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ACRONYMS AND ABBRIVIATIONS

BMN:	Broadband Multimedia Networks
DM	Decision Maker
ETC:	Ethiopian Telecommunication Corporation
FoM:	Faculty of Medicine of Addis Ababa University
HEW:	Health Extension Worker
HSDP:	Health Sector Development Program
HSEP:	Health Service Extension Program
ICTT:	Information and Communication Technology Transfer
ITU:	International Telecommunication Union
KAOS:	Knowledge Acquisition in autOmated Specification
MADM :	Multi-Attribute Decision Making
MAUT:	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Aid
MCDM:	Multiple Criteria Decision Making
MCDUS:	Multi-Criteria Doctor's Unit Selection
MCPS:	Multi-Criteria Provider Selection
MoH:	Minister of Health
NTCC:	National Telemedicine Coordinating Committee
NTS:	National Telemedicine System
OR/MS:	Operation Research and Management Science
RE:	Requirement Engineering
SSA:	Sub Saharan Africa
TSM:	Telemedicine System Model
ViCCU:	Virtual Critical Care Unit
VPN:	Virtual Private Network
VR:	virtual reality

ABSTRACT

Healthcare is essential for developing countries like Ethiopia which do have a number of medical problems exacerbating from time to time. Telemedicine , the use of telecommunication technologies to provide healthcare services and medical knowledge, can be applied to minimize these problems by offering better access and usage of the limited number of physicians. It solves the problem by providing remote consultation (which can be store and forward or real time) between the local doctor and a specialist. Previous works do not address the problem of selecting a specific physician needed for the remote consultation. In order to make use of all the physicians who are distributed in different healthcare providers of the country efficiently and equitably, there needs a mechanism for selecting a physician that best fits the consultation by applying decision aid techniques.

This thesis proposes a National Telemedicine System that can be deployed countrywide by studying its requirements using goal oriented requirement engineering. This work also proposes the National Telemedicine Network Architecture based on the current communcation technologies. The thesis specifically presents the Multi-Criteria Doctor's Unit Selection model that can be employed in the National Telemedicine System to aid physicians in making physician selection for the consultation. The selection model is simulated by a Multi-Criteria Doctor's Unit Selection System which is developed using Java programming and MySQL database.

Keywords: Telemedicine, Goal Oriented Requirement Engineering, Decision Aid Techniques, Multi-Attribute Utility Theory, Developing Countries

1. Introduction

1.1 Motivation

Telemedicine is the delivery of health care services, where distance is a critical factor, by health care professionals using information and communication technologies for the exchange of information for diagnosis, treatment and prevention of diseases and injuries, and for the continuing education of health care providers as well as research and evaluation, all in the interest of advancing the health of individuals and their communities. Application of telemedicine has dramatically increased over the years. Its applications become faster and more widespread and more independent of geographic locations [11].

The modern age telemedicine is more related to ICT and it is in its infancy in developing countries like Ethiopia. On the other hand, telemedicine has advanced to the extent of virtual reality in developed countries, where a surgery could be performed remotely using high speed network technology and robots.

Information and Communication Technology Transfer (ICTT) with respect to telemedicine could be applied to Sub-Saharan Africa (SSA). However, previous ICTT attempts from partners in developed countries have failed because of neglecting infrastructural, socioeconomic, and cultural factors that impact such transfers. Accordingly, understanding barriers due to infrastructural and cultural factors for telemedicine transfers or proposing systems that best fit for developing countries motivates this work.

Rationale that underscores the research significance include:

- Recent ICTs and telemedicine developments are encouraging. These developments include wireless ICT diffusion, Internet use, electronic information exchange, and remote consultation.
- Healthcare is essential for the SSA countries which do have a number of medical problems. It is reported that medical problems are growing in SSA from time to time [7]. There is a need to apply or make use of telemedicine to minimize these problems by providing better access at reduced cost.
- There is shortage of medical personnel and facilities.

Influence of ICTs due to governmental policies, economic, sociopolitical, cultural and infrastructural factors have attracted international collaborations.

1.2 Research Problem

Studies have been conducted in the past few years to propose e-Solutions for better healthcare service. These solutions are known as Telemedicine systems, which make use of telecommunication technologies. However, most studies are conducted for developed countries which vary from developing countries in a number of aspects like technology, culture, economy, etc. Little is done for developing countries like Ethiopia which have small number of specialists, high morbidity and mortality, high population social and economic problems.

Hence to improve the overall healthcare system and come up with quality and cost effective patient care, there is a need to make use of the small number of specialists in the country efficiently and equitably.

Previous works have shown the need for telemedicine system for developing countries like Ethiopia. Some of the works have developed telemedicine systems that could provide consultation service for a local doctor using both store and forward and real time consultations. Most works have supported either the store and forward telemedicine type or the real time one. However, these works do not address the problem of selecting specific specialist that is needed for the consultation, since they know who to contact as the consultation provider is already known and defined. But in order to make use of all the available specialists and physicians who are distributed in different healthcare providers of the country (i.e. Ethiopia) efficiently and equitably, there needs to be a mechanism for selecting the current available specialist when a consultation is needed.

Thus, the problem that this research work tries to address is how to develop a National Telemedicine System that could provide both the store and forward and real time consultation with a Multi-Criteria specialist Selection by using current and available telecommunication technologies. This is believed to have an effect on the overall outcome of patient care by improving healthcare services using the limited number of specialists efficiently and equitably.

1.3 Objectives

The general objective of this research is to develop a *National Telemedicine System with a Multi-Criteria Doctor's Unit Selection*.

The following are the specific objectives:

- Analyzing components of the telemedicine system and factors affecting Doctor's Unit selection.

- Designing a national telemedicine system network architecture that could be implemented countrywide.
- Designing a national telemedicine system model that could be implemented countrywide.
- Developing a Doctor's Unit selection model that could be employed in the telemedicine system.
- Developing a prototype to show the validity of the Multi-Criteria Doctor's Unit Selection model.

1.4 Major Research Activities

Background study of the target domain (telemedicine) and review of related works are the primary activities in this research. A number of studies have been conducted to show the appropriateness of telemedicine for countries like Ethiopia. After the primary activities, the research utilizes major findings to achieve the above stated objectives.

The course of action is started by proposing a National Telemedicine System model and its network architecture followed by the Multi-Criteria Doctor's Unit selection model which is proposed based on the results of the questionnaire. Finally, a prototype is developed.

1.5 Overview of the Thesis

The rest of the thesis is organized as follows: chapter two presents fundamental concepts that are helpful in understanding the rest of the document and the work done. It gives background information about telemedicine and health care (in Ethiopia). It also discusses telecommunications technologies for telemedicine. Goal oriented requirement engineering and decision aid techniques are also presented. In chapter three review of related work is presented. Previous works that are related to our work are presented. Chapter four presents the proposed National Telemedicine Network Architecture that is implmentable. It discusses basic components that are required from any health care provider to be part of the National Telemedicine System. Chapter five presents the National Telemedicine System model. It specifically discusses design considerations and processes. Chapter six discusses the Multi-Criteria Doctor's Unit Selection model. It presents characteristics, goals, criteria and model of the selection process. Results of the questionnaire are also presented in this chapter. Prototypic implementation of the Multi-Criteria Doctor's Unit Selection model is presented in chapter seven. Scope, features, development tools, design and architecture of the prototype are discussed. Lastly, in chapter 8, conclusions and future work are presented.

2. Background

This chapter deals with the review of important concepts that are used in this work. It provides a background information on telemedicine, health care in Ethiopia, and telecommunication technologies. Goal oriented requirement engineering and multi-criteria decision making techniques, which are applied in this work are also described.

2.1 Telemedicine

Telemedicine might be defined as the delivery of healthcare and medical knowledge over a distance using telecommunication [1]. The main aim of telemedicine is to provide medical care at any place where healthcare is needed. Telemedicine, as a concept, was introduced about 30 years ago when telephone and fax machines were the first telecommunication means used.

Telemedicine has been widely used in healthcare mainly for education, research and training purposes [2]. Its use in regular clinical care is still in development, especially in developing countries. Telemedicine may be as simple as two health professionals discussing a case over the telephone, or as complex as using satellite technology and video conferencing to conduct a real time consultation between medical specialists in two different countries.

Telemedicine applications span the areas of emergency healthcare, telecardiology, teleradiology, telepathlogy, teledermatology, teleopthalmology, teleoncology, and telepsychiatry [1].

Parallel advances in medical and information technology have created opportunities to the increasing focus, development and use of telemedicine systems and services around the world, particularly in developed countries. The goals of these systems include:

- Improve accessibility between patients and caregivers.
- Improve the quality and continuity of care to patients.
- Improve overall cost of healthcare.
- Education and training.
- Remote monitoring.

Telemedicine can be practiced on the basis of two concepts. Real time (Synchronous) and store-and-forward (asynchronous) [2].

Real Time Telemedicine (synchronous) also referred to as "Two way interactive television " can be as simple as a telephone call or as complex as sophisticated virtual reality (VR), robotic surgery or telesurgery [1, 2]. Healthcare providers and patients located at a distant are interacting with each other using communication technologies. Peripheral devices, apart from video conferencing, are also used by attaching them to the patient or the equipment to aid the interactive examination, for example, a tele-stethoscope to monitor patients heart beat or a tele-otoscope to examine patient ear.

Store-and-forward (asynchronous) technology involves acquiring medical data (images, bio-signals) and transmitting these data to a medical specialist for consultation, evaluation and other purposes. In store-and-forward technology, there is a need of simultaneous communication between both parties in real time. Teleradiology and teledermatology are the most beneficiary branches in using this type of service. Other branches of health care are also using it.

Wired communications have been used to implement telemedicine. Some of them include POTS and ISDN [4]. However, nowadays, modern wireless telecommunication like GSM, GRPS, UMTS mobile telephony standards, can be used.

The telemedicine unit consists of four basic modules [1]:

- Biosignal Acquisition Module: for biosignal acquisition through sensors and peripheral devices.
- Digital camera: for digital imaging or video capturing.
- Processing unit: computers.
- Communication module : GSM, POTS modem, Satellite, Internet, WAN, PAN.

2.2 Health care in Ethiopia

Continuous health threats, characterized by pandemic infectious diseases (HIV/AIDS, Malaria) and high level of infant–maternal mortality, low life expectancy and deteriorating health facilities are common in Sub-Saharan Africa. Sub Saharan Africa (SSA) with 24% of the global burden of diseases has 3% of the world's health workers and spends under 1% of world health expenditures[4].

Ethiopia experiences a heavy burden of diseases with a growing prevalence of communicable infections [5]. Many Ethiopians face high disease morbidity and mortality largely attributable to potentially preventable infectious diseases and nutritional deficiencies. A twenty year rolling health sector development program which proposes long term goals for the sector has been developed by the Ethiopian Government in response to such prevailing and newly emerging health problems.

Table 2.1: Summary of Health Indicators, 2006 GC (Ethiopia)

Indicators	1995 E.C	1996 E.C	1997 E.C	1998 E.C	1999 E.C
Total Population	67,220,000	69,127,021	73,043,501	75,067,000	77,127,000
PHS coverage (%)	61.3	64.0	72.1	76.9	86.7
PHS*coverage (%)	70.7	70.2	82.9	92.0	98.1
EPI coverage (%)	50.4	60.8	70.1	75.6	72.6
Health service utilization	0.29	0.36	0.3	0.33	0.32
Contraceptive acceptance rate	21.5	23.0	25.2	35.8	33.6
Antenatal coverage	27.4	40			
No of faculties					
Hospital	119	126	131	138	143
Health center	451	519	600	635	690
Health stations +NHC	2,396	1,797	1,662	1206	1,376
Private clinic not for profit	1,229	1,229	1,578	1,784	1,756
Private clinic for profit	1,229	1,299	1,578	1,784	1,756
Health posts	1,432	2,899	4,211	5,955	9,914
Pharmacies	302	275	276	246	302
Drug shop	299	375	381	1,754	2,121
Rural drug venders	1,888	1,783	1,787	1,754	2,121
Human resource in service					
Physicians	2,032	1,996	2,453	2,115	1,806
Health officers	631	683	776	715	1151
Nurses	14,160	15,544	18,809	17,845	18,146
Health assistant	6,856	6,628	6,363	4,800	3184
Para medical	4,641	5,215	6,259	5,431	3,863
Health extension workers			2,737	8,901	17,653
Human resource graduates					
Specialists	103	96	183	57	207
General Practitioners	182	193	309	188	161
Health Officer	181	249	333	247	789
Nurses	1,465	2,384	4,536	1618	1,846
Para Medicals	1,054	9,99	803	791	789`
Health extension workers		2,737	7,090	7,136	8560

As can be seen in Table 1 [5], the personnel and facilities available are far from satisfactory. When compared to other sub-Saharan countries, Ethiopia is a country with very poor health standards. In most cases, local services available do not provide patients with satisfactory medical care, especially when specialized skills are required. For instance there are 10 cardiologists for 72 million people [3].

The specialists and services that are available are concentrated mostly in cities. Current healthcare needs are hardly met due to inadequate capacity and competence, compounded by the limited number of healthcare specialists who are often concentrated in the urban areas.

In spite of high hopes, however, telemedicine has been slow to come into routine use. Problems related to telemedicine have been documented by various studies [4]. These studies often point out scarcity of resources, poor telecommunication infrastructure, policy related issues, and socioeconomic and cultural barriers as some of the problems.

Efforts to introduce telemedicine in Ethiopia started around 1997 [7]. The Ethiopian Telecommunication Corporation (ETC) recognized telemedicine as one of its services in June 1997. The Faculty of Medicine of Addis Ababa University was also attempting to create awareness of telemedicine and its benefits to concerned government and non-government organizations in the country in the same year.

A project which was funded by the International Telecommunication Union (ITU) was one development by the National Telemedicine Coordinating Committee (NTCC) [7]. Description about the project will be given later in the literature review chapter.

The need to use telemedicine for different disciplines in the health sector has been studied by different scholars in the area. Telemedicine for Teleopthalmology and Eye Care in Ethiopia, telecardiology are some of them [9, 12].

2.3 Telecommunication technologies

Telemedicine applications require both the use of telecommunication technology and medical technology [11]. The type of telecommunication technology used depends up on the specific need of the application. Digital data acquisition requires the need of advanced medical equipment technology together with additional hardware like digital camera, scanners, printers, and TV sets.

The telemedicine type (i.e. store and forward, and real time) determines the complexity of the technology applied. If, for example, the telemedicine type is a store and forward one, email will be sufficient. If there is, for example, a request from a referring physician to a specialist, it can be done using a system for sending the information electronically.

If the telemedicine type is real-time (synchronous) one, communication such as video conferencing may need a higher bandwidth technology such as Integrated Service Digital Network (ISDN) and satellite connection.

Poor communication infrastructure has been a major inhibitor of telemedicine in developing countries [4]. In such cases low cost connections like satellite could provide a viable and economic solution.

Very Small Aperture Terminal (VSAT), which can provide direct voice and data connectivity is one kind of technology that best suits for providing telecommunication services to rural areas. It can also provide telemedicine services. The Ethiopian Telecommunication Corporation (ETC) has already installed 470 VSAT terminals to provide services to rural areas.

An example of a VSAT network in the country is the SchoolNet [11]. The network connects all schools found in the country. The network was designed to provide services like video conferencing, Internet/Intranet, and VoIP solutions.

Another development with the VSAT technologies is the WoredaNet network. This network connects around 594 woreda administration centers across the country [9]. Its purpose is to form a kind of e-governance. The network was designed to support video conferencing which supports a two way interactivity of 45Mbps downlink to all terminals and 256 kbps uplink.

ETC has also introduced a multi-service digital data network (DDN) [17]. This type of network can provide services like frame relay, ISDN and digital leased line. The services reach to nine cities in the country and six node stations in the capital city. Some of the specific services that could reach to users via DDN are dedicated and dialup Internet access, managed private networks and distance education.

Currently the Broadband Multimedia Network (BMN) is one of the telecommunication advancement in the country. BMN is implemented based on different technologies such as Optical Network Systems and ATM (Asynchronous Transfer Mode) core networks. Regional cities are beneficiaries of this technology.

2.4 Goal Oriented Requirement Engineering

Requirement Engineering (RE) has moved from an immature software engineering phase to a well-recognized practice and research area spanning the whole system lifecycle [20]. RE requires a variety and richness of skills, processes, methods, techniques and tools. In addition, diversity arises from a variety of application domains ranging from business information systems to real time process control systems and from traditional to web based systems [34].

RE is concerned with producing a set of specifications for software systems that satisfy their stakeholders and can be implemented, deployed and maintained [20, 21]. Goal driven requirements engineering takes the view that requirements should initially focus on the why and how questions rather than on the questions of what needs to be implemented. “Traditional” analysis and design methods focused on the functionality of the system to be built and its interaction with users. Instead of asking what the system needs to do, goal driven methods ask why certain functionality is needed and how it can be implemented. Thus, goal driven methods give a rationale for system functionality by answering why certain functionality is needed while also tracking different implementation alternatives and the criteria to select among these alternatives.

As referred in [21, 34], goal oriented RE refers to the use of goals for requirements elicitation, elaboration, organization, specification, analysis, negotiation, documentation and evolution. Goals are objectives to be achieved by the system under consideration. Goals play a prominent role in the RE process. They derive the elaboration of requirements to support them.

Understanding the insistence on goals is a model of human organizations which views human and organizations as goal-seeking entities [22]. This model (goal driven RE) is prevalent in Information Technology (IT) and Information Systems (IS). In this model, information systems are considered to be built in order to help people and organizations achieve their goals.

Agents are active system components which may have choices of behavior to ensure the goals they are assigned to [21]. Achieving goals in general requires the cooperation of multiple agents. For example, the high level goal of “safe transportation” might require the cooperation of the pilot, the autopilot software, the on-board software, the on-ground tracking system, etc. Each goal is refined to sub goals so that each sub goal requires the cooperation of fewer agents; the refinement process stops when goals are reached that can be assigned as responsibility of single agents. Terminal goals assigned to agents in the software-to-be become requirements.

During goal oriented analysis, we start with initial stakeholders' goal such as "fulfill every book request" or "Schedule meeting" and keep refining them until we have reduced them to alternative collections of functional requirements each of which can satisfy the initial goals [19]. Initial goals might be contradictory, so the analysis must facilitate the discovery of tradeoffs and the search of the full space of the alternatives.

There are few goal driven approaches [20]. One is the KAOS (Knowledge Acquisition in automated specification) approach. It is a goal-oriented software requirements capturing approach in requirements engineering. It allows for requirements to be calculated from goal diagrams. The University of Oregon and the University of Louvain (Belgium) designed the KAOS methodology in 1990. It is now widely taught worldwide at university level and is a software industry de-facto standard for capturing software requirements [30].

The aim of the KAOS method is to provide assistance during the requirements engineering activity, starting from the elicitation of the objectives of the system and its integration into the environment, and ending with the formal definition of the specifications of the most critical parts of the system [30]. The model represents the required system using four different models. These four models are seamlessly integrated into one formal model and expressed using one formal language. The four models are:

1. *Goal Model:* The objectives can be refined into goals and sub-goals, allowing one to go from an abstract description to a more concrete one. The parent goal is explicitly linked to its children goals through "refinement" link.

2. *Object Model:* This model describes the objects, relationships, and events of the system and of the environment. It is equivalent to the UML object diagrams in many points.

3. *Responsibility (Agent) model:* This model presents agents of the system including software or human agents. The responsibilities and capabilities of each agent are modeled using the responsibility link between an agent and a requirement that must be made fulfilled by this agent and the capability link between an agent and operations it can perform.

4. *Operation Model:* Goals are eventually refined into operational software requirements.

2.5 Multi-criteria Decision Aid Techniques

Choice of the best alternative is a common problem in the activities of human beings [26]. In general, to make a choice individuals compare the features of the available alternatives while taking into consideration a number of aspects (criteria). As stated in [25], the multi-criteria choice problem is a great challenge, and the more criteria the problem involves, the more difficult the problem becomes.

Although the term multiple criteria decision making (MCDM) was hardly known some 20 years ago, MCDM has seen remarkable growth over the past two decades and is now an important area of Operations Research and Management Science. Moreover, in most recently published OR/MS survey texts there is usually one chapter devoted to topics in multiple criteria decision aid techniques [25].

As stated in [27], within a multi-criteria decision context, decision making problems could be realized in the following manner: A Decision Maker (DM) considers a set A of alternatives (e.g. Healthcare providers, physicians, healthcare services) and tries to take an optimal decision considering all factors that are relevant to the analysis. Since these factors (or criteria) usually produce conflicting results and conclusions, the end result might not be optimal.

Decisions made in the above context might be represented in different forms which are referred to as ‘Problematics’ [27].

- Problematic α: Choosing one alternative.
- Problematic β: Sorting the alternative in homogeneous groups defined in a preference order.
- Problematic γ: Ranking the alternatives from the best one to the worst one.
- Problematic δ: Describing the alternatives based on their performance in the criteria.

The first thing that should be considered in the decision making process involves the identification of the set A of alternatives [25, 27]. This set may have two different forms: i.e. continuous and discrete. In the continuous case, A is including infinite number of alternatives or at least a very large number of alternatives in which the enumeration is difficult. Where as in the discrete case, set A is containing finite number of clearly identifiable alternatives a1, a2, a3… an. This situation is met in each and every part of human life. In our case, selection of the best physician for a consultation is done among finite and small number of physicians in the country (so a discrete set A of Alternatives).

Making a decision in the multi-criteria context requires the appropriate aggregation of all the pertinent decision factors $g = (g_1, g_2, g_3\ldots g_m)$, which are referred to as criteria. A criterion g_i is a non-decreasing real-valued function that shows the performance of the alternatives and it also defines how the alternatives are compared to each other. For instance:

$g_{ij} > g_{kj} \leftrightarrow a_j > a_k$ (a_j is preferred to a_k)

$g_{ij} = g_{kj} \leftrightarrow a_j \sim a_k$ (a_j is indifferent to a_k)

Where g_{ij} is the performance of alternative a_j on criterion g_i

The aggregation of criteria is a crucial step in making decision within multi-criteria context. Aggregation of criteria can be done in one or different ways depending on the form of criteria aggregation model. As stated in [27], there are three aggregation models in the MCDA field.

- Outranking relations.
- Utility functions.
- Decision rules.

Brief description about the used aggregation model is discussed later in the Multi-Criteria Doctor’s Unit Selection chapter.

3. Related Work

Introducing telemedicine to Ethiopia is a cost effective way of providing health services to people of the country [7]. Telemedicine also helps to educate the public on prevention methods. But introducing telemedicine requires creating awareness and working or building up telecommunication infrastructure, to rural areas. There have been some attempts to introduce telemedicine in Ethiopia.

The first effort made in introducing telemedicine was in 1997 [7]. The effort was established by the National Telemedicine Coordinating Committee (NTCC). The NTCC was formed with the objective of organizing telemedicine effort in Ethiopia. The Committee was comprised of representatives from three local partners namely: Ministry of Health (MOH), Ethiopian Telecommunication Corporation (ETC), and the Faculty of Medicine of Addis Ababa University.

NTCC had submitted a proposal for ITU based on TIU's commitment to support telemedicine pilot projects in developing countries. The objective of the proposed project was to connect ten selected sites (hospitals and medical institutions) to the Internet [7]. Once the proposal was accepted by ITU, ITU had promised to provide material and expert support. Based on the promise, ITU experts visited selected sites to be connected in the first phase of the project. The expert's report, A project Implementation Document, specified that the project would be implemented in the following three phases:

- **Phase I:** Pilot program, involves connecting ten sites,

- **Phase II:** expanding the telemedicine network to more hospitals and health institutions in the country
- **Phase III:** Expanding it further to join International Telemedicine Networks.

In the pilot project, a telemedicine network was formed by connecting 10 hospitals across the country with dial up internet connection. Even though there was no full documentation about the network, the only document that can be found about the WAN connection showed how the nine hospitals are connected to the central hospital in a kind of star topology. From telemedicine point of view, the network depicts that the central site is where all the consulting specialists are stationed.

The conceptual network design of the existing telemedicine network for the pilot project is shown in figure 3.1.

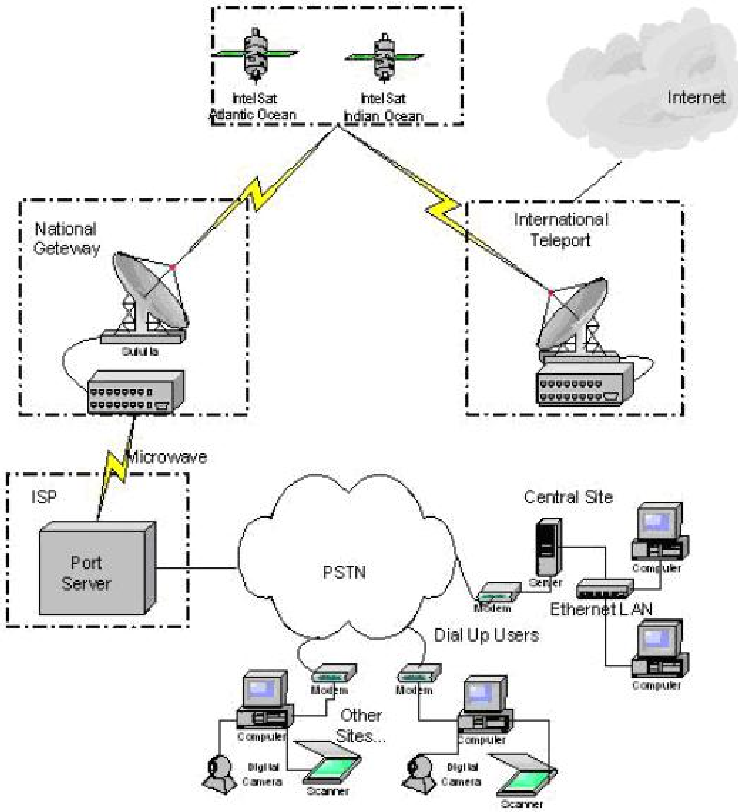

Figure 3.1: Conceptual network design of the existing telemedicine network

All the ten sites will have dial up Internet connection from the sole service provider ETC through the Public Switched Telephone Network (PSTN) [7]. Each hospital will be equipped with a digital camera and scanner for dermatology digital image acquisition. The national Gateway at the Sululta satellite ground station connects to the Intelsat Indian Ocean and Atlantic Ocean regional satellites. There are no firewalls or internetworking devices such as switches involved in the current telemedicine network. The only devices used to connect the 10 hospitals are the modems attached to each of the PCs.

The pilot project doesn’t contain designs specific to telemedicine [7]. This is because; the main objective of the pilot project was to connect hospitals so that doctors can communicate for consultation using e-mails.

As referred in [11] the schedule for the project had shown that testing the systems operation was scheduled for November 2003. But the information gathered from the ITU representatives had indicated that hardware required like cameras and servers for the central site were not purchased.

Some of the problems of the Pilot Project include the following:

- No application specific to telemedicine was devoloped. General purpose email programs are used for doctors to communicate.
- No database is designed for storage of patient/physician information.
- Network expansion is not considered in the design.
- Large files like medical images and x-ray files could not be sent vial general purpose emails.
- No mechanism was proposed for keeping patient information secure.

Local and International partners were supporting this pilot project. These partners include MoH, Faculty of Medicine of Addis Ababa University (FoM), ETC, Ethiopian Telecommunication Agency (ETA), ITU, World Health Organization (WHO), United Nations Economic Commission for Africa (UNECA) and United Nations Education, Scientific and Cultural Organization (UNESCO).

The study in [11] designed communication infrastructure for national telemedicine in the country. The design includes:

- Local Area Network (LAN) architecture for telemedicine network.
- Wide Area Network (WAN) architecture for the national telemedicine network.
- A prototype implementation of the proposed architecture.

Expandability, security, and cost were the primary goals that were given priority when the design was done.

The LAN architecture considered the central site, Tikur Anbessa Hospital. The hospital is organized into 16 departments [15]. The proposed architecture will follow the hierarchical structure of the hospital. The decision to make the selection between the various LAN technologies was done based on:

- Expected application to run on the network and their traffic pattern.
- Physical location of the offices and users to be connected in the buildings.
- The rate of network growth.
- The abundance of network technology in the market.
- Simplicity of installation and maintenance.

The WAN architecture design considered the issue of WAN service providers. The sole provider of the service is ETC. Among the services provided by ETC, the WAN infrastructures that are considered for the national telemedicine network include:

- Internet Services: provide basic internet services over dial-up or leased lines.

- Digital Data Network: provide dedicated internet, IDSN and frame relay services.
- SchoolNet VSAT network: covers secondary schools and institutes of higher learning.
- WoredaNet VSAT network: covers districts which are also called Woredas.
- Broadband multimedia Network (BMN): Provides high speed optical communications to major cities.

Selection of the infrastructure for the WAN was done based on the parameters which include geographical coverage, bandwidth, mode communication, rental cost of WAN connection and capacity to add more LANs. Based on the comparison made, the WoredaNet was selected as telemedicine network.

As stated in [15], the BMN would be best for it represents the state of the art services and higher bandwidth. Since there was no potential development of BMN at that time, it was not considerd as an independent infrastructure.

The solution proposed for designing the LAN architecture didn't consider the case for other health centers and hospitals which have less number of buildings and arrangements.

Instead of considering the central site, Tikur Anbessa Hospital, only it would be better to see other hospitals and health centers and propose one or more architecture for different groups.

The infrastructure selected for the WAN architecture didn't fully consider future technological advancements in the country. In addition to the current technology found in the country, the study had to consider future developments.

The prototype developed for the proposed architecture is a web based application. The main functions included were: providing user management services, patient management services, referral systems and physician lab request systems.

As future work, the study had recommended issues that include:

- Real time consultations via audio and video conferencing.
- Distributed databases at different sites.
- Expert systems where physicians can make use of it for querying to get experience.
- Systems that support physicians monitor patients over heterogeneous networks including handheld devices in 2G/3G mobile networks.

The design of a mobile teleconsultaion system is presented in [8]. The aim of the project was designing a system that would concentrate on a specific area: teleconsultation.

When designing, the following things were considered.

- Use of software and hardware which are based on the open system model.
- Use of a video camera that has a feature of being remotely controlled from distant location. This minimizes extra manpower which is required to adjust the pan, tilt or zoom function.
- Simple user interface.

The whole system consists of three modules: the patient module, the relay (fixed) and the physician module. The patient module consists of camera, scanner, and protocols for managing the camera remotely, and a video server for transforming the video stream into internet packets. The relay module consists of the receiving wireless serial interface and an Integrated Services Digital Network (ISDN) modem. It serves as a contact point for the patient module. The physician module consists of another ISDN modem connected to a desktop PC with a web browser. It controls the remote video camera.

The technology used for the communication was ISDN which has low data rates. Replacement of ISDN by ADSL or GSM mobile phones has been stated as future work. The system considered only real time consultation which doesn't store the video or audio streams for later reference or actions.

Virtual Critical Care Unit (ViCCU) is an advanced telemedicine system developed by CSIRO in conjunction with Sydney west area health service [10, 18]. The system allows an emergency care specialist in a major referral hospital to remotely lead a team in a small rural hospital during the treatment of critically ill patients.

High quality audio/video transmission was one of its features achieved by using DV (Digital Video) over IP (Internet Protocol) technology [18]. The hospitals, in the telemedicine network, are connected by a Gigabit Ethernet-based network. The system design used the iterative participatory design approach which requires the involvement of users intensively. Even though the system was successfully implemented and tested, the technology used (hardware and software) is not feasible to be used in developing countries like Ethiopia.

The study in [6] was conducted to examine the need of the adoption of Teleophthalmology in sub-Saharan Africa.

Ethiopia, like most sub-Saharan African countries, has a limited number of specialists who are concentrated in urban areas. In Ethiopia, the ratio of ophthalmologists to the population is 1:1,200,000, resulting in inadequate delivery of ophthalmology-related healthcare services.

Using both primary and secondary data collection approaches, the study concluded the need of telemedicine as well as the adoption of teleophthalmology applications in Ethiopia. According to the authors, the research is a starting point to investigate further teleophthalmology and other telemedicine services for Ethiopia.

A study in [3] examines the role of telemedicine in the healthcare systems and in addition it studies the costs and benefits of introducing telecardiology services in Ethiopia. The cost comparison is made between the treatments of cardiac patients traveling abroad versus patients treated via telecardiology. The finding shows telecardiology is more feasible and more cost effective compared to patients traveling abroad for treatment.

Recently a telemedicine initiative has made people in Ethiopia to get consultation from CARE Hospital, Hyderabad, India [15]. It is known as the Ethiopian Pilot project (funded by the Government of India). Under this project—the forerunner to the main Pan-African e-Network project of the Government of India— Telecommunications Consultants India Limited (TCIL) has established a fiber-optic based network between India and Ethiopia, to enable medical consultation and continuing medical education from the CARE Hospital to Black Lion Teaching Hospital and Nekemte Hospital in Ethiopia.

These two hospitals in Ethiopia are provided and equipped with medical equipment such as X-Ray machine with digitizer, electrocardiogram (ECG), ultrasound machine, telepathology microscope, glucometer, defibrillator, blood pressure measuring instrument, urine analyzer and others.

Doctors in at least two Ethiopian hospitals, including Addis Ababa's Black Lion Teaching Hospital, will consult their counterparts in India using digital technology. It is the start of a venture in which India plans to establish ten 'super specialty' hospitals in Africa under its Aid-to-Africa Budget programme. India hopes it might capitalize on its investment in the future by charging fees for advice given by Indian doctors.

The main objective of the pilot project is to connect two hospitals in Ethiopia with one hospital in India by using fiber-optic cable which is the most expensive technology.

This pilot project cannot reach to rural areas where the number of physicians is almost zero. When trying to see the feasibility of the pilot project, it is not practical for countries like Ethiopia which can't expand the fiber-optic technology through out the country.

Further information about the status of the project could not be found.

iPath is a collaborative platform for exchanging medical knowledge, distance consultations, group discussions and distance teaching in medicine [12]. It is an open source software project with the aim of developing a multi-purpose communication platform for telemedicine, distance teaching and medical knowledge management.

A specialist at the department of Pathology of Tikur Anbessa Hospital is using the system for communicating with other specialists located in other countries. He takes a picture of the kidney using a digital camera and after making the necessary modification using Microsoft photo editor, the picture will be sent to a specialist to make remote diagnosis. A remote specialist, after receiving the information and picture, he/she will make analysis and add comments which will be accessed by the local specialist via the website. Reply to the request most of the time takes one or more days. This store and forward concept could not be applied to when a quick response is required. Diagnosing critically ill patients is one example which doesn't benefit from this type of systems.

There are pilot projects which are conducted in developing countries like Mali [13]. These projects were basically aimed at evaluating the feasibility of telemedicine network in developing countries. Similar pilot project was applied in three developing countries (Peru, Brazil and South Africa) to alleviate the sever shortage of medical specialists [14].

4. National Telemedicine System Network Architecture

4.1 Design Goals

The overall goal of the national telemedicine network architecture is to provide connectivity among healthcare providers of the country with low cost and affordable facilities using current technologies like SchoolNet and WoredaNet.

The Network should be proposed in such a way that it could be cost effective, expandable and secure.

4.1.1 Security / Privacy

Patient information should be kept secured from unauthorized users. Confidentiality of the information could be kept by considering different security mechanisms like Virtual Private Networks (VPN) and encryption mechanisms by the time information is transferred from one healthcare provider to another.

4.1.2 Expandability

This work considers the current available healthcare providers only. But every year the number of providers is increasing at an alarming rate. As stated in [16], one of the major objectives of the Health Sector Development Program (HSDP) is to cover all rural Kebeles with Health Service Extension Program (HSEP) to achieve universal primary healthcare coverage. There is also an increase in private healthcare providers. The number and type of diseases is also increasing from time to time. Therefore, the proposed network architecture should consider all the above cases for its acceptability.

4.1.3 Cost

Implementing a national telemedicine system appears to be expensive. But to minimize the overall cost, available telecommunication technology infrastructures, open source software, and available healthcare facilities need to be thoroughly considered in the design.

4.2 Design Requirements

To save the overall cost of the telemedicine network, the design bases itself on available telecommunication technologies. Any healthcare service provider that wants to be part of the telemedicine network should be connected to at least one of the network technologies (WoredaNet, Broadband Multimedia Networks).

4.3 Proposed Network Architecture

The Telemedicine system network architecture has two basic components (The Patient Unit and The Doctor's Unit). Any healthcare provider can act as a Patient Unit at one time and a Doctor's Unit at another time. Overall national telemedicine system network setup is shown in figure 4.1.

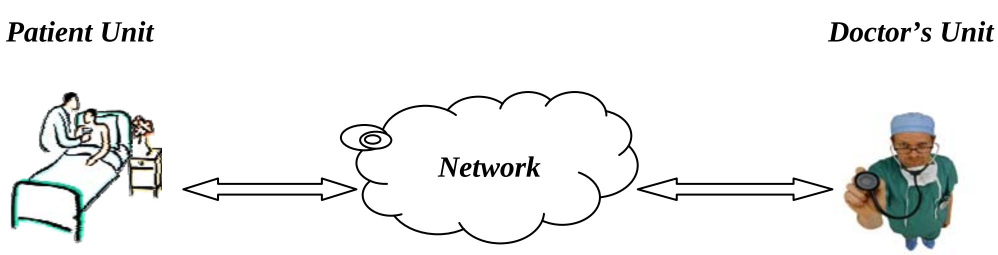

Figure 4.1: Overall national telemedicine system network setup

4.3.1 Patient Unit

The Patient Unit is the unit where remote consultation is initiated. It has the patient who will get remote diagnosis from a physician located at the Doctor's Unit. Here the patient might choose one of the telemedicine types.

Store and Forward Telemedicine

If the Patient Unit prefers this type of telemedicine, it will store all the information that is needed by the specialist in the Telemedicine server by specifying the recipient (Doctor's Unit). After reply from the Doctor's Unit, the remote diagnosis results can be accessed from the telemedicine server in the Patient Unit.

The basic elements of the Patient Unit network (for store and forward telemedicine type) are shown in Figure 4.2.

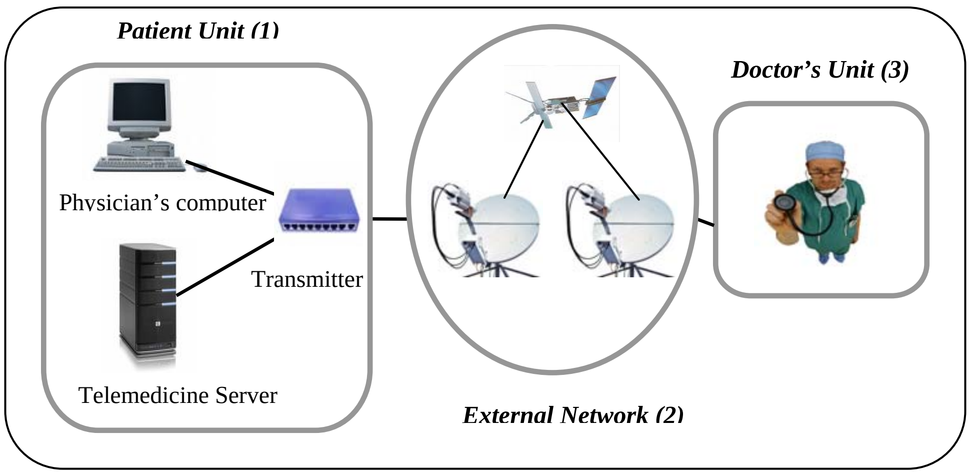

Figure 4.2: Network Architecture at the patient unit for store and forward telemedicine.

Real Time telemedicine

Once the Patient Unit decides to get remote consultation via real time telemedicine, it will request the Communication server to make connection with the Doctor's Unit. Once the connection is established, the information during the consultation will be stored in the telemedicine server found in the Patient Unit.

Web cameras, microphones, and a communication server are required for real time consultation. The communication server (for the whole national telemedicine system) could be installed at any one point in the network (for example at the telemedicine department of Tikur Anbessa Hospital).

The basic elements of the Patient Unit network (for Real time telemedicine type) are show in figure 4.3.

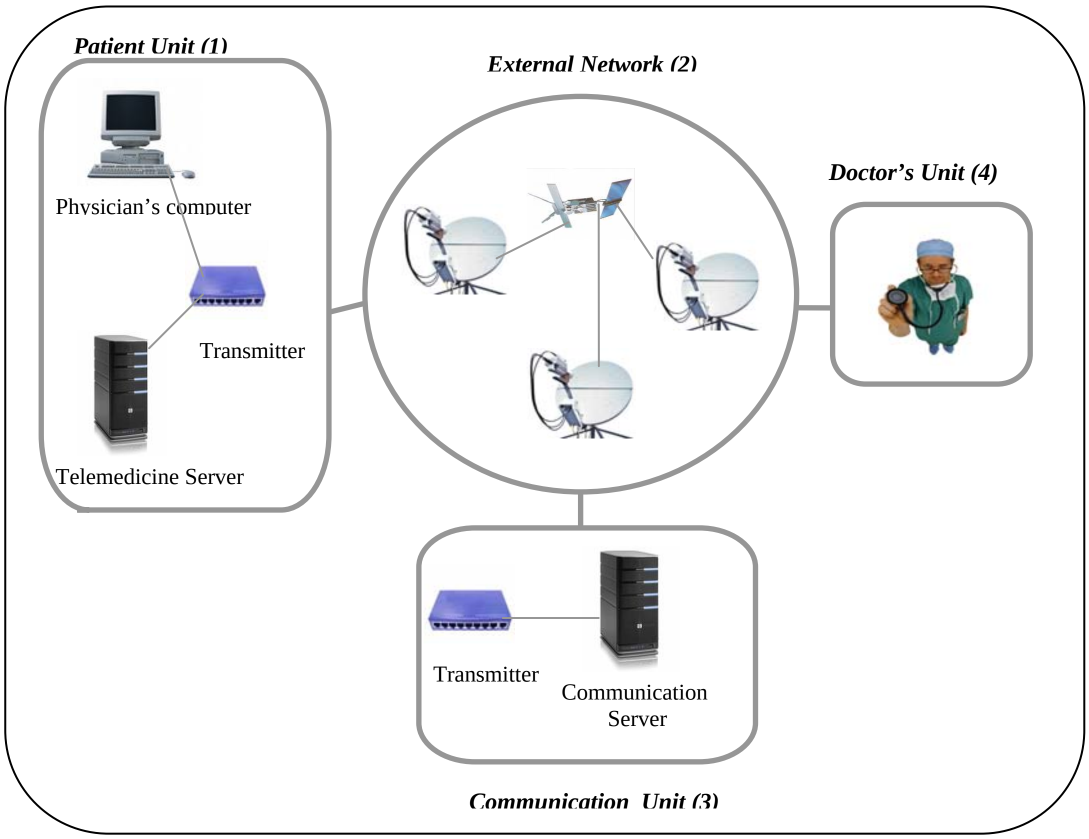

Figure 4.3: Network Architecture at the patient unit for real time telemedicine system

4.3.2 Doctor's Unit

This unit has the physician who gives the consultation to the Patient Unit. Once it accepts the request, it will react to the request depending up on the telemedicine type.

Store and Forward Telemedicine

For this type of telemedicine in this unit, the physician will respond to the Patient's Unit request. The physician will be notified for new requests.

The basic elements of the Doctor's Unit network (for store and forward telemedicine type) are shown in figure 4.4.

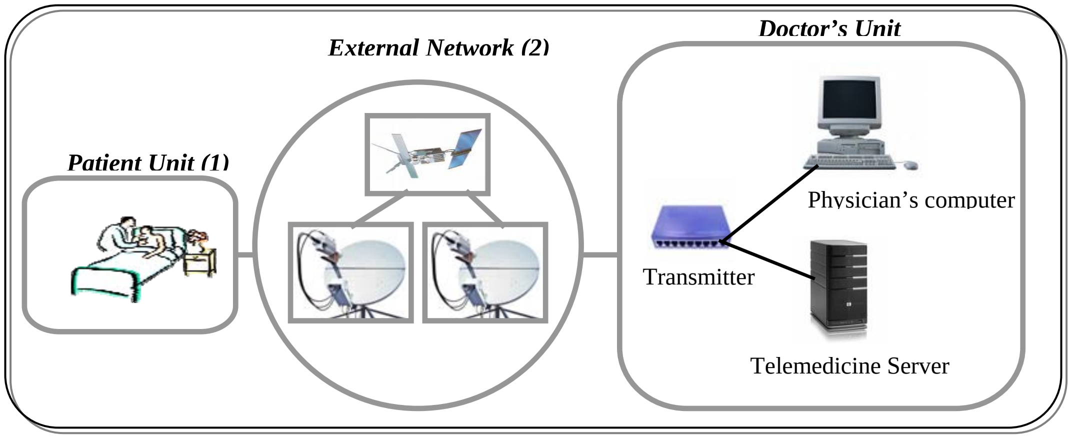

Figure 4.4: Network architecture at the Doctor's Unit for store and forward telemedicine

Real Time telemedicine

Here the physician will receive notification from the communication server for real time consultation. He/she will make communication with a physician located at the Patient's Unit using web cameras and microphones.

The basic elements of the Patient Unit network (for Real time telemedicine type) are show in figure 4.5.

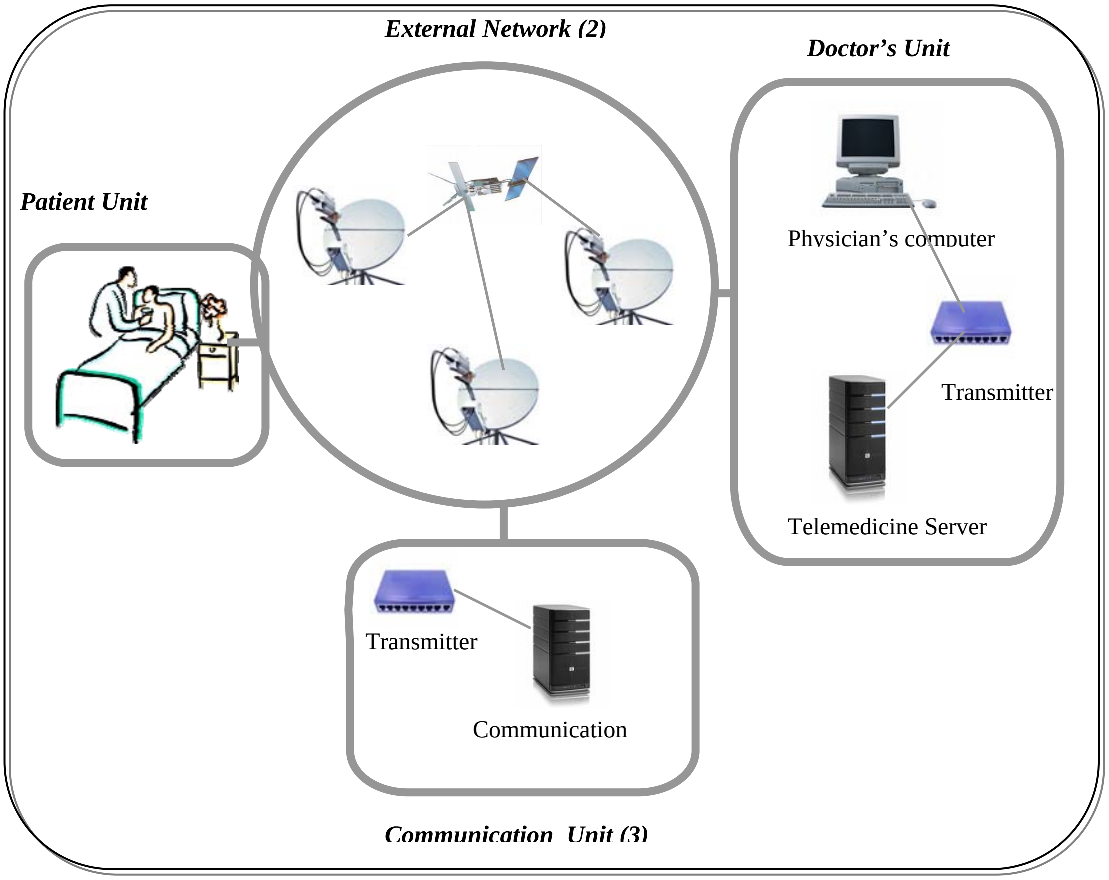

Figure 4.5: Network Architecture at the Doctor's Unit for Real time telemedicine.

4.3.3 External Network

As long as the existing infrastructure is concerned, WoredaNet is best suited for connecting the Patient's Unit and Doctor's Unit for the national telemedicine system. As stated in [9], WoredaNet has better geographical coverage than others (BMN, SchoolNet).

Even though BMN has better bandwidth than others, it is centered only in urban areas. It could be considered as possibility to be used integrated with the VSAT based networks.

When considering the Local Area Network used in each telemedicine Unit (Patient Unit, Doctor's Unit), computers in the telemedicine system could be connected using any one of the LAN technologies (bus, star, ring, mesh) depending up on the number and location. The logical topology in the Local Area Network should be client server architecture where each physician's computer will act as a client and the telemedicine server will be the server for storing information about previous consultations, diagnosis, patients, physicians and related information about the telemedicine.

4.3.4 Communication Unit

This unit contains one or more communication servers that enable both audio and video communication between the Patient Unit and the Doctor's Unit. Different protocols could be used for the real time communication (e.g. SIP, H323).

5. National Telemedicine System Model

5.1 Overview

This Chapter presents the proposed telemedicine system model aimed at providing store and forward and real time consultation with a multi-criteria Doctor's Unit selection. A three layered telemedicine system is proposed. The top layer of the model, referred to as the consultation layer, represents any one of the consultation services (i.e. a store and forward and real time one) that is held between the Patient and Doctor's Units. This layer will be used as an interface for the physician/specialist to communicate being at the Patient and Doctor's Unit. The middle layer, referred to as the Doctor's Unit selection layer, is used for processing physician selection for a particular consultation. The third layer, referred to as the communication layer, is the bottom layer that is used to achieve communication between the two units (i.e. Patient Unit and Doctor's Unit) using communication protocols and servers.

The rest of this chapter is organized as follows: section 5.2 presents design considerations and methodologies; section 5.3 discusses the National Telemedicine System model design; section 5.4 presents design of Multi-Criteria Doctor's Unit layer Architecture.

5.2 Design Considerations

5.2.1 Design Assumptions

The main assumptions considered in designing the telemedicine system are the following.

- **Target Healthcare system**: the system primarily targets at the context of the Ethiopian healthcare system.

- **System Design:** the design of the system mainly focuses on the designing of the Multi-Criteria Doctor's Unit Selection (MCDUS). The system design doesn't deal with the detail design. It shows only the basic components the system has to include.
- **Network infrastructure:** The design of the system will use the telemedicine network architecture proposed in Chapter 4. In addition, the system assumes to use an existing network infrastructure in the country (e.g. WoredaNet, SchoolNet, and BMN).
- **Communication Protocols:** The system assumes to use communication protocols for audio and video (like SIP, H323 and others) communications.

5.2.2 Design Methodology

A methodology can be simply defined as a set of procedures that one follows from the beginning to the completion of the software development process [24]. The nature of the methodology is dependent on a number of factors, including the software development environment, the organization practices, the type of software being developed, user requirements, and availability of software and hardware.

Different methodologies have been developed to resolve different types of problems. Specific methodologies have been developed to resolve certain classes of problems, also called domain of application, for which it is well suited.

These methodologies have a number of common characteristics:

- A mechanism for the translation of information domain representation into design representation,
- A way of representing functional components and their interfaces,

- Heuristics for refinement and subdividing, and
- Quality assessment guidelines.

The first phase in each methodology aims at collecting and organizing the specification or requirements. For our case, we use the Goal Oriented Requirement Engineering methodology for collecting and organizing the system specifications. The second phase is used to make analysis of the requirements that are obtained in the first phase. The third phase is designing the system.

In designing the NTS, we have followed the approach shown in Figure 5.1 that is used in [23] with little modification.

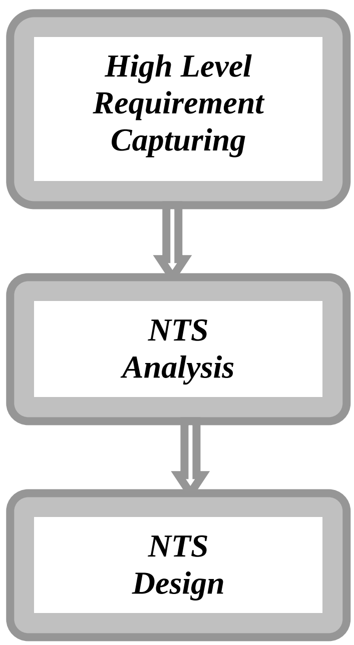

Figure 5.1: Phases of the system design process

5.3 National Telemedicine System Model Design

5.3.1 High Level Requirement Capturing

This phase is applied for capturing the requirements that need to be included in the system design. A goal Oriented Approach is employed in this process. This approach produces structured sets of goals which are derived from the initial system specification and objectives [31]. As referred in [23, 32], a goal is defined as an objective that the system under consideration should achieve. Goals always have a system level context, even though lower level constructs may inherit or be responsible for goals. In identifying system goals of the NTS, the following steps are done.

- Identification of generic goals from the initial objective of the system. The Goal model in KAOS is used.
- Structuring and refinement of goals using the tool *Objectiver*.

5.3.1.1. Goal Model

Goals are desired system properties that have been expressed by some stakeholders [29, 32, 34]. For instance a goal:

"*Each time a physician needs remote consultation, the system has to help him/her find all the available physicians that satisfy his/her requirements*".

Identification of goals is done using one of the goal oriented requirement engineering approach called KAOS. With KAOS, the analyst can find new goals by interviewing current and future users and by analyzing the existing systems, reading the available technical documents, etc. The analyst uses KAOS for structuring the collected goals using directed, acyclic graphs so that:

- Each goal except the root goal should be justified by at least another goal that explains *why* the goal was introduced in the model.
- Each goal except the leaves is refined as a collection of sub goals that shows how the refined goal can be reached.

Identifying goals is neither a top down nor a bottom up approach. Most of the time the two approaches are used simultaneously. Analysts might define intermediate goals first. Then they proceed for high level goals by asking "**why** do we want that?" To also discover more specific goals they have to ask themselves questions such as "**how** shall we achieve that objective?" [32].

Figure 5.2 is a generic goal model for the NTS with MCDUS. Identification of goals is done using the above two approaches.

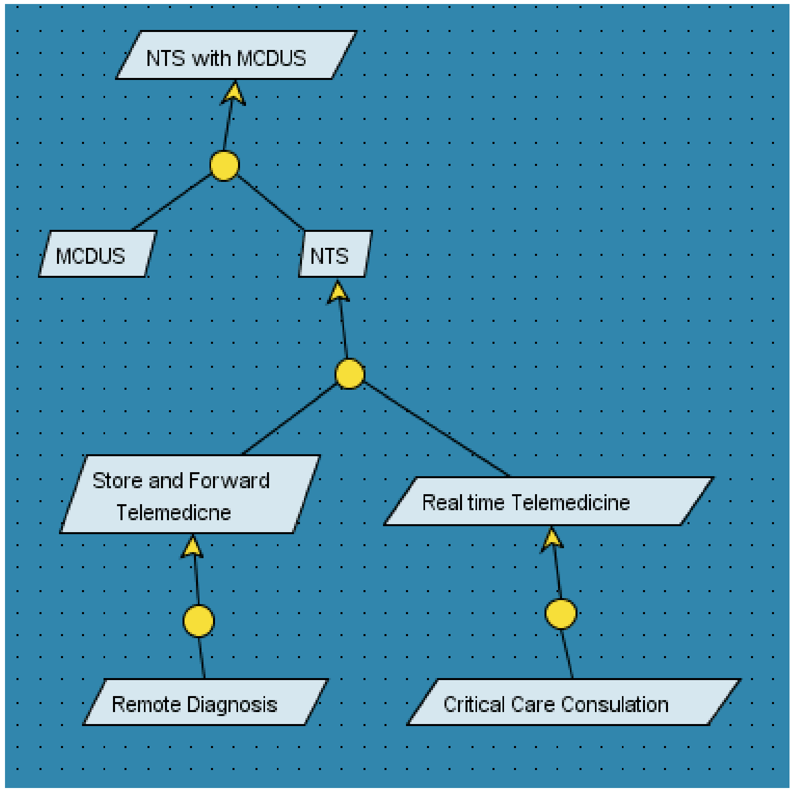

Figure 5.2: Generic goal pattern for the system using Objectiver tool

Each parallelogram in the figure represents a goal. Circles represent refinements of a parent goal and a list of sub goals. The diagram can be read as follows:

The main goal of the system is to build a NTS with a MCDUS model. The NTS could be implemented by using the store and forward and real time telemedicine that are used to give remote diagnosis and critical care consultation respectively.

There are different tactics for decomposing goals into sub goals. The tactic that was used here is a *case driven decomposition:* the sub goals enumerate all the cases that must be covered to fulfill the father goal. For instance, the MCDUS and NTS needs cover all the needs of the system. Each leaf (goals which does not have sub goals) in the above diagram can be decomposed into sub goals. In this work especial emphasis is given to the MCDUS goal only. So refinement of other goals is not done. For the MCDUS, the refined goal structure is as shown in Figure 5.3.

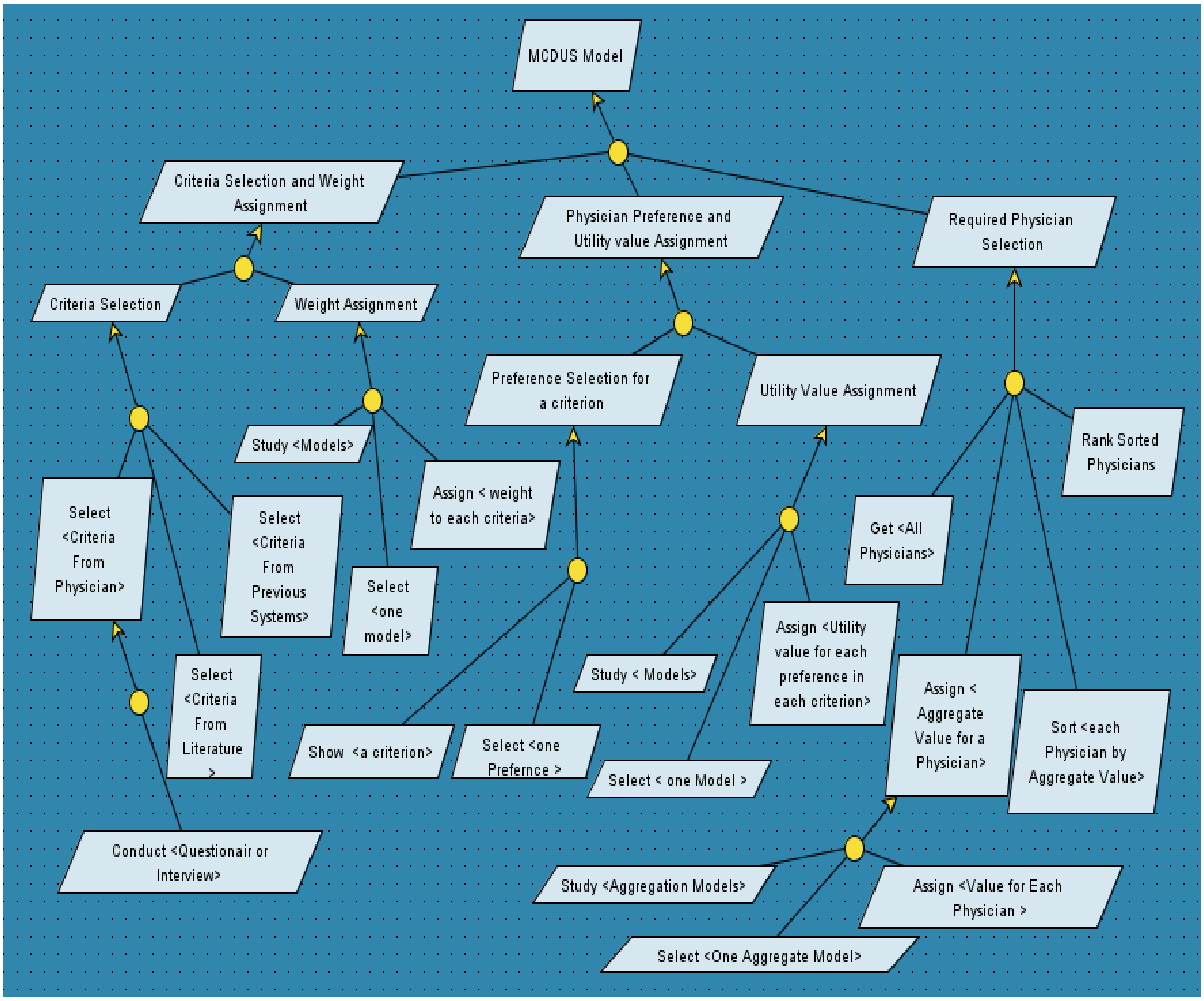

Figure 5.3: Refined goal structure for the MCDUS goal

5.3.2 National Telemedicine System (NTS) Analysis

This phase analyses the defined goals with the aim of organizing the system specification. The following main analysis steps are performed.

- ✓ Identifying Objects and Agents,
- ✓ Identifying responsibilities, and
- ✓ Identifying Operations.

All the above steps are performed using a tool called Objectiver that is developed based on the goal oriented Requirement Engineering approach called KAOS.

5.3.2.1. Object Model

The object model is used to define and document the concepts of the application domain that are relevant with respect to the known requirements [29, 31]. As part of the object model, one will find objects pertaining to the stake holder's domain and other objects introduced on purpose to express requirements or constraints on the operational system.

Three types of objects may coexist in the object model:

- *Entities*: they represent independent, passive objects. For instance, analyst, buttons, etc... 'independent' means that their description needn't refer to other objects of the model. They are 'passive' means they can't perform operations.
- *Agent*: represents independent, active objects. For instance, physician, selector System are agents. They are active meaning they can perform actions.
- *Association*: are dependent, active objects. 'Dependent' because their descriptions refer to other objects.

Object identification is driven by the goal definition process. Most goals' short and long term definition refer to domain objects worth being modeled and documented. Another way to identify new objects is by looking at the requirements and discover the system components that are necessary to satisfy the requirements. Objects are represented in goal diagrams; the **concerns** relationship links the object with the requirement.

Based on the above two identification methods, about six objects are identified. The object model for the MCDUS part is show in Figures 5.4-5.8.

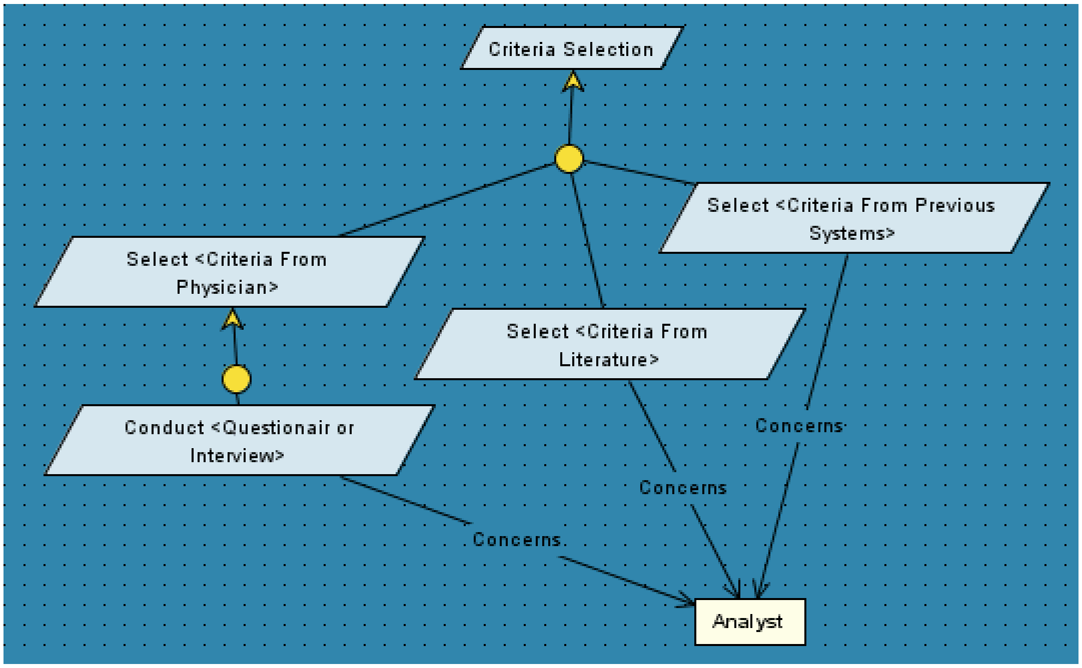

Figure 5.4: Object Model for the Criteria Selection Goal

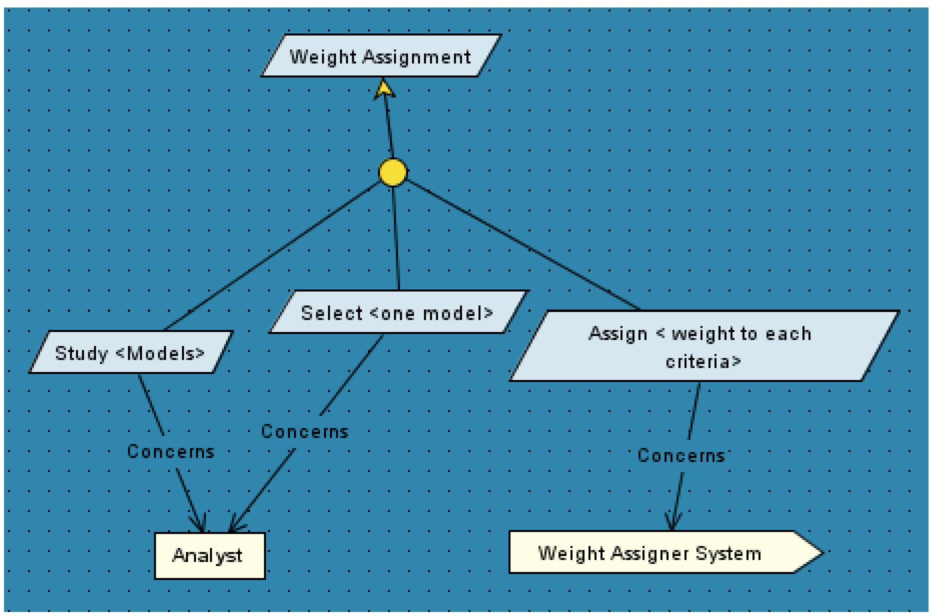

Figure 5.51: Object Model for the Weight Assignment Goal

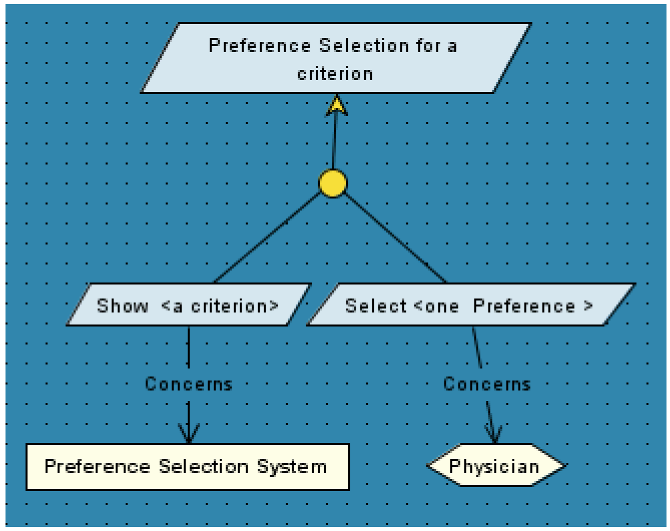

Figure 5.6: Object Model for the Preference Selection Goal

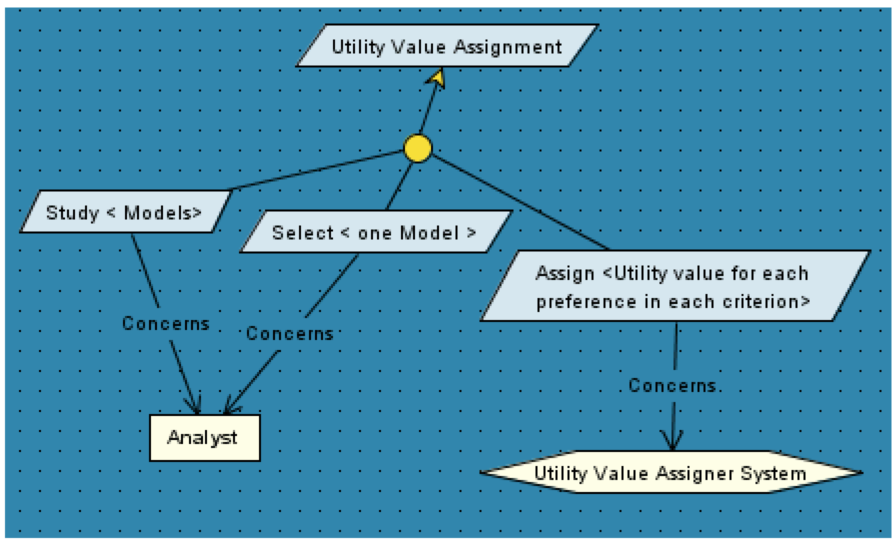

Figure 5.7: Object Model for the Utility Value Assignment Goal

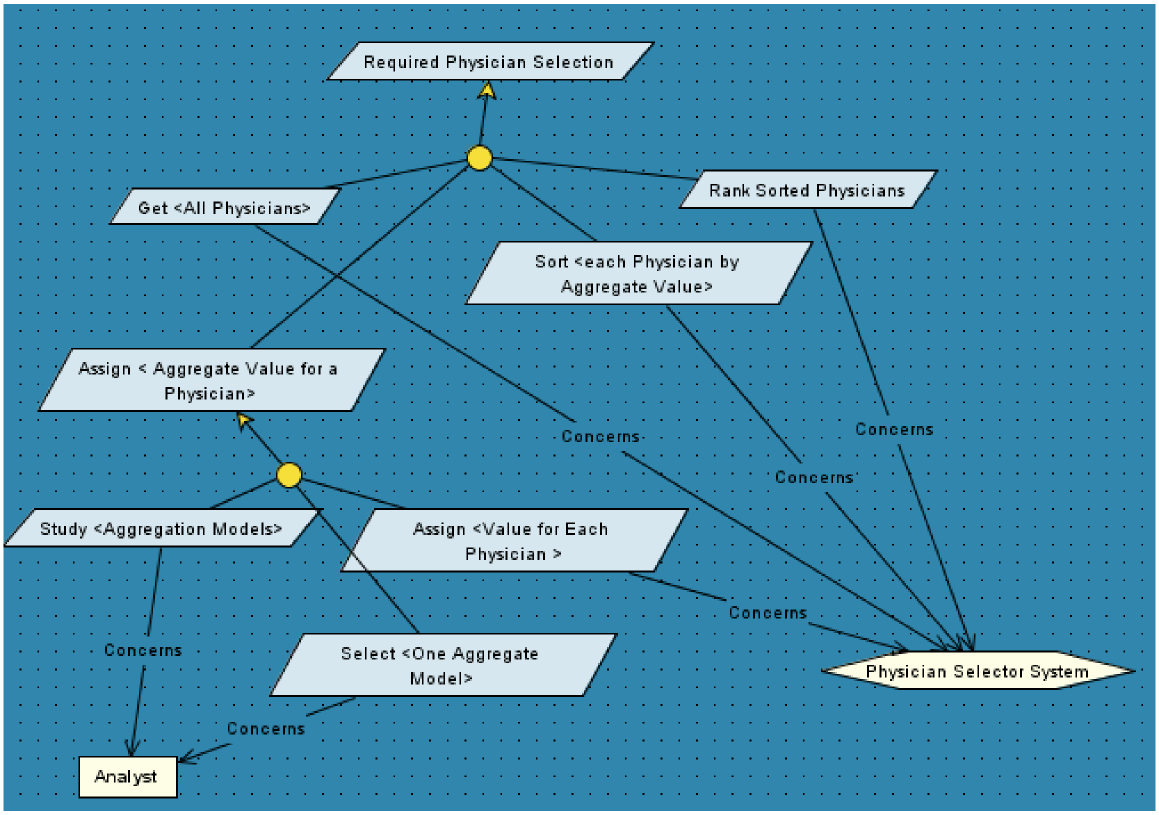

Figure 5.8: Object Model for the Required Physician Selection Goal

5.3.2.2. Responsibility Model

The responsibility model contains all the responsibility diagrams [29]. A responsibility diagram describes for each agent, the requirements and expectations that it is responsible for, or that have been assigned to it.

To build a responsibility diagram, the analyst reviews the different requirements and expectations in the goal model and assigns an agent to each of them. Figure 5.9 shows the responsibility diagrams for each agent.

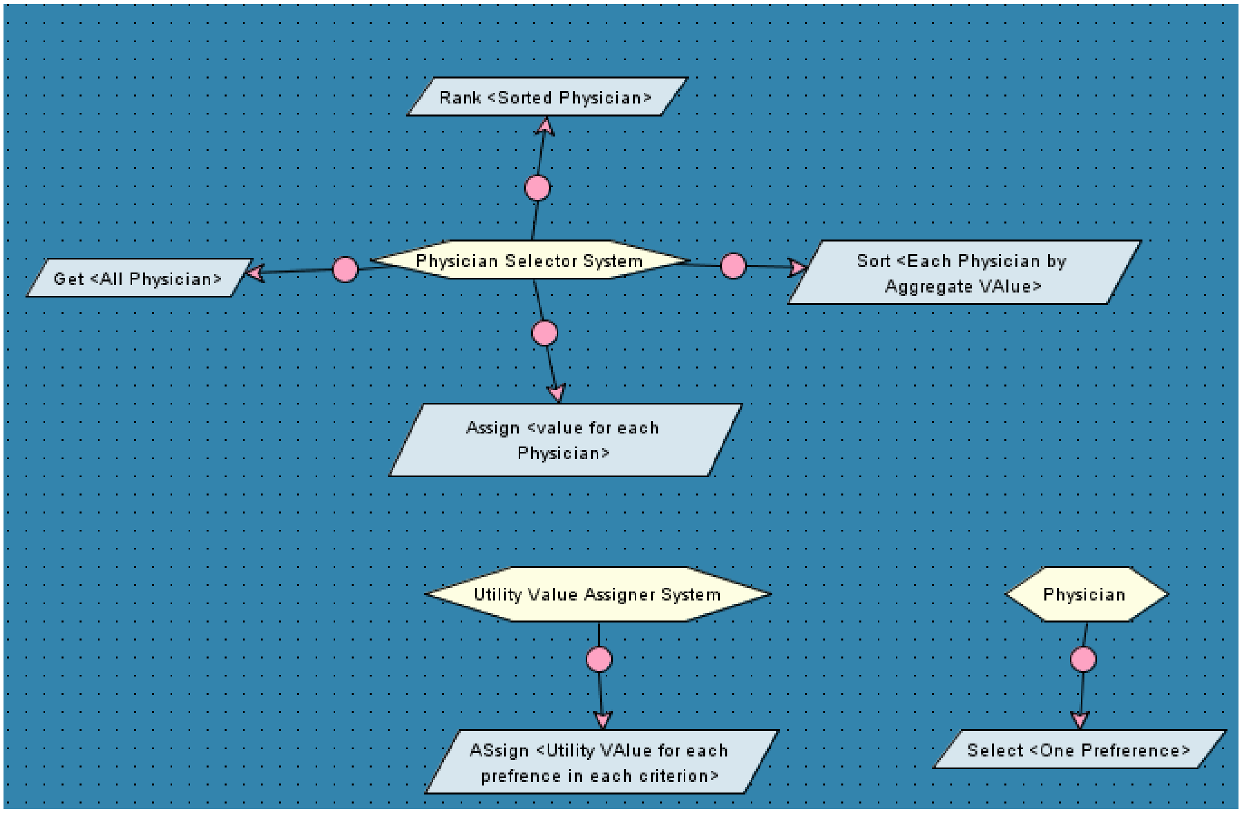

Figure 5.9: Responsibility Models for the MCDUS

5.3.2.3. Operation Model

The operation model describes all the behaviors that agents need to fulfill their requirements [29]. Behaviors are represented using operations performed by agents and operations work on objects.

Operations can be identified from two sources: they can be directly expressed by stakeholders during requirement elicitation or they can be identified by looking at all the existing requirements. In the MCDUS part of the system, some of the operations could be identifies as in figure below.

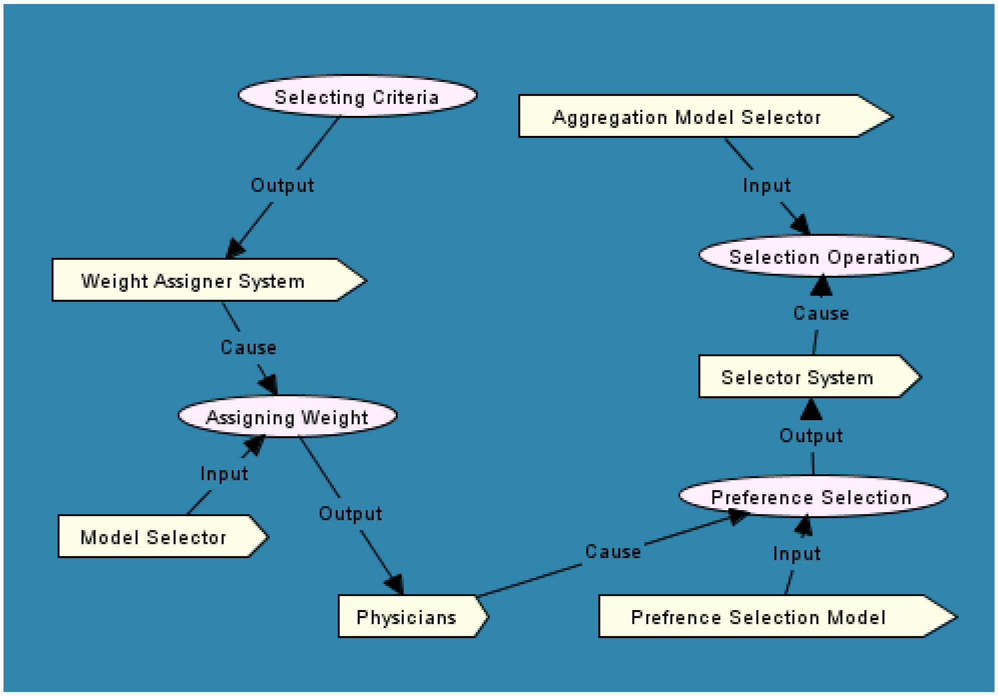

Figure 5.10: Operation Model for the MCDUS

5.3.3 National Telemedicine System (NTS) Design

The NTS in this work is primarily used to give remote diagnosis and critical care consultation services. In addition, the system will help a physician make selection of a remote physician for a particular consultation.

To achieve all these, we have chosen a design direction that could divide the above services in to layers. Therefore, the system is designed as three-layered system. This approach simplifies the design complexity of the overall system by decomposing it in to manageable tasks. The proposed architecture of the system is show in Figure 5.11 and each layer is described in the sequel.

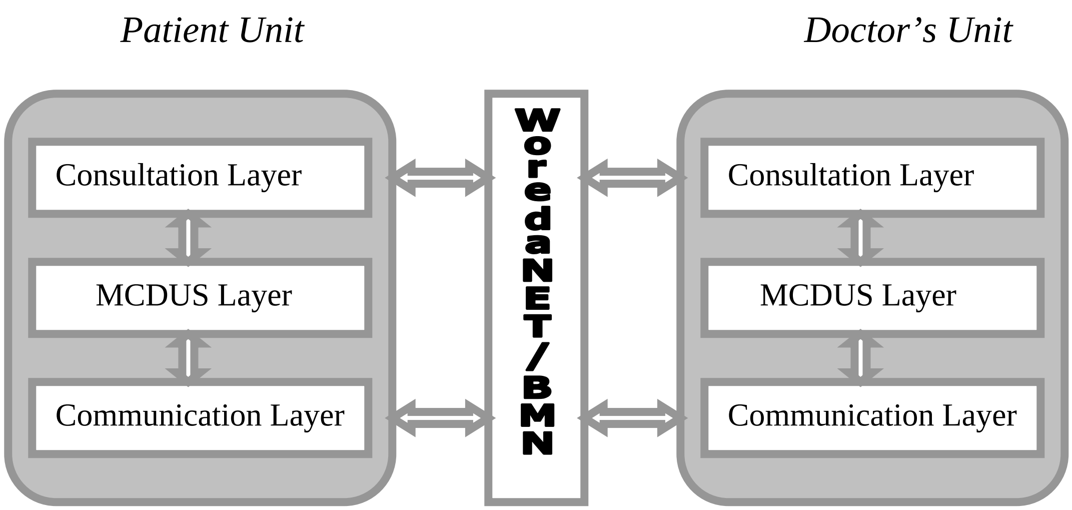

Figure 5.11: Three layered architecture of the NTS

Consultation Layer

The consultation layer is responsible for interfacing users with the system. The layer helps a physician communicate or interact with another physician. It facilitates interaction by providing an easy to use interface for sending and viewing patient information, and for making audio and video communication.

MCDUS Layer

The MCDUS layer is used for selecting a physician for a particular consultation. During the process, it analyses multiple criteria and proposes potential physicians for the consultation.

Communication Layer

The communication layer is responsible for the implementation of any communication protocol that helps physicians transfer information or make audio and video communication.

Inter-layer communication

Interaction among the three layers is as follows:

When a local physician decides to make remote consultation about his/her patient case, he/she passes his/her physician selection request to the MCDUS layer through the consultation layer. In addition to the request, the local physician passes multiple criteria and preferences that will be used in the selection process. The MCDUS starts analyzing the criteria and other relevant data to select a physician. The MCDUS layer sends the selected physician to the local one via the consultation layer. When communication is needed between the two physicians, the communication layer makes the link between them using the address of each one from the MCDUS layer. Once a link is established between the two physicians in the communication layer, they can communicate or interact using the consultation layer.

5.4 *The MCDUS layer Architecture*

The architecture designed for the MCDUS layer is also based on the layering approach. This approach breaks down the functionality of the layer in to pieces of tasks that could work together to achieve the services provided by the layer. The MCDUS layer has four sub-layers. Figure 5.12 shows the MCDUS layer architecture.

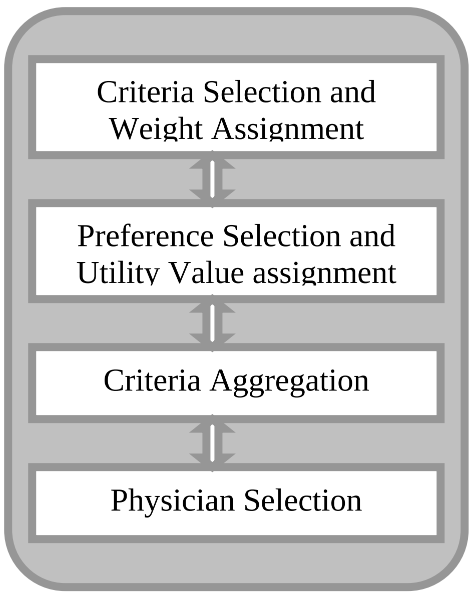

Figure 5.12: Architecture of the MCDUS layer

Criteria Selection and Weight Assignment

This sub-layer is responsible for choosing criteria for the physician selection process. The layer also assigns weights to the selected criteria using the selected model.

Preference Selection and Utility Value assignment

This sub-layer is used to present all the available preferences that a physician at the Patient Unit can select for a criterion. For instance, if physician specialty type is one criterion, a physician who will make the selection might prefer one type (e.g. Medical Practitioner, Dentist, Gynecologist, Internist, etc) for it.

Criteria Aggregation

This sub-layer is used to assign value for each candidate physician based on all the criteria used in the selection process. The utility value of each criterion for each physician will be aggregated using the selected aggregation model. The sub-layer finally produces list of physicians along with their aggregate values which indicate their overall performance.

Physician Selection

This sub-layer ranks each physician based on his or her aggregate value. Sorting physicians and sending the result which is ranked list of physicians is the task of this sub-layer.

6. Multi-Criteria Doctor's Unit Selection Model

6.1 Overview

This chapter deals with the Doctor's Unit Selection. Here a Multi-Criteria Doctor's Unit Selection (MCDUS) model is proposed to help physicians (in the Patient Unit) in making physician Selection.

This model partially employs the approach used in [23], Multi-Criteria Provider Selection model (MCPS). The main goal of the MCPS model was to locate the closest provider for referral to improve the overall outcome of patients by providing medical services at an appropriate location, and by minimizing transport time and associated costs.

The focal goal of our MCDUS model is to locate potential specialists or physicians for a consultation request that is coming from a physician in the Patient Unit. The selection of a specialist or physician for a particular consultation improves healthcare service by providing remote medical services at an appropriate time. This remote medical service eases the life of both patients and physicians by minimizing referral. It also helps critically ill patients to get better treatment at an appropriate time.

The overall approach followed in this work to develop the selection model is represented in Figure 6.1.

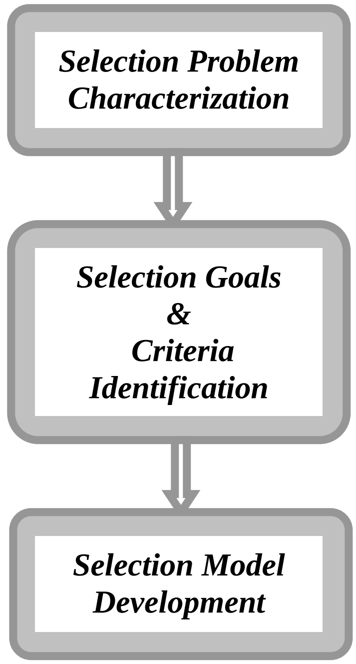

Figure 6.1: Overall approach to develop the MCDUS model

Characterization of the problem of Doctor's Unit selection with respect to decision aid theory and methodology is studied in the first step. The second step in this approach is identification of selection goals and criteria based on the characteristic feature of the problem. Finally, selection model development will be done based on the defined goals and criteria.

Organization of the rest of the chapter is as follows. Section 6.2 presents characteristic features of Doctor's Unit selection; sections 6.3 discusses goals and criteria of Doctor's Unit selection; section 6.4 presents the proposed model.

6.2 Characteristics of Doctor's Unit Selection

Before proposing the selection model, there is a need to study the available scientific approaches used in decision aid and select one that best fits our need. As discussed in the background section, there are different decision aid methods that could be used in selection process. The next topic overviews selected decision aid methodologies which will be used for proposing the model by studying characteristics of the selection process.

6.2.1 Methodology Selection for the model

As stated in [28], no two situations which call for a decision are ever identical. They differ due to a wide range of factors:

- *Problem Context:* For example, what are the external characteristics of the problem; is it well structured? is uncertainty present? how many options and possibilities need to be considered?
- *Social context:* For example, what are the characteristics of the organization in which the decision makers and how many are there; who are the decision makers and their number; the responsibilities and the accountability of the decision makers; and who are the stakeholders.
- *Cognitive factors of the Decision Makers:* For instance, the Decision Makers' intelligence, imagination and knowledge; can they live with risk and uncertainty; which behaviors do they exhibit (e.g. Biases).

In addition to the number of decision contexts, there are also small variations in the decision processes [28]. For Example:

- The type of players that are involved in the process (e.g. decision makers, experts, stakeholders, and analysts). The time they involve.
- The number of decision makers to whom ultimately all decision analyses are addressed (can be one or more);

- Available time for the decision analysis. It could be a couple of hours to a couple of months or, occasionally in the case of social decisions, seemingly decades.
- The need for communication among stakeholders during the decision making process.
- The involvement of decision analysts in the decision making.

Given these enormous range of contexts and processes, we tried to select a methodology that best fits our needs.

In our case, Doctor's unit selection is based on multiple criteria; and the decision aid service should help the physician (at the Patient Unit) in choosing the most appropriate specialist (or Doctor's Unit) from the list of alternatives. Therefore, the Doctor's Unit selection can be considered as a choice and ranking multi-criteria decision problem.

Determinants for the selection like available number of specialists, specialty level and others are assumed to be finite and predefined and therefore, Doctor's Unit selection can be considered as a Deterministic Multi-Attribute Decision Making problem. Decision making is made by a single physician located at the Patient Unit which leads us to use a method that assumes a single decision maker.

To sum up, the Doctor's Unit selection can be described as a *deterministic, choice and ranking MADM (Multi-Attribute Decision Making)* problem having assumptions like well defined, finite, discrete and predefined decision elements and single decision maker.

6.3 Goals and Criteria of Doctor's Unit Selection

6.3.1 Selection Goals

Doctor's Unit selection basically aims at locating or finding appropriate specialist/physician for a specific consultation. It improves healthcare service by providing remote medical treatment at an appropriate time, by minimizing referral which takes patient's time and money. Therefore, Doctor's Unit selection should in general ensure the following basic goals:

- Availability of the required medical services.
- Availability of the required physician.
- Minimal treatment time.

6.3.2 Selection Criteria

Based on the above specified goals, three mechanisms are applied for the selection of criteria in the process.

1. Criteria collected from Physicians.
2. Criteria from literature.
3. Criteria from previous systems.

By applying the above mechanisms, nine criteria are selected for the selection process. Some are related to patient cases, some to physicians and some other criteria are related to the healthcare provider where the required physician works.

These criteria are:

Patient Related Criteria

1. *Required Service:* This patient related criterion is used to select the required specialty type or required service for the consultation. This criterion might have values that could specify those specific specialty types signifying the required service. Values for the criterion include: General Practitioner, Internist, Surgeon, Pediatrician, Gynecologist, Ophthalmologist, Orthamologist, Orthopedist, ENT Specialist, Anesthologist, Dentist, Radiologist, Physiologist, Neurologist, Anatomist, Public Health, Dermatologist, Pharmacologist, and Psychiatrist. This criterion helps to select a physician with the required specialty type.

Physician Related Criteria

1. *Treatment (Assessment) Time:* This criterion describes the time that the required physician can give the consultation. It signifies the availability of the physician at the required time. Values for the criterion could be specified in terms of hours, day ranges, and week intervals. This criterion helps to select a physician who is free to give the consultation service in a short period of time.

2. *Physician Specialty Level:* This criterion describes the required physician's specialty level. Values include: Specialist, General Practitioner, Health Officer, Nurse, and Health Extension Worker. It is helpful for selecting the required physician based on his/her specialty level.

3. *Language:* This criterion is used to select language that the required physician speaks. Since consultation could be done using audio communication, language used by the

physicians determines the quality of information sharing. Values for the criterion include: Amharic, English, Oromiffa, Tigrigna, and others.

4. *Previous Consultation with the Physician:* This criterion is used to indicate previous communications with the required physician. Values for this criterion can be ‘yes’ or ‘no’ to show if there was previous consultation or not.

5. *Experience:* This criterion indicates the work experience the required physician could have. Values for it could be ranges of years like 0-2, 3-5, 6-10. The criterion is helpful for selecting a physician who has better experience.

Healthcare Provider (Doctor’s Unit) Related Criteria

1. *Location:* this criterion is related to the required physician’s hospital/clinic location. Location of the physician could be described using his/her hospital/clinic district, zone and region. Required physician’s location which is in the same district as the Patient Unit is more preferable in the selection process.

2. *Hospital/Clinic Specialty Level:* this criterion indicates the level of the required physician’s hospital/clinic specialty level. Values for the criterion include: Referral, Regional, District, Health Center, and Health Post.

3. *Previous Consultation with the Physician’s Hospital/Clinic:* This criterion is used to indicate previous communications with the required physician’s hospital/clinic. Values for this criterion could be ‘yes’ or ‘no’ to show if there was previous consultation or not.

6.4 Multi-Criteria Doctor’s Unit Selection Model

This section presents the four phased Multi-Criteria Doctor’s Unit Selection model (Figure 6.2). The responsibilities of each phase are also presented.

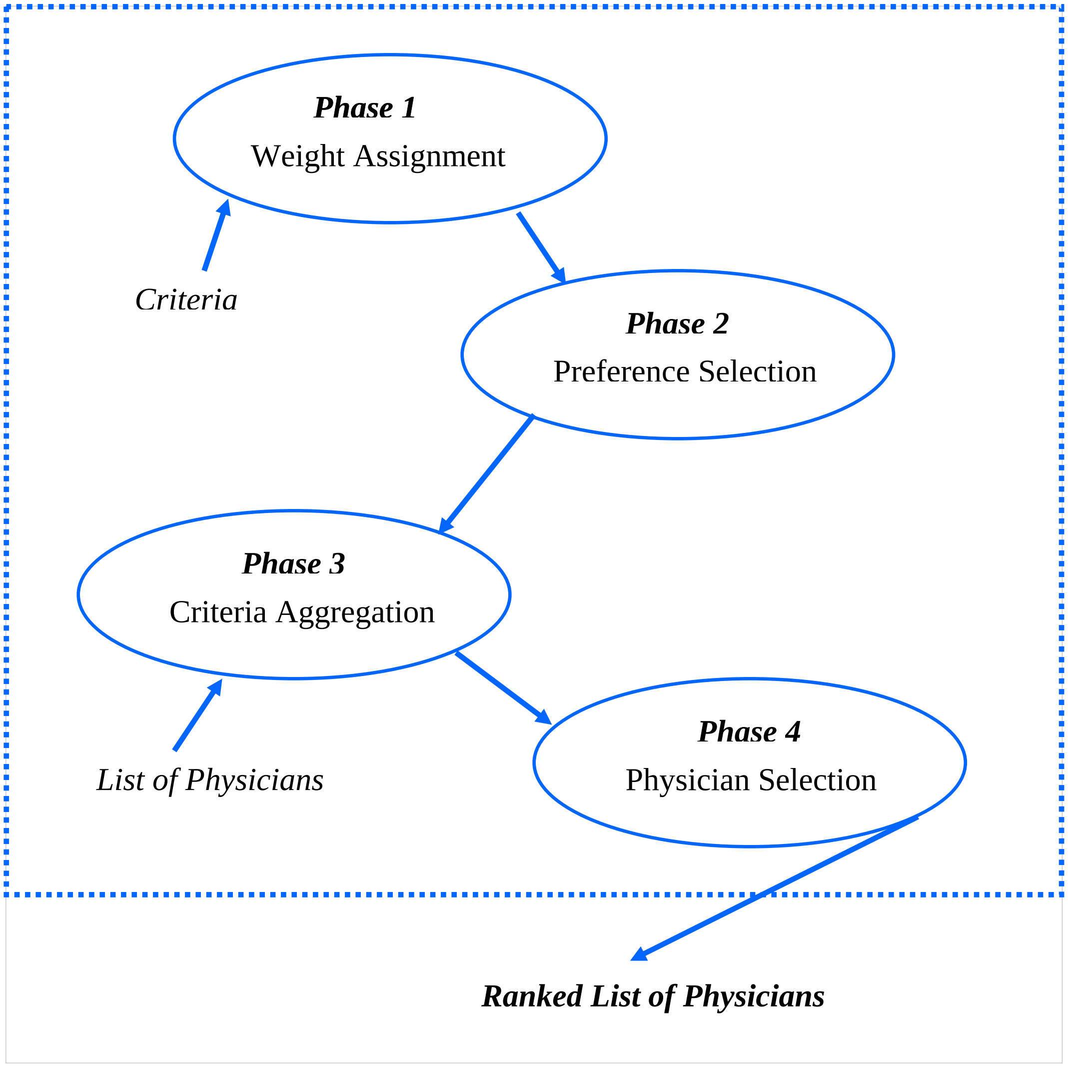

Figure 6.2: The Multi-Criteria Doctor's Unit Selection Model

6.4.1 Weight Assignment Phase

Once criteria for the selection process are selected, this phase assign weights to each of them. As stated in [35, 36], a weight of a criterion is an evaluation value that is assigned to it based on its relative importance with other criteria. If, during selection, a criterion is relatively more important than another criterion, it will be given higher weight.

The relative importance of criteria is a concept which is central to Multi-criteria Decision Making methods and is captured in many methods by some form of numerical weight parameter [37].

In this work, we propose a methodology for conversion of the ranks that are supplied for each criterion in to relative weights. The method used in [33] is partially followed in our work to convert ranking of a number of criteria in to numerical weights. The result of the questionnaire filled by medical professionals is used for the weight assignment process.

The questionnaire contains two basic categories for selection and assignment of weights to all criteria.

A. The first category is used to accept all the criteria that a physician could use for physician selection process. In this category, physicians who filled this part have chosen their own criteria and assign weights out of 100% based on their importance. The most important criterion (a criterion ranked 1) is given 100% weight.

B. In the second category, we have selected 10 criteria which we feel are factors to be considered in the selection of a physician. Physicians respond to this part by arranging these criteria in order of priority (most important to least important) and assigning weights to all the factors in the prioritized list starting from a weight of 100% for the most important criterion. The questionnaire is attached as Annex A.

In order to develop a methodology for weight assignment, the following steps have been taken.

Step 1:

First, we separated the data obtained from the questionnaire in to two categories. The first category is the data obtained from the physicians by answering all the factors they might use for the physician selection process; the second category is: the data obtained from them by prioritizing the criteria stated by the researchers.

We then separated the first category into distinct groups according to the number of criteria, n, given by each physician.

Step 2:

For each of the two categories and each value of n, we then calculated the average weight for each rank. The average weights of each rank for the two categories and groups are shown in Table 6.1. For the first category, if two or more physicians pick equal number of criteria, the average weight for each rank in the group will be calculated and combined together.

Table 6.1: Actual average weights for each rank according to the number of criteria n

n, number of Criteria

Rank , r	2	3	4	5	6	7	8	9
1	100	100	100	100	100	100	100	100
2	75	75.71	72.22	86	88.33	85	77.5	86.86
3		58.57	65	74	75	77.5	67.5	77.55
4			52.77	62	61.66	67.5	57.5	69.37
5				51	51.66	63.5	52.5	60.55
6					38.33	55	47.5	52.68
7						42.5	40	45
8							32.5	37.24
9								29.55

Step 3:

In this step, one model will be selected for assigning weight to each rank for each value of n. All these models are based on the assumption of an average association between rank and weight which is consistent across many decision makers [39, 40]. Four different models have been proposed by different scholars in the area which are presented below.

Model 1. Linear weights with variable slope: $w_r = 100 – S_n(r-1)$, where w is the weight, r is the rank, and S_n is the absolute value of the slope when the number of criteria (ranks) is equal to n. To find S_n, least square linear regression is applied. The relationship between S_n and the number of criteria n is determined in step 5. After step 5 (i.e. after finding S_n), this model is rewritten as:

$$W_{r,n} = 100 - (41.05 - 9.79n + 1.03n^2 - 0.03n^3) (r-1)$$

Model 2. Rank Sum Linear weights with fixed slope [38]: $w_r = 100(n + 1 – r)/n$

Model 3. Inverse or Reciprocal weights [38]: $w_r = 100/r$

Model 4. Geometric weights [41]: $w_r = 100 / (\sqrt{2})^{r-1}$

Figure 6.3 shows the four models and the actual weights for each rank for nine criteria that are selected by applying the mechanisms stated in section 6.3.2.

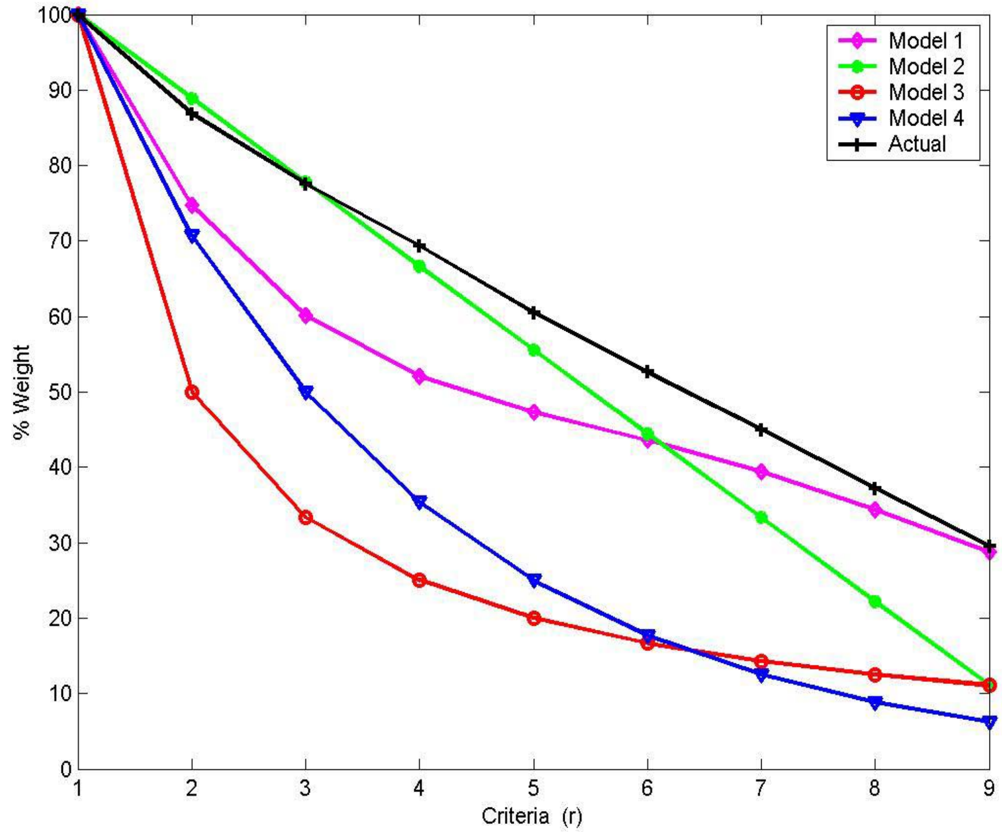

Figure 6.3: Actual and fitted weight values for each rank when the number of criteria is nine.

Step 4:

Closeness of each model with the actual weight is determined using Relative Error. Relative error values are calculated by comparing the actual weights with the theoretical weights derived from each model. Table 6.2 shows calculated relative error values for all four models and all values of r.

Table 6.2: RE values of the four models for each criteria (For n = 9)

r	Model 1	Model 2	Model 3	Model 4
2	0.1505	0.0231	0.5387	0.205
3	0.2535	0.0029	0.7975	0.432
4	0.2853	0.0397	0.9403	0.6496
5	0.2457	0.086	1.0068	0.8311
6	0.19	0.1696	1.0386	0.995
7	0.133	0.2979	1.0361	1.1304
8	0.0819	0.5051	0.9948	1.2327
9	0.0263	0.907	0.907	1.3017
Average	**0.1518**	**0.2257**	**0.8067**	**0.7531**

The (average) result shown in Table 6.2 clearly shows that model 1 outperforms all other models. Therefore model 1 is chosen to represent the relationship between the rank and weight as a straight line whose negative slope ($-S_n$) varies according to the number of criteria n.

Therefore, for any set of n ranked criteria, assuming weight of 100% for the first ranked (most important) criterion, the percentage weight of a factor ranked as r is given by

$$W_{r,n} = 100 - (41.05 - 9.79n + 1.03n^2 - 0.03n^3)(r-1)$$

Step 5:

To determine the relationship between S_n and n, we first determine the value of S_n for each n as displayed in Table 6.3 using the actual weight values found from the questionnaire.

Table 6.3: Model 1 slope (S_n) for each value of n.

n	2	3	4	5	6	7	8	9
S_n	8.8	25	20.71	15.74	12.25	12.33	9.58	9.64

In order to determine the relationship in model 1 between the slope ($-S_n$) and the number of criteria n, we plotted the values of S_n versus n and suggest three possible models to estimate absolute slope S_n as a function of the number of criteria n.

I. Linear model: $S_n = a + bn$

II. Quadratic model: $S_n = a + bn + cn^2$

III. Cubic Model: $S_n = a + bn + cn^2 + dn^3$

Where a, b, c and d are coefficients

Least square regression is applied to find the values of each coefficient in each model. We also calculated corresponding relative error values of each model to decide which one gives us the best fit for the slope. After applying lest square regression, the models are found to be:

I. $S_n = 26.51-2.22n$

II. $S_n = 36.64 - 6.68n + 0.40n^2$

III. $S_n = 41.05 - 9.79n + 1.03n^2 - 0.03n^3$

Table 6.4 shows relative error values for the three models for all values of n. Figure 6.4 shows actual and fitted values of S_n for each criterion.

Table 6.4: Relative Error values of the three models for all values of n

r	Model 1	Model 2	Model 3
2	0.1251	0.0043	0.0117
3	0.0437	0.0235	0.0378
4	0.1114	0.0399	0.0152
5	0.2261	0.0857	0.0728
6	0.0637	0.1035	0.0882
7	0.1302	0.0125	0.053
8	0.1039	0.0582	0.0272
9	0.3069	0.0549	0.0108
Average	**0.1389**	**0.0478**	**0.0396**

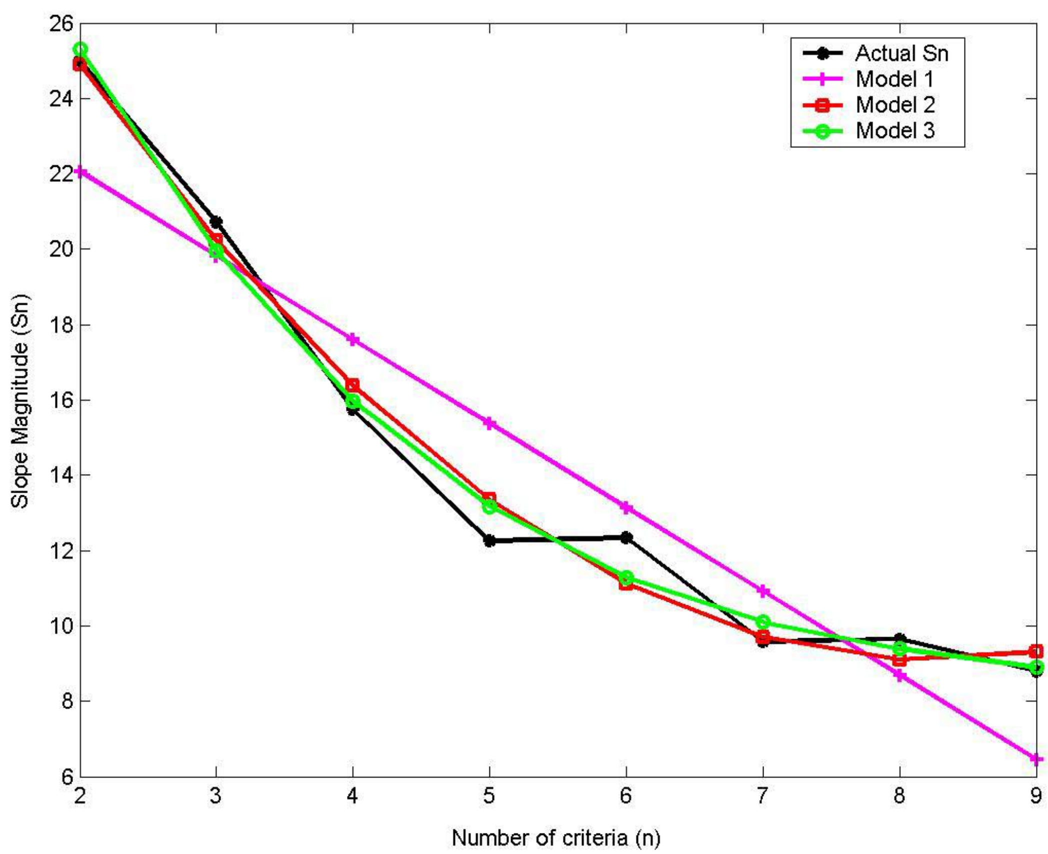

Figure 6.4: Actual and fitted values of S_n versus the number of criteria

Based on the error values from the Table 6.4 and from the Figure 6.4, Model III is selected as the best method for identifying the slope values.

6.4.2 Preference Selection Phase

When a physician decides to select another physician for a consultation, he/she will specify values for the criteria that the selection process should consider. This phase allows a physician to specify values for each criterion. For instance, for the criterion physician specialty level, the physician who makes the selection can select one of the preference values: specialist, General Practitioner, Health Officer, Nurse, and Health Extension Worker. These values that are given for each criterion are used for assigning utility values in the next phase of the selection process.

6.4.3 Criteria Aggregation Phase

Once the physician who instantiates the selection process shows his/her preference by assigning values to each criterion, this phase uses Multi-Attribute Theory based approach to relate the value with each candidate physician's performance.

Multi-Attribute Utility Theory (MAUT)

The purpose for using utility theory in decision making is to create a mathematical model to aid the process. It gives the decision maker the ability to quantify the desirability of certain alternatives [43, 44]. The end result of using this method is a function which represents the designer's preferences, given a certain set of design attributes.

The MAUT extends the traditional utility theory to the multidimensional case. Even from the early stage of the MCDA field, the strong theoretical foundations of the MAUT framework have been among the corestones of the development of the MCDA and its practical implementation.

The main objective of MAUT is to model and represent the Decision Maker's preferential system into a utility value function *U*. The utility function is a function defined on the criteria space [42]. If the set of alternatives $A = (a_1, a_2, a_3 \ldots a_m)$ Such that

$U(\boldsymbol{a}_j) > U(\boldsymbol{a}_k) \leftrightarrow \boldsymbol{a}_j > \boldsymbol{a}_k$ *($\boldsymbol{a}_j$ is preferred to $\boldsymbol{a}_k$)*

$U(\boldsymbol{a}_j) = U(\boldsymbol{a}_k) \leftrightarrow \boldsymbol{a}_j \sim \boldsymbol{a}_k$ *($\boldsymbol{a}_j$ is indifferent to $\boldsymbol{a}_k$)*

The most widely used form of utility function is the additive one:

$$U(\boldsymbol{a}_j) = p_1 u_1(g_{j1}) + \ldots + p_n u_n(g_{jn})$$

Where $u_1, u_{2\ldots}\, u_n$ are the marginal utility functions corresponding to the evaluation criteria. Each marginal utility function $u_i(g_i)$ defines the utility value of the alternatives for each individual criterion g_i. $p_1, p_2, \ldots, p_n$ are constants often considered to represent the weights of each criterion. Weight assignment for each criterion (i.e. values of $p_1, p_2, \ldots, p_n$) is done in the first phase of the model.

Marginal utility functions

The main use of utility functions is transforming the diverse criteria scores to one common, dimensionless scale (0 to 1) known as *Multi-Attribute utility* [45, 46]. The utility function, u_i, used in each criterion converts the candidate physician's performance score (g_{ji} for physician j) to utility score (0 to 1).

Our work uses utility functions that analyze each criterion independently. That means, for each criterion, we have proposed one utility function. Moreover, these utility functions are used to map the performance score of each potential physician (for the criterion) to a utility score by comparing the performance score with the corresponding attribute of the physician.

The proposed utility functions together with the suggested utility scores are presented below.

Utility Function One (u_1):

Criteria Name: Physician Location

Preferences and suggested utility Values:

- District = 1.0 , Zone = 0.67, Region = 0.33

Utility Function Two (u_2):

Criteria Name: Required Service (Physician Specialization)

Preferences and suggested utility Values:

- Preferences include: General Practitioner(GP), Internist, Surgeon, Pediatrician, Gynecologist, Ophthalmologist, Orthamologist, Orthopedist, ENT Specialist, Anesthologist, Dentist, Radiologist, Physiologist, Neurologist, Anatomist, Public Health, Dermatologist, Pharmacologist, and Psychiatrist.
- The utility value of each candidate physician could be 1 or 0 based on the similarity between his/her specialty type and the required service.

Utility Function Three (u_3):

Criteria Name: Physician Language

Preferences and suggested utility Values:

- Preferences include: Amharic, English, Oromiffa, Tigrigna, etc.
- The utility value of each candidate physician will be 1 if his/her language is matching with the required language specified; or it will be 0.

Utility Function Four (u_4):

Criteria Name: Physician Specialty Level

Preferences and suggested utility Values:

- Specialist = 1.0, GP = 0.8, Health Officer = 0.6, Nurse = 0.4, and HEW = 0.2.

Utility Function Five (u_5):

Criteria Name: Assessment Time

Preferences and suggested utility Values:

- 1 day = 1.0, 2-3 days = 0.75, 4-7 days = 0.5, and 1-2 weeks = 0.25.

Utility Function Six (u_6):

Criteria Name: Physician's Hospital/Clinic Specialty Level

Preferences and suggested utility Values:

- Referral Hospital = 1.0, Regional Hospital = 0.8, District Hospital = 0.6, Health Center = 0.4, Health Post = 0.2.

Utility Function Seven (u_7):

Criteria Name: Previous Consultation with the physician

Preferences and suggested utility Values:

- Yes = 1.0, No = 0.0.

Utility Function Eight (u_8):

Criteria Name: Previous Consultation with the physician's Hospital/ Clinic

Preferences and suggested utility Values:

- Yes = 1.0, No = 0.0.

Utility Function Nine (u_9):

Criteria Name: Physician Experience

Preferences and suggested utility Values:

- Above 10 years = 1.0, 6-9 years = 0.75, 3-5 years = 0.5, 0-2 years = 0.25.

Once the specific performance value of each alternative (physician in our case) in terms of each criterion (j = 1, 2, 3… n) is found using the utility functions, the overall performance of each alternative (physician) k (k=1, 2, 3… m) is calculated using the additive utility function below.

$$P_k = p_1 * u_{1k} + p_2 * u_{2k} + p_3 * u_{3k} + \ldots + p_n * u_{nk}$$

6.4.4 Physician Selection Phase

This last phase is responsible for ranking candidate physicians based on the overall performance found in the third phase. This phase uses any one of the sorting algorithms for sorting physicians based on their overall performance. It produces the last result of the overall process by presenting a list of ranked physicians for the required specific consultation.

7. Implementation

7.1 Overview

This chapter deals with the Multi-Criteria Doctor's Unit Selection System (MCDUSS) that implements the Multi-Criteria Doctor's Unit Selection Model. The system is used as a prototype to show the validity of the proposed MCDUS model.

The overall process of system development includes:

- Appropriate tools selection for the system development.
- Design and implementation of the system.
- Experimenting the system.

The chapter is organized as follows: the rest of this section presents the scope, main features and development tools; Section 7.2 presents an architectural design of the system; Section 7.3 presents interface design; section 7.4 presents a running example which illustrates the result of the system.

7.1.1 Scope of the Prototype

The prototype implements only the MCDUS layer of the NTS model. Even though the consultation layer of the NTS is responsible for interfacing users with the system, this prototype implements some basic interfaces for simulating it.

7.1.2 Features of the Prototype

The MCDUSS provides the following services:

- *Physician Information Maintainer:* this service is used for registering and editing physician information that are found in all healthcare providers. Information about a physician includes: full name, place of work (healthcare provider he/she works), specialty level, specialty type, language, location of place of work, schedule, experience, specialty type, and others. Schedule of the physician indicates his/her availability for consultation and is assumed to be entered into a database.

- *Healthcare Provider Information Maintainer*: this service is used to handle any type of information related to any healthcare provider that is part of the National Telemedicine System. It helps administrators of the system register and edit information about any healthcare provider. Information about healthcare providers includes: name, location (District, Zone, Region), specialty level, services providing, and others.
- *Weight Assigner:* Weights that are calculated for each criterion in the first phase of the MCDUS model are assigned and stored in a database using this service. Information that could be stored in the database includes: name of the criteria, weight assigned, and others.
- *Doctor's Unit Selection Process:* This service is responsible for implementing:
  - ✓ An interface that instantiates Doctor's Unit Selection process by accepting preference values of each criterion that are given by a physician who makes the selection process.
  - ✓ Functions that evaluate the performance of each candidate physician based on selected preferences.
  - ✓ Functions that show (print) the performance of each candidate physician over each criterion; and also show the overall performance of each physician for all criteria when aggregated as one.

7.1.3 Development Tools

Tools used for developing the MCDUSS include:

- Java JDK
- NetBeans IDE
- MySQL Server

Java Platform, Standard Edition 6 Development Kit (JDK 6)

This tool (JDK 6) is a development Environment for building applications, applets, and components using the Java programming language [47]. The JDK includes tools for developing and testing programs written in the Java programming language and running on the Java Platform.

NetBeans IDE 6.0.1

NetBeans IDE and platform are based on software from netbeans.org. It is used to write, compile, test, and debug applications for Java platform. Its integrated environment (IDE) includes a full-featured text editor with syntax highlighting and error checking, visual design tools and many other features [48]. Implementation of the MCDUSS is done using this IDE.

MySQL Server 5.0

This tool is used for developing a database that stores information about physicians, healthcare providers, criteria, and others.

MySQL, the most popular open source SQL database management system, is developed, distributed and supported by MYSQL AB [49]. The tool has features to:

- Create, drop, and alter databases, tables, views, procedures, triggers and other database objects.
- Insert, delete, update and retrieve data.
- Import and export data to and from other database applications.

7.2 System Design

The design and structure of an application is more important, as the technical details of its implementation [50]. Upon developing any new system, we should settle on the issues such as the Technologies to use, Database Engine to employ, the Physical Architecture of the application, etc. This section will provide some idea on the designing issues.

7.2.1 System Architecture

The architecture of the prototype is based on two tier application architecture. Figure 7.1 shows the system architecture of the prototype.

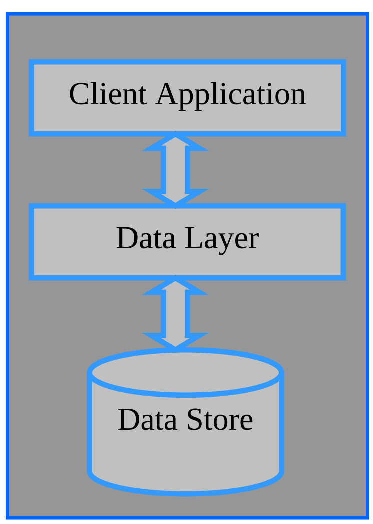

Figure 7.1: Two tier architecture of the prototype

This Client Application layer presents data to the user and optionally permits data manipulation and data entry. The two main types of user interface for this layer are the traditional application and the Web-based application. Users will interact with the system using this layer. This layer is a layer where user services (such as session, text input, dialog, and display management) reside. In our prototype implementation, this layer is implemented by producing interfaces that are used for processing physicians, healthcare providers, and criteria information. The layer also contains an interface for processing physician selection.

The Data Layer is used to interact with persistent data usually stored in a database or in permanent storage. This is the actual DBMS access layer. It can be accessed through the client application layer. This layer is implemented using any of the database connector between the Client Application layer and the data store.

7.3 Interface Design

This section presents the interfaces designed in the MCDUSS. Information about physicians, health care provider is stored in the database using the graphical user interfaces as shown in Figure 7.2 and 7.3. Criteria weight assignment is also done using an interface as shown Figure 7.4. Physician selection process is performed by using the physician selection graphical user interface as shown in Figure 7.5.

I. Physician GUI

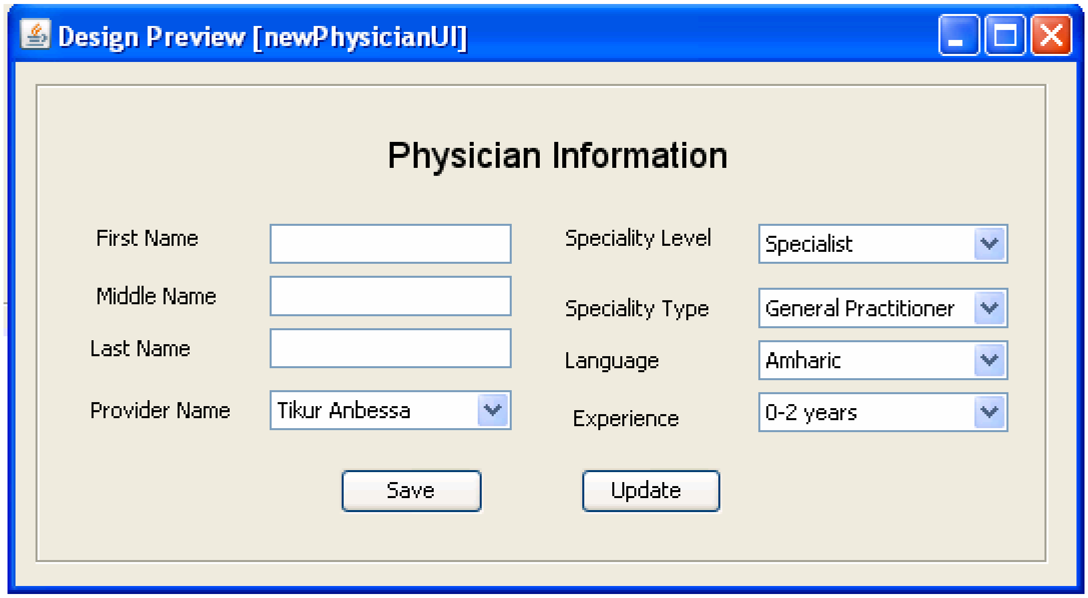

Figure 7.2: Screenshot of Physician Information Maintainer

II. Healthcare Provider GUI

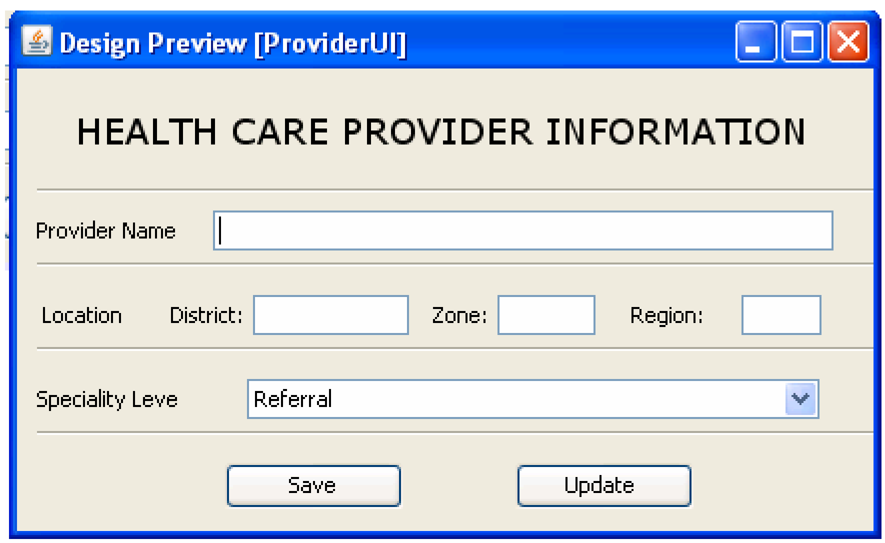

Figure 7.3: Screenshot of Healthcare Provider Information Maintainer

III. Criteria Assigner GUI

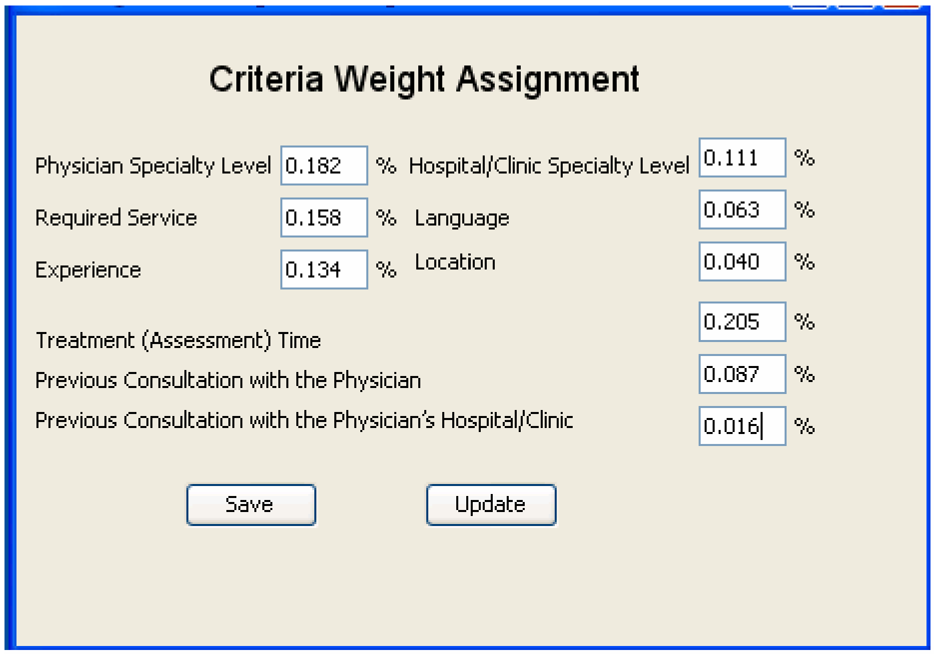

Figure 7.4: Screenshot of Weight Assigner GUI

IV. Physician Selection GUI

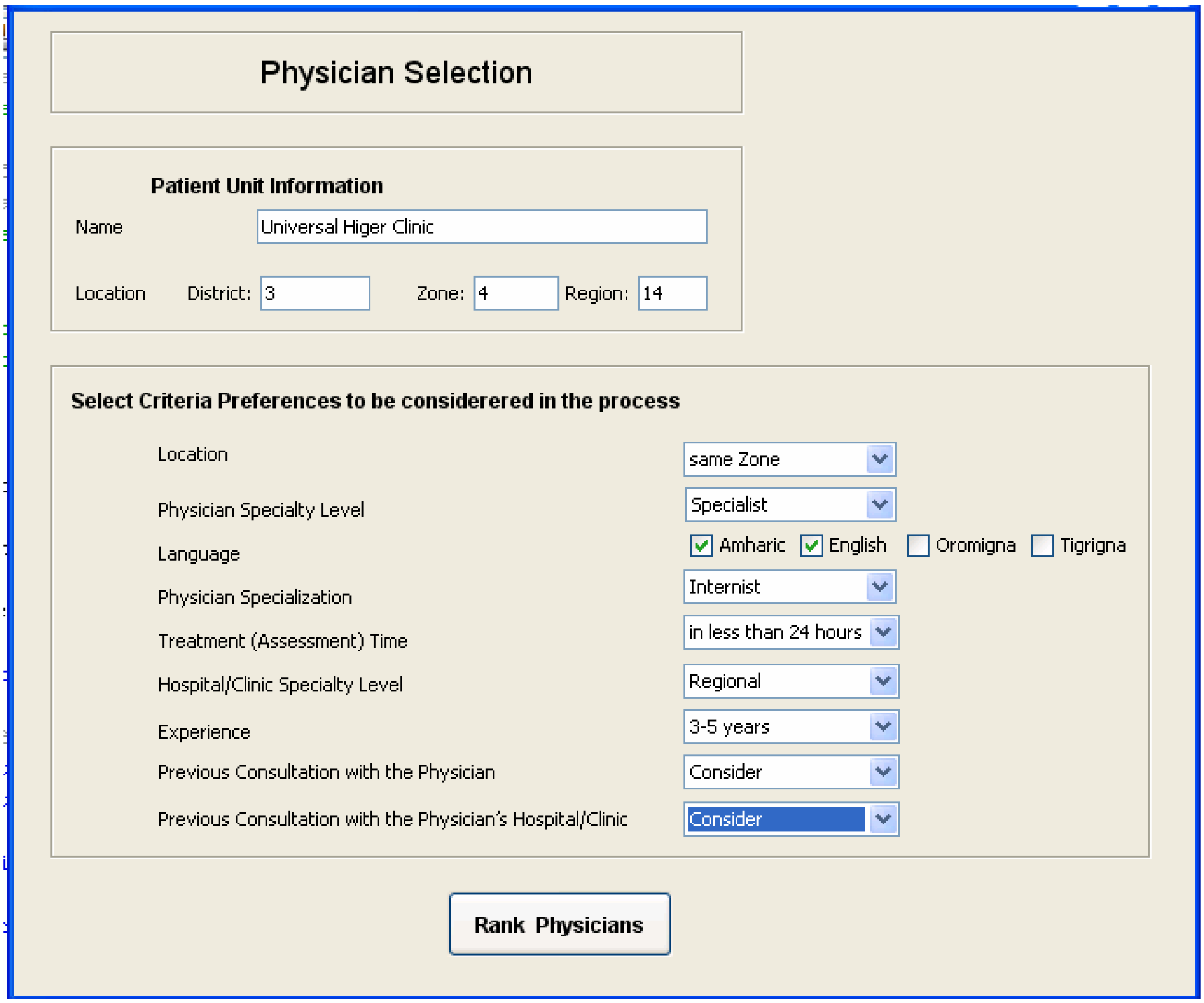

Figure 7.5: Screenshot of Physician Selection GUI

7.4 Running Example

We have considered a typical physician selection request described in Table 7.1 and table 7.2

Table 7.1: Patient Unit Information

Patient Unit Name	Universal Higher Clinic
Location	District 4, Zone 5, Region 14

Table 7.2: Criteria selection and Value assignment

Criteria Name	**Values**
Location	Same Zone
Physician Specialty Level	Specialist
Language	Amharic or English
Specialization	Internist
Assessment time	In less than 24 hours
Hospital Specialty Level	Regional
Previous Consultation with Physician	Consider
Previous Consultation with Physician Hospital	Consider
Experience	3-5 years.

Here in this running example, Physicians' information and their previous consultation history, healthcare providers' information and their previous consultation history are assumed to be stored in the database. When running this example, about 10 physicians' information, 10 previous consultations are stored in the database. Table 7.3 shows partial information about all the physicians stored in the database.

Table 7.3: Candidate Physicians' partial information for the selection process

	First Name	**Middle Name**	**Last Name**	**Location**	**Phy. Specialty Level**	**Pro. Specialty Level**	**Language**
1	Abraham	Tikeher	Getnet	Yekatit 12	1	1	13
2	Habtamu	Ayele	Kebede	Bahirdar Referral	2	2	2
3	Yonas	Eyasu	Kidane	Tikur Anbessa	3	0	1
4	Dessalegn	Ejigu	Alemu	Teklehaimanot Clinic	4	3	23
5	Besira	Antenehi	Shibru	Nazreth Referral	1	0	123
6	Selamawit	Ayele	Mulunehi	Awassa Clinic	4	1	14
7	Tigist	Gurja	Dinsamo	Awassa Referral	0	4	2
8	Mengistu	Mishamu	Dinka	Arbaminchi	2	3	13
9	Wubalem	Getinet	Wakijira	Afar	1	0	124
10	Yosef	Abeje	Tessema	Diredawa	2	2	23

How information is stored in the database is presented in Annex C.

Finding weight values of each criterion is done by using the model selected in the weight assignment phase section. And then assigning these weight values for each criterion is submitted to the selection process using the interface presented in the interface design section. Since the model uses ranks for finding corresponding weight values, these ranks for the selected nine criteria are derived based on the average weight values collected from the questionnaire. Based on the weight assignment model and ranks found from the questionnaire, table 7.4 shows weight values of each criterion ranging from 0 to 1. The sum of all the criteria weight values is one.

Table 7.4: Weight values for the selected criteria

Rank	**Criteria Name**	**Weight**
1	Treatment Time	0.205
2	Physician Specialty Level	0.182
3	Physician Specialization	0.158
4	Experience	0.134
5	Hospital Specialty Level	0.111
6	Previous consultation with Physician	0.087
7	Language	0.063
8	Location	0.040
9	Previous consultation with Physician Hospital	0.016

The values stated in the above tables could be inputted to the system using interfaces shown in Figure 7.4 and 7.5.

Once Patient Unit information, Criteria Weight values and preferences are given as input to the selection process, the MCDA technique is implemented to produce ranked list of physicians. Ranked list of physicians together with their overall performance is given in table 7.5 (The performance of each physician for each criterion is presented in Annex B).

Table 7.5: Ranked list of physicians

Overall Performance	**Overall Performance**
Abraham Tikeher Getnet	0.7394
Wubalem Getinet Wakijira	0.6251
Besira Antenehi Shibru	0.6073
Tigist Gurja Dinsamo	0.5391
Selamawit Ayele Mulunehi	0.5294
Habtamu Ayele Kebede	0.4930
Yonas Eyasu Kidane	0.4431
Mengistu Mishamu Dinka	0.4198
Yosef Abeje Tessema	0.4123
Dessalegn Ejigu Alemu	0.2405

From Table 7.5, it is found that Abraham Tikeher Getnet is selected by the MCDUSS for this particular consultation since his overall performance is higher than the rest.

8. Conclusion and Future Work

8.1 Discussion

The health care sector is characterized with diverse organizational and technical challenges. Providing a software solution to such an area is a difficult task as it required a coordinated effort of professionals from various fields.

This thesis has presented a study conducted on the possibility of implementing a National Telemedicine System for developing countries like Ethiopia by analyzing the country's technological, cultural, and economical status. The aim of the National Telemedicine System is providing remote consultation between physicians located at different places.

A Multi-Criteria Doctor's Unit Selection model has been proposed to aid physicians in making better physician selection for a consultation. The model employs four phases to produce ranked list of physicians as candidates for the specific consultation.

The core part of the selection model has been implemented by the Multi-Criteria Doctor's Unit Selection System. Even tough the system requires intensive validation and testing, it has shown the validity of the proposed selection model. In general, the result of this work is strongly believed to be one step towards implementing a National Telemedicine System for countries like Ethiopia in order to use the limited number of specialists efficiently and equitably.

8.2 Contributions

The following are the main contributions of this thesis work.

- A National Telemedicine System is proposed with the intention of extending capabilities of most telemedicine systems with Multi-Criteria Doctor's Unit Selection support by employing decision aid techniques. The layering approach followed in the process simplifies the design complexity of the overall system by decomposing it into manageable pieces.

- A National Telemedicine System Network Architecture is proposed to connect healthcare providers of the country. The architecture is designed in such a way that it could make use of current communication technologies. Considering current technologies and infrastructure in the design process will minimize the overall cost of the telemedicine system installation.
- A Multi-Criteria Doctor's Unit selection model is developed to help physicians in making physician selection for a particular consultation. This model is developed by first selecting criteria or factors that need to be considered in the selection process. Second of all, a methodology that assigns weight values which indicate the importance of one criterion over the rest of the criteria is derived. Physician preference and value assignment for a particular consultation is done in third step. Finally, a MAUT based approach is followed to rank list of physicians depending up on their overall performance.

8.3 Future Work

The NTS and MCDUS model proposed in this work could be used as a basis for a number of research development works towards the use of Information Technologies for the health sector in our country.

Some of the future works include:

- Further study is required to come up with a NTS that incorporates all aspects of the target health sector like healthcare policy of a country.

- Further study is needed on how to design and develop a store and forward and real time telemedicine that could be deployed countrywide.

- The Consultation and Communication layers of the proposed NTS could be further studied.

- In the MCDUS model, criteria selection methods needs to be further studied.

- In the selection model, Multi-Attribute Theory (MAUT) has been chosen simply for its clarity and simplicity. Thus, further study is required to choose a decision aid technique that best fits to the specific requirement of the selection model.

- Design and development of the prototype needs further study. Deployment of the system could consider distributed environment and multi agent technologies. The development process needs to have extensive testing and validation.

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Annex A: Questionnaire

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Questionnaire to be completed by Medical Professionals

Introduction

Health systems need to use Information and Communication Technology (ICT) more effectively in order to facilitate information sharing. The use of ICT in the health system for different purposes like diagnosis, treatment, education and consultation in general is called *Telemedicine.*

Studies show that telemedicine has been experienced since the time medical practitioners consult with one another over the old telegraph or telephone. Since the introduction of digital computers and telecommunication technologies, the amount of information and interaction has changed. Exchange of information could be done in the form of text, image, video and audio.

The objective of this questionnaire is to explore the different issues related to the selection of a physician for a specific consultation. This consultation can be a request for better diagnosis or discussion of a case over video and audio communication.

By completing this questionnaire, you can play a role to support our effort in introducing telemedicine to the health sector of the country. We also would like to assure you that the response will be kept confidential and it will only be used for academic purposes.

Personal Information

1. Sex ☐ Male ☐ Female
2. Age ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ above 50
3. Profession ________________________________
4. Specialization (if any) ______________________________

Teleconsultation Experience

1. Do you have any experience of using a system (like computer, telephone, postal service) to request a second opinion from a specialist or from a more experienced physician about patient cases?
   ☐ Yes ☐ No
2. Do you have any experience of using a system for providing medical consultation to another medical professional? (The system might be used to handle patient case without a face to face encounter with the patient; provided that you have received the consultation request and enough information about the patient such as lab results, x-ray, etc.) ☐ Yes ☐ No

3. If yes (for one of the above two questions)
   3.1 How far, were the consulting and referring health professionals located? (You can tick more than one)
   ☐ in the same hospital ☐ in the same town ☐ in country ☐ abroad

   3.2 What communication media were used for such physician to physician consultations? (You can tick more than one)
   ☐ Telephone ☐ postal service ☐ email ☐ video and audio conferencing
   ☐ other, please specify
   ____

Physician Selection

Let us assume the following simple telemedicine scenario your hospital or clinic provides:

- The system is available for authorized users (like personnel, physician).
- One or more services could be supported by the system. Some of them include:
  - ✓ Information storage about physicians and patients electronically.
  - ✓ Consultation request to any physician located in the country. In this case, the system allows the physician to make selection of a physician for that particular consultation based on a number of factors (criteria). The factors considered in the selection process will take account of patient case, medium of consultation (text messaging, audio and video communication), services required, required physician type and others.
  - ✓ Consultation reply to a physician who made the consultation request. In this case the system allows the physician to view patient information (in the form of text, image, audio and video), will help him/her order further tests, or treatments as necessary without a face to face encounter with the patient. The two physicians could have a face to face communication through video conferencing.

Please answer the following questions based on the above scenario.

1. If my local hospital/clinic has such a system, my concern will be mostly on (you can select more than one) :
   - ☐ Privacy of patient information
   - ☐ Cost for operation and patients
   - ☐ Effectiveness
   - ☐ Physician selection for the consultation
   - ☐ other, please specify

   ____

2. If you are given the opportunity to consult any physician in the country about your patient case, what are all the criteria (or factors) you use to make the physician selection? Criteria for the selection might consider patient cases, location, assessment time and many more. Please give weights to all factors in the list starting from a weight of 100 % for the most important criterion.

	Weight (out of 100%)
1.________________________________	__________
2.________________________________	__________
3.________________________________	__________
4.________________________________	__________
5.________________________________	__________
6.________________________________	__________
7.________________________________	__________
8.________________________________	__________
9.________________________________	__________
10.________________________________	__________
11.________________________________	__________
12.________________________________	__________
13.________________________________	__________
14.________________________________	__________
15.________________________________	__________

3. We feel that the following are factors (criteria) that need to be considered in the selection of a physician.

    1. Patient Type (to indicate whether it is emergency , regular, or critically ill patient)
    2. Required Service (to show if the needed treatment is a general one or a specific one like eye, ear, or other specific treatment)
    3. Assessment time (It is the time that the required physician can give the service)
    4. The required physician's hospital/clinic specialty level
    5. Previous consultation or communication to the required physician's hospital/clinic
    6. Previous consultation or communication to the required physician
    7. Required physician's location
    8. Required physician's specialty level
    9. Required physician's language
    10. Required physician's experience

Please arrange them in order of priority (most important to least important). And give weights to all factors in the prioritized list starting from a weight of 100% for the most important criterion.

Number	Weight
_____	______
_____	______
_____	______
_____	______
_____	______
_____	______
_____	______
_____	______
_____	______
_____	______

Annex B: Physician Performance Description

Physician selection process contains intermediate results that will be combined together to produce the final result which is ranked list of physicians. Here the performance of each physician is presented for each criterion for the running example presented in section 7.4. The tables below show the performance of each physician for each criterion when the system is executed for the running example presented in section 7.4.

Criterion 1

Physician Name	Location(D,Z,R)	Performance Value
Abraham Tikeher Getnet	2,3,14	0.012
Habtamu Ayele Kebede	1,2,3	0.0
Yonas Eyasu Kidane	1,4,14	0.0268
Dessalegn Ejigu Alemu	5,6,14	0.012
Besira Antenehi Shibru	7,8,4	0.0
Selamawit Ayele Mulunehi	3,4,6	0.0
Tigist Gurja Dinsamo	4,5,6	0.0
Mengistu Mishamu Dinka	8,9,10	0.0
Wubalem Getinet Wakijira	4,6,1	0.0
Yosef Abeje Tessema	2,3,5	0.0

Criterion 2

Physician Name	Speciality Level	Performance Value
Abraham Tikeher Getnet	General Practitioner	0.1456
Habtamu Ayele Kebede	Health Officer	0.1092
Yonas Eyasu Kidane	Nurse	0.0728
Dessalegn Ejigu Alemu	HEW	0.0364
Besira Antenehi Shibru	General Practitioner	0.1456
Selamawit Ayele Mulunehi	HEW	0.0364
Tigist Gurja Dinsamo	Specialist	0.182
Mengistu Mishamu Dinka	Health Officer	0.1092
Wubalem Getinet Wakijira	General Practitioner	0.1456
Yosef Abeje Tessema	Health Officer	0.1092

Criterion 3

Physician Name	Lanaguage	Performance Value
Abraham Tikeher Getnet	Amharic,Oromigna	0.063
Habtamu Ayele Kebede	English	0.063
Yonas Eyasu Kidane	Amharic	0.063
Dessalegn Ejigu Alemu	English,Oromigna	0.063
Besira Antenehi Shibru	Amharic,English,Oromigna	0.063
Selamawit Ayele Mulunehi	Amharic,Tigrigna	0.063
Tigist Gurja Dinsamo	English	0.063
Mengistu Mishamu Dinka	Amharic,Oromigna	0.063
Wubalem Getinet Wakijira	Amharic,English,Tigrigna	0.063
Yosef Abeje Tessema	Oromigna	0.0

Criterion 4

Physician Name	Specialty Type	Performance Value
Abraham Tikeher Getnet	Internist	0.158
Habtamu Ayele Kebede	Surgeon	0.0
Yonas Eyasu Kidane	Pediatrcian	0.0
Dessalegn Ejigu Alemu	Opthamologist	0.0
Besira Antenehi Shibru	Pediatrcian	0.0
Selamawit Ayele Mulunehi	Orthopedist	0.0
Tigist Gurja Dinsamo	General Practitioner	0.0
Mengistu Mishamu Dinka	Surgeon	0.0
Wubalem Getinet Wakijira	Radiologist	0.0
Yosef Abeje Tessema	Dentist	0.0

Criterion 5

Physician Name	Available within	Performance Value
Abraham Tikeher Getnet	1 day	0.205
Habtamu Ayele Kebede	2-3 days	0.1537
Yonas Eyasu Kidane	4-7 days	0.1025
Dessalegn Ejigu Alemu	1-2 weeks	0.0513
Besira Antenehi Shibru	2-3 days	0.1537
Selamawit Ayele Mulunehi	2-3 days	0.1537
Tigist Gurja Dinsamo	1 day	0.205
Mengistu Mishamu Dinka	2-3 days	0.1537
Wubalem Getinet Wakijira	1 day	0.205
Yosef Abeje Tessema	4-7 days	0.1025

Criterion 6

Physician Name	Hospital Specialty Level	Performance Value
Abraham Tikeher Getnet	Regional	0.0888
Habtamu Ayele Kebede	District	0.0665
Yonas Eyasu Kidane	Referral	0.111
Dessalegn Ejigu Alemu	Health Center	0.0444
Besira Antenehi Shibru	Referral	0.111
Selamawit Ayele Mulunehi	Regional	0.0888
Tigist Gurja Dinsamo	Health Center	0.0444
Mengistu Mishamu Dinka	Health Center	0.0444
Wubalem Getinet Wakijira	Referral	0.111
Yosef Abeje Tessema	District	0.0665

Criterion 7

Physician Name	Pre. Cons. With Physician	Performance Value
Abraham Tikeher Getnet	No	0.0
Habtamu Ayele Kebede	No	0.0
Yonas Eyasu Kidane	No	0.0
Dessalegn Ejigu Alemu	No	0.0
Besira Antenehi Shibru	No	0.0
Selamawit Ayele Mulunehi	Yes	0.087
Tigist Gurja Dinsamo	No	0.0
Mengistu Mishamu Dinka	No	0.0
Wubalem Getinet Wakijira	No	0.0
Yosef Abeje Tessema	No	0.0

Criterion 8

Physician Name	Pre. Cons. With HCP	Performance Value
Abraham Tikeher Getnet	No	0.0
Habtamu Ayele Kebede	No	0.0
Yonas Eyasu Kidane	No	0.0
Dessalegn Ejigu Alemu	No	0.0
Besira Antenehi Shibru	No	0.0
Selamawit Ayele Mulunehi	No	0.0
Tigist Gurja Dinsamo	No	0.0
Mengistu Mishamu Dinka	Yes	0.016
Wubalem Getinet Wakijira	No	0.0
Yosef Abeje Tessema	No	0.0

Criterion 9

Physician Name	Experience	Performance Value
Abraham Tikeher Getnet	3-5 years	0.067
Habtamu Ayele Kebede	6-9 years	0.1005
Yonas Eyasu Kidane	3-5 years	0.067
Dessalegn Ejigu Alemu	0-2 years	0.0335
Besira Antenehi Shibru	10 years and above	0.134
Selamawit Ayele Mulunehi	6-9 years	0.1005
Tigist Gurja Dinsamo	3-5 years	0.067
Mengistu Mishamu Dinka	0-2 years	0.0335
Wubalem Getinet Wakijira	6-9 years	0.1005
Yosef Abeje Tessema	10 years and above	0.134

Annex C: Database Description

The database developed in the prototype implementation contains tables tbl_physician, tbl_criteria, tbl_previousConsultations and others that are used to store physician, criteria, and previous consultation history respectively.

The table responsible for storing physician information has fields: First Name, Middle Name, Last Name, Provider Name, Physician Specialty Level, Provider Specialty, Language, Location, and schedule.

The table used for storing criteria information has fields: Criteria Name, Weight.

The table used to store previous consultations has fields: name of the physician, provider name, patient unit name.

Tables used in the prototype implementation have the following schema.

```
create table `tbl_criteria` (   `CriteriaID` double ,  `CriteriaName`   varchar(50),
    `PreferenceValue` double ,   `Weight` double );

create table `tbl_physician` ( `PhysicianID` double , `FName` varchar (50), `MName` varchar
    (50), `LName` varchar (50), `ProviderName` varchar (50), `PhySpecialityLevel` varchar
    (50),  `ProviderSpecialityLevel` double , `Language` varchar (50), `Location` varchar
    (50),  `Schedule` varchar (30), `Experience` double , `SpecialityType` double );

create table `tbl_physicianschedule` ( `ScheduleID` double , `PhysicianID` double ,
    `ProviderName` varchar (50), `PatientUnit` varchar (50) );
```

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials for the thesis have been duly acknowledged.

FASIL TEREFE ALEMU

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

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September 2008