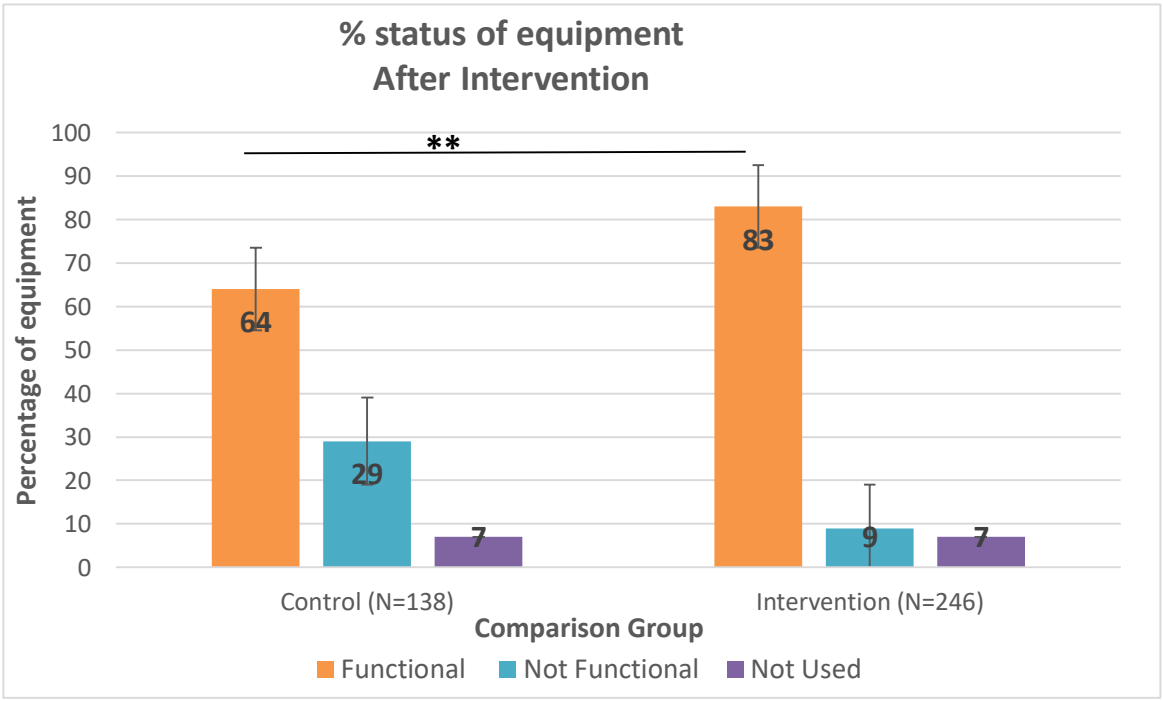
A total of 384 pieces of medical equipment in the class of 11 study equipment were examined. In total, 78 PM instances, along with 81 CM instances, were registered. 170 separate activities resulted in other workflow actions, including user training, calibration, testing, and adjusting equipment settings. No data, unless otherwise stated, has been omitted or excluded from the study. Of all the class of equipment surveyed in the 6 hospitals, 76% was in-service, 16.7% was out of service and 7.3% was not needed (which are ready to decommission or already decommissioned). The contracted instruments were excluded from analysis in order to compare intervention and control hospitals. As reported in technician and director interviews, technicians do not fix or operate the contracted equipment.

As shown in Figure 5.1, before the intervention, the odds of out-of-service equipment in control hospitals were just 1.38 (29% vs 21%); but, after 4 months, the odds of out-of-service equipment in control hospitals were 2.11 times higher than in intervention hospitals (odds ratio, 2.11, $P < .05$). This suggests that intervention technicians retained the equipment that they had training in-service significantly more frequently than technicians kept the same types of equipment in-service in control hospitals (83% vs. 64%, $P < .05$). This indicates that equipment-specific training is essential.

Other measures of better management include an improvement in the number of not-needed equipment available in intervention hospitals before and after intervention (5% vs. 7%). The four-



A)



B)

Figure 5. 1 Available frequency and functional status of equipment before and after intervention. The class of 11 medical equipment was surveyed in the 6 hospitals (both in control and intervention groups). A) Before intervention in June, 2019. B) Four months after intervention in Dec, 2019. Out-of-service equipment was in disrepair or there was a shortage of a required part and was thus not currently in operation. Compared to intervention hospitals, the likelihood of a piece of equipment being out-of-service in control hospitals was 2.11 times greater (odds ratio, 2.11; $P < .05$, X^2). In addition, over a four-month span, the amount of usable equipment decreased by 7% at control hospitals. The occurrence frequency of the equipment is represented by the numbers shown on the bar graph.

month rise in the quantity of unnecessary equipment at intervention hospitals suggests that trained technicians are shifting the equipment from broken to retired or duplicated, rather than leaving it out-of-service on the bedside.

Autoclaves, suction machines, oxygen concentrators, and Anesthesia machines with 18, 14, 13, and 9 in number respectively were the most common types of out-of-service equipment. Trained technicians work, adding to their performance, on more equipment. Over the past 4 months, intervention technicians have worked on 8 different types of equipment, while control technicians have worked on 7 types. 73.5% of repairs were recorded on paper in the intervention hospitals when fixing the equipment, compared to just 25.5% of repairs in control hospitals (188 percent rise, P < .01, Figure 5.2).

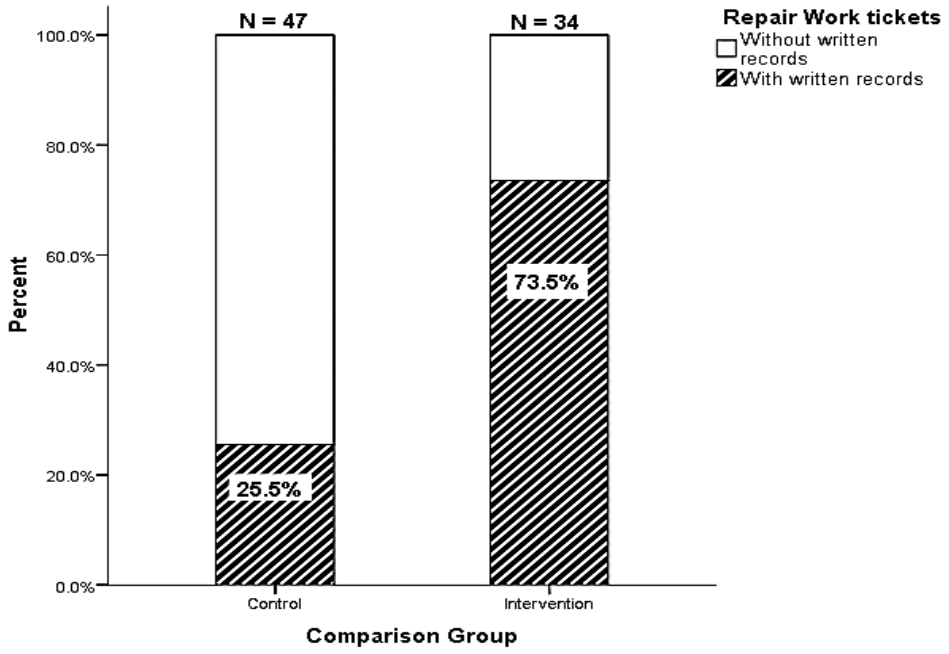


Figure 5. 2 Percentage of recorded repairs on paper. Both from written records and memory, all equipment repairs made in the last 4 months were surveyed. The quantity of repairs with written records in the intervention hospitals increased by 188% (*p < .01, X^2).

Five types of equipment suction machines, autoclaves, anesthesia machines, oxygen concentrators and infant warmers are the most often repaired. On average, untrained technicians worked on 16 corrective maintenance cases, while in the last 4 months, trained technicians worked on only 11 corrective maintenance cases (P < 0.1). In other words, because of low PM productivity, untrained technicians work on a greater percentage of class medical equipment. The fact that trained technicians are more efficient in requiring less corrective measures means that trained technicians are more diligent in handling the equipment in their work. Besides, all intervention hospitals have

paperwork for the request when a piece of equipment is broken, which is filled by equipment users. However, only one control hospital uses a request paperwork.

For each piece that was not completely functional, the barriers to repair were established. Unquestionably, the technician's confidence strengthens his/her ability to fix equipment. Training technicians were statistically substantially less likely to state that they did not touch the equipment, were afraid to make the issue worse, or required more training. Seventy percent of the out-of-service equipment is due to shortage of parts, and accessories and consumables in intervention hospitals, compared to 36% in control hospitals (95% rise, $P < .05$). At control hospitals, technicians said that 57% of the time, they needed training to fix equipment. This is substantially more than in intervention hospitals where 27% of the time (110% decrease, $P < .05$) a lack of training is cited as the barrier to repair. Lack of tools was seldom cited by either of the two groups as an obstacle. This could be seen to contradict the theory that the absence of tools is an obstacle to biomedical technicians' maintenance, or this could suggest a continued lack of knowledge of task-specific tool values.

In all hospitals, users point to a lack of training as an obstacle to fewer than 3% of not fully functional equipment being used. This, however, contradicts technicians report of user error, contributing to at least 29% of broken equipment. Workshop, and access to tools and manuals questions indicated that each hospital had approximately the same number of basic tools (multi-meters, screwdrivers, pliers, wire cutters, etc.), with the exception of JUMC, which had access to a set of specialized tools and other testing equipment which includes analyzers for electrical safety, defibrillator, and electrosurgical machine as well as cardiac simulators.

All of the intervention hospitals were doing routine PM and paper documentation. All control hospitals except AwGH also have a schedule for PM, but none of them had a paper documentation. At intervention hospitals 27.57% of total technician productivity is PM, and 15.89% is corrective. In contrast, at control hospitals, only 16.52% of the productivity was PM, and 40.87% was corrective (Figure 5.3). Intervention technicians are able to complete the scheduled preventative maintenance more than 70% of time with 1 day to 2 weeks' delay whereas control hospitals are eventually able to complete 30-50 % of PPM with 1 week to 1-month delay. At all hospitals, workload is indicated as the main barriers to complete performing PM as scheduled.

The 'Informal Equipment Interaction' interview-assisted survey also allowed to gain information about times when the technician checked on the medical equipment but did not perform planned

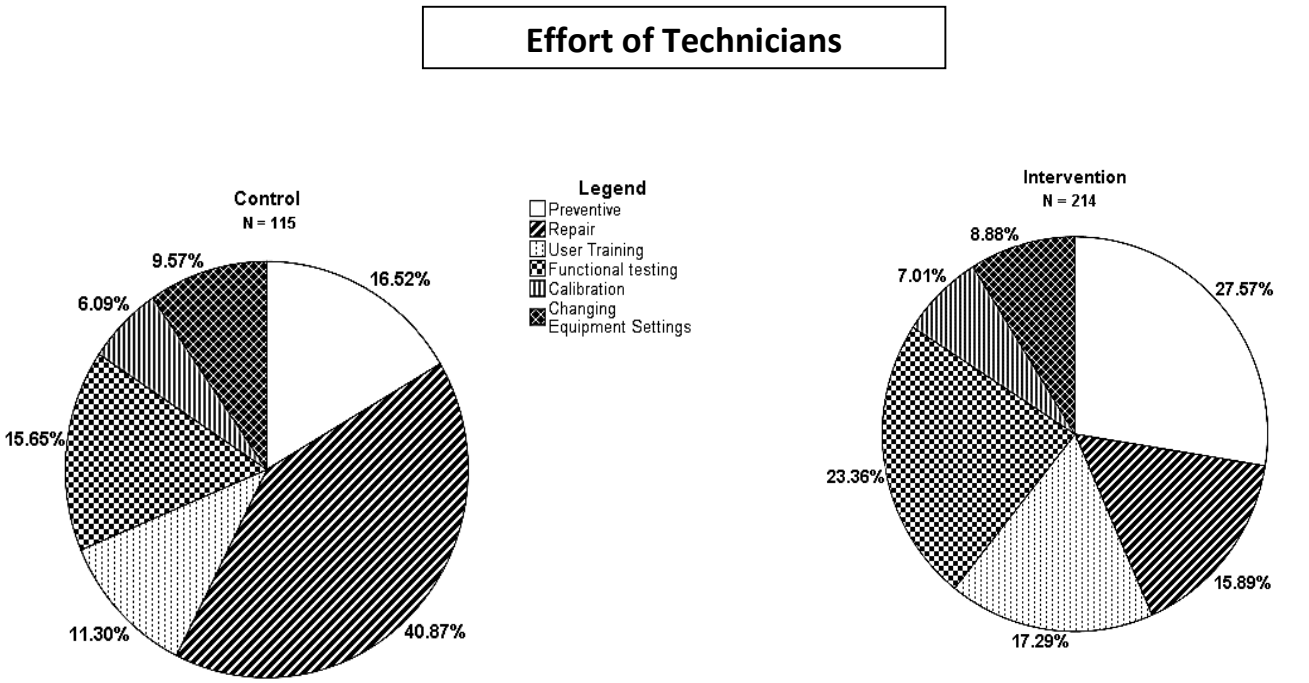


Figure 5. 3 For all work-related activities, the efforts of technicians were compared. In summary, in intervention hospitals, 214 actions were recorded and 115 in control hospitals. There was a substantial rise in the number of preventive actions in intervention hospitals, resulting in less repairs to equipment (67% increase, *p = .05).

preventative maintenance. It allowed to gain more extensive information that re-categorized activities as either a management or corrective action. Intervention hospitals made significant difference on number of all informal equipment interactions; have provided user training (37 vs. 13), performed functional test (50 vs. 18), calibrated medical equipment (15 vs. 7), changed equipment settings (19 vs. 11), and used testing equipment (21 vs. 7) over the past 4 months. Appendix A.4 outlines survey findings for individual hospitals.

The results of the management action survey showed that intervention technicians were more engaged in the procurement process, including staff training, purchasing, acquiring, and installing the equipment. On these steps, the gap between intervention and control hospitals is significant (Figure 5.4). Control hospitals purchased 9 medical equipment total in the last 4 months whereas intervention hospitals bought 13 and among those, 6 equipment each from both group were part of the class of 11 study equipment. Of those equipment, intervention hospitals involved in receiving all new equipment and they involved with purchase, and installation and user training for 10 and 9 of them respectively whereas control hospitals involved with receiving and installation for 7 of new equipment and involved with purchasing and user training for only 4 and 5 of them respectively.

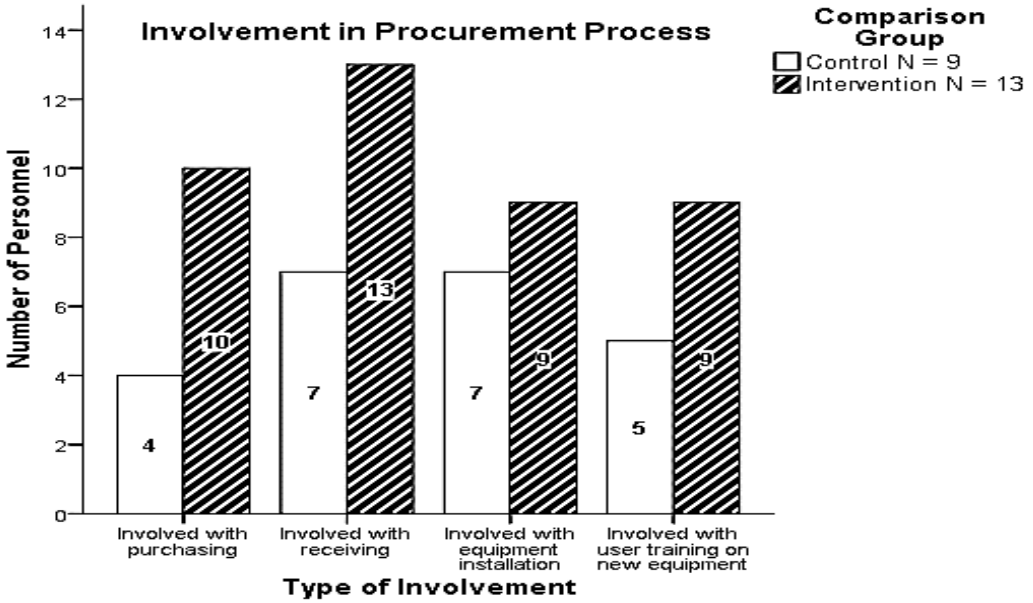


Figure 5. 4 Engagement with the method of procurement. Technicians and managers from each hospital were questioned about the role of technicians in the procurement stages. Intervention hospitals were involved with more technicians.

Besides, all intervention technicians maintain inventories of new medical equipment while only one control hospital had a log of purchased equipment. This indicates the HTM training was very essential.

The management action survey also allowed information about technician's interactions with administrators. All intervention technicians have a regular monthly meeting with and provide reports to the hospital administration. One of the control hospital SGGH technicians responded to have monthly meetings with MD, but the rest only had occasional meetings with administrators. Most commonly talked topics include: about spare part purchase, HT problems, SC, user errors and other medical equipment issues. Administrators use provided written reports to manage in-service and out-of-service equipment, stock levels, training needs, and to prevent problems pertaining to healthcare technology. Appendix A.3 outlines the interview-assisted questions used for the management actions survey and recorded participants' responses in detail with description of steps.

Another explanation why trained technicians were more active is that, both within Ethiopia and outside Ethiopia, they were more likely to request technical assistance. The technicians at intervention hospitals communicate to people outside the hospital for help far more often than control hospitals. Over four months, intervention technicians had an average of 11 in-country contacts with importer companies and other technicians, compared to an average of 5 in-country contacts in control hospitals. Intervention technicians also contact individual outside Ethiopia on

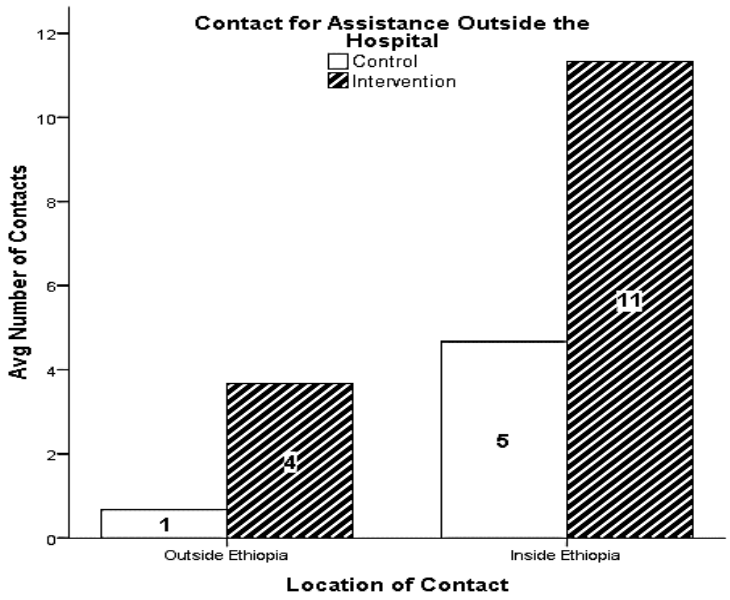


Figure 5. 5 Amount of contact for assistance outside hospital. Technicians were asked how often they requested assistance over the past 4 months. Intervention technicians asked for assistance more often inside and outside the country than the control technicians did. In-country contacts included friend technicians and experts from importer companies. Outside contacts included online forums and experts from other countries. Part of the reason that the unique evidence-based curriculum is successful is that it stresses non-equipment-specific training, such as networking skills.

on average at least 4 times in four months, compared to 1 time in control hospitals (Figure 5.5). Perhaps even more relevant is the opportunity to obtain information from outside the country about their medical equipment, where the equipment has been made, and for finding a manual or spare component.

Part of the reason for the accomplishment of the unique evidence-based program is that it emphasizes training that is non-equipment-specific, such as networking skills. In-country contacts included helpful technicians and importer companies' experts. Online forums, and experts from other countries included outside contacts. The knowledge shared included access to parts or supplies, methods for diagnosing or fixing a problem, and the acquisition of manuals. Calling for in-country contacts, and email and forums for foreign contacts were the communication modes for assistance. Given that there is minimal Internet connectivity at home or at their hospitals, this is especially remarkable.

Both trained and untrained technicians had a higher degree of English proficiency (100 percent answering all 3 questions correctly). This is relevant when considering that almost all medical equipment providers and user manuals (forums, browse, or e-mail) are accessed using English on the Internet. In the last four months, trained technicians reported using a search engine on average

9 times, where non-trained technicians used just 3 times as. They mentioned using the Internet for finding technical details and manual for a piece of medical equipment.

5.7 CMMS Results

The full assessment review indicated that CMMS was required. The assessment is used to develop a clear technical specification for both mandatory and optional features for the scope of the system. The model is a customized CMMS software, a package designed to meet the exact needs of hospitals in the Jimma zone without requiring any alteration of the departments' functions and procedures.

5.7.1 Justification of CMMS Significance

The RMI feature is used to increase the accessibility of the system as well as minimizing the complexity of the application usage, and allows working with local and remote objects. One of the notable functional qualities of phpMyAdmin, which is used to manage the CMMS database is that the queries can be edited or manipulated using the flexible web-supported medium and it is highly supportive for data migration activities. The application also has a provision to setup the server details of the database, which can be used to connect to the database that needs to be managed. With an intuitive web interface, it support for most MySQL features: browse and drop databases, tables, views, fields and indexes; create, copy, drop, rename and alter databases, tables, fields and indexes; maintenance server, databases and tables, with proposals on server configuration; execute, edit and bookmark any SQL-statement, even batch-queries; manage MySQL user accounts and privileges; manage stored procedures and triggers, import data from CSV and SQL; export data to various formats: CSV, SQL, XML, PDF, Spreadsheet, Word, and others [41].

Under ‘Medical Equipment Management’ section of the 2012 EFY (2019/2020) FMoH annual performance report, it was described that FMoH has developed a web-based medical equipment management information system (MEMIS) for efficient use and proper management. The system enables medical devices registration, reporting, maintenance referral system and requests, inventory management and specifications modules with each specific privilege at each level of health systems. In 2012 EFY, the MEMIS implementation was successfully pilot tested in three hospitals and Millennium makeshift hospital (COVID site). The document reported that MEMIS will be implemented in 25 selected hospitals in the coming years. The report further mentioned that that unavailability of computerized inventory management system and updated inventory was one of the major challenges to implement MEMIS and Supporting hospitals to update their inventory to implement MEMIS was one of the way forward activities projected. Hence our designed CMMS

model will be highly compatible and could provide important data for the MEMIS implementation since it has the proper data migration system for importing and exporting data from the system [42].

Furthermore, to provide a more satisfactory solution that meets local needs, it was well planned and maintained. It will also serve as a method for a range of practical measures, including maintenance, preparation, record-keeping, workplace management, stock management and management of workers. There will also be several advantages of CMMS. For data entry, maintenance monitoring and reporting, far less staff time is needed; it will reduce human errors; and it will allow more efficient monitoring of performance metrics and productivity of staff. In addition, electronic documentation of inventories of equipment, inspections, repairs, maintenance and equipment history will be available. These will allow the technicians to take care of their equipment and continue to provide health services. In addition, it would help to provide a responsible and comprehensive approach to ensuring that cost-effective, effective, sufficient and secure facilities are available to meet the requirements of quality patient care.

5.7.1 The CMMS Software Structure

In a database consisting of fields, tables, modules and screens, the developed CMMS program incorporates all medical equipment services. There are 13 screen window tabs for the basic layout of the built system. The RMI system used to create the distributed application allows users to get access to the system by entering their username and password using the Login window and able to work all HTM activities in anywhere inside of the LAN using the incorporated pure java solution to Remote Procedure Calls (RPC). Stub and Skeleton objects are used for communication between client and server side. Whenever a client invokes the method that accepts parameters on a remote object, the parameters are bundled into a message before being sent over the network, then they are serialized. At the server side, the packed parameters are unbundled and then the required method is invoked.

After they logged in, the first main window allows the user to generate and analyze data from a selection of fields, tables and modules via a user-friendly filtering interface. The rest 12 windows allow the user to enter, update, delete, and select data with also a user-friendly interface. The (table name, and number of related fields) used to develop the system are: (Equipment type, 7), (Equipment model, 8), (Manufacturer, 6), (Seller/vendor, 6), (Spare parts, 13), (User & staff management, 10), (Training, 3), (Service provider, 2), (Maintenance, 10), (Health facility, 7), (Department, 2), and (Building, 2). The following section gives a brief explanation of the basic structure of the developed system that is suitable for the identified needs.

I. Fields and tables

A field is a single piece of data, such as a 'equipment serial number,' for instance. A table is a collection of similar fields, e.g. the 'Equipment Model' table which consist of the 'model number',' Serial number',' Installation date',' IPM procedures' and other fields. Tables and their related fields used to develop the system are shown in Table 5.6 below.

Table 5. 6 Designed database tables and their related fields used to develop the system.

	TABLE	FIELDS
I.	**EQUIPMENT_TYPE**	1. Equipment_inventory_number 2. Equipment description (type) and class code 3. Equipment_name_and_class_code 4. IPM_frequency 5. Risk_level 6. Responsible_staff_id 7. Model_id
II.	**EQUIPMENT_MODEL**	1. Model_number 2. Serial_number 3. Current_software_revision 4. Purchase_price 5. Installation_date 6. Warranty_expiration_date 7. IPM_procedures 8. Status_flag
III.	**MANUFACTURER**	1. Code 2. Name 3. Email 4. Telephone 5. Address 6. Contact_person_name
IV.	**SELLER_OR_VENDOR**	1. Code 2. Name 3. Email 4. Telephone 5. Address 6. Contact_person_name
V.	**SPARE_PARTS**	1. Parts_code 2. Part_name 3. Stock_or_inventory_number; 4. Manufacturer_name 5. Serial_and_part_number 6. Equipment_model_id 7. Minimum_stock_level; 8. Current_stock_level 9. Store_code 10. Store_name 11. Price_purchesed 12. Date_purchased 13. Parts_order_number
VI.	**USER_AND_STAFF**	1. First_name

		2. Father_name 3. Grand_father_name 4. Username 5. password 6. Staff 7. Employee_code 8. Employee_name 9. Employee_position 10. Access_level
VII.	**TRAINING**	1. Training_name 2. Training_detail 3. Staff_id
VIII.	**SERVICE_PROVIDER**	**I.** Provider_name **II.** Description
IX.	**MAINTENANCE**	1. Equipment_type_id 2. Service_provider_id 3. Fault_code 4. Fault_name 5. Work_order_number 6. IPM_procedures 7. IPM_schedule 8. Frequency_of_fault; 9. Estimated_running_hours. 10. Staff_id
X.	**HEALTH_FACILITY**	1. Facility_code 2. Facility_name 3. Building_code 4. Building_name 5. Department_code 6. Department_name **7.** Type_of_facility
XI.	**DEPARTMENT**	1. Department_code 2. Department_name
XII.	**BUILDING**	1. Building_code 2. Building_name

II. Modules

A set of tables and data screens is a module. For example, the inventory module is composed of the 'equipment type' table, the 'equipment model' table, the 'manufacturer information' table, the 'equipment building' table, and 'equipment department' table. Basic modules of the CMMS software are defined in the following sections.

Equipment inventory module:

The inventory module is the basic of the CMMS and the first developed. When new equipment is added to the inventory, the data entry screens are used to record it in the CMMS database. It was designed to dropdown previously stored and default values when we enter data for new equipment, which is highly beneficial for reducing entry time and avoiding human error. For instance, the module containing information about ‘equipment type' contains pre-stored values such as specific

IPM procedures, risk level, model type, responsible personnel, as well as information about the health facility, building, and department for each type of equipment. It is therefore only required to enter the inventory code, name and description of a new piece of equipment into the equipment management screen and all associated pre-stored values will be included to the inventory.

Spare parts inventory and management module:

The module for the management of spare parts is an extension of the inventory module that records equipment-related spare parts and helps to maintain stock levels. Parts that are more exclusive to a particular model, such as power supplies, circuit boards, X-ray tubes, and ultra-sound probes, are among the stocked parts, as are fuses, cables, batteries, and simple electronic components, which are essential to a number of various pieces of equipment. These data can be entered manually, populating inside the database the relevant spare part management fields and related pre-stored values of the name, model and manufacturer of the equipment. The data can be used to generate information to measure minimum stock levels for specific parts; to generate reports on the frequency of replacement parts, which can help predict maintenance schedules and future stock levels; and which parts may need to be ordered and when all the parts required for certain parts of equipment are listed together.

Maintenance module:

The maintenance module assists the CMMS software user in managing their maintenance schedule effectively. The CMMS combines with a hospital regular maintenance system and can be used both for PPM and for CM. The computerized system will indicate with the necessary inputs when a piece of equipment may need maintenance (IPM schedule) and its IPM procedures. The clinical engineering department will also record the work order number, date, fault code and name, frequency of fault, and estimated running hour in the CMMS system when a user reports a problem with a piece of equipment.

In addition, the software would allow the system's manager to delegate the job to an engineer/technician. In order to assist with this decision, the CMMS can also provide information about the workload, training and skills of individual engineers. The computerized system also provides the spare part type with the correct ordering information if an initial fault evaluation concludes that a certain item is required to complete the job. When the job is over, the state of the equipment will be entered into the system.

III. Screens and reports

A screen provides a user-friendly interface for entering, updating, deleting, and selecting data as well as collecting and analyzing data from a variety of fields, tables, and modules. The ‘main window' screen, for instance, allows us to create a list of data from multiple modules that summarizes the HTM activity connected to a specific piece of equipment. The user will recall equipment history details and check for equipment by entering a particular serial number. It is the CMMS's key function which contains information such as inventory data, work order details, service activities, replacement parts used with related costs, and responsible personnel as well as health facility and departments names. It can be used to generate information that will aid in the tracking of medical equipment maintenance activities. This enables administrators to assess the cumulative success of their HTM program. A number of other easy-to-use interface module screens allow the user to access, edit, delete, and pick information from the database to retrieve and evaluate.

Sample screenshots for windows of the backend database management system are shown on Figure 5.6 to Figure 5.10 below. The screenshots include the XAMPP control panel, phpMyAdmin login window, phpMyAdmin localhost window, CMMS database window, and Equipment type table in the database. Sample screenshots of screens from the frontend of the developed CMMS software for login window, main window, user management, equipment type management, manufacturer details, equipment model management, and maintenance management are given in Figures 5.11 to Figure 17 below. The system also contains individual database tables and screens for information about sellers, service providers, health facilities, replacement parts, buildings, departments, and technician training details.

After the initial data entry for all designed modules and fields has been completed, the complete system has been put into operational testing and all user specifications and comments have been considered and no problems have occurred. Before entering data, the system was configured and customized using existing processes and procedures, such as basic workflow, access and security, and user preferences. However, for individual hospitals, facility-specific workflow and additional customization of data fields have not been achieved.

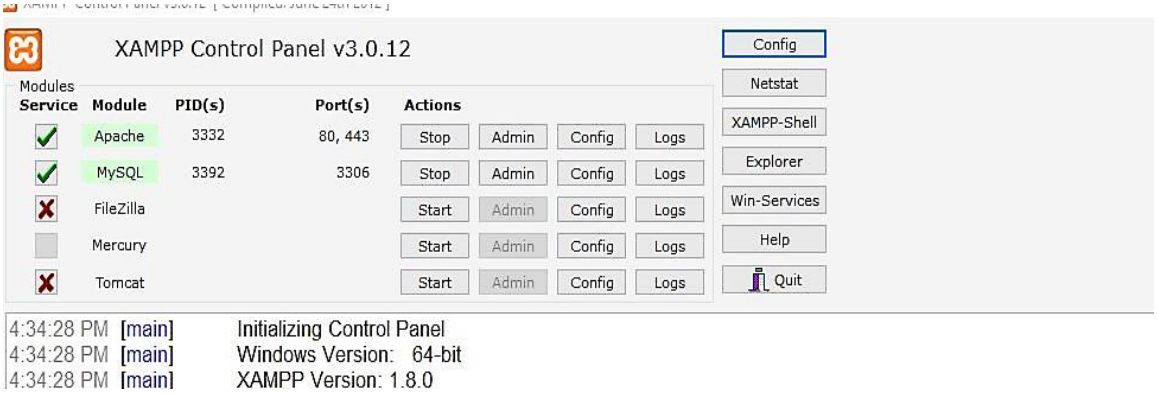


Figure 5. 6 The XAMPP control panel window for Apache and MySQL modules service.

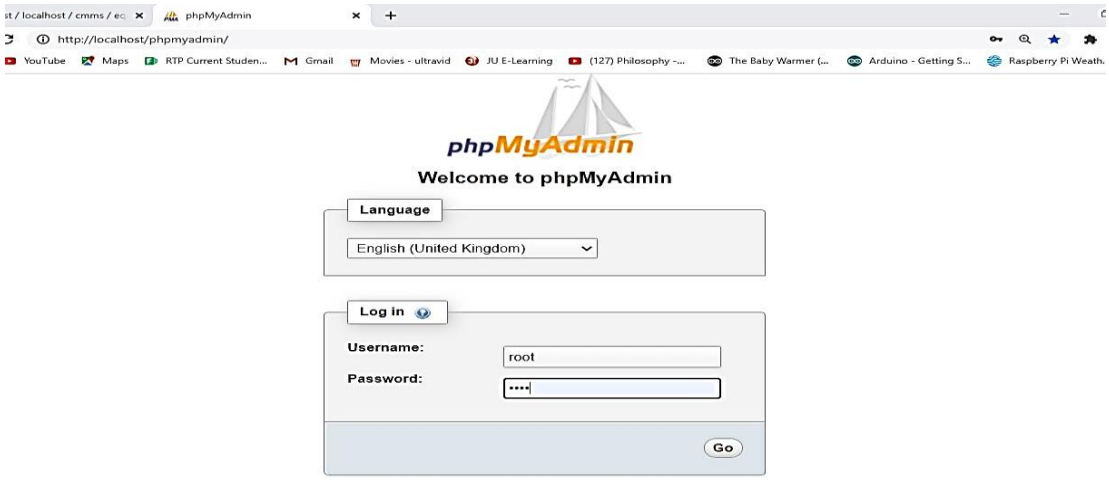


Figure 5. 7 The phpMyAdmin Login window for getting access to the database management.

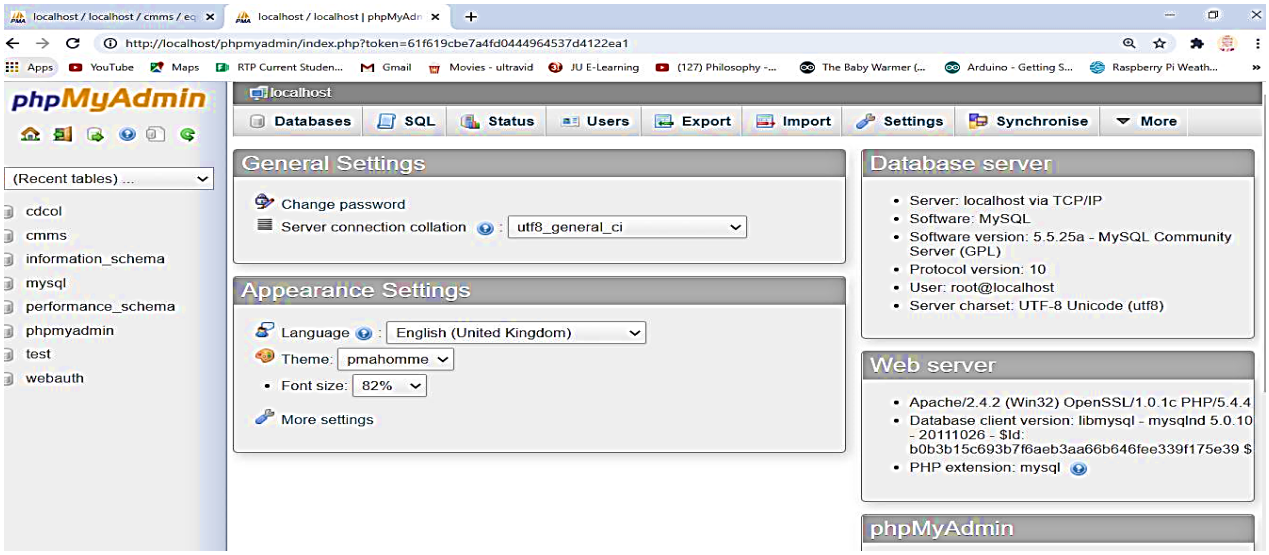


Figure 5. 8 The phpMyAdmin localhost window.

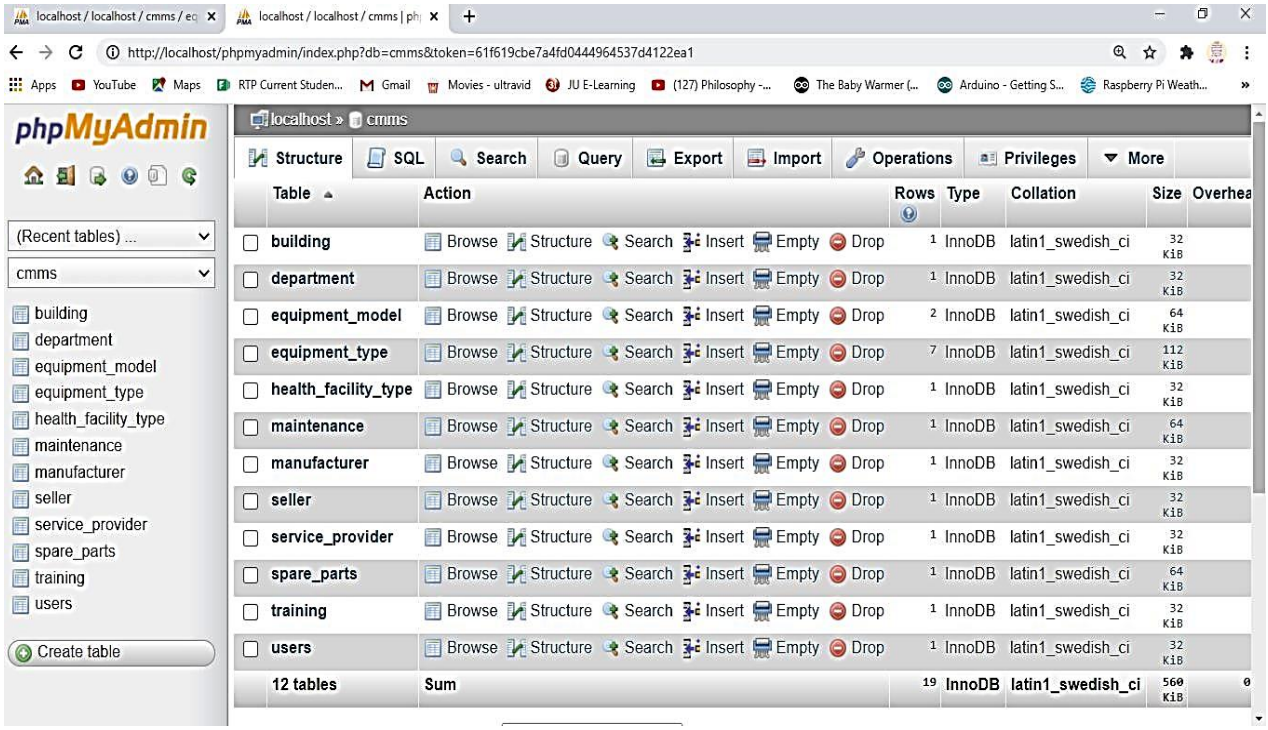


Figure 5. 9 The CMMS database window.

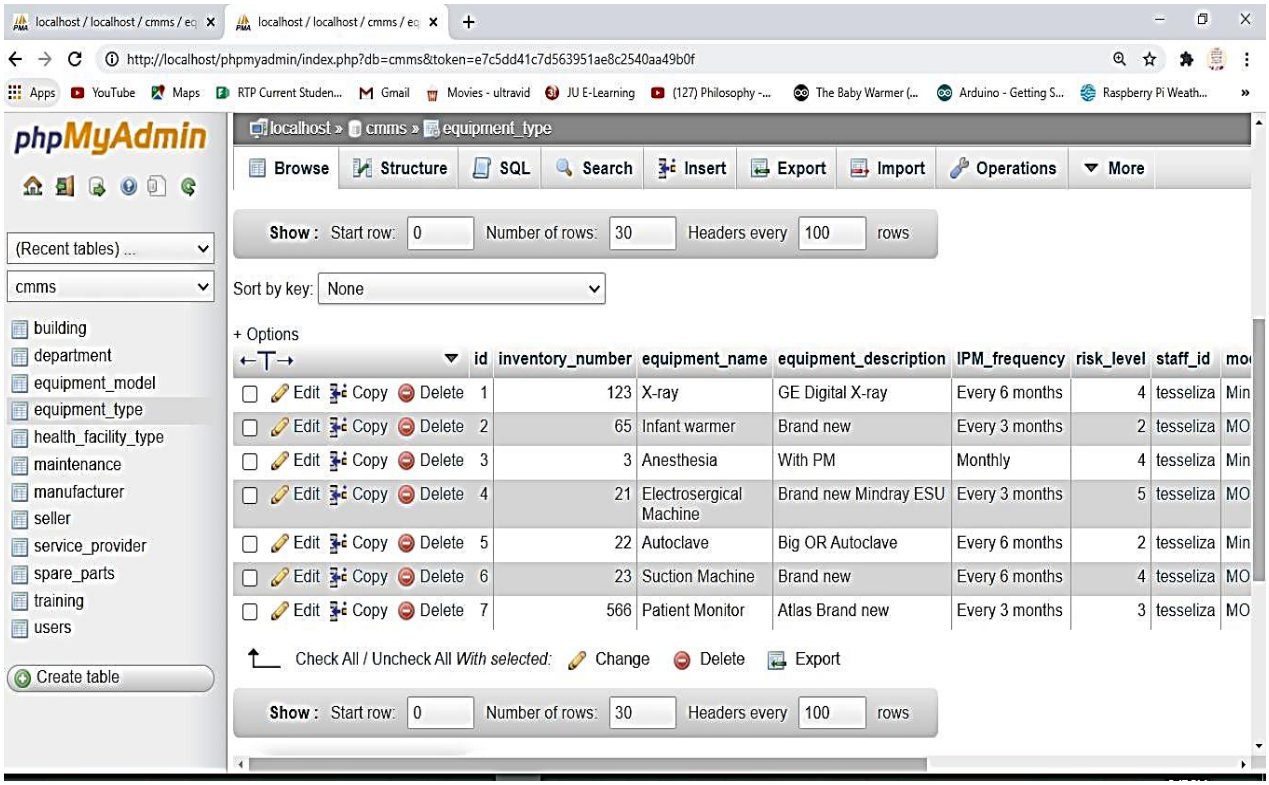
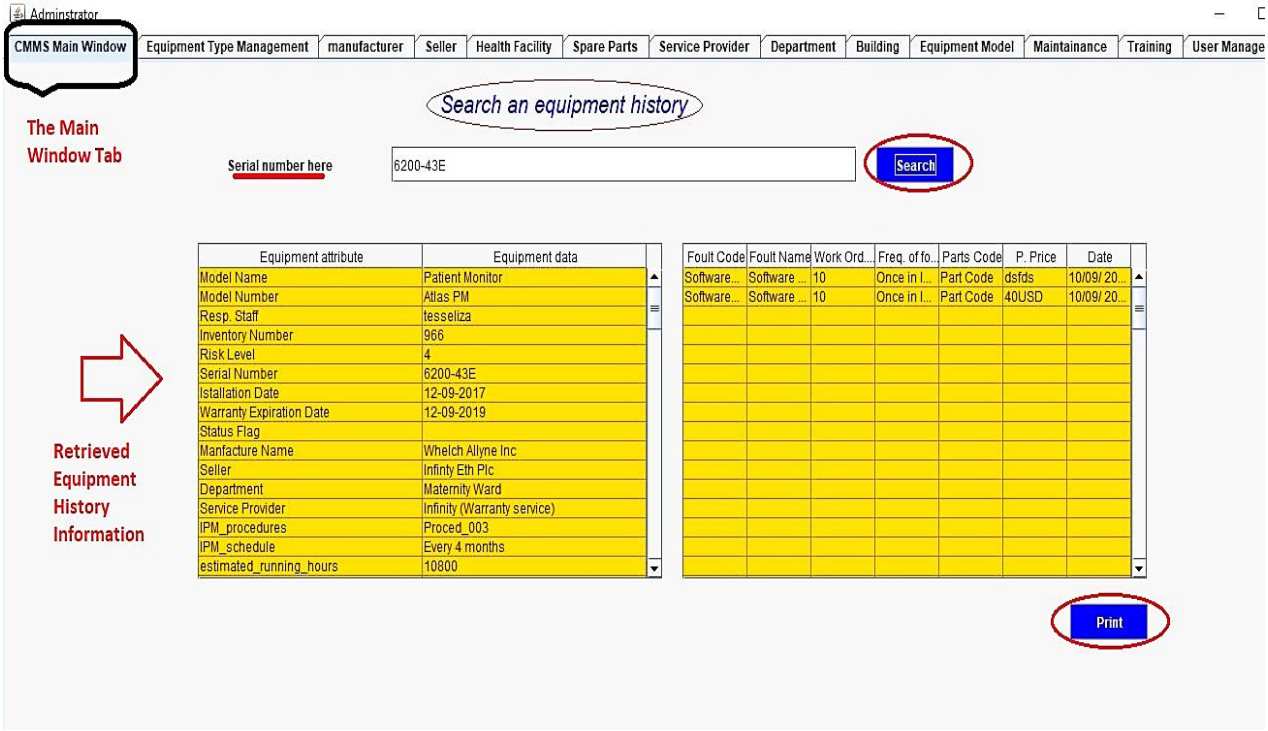


Figure 5. 10 The Equipment type table in the CMMS database.

Figure 5. 11 The frontend login window that helps to get access to the system.



Equipment attribute	Equipment data
Model Name	Patient Monitor
Model Number	Atlas PM
Resp. Staff	tesseliza
Inventory Number	966
Risk Level	4
Serial Number	6200-43E
Istallation Date	12-09-2017
Warranty Expiration Date	12-09-2019
Status Flag	
Manfacture Name	Whelch Allyne Inc
Seller	Infinty Eth Plc
Department	Maternity Ward
Service Provider	Infinity (Warranty service)
IPM_procedures	Proced_003
IPM_schedule	Every 4 months
estimated_running_hours	10800

Fault Code	Fault Name	Work Ord...	Freq. of fo...	Parts Code	P. Price	Date
Software...	Software ...	10	Once in l...	Part Code	dsfds	10/09/ 20...
Software...	Software ...	10	Once in l...	Part Code	40USD	10/09/ 20...

Figure 5. 12 The CMMS main window screen to generate a list of data from multiple modules that summarizes the HTM activity connected to a specific piece of equipment.

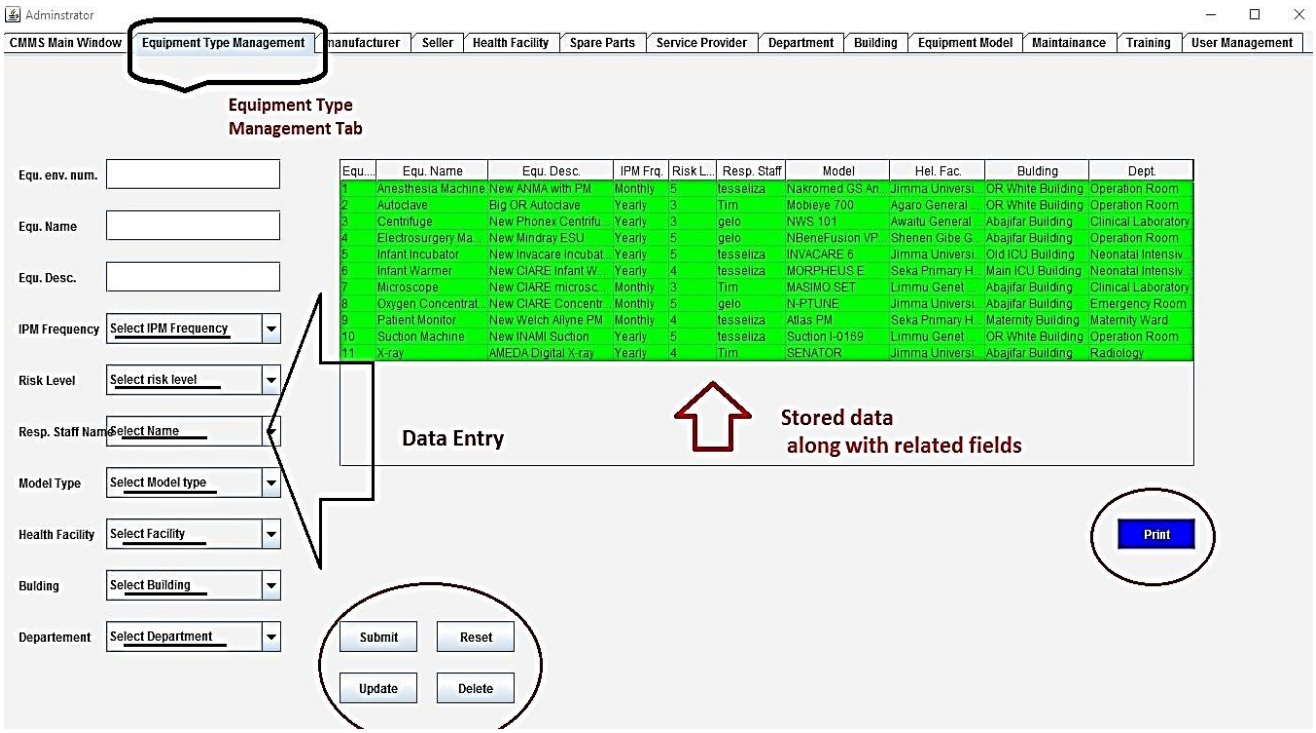


Figure 5. 13 The equipment type management screen allow the user to enter, update, delete, and select the basic inventory information.

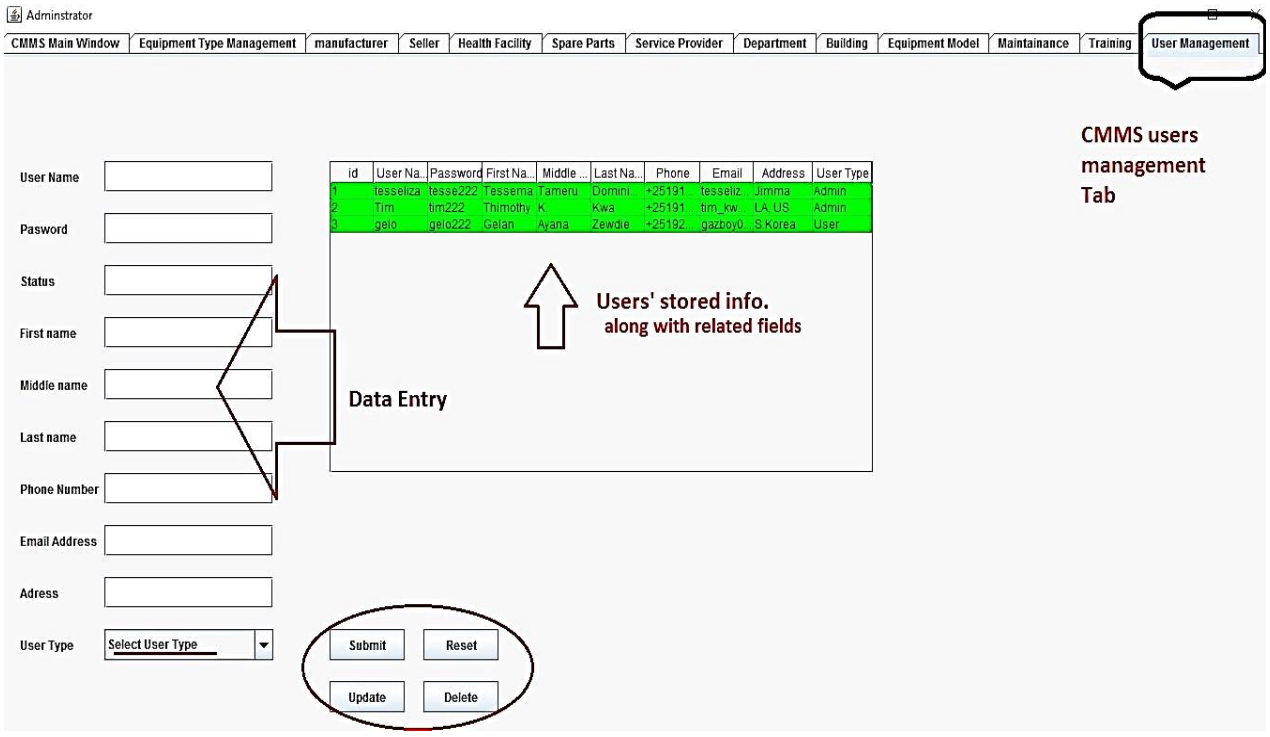


Figure 5. 14 The user management screen which allows management of staffs (admins and users).

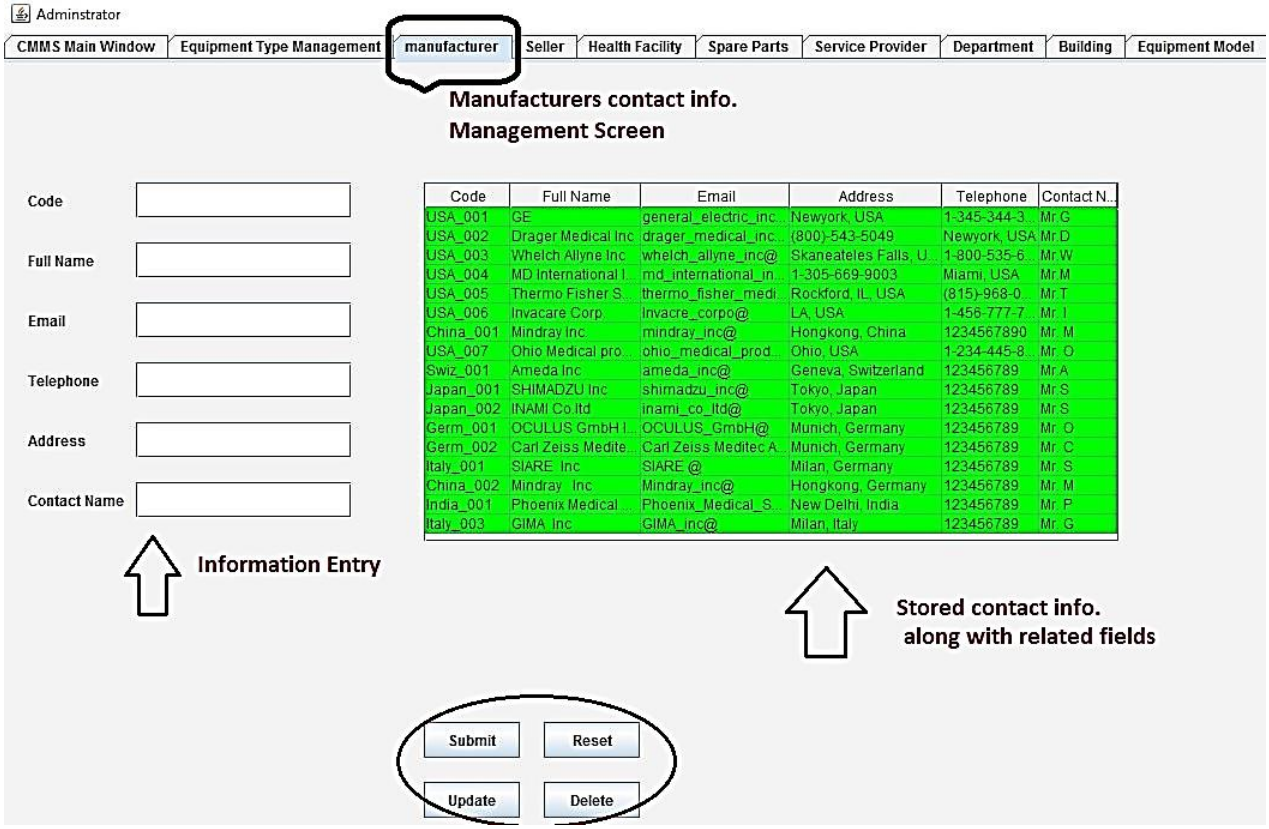


Figure 5. 15 The manufacturers contact information management screen.

Figure 5. 16 Equipment model management screen.

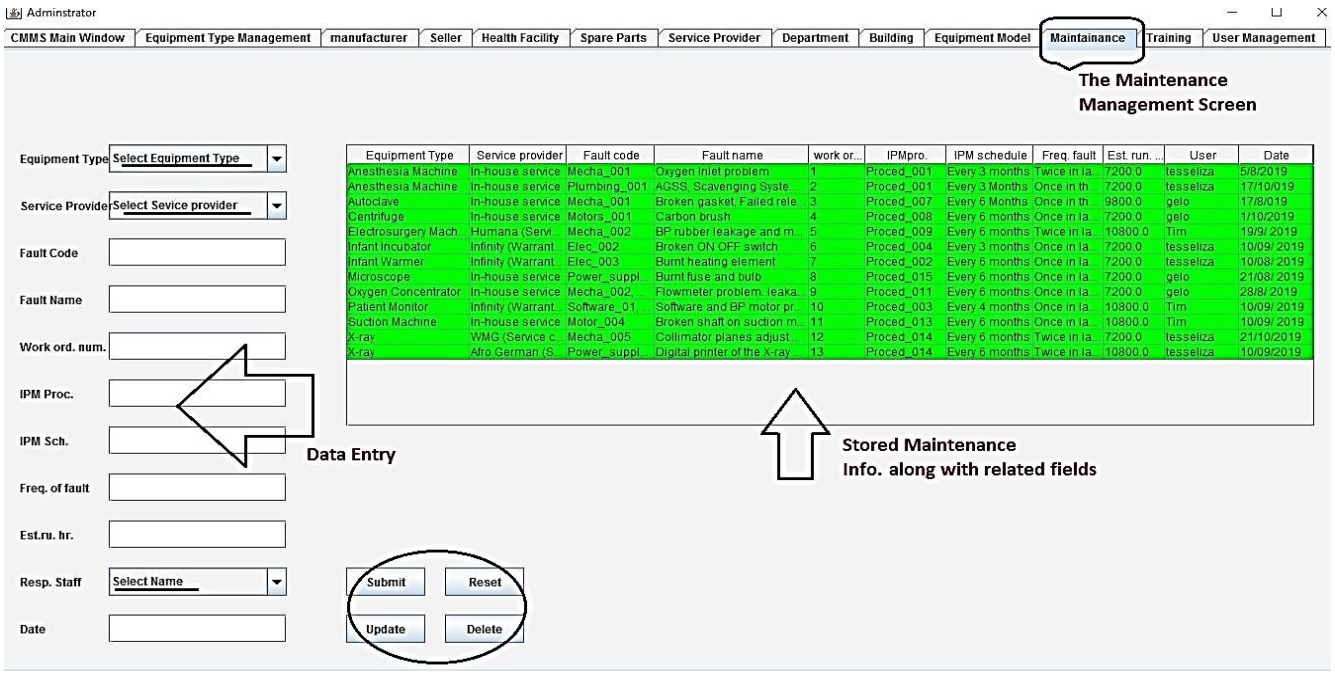


Figure 5. 17 The maintenance management screen.

A periodic review to analyze and determine training needs is one of the main follow-up work after this completed project work, since there can be a tough challenge when using such systems. In order to ensure that it actively contributes to the improvement and effective operation of the HTM program, regular testing of the system will also be carried out. Elements to be tracked include: the ability of the system to effectively produce all the performance metrics needed for the HTM program, such as down time and inspection and compliance with PM; evaluation of the speed of operations such as reporting and data input; accessibility and user satisfaction (gathered using a survey). These feedbacks will be organized and analyzed to make improvements to our system. In addition, we will focus on preparing comprehensive manuals and an assist menu to increase usability. We will also work on providing support in local languages in the future to make the implementation of CMMS more successful.

CHAPTER SIX

DISCUSSION

6.1 Introduction

This study was conducted with the goal of identifying and discussing the key factors (special barriers) to the effective utilization of healthcare technology, and developing and implementing a unique evidence-based solution required for intervention in the capacity building of technicians at six hospitals in the Jimma zone by considering all major components and contributing factors directly involved in the problem. The impact of the intervention is measured in terms of the efficiency of the technician for enhanced HTM and healthcare. In addition, a CMMS is built and implemented locally that best suits the needs of study hospitals. This chapter discusses the questions addressed in the study and new addition to the knowledge provided for the field, as well as comparing study results with previous works and other main objective interpretations. Literature on this subject in our country is limited so that comparison of the results of the study was made with other countries where the setup of health institutions, health policy and other variables are quite distinct.

6.2 Discussion on Study Findings

The study hospitals varied in size (1–8 operating rooms, 35–659 beds with all occupancy rates higher than 60%, and 570,000-15 mill population served). JUMC is the only hospital which has an ICU with 24 beds and it also has 8 ORs. AgGH and SGGH have 2 ORs and the rest three hospitals have only 1 OR for delivering medical service. All hospitals except AwGH have NICU with a number of beds in the range 10-28.

During the identification of the need for change in June of 2019, 861 medical devices were available in the six hospitals, with 382 (44.4%) being available at JUMC, 116 (13.5%) at SGGH, 108 (12.5%) at SPH, and 99 (11.5%) at AgGH, as well as 82 (9.5%) and 74 (8.6%) being available in LGGH and AwGH, respectively. These study findings point to the fact that, even though the requirements of Ethiopian health institutions for hospitals suggested that equipment should be available in specialized and general hospitals, all hospitals lacked useful medical equipment. This unavailability can be explained by the fact that hospitals have limitations on the purchase of such costly medical devices and/or donors' unwillingness to donate such expensive equipment. This will limit the healthcare services of patients, in particular those medical devices that are highly appropriate for medical diagnosis and treatment [11, 13].

At JUMC, there are 7 BME and 5 BMET workers. Biomedical department staffing in other hospitals, however, is very small. AgGH, SGGH and SPH each have only 1 BME staff, and LGGH and AwPH respectively have only 1 and 2 BMET employees. Small staffing was a factor in the low productivity and efficacy of their work to handle department activities at all hospitals, along with no work performance requirements or evaluation criteria found to assess department programs.

Hospital administrators estimated that 80-95 percent of the equipment is functional (survey average: 85%). Physical survey inventories produced by the researchers, however, indicate that the percentage of working equipment was overestimated by the administration. To build the review, we have relied on our own equipment status reports. Hospitals, however, may neglect some donated or idle equipment that never entered their inventory, or did not perform a thorough inventory by the technical staff. In any event, we found that they were underreporting their non-functional equipment. In June 2019, while identifying the need for change; only 668 (77.6%) of the 861 medical devices available in the 6 hospitals were functional and the remainder 148 (17.2%) and 45 (5.2%) were not functional and not in use respectively.

Many scholars have dramatically claimed that in the developing world, much of the medical equipment is defective. For example, Frize and Cheng [11] reported that in developing countries, more than 60% of medical equipment is out of use. WHO reports that about 50% of medical equipment in developing countries is not working, and not used properly and optimally [7]. A research by Franc Eric Zomboko et.al also found that 40% of medical devices were out of use in the developing world [34, 35]. Just about 61% of medical equipment used in public hospitals and other health facilities in Ethiopia is functional, according to two studies worked on Ethiopian hospitals' situation [9, 12].

So, at Jimma Zone hospitals, how much equipment is out of service? More than 40% would be the answer. We found no evidence to support the contention that any or nearly all equipment in resource-poor environments is defective, as seen in this study, with just 23% of 861 medical equipment was out-of-service. This discrepancy may be due to the sample size they used where the setup of health institutions has limited technical personnel or clinical engineering facilities that are not completely developed or inaccessible, and where health policy and other variables are very different and allow a general inference for all resource-poor settings, whereas the data provided here are results from a more comprehensive study about only six selected hospitals.

Purchasing and donating were the main sources of equipment in the study hospitals. More than 65% of medical equipment found in the six hospitals was donated by governmental and non-

governmental organizations. The Regional Health Bureau and NGOs such as KOFIH and CDC provide medical equipment training on an occasional basis. This result is close to studies by authors that have shown that a substantial number of medical devices are donated in developing countries [6, 7, 19, 20].

6.2.1 Barriers to Successful HTM and Utilization

The systematic study that examined the maintenance and repair programs of the hospital's medical equipment in June 2019 showed that all hospitals did not have sufficient program scope, effectiveness and efficiency for biomedical equipment use, maintenance and repair. There was no sufficient and accurate documentation for in-house and external sources of work. There was no full collection of biomedical policies and procedures/guidelines in all hospitals for - the use of equipment, the scope and operation of PM and repair facilities, the handling of warnings of equipment hazards and their appropriate corrective measures, and for the management of the procurement of biomedical equipment. There were no quarterly reports given to the administration and no periodic assessments were conducted to assess the appropriate combination of in-house and outside service sources.

In general, all hospitals did not meet substantial program specifications required to provide all the health care technology services that were essential or required. The key reasons (unique obstacles) found for the lack of proper coordination and implementation of maintenance and repair programs in the study hospitals fell into two main categories: lower levels of skilled in-house staffing and lack of sufficient infrastructure. Other factors affecting device use and long-term efficiency included employees' attitudes toward equipment care and maintenance, medical device and supply sustainability, a lack of expertise in medical device management, and reliance on donations. Other studies in the developing world has shown similar findings. Inaccessibility of medical devices, a lack of spare parts and service manuals, and a lack of facilities for implementation activities were identified as factors influencing access to and use of medical devices in selected hospitals and health centers in a study conducted in Benin [36]. Factors affecting the availability and usage of medical devices described as factors in other previous studies [19, 29] were the lack of market availability, budget insufficiency, lack of spare parts, incompetence, staff dissatisfaction, less sense of responsibility, staff workload, and referral system problems.

More importantly, the absence of a national policy and a clear regulatory strategy for selection, procurement, use and management can pose a significant risk to patients and lead to a disproportionate increase in the cost of providing health care. Medical devices are broken and

malfunction rapidly without providing the necessary life cycle service and eventually disrupting services. Even the lack of frequent monitoring of medical device functionality can have a detrimental effect on patient outcomes, as medical devices can pose a danger to patients and staff [27], requiring hospital management to pay attention to their regular monitoring and maintenance plans.

6.2.1.1 Strategic Decisions Needed

An efficient maintenance program for medical equipment consists of appropriate planning, management and execution. Planning takes into account the economical, physical and human resources needed to carry out maintenance activities adequately. Once the program has been developed, it is critical to continually review and monitor the financial, staffing, and operational aspects and ensure that it runs smoothly and progresses as needed. Finally, proper program execution is critical to ensuring the equipment's optimal functionality. This and the following section outlined the strategic measures defined and recommended to be taken to resolve the aforementioned barriers.

Finding a reliable, quantitative method for evaluating the elements of any given program is critical for a manager. There are no absolute scales to which different hospitals' programs can be compared, but the implementation of assessment approaches that provide a straightforward means of evaluating success against defined benchmarks and assessing the effect of switching to alternate options is a must. Recognizing that the biomedical repair program is not usually a hospital administrator's top priority, the program should allow the program manager to engage with hospital management as effectively as possible. The program manager must project complete knowledge and control of the program to gain the desired level of respect and trust from management. Admin, on the other hand, must understand that the program requires a significant amount of attention and funding.

To address the 'Resident Staff Skills' question, hospitals should assess if the skills exist in the current staff, as a first step, to conduct HTM and to maintain and repair the equipment in question. It can be carried out as simply as a determination of "yes" or "no". Administrators with the clinical engineering department should make the decision. If employees lack the requisite expertise to handle and repair these medical equipment, it is necessary to determine whether training is available through collaborations or through commercial sources. Training for maintenance and repair can also be a part of the purchasing agreement. The training can receive a higher utilization rating when

several units are in the equipment inventory. As part of the in-service training programs, acquired training can also be passed along.

Certain medical devices have advanced to the point that training in-house technicians, purchasing testing and calibration instruments, and retaining expensive spare parts are all deemed economically difficult. These medical devices are, for the most part, high-priced products, with usually only one available in a hospital. These products will also have high-tech components, and service manuals or schematics for such internal parts will not be issued by the manufacturers. Therefore, a detailed contract that requires lifetime support should be planned and enforced for such equipment.

The response to 'Resident Staff Time' needs a long process that begins with a full inventory list of medical equipment. The second step of the previously mentioned operation is to compile the annual working time required for PPM, calibration, performance reviews, and routine electrical safety checks on medical equipment and other potentially hazardous items. These periods can be found in manufacturer literature or in many of the numerous hospital medical equipment management systems on the market. The estimated annual man-hours for each instrument in the inventory should then be totaled to obtain the predicted man-hours per year.

It is rare for someone to have all of the job skills required to work on several piece of equipment. Thus, the annual man-hours are divided into the fundamental work skill areas of electronics, electro-mechanics, laboratory, x-ray, and other clinical engineering. To suit the individual hospital, this breakdown can be extended or retracted. A large hospital, for example, may choose to add a field of expertise for nuclear medicine or ultrasound. The day work capacity information can be recorded by department charged to a specific equipment. There must also be an allotted period for incoming inspections, and in-service maintenance control preparation (admin time). It is possible to convert the corresponding existing annual man-hours into full time equivalents (FTE). This technique should be used to promote good staffing practices and to consider the availability (or lack thereof) of time for existing staff to take on extra responsibilities for the maintenance and repair of medical equipment. The completion of a semi-annual efficiency assessment can be used as a check on this method. It will show whether technicians use their time effectively for productive tasks or not. This consists of a list of items considered to be productive activities (IPM, repairs, etc.) and a list of items considered to be non-productive activities (meetings, maintenance of inventory, training, etc.). When the time spent on productive activities is divided by the existing annual man-hours and multiplied by 100, the result is a percentage of productivity.

6.2.1.2 Major Policy Issues

Medical device policy helps in improving the affordability and availability of core medical devices required to the country's health needs. The policy also improves accessibility of basic health service thereby reduces inequality. The identified core medical device policy issues include:

I. Quality standards of medical devices:

Substandard and unsafe devices not only cause harm to the patient & healthcare worker but wasted the scarce country resources. Therefore, FMoH should prepare or adopt acceptable international standards in order to ensure the efficacy, quality and safety of medical devices. Besides, the standards should be suitable and applicable to the country's local situation. The ministry should also establish a system to ensure agreed quality standards are always met and legal sanctions are in place if standards are infringed.

II. Standardization of medical devices procurement:

Medical devices should be standardized and procured in an open and transparent process fully complying the country's procurement law. Procurement of medical devices needs to be based on a clear strategy and actual needs assessment. The ministry should establish a system to standardize type and quantity of devices for each level of health facility. It should also limit the makes and models of medical devices procured to optimize the associated training, logistics and management costs. A comprehensive contract, which covers the life of medical devices, should also be prepared and enforced.

III. Safe and effective utilization of medical devices:

Medical devices should be utilized safely and effectively throughout the device life. Medical devices should be safely and responsibly operated by skilled professionals and should be properly maintained and continuously operated without causing disruption to the health service.

IV. Governance and financing of medical devices:

Strong governance structure should be established at all levels of the system. Governance should be led by information and evidence. Partnership with relevant stakeholders should be encouraged to augment the financial and technical requirements.

6.2.2 Repair Examples and Needed Skills

In the understanding of this presentation, there are several complicated variables. Previous work has stated that the absence of replacement parts and disposable accessories in resource-poor settings is a primary cause of potentially functional equipment being out-of-service [12, 22, 23, 27]. This conclusion was, however, based on interviewing technicians from the developing world. Our findings contradict data from their surveys. We found that most of the equipment failure experienced by the study hospital (82%) could be fixed without importing parts. The inconsistency most likely emerges from the fact that, due to the available infrastructure, surveyed technicians were not exposed to seeking alternative solutions for broken equipment, or there might be a tendency to mark a piece of equipment as not-functional and make a general inference for all resource-poor settings, while the data presented here are findings from a more comprehensive study about only six selected hospitals.

On the other hand, like this research, there are few prospective studies that have produced the same conclusion. For example, Malkin and Keane [18] discovered that 66 percent of out-of-service equipment (out of around 3,000 items studied) could be repaired for less than $50 using only locally available materials. They went on to say that in low-resource settings, the vast majority of laboratory and medical equipment can be repaired with only minimal expertise and without importing spare components. The unique characteristics of research hospitals (available facilities and technological skills) and their effect on the study's conclusion are obviously one aspect that is hardly explored.

In resource-poor settings, capacity building should first concentrate on a specific range of skills by implementing an evidence-based curriculum. There are a number of institutes offering BME and BMET education in Ethiopia for clinical engineering capacity building. At Jimma Institute of Technology (JiT) and Addis Ababa Institute of Technology (AAiT), for example, there are BME programs focused on training preparatory graduates. In recent years, Gonder, Hawassa, and Wolo Universities have also begun offering the BME curriculum. Also, Tegbared TVET college and Debremarkos TVET college are preparing graduates of high school to become BMET. In hospitals and health centers, the role of BMEs and BMETs is often to perform repair, maintenance, and management laboratory and medical equipment, while some are employed in federal, regional and zonal health offices to perform work related to healthcare technology.

Evaluation of current BME and BMET programs has shown that they are mainly designed by adapting curricula built in and for resource-rich environments such as the United States or Europe.

This approach, however, assumes that the problems faced by our country's technicians are similar to those faced by technicians in a resource-rich environment. An analysis of their curriculum shows significant differences from the identified most needed domain of knowledge for medical equipment maintenance and management problems faced by technicians in the resource-poor settings of healthcare facilities in Ethiopia, particularly Jimma zone hospitals. One body of knowledge does not require reparation of medical equipment (BME). Both (BME, BMET) require or presume fundamental electronics. They also include basic knowledge of physiology and anatomy, and explicit theoretical approaches to discovering the root cause of any single piece of equipment malfunction. Some knowledge bodies concentrate completely or significantly on unique issues for particular pieces of equipment. The generated 4 basic knowledge domains and 24 unit skills are greatly surpassed by these curricula, though some units may be lacking. More importantly, most of these bodies of knowledge are considered achievable only after years of post-secondary training (5 years for BME and 3 years for BMET).

Therefore, the evidence given here indicates that the creation of curricula for our country requires a new approach. The body of knowledge generated from this study poses the possibility of an independent alternative curriculum or its inclusion in the existing programs. The evidence presented here indicates that in order to achieve 82% of the repairs, only 24 units of knowledge with 86 basic skills need to be learned. Since each of these skills by definition takes about 1–2 h to learn, only roughly 5 weeks of classroom training will be needed to teach the body of knowledge presented here.

Although the body of knowledge can be taught within 5 weeks, it should be known that there are vast differences between the technicians of the study hospital, the researcher and other participating experts who contributed to this study and possible future students. The technicians in this research, for instance, were already acquainted with the names of the tools and the medical equipment in their hospitals. Those interested in studying this body of knowledge may also not be likely to be good learners in the classroom.

6.2.3 The Unique Evidence-based Curriculum

There can be major variations between the institutes and other organizations in the curriculum they offer. The most notable distinction is probably the relative focus put on equipment-specific training, such as ECG and X-ray training, as opposed to the emphasis on skills such as soldering and broken housing or replacement of heating element and temperature sensing device that are not equipment-specific and can be applied to many medical devices. The training given here adds at least 1

additional dimension, the fundamental knowledge and skills that emphasize generic skills adapted to resource-poor environments (in particular, study hospitals), such as seeking replacement fuses and improvising clamps, fitting adaptors and filters.

It is not practical for most of the surveyed technicians to get manufacturer-recommended parts when faced with large quantities of out-of-service equipment and with a virtually complete lack of a maintenance budget. Technicians were therefore frequently met with the need to improvise solutions to simple problems such as broken fuses, leaking/corrosive batteries, Wire/ rod to replace pins of a connector, leakage, rust on moving parts, and filters that could not be identified. However, the specific instruction of these improvisation skills was not included in any prior curriculum. This is a particular attribute of our curriculum.

Medical devices are assets that impact human lives directly. They are substantial investments and have high maintenance costs in many situations. As a result, having a well-planned and managed maintenance schedule that can keep medical equipment secure, safe, and ready for use in a health-care facility where it's needed for patient diagnostic operations, therapy, medication, and monitoring is important. Besides, such a program prolongs the useful life of the equipment and minimizes the expense of owning the equipment. Hence, effective medical equipment repair program preparation, management and implementation methodologies were also included in the curriculum.

Other aspects of the program that are non-equipment-specific, including professional development, such as Internet skills, are also relevant. In order to achieve a repair, a competent technician using modern medical equipment would also require assistance from others, needing help to do items such as locating parts, troubleshooting issues, collecting manuals, and deciphering diagnostic codes. In a resource-rich area, such issues are often handled with the assistance of the manufacturer's representative, the user manual provided by the manufacturer, or even the service manual. None of the study hospitals had dependable access to the manufacturer representative, nor did they have large manual collections and most had no manuals at all, due to the fact that their medical equipment had been donated and used without manuals. The most valuable skill in such settings is the ability to acquire a user's manual, difficult when the manufacturer probably has long stopped providing support or possibly existing to evaluate the function of the equipment without the manual. This support not only helps them fix individual pieces of equipment, but their trust, willingness to change, and job satisfaction can also be enhanced through the sense of community provided through contact. There are secondary influences on these findings. They are more respected in their hospitals as the technicians become more efficient.

We also held workshops for hospital administrators on the importance of including technicians in the procurement of medical equipment, the management of medical equipment budgets, and the training of staff in the use of equipment. Having any training for hospital directors is unusually uncommon for a technical training program. This is another distinctive aspect of our program.

They continued to suffer from a shortage of resources and not just financial resources, in spite of the improved performance of the trained technicians. Many lacked daily Internet access, and some lacked a budget for replacement parts altogether. Equipment was donated without a manual in many cases. It was difficult for the technician to determine which component was required in the absence of a service manual. In certain cases, the equipment was no longer made, so they would not be able to locate it even though they knew what part was required. It would be difficult for them to find guidance on replacement parts for out-of-date equipment without the means of communicating between technicians around the globe.

The governance of medical device management should therefore be improved by developing adequate structure, personnel and equipment at the agencies of FMoH, RHB and lower health system levels. The medical device budget can also be increased to cover the medical device's entire lifespan (total cost of ownership) by increasing the allocation and knowledge of health managers at all levels. In addition, FMoH needs to build a collaboration forum to effectively organize stakeholders involved in research & development, HTM, the design of infrastructure for health facilities, and others. In addition, private sector participation in the management of medical devices through a public-private partnership (PPP) or other long-term agreement (LTA) should be strongly encouraged. Leasing, lending, procurement of spare parts, maintenance of equipment and training facilities for medical equipment should be considered a priority area of the partnership. Donors should ensure that the hospital is supplied with additional accessories (such as cables and connectors) and consumables, or that they are locally accessible and financially viable.

6.2.4 Impact

Overall, in the six Jimma zone hospitals, the training program strengthens healthcare. Intervention technicians have approximately 19% fewer out-of-service equipment, change their repair obstacles to more intractable issues (missing components and accessories), and less often cite lack of expertise as an obstacle. This indicates that intervention technicians benefit from the unique program and are likely more confident in their repair abilities. We assume that the drastic improvement in healthcare and the similarly dramatic improvement in the efficiency of technicians

are at least partly due to the clear teaching of basic skills adapted to the settings of the Jimma zone hospital.

Although training strengthens the healthcare system, the effect on the health outcomes of the patients is more difficult to determine. It is fair to suppose that better care is feasible with more working equipment. In addition to repairing equipment that is not fully usable, it is necessary to return partially functional equipment to full use. Although not explicitly calculated in this research, we can extrapolate the amount of health effect theoretically obtained (as opposed to healthcare). Any of this can be derived from the anecdotal proof of the technicians. The engineer in AgGH had repaired two anesthesia machines in the hospital, which had not been working for more than a year and surgeries were delayed or referred out.

On the other hand, as a consequence of the increased amount of PPM, intervention technicians are reducing the need for CM. PPM would avoid future problems which entail corrective measures. In this research, for example, the absence of PPM actions resulted in several work tickets in control hospitals. This possibly affects patient health because when less CM is necessary, less out-of-service equipment is available while treating a patient.

The data indicate promising progress in communication both inside and outside the hospital, in addition to achievements in management and repair. In order to enhance equipment-specific knowledge and obtain professional development guidance, technical assistance, or communication to the acquisition of parts and accessories, more regular contact outside the hospital can be highly beneficial. Communication participation opens the technicians to a new group of experts and increases their confidence in asking for assistance. The increased contact within the hospital increases the involvement of technicians in the procurement process, including the purchasing, accepting and installation of equipment, and it demonstrates a positive correlation with the administration of the hospital. Increased coordination often contributes to more detailed evaluation of their ability to operate on any specific piece of equipment.

Another way to look at the effects of healthcare is to compare the two choices a funder may face, whether it is to finance a donation of medical equipment or to fund local technicians' training to repair the equipment they already have. After 4 months, we mentioned that 11% less of the hospital's inventory is out-of-service with intervention hospitals, shifting from 8% to 19% difference. Because these hospitals have an almost infinite supply of broken equipment, it is fair to conclude that, for the next period of time, trained technicians will continue to repair an equivalent amount of equipment. A hospital with a total of 500 pieces of equipment is equal to 55 more pieces available

for clinical treatment in hospitals with trained technicians every four months (165 per year), given that much of the skills could be transferable to other types of equipment. Therefore, over 5 years, a donor will need to supply the hospitals with 825 working pieces of equipment to provide a donation as effective as the training program. There are 95 pieces of donated equipment in our data covering donations of equipment to the three intervention hospitals in the last five years. Therefore, over 5 years' period, donors would need to donate 9 times their average four months' contribution (825/95) to match the impact of the training program demonstrated here.

The locally developed CMMS is intended to effectively suit the six hospitals and address the users' needs in a systematic manner. Therefore, it can be used by hospitals and their clinical engineering departments as an efficient tool to supplement their current systems and enhance overall technology management. It will also be a tool that helps decision-makers monitor not only the most common indices for the management of healthcare technology, but also others, such as user errors, efficiency of technicians, data on work orders and obsolescence of equipment to enhance preparation in future years. The newly developed CMMS would therefore provide HTM managers with resources to maintain medical equipment and automatically track their related costs.

CHAPTER SEVEN

CONCLUSIONS

7.1 Introduction

By offering practical guidance on the maintenance and repair of a variety of medical equipment, our approach has created remedial solutions for situations explained in problem statements. The intervention training also included management and professional development skills necessary for the capacity building of technicians by considering all major components and variables that directly contribute to the problems stated. Our approach differs from others because it implemented a real evidence-based training program and CMMS model by defining the reasons for the availability and usage of medical devices and engaging with and overcoming the most significant specific obstacles to medical devices.

The curriculum includes subjects that are meant to help technical staff manage healthcare technology on a daily basis. It included the whole chain of processes, from planning and budgeting to procurement, regular operations and safety, and maintenance management. The training also outlined a range of practical measures for: planning, record keeping, workplace management, inventory management, and personnel management, as well as efficient planning, management and implementation methodologies for the maintenance program of medical equipment. In addition, sample policies and procedures on various activities in healthcare technology, equipment-specific training in the class of most available equipment, non-equipment-specific repair skills developed from the review of data from the six study hospitals out-of-service medical equipment, communication and networking skills, professional development skills, and the use of common electrical equipment analyzers were included. Furthermore, locally built CMMS can be used to improve overall technology management while also contributing to more effective health-care delivery by further assisting in the handling and maintenance of medical equipment. The CMMS software would be able to transform medical equipment management while also enhancing the availability and reliability of the technology required for disease prevention, diagnosis and care.

The four-month review of intervention indicates that the training enhances the healthcare of the research hospitals. Intervention hospitals demonstrate enhanced equipment control and less out-of-service equipment. The emphasis on teaching evidence-based knowledge has a dramatic effect on hospital facilities. Improvements in infrastructure are likely to result in better patient outcomes. As a result of the training of technical staff, we know of no other research that has consistently

demonstrated an improvement in hospitals. Focus on locally available components, rather than recommended parts from suppliers, tends to be an important factor in the success of the program.

Professional development balanced with equipment-specific subjects is adequately emphasized by the training program. The promotion of further networking in a formalized way both within the country and internationally to take advantage of the increased contact by technicians outside the hospital could be a further addition to the curriculum. The shortage of consumables, supplies and parts, was the most significant barrier to repair for intervention technicians. Future efforts should put high emphasis on the procurement of parts and accessories. This may be by using contracts more appropriately, and by involving technicians in buying and budgeting for parts and accessories.

7.2 General Conclusions

This is the first study to quantitatively and qualitatively demonstrate where and why medical equipment found at Jimma Zone hospitals is out-of-service, and generate and implement evidence-based solutions with evaluating the extent of impacts. Our findings should be used as guideline by partners and policy makers towards a better investment of resources. Significant problems with the donation and procurement of facilities, combined with a significant amount of broken medical equipment already in hospitals, indicate that donors, aid organizations and governments may overinvest in the provision of facilities rather than address the environmental factors that trigger lack of access to usable equipment.

From the review of out-of-service medical equipment data from the six study hospitals with the key causes of failures and knowledge required to bring the equipment back into service for a class of medical devices, we conclude that the majority of medical equipment can be returned to service using only a relatively limited collection of skills and without importing spare parts. We propose that training local technicians with evidence produced from their circumstances is the most economical, immediate solution for providing improved access to medical equipment and therefore vital medical procedures, when resources are limited.

Training will provide legitimacy and the skills necessary for technicians to submit useful and timely reports on the state of equipment, repairs and expected parts needs. Training, cited for the cause of 57% of out-of-service equipment in control hospitals, may also resolve the problems of insufficient skills and expertise. Our focused training has shown that the ability of technicians to fix repairs has been enhanced. It helps technicians locally procure spare parts (including replacements), navigate

international order forms, and find alternate repair methods, all of which will help eliminate equipment that have components as a repair barrier.

Timely and cost-effective maintenance activities maximize the value of resources in healthcare technology, which is particularly important when resources are limited. A successful program that meets the needs of a particular hospital context could be designed and executed with carefully examined different financial, physical and human resources aspects, even with certain resource constraints. An integral part of health-care delivery with a minimum set of resources designated to fulfill the tasks outlined by the program should be considered in the program design procedure. Which would have a significant impact on patients' opportunity to reach clinical services that will provide them with a precise diagnosis, effective treatment, or proper rehabilitation.

One of the strategic goals of WHO and FMoH [2] is to "ensure improved access, quality and use of medical products and technologies in Ethiopia." The findings of this research project will aid in the implementation of critical Ethiopian national health technology projects that will have a direct impact on disease burden and ensuring that services are successfully used to address major health issues. In addition, the project's outcomes provide business and scientific communities with knowledge and information to identify and adapt innovative technologies with effective designs that can have a substantial impact on public health and make key healthcare technologies available at an affordable price at resource-limited healthcare institutions in Ethiopia, especially in Jimma communities. It will also contribute to the creation of an agenda, an action plan, tools, and guidelines for increasing access to appropriate medical devices through FMoH and collaborators.

In addition, we hope that the findings will assist NGOs with efforts to design effective healthcare interventions that reduce the cost and impact on the availability of equipment with increased uptime, thereby having a greater impact on improved patient outcomes and greatly reduced morbidity rates by reducing problems as surgeries are interrupted or canceled, increasing treatment options, and correct and prompt diagnosis. For alternative designs that could maximize service and avoid problems related to the current healthcare technologies in the country, engineering design problems for the developing world can also be envisioned. It will also assist hospital administrators and other partners in raising concern through communication as a way of addressing challenges and taking informed steps to improve healthcare delivery. The program can be generalized and seen as the most critical component in achieving healthcare infrastructure and service enhancements for most health care organizations in the country.

CHAPTER EIGHT

RECOMMENDATIONS

In addition to the results relating to the study topic, other findings were also found when collecting and analyzing data to meet the project's objectives. The analysis and evaluation of the research project yielded the following resulting recommendations for specific groups to which the recommendations are directed. The following sections set out and report recommendations for specific organizations or health needs.

1. **To the head of departments managing medical equipment programs at respective hospitals:**

    a. Before designing, implementing, and using maintenance programs, the various financial, physical, and human resource aspects should be thoroughly examined, with the current program being evaluated by completing the nine components of the performance efficiency checklist for a full-service program developed by the American Society for Hospital Engineering. This would assist them in meeting the needs of their hospitals' specific context for a cost-effective management program.
    b. A manager must find a reliable, quantitative approach for assessing the elements of any given program. To achieve the optimal degree of management respect and confidence, program managers should be required to collaborate as efficiently as possible with hospital administration. They should aim to project maximum program comprehension and control.
    c. Technicians should be required in order to condition code the medical equipment at the time of repairs or PPM. To generate automated reports that reflect the information, this information should be recorded on the work order forms and added to the CMMS.
    d. Technicians should be expected to record the cost of all replacement parts included in the preventive maintenance history file request process, and this detail should only be added to the history file report..
    e. Technicians should be required to assess medical equipment semi-annually for the purpose of suggesting replacement according to maintenance history and estimated life time. This details should be registered and added to the PM history file. There should

also be a way to provide this information to the relevant department. This assessment must be carried out in compliance with PPM.

f. In a master file located in clinical engineering department, a second copy of each equipment instruction booklet should be held.
g. Annual surveys of the departments should be performed to ensure consistency with the medical repair program. Completed survey reports should be sent to the hospital administration, and departments should be required to reply in writing within 30 days if program aspects are not being followed.
h. For faulty medical equipment, departments should use Hazard Warning labels.
i. Those contracts with outside suppliers for provision of preventive maintenance and repair services should regulate the supplier to comply with international and/or national requirements for such services.

2. To human resource personnel, matron, and CEO's of respective hospitals:

a. Promote the initiative and advise department employees that PM is a joint responsibility between medical technicians and equipment operators.
b. Create a local framework that spells out the roles and duties of the medical equipment and maintenance management departments.
c. Ensure command recognition that without a safety check label attached, medical equipment must not to be used.
d. For any piece of medical equipment under their supervision, departments should be allowed to retain one copy of the operator's manual. Placed a label showing the location of the operating manual on the equipment is required if the operating manuals are part of a technical manual kept at the clinical engineering department. This mark is only needed where the operating manuals are not in the general vicinity of the equipment.
e. Departments may be required to inventory their medical equipment semiannually for the purposes of tracking, location, PM marks, and estimated replacement schedule.
f. Departments should be needed to inform clinical engineering when, under their knowledge and understanding, medical equipment changes its place of use.
g. Under the PM activities, departments should be expected to designate a responsible person to manage the department's operations. This person will act as an intermediary between the department and technical staff.

h. Departments should ensure that two copies of an operator's manual are included with requests for the purchase of a medical device.

3. To Federal Ministry of Health

In order to strengthen the countries health sector development goals and strategies that works to ensure people get safe and quality health services through the provision of latest technologies, to promote efficient and effective use of medical devices, and to ensure rational use and allocation of countries resource, the following major policy strategies should be implemented.

3.1 Safety and quality of medical devices:

a. International standards for Medical devices such as ISO, GMP, CE markings or other equivalent standards should be adopted as a mandatory requirement and used to ensure quality of all medical devices imported or locally manufactured.
b. The medical device regulatory system should be developed/strengthened to ensure quality at all phases of medical device life: regulation of pre market, placing into market and post market phases. In addition, regulation capacity should be strengthened at all levels through structuring and proper staffing of regulatory bodies.
c. Mandatory requirements should be implemented to ensure the safety, appropriateness and continued utilization of new and used donated medical devices.

3.2 Standardization of medical device acquisition and procurement:

a. A proper system of evaluating the appropriateness, safety and cost effectiveness of medical devices should be developed and used for decision making.
b. Standard list and specification of medical devices should be developed to standardize the type and quantity of medical devices by level of health facilities.
c. The range of makes and models of certain medical devices procured by the public sector should be limited so that the training, logistics, maintenance and other costs could be optimized.
d. A comprehensive procurement contract that includes medical devices installation, commissioning, warranty management, provision of maintenance service, spare parts and consumables should be developed and implemented.

3.3 Safe and effective utilization of medical devices:

a. A system for medical device preventive maintenance, repair and periodic calibration should be developed and implemented at all levels of the health system.

b. Proper guidelines for medical equipment decommissioning and disposal systems should be developed and implemented.
c. The knowledge and skill of medical device users should be standardized through implementing a system for user training, certification and authorization of device operation.
d. A strategy for efficient and effective use of high value equipment such as MRI should be developed and used to guide the acquisition and use.
e. Appropriate Standard of Operations (SOPs) should be developed & implemented at health service delivery points to properly monitor staff performance, accountability, and effective use of resources.

3.4 Governance and financing

a. The medical device management governance should be strengthened through establishing appropriate structure, staffing and equipping at Federal Ministry of health FMoH agencies, regional health bureaus and lower levels of the health system.
b. Automated Medical Device Management Information System (MDMIS) with a central database should be developed and implemented to improve evidence based decision making at all levels.
c. Budget for medical devices should be improved to cover the full lifetime of medical devices (total cost of ownership) through increasing allocation and raising awareness of health managers at all levels.
d. Coordination platform should be created to effectively coordinate stakeholders involved in research & development, medical devices management, health facility infrastructure design, and other HTM activities.
e. Engagement of the private sector in medical device management through public private partnership (PPP) or other Long Term Agreement (LTA) is highly encouraged. Medical equipment leasing, renting, provision of spare parts, maintenance and training service should be considered priority areas of partnership.

4. To Oromia Health Bureau, and Jimma Zone Health Bureau:

They should establish local guidelines that outline the roles and obligations of medical equipment management and medical repair departments in all hospitals for proper maintenance programs with comprehensive protocols for all medical equipment work. In addition, policies and procedures for

risk-based biomedical equipment management schemes, initial testing and assessment, IPM procedures, CM work order systems, and corrective actions detected during PM and infection control should be enforced and controlled.

5. For MoSHE, Universities, TVETs and Schools who teaches BME and BMET programs:

This recommendation goes to educational institutions particularly BME programs at JiT, AAiT, Gonder university, Hawassa university and Wolo universities and BMET programs at Tegbared TVET, Debremarkos TVET. They should focus and involve in their curriculums with the most needed domain of knowledge for the healthcare technology problems found in the country. The evidence provided in this study suggests that a new approach is needed for developing curricula that could suit with the resource-poor setting hospitals in the country.

Although the training model was created with Jimma zone hospitals in mind, there are no known explanations why it couldn't be used in any Ethiopian hospital, as most healthcare technology issues in the county are similar. Over time, we will be able to do a more in-depth review of the material in order to make changes, and the curriculum's materials will be expanded to include more accurate details to make it more comprehensive in order to make the most of the resources that can be made available as the program continues to be implemented.

Finally, replication of this study in different regions and further studies with larger samples and study period including major hospitals in the country are also suggested to identify further causes for failures and knowledge required to place the equipment back to service to increase access to appropriate medical devices and ensure effective use of resources to effectively control important health problems in the country. In addition, medical technology interventional programs and studies are suggested to use evidence presented here to deliver successful impact on current inherent problems.

9 REFERENCES

[1] S. R. Sinha, and B. Michele, "Health Technologies and Innovation in the Global Health Arena," *N Engl J Med,* vol. 365, no. 9, pp.779, 2011.

[2] WHO, "Local production for access to medical products: Developing a framework to improve public Health," *WHO Press,* 2011. [online]. Available: http://www.who.int. [Accessed: May15, 2019].

[3] WHO, "Medical Devices, Managing the Mismatch: An outcome of the priority medical devices project," *WHO Press,* 2011. [online]. Available: http://www.who.int. [Accessed: May17, 2019].

[4] M. D. Chesnay, *Caring for the vulnerable: Perspectives in nursing theory, practice and research*. 3rd edition. Publisher Jones & Bartlett Learning, pp. 292, 2005.

[5] WHO, "Health technology assessment of medical devices, Medical device technical series," *WHO Press,* 2011. [online]. Available: http://www.who.int. [Accessed: May17, 2019].

[6] UN, "UN Human Development Report, United Nations Development Programme," *UN*, NY, USA, 2004.

[7] P. Heimann, A. Issakov, and S. Y. Kwankam, **"**Guidelines for health care equipment donations," *WHO*, Geneva, Switzerland, 2000.

[8] WHO, "Formulating strategies for health for all by the year 2000," *WHO,* Geneva, Switzerland, 1979.

[9] M. J. Free, "Health technologies for the developing world: Addressing the unmet needs**,"** *Int. J. Technol. Assess. Health Care,* vol. 8, no. 4, pp. 623–634, 1992.

[10] M. Bracale, and A. Pepino, "Medical technologies in developing countries: a feasibility study on the maintenance of medical equipment in Ethiopia," *Med Biol Eng Comput,* vol. 32, pp. 131–137, 1994.

[11] M. Frize, and M. Cheng, "Technical services for healthcare facilities: a model for developing countries," *Med. Biol. Eng. Comput,* vol. 32, pp. 335–337, 1994.

[12] H. Bekele, "Assessment on medical equipment conditions," *Ethiopian Science and Technology Agency Ethiopian Scientific Equipment Center,* Addis Ababa, 2008.

[13] Ethiopian Standard Agency. Ethiopian standard; Comprehensive Specialized Hospital – Requirements. 1st ed. Addis Ababa, 2012.

[14] Y. Assefa, Y.A. Gelaw, P. S. Hill, and et. al., "Community health extension program of Ethiopia, 2003–2018: successes and challenges toward universal coverage for primary healthcare services," *Globalization and Health,* vol. 15, no. 24, pp. 4–11, 2019.

[15] FMoH and FMoI. National strategy and plan of action for pharmaceutical manufacturing development in Ethiopia (2015–2025). Abridged version, Inís Communication, Thailand, July 2015.

[16] WHO, "Computerized maintenance management system, WHO Medical device technical series," *WHO Press*, 2011. [online]. Available: http://www.who.int. [Accessed: May 24, 2019].

[17] H.D. Banta, "Medical technology and developing countries: the case of Brazil," *Int J Health Serv*, vol. 16, pp. 363–373, 1986.

[18] R. Malkin, and A. Keane, "Evidence-based approach to the maintenance of laboratory and medical equipment in resource-poor settings," *Med. Biol. Eng. Comput*, vol. 48, pp. 721–726, 2010

[19] L. Perry, and R. Malkin, "Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world?," *Med Biol Eng Comput*, vol. 49, pp. 719–722, 2011

[20] D. Emmerling, A. Dahinten and R. A. Malkin, "Problems with systems of medical equipment provision: an evaluation in Honduras, Rwanda and Cambodia identifies opportunities to strengthen healthcare systems," *IUPESM and Springer-Verlag GmbH Germany*, Nov 3, 2017.

[21] Engineering World Health, "Cambodia medical equipment inventory report," Durham, Feb 2011.

[22] O.A. Erinosho, "Health care and medical technology in Nigeria," Int. J. Technol Assess. Health Care, vol. 7, pp. 545–552, 1991.

[23] International Aid, "Aceh province medical equipment inventory and assessment report," *International Aid*, Spring Lake, Indonesia, 2005.

[24] Pan American Health Organization, "Health conditions in the Americas," *PAHO Scientific Publication*, no. 500, pp. 1981–1984, 1986.

[25] Pan American Health Organization, "Health conditions in the Americas," *PAHO Scientific Publication*, no. 501, Oct,1987.

[26] Pan American Health Organization, "Maintenance of Hospital Equipment," In 21st Meeting of PAHO executive committee of the directing council, Washington, DC, Dec 9–10, 1993.

[27] R.A. Malkin, "Design of healthcare technology for the developing world," *Annu Rev Biomed Eng*, vol. 9, pp. 567–587, 2007.

[28] R.A. Malkin, "Medical instrumentation in the developing world," *Engineering World Health*, Memphis, TN, 2005.

[29] B. W. Ademe, B. Tebeje. and A. Molla, "Availability and utilization of medical devices in Jimma zone hospitals, Southwest Ethiopia: a case study," *BMC Health Services Research*, vol. 16, pp. 287, 2016

[30] Population Census Commission, "The 2007 Population and Housing Census of Ethiopia: Statistical Report for Oromia Region," *Population Census Commission*, 2007. [online]. Available: http://pheethiopia.org/pdf/oromiya.pdf. [Accessed May 10, 2019].

[31] JUMC. “Specialized hospital history document,” *The Official Website of Jimma University*, 2015. [online]. Available: http://www.ju.edu.et [Accessed: June 12, 2019].

[32] American Society for Hospital Engineering and American Hospital Association. “Medical Equipment Management in Hospitals,” *ARA Publication,* no.190105, pp.19, 1982.

[33] NetBeans. “NetBeans IDE Features,” *The Official Website of NetBeans,* 2019. [online]. Available: http://www.netbeans.org [Accessed: August 4, 2019].

[34] The Republic of Uganda, “Ministry of Health National Medical equipment policy,” 4th Edition, 2009. Available: http://www.who.int/medical_devices/survey_resources/health_technology_national_policy_uganda.pdf. [Accessed: May 15, 2019]

[35] F.E. Zomboko, S.E. Tripathi, and F.K. Kamuzora, “Challenges in procurement and use of Donated medical equipment: study of a selected referral hospital in Tanzania,”. J Arts Sci Commerce, vol. 3, no. 4, pp. 41-45, 2012

[36] P.T. Houngbo, D. Medenou, and et. al., “Policy and Management of Medical Devices for the Public Health Care Sector in Benin,” in 5th IET Seminar on Appropriate Healthcare Technologies for Developing Countries, London, UK, May 21-22, 2008. [Online]. Available: https://ieeexplore.ieee.org/document/4577638

[37] G. D. Ruxton, "The unequal variance t-test is an underused alternative to Student's t-test and the Mann–Whitney U test," Behavioral Ecology, vol. 4, no. 17, pp. 688–690, 2006

[38] GeeksforGeeks. “Remote Method Invocation in Java,” *Last Updated: 09 Feb, 2018*. [online]. Available: https://www.geeksforgeeks.org/remote-method-invocation-in-java/ [Accessed: January 5, 2021].

[39] Tutorialspoint SimplyEasyLearning. “Java RMI - Introduction,” [online]. Available: https://www.tutorialspoint.com/java_rmi/java_rmi_introduction.htm [Accessed: January 6, 2021].

Medical Device Manufacturers in Ethiopia - Page 2 - Medical Devices1.com

[40] Medical Devices1.com. “Medical Device Manufacturers in Ethiopia.” [online]. Available: https://www.medicaldevices1.com/medical-device-manufacturers/ethiopia [Accessed: January 4, 2021].

[41] phpMyAdmin. “Functionalities of phpMyadmin,” [online]. Available: https://www.phpmyadmin.net/ [Accessed: January 7, 2021].

[41] Ministry of Health Ethiopia, “Annual performance report for 2012 EFY (2019/2020),” Document of the official website of FMoH, pg. 125-127, 2020

APPENDIX

Appendix A: Data collection instruments for identifying the need for change, and for evaluating the extent and impact of intervention.

Appendix A.1: Director Survey Script and Checklist

Purpose: The Director Survey allows to be formally introduced to the hospital administration, gain demographic information about the hospital, understand the level of involvement the administration has with the hospital technicians, and confirm information used for study creation and matching of hospitals.

Method: This was an interview-assisted survey. The questions were asked via the Director Survey to the participants according to Script listed below and recorded the participants' responses were recorded and any physical documents presented during the meeting was collected/taken pictures.

1. The meeting was started with an introduction and an exchange of business cards. Then covered the purpose of the research, the specific actions I will perform, the amount of time needed with the Director, the amount of time needed for the list of equipment in each departments and with the technicians, and a formal request for confirmation of the Director's permission for this research to be conducted in the hospital.
2. The position, name, phone number, email address, and number of years at the hospital of each participant was recorded.
3. The Director interviewed according the left hand side of the Director Survey labeled "Script" and the participant's responses were recorded on the right hand side of the Director Survey labeled "Form"
   - Anytime this symbol [👁] is present, circled the 👁 if I have seen the requested document
   - Anytime this symbol [📷] is present, circled the 📷 if I took a picture or scanned the requested document

Table 10. 1 Director survey script and checklist

Position	Name	Phone Number	Email	Years at Hospital

Script	Form
General Information	**General Information**
1. What population does your hospital serve?	1. Population Served:
2. How many beds are in your hospital?	2. # of Beds:
3. What is your usual occupancy rate? (% of beds filled on average)	3. Occupancy rate:
4. How many inpatients does your hospital see in a year?	4. Inpatients:
5. How many outpatients does your hospital see in a year?	5. Outpatients:
6. How many operating rooms are in use?	6. # OR:
7. How many ICU beds does your hospital have?	7. # ICU Beds:
Equipment Information	**Equipment Information**
8. What % of your equipment do you estimate is donated?	8. % Donated:
9. What % of your equipment do you estimate is in service?	9. % in service:
10. Did your hospital buy any medical equipment in the last 4 months?	10. Bought: Y/N
11. Do you have a log of purchased equipment you have bought? May I see the log? May I take a picture of this log?	11. Log: Y / N 👁 📷
12. Does your hospital have money set aside each year to spend on equipment? If yes, how much? May I see the budget? May I take a picture of the budget?	12. Equipment Budget: ☐None, ☐ _____ 👁 📷
13. Does your hospital have money set aside each year to spend on spare parts and accessories? If yes, how much?	13. Components Budget: ☐None, ☐ _____
14. Over the past 4 months, how much money has been spent on spare parts and accessories?	14. Money spent:
15. Who approves the order of the spare parts and accessories?	
16. Who orders the spare parts and accessories?	
17. How many times in the last 4 months was a request for spare parts and accessories approved?	
18. Does the hospital maintain an inventory of medical equipment?	

May I see the inventory? May I take a picture of the inventory?	15. Who approves: 16. Who orders: 17. # times: 18. Inventory: Y / N 👁 📷
Interaction with Technician 19. How many medical equipment technicians are there at the hospital? (technician = anybody who repairs medical equipment) 20. Do you have a regular meeting with the technicians? 21. How often do you talk with your technician? 22. What topics do you most commonly talk about with the technician?	**Interaction with Technician** 21. # Techs: 22. Regular meeting: Y/ N 23. How often: 24. Topics:
Technician Satisfaction 25. When was the last time you hired a technician? 26. When was the last time you fired a technician? 27. When was the last time a technician was promoted? Why were they promoted? o What increased responsibilities result from promotion? 28. Has overall number of technicians increased, decreased, or stayed the same in the last five years? By how many technicians has the overall number changed?	**Technician Satisfaction** 25. Technician hired: 26. Technician fired: 27. Promoted: Why? _____ Increased responsibilities: ____ 28. Change in number: Increased/Decreased/Stay Same How many:
Reporting 29. Does your technician provide you any written reports? 30. What was the date of the last report you received? 31. What do you use the information in reports for?	**Reporting** 29. Tech provides reports Y/ N 30. Date: 31. Use:
Presence of other programs/NGOs 32. Which aid organizations (NGO or governmental) donate medical equipment to your hospital? 33. Which aid organizations (NGO or governmental) provide training on medical equipment? 34. In the last 4 months, how many pieces would estimate you have received? 35. In the last four years, how many pieces would you estimate you have received?	**Presence of Other Programs/NGOs** 32. Donate Equipment: 33. Provide Training: 34. Last Four months: 35. Last four years:
Service Contractors/ Service Providers 36. Does the MOH provide service contracts for any equipment? 37. Does the hospital negotiate for service contracts for any equipment? 38. Does your hospital use fee for service / one time providers? *If yes to SC probe on:* 39. Are parts, accessories, & consumables included in the contract? 40. What are the names of the service contractors? What type of equipment do the contracts cover? 41. Who negotiates and signs the contract? (title, department) *If yes to fee for service probe on:* 42. What is the budget for fee for service? 43. How many times in the 4 months have you contact a fee for service technician? 44. Has this changed over the four years?	**Service Contractors/ Service Providers** 36 Use MOH SC? Y / N / Don't Knw 37. Use Hospital SC? Y / N / Don't Knw 38. Fee for service? Y / N / Don't Knw 39. Parts: Y / N / Don't Know 40. Names | Types 41. Who: 42. Budget: 43. 4 months: 44. Changed:

Appendix A.2: Equipment Survey Script and Checklist

Purpose: The Equipment Survey allows to document the amount of functional equipment in selected set of equipment. Furthermore, this survey allows to understand the barriers the technician faces to repairing the partially and non-functional equipment.

Method: This was an interview-assisted survey. The questions were asked via the Equipment Survey Checklist listed below and the participants' response was recorded.

Table 10. 2 Equipment survey checklist

Equip # ___1	**Type:**	**Manf and H#:**	**Problem:**			
Dept:	Source: **D P L**	**Name of Source:**	**Time in Hospital:** yrs		Down: **d m y**	**NU:** R NU NCN NUT D Other:
Room # & Description:	Fixer: **I O B N**	**War / Cont / FFS** Name:	Status: **F PF NF NU**	**PPM / R / MANG**	TO:	UO: / SCO:
					Have it: CNIP / time / money / Not available locally / Have it **How long:** Single Use / Many Patients / Lifetime **From:** LM / Capital / MOH / Intl / Other	

Appendix A.3: Management Actions Survey Checklist and Findings

Purpose: The Management Action Survey allows to gain information about technician's involvement in the management of the medical equipment and their interactions with administrators.

Method: This was an interview-assisted survey. The questions were asked via the Management Actions Survey to the participants according to Script listed below and the participants' responses were recorded.

Table 10. 3 Management actions survey script

Script	# of times	Description of Steps
1. Did you created or update the inventory within the last 4 months? Please describe your process.		
2. How many times have you created a Planned Preventative Maintenance Schedule? Please describe how your process.		
3. How many times have you ordered spare parts? Please describe your process to order spare parts.		
4. How many times have you written a report for the hospital administration? Please describe what topics are covered in your reports.		
5. How many times have you written a report for Ministry of Health? Please describe what topics are written in your reports.		
6. How many times have you developed a budget? Please describe how you develop a budget.		
7. How many times have you written a budget request? Please describe what you include in your budget request.		
8. How many times have you planned for the replacement of medical equipment? Please describe how.		
9. How many times have you decided a broken piece of equipment should stay permanently broken? Please describe which and how many of each type.		

10. How many times have you installed a piece of equipment? Please describe the process.		
11. How many times have you attended meetings with hospital administrators? Please describe what you discuss during these meetings.		
12. How many times have you attended meetings with your boss? Please describe what you discuss during these meetings.		
13. How many times have you called a service contractor? Please specify which service contractors you called and for what reasons.		
14. How many times have you called a private company or private technician? Please specify which private companies or technician you called and for what reasons.		
15. How many times have you developed purchasing goals? Please describe your process.		
16. How many times did you identify training needs of the users? Please how you identify needs.		
17. How many times did you perform user training?	*Gather this information from the informal survey sheet*	

Table 10. 4 Management actions survey findings

	AgGH		**AwGH**		**JUMC**		**LGGH**		**SPH**		**SGGH**	
Script Qn #	**# of times**		**# of times**		**# of times**		**# of times**		**# of times**		**# of times**	
1	**1**	After new equ. Installation, & decommissioning	**0**		**2**	After new equ. Installation, & decommissioning	**1**	After new equ. Installation, & decommissioning	**0**		**0**	
2	**4**	According to z equ. manual	**0**		**7**	According to z equ. manual	**3**	According to z equ. manual	**1**	According to z equ. manual	**0**	
3	**4**	Purchase request to CEO	**2**	Purchase request to CEO	**8**	Purchase request to BME Dept. Head->CEO	**7**	Purchase request to CEO	**4**	Purchase request to MD	5, CEO, sometimes finance	
4	**2**	Over all HT conditions including status of equ.	**0**		**2**	Spare part purchase, HT problems, SC, user cases and stock levels	**1**	Spare part purchase, HT problems,	**0**		1, HTM problems, #of functional & non-functional equ.	
5	**0**		**0**		**0**		**0**		**0**		**0**	
6	**0**		**0**		**0**		**0**		**0**		**0**	
7	**1**	Spare part purchase	**1**		**2**	Spare part purchase	**1**	Spare part purchase	**0**		**0**	
8	**0**		**0**		**4**	After doing performance tests	**2**	Due to old model & low performance	**0**		**1,** Due to old model & low performance	
9.	**2**	**Autoclaves,** Due to old model & low performance	**0**		**4**	Autoclave(1), Anesthesia(2), Infant Incubator(1), Due to old model & low performance	**2**	Autoclave and microscope, Due to old model & low performance	**0**		**0**	
10	**4**	With Company rep after performing acceptance tests	**2**	With Company rep after performing acceptance tests	**7**	With Company rep after performing acceptance tests	**3**	With Company rep after performing acceptance tests	**3**	With Company rep after performing acceptance tests	**4,** With Company rep after performing acceptance tests	
11	**2**	Over all HTM problems	**2**	HT problems, SCs	**3**	Over all HTM problems, SCs	**2**	overall Medical equipment issues and	**0**		**1,** Over all HTM problems	

								problems, reporting			
12	**6**	Spare part purchase, HT problems, user issues, reporting	**2**	HT problems, SCs	**6**	Spare part purchase, HT problems, SCs	**8**	Spare part purchase, HT problems, user problems, reporting	**2**	Spare part purchase, HT problems	**4,** Spare part purchase, HT problems, report
13	**0**		**4**	Agmas (2)> To remind PPM Schedule WMG (2)> Requests for technical assistance	**5**	Infinity(1), Philips(1), Setema(1), Pharma(1), > To remind PPM Schedule Infinity(1)>Requests for technical assistance	**0**		**0**		**0**
14	**6**	WMG, Biftu, Tech frnds, Foreign support >Requests for technical assistance	**1**	Tech frnds>Requests for technical assistance	**16**	Infinity, Philips, Setema, Pharma, Altai, Tech frnds, Foreign support >Requests for technical assistance	**4**	Tech frnds>Requests for technical assistance	**1**	Tech frnds>Requests for technical assistance	6. WMG, Biftu, Afework, Tech frnds>Requests for technical assistance
15.	**2**	By identifying the workload in depts..	**0**		**4**	By identifying the workload in depts..	**1**	By identifying the workload in depts..	**1**	By identifying the workload in depts..	**1,** By identifying the workload in depts..
16	**5**	After installation of new equip. & Due to user errors	**2**	After installation of new equip. & Due to user errors	**10**	After installation of new equip. & Due to user errors	**4**	After installation of new equip. & Due to user errors	**3**	After installation of new equip.	**4,** After installation of new equip. & Due to user errors
17	**3**		**0**		**8**		**4**		**1**		**4**

Appendix A.4: Informal equipment interaction survey findings

Purpose: The Information Equipment Interaction Sheet allows to gain information about times when the technician checked on the medical equipment but did not perform planned preventative maintenance and it allows to gain more extensive information that will get re-categorized as either a management or corrective action. **Method:** This was an interview-assisted survey. The questions were asked via the Equipment Interaction Sheet listed below and the participants' response was recorded.

Table 10. 5 Informal equipment interaction survey findings

Hospital name	**User training: (frequency, #ppl)**	**Used testing equipment(frequency)**	**Changed equipment settings (frequency)**	**Functional testing (frequency)**
AgGH	(1,4), (1,2), (2,1), (1, 2),	4	5	14
AwGH	0	2	0	4
JUMC	(1,5), (1,4), (2,2), (2,3), (2,1)	17	8	25
LGGH	(2,2), (2,1)	8	6	11
SPH	(1,1)	2	4	5
SGGH	(2,1), (2,3)	3	7	9

Appendix A.5: Preventive Maintenance Survey Checklist

Purpose: The Preventative Maintenance Sheet allows to gain information about the number of times the technicians perform preventative maintenance on the medical equipment in the hospital. This sheet records the details of how the technicians perform preventative maintenance.

Method: This was an interview-assisted survey. The questions were asked via the Preventative Maintenance Sheet to the participants according to Script listed below and the participants' responses were recorded.

Equipment Type	Memory / Paperwork	Times Completed / Times Planned	# worked on	Contact anyone for assistance	Open the machine	Clean the machine	Calibrate	Use any parts	What did you do? [describe, list, info from other questions]
	M / P	/		Y N Who:	Y N	Y N	Y N	Y N Parts:	
	M / P	/		Y N Who:	Y N	Y N	Y N	Y N Parts:	

Table 10. 6 Preventive maintenance survey script and checklist

Script	Form
General Information 1. Do you have paper documentation for preventative maintenance? 2. Do you have a schedule for the preventative maintenance you perform? 3. How often are you not able to complete the scheduled preventative maintenance? 4. What percentage of PPM are you eventually able to complete? 5. How many days' delay does it take for you to complete the preventative maintenance? 6. What barriers to performing preventative maintenance do you face to complete it as scheduled?	**General Information** 1. PPM: Y / N 2. Schedule: Y / N 3. Not Able: 4. % Unable: 5. Days Delay: 6. Barriers:

Appendix A.6: Repair Survey Script and Findings

Purpose: The Repair Survey allows the research team to gain information about the number of times the technicians perform corrective maintenance on the medical equipment in the hospital. This sheet records the details of repairs including the date of the repair, the problem addressed, if outside assistance was used, and how long it took for the technician to perform the repair.

Method: This was an interview-assisted survey. The questions were asked via the Repair Survey Checklist to the participants according to Script listed below and the participants' responses were recorded.

Table 10. 7 Repair survey checklist

Case #: ___	**Problem:**	Date Began: **_____ / 201___**	Assistance? **N / Y Who? Phone Email F to F**
		Internet? **N / Y**	Opened? **N / Y**
Equip Type:	**What they did**:	Parts: **Single Use / Many Patients / Lifetime**	
		Type Part:	
# of pieces:		Where stocked: **L / MOH / Int /Capital**	
Paperwork: **Y / N**	**BTA skills:**	Repair Time: **d m y**	
		Resolved: **Fully / Partially / Unresolved**	

Appendix A.7: Technician Survey Script and Checklist

Purpose: The Technician Survey allows to gain information about the technician's educational background, the proportion of the technician's time spent working on medical equipment, relationship between the technician and the administration, and how the technician acquired spare parts and accessories needed for medical equipment.

Method: This was an interview-assisted survey. The questions were asked via the Technicians Survey to the participants according to Script listed below and the participants' responses were recorded and any physical documents presented during the meeting was collected/taken pictures.

1. The technicians interviewed according the left hand side of the Technician Survey labeled "Script" and the participant's responses recorded on the right hand side of the Technician Survey labeled "Form"
   - Anytime this symbol [👁] is present, circled the 👁 if I have seen the requested document
   - Anytime this symbol [📷] is present, circled the 📷 if I took a picture or scanned the requested document
2. For question 9, the "English Test" Reference Sheet was used. If the technician reported that he/she can speak English, then the English Test was given. For every question the technician answers correctly, the technician allotted one point. Therefore, the final score was of 3 points.
3. For the section titled "Shop", the "Tool List" Reference Sheet was used. The reference sheet to the technician was handed and guided the technician through the reference sheet inquiring if the technician has each tool. And the corresponding box was checked if the technician has positively identified having the tool. For tools 36-42, if the technician identifies having the tool, it was asked if the technician uses that tool daily, weekly, or monthly.
4. For the section titled "Supplies", the "Supply List" Reference Sheet was used. The reference sheet to the technician was handed and guided the technician through each supply and inquired if the technician has access to that each supply Always, Often, Rarely, or Never.
5. For question 47, each person or company the technician reached out to for help over the past 4 months was listed. For each person/company listed, the number of times the technician contacted the person/company, how the technician contacted them, and if the person/company was located inside or outside the country was recorded.

Table 10. 8 Technician survey script

Introduction	**Introduction**
1. What is your name?	1. Name:
2. What is your email address?	2. Email Address:
3. What is your phone number?	3. Phone Number:
4. How many years have you worked at this hospital?	4. Years:
5. What is your job title?	5. Title:
6. Did you attend our intervention training program?	6. Intervention training: Y / N
7. Have you had any previous BMET Training? If yes, ask the technician to describe their previous trainings.	7. BMET Training: Y / N Description:
8. What languages do you speak?	8. Languages:
9. Do you speak English? (If yes, the technician was given the English test and recorded appropriately.)	9. English: Y / N Test Score:
10. Did you graduate from high school?	10. High School: Y / N
11. Did you graduate from Technical School? What was your major?	11. Technical School: Y / N Major:
12. Did you graduate from University? What was your major?	12. University: Y / N Major:
13. Did you attend any other forms of education? If yes, please ask the technician to describe that form of education.	13. Other: Y / N Description:

----------Talk to the <u>lead technician and other technicians that are responsible for repairs and maintenance</u> in the maintenance department ----------

Parts	**Parts**
14. When you are repairing medical equipment and you need a replacement part, how do you get the replacement parts?	14. How:
15. Where do you get the spare parts you need?	15. Where:

16. Do you have any paperwork?
May I see a copy? May I take a picture?
17. Who do you have to request the part from?
18. When was the last time you requested a spare part?
19. How long did it take you to receive it?
20. Do you feel you are able to get the parts you need?
21. What are the barriers to getting the parts you need?
22. Do you have a room or cabinet of spare parts at the hospital?
May I see a copy? May I take a picture?
23. What part of the budget does money for spare parts come from?

16. Parts acquisition paperwork? Y / N
17. Who request:
18. Last request:
19. Wait time:
20. Able to get parts: Y / N
21. Barriers to parts:
22. Parts storage: Y / N
23. Parts budget:

Hospital Hierarchy

24. Who is your boss? Who is that person's boss? (continue until director to draw hierarchy)

25. Do you provide any reports to the hospital administration? May I see a copy? May I take a picture of the reports?

Hospital Hierarchy

Tech ☐

25. Reports to administration? Y / N

Effort percentage

26. What percentage of your time do you spend working on facilities issues (electricity, water, air conditioning)?
27. What percentage of your time do you spend working on medical equipment?
28. Of the time you work on medical equipment, what percentage is on repairs?
29. Of the time you work on medical equipment, what percentage is on preventative maintenance?
30. Of the time you work on medical equipment, what percentage is on management actions (paperwork, work tickets, reports)?
31. What are the other responsibilities you have at the hospital?
32. What percentage of your time do you spend on these other responsibilities?
33. Are there any types of equipment you are not allowed to work on?
34. Are there any departments that you are not allowed to work in?
35. Are there any types of equipment you choose not to work on?

Effort Percentage

Tech 1	Tech 2
26. Facilities:	
27. Equipment:	
28. Repairs:	
29. Maintenance:	
30. Paperwork:	
31. Other Resp:	
32. % Other Resp:	
33. Allowed:	
34. Departments:	
35. Choose:	

Service Contractors/ Service Providers

36. Does the Ministry of Health provide service contracts for any medical equipment?
37. Does the hospital negotiate for service contracts for any medical equipment?
38. Does your hospital use fee for service one time providers?

If yes to SC probe on:

39. Are parts, accessories, & consumables included in the contract?
40. What are the names of the service contractors? What equipment do they work on?

41. Who negotiates and signs the contract? (list title, department)

If yes to fee for service probe on:

42. What is the budget for fee for service?
43. How many times in the last four months and year have you contact a fee for service technician?
44. Has the number of times the hospital contacted a fee for service technician increased, decreased, or stayed the same over the past four years? Why?

Service contract

36. Use MOH SC? Y / N / Don't Know
37. Use Hospital SC? Y / N / Don't Knw
38. Fee for service? Y / N / Don't Know
39. Parts: Y / N/ Don't Know
40.

Names	Types

41. Who:
42. Budget:
43. Last year:
44. Changed: Increase/Stay Same/Decrease

Why:

Shop Which of the following tools do you have? *36-42: How often do you use it (D W M)?*

☐ 1	☐ 6	☐ 11	☐ 16	☐ 21	☐ 26	☐ 31	☐ 36	☐ 41 ____
☐ 2	☐ 7	☐ 12	☐ 17	☐ 22	☐ 27	☐ 32	☐ 37 ____	☐ 42 ____
☐ 3	☐ 8	☐ 13	☐ 18	☐ 23	☐ 28	☐ 33	☐ 38 ____	☐ 43
☐ 4	☐ 9	☐ 14	☐ 19	☐ 24	☐ 29	☐ 34	☐ 39 ____	
☐ 5	☐ 10	☐ 15	☐ 20	☐ 25	☐ 30	☐ 35	☐ 40 ____	

May we take see your workshop and your tools? May we take a picture of your shop?
Shop condition:

Supplies: How often are you able to get these items for the repairs you need: *Always (A), Often (O), Rarely (R),Never (N)*

☐ 1_____	☐ 4_____	☐ 7_____	☐ 10_____	☐ 13_____	☐ 16_____	☐ 19_____	☐ 22_____	☐ 2_____
☐ 5_____	☐ 8_____	☐ 11_____	☐ 14_____	☐ 17_____	☐ 20_____	☐ 23_____		
☐ 3_____	☐ 6_____	☐ 9_____	☐ 12_____	☐ 15_____	☐ 18_____	☐ 21_____	☐ 24_____	

Interaction with Director

45. How often do you meet with the director?
46. What topics do you typically discuss?

Interaction with Director

47. Interactions:
48. Topics:

Requests for technical assistance

49. In the last 4 months, who did you contact when you needed assistance with a repair?

Name: What is the name of the company or the person's name who you contacted? (Other technicians, regional repair unit, foreign support, outside repair agency, service contractors)
Time: How many times did you contact this person in the past 4 months?
Mode: How did you contact this person? (Phone call, email, face to face, facebook)
In/Out: Was the person located inside or outside of the country?

Requests for technical assistance

Name	# times	Mode	In/Out
1.			
2.			
3.			
4.			

Incoming Equipment & Tech Status

50. Who purchases medical equipment at the hospital? Are you involved when a piece of equipment is purchased?
51. Is incoming equipment recorded?

May I see a copy? May I take a picture of this record?

52. Who accepts incoming equipment? (title and department) Are you involved?
53. Who installs incoming equipment? (title and department) Are you involved?
54. Who trains users on how to use the equipment? (title and department) Are you involved?
55. Where do you keep the medical equipment manuals?
56. How many do you have?

May I see the manuals? May I take a photo of the manuals?

Incoming Equipment & Tech Status

57. Purchased by:
Tech involved: Y / N
58. Recorded? Y / N
59. Received by :
Tech involved: Y / N
60. Installed by: _
Tech involved: Y / N
61. User training by:
Tech involved: Y / N
62. Manuals placed:
63. Number of Manuals:

Workflow – *Fill out work tickets*

64. When a piece of equipment is broken, which person lets you know that it is broken?
65. How does this person let you know?
66. Do you have any paperwork for the request?

May I see a copy? May I take a picture of the paperwork?

67. (If 2+ tech) After you know a piece of equipment needs repair, how do you decide who repairs it?
68. Do you record the repairs you make?

May I see a copy? May I take a picture of the repairs?

Workflow

69. Who:
70. How:
71. Request Paperwork: Y / N
72. Delegation if more than one tech:
Whoever available Head Tech
By Specialty
73. Repair Paperwork: Y/ N

Appendix B: Identified needed biomedical technician's skills along with units and knowledge domain required to repair the out-of-service equipment at Jimma zone hospitals.

Electrical (11)

- **Connections**
  1. Broken Wires inside cable
  2. continuity tester
  3. Desoldering
  4. heat shrink tubing (diameter)
  5. Proper use of electrical tape
  6. Selecting wire (diameter, type(solid/stranded), insulation,
     a. material (aluminum, copper))
  7. Soldering (stranded wires, solid wires, to PCB board)
  8. Wire nuts
- **Connectors**
  9. Broken housing
  10. Cleaning of connections (Q-tips, isopropyl alcohol)
  11. Conductive epoxy
  12. Loose Connectors
  13. Strain Relief
  14. Wire/ rod to replace pins of a connector
- **Fabrication (cables, electrodes, plates)**
  1. Cables (simple cables, shielded cables)
  2. ECG Cables
  3. ECG Electrodes
  4. Patient Reference Plates for ESUs
  5. Temperature Probe Cables
- **Heating Element**
  1. Replacement of Heating Element
  2. Replacement of temperature sensing device
- **Lighting/ Indicators/Switches**
  cleaning bulb connections
  1. cleaning high temperature/high intensity bulbs
  2. Fixtures (electrical rewiring, mechanical adaptations)
  3. Replacement of Light bulbs (incandescent, fluorescent, LED)
  4. Replacing Analog Meters
  5. Cleaning Contacts
  6. Selecting Replacement Switches
- **Brush Substitution**
  1. Filing down
  2. Shim
  3. Spring adjustment (attached to brush)
  4. Spring repair
- **Batteries**
  1. Building/ adapting a charger for rechargeable cells
  2. Identification of leaking/corrosive batteries
  3. Replacing batteries with a wall transformer
  4. substituting for batteries for primary cells
  5. substituting for batteries for rechargeable cells
- **Fuse**
  1. fuse substitution
  2. identifying a blown fuse
- **Plug/cable**
  1. Adding proper grounding
  2. Fabricating power cords
  3. Outlets and plugs for different voltages/countries (determine frequency voltage, determine configuration)
- **Regulator**
  1. Diagnose regulator problems
  2. Replacing/adapting regulators
- **Transformer**
  1. Adapting wall transformers

Diagnosing a transformer that needs to be rewound (appropriate people to rewind transformers)

  2. Voltage conversion transformers

Mechanical (7)

- **Attachment**
  1. drilling holes (in metal, ceramic & wood)
  2. epoxy
  3. loosening frozen nuts
  4. nails/ hammer
  5. plastic anchors
  6. Selecting replacement screws
  7. soldering (brass tubing)
  8. superglue
  9. tightening nuts
  10. tools for adjusting bolt/screw choosing different heads
  11. understanding welding
  12. zip ties
- **Calibration**
  1. BP machines
  2. Centrifuge
  3. Defibrillator
  4. ECG monitor
  5. Oxygen concentrator

6. Scale
7. Sphygmomanometer
8. Training
9. Ventilator volume/ rate

- **Casing**
  1. hinges
  2. latches/locks/interlocks
  3. Panels/ doors (from wood, sheet metal)
- **Cleaning**
  1. Cleaning inside of things (pipe cleaners, Q-tips, tweezers with a bit of cloth)
  2. cleaning lens/using lens paper
  3. compressed air
  4. rust/ sanding
  5. Using a damp cotton cloth (water, soap and water, clorox, acetone, alcohol)
  6. Arcing grooves in commutator (removal with emery paper)
  7. Arcing grooves in commutator (Removal with lathe)
  8. Brush frozen away from commutator (cleaning)
  9. Grinding/ high pitched squeal (foreign objects)
- **Lubrication**
  1. greasing/ oiling
  2. thin penetrating oils
  3. unfreezing painted joints
  4. Lubricant (type, reservoir)
  5. Repack bearings
  6. Squealing/ Grinding/ Overheating

- **Belts/ Gears/ Shafts/ Coupling**
  1. Bent Shaft (vibration and wobbling)
  2. Loose/ tighten
  3. Lovejoy Coupling (vibration/slipping)
  4. Squealing/slipping/ low power
  5. worn cracks/ glazing (replacing belt)
- **Tightening/ Attachment/ Balance**
  1. Mounting of motor
  2. Set Screws(Loc-tite/superglue)
  3. Vibration and motor

Plumbing (6)

- **Blockages**
  1. Cleaning
  2. Descaling
  3. Routing
- **Connections**
  1. Clamps
  2. Fitting adaptors
  3. Hose Barb w/ clamp
  4. Threaded pipe connector
- **Filters**
  1. Cleaning
  2. Fabrication
  3. Substitution
- **Leaking**
  1. Cutting Tubes
  2. epoxy
  3. Finding Holes
  4. Melting Tube
  5. Rubber Patches
  6. superglue
  7. Tape
- **Seal**
  1. Caulk
  2. Creating a gasket
  3. Jars/lids for Suction machines
- **Rings**
  1. O-rings
  2. Sealing autoclave doors