Web-based Medical Equipment Management System in Seven Referral Hospitals

A master thesis

Presented in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering

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Declaration

I, the undersigned, declare that this thesis is my original work. It has never been presented for a degree in any other institution and that all sources of the materials used in it have been duly acknowledged.

Name: _____

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Date: _____

This MSc. thesis has been submitted for examination with my approval as an advisor.

_____

Masreshaw Demelash(PhD.)

Certificate of Examination

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Chief of Department or Graduate Program Coordinator

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Abstract

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Medical devices are an integral part of healthcare service delivery and they are used for monitoring, diagnosis, treatment and rehabilitation of patients. Proper utilization of medical devices is important for ensuring the safety of users and patients, reducing downtime, improving the quality of health services and increasing the benefit of financial investment.

The aim of this study was to assess the utilization of medical devices and to develop web-based medical equipment management system. Both quantitative and qualitative data has been collected for the study. The data collection was conducted between August 26, 2017 to September 20, 2017 in all the seven government owned teaching hospitals which are found in Addis Ababa and Hawassa cities. On average, each hospital delivered services for more than 3 million populations, and had more than 17 service standards, 330 medical equipment and 500 beds during the research period. Data were collected by observation of available resources, interviewing selected professionals about their services and also through questionnaire which was filled by biomedical engineers and biomedical technicians who assessed the utilization phase of healthcare technology management in the seven hospitals.

According to the data collected, more than half (17/31) of the respondents did not know the exact number of medical equipment in their facility and there were only 29% (2/7) of hospitals which had recommended test equipment and workshop space in their facilities and almost all hospitals did not have international standards and guidelines and also service manuals. The percentage of respondents who didn't agree on the availability of reference materials, electrical safety and performance test equipment, sufficient user and maintainer training, sufficient maintenance staff, preventive maintenance schedule for all medical equipment were 74%, 77%, 65%, 54% and 36% respectively.

In order to better manage medical devices, we have designed and developed an automated medical equipment management system that can be deployed in a hospital. The system is developed using

HTML5, CSS3, JavaScript, PHP, and MySQL. We strongly believe that such automated system helps to improve communication between system users, decrease resilience on human role, reduce data redundancy, allow multiple users to access the data, enhance the security of the equipment, improve planning and budgeting for medical equipment.

Keywords: Healthcare technology management, web-based technology, automated system, medical device, medical equipment management system

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List of Abbreviations

Acronyms

CSS	Cascading Style sheet
CT	Computed Tomography
DFID	Department for International Development
ECG	Electrocardiogram
EFY	Ethiopian Fascial Year
EU	European Commission
FDA	Food and Drug Administration
FMHACA	Food, Medicine, and Healthcare Administration and Control Authority
GAVI	Global Alliance for Vaccine and Immunization
GTZ	German Technical Corporation Agency
HSDP	Health sector development plan
HTM	Healthcare Technology Management
HTML	Hypertext Markup language
IEC	International Electrotechnical Committee
ISO	International Standard Organization
IVD	In-vitro diagnostics
MRI	Magnetic Resonance Imaging
MoH	Ministry of Health
PFSA	Pharmaceuticals, Funds and supply agency
PHP	PHP hypertext preprocessor
UML	Unified Modeling Language
UN	United Nations
US	United states
USD	United states dollar
WHO	World Health Organization

Chapter 1 Introduction

1.1 Medical device definition

The term medical devices cover a large number of instruments and appliances, from every day object such as sticking plasters, syringes, gloves, pregnancy test, wheelchairs, hearing aids, tongue depressor, stethoscope, sphygmomanometer to highly sophisticated computerized medical equipment such as MRI, CT-scan, life supporting machines, implantable devices such as heart valve and pacemakers, replacement joints for knee and hips. There are more than 10,000 types medical devices [1].

Medical devices are grouped into two categories. These are medical devices other than In-vitro diagnostics (IVD) and In-vitro diagnostic medical devices. The Ethiopian Food, Medicine, and Healthcare Administration and Control Authority (FMHACA) and the United States Food and Drugs Administration (FDA) use the same expression for medical devices other than In-vitro Diagnostics definition [2,3].

FMHACA defined medical devices other than IVD as "an instrument, apparatus, implement, medical equipment, contrivance, implant, in vitro reagent, or other similar or related article, including any component, part or accessory that is:

a. Recognized in a pharmacopoeia or any supplement to it

b. Intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or preventive of disease, in man or other animals, or;

c. Intended to affect the structure or any function of the body of human being or other animal and which does not achieve any of its principals intend purpose through chemical action within the body of human being or other animals and is not dependent upon being metabolized for the achievement of any of its principal intended purpose."

In-vitro diagnostics medical devices are used to identify diseases, infections, or tissue form the body and give true or false result to the individual or public health. Some examples of in-vitro

diagnostic medical devices are pregnancy self-testing, glucose self-testing, HIV blood diagnostics, urine testing strips etc.

1.2 Overview of global medical device market

In 2015, the global medical device market was worth about USD 311 billion and it is estimated to reach around USD 435.8 billion in 2020. It will grow with an approximately 6.75 percent rate per year for the coming five years as illustrated in figure 1-1.

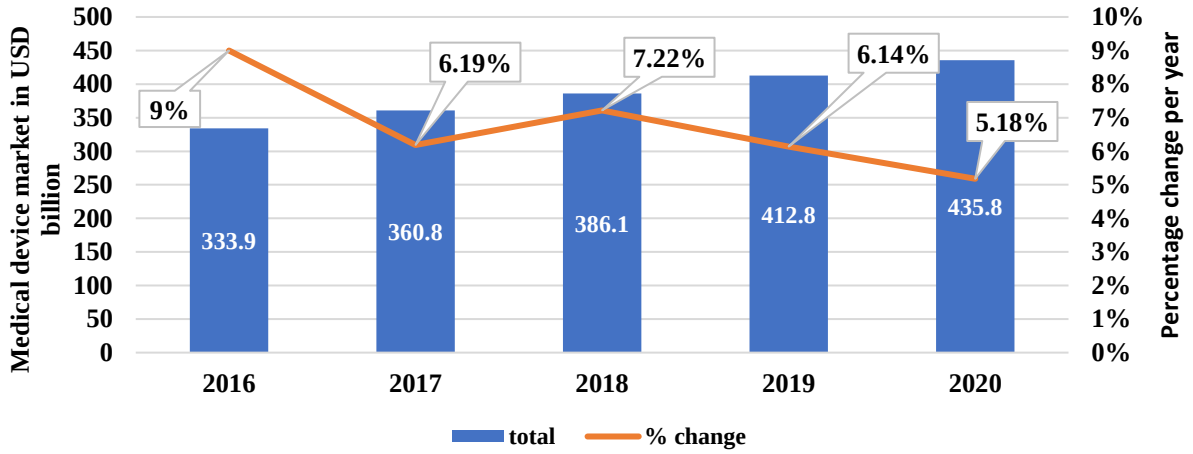

Figure 1-1: Global medical device market forecast from 2016 – 2020 [4].

The United States (US) and European Union (EU) together accounted for 71 percent of the total with 42 percent and 29 percent respectively as shown in the figure 1-2 [4,5].

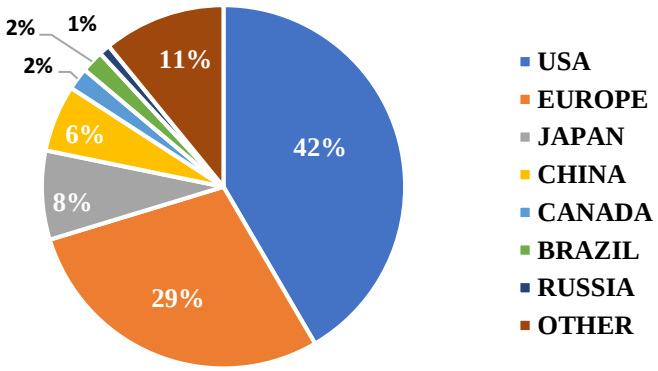

Figure 1-2: Medical device market share by countries in 2015 [5].

The medical device technology is one of the most innovative and highly competitive market in the world. In 2015, there were more than 12,400 patent applications submitted to European Patent Office (EPO) in the field of medical devices that made up 7.8 percent of the total patent

applications. From 12,400 patent applications, 40 percent of the applications were form European countries whereas 41% were from the US as shown in the table 1-1. In the same year (2015), there were approximately 30,800 medical device companies in the Europe and the US only [4,5].

Table 1-1: Top 10 technical fields submitted to European patent application in 2015 [5].

Rank	Technical Fields	No. patent applications
1	Medical Technology	12,474
2	Digital Communication	10,762
3	Computer Communication	10,549
4	Electrical machinery, apparatus, energy	10,198
5	Transport	7,802
6	Measurement	7,727
7	Organic Fine Chemistry	6,414
8	Engine, pumps, and turbines	6,374
9	Biotechnology	6,048
10	Pharmaceuticals	5,884

In 2014, medical device for in-vitro diagnosis, cardiology, orthopedics and diagnostic imaging were the top four leading areas of medical technology accounted for 13%, 11.2%, 9.3% and 9.5% the total market shares respectively. In-vitro diagnosis, endoscopy, ophthalmic and cardiology will be the top four fastest growing area which sales will increase by 5.1%, 4.8%, 4.7% and 4.4% per annum respectively until 2020 [6].

The global medical device demand will increase significantly due to a pronounced rise in the world aging population (aged 60 and over) and the number of aged populations are increasing faster than any age groups everywhere in the world. Globally, there were 901 million aged populations in 2015 and this is expected to increase by 56 percent and reach 1.4 billion by 2030. The aging population in Sub-Sahara Africa is also projected to increase by 64 percent between 2015 and 2030 with Rwanda the highest increase by 88 percent [7,8].

Japan, Germany, Italy and Finland were the top four most aged populated countries in the world which were represented by 33, 28, 28, and 27 percent of their total population respectively and

China, India, the United States, Japan and Russia Federation accounted for 50 percent of the total aged 60 or above population in the world in 2015 [8].

These growing aged population are exposed to several health-related problems and the most common generic problems related to aging are cardiovascular diseases, malignant neoplasms, respiratory diseases, sense organ diseases and neuropsychiatric and world health organization also identified the necessary medical equipment for such health problems [9].

1.3 Overview of Ethiopian healthcare sector

Ethiopia is the second most populated country in Africa next to Nigeria. Its population is estimated to be reach 100 million in 2015 [10].

In the last 20 years (1997/1998 – 2015/2016), The government of Ethiopia has developed Health Sector Development Plan (HSDP) for implementing its policy. During this period, there was a pronounced progress in the health status of people. In 2014, the number of under-five mortality rate reduced significantly by 67 percent. The average life expectancy at birth rose by 19 years from 45 to 64 and also there was a marked decrease of maternal mortality rate by 69 percent as compared with 1990 [11].

Between 2009 and 2012, there was a significant reduction in mortality and morbidity rate of HIV/AIDS, Tuberculosis and Malaria. The admission and death rate of under-five children as a consequence of malaria fell significantly by 81% and 74% respectively and there was a massive decline on HIV new infections and mortality rate by 90% and 50% respectively. As the same time, there was a marked decrease in mother-to-child transmission of HIV/AIDS by 50%. The incidence and the mortality rate due to Tuberculosis dropped by half [11].

Even though there was a significant progress on improving the health status of the citizen, Ethiopia is now facing a huge problem on non-communicable diseases and injuries. In 2013, the mortality rate due to non-communicable diseases was 476 per 100,000 of the population and this number will increase by 38.24% and 27.5% in 2025 and in 2035 respectively [11]. In 2013, the mortality rate due to vehicle injuries was 68.5 per 100,000 vehicles [12].

In EFY 2008 (2015/2016), the total expenditure of Ethiopian Ministry of Health (MoH) was USD 249.95 million. From this expenditure around 95.5% (USD 238.7 million) was covered by donor grant funds as shown in the figure 1-3 and in the same year USD 64.6 million was spent on the procurement of medical equipment and pharmaceuticals. Among USD 238.7 million expenditure, about 80% was accounted by Global fund, Department for International Development (DFID), Global Alliance for Vaccines and Immunization (GAVI) and World Health Organization (WHO) [13].

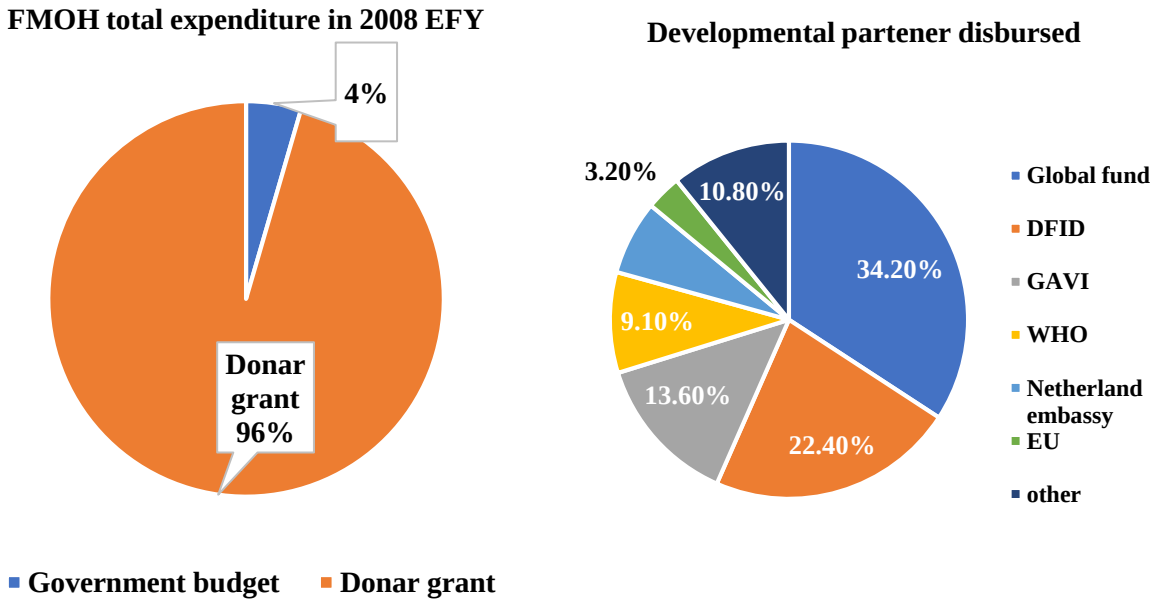

Figure 1-3: EFY 2008 (2015/2016) Federal Ministry of Health annual expenditure [13].

The Ethiopian Pharmaceuticals Fund and Supply Agency (PFSA) has forecasted the quantities of essential pharmaceuticals and medical devices that are required at public health facilities for the coming three years (from 2010 E.C (2018/2019) to 2012 E.C (2020/2021)) which are covered though revolving drug fund (RDF) and also the number of purchased medical devices are going to increase year after year. Eight sample lists of medical equipment that are going to be purchased in the coming three years are listed in table 1-2 [14].

Table 1-2: Sample lists of medical devices plan to be purchased from 2010 – 2012 EFY [14].

List of medical devices	2010 E.C	2011 E.C	2012 E.C
Stethoscope (adult & pediatric)	22,050	30,871	40,131
Sphygmomanometer	37,054	51,874	67,437
Binocular microscope	638	893	1,163
Centrifuge, Hematocrit	575	805	1,046
Suction machine, mobile	1,146	1,598	2,078
Drum sterilizer	5,457	7,641	9,932
Diagnostic set	2,080	2,911	3,785
Fetoscope	9,079	12,710	16,523

1.4 Ethiopian health service delivery structure

The Ethiopian health service has a three-tier system structure. These are primary, secondary and tertiary healthcare levels. The primary hospital, health center and health post are categorized under the primary healthcare levels as shown in the figure 1-4 [13].

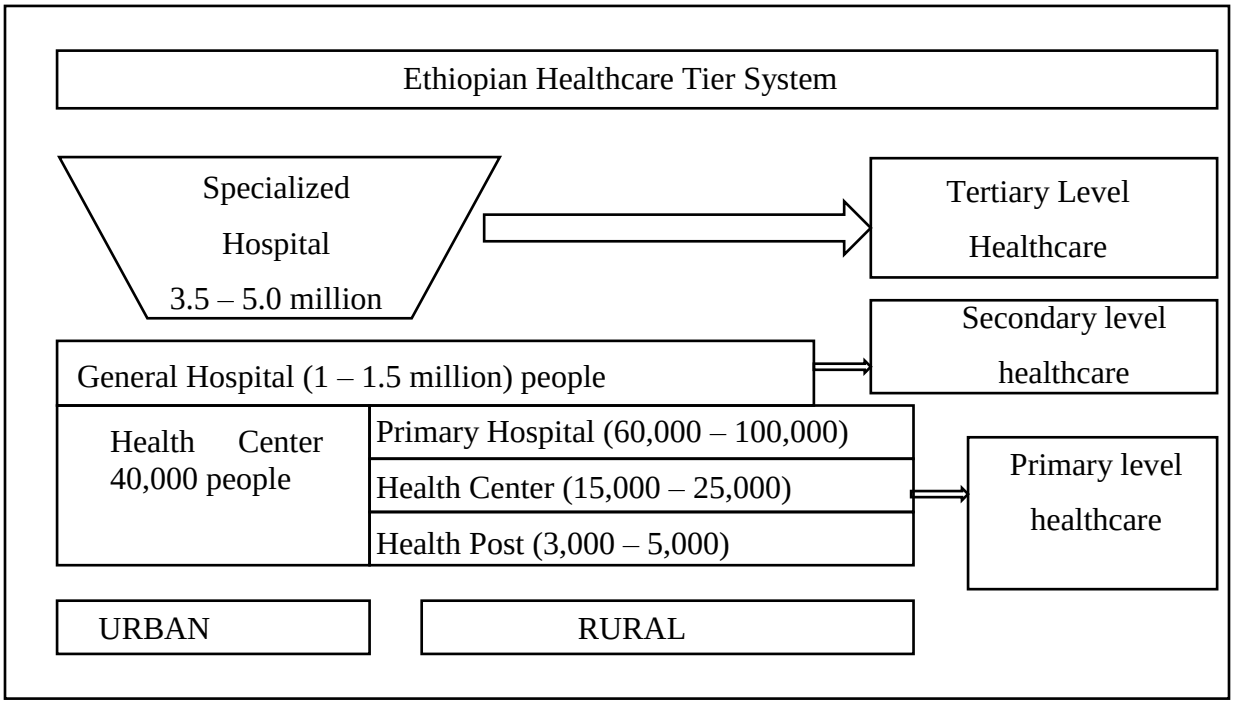

Figure 1-4: Ethiopia's health tier system [13].

By the end of EFY 2008 (2015/2016), there were a total number of 20,283 functional government owned health facilities which include 16,489 health posts, 3,562 health centers and 241 hospitals. The number of hospitals in EFY 2008 (2015/2016) increased by 28% that is from 189 to 241 and there was an increase in health centers by 15 from that of EFY 2007 (2014/2015) and there have been 153 hospitals and 165 health centers under construction in EFY 2008 (2015/2016) as shown in the figure 1-5 [13].

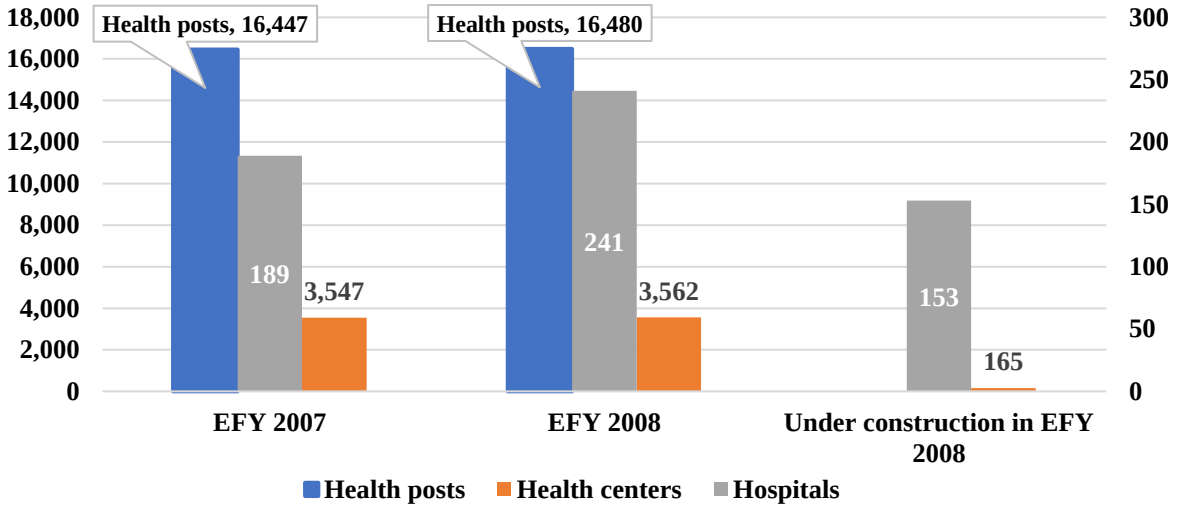

Figure 1-5: Public health facilities available in Ethiopia in 2007 and 2008 EFY [13].

In order to deliver these services, the hospital shall have skilled professionals, curable medicines and safe and effective medical equipment's. The Ethiopian Standard Agency has identified the minimum medical devices required to give the services at each level of healthcare. Table 1-3 gives information about the minimum type of medical devices that are required for comprehensive specialized hospitals excluding the basic sets such as surgical sets [15].

Table 1-3: Sample Minimum medical devices requirement for tertiary hospitals [15].

No.	Service Standard	# Healthcare technology	Some examples of medical equipment
1	Outpatient service	13	Weight scale, stethoscope, otoscope, fundoscopy, reflex hammer, x-ray film viewer etc.
2	Inpatient service	19	Bed with wheels, urinals, resuscitation set, suction machine, fundoscopy thermometer etc.
3	Emergency service	13	Electrocardiography, mobile examination light, suction pump, defibrillator, iv-stand etc
4	Internal medicine	35	Ophthalmoscope, Electrocardiography, infusion pump, laryngoscope, pulse oximetry etc
5	Surgical care service	43	Infusion pump, or light, patient monitor, anesthesia with ventilator, suction machine etc.
6	Orthopedics service	30	More mechanical, anesthesia with ventilator, suction pump, electrocautery, tender hammer
7	Ophthalmology (without set)	22	Slit biomicroscope, glucometer, A-scan ultrasound, autoclave, patient monitor, retinoscopy etc.
8	Dentistry services		Many instruments
9	Dermatology service	18	Cautery machine, magnifying glass, radiation monitoring equipment, examination lamp
10	Gynecology and obstetrics	25	Fetal doppler, incubator, infusion pump, pulse oximeter, baby warmer
11	Medical laboratory service	32	Chemistry analyzer, glucometer, hematology analyzer, microscope, different counter, colorimeter etc.
12	Radiology service	7	CT scan or/and magnetic reso, digital x-ray, ultrasound, mammography, fluoroscopy, angiography etc.

Comprehensive specialized hospital is a tertiary level healthcare service provider that delivers services to cure, diagnosis, treat and prevent diseases and rehabilitate disability. There are fifteen minimum service standards that should be provided by specialized hospitals. A governmental or non-governmental comprehensive specialized hospital shall have at least 300 and 110 beds capacity and two and four sub specialties respectively and an average of 440 professionals should be available [15]. General hospital is a secondary level of healthcare service provider which gives services for prevention, treatment, diagnosis, rehabilitation for patients. The secondary hospital should at least offer eleven service standards. There should be at least 50 beds available to deliver the services. The general hospital staffed with an average of 234 professionals [16].

The primary hospital shall have a minimum of 35 beds and also it shall deliver at least nine service standards and it has an average staff of 53 professionals [17]. Health centers are one of the primary level health facilities which provide preventive, promotive, curative and rehabilitation services and They provide seven service standards. They shall have a minimum of 10 beds and they should have more than 50 types of medical devices [18].

Health posts are primary level of health facilities. They deliver preventive services for diseases such as poliomyelitis, measles etc. and promotive services about sexual transmitted diseases, Tuberculosis, leprosy, malaria etc. and limited curative services and they have to be staffed with at least two extension workers. They shall have a minimum of ten medical devices such as stethoscope, sphygmomanometer, delivery set, adult and child weight etc. [19].

1.5 Statement of the problem

In Ethiopia, improper utilization of healthcare technology has restricted the capacity of healthcare provider to deliver adequate healthcare services. Among the equipment that are found in Ethiopia, it is estimated that more than 40% of the medical equipment are not work properly at any time [20]. The reported reasons for the increase in downtime of the equipment are insufficient availability of staffs, reference materials, tools and test equipment, training, accessories and consumables, maintenance activity and medical equipment management system.

In contemporary situation, the government hospitals in Ethiopia are using excel or access-based inventory system that has certain drawbacks. Some of them are data redundancy, the information may not be periodically updated since updates are performed by a single person, difficult to access

by concerned body, no notification method regarding data manipulation such as adding, editing, and deleting equipment etc.

In this work, we have attempted to assess the current status HTM in government owned teaching hospitals in Addis Ababa and Hawassa cities and proposed and developed a web-based medical equipment management system.

1.6 Research objective

General objective

The general objective of this thesis was to assess the utilization phase of healthcare technology management in government owned teaching hospitals in Addis Ababa and Hawassa cities and to develop medical equipment management system.

Specific objective

- Identify major elements of utilization of healthcare technology management
- Assess the utilization of medical equipment management system in selected government owned teaching hospitals.
- Provide recommendation for proper utilization of medical equipment.
- Propose, design and develop a medical equipment management system.

1.7 Scope and limitation of the study

The scope of this study is to assess the utilization phase of HTM in government owned teaching hospitals that are found in Addis Ababa and Hawassa cities and propose and develop medical equipment management system that can used to add, edit, delete, and related to medical equipment that can be used for a single hospital.

This paper does not assess planning, procurement and decommissioning phase of HTM and propose medical equipment management system which can be used by a single hospital. The assessment is limited to government owned hospitals in Addis Ababa and Hawassa.

1.8 Materials and methods

Data were collected through observing available reference materials, workshops, tools and test equipment, spare parts and consumables, medical equipment management systems etc., Professionals were selected and interviewed about their services. In addition, more than 40 questionnaires which were filled by biomedical engineers and biomedical technicians assessed the utilization phase of healthcare technology in the seven hospitals.

System analysis and design were done through object-oriented analysis tool called unified modeling language. This tool was used to construct both the structural and behavioral models of the system. They used to analyze, design and construct the system.

Web-based medical equipment management system which contains information about medical equipment inventory system, spare part inventory system, training information, preventive maintenance schedules, corrective maintenance requests, supplier information, manufacturer information and system user information was developed.

The web-based medical equipment management system was developed by using HTML5, CSS3, twitter bootstrap framework, JavaScript as front-end programing language and PHP, CodeIgniter framework and MySQL as a backend programming language and to construct a system a package of software called XAMPP and open source text editor NetBeans software development kit was used.

1.9 Relevance of the research

Proper utilization of healthcare technology is important to ensure proper, continuous and safe operation of healthcare technology. In Ethiopia, there are major challenges in proper utilization of medical devices. In this research, resources and activities are identified for proper utilization of medical devices for healthcare facilities and web-based medical equipment management system which contains medical equipment inventory, spare part inventory, training information, preventive maintenance schedule, corrective maintenance request, supplier information and manufacture information was developed.

The developed web-based medical equipment management system helps to add, edit, search, access, and generate report related to medical equipment and get reliable information about the

equipment. This system can export data from the database into Microsoft excel for further evaluation, analysis and reporting. It is also used to identify technology needs and budget required for purchasing, to select suitable brands and reputable suppliers for procurement of medical equipment, to facilitate preventive maintenance schedule and to track corrective maintenance request, identify the skill required and number of staffs for managing medical devices.

1.10 Organization of the thesis

The thesis contains six chapters, Chapter 1 deals about the nationally accepted definition and classification of medical devices and present about the global overview of medical device industry. The major achievement and challenges of Ethiopian health sector are also explained and Ethiopia health service delivery structure are briefly discussed. The general and specific objective of the study, materials and methods used and relevancy of the research are described in this chapter.

Chapter 2 presents a general introduction about healthcare technology management and brief description on the elements on utilization phase of healthcare technology management.

Chapter 3 describes about the methods and materials that have been used in this thesis. Observation on available resources, interviewing of selected professionals and quantitative and qualitative data were collected through questionnaire. HTML5, CSS3, twitter bootstrap framework, JavaScript, PHP, CodeIgniter, MySQL were used to develop the web-based system and unified modeling language (UML) were used to analyze and design the system.

Chapter 4 presents introduction and overview of web-based technology and web-based system analysis and design. Object-oriented analysis tool called unified modeling language (UML) was used to analysis and design of the system and sample user interface diagram was presented.

Chapter 5 describes the results obtained by using the method in chapter 3. Graphical presentations are used to express the result obtained on the assessment of healthcare technology utilization in government-owned teaching hospitals in Addis Ababa and Hawassa cities. Finally, chapter 6 presents the conclusion and proposed recommendations for future work.

Chapter 2 Healthcare Technology Management

2.1 Introduction

Healthcare technology management (HTM) is used to ensure the availability of sufficient medical devices and staffs, the proper and continuous operation and functioning of equipment and it also improves the quality and the safety of health service delivery. HTM is a cyclic process. It is grouped into four phases and nine major activities. The four phases of HTM are planning, procurement, utilization and decommissioning. Planning and assessment, budgeting and financing, technology assessment and selection, procurement and logistics, installation and commissioning, training and skill development, operation and safety, maintenance and repair, and decommissioning and disposal are the nine major activities of the HTM as shown in the figure 2- 1.

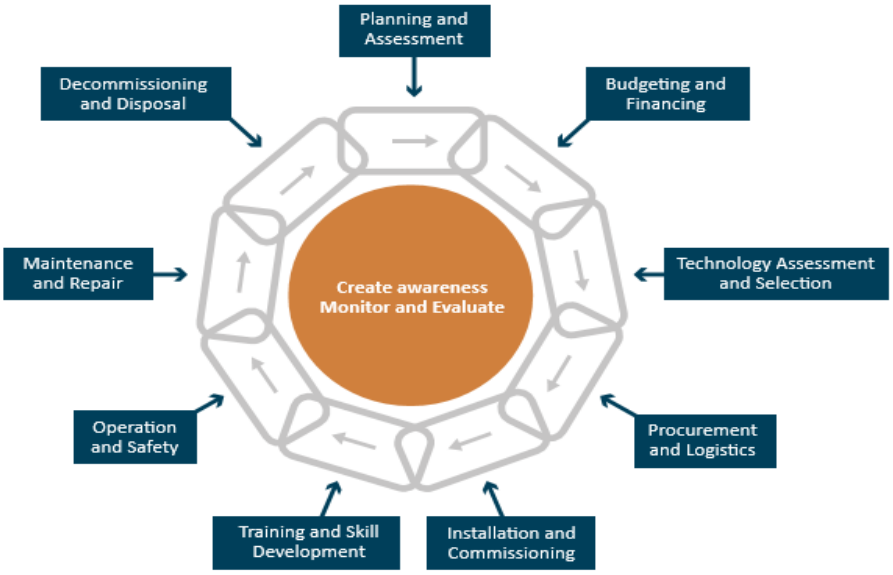

Figure 2-1: Healthcare technology management life-cycle [21]

Planning phase includes the first two major activities which are planning and assessment, and budgeting and financing. The technology assessment and selection, procurement and logistics, installation and commissioning are grouped under the second phase called procurement. Training and skill development, operation and safety, maintenance and repair are included in the utilization

phase where the actual life time starts and the last major activities are called decommissioning and disposal after the end of its life time as shown in the figure 2-2.

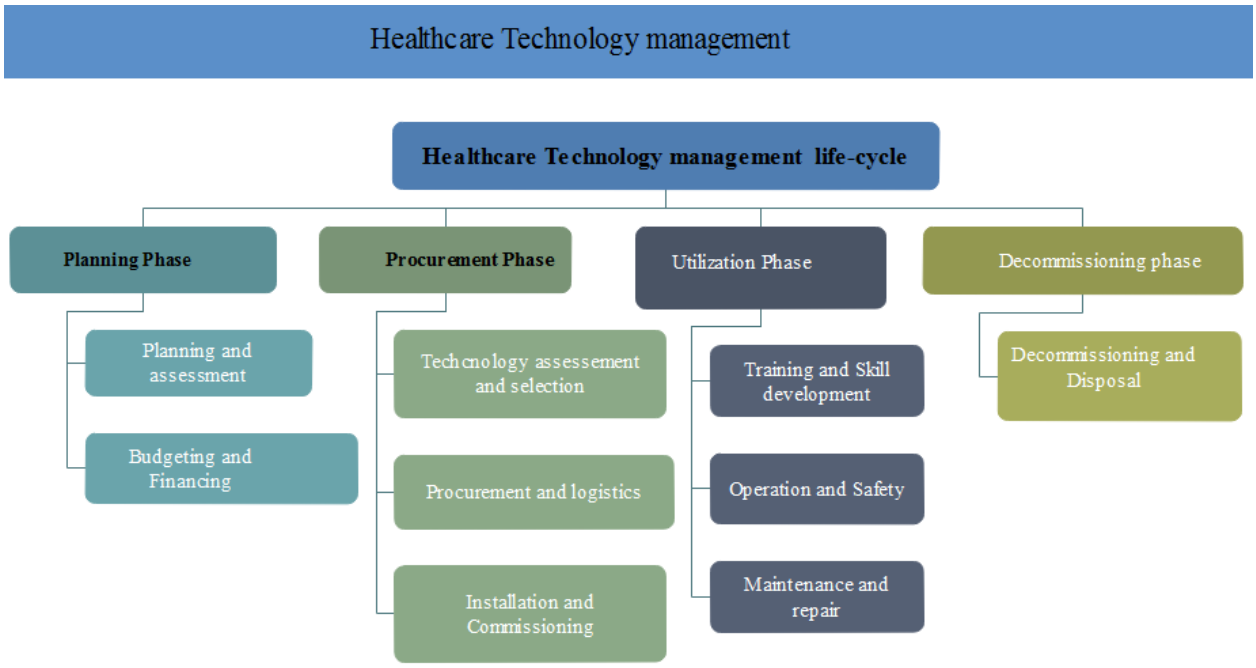

Figure 2-2: Major activities of healthcare technology management under each phase

According to ziken international studies, improper medical equipment planning will increase the extra-costs from 30 percent to 50 percent and it also uplifts the downtime of the sophisticated equipment from 20 percent to 40 percent. Poor specification during procurement process will also result an increase of unplanned costs from 10 percent to 30 percent. In addition, medical equipment lifetime will be reduced from 30 to 80 percent as a consequence of insufficient training and there will be a rise of unfunctional equipment from 25 percent to 35 percent because of poor preventive maintenance activities [21].

2.2 Planning phase

Planning is used to identify the long term (three or five years) and short-term (one or two years) needs and actions. It is used to minimize wastage and make sure scare finance is properly allocated and reduce unnecessary purchases. Planning phase is used to identify the necessary equipment required, the budget allocated to procure it and determine the source of funds and prioritize to purchase the most appropriate medical equipment.

2.2.1 Planning tools

Before planning and budgeting are carried out it is important to know the current equipment situation and the future equipment needs. There are four tools that are used to understand the current equipment situations. These are up-to-date equipment inventory, stock value of the equipment, budget line for equipment expenditure and usage rate of equipment related consumables. There are also five additional tools used to analyze future equipment needs. These are reference materials, clear vision, model equipment list, purchase, donation, replacement and disposal policy and generic equipment specifications.

2.2.2 Budgeting tools

Planning tools are used to determine the equipment that should be replaced or/and purchased. Whereas, the cost allocated for purchasing or replacing the equipment are determined by budgeting tools. Insufficient budget allocation for purchasing and replacing equipment will result absence of required equipment for the service and underutilization of the new equipment purchased.

There are two types of equipment related expenditures. These are capital funds and recurrent funds. Capital fund is used cover large one-time annual expenses. These includes expenditures for replacing existing equipment, buying additional equipment, pre-installation work, support activities such as installation, commissioning, and training and large rehabilitation projects. Whereas, recurrent funds used to cover small regular weekly or monthly expenses that used to run and keep the equipment properly. These usually includes expenditure for buying consumables, spare parts and technical supports for equipment maintenance, repair, and minor works, administrative expenses and ongoing skill training expenses.

In order to run the equipment properly there must be a link between the budget line for planned capital expenditure and recurrent budget for maintenance, consumable items and training. The failure to balance the capital budget and the recurrent budget will result longer downtime of the equipment for several months. Figure 2-3 gives information about the life-cycle costs for running the equipment until the end of its lifetime.

As it is known, the tip of the iceberg which easily seen accounts for 10 to 20 percent of the total and the other 80 – 90 percent of the iceberg is often hidden and dangerous. Unfortunately, the tip of the ice is attached with the bulk of the iceberg underneath the water. The tip of the iceberg

represents the capital fund that used to purchase or replace equipment and what is often hidden represent the small recurrent costs that used to run the equipment throughout its lifetime. Ignoring the huge portion of the recurrent budget will deteriorate the service that health facilities provide.

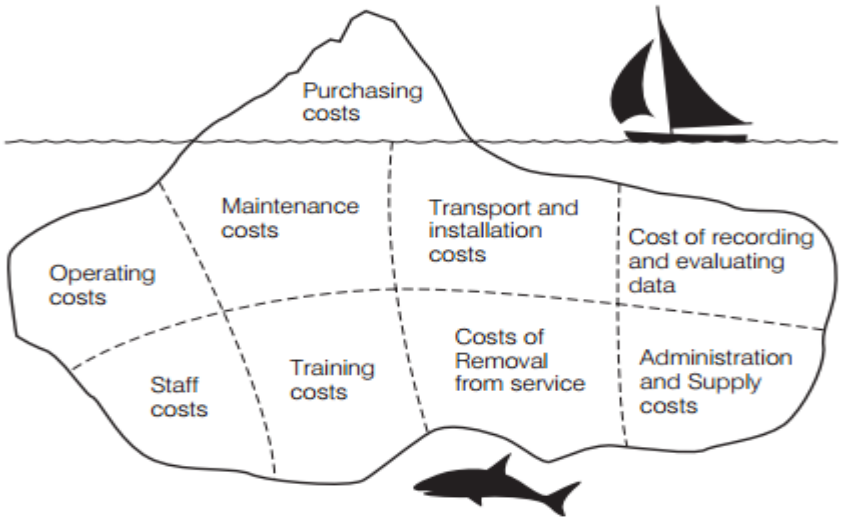

Figure 2-3: The iceberg syndrome of life-cycle costs for medical devices [23]

2.2.3 Financial tools

Once the total expenditure is identified by using the budgeting tools, financial tool is used to determine the total available incomes that comes from different sources and the health facility can get funds from internal, national and international sources.

2.2.4 VED (Vital, Essential and Desirable) prioritization

During financial limitation for purchasing medical equipment, the health facilities use system of prioritization in order to select the most important devices for delivering the intended services. Medical equipment prioritization is decided based on equipment availability to provide health services but not the costs or the technology advancement to provide the basic healthcare's. Based on this factor, equipment is classified as vital, essential and desirable or not so essential.

Vital items are very important items to deliver the basic health services and they should be available and functional at any times such as electrical generator, operational theater light, suction pump in the theater etc. Essential items are necessary but not absolutely relevant for delivering

basic health services and their out of service could be tolerated such as physiotherapy ultrasound, suction pump in the ward etc. Desirable devices are not very essential for giving basic healthcare and it is possible to provide the service without them.

2.3 Procurement phase

After planning is completed, the procurement phase is time consuming and with expensive activities will have to be carried out for purchasing medical devices that are suitable to the health facilities. Procurement process starts by preparing the procurement document and ends by accepting the equipment and after acceptance process is completed and the equipment will start its lifetime.

According to Ethiopian public procurement and administrative agency (PPA), the procurement process for national competitive biddings will take from four months to ten months and for international competitive biddings, it will last from five months to one and half year [22]. Before the procurement process undertaking, it is better to decide the best procurement model, purchasing method and the types of reputable supplier for ordering the purchase.

There are many activities that are conducted for the procurement of medical equipment and every activity are controlled and monitored by using Gantt chart. It is used to represent all activities over agreed time period. It shows different activities that can be performed at the same time, some activities that are carried out in sequence. It used to monitor progresses of the orders, keep up to date and informed about the progress. If there are delayed activities, certain corrective actions will undertake to get back to the schedule and this correction action should be informed to the relevant parties. The Gantt chart in figure 2-4 shows sequence of activities, duration and the percentage completed of sample procurement processes.

ID	Sample procurement task	Start	Finish	Duration	Complete
1	Preparation of bid document	1-May-17	9-May-17	1.0 w.	100%
2	Prior review	10-May-17	18-May-17	1.0 w.	100%
3	Advert/ Tender invitation	19-May-17	7-Jun-17	2.0 w.	100%
4	Tender Close	7-Jun-17	7-Jun-17	0.0 w.	100%
5	Tender evaluation/award	7-Jun-17	15-Jun-17	1.0 w.	100%
6	Contract Signiture	15-Jun-17	23-Jun-17	1.0 w.	100%
7	Letter of credit	23-Jun-17	3-Jul-17	1.0 w.	100%
8	Delivery	3-Jul-17	29-Aug-17	6.0 w.	40%
9	Site Preparation	14-Jul-17	22-Aug-17	4.0 w.	60%
10	Recite of Equipment	30-Aug-17	30-Aug-17	0.0 w.	0%
11	Inspection/Verification	30-Aug-17	7-Sep-17	1.0 w.	0%
12	Preparing training material	25-Jul-17	22-Aug-17	3.0 w.	30%
13	Installation	7-Sep-17	15-Sep-17	1.0 w.	0%
14	Commissioning	15-Sep-17	25-Sep-17	1.0 w.	0%
15	Initial Training	26-Sep-17	4-Oct-17	1.0 w.	0%
16	Acceptance	4-Oct-17	12-Oct-17	1.0 w.	0%
17	Handover	13-Oct-17	13-Oct-17	0.0 w.	0%
18	Payment	13-Oct-17	10-Nov-17	3.0 w.	0%

Figure 2-4: Sample Gantt chart for monitoring the procurement activities.

2.4 Utilization phase

Once medical device accepted, it triggers to the start of its life time. Medical devices are important for delivering healthcare services and they have to be effectively utilized in order to get the maximum benefit from them. Proper medical devices utilization is important for ensuring the safety of the users and patients, reduce the downtime, increase the benefit for financial investment and to keep them in the good working conditions.

For ensuring continuous operation of medical devices, there are some activities that should be carried out by health facility staffs. These are making accountable staffs, ensuring availability of sufficient accessories and consumables, providing access of reference materials, understanding correct operation and application of medical devices, addressing equipment safety issues, and preparing ongoing training, conducting maintenance activities.

2.4.1 Accountability

Equipment users have a feeling of ownership for the equipment that they use. They have to be responsible for the proper functioning of the equipment as well as proper usage of consumables and accessories and they have to know and write down good practices and procedures when handling with equipment. Health facility human resource have to put such responsibility into their job description. Proper equipment handling should be considered as a part of their promotion and there have to be a mechanism to charge for a damage or breakdown due to series negligence.

2.4.2 Availability of sufficient accessories, consumables and supplies

Equipment accessories are items that used to connect the machine and the patient (such as breathing circuit, ECG leads, probes, transducers) and that assist the use of medical devices (such as foot switches, computer mouse etc.) however, consumables are items that used up daily during the operation of the equipment such as x-ray films, disposable electrodes, laboratory reagents, ultrasound gels etc. supplies consists of cleaning and lubricating agents that are used for care and cleaning of medical equipment.

Medical devices can operate effectively when there are sufficient accessories and consumables. Even though, the equipment is in perfect conditions, it is only working if there is a sufficient

number of accessories and consumables. The availability of accessories indicates that proper utilization of medical equipment

2.4.3 Reference materials

Healthcare technology management related literatures are useful to increase information and knowledge regarding on continuous operation of medical equipment and its management. They are important for preparing equipment related trainings, conduct medical devices operation and maintenances, monitoring performance and safety procedures. Establishing medical equipment proper procedures etc. medical equipment references cover a broad range of documents. Some of them are operators and service manuals, manufacturer operational and safety guidelines, model equipment lists, equipment specification, technology assessment literatures, national and international medical devices regulation guidelines, international available advices on medical device issues, text books on various subjects such as planning and budgeting etc. and it is advisable for health facilities to have such types of medical equipment literatures.

2.4.4 Equipment maintenance program

Medical equipment maintenance is necessary for keeping the equipment safety, increase availability for use, prolong the useful time of the equipment, preventing breakdown, enhancing reliability and accuracy, and reduce the ownership costs. Medical equipment maintenance can be classified into two categories. These are inspection and preventive maintenance and corrective maintenance. The inspection and preventive maintenance are further classified into inspection maintenance and planned preventive maintenance and inspection maintenance also grouped into performance inspection and safety inspection maintenance as shown in the figure 2-5.

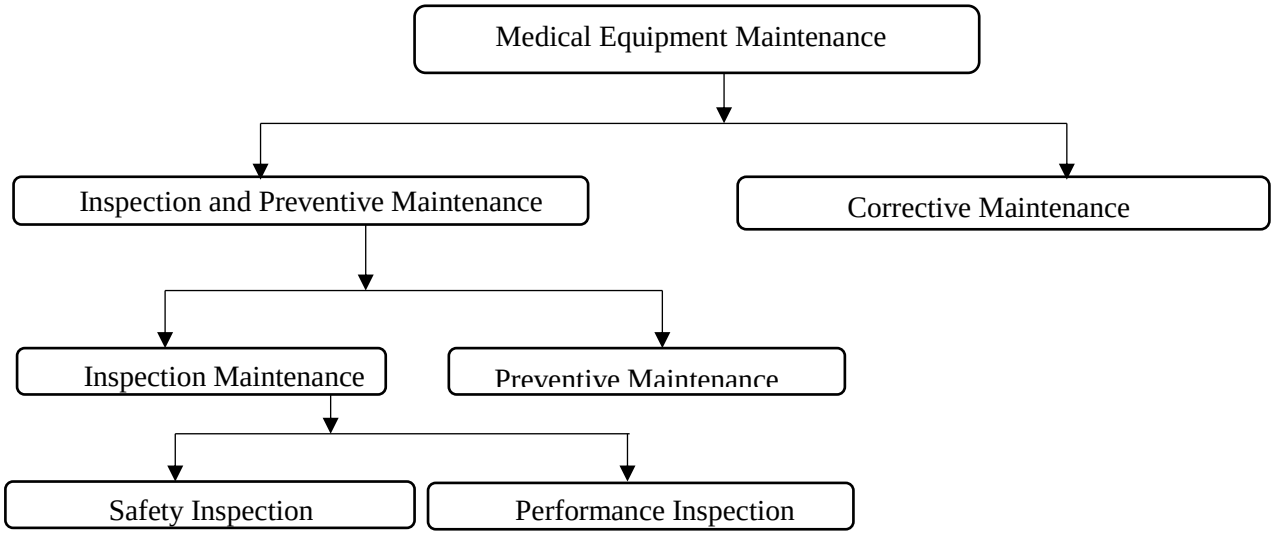

Figure 2.5: Medical equipment maintenance classification

For example, a good quality anesthesia machine has an average life of 15 years if appropriately maintained [23]. Without maintenance, it will be outdated after 5 years according to the study done by German Technical Cooperation Agency (GTZ) as shown in table 2-1. Due to improper planned preventive maintenance, we will lose 10 years of the potential life of the equipment. This will cost 3 new anesthesia machines in order to run the service effectively for 15 years [23]. So, introducing an HTM will benefit you economically and clinically by ensuring the healthcare technology continues to meet the standards required throughout its working lifetime.

Table 2-1: Sample German government technical aid agency (GTZ) findings [23].

Equipment type	Lifetime in years			
	Poor quality makes		Good quality makes	
	Poorly maintained	Well maintained	Poorly maintained	Well maintained
Air-conditioner (window type)	3	5 – 7	5 – 6	10 - 12
Anesthetic machine (Boyles)	2 – 5	5 – 10	5 – 10	10 - 15
Centrifuge	3 – 6	7 – 8	6 – 9	10 - 12
Microscope	3 - 6	5 - 10	6 – 10	10 - 20
Refrigerator (electrical)	3 - 5	5 – 8	5 - 8	10 - 15
Sphygmomanometer (mercury)	1 - 2	3 - 5	3 – 5	8 - 10
Sterilizer, bench-top	3 - 5	5 - 8	6 - 10	10 -14

Planned preventive maintenances are a serious of activities that are important to increase the equipment lifetime, minimize the downtime and solve the hidden problems whereas corrective maintenance is used to return failed equipment back into services. Performance inspection maintenance is used to ensure correct operation of the equipment whereas safety inspection maintenance is used to check whether the equipment is safe for users and patients.

For delivering proper maintenance program, it requires knowledgeable and experienced staffs, sufficient finances to cover equipment maintenance expenditure, physical resources such as workshops, tools and test equipment, supplies, replacement parts and operational and service manuals used to undertake maintenances.

2.4.4.1 Sufficient knowledgeable and experienced staff

The maintenance workload is used to determine the number of staffs required to conduct maintenance activities. It is determined by multiplying the number of devices that required preventive maintenance by estimated time. The maintenance workload also includes the time take for creating inspection preventive maintenance forms, the time required for getting the work ready, the time taken to arrive the site where the maintenance is undertaken and completing the paper work after completing the work done.

2.4.4.2 workshop

According to Ethiopian hospital reform implementation guideline (EHRIC), it is suggested to have an area of $90m^2$ workshop for hospitals that have 100 beds. It is also equipped with sufficient tools, test equipment, good utilities and lightings. It also has workbenches and stores that used to keep necessary equipment and manuals [20].

2.4.4.3 Tools and test equipment

Having appropriate tools and test equipment will determine the productivity of clinical engineers and biomedical technologists in the health facilities. They are used to perform corrective maintenance and inspection preventive maintenances. They are also used to increase calibration accuracy, reliability of readings, and monitoring the safety of the equipment. For large health facilities that are having more complex equipment, it is necessary to have advanced tools and test equipment which are used for calibration, maintenance and repair a broad range of medical

equipment [20,24]. Table 2-2 shows lists of different test equipment that are used to monitor different equipment.

Table 2-2: Lists of test equipment per medical device categories [24].

Medical device category	Test equipment required
Electrosurgical units	Radio frequency electrosurgical analyzer
Defibrillators	Defibrillator analyzer
All electrical equipment	Electrical safety analyzer
Anesthesia machine, ventilator	Ventilation analyzer, test lung, gas flow meter
Physiological monitors	Physiological simulator
ICU monitor, ECG machine	Arrhythmia simulator
Surgical and ophthalmic lasers	Laser power meter, laser thermal imaging plate
Radiographic and fluoroscopic equipment	Ionization chamber, radiation analyzer/kVp meter
Medical gas systems, suction regulators, hemodialysis machines	Pressure meter
Incubators, infant warmer, laboratory oven	Temperature probe/ thermometers
Dialysis machine	pH/ conductivity meter
Radiographic, mammography, ultrasound, CT, MRI	Phantoms
Most electronics equipment	Multimeter/oscilloscope/ function generator

2.4.5 Safety inspection

Medical equipment safety can be viewed as a relative term. Every different type of medical devices has a certain degree of risks. In 2012, there were 51,944 medical device incident reports in England. From these reports, there were 313 deaths and 4,577 sever injuries related to medical devices. Among these incidents, failure of the devices and user error represents 40% (20,574 incidents) and 15% (7,610 incidents) of total causes of the incidents [25]. These incidents are supposed to be increased in developing countries like Ethiopia.

Inadequate cleaning of flexible endoscopy, missed alarms, failure to effectively monitoring to postoperative patients, inadequate surveillance of monitored patients in telemetry setting and insufficient training of clinician on operating room technology were the top 5 technology hazards in the world in 2016 [26].

To minimize the risks associated with the medical devices, the health facilities should consider the national and international policies and standards which are used to ensure the safety, compatibility and functionality of medical devices. Standards are an essential element in development, comparison and assessment of medical devices. Ethiopia has accepted international standards which are published by International electrotechnical committee (IEC) and International standard organization (ISO) regarding on medical equipment safety procedures as shown in figure 2-6 [27,28].

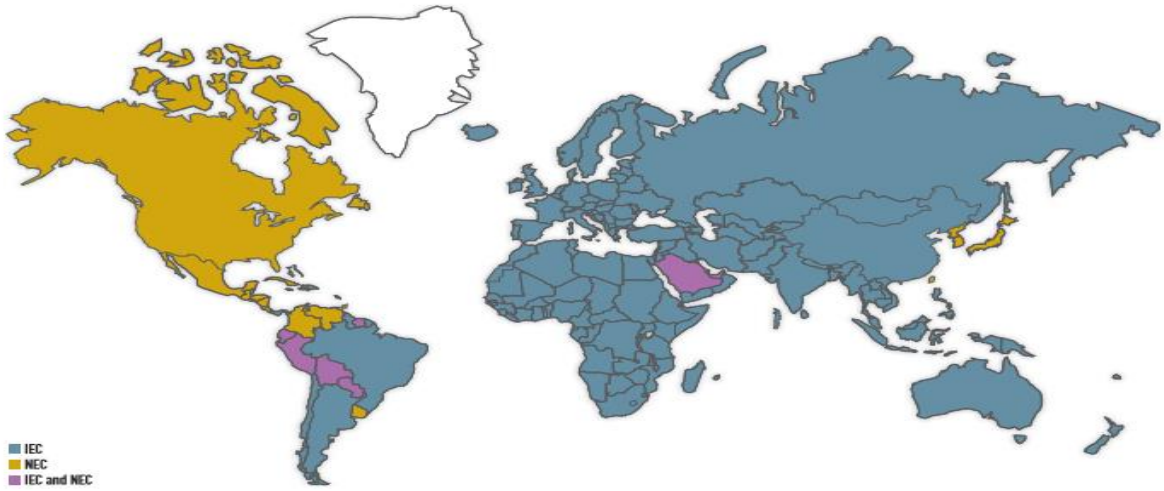

Figure 2-6: Global map for international electrical standards and regulations [30].

The IEC 60601 series standards are the most common standards for electrical medical equipment which are prepared by IEC for the vast range of electrical and electronics equipment. The IEC 60601 series is sub-divided into two categories. These are IEC 60601-1 and IEC 60601-2. The former represents the general standards for medical electrical equipment and the later is used to denote the specific categories of medical equipment. These two series standards have the collateral standards to express more selective categories of the standards as shown in table 2-3. There are different categories of medical equipment related safety issues that can cause hazard for the patients or the users. These are Electrical safety, Radiation safety, Gas safety etc.

2.4.5.1 Electrical Safety tests

Sixty percent of the medical equipment that are found in health facilities are Electrical Medical equipment [31]. Electrical medical equipment is electrical equipment that have applied parts which are used for transferring or detecting energy from or to the patients and having only one connection

for a single main supply and are used to monitor, diagnosis and treat patients or alleviate diseases, injuries or disabilities.

Table 2-3: Sample lists of standard of International Electrotechnical committee [30].

General Standards	
Standard number	Standard for safety and essential performance
IEC 60601-1-1	Basic safety and essential performance of medical electrical equipment
IEC 60601-1-3	Radiation protection in Diagnosis X-ray equipment
IEC 60601-1-6	Usability (Documentation review)
IEC 60601-1-54	X-ray equipment for radiography and radioscopy
Particular Standards	
IEC 60601-2-18	Endoscopic equipment
IEC 60601-2-19	Infant incubator
IEC 60601-2-52	Medical bed
IEC 60601-2-13	Anesthesia system
IEC 60601-2-16	Hemodialysis Equipment
IEC 60601-2-25	Electrocardiographs
IEC 60601-2-33	Magnetic resonance equipment
IEC 60601-2-44	x-ray equipment for computed tomography
IEC 60601-2-45	Mammographic x-ray equipment
IEC 60601-2-49	Multifunctioning patient monitoring equipment

Electric current is the source of major injuries and deaths. A small amount of electric current which are more than 50 mA can cause major burns, muscular contraction, irregular heartbeat, cessation of normal breathing as shown in the table 2-4 [30].

Table 2-4: The effect of electric current on human body [30]

Current	Reaction
0.9 – 1.2 mA	Perceptible
15.0 – 20.0 mA	Painful shock and inability to go
50.0 – 100.0 mA	Ventricular fibrillation, respiratory arrest, leading directly to death
100.0 – 200.0 mA	Series burns and muscular contraction, cardiac arrest

There should be a regular inspection and testing of medical equipment in order to minimize the risks of electrical current. Different types of tests should be carried out to ensure the safety of the medical devices, the users and the patients. These are Earth bond test and leakage current tests. The leakage current test includes earth leakage test, enclosure or touch leakage test, patient leakage current test, patient Auxiliary leakage tests.

2.4.5.2 Radiation Hazard

Ionization radiation is a form of energy which are released by atoms in the form of electromagnetic waves such as x-rays or Gamma rays or particles such as neutrons, alpha and beta particles. Ionization radiation significantly improved the diagnosis and treatment procedures of the health facilities. There are more than 3,600 million x-ray examinations, 37 million nuclear medicine diagnoses, and 7.5 million treatments around the world each year [31]. However improper utilization of medical radiation devices could result a series of injuries such as skin redness, hair loss, radiation burn, acute radiation syndrome and in long term it may result cancer. As a result, it requires a stringent regulations and standards for controlling and minimizing the health risks and increases the benefit of radiations.

The potential damage of the ionization radiation depends on the absorbed/received dose, type of radiation, and sensitivity of the tissues. The amount of radiation which are received by the tissue and/or organs is referred to as absorbed dose and it is measured in gray (Gy). The potential harm resulted from the ionization radiation is expressed as effective dose and it is measured in Sievert (Sv) and in addition effective dose, the rate at which the dose is supplied called dose rate measured in microsievert/hour (μSv/hour) or millsivert per year (mSv/year) determine the risk level.

The Ethiopian radiation protection authority (ERPA) has set minimum standards regarding on size of the lead apron, area of the room, performance parameters, documentation requirement, safety requirement, dosimeter limits for conventional diagnostic radiology, dental radiology, mammography and CT-scan. For example, the maximum dose rate outside the control cubicle where occupied by public as 1μSv/hr and 1mSv/year and inside the control cubicle where the radiation staff work at as 7μSv/hr and 12mSv/year and the maximum and minimum workload for these devices also 120 patients per week and 40 patients per week respectively. The authority also accepted and adopted the standard of IEC and ISO [27].

2.4.5.3 Medical gases

In health facilities, there are different type of medical gases that are used to administrate patients. These includes oxygen, carbon dioxide, nitrous oxide, liquid nitrogen, propane etc. the improper handling and storage of these medical gases would result burning, poisoning, fires, blasts, injuries etc. The health facilities should have a standard to inspect and control the risks associated with such gases and fuels.

2.4.6 Performance tests

Performance inspection is used to check the proper operation and function of the equipment and the proper medical equipment operation and function is as important as the function it delivers. medical equipment has the probability to fail any times and also any failure or wrong reading might result for serious consequences for patients and users. Therefore, it is important to conduct performance test.

Even though, performance inspection is an important part of preventive maintenance, there is no benchmark or standards for most of the performance tests and health facility maintenance team should prepare performance schedules based on the international standards and manufacturer service and operational manuals of the equipment. In order to carry out performance test, it is necessary to have skilled technician or engineers as well as appropriate performance test equipment and the performance inspection should be performed before initial use, after corrective maintenance and based on the manufacturer recommendations.

For example, in order to ensure the proper operation and function of the ECG machines, it is better to conduct the following types of ECG performance tests. Some of them are linearity of the heart rate measurement, QRS beep, Alarms (High and low), Arrhythmic recognition, gain test, sensitivity test, frequency responses etc. [32].

2.4.6 Training

In order to cope up with wide range of new makes and models of medical equipment coming to market every year users and maintainers should update and upgrade their knowledge and skills regarding on medical equipment. Training also used to ensure the continuous operation of the equipment. More than 65 percent of medical devices problems are a result of user operation problems and easy to solve problems such as blown fuses or bulbs or loosen power cable which can be solved by properly train equipment users and only 35 percent of the equipment problems needs specially trained technicians [23].

There are three types of training for users and maintainers. Those are induction training, initial training (training at commissioning) and refresher training. Induction training is prepared for those who new for the post and transfer to other departments and initial training or training at commissioning is prepared when the new equipment is arrived to the site and as a part of procurement process or can be prepared by in-house senior technicians or engineers and whereas, refresher trainings are conducted to renew or update the skills and knowledges of the users or maintainers.

Training for maintainers and users could cover the following topics. These are good practice of equipment handling, operation of medical devices, application of healthcare technology, care and cleaning, safety procedures, planned preventive maintenance for users and maintainers, corrective maintenance for biomedical technicians, medical equipment management for user and maintenance staffs.

2.5 Decommissioning phase

When a piece of medical equipment reaches the end of its life time, decommissioning, disposal and replacement process should be carried out. Condemnation process of medical equipment that are not safe or taken out of service or use is referred to as Decommissioning. Medical equipment

life time depends on the type of equipment and the technology where it has been made. For example, blood cell counter may have five years life time, autoclave might have 10 years and patient bed might have 15 years. After the end of equipment lifetime, any intervention such as maintenance could not be cost effective and it is better to replace it in order to keep the intended function which are delivered by this equipment.

The lifetime of medical equipment depends upon different factors. Some of them are utilization rate of the equipment (how many patients are treated or diagnosed per day or month), number of available backup unit, proper operation and care of the equipment, available planned preventive maintenance schedule, initial quality of the equipment, and environmental condition of the health facilities.

There are different reasons for replacing medical equipment. These are being damaged/old beyond repair, unreliable or safe for patients or users, clinically or technically being obsolete, unavailability of spare parts, being not economical to repair, over utilization of certain equipment, and higher clinical and operational needs of certain equipment.

There are four steps in decommissioning, disposal and replacement processes. These are condemnation of the equipment, safe and prompt disposal of condemned equipment, remove it from medical inventory and triggering of medical equipment replacement process. The biomedical technicians and clinical engineers have the responsibility to identify the equipment that need decommissioning and they have to prepare the technical report that explain about the reasons for condemnation. The owner of the property (governmental or private health facilities) will visit and decide the official decommissioning process. After decommissioning, the HTM committee identified usable, hazardous and unusable parts and components of the condemned equipment. The parts or components that can be reused such as metal parts could store in the facility stores or auctioned it to bring income for the health facilities. The hazardous parts or components such as radioactive sources, mercury etc. must be disposed according to waste management and hygiene guidelines and unused parts and components will put outside the facilities designed for such purposes.

Chapter 3 Materials and Methods

3.1 Research method

The data collection was carried out between August 26, 2017 to September 20,2017 in all the seven government owned teaching hospitals which are found in Addis Ababa and Hawassa town. The selection criteria for these health facilities were a number of populations that provides service, service standards and beds.

The study was aimed to assess the utilization phase of healthcare technology management and biomedical engineers and biomedical technicians are responsible for these activities. Due to these reason, purposive sampling technique was used to represent limited biomedical staffs in these facilities and the sample size included all biomedical staffs in these facilities.

The seven government owned teaching hospitals were Tikur Anbessa Comprehensive Specialized Hospital (TACSH), St. Paul Hospital and Millennium Medical College (SPHMMC), St. Peter TB Specialized Hospital (SPTSH), St. Amanuel Mental Specialized Hospital (SAMSH), Yekatit 12 Hospital and Medical College (YHMC), Menelik II Referral Hospital (MRH) and Hawassa University Comprehensive specialized hospital (HUCSH). The first six hospitals are found in Addis Ababa and the last hospital is found in Hawassa town.

Data were collected by observation of available reference materials, workshops, tools and test equipment, spare parts and consumables, medical equipment management systems etc., interviewing selected professionals about their services and also through more than 40 questions of questionnaire which were filled by biomedical engineers and biomedical technicians which assess the utilization phase of healthcare technology in the seven hospitals as shown in annex A. The result of the data was summarized by using tables, pie charts and bar charts.

Web-based medical equipment management system was developed which contains information about medical equipment inventory system, spare part inventory system, training information, preventive maintenance schedules, corrective maintenance requests, supplier information, manufacturer information and system user information and by using user-friendly graphical interfaces, system user can add, edit, search, access, analyze and generate a report related to medical equipment and they also export the data from database into Microsoft excel for further

evaluation and presentation and it also help managers to monitor activities associated with healthcare technology management.

The web-based medical equipment management system was developed by using HTML5, CSS3, twitter bootstrap framework, JavaScript as front-end programing language and PHP, Codeigniter framework and MySQL as a backend programming language and to construct a system a package of software called Xampp and open source text editor NetBeans software development kit was used.

System analysis and design were done through object-oriented analysis tool called unified modeling language. This tool was used to construct both the structural and behavioral models of the system. They used to analyze, design and construct the system.

3.2 Tools used for system development

3.2.1 Front-end programming language

3.2.1.1 HTML5

HTML stands for Hypertext Markup Language and it is used to describe web contents such as headings, paragraphs, lists etc. The first version of HTML which is HTML 1.0 was released in 1993 and it was also enhanced into different versions. The latest version of HTML is called HTML5 and it was developed and released by non-profitable organization called world wide web consortium (W3C) in 2011 [33].

HTML5 included many features from the previous version of HTML and it also adds some simple additional contents such as articles, figures, sections etc. and some advanced features such as audio and video playbacks [34]. HTML5 is open and doesn't require specialized software to implement it and it is also supported by different major browsers such as chrome, internet explorer, Firefox, opera, and safari etc.

3.2.1.2 CSS3

CSS stands for cascading style sheet and it is designed to separate the presentation part with its html content and it is used to stylish the html web pages by changing typefaces, sizes, colors,

indentations etc. The first version of cascading style sheet was developed in 1996 and the latest version of cascading style sheet is called CSS3 and developed and released by world wide web consortium (W3C) in 2011 and it has more features than the previous versions such as text effect, round corners, multiple column layout, animations etc. [34].

3.2.1.3 JavaScript

JavaScript is the most popular client-side scripting language that is used to made dynamic and interactive web pages and it was created by Netscape communication corporation in 1995 and it is interpreted by the browsers [35]. JavaScript is supported by most popular browsers and it is used to make pop-up images, texts and figures dynamically and it also used to create drag able images or figures. It also has similar syntax with C programming languages and it is easy and fast scripting language. It is embedded with the opening <script> and the closing </script > html tags. The most common framework JavaScript framework that we used in this paper are jQuery.

3.2.2 Backend programming language

When building web-based applications, it is necessary to consider the following issues. These are hardware for web server, operating system, webserver software, database management system, programing language etc. This is because all not all operating system is working on all hardware, or not all web servers support all programming languages and so on. However, for PHP and MYSQL, hardware, operating systems, web server is not the point of consider since they run on major operating systems and web servers [36].

3.2.2.1 PHP

PHP stands for PHP hypertext preprocessor and created specifically for web application. It was developed by a Danish-Canadian programmer called Rasmus Leordof in 1994. It is the most popular back end language for social sites, governmental and educational websites.

Nowadays, more than 500 million websites are using PHP globally and nearly 30 percent of websites worldwide were made up of PHP followed by ASP.Net and java accounted for 16.6 percent and 8.8 percent respectively as shown in the figure 3-2 [37,38]. Facebook.com, wikipida.org, Washingtonpost.com, Stanford.edu are the most common social sites, governmental and educational websites which used PHP as their server-side languages [39].

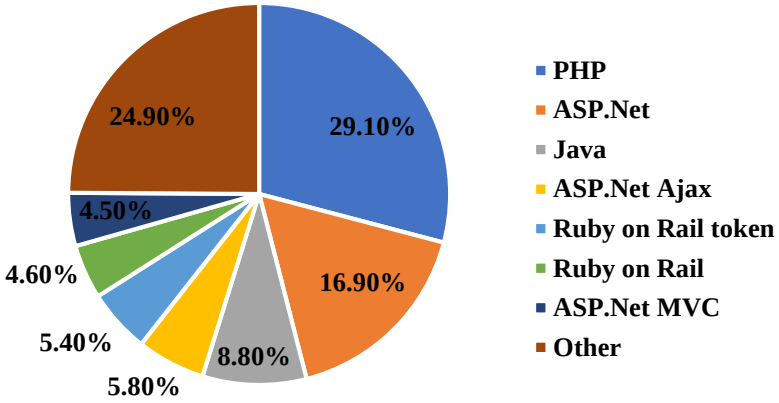

Figure 3-1: Backend programing language for web application [38].

PHP supports different platforms and tools using interfaces and application programing interface (API). PHP supports different database management system connectivity, extended markup language (XML), mail protocols, image functions, network management protocols, object-oriented programming features, frameworks such as model view controller etc.

PHP supports different database management systems such as Adbase, dBase, Empress, Filepro, Informix, interbase, mSQL, MYSQL, Oracle, PostgreSQLQL, Solid, Sybase, velocis etc. and it also support mail protocol such as interactive mail protocol (IMPA) and small mail transfer protocol (SMTP) which are used to send and receive messages.

PHP is also robust, fast, free, available for many operating system, full featured with very important build-in libraries and easy to learn programing language. PHP is used to send and receive millions of messages per day. It is easy to download the latest version from their official web site for free and it is available for different operating systems such as Linux and FreeBSD, different versions of Microsoft windows, commercial Unix, OS X etc. and PHP is a light weight programming language which is similar with other programming language such as C, C++, Java and perl. PHP has also several build-in libraries for performing many useful web-based

applications. Some of these libraries are image retrieval, network service connectivity, XML parsing, email, pdf generating, session management libraries etc.

3.2.2.3 CodeIgniter Framework

CodeIgniter is a PHP-based framework which have good documentations and user guides and it is used to minimize the amount of code by letting you to concentrate on the projects and it uses the model-view-controller approach that separates the presentation unit with the logical unit and it uses to create clean, search-engine friendly uniform resource locator (URL).

CodeIgniter has a wide range of libraries that used to perform most commonly tasks of web applications. Some of the wide range of CodeIgniter framework features are model-view-controller based system, fully featured database classes which are compatible with several platforms, form and data validation libraries, security and cross site scripting (XSS) filtering, session management, image manipulation libraries, file transfer protocol (FTP) classes and many more [40].

Model-view-controller development pattern is a software approach used for separation of the logical unit with the presentations and the model represents the functions that are used for retrieving, inserting, updating and deleting information in the databases whereas, the view represents the information that are being displayed for the users and also referred as web pages and the controller act as intermediate the model and the view and used to process the HTTP request and generate the web pages.

3.2.2.2 MySQL Database Management System

MySQL is a multiuser, multithreaded database servers that uses structural query language (SQL) which is the standard database languages. It is the world most popular open source database management system which is produced and marketed by the computer software company called Oracle Corporation. Its fast performance, low cost and easy to use feature make it the leading database choice for web-based applications of highly profile social media sites such as Facebook, Twitter, YouTube, Yahoo etc. [41].

MySQL is supports a large number of operating systems and it can be accessed by using different types of programing languages such as PHP, Perl, C, C++, Java etc. it is used for small and large

databases and it can support more than 50 million rows in a table and the default size of a table is 4GB and this can be increased to 8 million terabytes (TB) if the operating system can handle these capacity [42].

MySQL is available in dual licenses. These are community edition and commercial edition. The community edition is available with no cost and it is open source whereas, the commercial edition is available at low cost for redistributing it as a part of your application. There are three types of commercial edition and these are MySQL Standard Edition, MySQL Enterprise Edition and MySQL Cluster Carrier Graded Edition (MySQL Cluster CGE) [43]. It is much cheaper than other types of database management system. When it is compare with Microsoft SQL server, Microsoft SQL Server Enterprise Edition is 12 times more expensive than that of MySQL Enterprise Edition at have three-year term for product matric and update without no cost as shown in the figure 3- 3 [44].

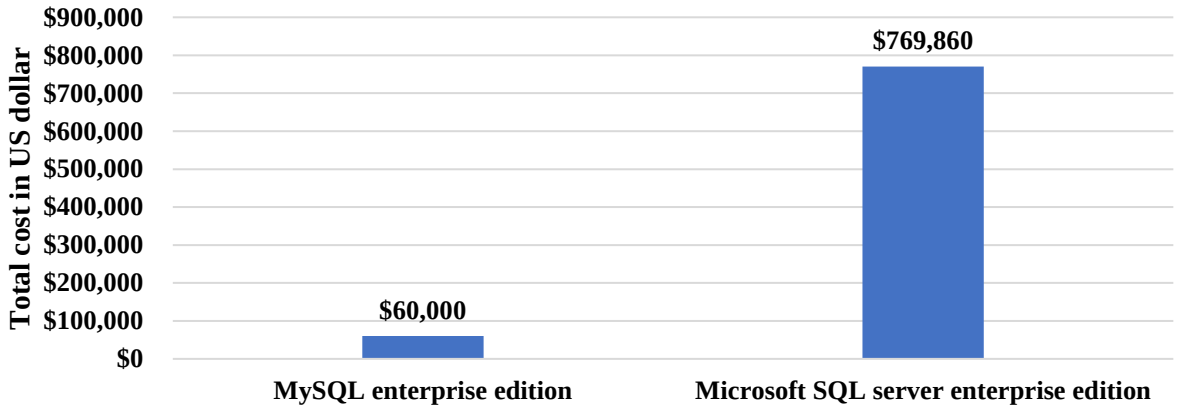

Figure 3-2: Costs of MySQL enterprise edition Vs Microsoft SQL Server enterprise edition [44].

3.3 Tools for system development

3.3.1 XAMPP

XAMPP is a package of software that contains most common web development technologies. It provides web servers, database management software, programming languages etc. Due to its small size, portability and content. It is used for development and testing of web-based applications. XAMPP is available in two specific packages and these are lite package and the full package. The full package provides the necessary technologies for web development and it contains Apache web server, MySQL which is open source database systems, PHP that is a server-side programing language, phpMyAdmin which is used for administrating MySQL and Openssl

which is secure socket layer support whereas, the full package contains a wide range tool [45]. XAMPP also support both Microsoft and Linux Operating systems.

3.4 Tools for system analysis and design

3.4.1 Unified modeling language (UML)

Unified modeling language is a graphical modeling language that are used to visualize, describe, specify software and non- software systems. It is used for communicate between users, architect, developers, system testers etc. it is important for analysts and end users for specifying and analyzing the system, designer used it to design the system requirement, and for developer to change the design into executable codes.

This modeling language was created by Grady Booch, Ivar Jacobson and James Rumbaugh. They were developed their own modeling language before they created unified modeling language. Grady Booch developed the Booch model, Ivar Jacobson developed object-oriented software engineering (OOSE) and James Rumbaugh developed Object \modeling language but these models have their own strength and weakness and they combined the strength of each model and finally developed the UML [46].

3.4.1.1 UML diagram

UML diagram is used to understand the system clearly and these diagrams describes different aspects of the system. UML diagram are classified into two groups. These are structural diagram and behavioral diagram. The structural diagram represents the static part of the system while the behavioral diagram is used to represent the interaction or the dynamic part of the system. There are four types of structural diagram, these are class diagram, object diagram, component diagram and deployment diagram and the behavioral diagrams are grouped into five categories these are use case diagram, sequence diagram, collaboration diagram, state chart diagram and activity diagram.

3.4.1.1.1 Class diagram

It is the most commonly used structural diagram which are made up of classes, interfaces, collaborations and relationships. It can be translated into executable codes by using object-oriented programing languages.

3.4.1.1.2 Object diagrams

It is an instance of class diagram used to visualize the real-life scenario and used to understand the implementation of the system.

3.4.1.1.3 Component diagram

Component diagram is used to visualize a set of components and its relationships and it is made up of classes, interfaces, or collaboration that are arranged in different groups depending up on their relationships.

3.4.1.1.4 Deployment diagram

Deployment diagram represent the different nodes and their relationships and it represent the deployment view of the system.

3.4.1.1.5 Use case diagram

Use case diagrams are a set of use cases, actors, and their relationships and they represent the use case view of the system.

3.4.1.1.6 Sequence diagram

Sequence diagram is used to visualize the sequence of messages form one object to another and it is important to understand the implementation and execution of a specific task and it is used for the realization of usecases.

3.4.1.1.7 Collaboration diagram

It shows how the structural organization of the system and the message are interacting. The purpose of the collaboration diagram is the same as the sequence diagram and it is used to express the organization of the object and its interaction.

3.4.1.1.8 State chart diagram

State chart diagram is used to understand the reaction of the system for certain internal and external events and the events are the cause for the state changes and it is used to express the state change of the system as a consequence of certain events.

3.4.1.1.9 Activity diagram

It shows the entire flow of the system and it is used to visualize how the system works when it is executed and it consists of activities and their links, and there are three types of links and these are sequential, concurrent or branched.

Sequence diagram and collaboration diagram are called isomorphic because they can convert one another without missing any information. The activity diagram and statechart diagram are also isometric diagrams.

Chapter 4 Result and Discussion

The result of the study reveals the findings about the utilization phase of HTM in government owned teaching hospitals in Addis Ababa and Hawassa cities. There are seven government owned teaching hospital in Addis Ababa and Hawassa. These are Tikur Anbessa comprehensive specialized hospital (TACSH), St. Paul Millennium medical college (SPHMMC), St. Amanuel mental specialized hospital (SAMSH), St. Peter TB specialized hospital (SPTSH), Menelik II referral hospital (MRH), Yekatit 12 hospital medical college (YHMC), Hawassa university comprehensive specialized hospital (HUCSH).

Each hospital provides healthcare service for more than 3 million populations and they also provide more than 17 service standards on average as shown in the table 3.1 and each hospital also had an average of 500 beds during the research period. There were more than 330 medical equipment in each hospital on average and there were 47 biomedical engineering staffs and among them 21 were biomedical engineers and 26 were biomedical technicians in the seven hospitals as shown in the figure 4-1 and table 4-1.

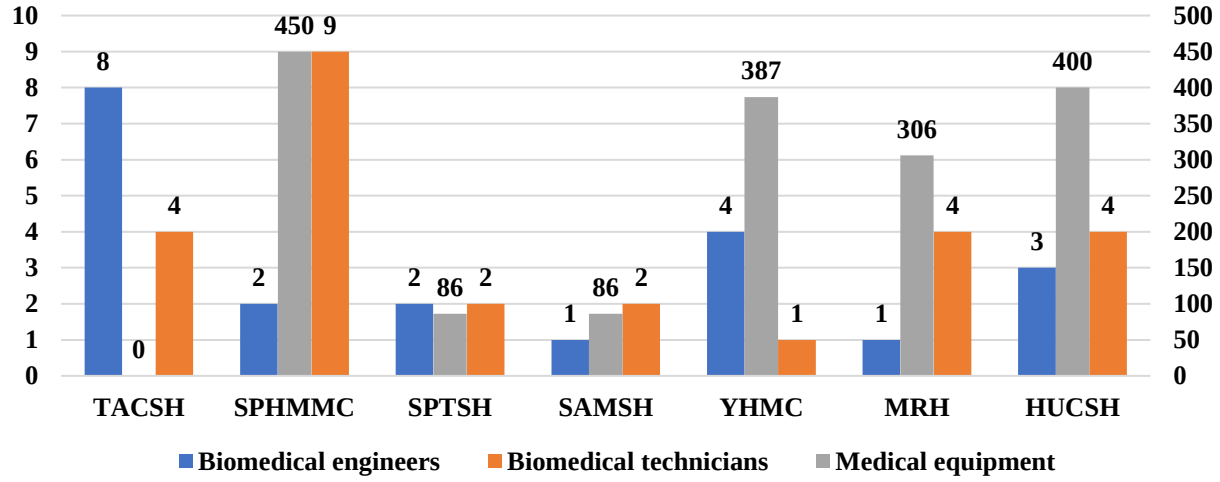

Figure 4-1: Number of biomedical staffs and medical equipment in each hospital

Table 4-1: Healthcare services which were delivered by each hospital

No.	Healthcare services	Names of government owned teaching hospitals in Addis Ababa and Hawassa city						
		TACSH	SPHMMC	SPTSH	SAMSH	YHMC	MRH	HUCSH
1.	Outpatient service	✓	✓	✓	✓	✓	✓	✓
2.	Inpatient service	✓	✓	✓	✓	✓	✓	✓
3.	Emergency service	✓	✓	✓	✓	✓	✓	✓
4.	Internal medicine service	✓	✓	✓	✓	✓	✓	✓
5.	Pediatrics service	✓	X	✓	X	✓	✓	✓
6.	Surgical service	✓	✓	✓	✓	✓	✓	✓
7.	Orthopedics service	✓	✓	✓	X	✓	✓	✓
8.	Gynecology and obstetrics	✓	✓	✓	X	✓	X	✓
9.	Psychiatry	✓	✓	✓	✓	✓	✓	✓
10.	Ophthalmology service	✓	✓	✓	X	✓	✓	✓
11.	ENT	✓	✓	✓	X	✓	✓	✓
12.	Dentistry service	✓	✓	✓	X	✓	✓	✓
13.	Dermatology service	✓	✓	✓	X	✓	✓	✓
14.	Radiology service	✓	✓	✓	X	✓	✓	✓
15.	Medical laboratory service	✓	✓	✓	✓	✓	✓	✓
16.	Pharmaceutical service	✓	✓	✓	✓	✓	✓	✓
17.	Intensive care unit (ICU) service	✓	✓	✓	✓	✓	✓	✓
18.	Cardiac service	✓	X	X	X	X	X	X
19.	Renal service	✓	✓	X	X	X	X	X
20.	Neurology service	X	X	✓	✓	X	✓	X
21.	Care after death service	X	X	X	X	X	✓	X
22.	Toxicology service	X	X	✓	X	X	X	X
23.	Endoscopy service	✓	✓	X	X	X	X	X

There are seven essential elements that are used for assessing the utilization of medical equipment which were evaluated by Biomedical Engineers and Biomedical Technician in each hospital. These are the availability of reference materials, workshop facilities, tools and test equipment, training, accessories and spare parts, maintenance activities and proper inventory system. The results are presented on the basis of the elements.

4.1 Reference materials

More than 74% (23/31) of the respondents disagreed and strongly disagreed on the availability of sufficient reference materials such as international standards and guidelines, national policies, guidelines, standards, user manuals, and service manuals regarding on healthcare technologies. Among them, more than 80% (25/31) of the respondent disagreed and strongly disagreed on the availability of international standards and guidelines which are prepared by IEC, ISO, and WHO.

More than 61% (19/31) of the respondents also disagreed and strongly disagreed on the availability of national policies, guidelines, standards etc. prepared by Ethiopian MoH, Ethiopian FMHACA, Ethiopian Standard Agency (ESA), Ethiopian Radiation Protection Authority etc. and more than 58% (18/31) respondents disagreed and strongly disagreed about the availability of user manuals and more than 93% (29/31) of the respondent disagree and strongly disagree on the availability of service manuals as shown in the figure 4-2 below and there were not more than two service manuals in each teaching hospital during the study.

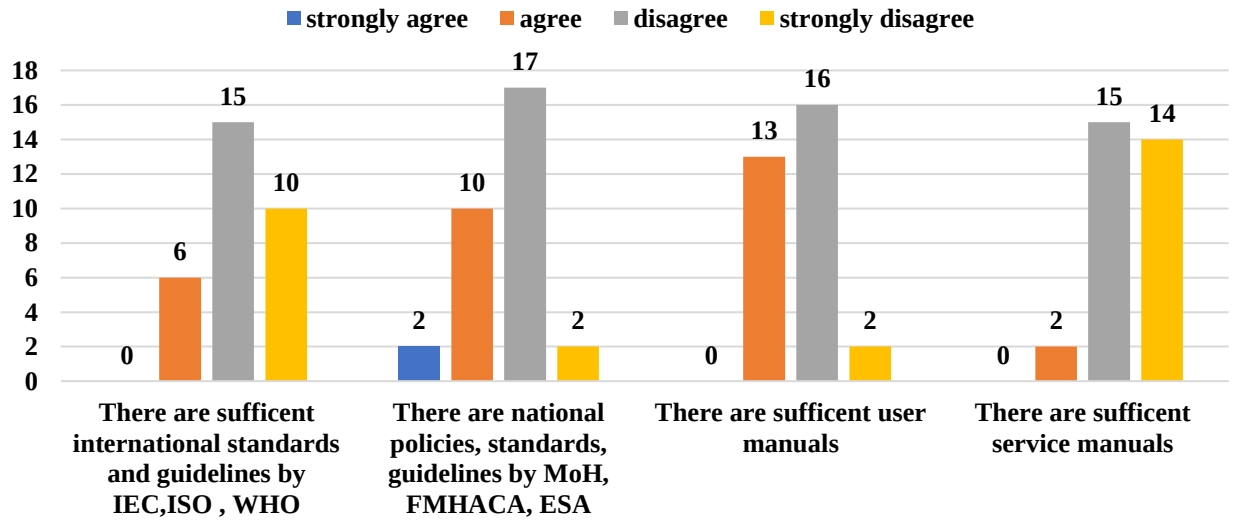

Figure 4-2: Availability of reference materials.

Quite surprisingly, there were no sufficient reference materials especially international standards, policies and guidelines which are prepared by ISO and IEC and accepted by the Ethiopian government [27,28] and service manuals of medical equipment that are used for understanding the operation and function of medical equipment, prepare medical equipment related training, monitor safety and performance of medical equipment and establish standard procedures.

The expected reasons may be the availability of insufficient finance for purchasing such literatures, the procurement process may exclude the availability of service manuals, and medical equipment may be received through donation process and further research is needed to identify the most relevant literatures for each health facilities and check the availability of such reference materials.

4.2 Workshop facilities

Out of 7 government owned hospitals in Addis Ababa and Hawassa, only 2 hospitals (St. Paul hospital and millennium medical college and Menelik II referral hospital) have the recommended workshop space and more than half of the respondents disagreed and strongly disagreed on the availability of workshops that have enough space, store rooms with cabinets, workbenches and sufficient utilities like light, water, toilet etc. as shown in the figure 4-3.

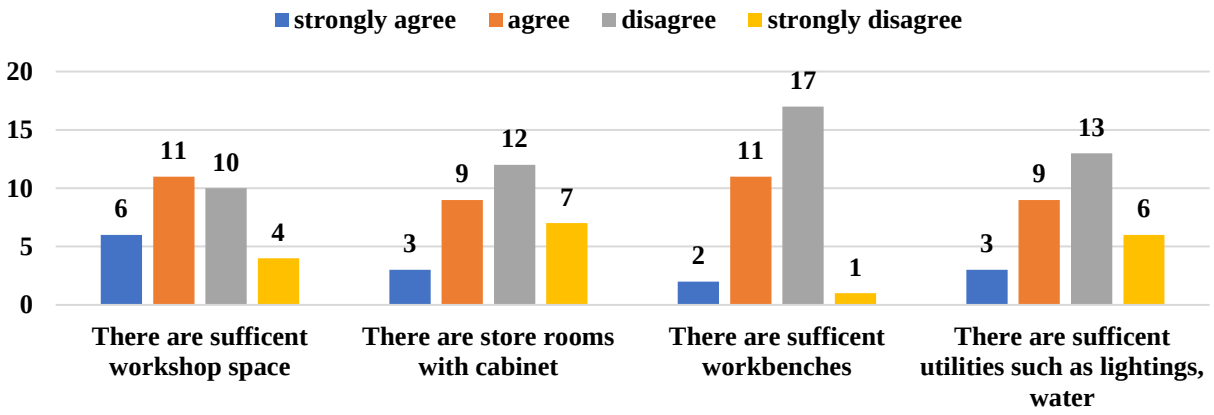

Figure 4-3: Availability of workshop facilities

Workshop facilities should have adequate space for different maintenance works, for putting different workbenches, for store rooms to keep tools and equipment, office space for workshop managers and technical libraries. For health facilities that have more than 100 beds, it is recommended to have an area of 90m^2 workshop spaces [20]. surprisingly, most of the surveyed hospitals didn't have the recommended workshop spaces that hinder the performance of

biomedical engineering staffs and the expected reasons such problems may be the attention given for these department is small, design problem or insufficient spaces of the health facilities.

4.3 Tools and test equipment

Out of the total 7 teaching hospitals, 70% of them had only 2 testing equipment among the eight-recommended test equipment. Hawassa University Comprehensive Specialized Hospital has 75% (6/8) of nationally recommended test equipment followed by St. Paul hospital and millennium medical college, Tikur Anbessa comprehensive specialized hospital, St. Peter TB specialized hospital, accounted for 50% (4/8), 25% (2/8), and 25% (2/8) respectively. The other three hospitals (St. Amanuel mental specialized hospital, Yekatit 12 hospital and medical college, Menelik II Referral hospital) only have multimeters for conducting maintenance activities and only 2 hospitals (Hawassa university comprehensive hospital and St. Paul hospital and millennium medical college) have electrical safety analyzer which was donated from Korean foundation for international healthcare (KOFIH) during the research as shown in table 4-2.

Table 4-2: Presence of test equipment on each teaching hospital

No.	Test equipment	TACSH	SPHMMC	SPTSH	SAMSH	YHMC	MRH	HUCSH
1	Multimeter	✓	✓	✓	✓	✓	✓	✓
2	Oscilloscope	X	X	X	X	X	X	✓
3	Function generator	X	X	X	X	X	X	X
4	Thermometer	✓	✓		X	X	X	✓
5	Electrical safety analyzer	X	✓	X	X	X	X	✓
6	Ventilator analyzer	X	✓	X	X	X	X	✓
7	Patient simulator	X	X	X	X	X	X	✓
8	Radiation analyzer	X	X	X	X	X	X	X

More than 93% (29/31) of the respondents agreed and strongly agreed about the availability of sufficient tools such as Allen key, screw driver, drills etc. however, more than 77% (24/31) of the respondent disagreed and strongly disagreed about the availability of sufficient electrical safety analyzer and performance test equipment such as patient simulator, defibrillator analyzer, ventilator analyzer, and radiation analyzer and more than 70% (22/31) of the respondent disagreed and strongly disagreed about the presence of basic electronics test equipment such as multimeter, oscilloscope, function generators etc. as illustrated on figure 4-4.

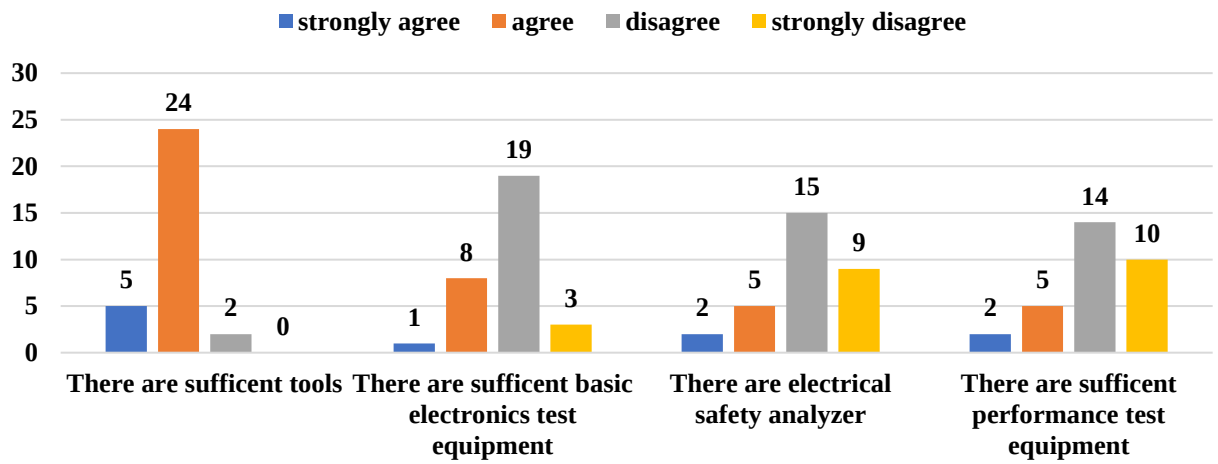

Figure 4-4: Availability of tools and test equipment

Form the findings of result, there were sufficient number of tools such as allen key, drills, fills etc. however, the availability of test equipment were below the recommended and their unavailability will decrease the performance of biomedical staffs and also it is difficult to know the safety and proper functionality of medical equipment. Their unavailability may be due to the lack of sufficient budget to purchase them, their cost, or improper understanding of their uses. Further research is needed to identify the minimum types of test equipment that should be available in each facility and check the awareness of higher officials of health facilities on importance of these test equipment.

4.4 Training

Nearly two third (20/31) of the respondents disagreed and strongly disagreed on the availability of training on medical equipment for both equipment users and maintenance staffs and nearly three-fourth (23/31) of the respondents disagreed and strongly disagreed on the availability of refresher training and in-house training inside their facilities as shown in the figure 4-5.

According to the result of the study, significant number of the respondents disagreed on the availability of sufficient training for equipment users and maintenance staffs that used for coping up with the new brands and models that are coming to market every year. Training is also used to understand proper handling, operation, and application of medical equipment.

More than 65% of medical equipment failure are due to users' error and these can be solved by properly train the equipment users. Medical equipment users and maintenance staff should train on correct operation, handling, application and care and clean of medical equipment. There should have a training on proper maintenance and repair of medical equipment for maintenance staff in particular. The reason for unavailability sufficient medical equipment training may be lack of skilled and knowledgeable biomedical staffs in the health facilities, shortage of well-organized private organizations which deliver medical equipment training, allocation of insufficient budget for these activities.

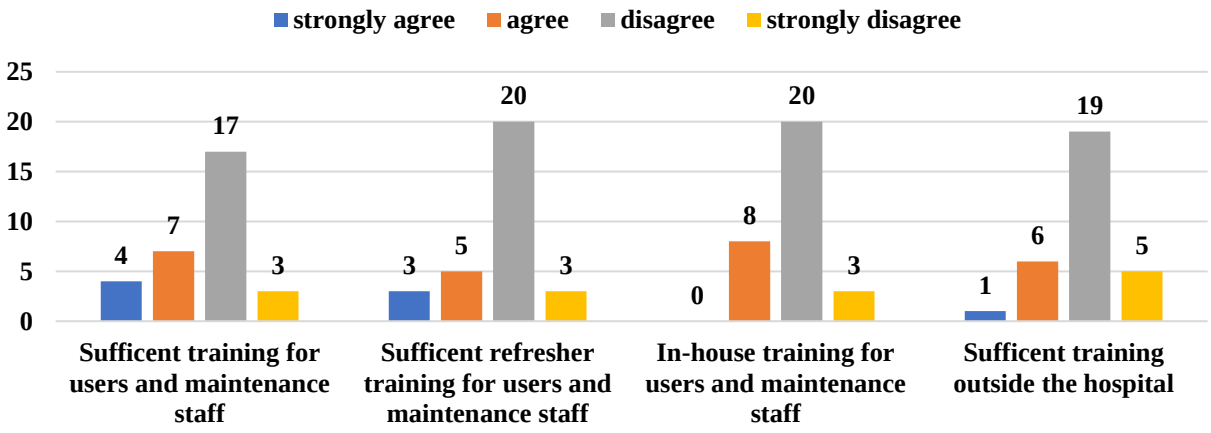

Figure 4-5: Availability of training

4.5 Maintenance activities

During the study, almost all biomedical engineering staffs in each teaching hospital spent their time for corrective and preventive maintenance activities. More than half (17/31) of the respondents disagreed on the availability of sufficient maintenance staff in each hospital and more than 64 % of the respondents agreed on the availability of preventive maintenance schedule for all medical equipment and more than 75% disagreed and strongly disagreed on the availability of electrical safety inspection for medical equipment. More than 84% of the respondents agreed on

the fast response of corrective maintenance request of different departments of the hospitals as shown in the figure 4-6.

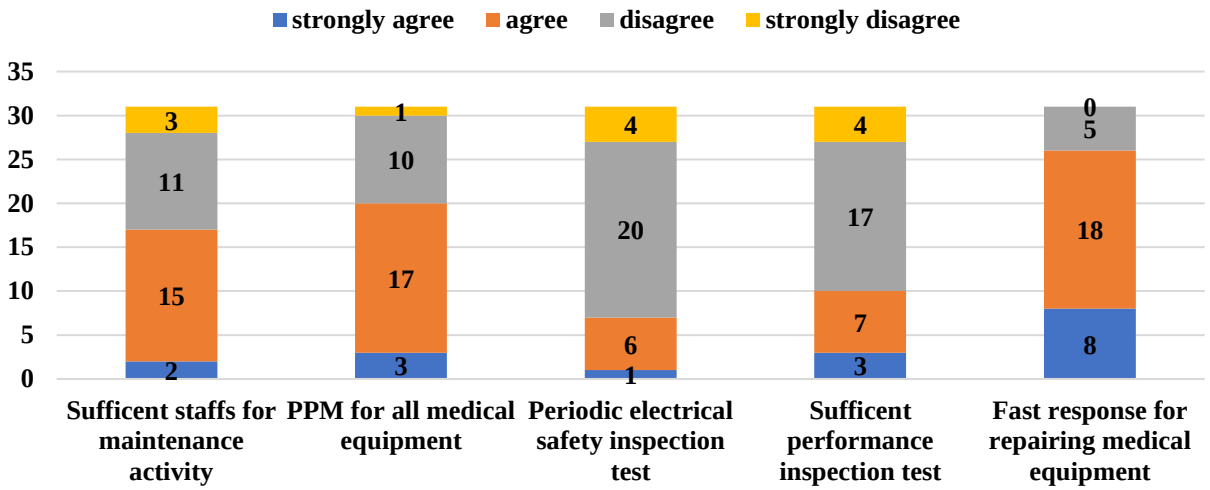

Figure 4-6: Availability of maintenance activities

Even though, significant number of respondents agreed on the availability of planned preventive maintenance and fast response for repairing maintenance, their performance is strongly restricted by the availability of test equipment and work shop spaces in their facilities and also pronounced number of respondents disagreed on the availability of electrical safety inspection due to unavailability of electrical safety analyzers.

In order to undertake proper maintenance activities which can ensure the availability of medical equipment, increase lifetime, prevent breakdown and improve the safety and performance of medical equipment, each health facilities should have sufficient skilled and knowledgeable biomedical staffs, tools and test equipment, accessories and consumables and workshop facilities.

4.6 Spare parts and consumables

More than 90 % (28/31) of the respondents disagreed and strongly disagreed on the availability of sufficient spare parts and consumables in their facilities. More than 94% (29/31) disagreed on the availability of sufficient spare parts such as filters, bearings, O-rings etc. and more than 84% (26/31) disagreed on the availability of consumables such as electrodes, jells, papers etc. as shown in the figure 4-7.

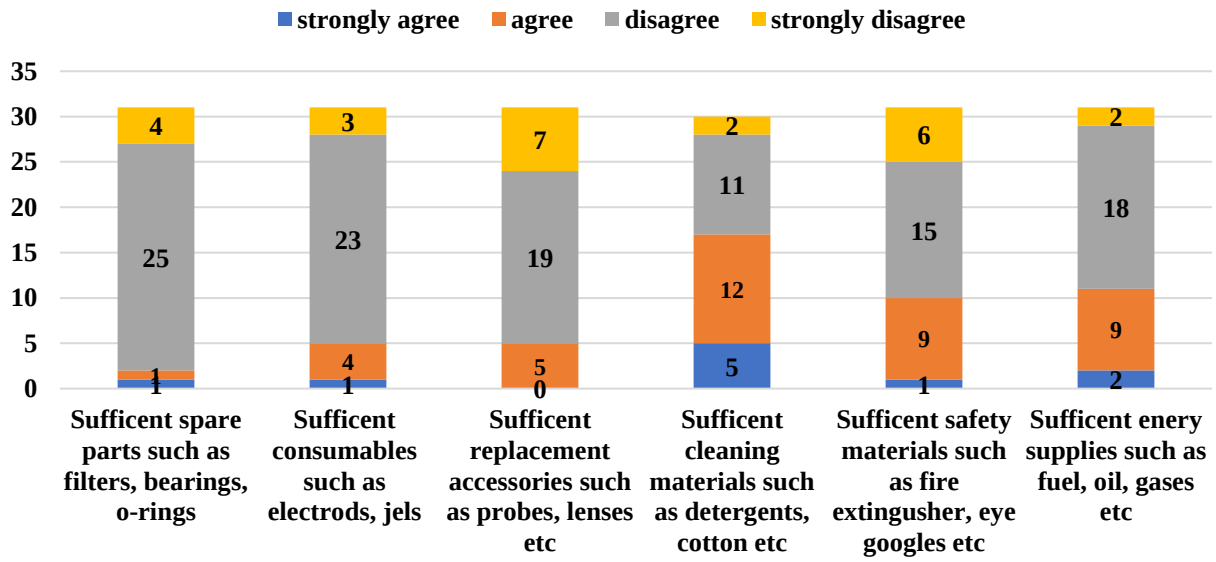

Figure 4-7: Availability of spare parts and consumables

According to the result of the study, remarkable numbers of respondents disagreed on the availability of sufficient accessories and consumables in their health facilities and their insufficient availability will prevent the potential operation and functioning of the medical equipment and as a result, it will reduce the quality of health services. The expected reasons for these problems may be lack of proper knowledge on types of accessories and consumables on newly purchased equipment, ignorance of necessary accessories and consumables during medical equipment procurement, purchasing of poor-quality accessories which may rub, corrode and easily damaged. For further research, it would be better to determine estimated stock value of spare part for vital medical equipment on the basis of each health facilities.

4.7 Proper inventory system

According to survey result, only St. Amanuel Mental Specialized hospital was using only paper-based inventory system, but the other six hospitals were using both paper-based and computer-

based inventory system. From the six hospitals, only St. Peter TB specialized hospital was using Microsoft access-based inventory system whereas, other five hospitals (Tikur anbessa comprehensive specialized hospital, St. Paul hospital and millennium medical college, Yekatit 12 hospital and medical college, Menelik II Referral hospital and Hawassa university comprehensive specialized hospital) were using excel-based inventory system.

According to the survey result, most of hospitals are using excel or access-based inventory system and these have certain drawbacks. Some of these are they could not contain up to date information since update was performed by single person and it is difficult for responsible body to access the system. In addition, there is no notification mechanism for any activities. These systems were also only contained information about medical equipment inventory but these systems should contain information about maintenance, training, supplier, and manufacturer, etc.

As a result, more than half of the respondents (17/31) did not quantify the exact number of medical equipment that are found in their health facilities. Specially, all the respondents from Tikur Anbessa Comprehensive specialized hospital did not know the exact number of medical equipment in their facility and more than 77% (24/31) did not know the number of diagnostics, threptic and laboratory equipment in their facilities.

In order to overcome these problems, we have designed and developed a web-based medical equipment management system which can used for facilitating communication between system users, decrease resilience human role to get data, reduce data redundancy, allow multiple user to access the data at the same time, notify data manipulation on relevant tasks. Such automated system will enhance the overall management of medical devices at all health facility level and improves decision making regarding on healthcare technologies.

The system developed also contains information about medical equipment inventory, spare part inventory, training information, preventive maintenance schedules, corrective maintenance requests, supplier information, manufacturer information and system user information. By using user-friendly graphical interfaces, system user can add, modify, search, sort, paginate, access, analyze and generate a report related to medical equipment, view notification, and they also export the data from database into Microsoft excel for further evaluation.

Chapter 5 Web-based System Design and Development

5.1 System analysis

System analysis is the first step for software development and it is used to identify the functional requirement of system and it is depicted by the use case diagrams and the use case diagram basically describe the functionality of the system and it is further realized by behavioral diagrams such as sequence diagram and activity diagram.

5.1.1 Use case diagram

Use case diagrams are a set of use cases, actors, and their relationships and they represent the use case view of the system. Sample use case diagrams are shown in the figure 5-1.

Actors of the system

There are four users of the system and these are Admin, Technical, Management and unprivileged staff. Admin users are biomedical engineers who have full privileges on the system and technical staffs are biomedical engineers or biomedical technicians that have certain privileges on acceptance, inventory, user modules and have full privilege on spare part, corrective, preventive and training modules and management users are members of medical equipment committee or healthcare management staff that have privileges to view healthcare technology information and unprivileged users are staffs that are registered on the system and have no any privileges.

Use cases of the system

Use cases are functional requirement of the system and each user have different privileges. The admin users have privileges for more than 95 usecases shown in the table 5.1 below and sample usecase scenarios are shown in the table 5-2 and table 5-3 below.

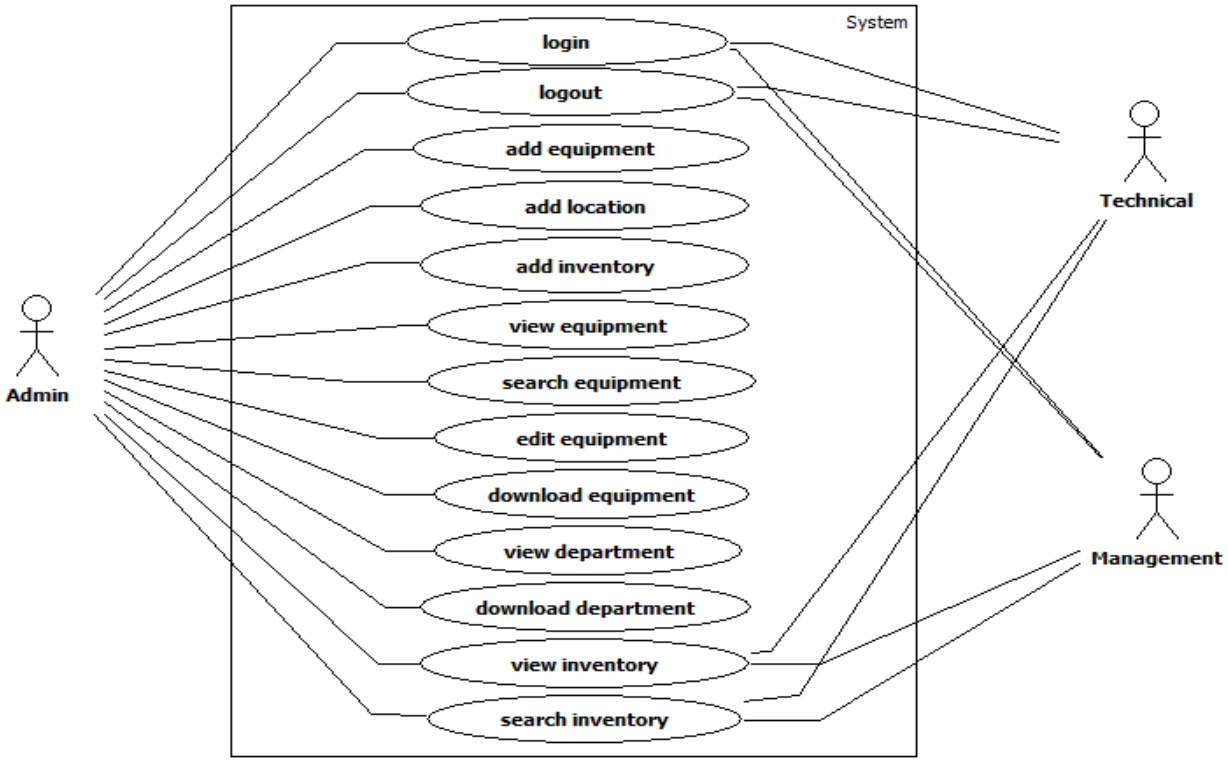

Figure 5-1: Sample usecase diagram.

Table 5-1: Lists of usecases for admin user

Admin user usecases		
Login	View user detail	Add manufacturer
Logout	View add user notification	View acceptance
Add equipment	Search add user notification	Search acceptance
Add location	View edit user notification	View acceptance detail
Add inventory	Search edit user notification	Edit acceptance
View equipment	Add spare part	Download acceptance
Search equipment	Add received spare part	View supplier
Edit equipment	Add issued spare part	Search supplier
Download equipment	Add loss spare part	Edit supplier
View department	View received spare part	View supplier detail
Download department	Search received spare part	Download supplier
View inventory	Edit received spare part	View manufacturer
Search inventory	View received spare part detail	Search manufacturer
Edit inventory	Download received spare part	Edit manufacturer
View inventory detail	View issued spare part	View manufacturer detail
Delete inventory	Search issued spare part	Download manufacturer
view add inventory notification	Edit issued spare part	View add acceptance notification
Search add inventory notification	View issued spare part	Search add acceptance notification
view add notification detail	Download issued spare part	View add acceptance notification detail
View edit inventory notification	View loss spare part	Add PM
View edit notification detail	Search loss spare part	View PM
View delete inventory notification	Edit loss spare part	Search PM
View delete notification detail	View loss spare part	Edit PM
Search delete notification	Download loss spare part	View PM detail
Add user	View spare part report	Download PM
Update user	Download spare part report	Add CM
Change password	Add training	View CM
Reset password	View training	View CM detail
View user	Edit CM	
Search user	Search training	
Activate/deactivate user	Edit training	
Search CM	Add acceptance	
Download CM	Add supplier	

Use case scenarios

Table 5-2: Usecase scenario for login

Usecase:	Login
Introduction	To interact with the system, system will validate its input value and redirect to the privileged page
Actors	Admin Technical Management
Pre-conditions:	System user should have username and password
Post-conditions:	System should redirect to the user main screen to perform desired further actions.
Basic flow:	System show login screen Enter username and password If valid, redirect to privileged page
Alternative flow:	Username or password is incorrect and back to login screen
Special requirement	User should have username and password

Table 5-3: Usecase scenario for add user

Usecase:	Add users
Introduction:	To interact with the system, the admin user login first and select the user link and then click add user link
Actors:	Admin
Pre-condition:	System user must have latest browser version on client computer
Post-condition:	The admin fills the user registration form
Basic flow:	System show user registration form Enter first name, last name, role, phone number, email address, address, username, password and password confirm. Click "add user" button Save their profile in the database successfully
Alternative flow	6a. If first name, last name, username, password, email fields are empty: It gives error message 6b. if the email address is invalid It gives error message 6c. if the password and confirm password doesn't match It gives error message 6d. if the username and email are not unique. It gives error message
Special requirement	None
Success guarantee	You add user successfully

5.1.2 Sequence diagram and activity diagram

Sequence diagram and activity diagram are types of behavioral diagram that used to represent the dynamic part of the system. Sequence diagram used to describe the sequence of messages from one object to another whereas, activity diagram shows how the system works when it is executed and both diagrams are used for the realization of use cases. From figure 5-2 to figure 5-7 show sample sequence diagrams and activity diagrams of the system.

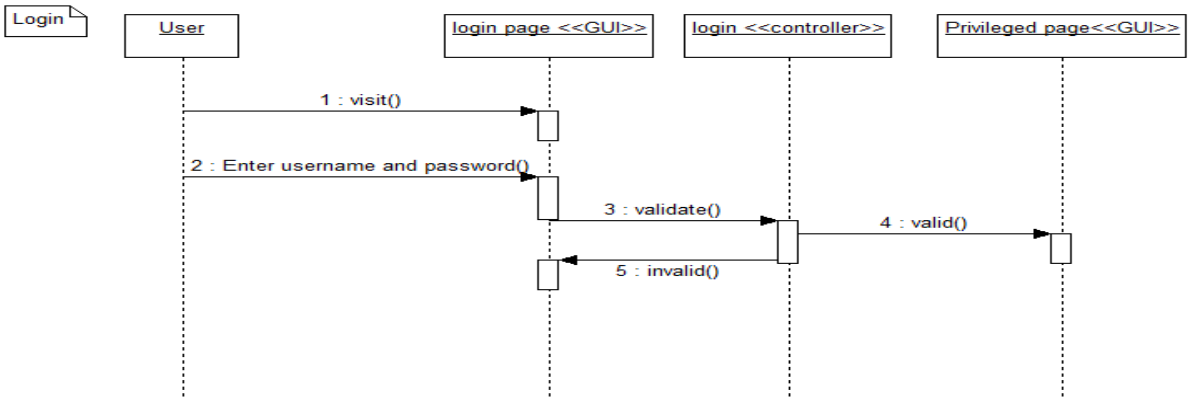

Figure 5-2: Sequence diagram for login

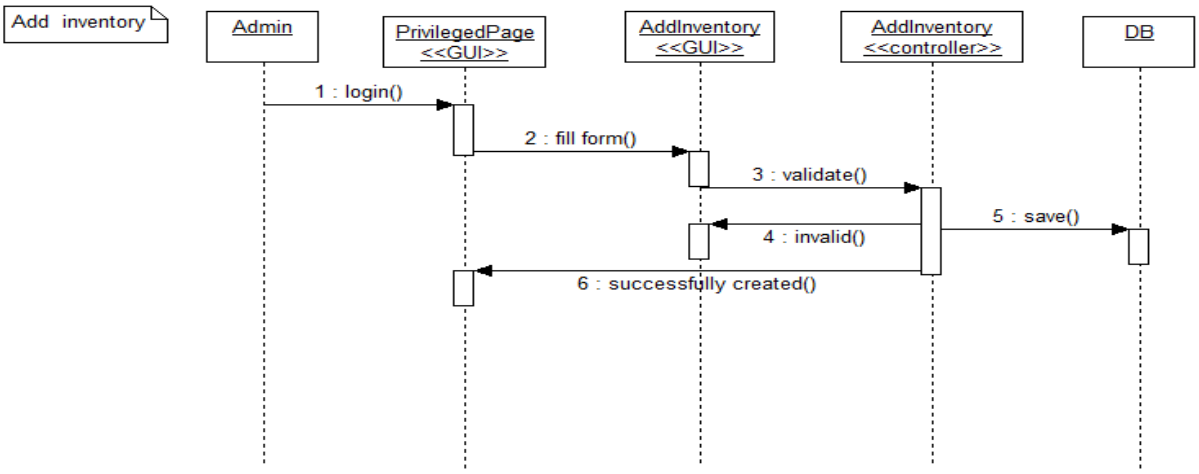

Figure 5-3: Sequence diagram for add equipment inventory

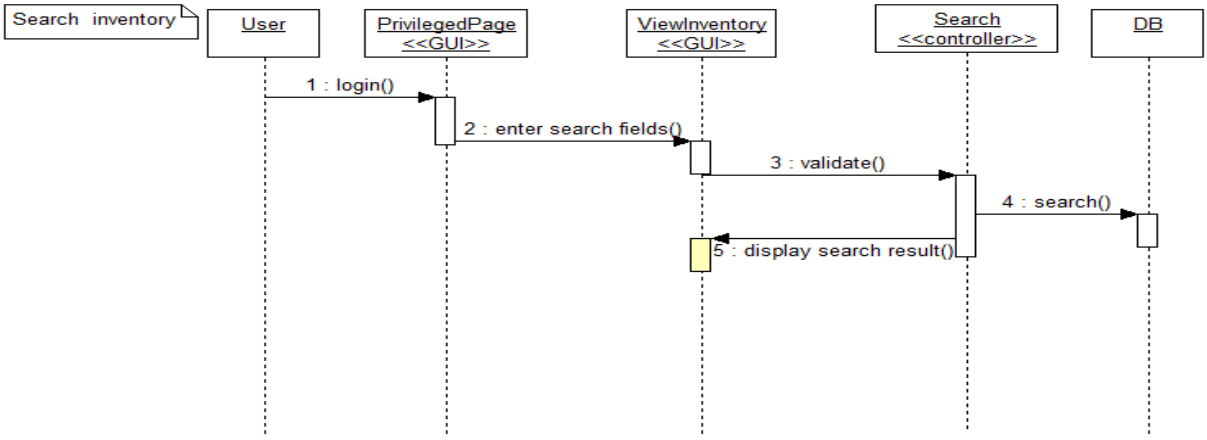

Figure 5-4: Sequence diagram for search equipment inventory

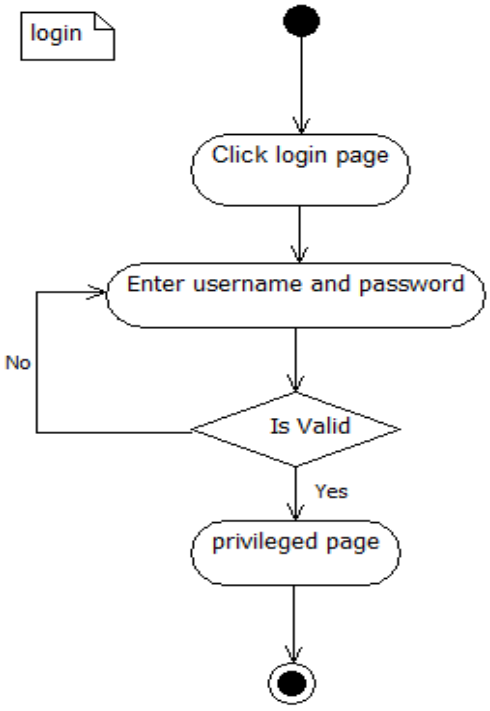

Figure 5-5: Activity diagram for login

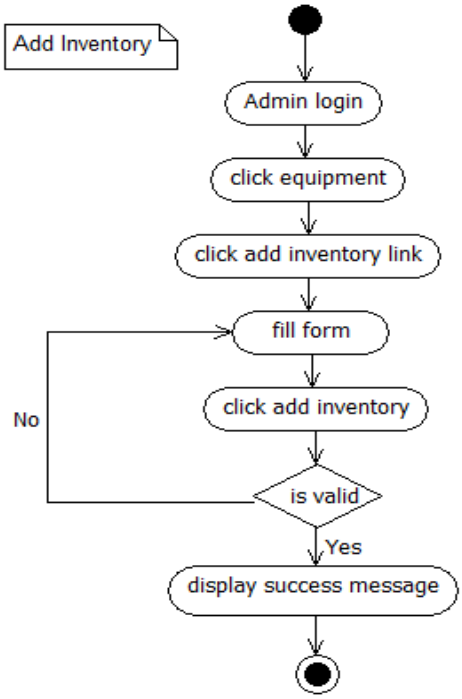

Figure 5-6: Activity diagram for adding inventory

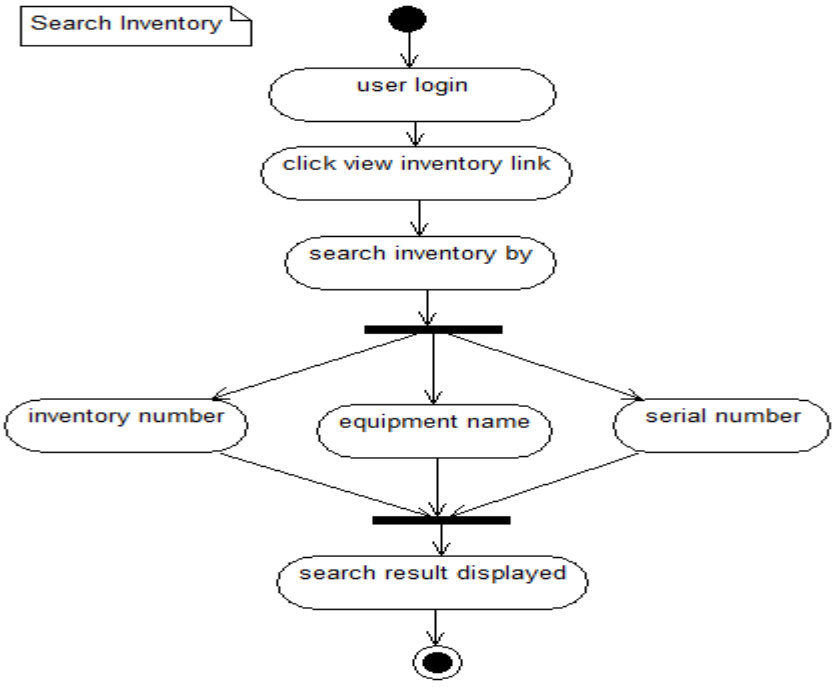

Figure 5-7: Activity diagram for search equipment inventory

5.2 System design

System design is conducted after system analysis have been completed. In this phase, objects are collaborated by using relationship things. Class diagram is used to design the relationship of the objects during the implementation phase.

5.2.1 Class diagram

Class diagram is the most commonly used UML diagram and it consists of classes, interfaces, relationships and collaboration. It is one of the structural diagrams which depicts the static part of the system and also it can be translated into executable codes by using object-oriented programming language such as java, C++, PHP etc. The class diagram for this web-based system is illustrated in figure 5-13.

5.3 User interface design

The user interfaces are graphical interfaces which are displayed when users are interacting with the system. The user interface of this system was developed by using HTML, CSS, JavaScript framework called Twitter Bootstrap. This enabled the user interface flexible and responsive that can adjust its layout with respect to the devices. Some of the user interfaces of the system are presented from figure 5-8 to figure 5:12.

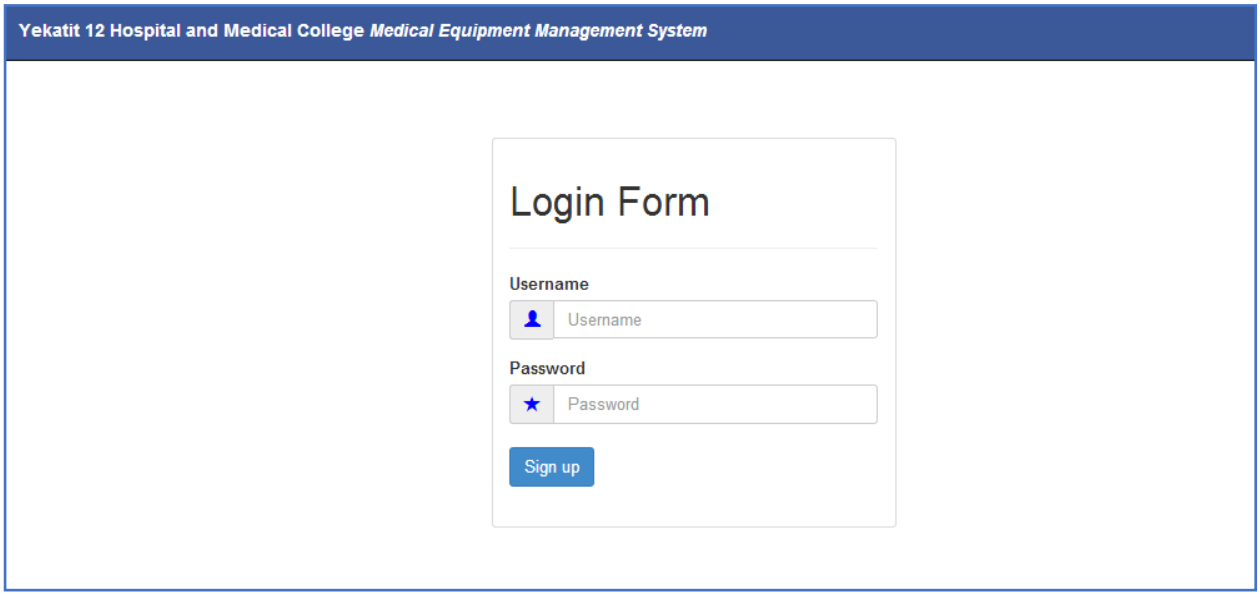

Figure 5-8: User interface for login page

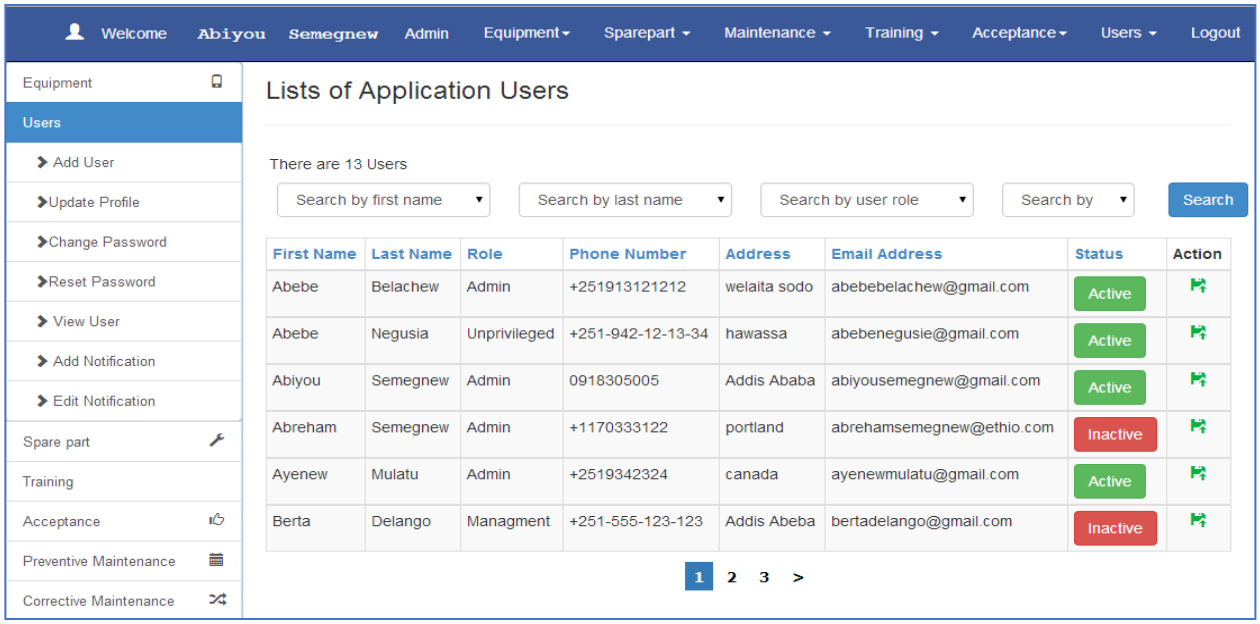

Figure 5-9: User interface for activating/deactivating users

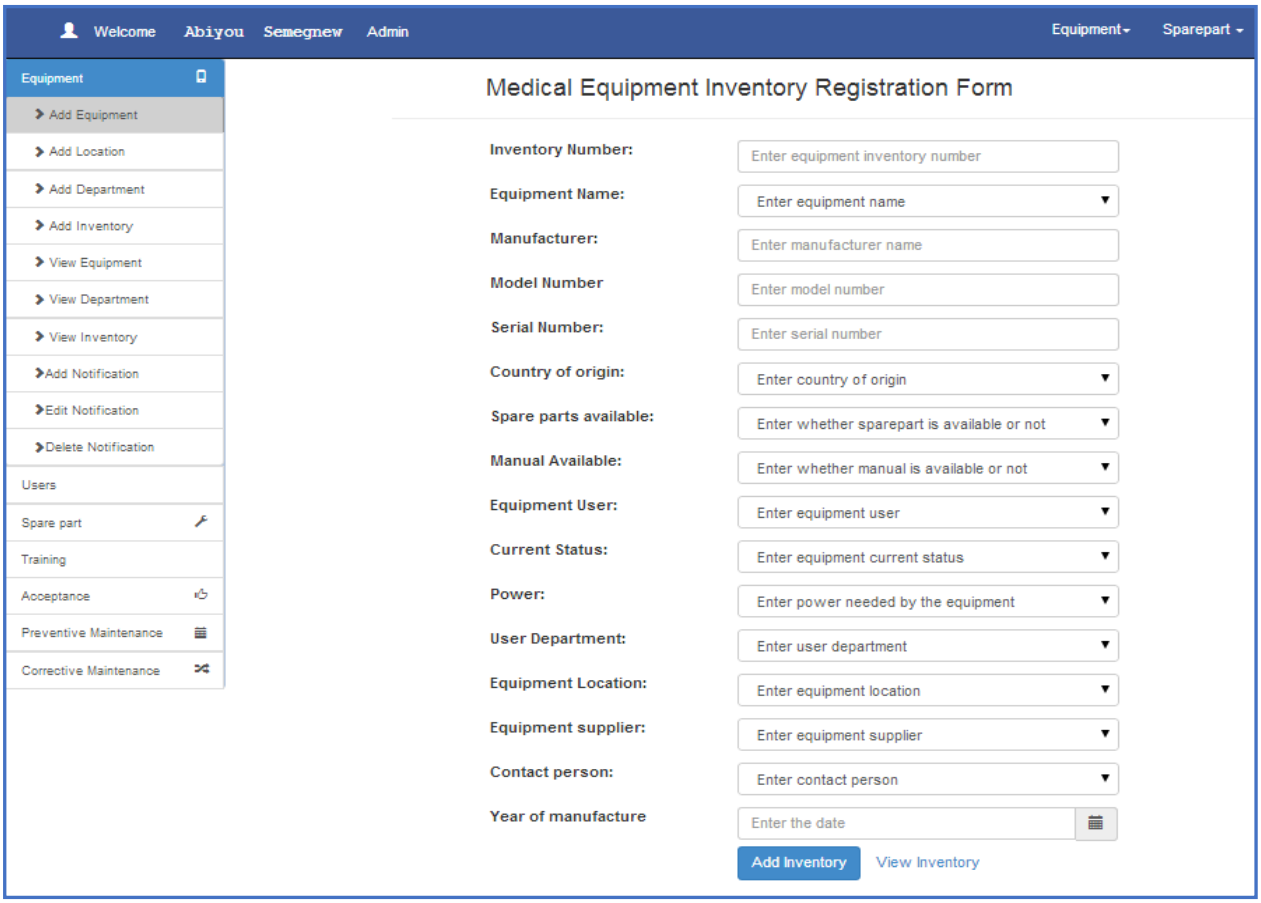

Figure 5-10: User interface for registering medical equipment inventory

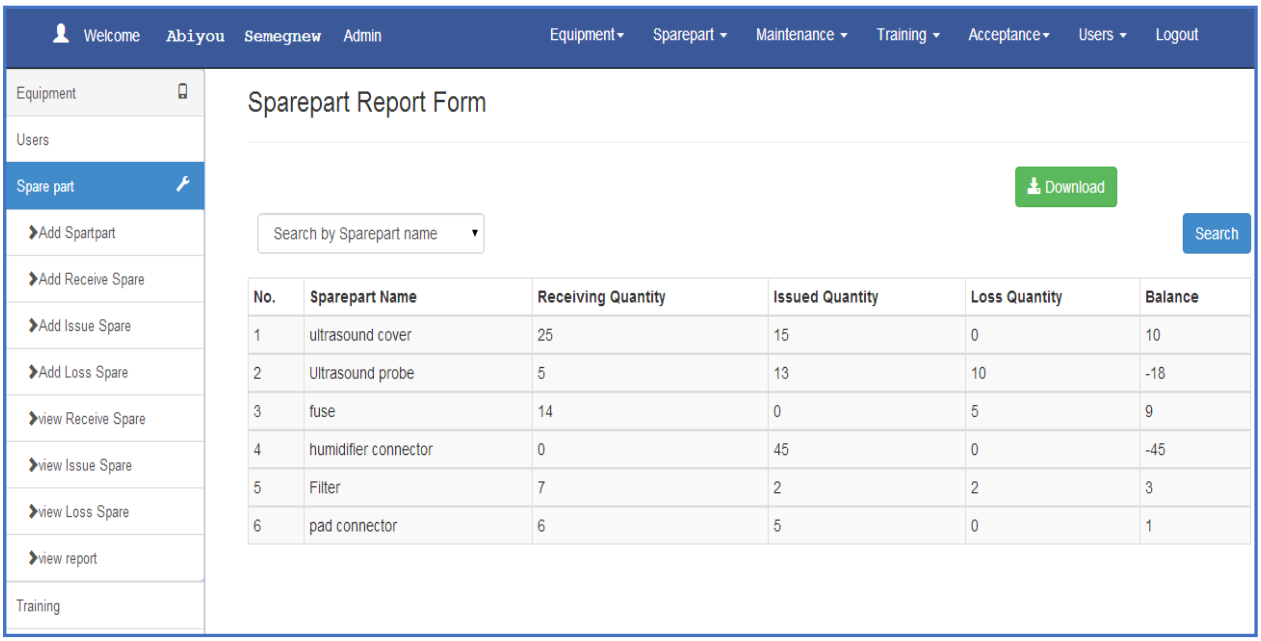

Figure 5-11: User interface for viewing spare part report

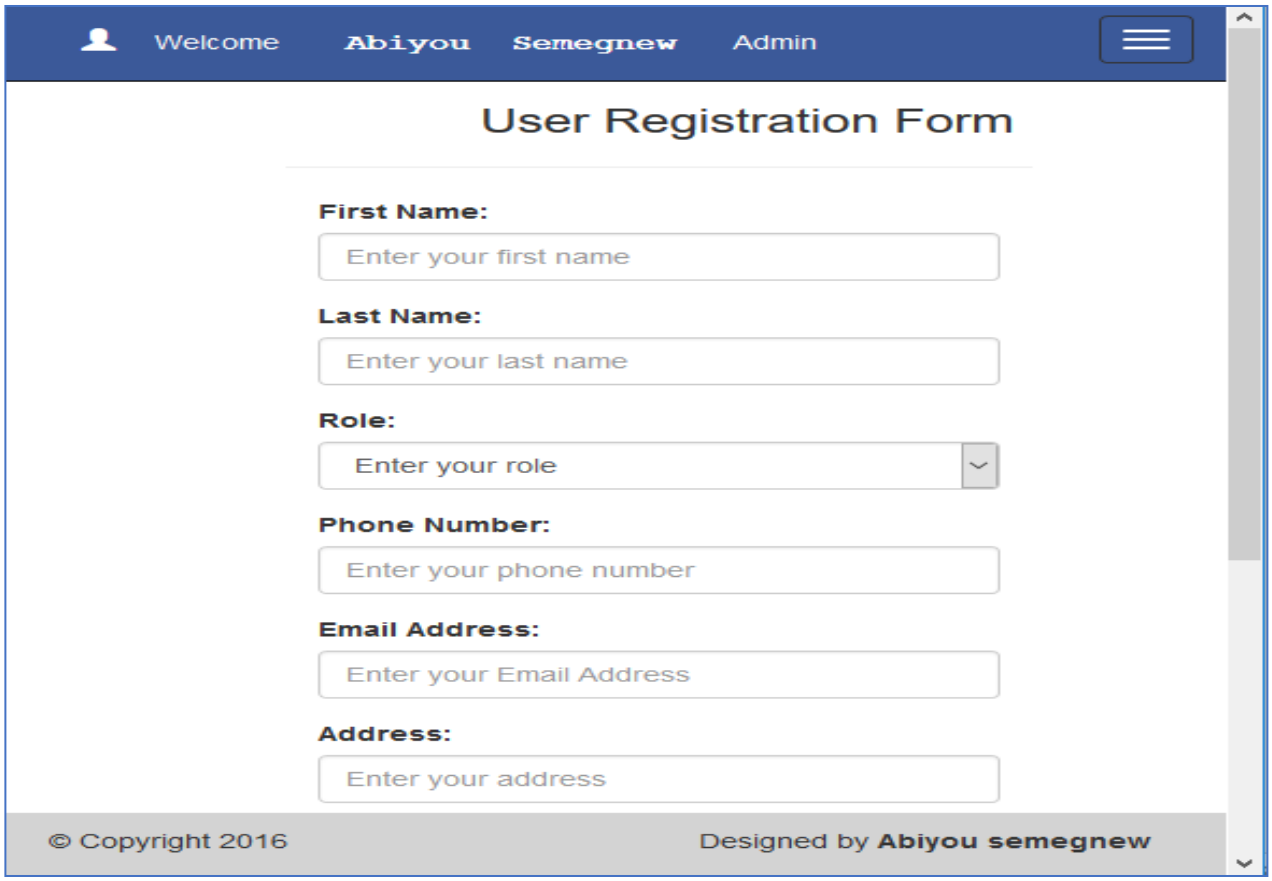

Figure 5-12: User interface for user registration using mobile device

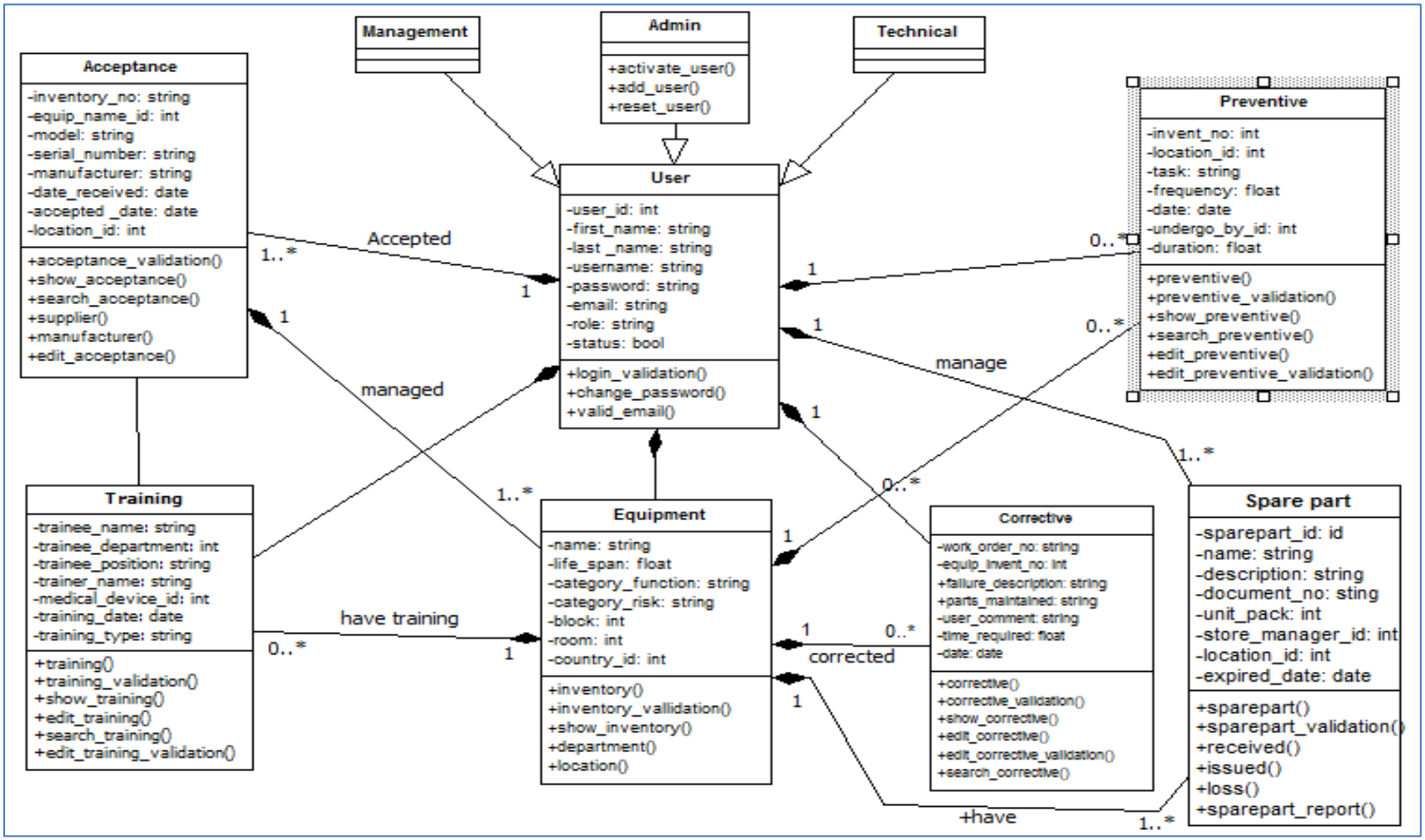

Figure 5-13: Class diagram of web-based medical equipment management system

Chapter 6 Conclusion and Recommendation

6.1 Conclusion

Medical devices are inseparable parts of healthcare delivery and they are used to monitor, diagnosis, and treat patients and alleviate diseases, injuries, and disabilities. However, improper utilization of medical equipment could result in unreliable diagnosis result, wrong operation and function of equipment, increase downtime of equipment, extra waste of finance and series injuries and even loss of life. There are different elements that can ensure proper utilization of healthcare technology. These are availability of sufficient reference materials, workshop facilities, tools and test equipment, training, accessories and spare parts, maintenance activities and medical equipment management system.

For larger health facilities like government-owned teaching hospitals in Addis Ababa and Hawassa which provides more than 17 service standards for more than 3 million populations and having more complex medical equipment, they should have appropriate and sufficient staffs, reference materials, workshop facilities, tools and test equipment, training, spare parts and consumables, maintenance activities and medical equipment management system.

However, almost all these hospitals did not have international standards and guidelines which are accepted and adopted nationally. Moreover, there were not more than 2 service manuals on average in each hospital and more than 74 % (23/31) of the respondents were disagree on the availability of sufficient international standards and guidelines, national policy, regulation and standards, user manuals, and service manuals.

Out of seven hospitals, only two government-owned teaching hospitals have nationally recommended workshops and test equipment that are used for calibration, maintenance, repair and safety inspection of broad range of medical equipment. The number of respondents who didn't agree on the availability of sufficient spare parts and consumables, training, preventive maintenance schedule for all equipment and sufficient staffs for maintenance activities were 90%, 65%, 64%, and 55% respectively.

More than half of the respondents (17/31) did not quantify the exact number of medical equipment that are found in their health facilities. Specially, all the respondents from Tikur Anbessa Comprehensive specialized hospital did not know the exact number of medical equipment in their facility.

This shows that the availability of reference materials, workshop facilities, tools and test equipment, training, spare parts and consumables are not sufficient as compared with the standard set by the Ethiopian hospital reform implementation guideline.

According to the survey result, all the surveyed hospitals are using paper-based, or either excel or access-based medical equipment management system and these systems have certain drawbacks. To mention few, they could not contain up to date information since update was performed by single person and it is difficult for responsible body to access the system. In addition, there is no notification mechanism for any activities, data redundancy and also their system only contains information about medical equipment inventory.

In order to overcome these problems, we have designed and developed a web-based medical equipment management system which used to facilitate communication between system users, decrease resilience human role to get data, reduce data redundancy, allow multiple user to access the data at the same time, view system notifications and enhance the overall management of medical devices at all health facility level and improves decision making regarding on healthcare technologies.

The developed system contains information about medical equipment inventory, spare part inventory, training information, preventive maintenance schedules, corrective maintenance requests, supplier information, manufacturer information and system user information and by using user-friendly graphical interfaces, system user can add, modify, search, sort, paginate, access, analyze, view notifications on adding, editing and deleting relevant information and generate a report related to medical equipment and they also export the data from database into Microsoft excel for further evaluation.

The system developed can used to identify medical devices needs, to calculate budget required for training, maintenance, and purchasing spare parts and consumables, to select suitable models and reputable suppliers for procurement of medical equipment, to determine sufficient biomedical

staffs, to improve quality and safety of the equipment, to determine maintenance workload, to facilitate preventive maintenance schedule, to track corrective maintenance request, etc.

6.2 Recommendation

Ministry of health should encourage and support development of appropriate web-based medical equipment management system in each hospital which contain information about medical equipment inventory, spare part inventory, preventive maintenance schedule, corrective maintenance request etc., and should provide necessary reference materials especially international standards which are published by ISO and IEC related with medical devices since these standards are used for development, comparison and assessment of medical devices.

Testing equipment are important part of medical devices utilization and they are used to conduct safety and performance inspection, preventive maintenance and corrective maintenance. Without these tools, it is impossible to ensure the safety and the proper functioning of medical equipment. The productivity of biomedical staffs is highly affected due to these testing tools. We strongly recommend that MoH should at least provide the minimum recommended testing equipment for larger health facilities such as government owned teaching hospitals.

Larger health facilities like government owned teaching hospitals in Addis Ababa and Hawassa cities should allocate sufficient budget to purchase spare parts, consumables and accessories and to conduct on-going training. They should also hire sufficient biomedical staffs for performing healthcare technology management activities such as planning, procurement, maintenance and disposal. The hospitals should have necessary infrastructure to deploy web-based medical equipment management system such as server computers, client computers, internet cables, offices etc.

Biomedical staffs should be responsible for injuries, illness and even death due to medical devices safety and operation problems as a result of improper functioning of medical equipment. They should conduct safety and performance inspection to minimize the risk associated with the equipment during initial use, after corrective maintenance and based on the manufacturer recommendation. Planned preventive maintenance should be performed based on the manufacturer recommendation to increase lifetime, prevent hidden problems and to increase the uptime of the

medical equipment. To minimize the user errors during operation of the equipment, user training should be delivered to them.

The medical equipment management systems which were found in government owned teaching hospitals are only contain information about medical equipment inventory but these systems should contain additional information about maintenance, training, supplier, manufacturer. For example, Information related to maintenance information is important for preparing training based on the frequency of equipment failure, to determine the maintenance workload which is used to decide the number of biomedical technicians needed to`be hired, to evaluate the completion rate of planned preventive maintenance, to check the response time for corrective maintenance, to estimate the budget required related to medical equipment.

This study focused on the assessment of utilization phase of healthcare technology management of seven government owned hospitals and web-based system development for single hospital. This study can be expanded to assess the other phases of healthcare technology management and cover more referral and comprehensive hospitals in Addis Ababa and other parts of the country.

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Annex A: Questionnaire for Assessing Utilization of medical equipment

Addis Ababa University

School of Graduate Studies

Centre of Biomedical Engineering

Dear Participants;

The researcher has been conducting a research in the area of Medical equipment management system for partial fulfillment of my M.SC in Biomedical Engineering in AAU. With sincerity, he would like to extend his deep appreciation to your Hospital and staff for the willingness and enthusiasm in participating in this research. Thank you for your kind cooperation in answering the questions as truthfully as possible. Your response will be highly confidential. For any other questions pertaining to this study, please contact Dr.Masreshaw Demelash at the Centre of Biomedical Engineering via his email masreshaw.demelash@aau.edu.et.

Thank you for giving your valuable information.

Objectives of the study:

- ***To assess the availability of spare parts and consumables***
- ***To assess the availability of resources and trainings***
- ***To improve the current utilization of medical equipment***
- ***To ensure the quality, safety of the medical equipment***
- ***To assess medical equipment management system***
-

Contact Advisor: Dr. Masreshaw Demelash

This questionnaire has two parts.

Part I: - Personal data

Part II: - Questionnaire about utilization of medical equipment

Part I

Personal data

Current position_____

Qualification_____

Service year _____

Part II

Questionnaire about utilization of medical equipment

NO	**Questions**			
1	**Assess the availability of reference materials**	**Yes**	**No**	**Remark**
1.1	*International Guidelines and Standards about medical devices*			
1.1.1	Do you have safety standards prepared by International Electrotechnical Committee (IEC)			
1.1.2	Do you have safety standards prepared by International Standard Organizations (ISO)			
1.1.3	Are there any guidelines prepared by World Health Organization (WHO)			
1.2	*National Policy, guidelines, standards, reports etc.*			
1.2.1	Is there a medical equipment donation directive prepared by FMHACA?			
1.2.2	Do you have generic medical specification document organized by FMHACA?			
1.2.3	Do you have public procurement manual prepared by Federal Minister of Finance and Economic development			
1.2.4	Are there radiation guidelines prepared by prepared by Ethiopian Radiation agency			
1.2.5	Are there specialized/general hospitals requirement guidelines prepared by Ethiopian standard Agency			
1.3	*Availability of users and service manuals*			
1.3.1	Are there any equipment operator manuals			
1.3.1.1	If the answer for question 1.3.1 is yes, how many operator's manual do you have?			

1.3.2	Do you have any equipment service manuals			
1.3.2.1	If the answer for question 1.3.2 is yes, how many operator's manual do you have?			
2	**Assess workshop facility**	**Yes**	**No**	**Remark**
2.1	Do you have workshop facility			
2.1.1	If question 2.1 is yes, what is the area of the workshop			
2.1.2	If question 2.1.1 is yes, are there sufficient workbenches			
2.1.3	If question 2.1.1 is yes, are there sufficient lightings and utilities			
2.1.4	If question 2.1.1 is yes, does it have enough stores for serviced equipment			
2.1.5	If question 2.1.1 is yes, does it have shelves for putting reference materials			
3	**Assess the availability of tools and test equipment**	**Yes**	**No**	**Remark**
3.1	Are there sufficient tools for conducting medical equipment maintenance			
3.2	Are there sufficient test equipment			
3.2.1	If yes, do you have multimeters			
3.2.2	If yes, do you have oscilloscopes			
3.2.3	If yes, do you have function generators			
3.2.4	If yes, do you have thermometer			
3.2.5	If yes, do you have Electrical safety analyzer			
3.2.6	If yes, do you have physiological simulators			
3.2.7	If yes, do you have defibrillator analyzer			
3.2.8	If yes, do you have radiation analyzer			
3.2.9	If yes, do you have ventilator analyzer			
3.2.10	If yes, do you have electrosurgical analyzer			
4	**Assess training activities**	**Yes**	**No**	**Remark**
4.1	Are there any training program in this year			
4.1.1	If yes, how many trainings are conducted			
4.1.1.1	If yes, how many **initial trainings** are delivered from the total training			
4.1.1.2	If yes, how many **induction trainings** are carried out from the total trainings			
4.1.1.3	If yes, how many **refresher trainings** are conducted from the total			
4.1.1.4	If yes, how many training are given **for users** from total			

4.1.1.5	If yes, how many training are given **for technicians** from total	
4.1.1.6	If yes, how many trainings are given by in-house staffs	
4.1.1.7	If yes, how many trainings are conducted by trainers outside the hospitals	

5	**Assess the availability of accessories and spare parts**	strongly agree	agree	disagree	strongly disagree
5.1	Are there sufficient spare parts such as filters, bearings, O-rings for maintenance				
5.2	Are there sufficient consumables such as electrodes, jells, papers etc. for medical equipment				
5.3	Are there enough replacement accessories such as probes, lenses for equipment				
5.4	Are there sufficient cleaning materials such as cotton, wool, detergents and disinfectants for equipment				
5.5	Are there appropriate safety materials like fire extinguisher, eye google, boots etc.				
5.6	Are there enough energy supplies such as oils, fuels and gases for medical equipment				

6	**Assess the health care technology management system**	**Yes**	**No**	**Remark**
6.1	Do you have medical equipment management system			
6.1.1	If yes, what type of system do you have? (tick the checkbox, if what you have) ☐ Paper Based ☐ Computer Based			
6.1.2	If you use computer based system, what type of management system do you use? (if you have, select checkbox) ☐ Desktop Application ☐ Web Based Application			
6.1.3	If you have desktop Application, what type of application do you use (tick the checkbox what you use) ☐ Microsoft Excel ☐ Microsoft access ☐ Database System ☐ Other			
6.1.4	If you have system, what information does it have (tick the checkbox if you have)			

	☐ Equipment inventory management system ☐ Spare part inventory management system ☐ Acceptance test ☐ Preventive maintenance records ☐ Corrective maintenace records ☐ Supplier Information System ☐ Manufacturer information system ☐ Training information system ☐ lists of available litrature resources ☐ Lists of test equipments ☐ other
6.1.4.1	If you have other information that you keep in your system, please write it on the text box below

7	**Assess maintenance activities**	**Yes**	**No**	**Remark**
7.1	Do you have maintenance department in your health facilities?			
7.2	Do you have medical equipment breakdowns			
7.2.1	If you have breakdown, how many breakdown records are there annually?			
7.3	Are there any equipment that are failed and not repaired			
7.3.1	If question 7.3 is yes, how many unrepaired equipment do you have			
7.4	Do you have periodic planned preventive maintenance schedule			
7.4.1	If question 7.4 is yes, for how many types of equipment			
7.5	Do you have periodic performance inspection schedule			
7.5.1	If question 7.5 is yes, for how many types of equipment			
7.6	Do you have periodic safety inspection schedule			
7.6.1	If question 7.6 is yes, for how many types of equipment			

Annex B: Sample Support letter from Addis Ababa University, Institute of Technology

AAiT

Addis Ababa Institute of Technology
Center of Biomedical Engineering
Tel: +251-(0)11-157-7887
Mob: +251-(0)922-541154
Web: http://www.aait.edu.et
E-Mail: bmec@aait.edu.et

Date: 10 August 2017
Ref. No.: BMEC/326/09

To : St. Paul Millinum Medical College

Subject: **Request support**

Student Absyou Semegnew (ID: GSR/8497/05) is one of our students pursuing his master's degree in Biomedical Engineering at the center of Biomedical Engineering in Addis Ababa University.

He is currently working on his MSc thesis in the area of Healthcare technology management. This is therefore to kindly request your organization to support the student in providing the support he needs for his research.

Thank you in advance for supporting the center in its effort of producing problem solving biomedical engineers who will play significant role in enhancing the quality of the health care services in the country.

Thank you

Fre[illegible] Dr.
Head, Center of Biomedical Engineering,
Addis Ababa Institute of Technology, AAU

Annex C: Sample Ethical and Clearance and Institutional permission letter

St. Peter TB Specialized Hospital
Ethical Clearance and Institutional Permission

Principal Investigator (PI): Abiyou Semegnew

Title of the Project:

Assessment of Health Care Technology Management in Addis Ababa Hospital

The ethical committee of St. Peter TB Specialized Hospital has assessed the ethical acceptance of the proposal by the Ethics Committee of the hospital based on national and international scientific and ethical standards. It is a cross sectional research project. Confidentiality will be kept to a maximum. The committee has approved the project with recommendation on its meeting 06/09/2017. The PI should notify the Ethics Committee ahead of any amendments or modifications in the research project.

Ethics Review Committee Members: **Signature**

Dr Addisu Admasu (MD, MPH) _____

Ato Tsegaye Korsa(Human Resource Head) _____