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A FRAMEWORK FOR MULTI-AGENT REFERRAL DECISION SUPPORT

BY

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A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Computer Science

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ACRONYMS AND ABBREVIATIONS

ACL:	Agent Communication Language
AMS:	Agent Management System
DF:	Directory Facilitator
GP:	General Practitioner
GUI:	Graphic User Interface
H-EXT:	Health Extension
H-OFF:	Health Officer
HRC:	Healthcare Provider Referral Coordinator
JADE:	Java Agent DEvelopment Framework
LAB:	Laboratory
MADM:	Multi-Attribute Decision Making
MADMA:	Multi-Attribute Decision Making Agent
MAS:	Multi-Agent System
MAUT:	Multi-Attribute Utility Theory
MCA:	Medical Consultant Agent
MCDM:	Multi-Criteria Decision Making
MCPS:	Multi-Criteria Provider Selection
MED:	Internal Medicine
MeR:	Multi-Agent e-Referral
MPSS:	Multi-Agent Provider Selection System
MARDS:	Multi-Agent Referral Decision Support
NMB:	National Medical Broker Agent
NRC:	National Referral Coordinator
NUR:	Nurse
PCP:	Primary Care Provider/Physician
PCP:	Primary Care Provider
PFA:	Provider Filtering Agent
PRH:	Primary Referral Hospital
PSA:	Provider Selection Agent

PSY:	Psychiatry
RAA:	Referral Analyst Agent
RAD:	Radiology
RCA:	Referral Coordinator Agent
RGK:	Referral Guideline Knowledgebase
RMB:	Regional Medical Broker Agent
RMI:	Remote Method Invocation
RPK:	Referral Policy Knowledgebase
RRC:	Regional Referral Coordinator
RSA:	Referral Specialist Agent
SAW:	Simple Additive Weighting
SP:	Specialist
SRH:	Secondary Referral Hospital
S-SP:	Sub-specialist
TRH:	Tertiary Referral Hospital
UIA:	User Interface Agent
ZMB:	Zonal Medical Broker Agent
ZRC:	Zonal Referral Coordinator

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ABSTRACT

Medical Referral Systems aim at achieving high standards of care by improving patient outcomes and decreasing costs through optimal use of medical services. The success of these systems is highly dependent on the quality of referral decisions. A referral decision is a clinical decision by which physicians determine referral indication, type of required services and selection of appropriate providers. This inherently complicated process depends on a complex mix of patient, provider and healthcare system determinants. It requires medical and non-medical knowledge that exist distributed among several healthcare providers. In addition, the process requires communication and coordination of information between providers. Little research is done in studying how to provide an intelligent decision support that can help physicians in making better referral decisions. Most of the works focus in studying how to improve referral communication by employing e-Referral systems. This in turn leads to minimal effect in terms of achieving the objectives of Medical Referral Systems.

This thesis proposes a **M**ulti-**A**gent **R**eferral **D**ecision **S**upport (MARDS) framework aimed at improving quality of referral decisions. It specifically presents a **M**ulti-**C**riteria **P**rovider **S**election (MCPS) model that can be employed by the MARDS to aid physicians in making a better provider selection. The core part of the selection model is simulated by a **M**ulti-Agent **P**rovider **S**election **S**ystem (MPSS), which is developed using JADE (**J**ava **A**gent **DE**velopment Framework). The system is experimented with limited but relevant data and has shown the feasibility of the selection strategy.

The result of this work is believed to be one step towards enhancing existing e-Referral systems with intelligent referral decision support. Moreover, there is a possibility of employing the decision support framework to other application areas of e-Health (like e-Consultation) with some modifications.

Keywords: Medical Referral Systems, Referral Decisions, e-Referral Systems, Multi-Agent Systems, Decision Support Systems, Distributed Systems

CHAPTER 1 Introduction

1.1 Motivation

Agent-based systems are one of the most vibrant and important areas of research and development to have emerged in IT in recent years [1]. They are one of the most promising approaches for designing and implementing autonomous, intelligent and social software assistants capable of supporting human decision-making [2]. These kinds of systems are believed to be appropriate in many aspects of the healthcare domain [3]. As a result, there is a growing interest of researchers in the application of agent-based techniques to problems in the healthcare domain [4].

Recent studies [3, 4, 5] show that multi-agent systems have a set of characteristics that make them appropriate to be used to improve the provision of health-care to citizens. These studies also tried to identify features of an application area that indicate an agent-oriented approach. Some of the identified features are: distributed nature of data, complexity of software solution, lack of centralized solution, need of maintaining independence between healthcare providers, need of coordination among healthcare providers, and others. One potential application area characterized by such features is the medical referral system.

A referral system at all levels is used as a means to facilitate flow of patient referrals among healthcare providers [6]. It is an important activity in any healthcare system for it is a critical component of quality clinical care [7, 8]. If practiced efficiently, it can contribute to high standards of care by improving patient outcomes and decreasing costs through optimal use of medical services [9, 10]. Especially, in a developing country like Ethiopia with one of the lowest physician-patient ratio and scarce medical facilities, this has a magnified effect in utilizing the available resources efficiently. On the other hand, if practiced ineffectively, patient referral may affect the process of patient evaluation, treatment, and continuity of care, which in turn affect clinical outcomes and costs [11]. Therefore, an optimal referral process should be in place for the effectiveness, safety and efficiency of high standard medical care [12].

However, a referral process is an inherently complex activity, which involves referral decision and referral communication. A referral decision is a clinical decision made by physicians about referral indication (whether referral is needed or not), service identification, and provider selection [13]. On the other hand, referral communication deals with subsequent interactions that exist between referring and referred-to providers once a referral decision is made. These two key aspects of a referral process require the transfer and coordination of complex and diverse forms of information distributed between providers [14]. The complexity of the process often causes inefficient referral decisions and referral communication, which in turn affects the quality and cost of care [13, 14]. ***Hence, it is important to improve both the decision-making as well as communication aspects of the process to enhance the overall outcome of the referral system***.

1.2 Research Problem

Studies have been conducted in the past few years to propose e-Solutions to the problems of referral systems [15, 16, 17]. These solutions, referred as e-Referral Systems, attempt to improve the efficiency of the referral process. However, most of these studies focus only on referral communication with the intention of facilitating flow of patient referrals from one provider to another. Little is done in developing a comprehensive decision support mechanism to aid physicians in the process of making referral decisions. This leads to minimal effect in terms of facilitating the overall process and achieving the promised e-Referral benefits.

Hence, to improve the overall referral process and come up with quality and cost-effective patient care, there is a need to complement existing e-Referral systems with intelligent decision support. Thus, the problem that this research work tries to address is ***how to extend the capabilities of current e-Referral systems with referral decision support by adopting the emergent multi-agent technology.*** This is believed to have an effect on the overall outcome of patient care and cost by improving the quality of referral decisions.

1.3 Objectives

The general objective of this research is to ***develop a multi-agent referral decision support framework that can improve the quality of referral decisions.*** The decision support specifically focuses on the selection of appropriate provider.

The following are the specific objectives:

- Analyzing components of a referral decision and studying the associated determinant factors affecting the decision.

- Designing a multi-agent referral decision support framework which helps physicians in making quality referral decisions.
- Studying determinant factors that affect selection of providers and develop a provider selection model that can be employed by the framework

1.4 Scope

e-Referrals are large-scale complex systems characterized with distribution, sociability and cooperation. Their scope can span from local to international level and the underlying healthcare system varies from country to country. In addition, these systems can be designed to support physician referrals, self referrals, or both.

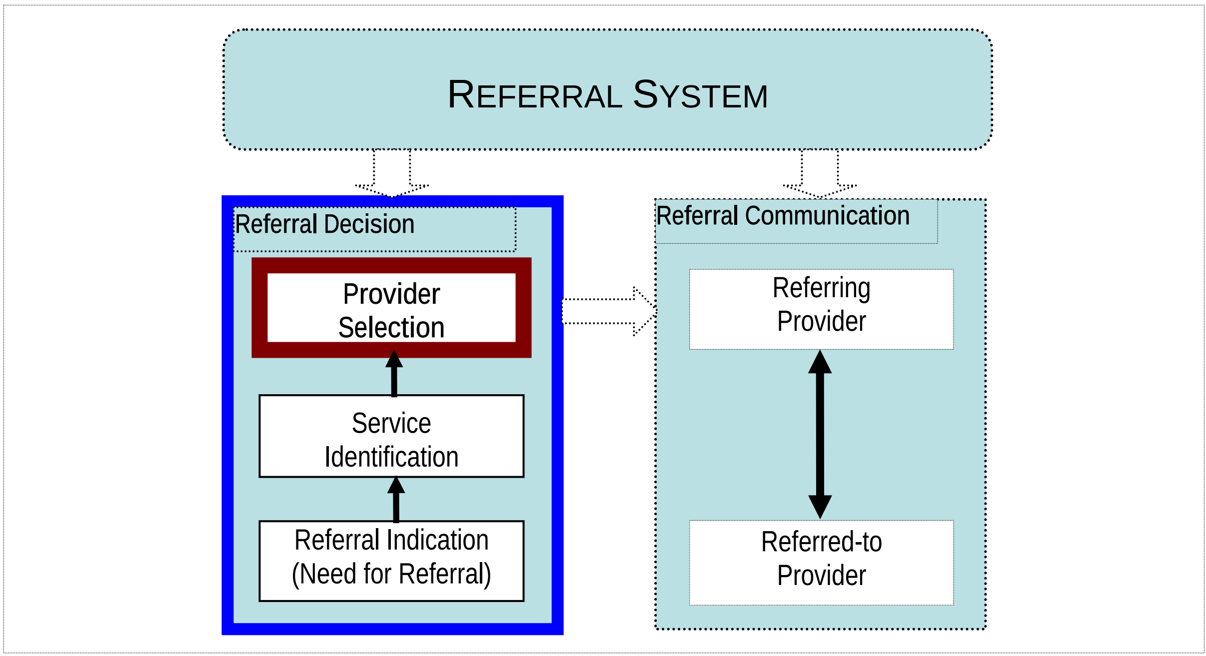


Figure 1.1 Key Components of a Referral System

As described in section 1.1, the two key components of referral systems are referral decision and referral communication (see Figure 1.1). Hence, e-Referrals can be designed to support one or both components. The referral decision support component deals with improving the three aspects of referral decision-making of physicians. On the other hand, the referral communication component deals with improving the communication between referring and referred-to providers. It includes generation of e-Referrals, sending and receiving of e-Referral requests (e-Request), e-Referral replies (e-Reply), and e-Referral feedbacks (e-Feedback).

The scope of this research is limited to the study of referral decision support for physician referrals with a special focus on provider selection. Besides, this work primarily targets the healthcare system of Ethiopia. However, extensibility to any other country's healthcare system is also considered.

1.5 Major Research Activities

The preliminary activity of this research has been background study of the basic features of the target domain (referral system) and multi-agent systems, and review of related works. Here, a number of works have been studied and analyzed to assess the appropriateness of multi-agent approach to the target domain and review works conducted in this area.

After the preliminary study, the research employed four major activities to achieve its objectives (see Figure 1.2). The course of action started from the study and analysis of referral decision making, which is followed by development of the decision support framework. Then, analysis and modeling of provider selection is conducted. Finally, a prototype is developed for the model.

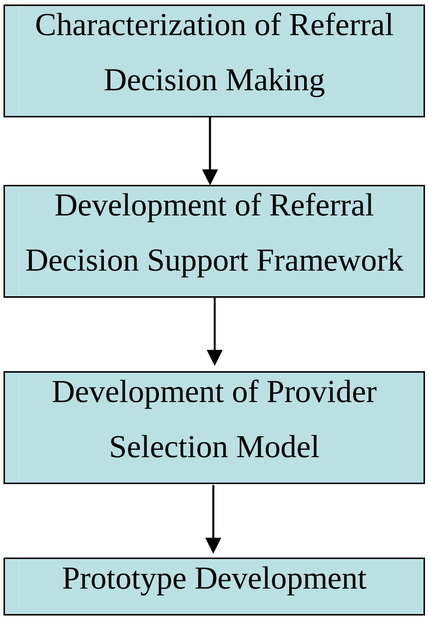


Figure 1.2 Major Research Activities

Characterization of Referral Decision Making

In this activity, the main components of referral decision (referral indication, service identification, provider selection) are identified. Besides, for each component, determinant factors (patient, provider, system) that affect the quality of the decision are identified. Here, a special attention is given to the Ethiopian healthcare system.

Development of Referral Decision Support Framework

Once the components and parameters of referral decision are identified, a study is conducted on how to employ features of multi-agent systems to design a decision support framework (that can be integrated with existing e-Referral systems). Here, the first step has been selecting a MAS (Multi-Agent System) design methodology. Then, a multi-agent decision support framework is designed based on the selected design methodology.

Development of Provider Selection Model

After designing the decision support framework, the process of provider selection is studied in further detail. In this activity, provider selection is defined as a Multi-Criteria Decision Making (MCDM) problem by reviewing theory and method of decision aid. Then, selection goals and parameters are defined. Finally, the selection model is designed.

Prototype Development

A Multi-Agent Provider Selection System (MPSS) is designed and implemented for the core part of the provider selection model. In its development process, first an appropriate agent platform is selected, and then major agents and inter-agent communication strategies are designed and implemented in the platform. The system is then experimented with relevant but limited data to evaluate the feasibility of the selection strategy.

1.6 Overview of the Thesis

The rest of the thesis is organized as follows:

- Chapter 2 introduces concepts that are fundamental for understanding the rest of the document and the work done. It first presents a general discussion about multi-agent systems and their application in decision support systems. It then discusses referral systems with a special focus on referral decision making. Finally, it discusses the appropriateness of multi-agent systems for referral decision support.
- In Chapter 3, review of related works is presented. It discusses some of the works conducted relevant to this work which have contributed concepts and frameworks that are used as a basis for this work.
- Chapters 4 and 5 discuss the main work of the thesis. Chapter 4 presents the framework developed to support referral decisions. Here, two important architectural frameworks are presented. The first is an architectural design of a Multi-Agent e-Referral (MeR) system, which is proposed to extend e-Referrals by introducing a new multi-agent system layer defined for referral decision support. The second is a detailed architectural design of the multi-agent system layer proposed to support the overall referral decision-making process (referral indication decision, required service

identification, and appropriate provider selection). Chapter 5 presents a detailed description of the model developed for provider selection strategy. The model is intended to be employed by the multi-agent referral decision support framework to assist physicians in provider selection.

- In Chapter 6, a prototypic implementation of the selection model is discussed.
- In Chapter 7, a general conclusion, thesis contributions, challenges and possible future works are presented.

CHAPTER 2 Background

2.1 Agent Technology and Multi-Agent Systems

2.1.1 Agent Technology

The recent roadmap of agent technology [1] describes the new metaphor of computation and its enabling technology as follows:

> "In its brief history, computing has gone through different metaphors for the notion of computation. In its early days, most people thought of computation as calculation, or operations undertaken on numbers. With the widespread of digital storage and manipulation of non-numerical information from the 1960s onwards, computation was re-conceptualized more generally as information processing, or operations on text, audio or video data.
>
> With the growth of the Internet and the WWW over the last 15 years, it has been reached at a position where a new metaphor for computation is required: computation as interaction. In this metaphor, computing is something that happens by and through communication between computational entities. It is an activity that is inherently social, rather than solitary, leading to new ways of conceiving, designing, developing and managing computational systems.
>
> Agent technology is a solution introduced to exploit this new metaphor of computing as social activity, as interaction between independent and sometimes intelligent entities, adapting and co-evolving with one another."

An **agent** is defined in [18] as a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives. An agent functions continuously, flexibly and autonomously in a dynamic environment, which may contain other agents and processes [1, 19].

Figure 2.1 depicts an abstract view of an agent as given in [18]. The agent takes sensory input from the environment, and generates as output actions that affect it. Agents are usually best described by the behavior they should exhibit. The most commonly accepted ones are autonomy, reactivity, pro-activity and sociability [3, 20]. Autonomy is a common behavior exhibited by all agents. However, reactivity, pro-activity and sociability are behaviors expected to be exhibited by intelligent agents [18].

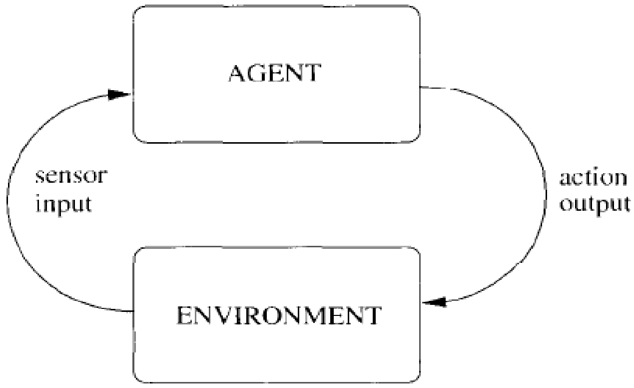


Figure 2.1 An agent in its environment

Autonomy: Each agent can take its own decisions, based on its internal state and the information that it receives from the environment. Therefore, agents offer an ideal paradigm to implement systems in which each component models the behavior of a separate entity that wants to keep its autonomy and independence from the rest of the system.

Reactivity: Intelligent agents are able to perceive their environment, and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives.

Pro-activity: Intelligent agents are able to exhibit goal-directed behavior by taking the initiative in order to satisfy their design objectives. Using this behavior, agents could perform tasks that may be beneficial for the user, even if he/she has not explicitly demanded those tasks to be executed. For instance, using this property an agent may find relevant information and show it to the user before he/she has to request it.

Sociability: Intelligent agents are capable of interacting with other agents (and possibly humans) in order to satisfy their design objectives. This behavior shows the capability of intelligent agents to communicate among themselves using some kind of agent communication language, in order to exchange any kind of information. In that way they can engage in complex dialogues, in which they can negotiate, coordinate their actions and collaborate in the solution of a problem.

As discussed in [21], it is very difficult to solve complex, realistic, and large-scale problems by employing only one intelligent agent. These types of problems are beyond the capabilities of an individual agent. This is because the capacity of an intelligent agent is limited by its knowledge, its computing resources, and its perspective. This is one of the underlying reasons for creating problem-solving organizations and why multi-agent systems have been found to be ideal for such an approach [21].

2.1.2 Multi-Agent Systems

A multi-agent system (MAS) can be defined as a collection of autonomous agents that interact with each other to coordinate their activities in order to solve collectively a problem that can not be tackled by any agent individually [18,22]. In recent years, it has been argued that multi-agent systems may be considered as the latest software engineering paradigm [23, 24].

As stated in [21], MASs are characterized by the following four main features.

- Each agent has incomplete information or capabilities for solving the problem and, thus, has a limited viewpoint;
- There is no system global control;
- Data are decentralized; and
- Computation is asynchronous.

Such systems may be used in domains with the following features [3]:

- The knowledge required to solve the problem is spatially distributed in different locations.
- Several entities, while keeping their autonomous behavior, have to join their problem solving abilities to be able to solve a complex problem
- The problems in the domain may be decomposed into different sub-problems, even if they have some kind of inter-dependencies.

Studies [3, 4, 5] indicate that various problems in the healthcare domain are characterized by the above-mentioned features. Consequently, there is a growing interest to adopt multi-agent techniques for the various aspects of the domain [4]. One potential aspect, which this thesis work tries to address, is the referral system. The following section discusses the concepts and features of referral systems focusing on referral decision making. Then the last section discusses the appropriateness of a multi-agent system approach for developing a referral decision support.

2.2 Referral Systems and Referral Decisions

2.2.1 Referral Systems

Referral systems are critical components of quality clinical care in any healthcare system. They are determinant factors for the cost-effectiveness, efficiency and quality of patient care. These valuable medical systems contribute to high standards of care by limiting over-medication, permitting an efficient division of tasks between generalists and specialists, freeing specialists to develop their special knowledge, and by decreasing the cost of medical care [25].

Referral systems can be described in terms of three important attributes: referral structure, referral process, and referral policy. A referral structure describes the organization of healthcare providers and referral process refers to flow of patient referrals among these providers. Referral policy refers to a set of guidelines and procedures designed to govern the way providers should process patient referrals.

2.2.1.1 Referral Structure

A referral system is commonly structured into primary, secondary and tertiary care. Primary care medical services are provided by a physician or other health professional who has first contact with a patient seeking medical treatment or care. Secondary care medical services are provided by medical specialists for a patient referred by a primary care provider who first diagnosed or treated the patient. Tertiary care medical services are provided by specialist hospitals equipped with diagnostic and treatment facilities not generally available at local hospitals [26].

In the Ethiopian case, healthcare providers are structured in a four-level pyramidal hierarchy (see Figure 2.2) [27]. In this structure, healthcare centers are organized as primary care providers. On the other hand, hospitals are organized as primary, secondary and tertiary referral hospitals depending on their level of facilities to provide medical services.

Primary Care Providers: These are healthcare centers, which provide primary care services to patients. Each primary care provider is organized in a way to give healthcare services for approximately 25,000 people.

Primary Referral Hospitals: These are district hospitals supposed to provide healthcare services that could not be managed by primary care providers. Each primary referral hospital is intended to offer healthcare services for about 250,000 people.

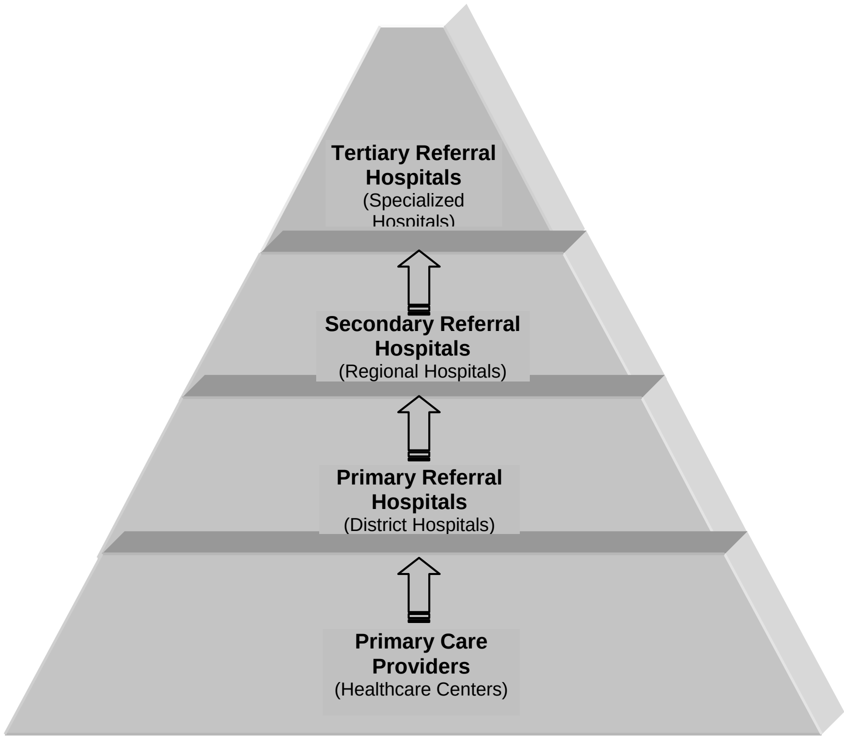


Figure 2.2 Structure of Ethiopian Referral System

Secondary Referral Hospitals: These are regional hospitals that are assumed to provide healthcare services that could not be managed by primary referral hospitals. Each secondary referral hospital is intended to provide healthcare services for approximately 1,000,000 people.

Tertiary Referral Hospitals: These are specialized hospitals supposed to provide specialized healthcare services that could not be managed by primary or secondary referral hospitals. Each tertiary referral hospital is intended to offer healthcare services for about 5,000,000 people.

2.2.1.2 Referral Process

The referral process deals with the generation of a clinical referral for a patient and the resulting transfer of information from a referring provider to a referred-to provider and back again to the referring provider [13]. Patient referral can be initiated either by health-care providers or by patients [16]. Patient referral initiated by a patient's health-care provider to see a specialist for a problem that is not being managed adequately by his/her current provider is known as ***physician referral***. Alternatively, patient referral initiated by a patient to contact with a specialist on his/her own, avoiding the involvement of a referring physician is known as ***self-referral***. Both types of referrals are usually initiated for the reasons of diagnosis, treatment, surgery, or second opinion of a problem [16]. In the Ethiopian case, self-referrals are not common and hence, they will not be addressed in this work.

Often, the referral process is employed in an environment of distributed and dynamic agency of autonomous/semi-autonomous health-care providers. These providers have different methods and systems of capturing, processing and storing patient referrals. Hence, there are some variations in the business process and data models of the referral process among various healthcare systems. However, the common aspects of the referral process model can be generalized as follows: The referring provider makes a referral decision, generates a referral and transfers it to the referred-to provider, which evaluates the referral and responds to the referral request. It is also highly probable that subsequent provider-to-provider communication occurs. In addition, the referred-to provider sends a referral feedback to the referring provider, once the required service is provided. Figure 2.3 shows a simplified diagram of the referral process model.

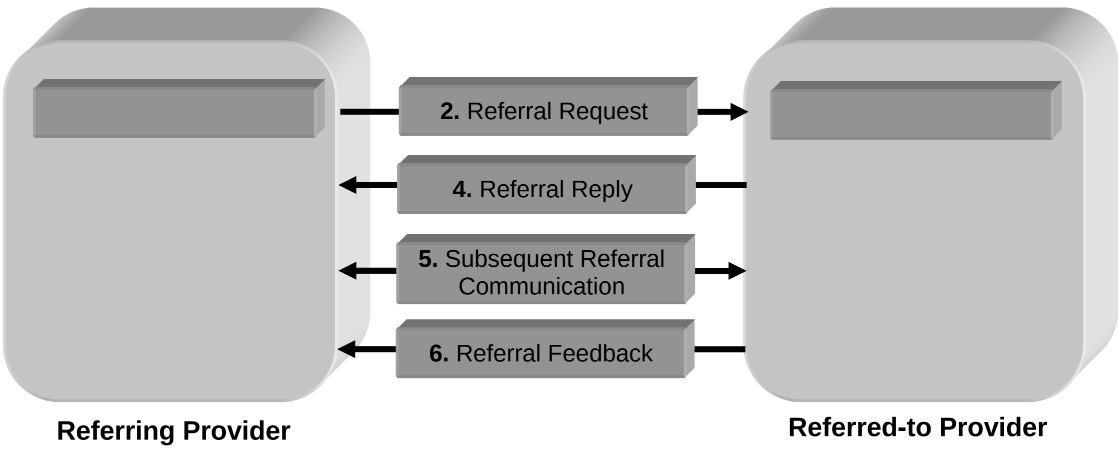


Figure 2.3 Simplified Referral Process Model

Referral Decision: In this step, the referring provider makes a referral decision regarding the need for referral, type of required services and preferred service provider based on various clinical and non-clinical factors. A referring provider is one that requests the services of another healthcare provider (a referred-to provider).

Referral Request: Once a referral decision is made, the referring provider generates a referral request containing basic patient and provider information. It then sends the patient along with the referral request to the referred-to provider. A referral request may be as simple as a physician sending a patient to another physician for a consultation, or it may be as complex as a primary care provider sending a patient to a specialist for specific medical procedures to be performed.

Referral Evaluation: When the patient arrives at the referred-to provider, the referral request is evaluated for eligibility based on the current patient condition, availability of requested services and referral rules. A referred-to provider is one that performs one or more services requested by a referring provider.

Referral Reply: After evaluating the referral, the referred-to provider sends a referral response to the referring provider. If the referral request is found to be valid, the patient will be admitted and assigned to a specific physician. Otherwise, the referral request will be rejected.

Subsequent Referral Communication: When a patient is referred by a referring provider to a referred-to provider or is pre-admitted, there is a great likelihood that subsequent communication will take place between the two providers. The subsequent communication might include a variety of queries, orders, etc. For instance, the specialist may send out updates to the primary care provider concerning the status of the patient as regards any tests performed, their outcomes, etc. This is not common in the Ethiopian case. However, it is an important component of a referral system that can affect clinical outcomes and costs.

Referral Feedback: Once an admitted patient is provided with the required services, the referred-to provider produces a referral feedback and sends it to the referring provider. Again this is not a common practice in Ethiopian referral system. However, it can create an opportunity for generalists to share experience of specialists. This in turn has its own input in reducing inappropriate referrals.

2.2.1.3 Referral Policy

Referral policy refers to a set of guidelines and procedures used to direct how patient referrals should be processed. It can be defined at different levels (local, regional, or national) and is supposed to be employed by providers in sending and receiving patient referrals.

In the Ethiopian case, though it is not complete and fully functional, there is a referral guideline [27] that is intended to ensure efficient flow of patients from provider to provider. According to this guideline, the national referral system is supposed to operate at the level of regional states. Hence, it is the responsibility of each region to define a referral map of healthcare providers in line with the national referral guideline. The referral map is defined according to population size, distance between providers and type of services provided. It shows which provider can make/receive referral to/from which provider for which services. Each provider is expected to process patient referrals according to this map and the national referral guideline. The following are some of the basic referral rules included in the guideline.

- A patient should get primary care service at his/her nearby health center (primary care provider) without referral.
- If a patient case cannot be managed by a healthcare center, the patient should be referred to a nearby district hospital with respect to the referral distribution map.
- If a district hospital cannot manage the case of a patient, the patient should be referred to a nearby regional hospital.
- If a patient case needs special medical service that cannot be provided by a district/regional hospital, the patient should be referred to a nearby specialized hospital.
- Patient referral for an emergency case should be accepted without any restriction.
- Referred-to providers should send referral feedback to referring providers.

As discussed in section 2.2.1.2, the two key aspects of the referral process are referral decision making and inter-provider communication. Since it is the focus of this work, the following section discusses components of referral decision and factors that affect the decision in further detail.

2.2.2 Referral Decision Making

A referral decision is a clinical decision-making process by which physicians determine referral indication, type of required services and selection of appropriate providers [13].

2.2.2.1 Referral Indication Decision

Here, a physician decides whether a patient needs a referral or not. This decision is vital for it determines the clinical outcomes and costs of patient referral. If the decision is appropriate, it can lead to improved clinical outcomes and decreased costs. On the other hand, if it is inappropriate, it leads to under-referral (not referring patients who should have been referred) or over-referral (referring patients who should have not been referred) and all the associated problems. As studies show [24], this decision is influenced by various medical and non-medical factors related with a complex mix of patient, physician and healthcare system determinants as shown in Figure 2.4.

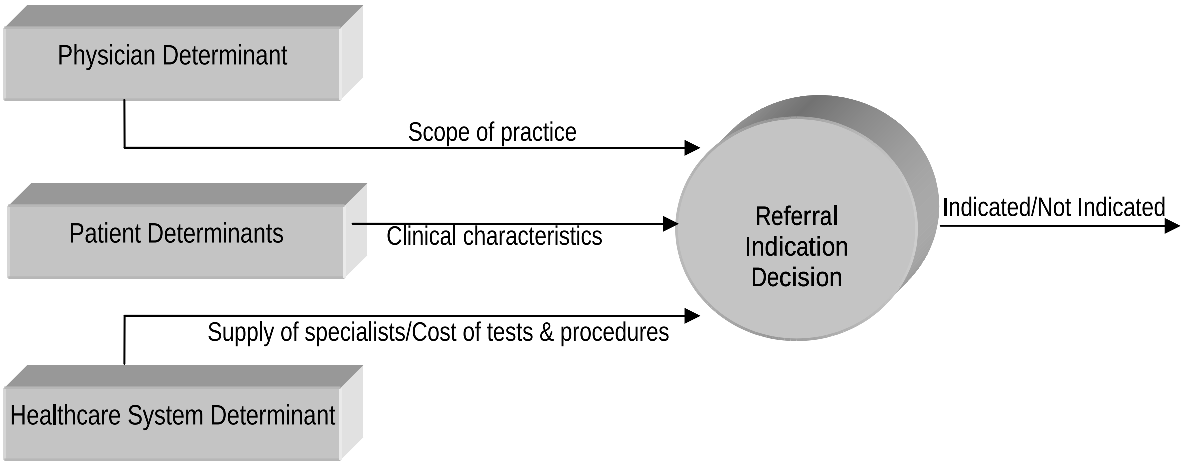


Figure 2.4 Referral Indication Decision Process

Patient Determinants: these mainly refer to the clinical characteristics of the patient's present health problem. Physicians use this information to indicate referrals based on their scope of practice.

Physician Determinant: this refers to the scope of practice of the physician, which is mainly related with the tolerance level of clinical uncertainty as well as perception of disease severity and its potential impact on future health. Less tolerance level indicates high degree of referral indication.

Healthcare System Determinants: these mainly refer to the supply of specialists and cost of specialized tests and procedures. Less supply of specialists and/or high cost of specialized tests and procedures indicate increase in number of referrals.

Each of the above-discussed determinants can influence the decision of referral indication. However, studies [24] show that clinical characteristics associated with the patient's present health problem are the most important inputs to the referral decision. The majority of variations in referral decision making appears to be related to diagnostic or case-specific factors. The other important input is physician's perception of disease severity and its potential impact on future health. Compared to others, healthcare system factors have a little input.

2.2.2.2 Required Services Identification

Once a physician has decided to refer a patient, the next step is to determine the type of required services (diagnostic tests, surgery, etc), and level of case criticality. This decision mainly depends on the current clinical condition of the patient as shown in Figure 2.5.

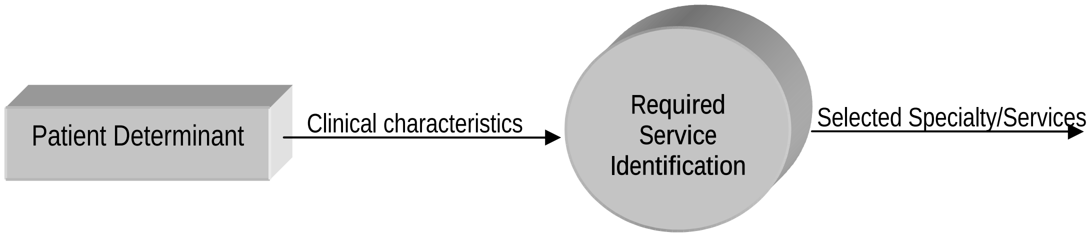


Figure 2.5 Required Services Identification Process

2.2.2.3 Provider Selection

After a physician has made a decision on the need of a referral and all required services, the next step is to select an appropriate provider. Like that of referral indication decision, this is also an important aspect of the decision-making process that may influence the clinical outcome and cost.

The selection of appropriate provider depends on various clinical and non-clinical factors related with a complex mix of patient, provider and healthcare system determinants as shown in Figure 2.6. This decision requires clear understanding of patient problem and knowledge of potential providers and referral rules so that it would be possible to choose an appropriate provider.

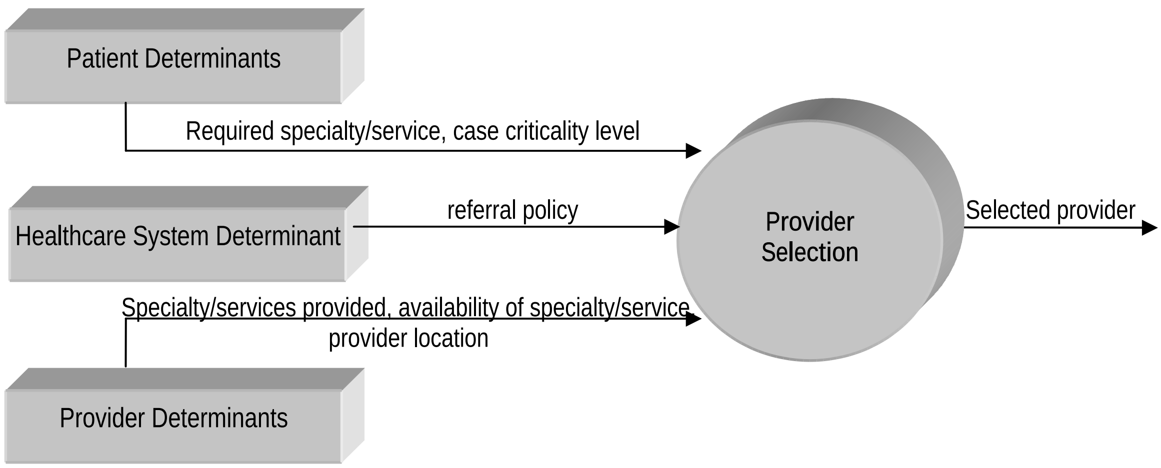


Figure 2.6 Provider selection process

Patient determinants: these refer to the clinical characteristics of the patient, which include type of required specialty, type of required services, and the criticality level of the patient case.

Healthcare System Determinant: this refers to the referral policy that governs the referral process.

Provider determinants: these refer to the characteristics of potential providers, which include type of services/specialty provided, availability of service/specialty, location of provider.

Figure 2.7 summarizes the overall referral decision-making process.

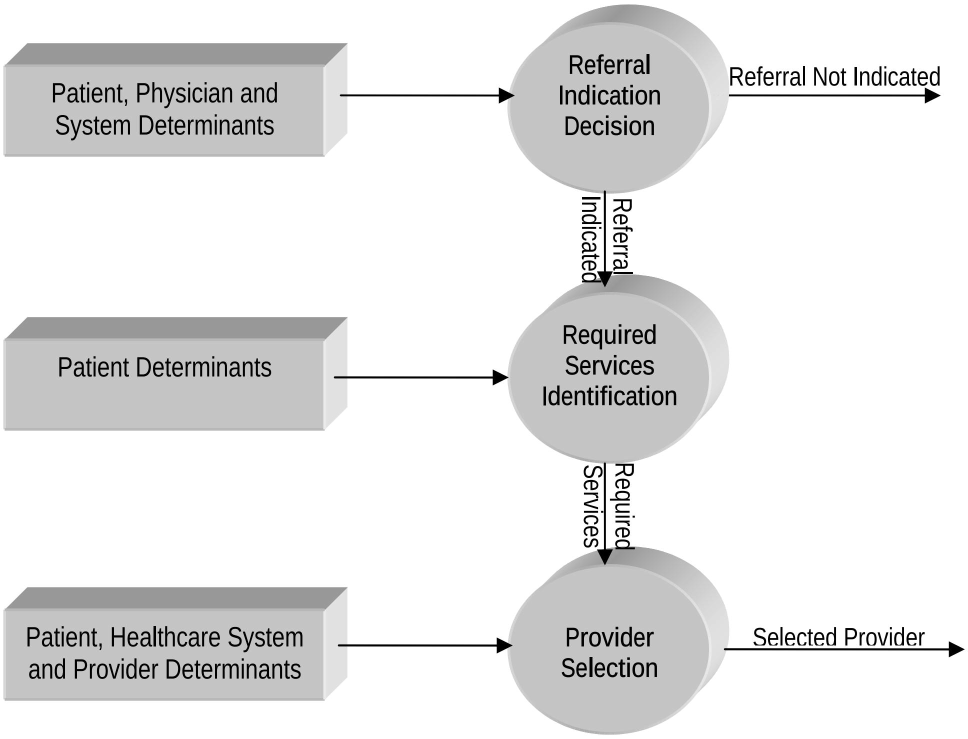


Figure 2.7 Referral Decision-Making Process

2.2.3 e-Referral Systems

Despite their promised advantages, referral systems are large-scale complex systems characterized of distribution, coordination and sociability. The activities involved in a referral system require transfer and coordination of complex and diverse forms of information distributed among providers in the target healthcare system. The complexity of the system often causes inefficient referral decisions and referral communication, which in turn affects the quality and cost of care.

Inefficient referral decisions may result in under-referrals (not referring patients who should have been referred) or over-referrals (referring patients who should have not been referred) [11]. Under-referrals can lead to inappropriate, cost-ineffective, or even dangerous treatment. Over-referrals can lead to fragmented care “by committee”; over-testing and repetitive testing; dangerous poly-pharmacy; and contentment on the part of generalists who lose their motivation of continually acquiring new knowledge. Even when a referral is required, inefficient referral decision may cause inappropriate provider selection. This in turn can greatly affect clinical outcomes and costs.

On the other hand, even though a good referral decision is made, inefficient referral communication can still decrease the quality of care by causing poor continuity of care, delayed diagnoses, poly-pharmacy and unnecessary testing [8].

Hence, it is important to improve both the decision-making as well as the communication aspects of a referral system to enhance the quality and cost-effectiveness of healthcare delivery. One strategy for achieving this is employing e-Referral (electronic referral) systems.

An e-Referral system is one promising application area of e-Health [29] aimed at improving the quality of referral process. Besides, it is a key element in the creation of regional e-Health network [30]. An e-Referral network is believed to be a better way to hospital service coordination and it may be considered as the first component required for the integrated regional delivery of e-Health services [29, 31, 32].

However, studies conducted on e-Referral systems focused on improving the communication aspect of the referral system. Little is done in studying and modeling the referral decision making to provide a decision support service to physicians. This in turn may lead to minimal effect towards achieving the objectives of referral systems. Hence, this work aims at studying the process of referral decision making to analyze and model a comprehensive referral decision support by employing the emergent multi-agent technology. A justification for the appropriateness of adopting multi-agent approach is provided in the next section.

2.3 Multi-Agent System for Referral Decision Support

As discussed in the previous section, referral decision making is a process affected by a complex mix of patient, physician, provider and system determinants. This complex process operates in an environment of distributed and dynamic network of health-care providers and it is characterized by the following main features.

- The knowledge and information required to make a referral decision (especially for provider selection) is spatially distributed across autonomous/semi-autonomous healthcare providers.
- The healthcare providers need to communicate and coordinate their effort to solve the decision making problem while keeping their autonomy.
- The referral decision problem can be decomposed into different interdependent sub-problems.
- Making an optimal referral decision has no a straightforward solution.

For automating such a complex process, a multi-agent approach can provide an adequate solution [3] by providing the following main features:

- Intelligent agents enable each healthcare provider to keep and maintain the portion of the knowledge required for the referral decision-making process.
- The sociability of agents helps to realize the distributed referral decision support
- The autonomy of agents helps each healthcare provider to keep its private data and employ its own method of processing patient referrals.

Thus this approach allows structuring the referral decision support system around several intelligent, autonomous, communicative and cooperating agents. This is believed to improve the conceptualization, design and implementation of the decision support system. This work specifically targets to address the problem of provider selection component of a referral decision.

The following chapter discusses some related works conducted in adopting multi-agent technology to the area of healthcare in general and to problems of referral systems in particular.

CHAPTER 3 Related Works

3.1 Agent-based Healthcare Applications

Healthcare is a diverse and complex domain which aims at the delivery of cost-effective and quality health-care services to citizens [26]. It is a vast, open and dynamic domain characterized by distributed decision making and management of care, which require communication and coordination of complex and diverse forms of information distributed among providers [5]. In the past years, many research works have been conducted to provide Information Technology solutions to the diverse problems of the domain. Specifically, in recent years several studies have been conducted to investigate the possibility of adopting agent technology and to identify features of the domain, which suggest an agent-based solution. Some of the works that contributed to the motivation of this work are discussed below.

The research works in [4, 5] show that multi-agent systems do have an increasingly important role to play in the healthcare domain by enhancing the ability to model, design and build complex, distributed healthcare software systems. In these works, multi-agent systems are indicated to have a set of characteristics that make them appropriate to be used to tackle healthcare problems. Moreover, features of an application area that makes an agent-oriented approach appropriate are identified. Some of the identified features are the distributed nature of the data; complexity of the software solution; lack of centralized solution; need to maintain independence between health-care entities; need to coordinate in order to provide specific services to individuals; and need to receive information and advice proactively. In addition, based on this characterization, some potential application areas are identified and exemplary agent-based applications are discussed.

The work in [33] proposes an agent-based healthcare system referred to as MEDUSA (Medical Information System Using Agent Technology). The major goal of MEDUSA is to design and develop a multi-agent based integration of patient-referred professional data for the establishment of EHR (Electronic Health Record). It is proposed for an extensive information exchange between the participants of the health service and for improved medical care of patients.

The research work in [34] presents an agent-based healthcare system referred to as MAMIS (Multi-Agent Medical Information System). The system is designed with the goal of providing a solution for patient information search on a community of autonomous health-care units and to provide ubiquitous information access for physicians and health-care professionals in a variety of situations. The system assumes health-care units with identical structure linked by an information network.

The study in [35] discusses how Multi-Agent Systems (MAS) should be designed in the context of diabetic health-care. The work aims at improving the diabetic health-care by introducing agent-based services to the care-providers and care-receivers.

In [36], a multi-agent system that provides information about medical services is proposed. The system incorporates agents that maintain information about medical centers, medical departments and doctors available in a city. Users may interact with these agents to request information about the medical centers satisfying a set of conditions, or to request a booking to be visited by a particular type of doctor. The key points in the design of the system are definition of a medical ontology and the implementation of security measures that ensure the confidentiality of medical information.

The above discussed studies indicate the potential of multi-agent techniques to tackle problems in the healthcare domain, and the growing interest of researchers to adopt these techniques to the domain. This is the main reason behind our motivation in employing multi-agent approach for the decision problem of medical referral systems. In the following section, appropriateness of multi-agent technology for clinical decision support is discussed.

3.2 Agent-based Clinical Decision Support Systems

Decision Support Systems (DSSs) are software systems designed to support and improve decision making [37]. They are model-based set of procedures for processing data and judgments to assist a decision-maker in his decision-making [38]. Clinical Decision Support Systems (CDSSs) are aimed at helping healthcare professionals in making quality clinical decisions. These systems are one of the potential healthcare application areas that can be adequately tackled by employing multi-agent techniques [4, 5]. The work in [39] indicates that agent-based decision support systems can be used to improve the quality of healthcare in many ways. Some of the works conducted in this area are discussed below.

The work in [40] proposes multi-agent system architecture to provide a decision support for heart failure management in a generic home care system. The system incorporates various processing modules based on statistics, rules and models that are applied to the medical data of patients, as well as learning capabilities based on the medical interventions that take place, and negotiation schemes among agents. The main goal of the system is the characterization of the patients' health status and accordingly the notification of the corresponding medical personnel to take medical actions.

In [41], a multi-agent decision support system is proposed to assist a coordinator of organ transplants of a hospital in the determination of the most suitable receivers for a given organ at a national level. The goal is to obtain a ranking of the list of waiting patients according to their matching with the characteristics of the organ that is available at a particular time. The preference list obtained can be used by the medical specialists in order to make a better selection and increase the transplant success.

In [42], another agent-based organ transplant management system is proposed to serve as smart software support for data management and decision-making process. Its first objective is to improve the complex task of characterizing potential recipients and donors by collecting, storing, processing and dynamically maintaining relevant data by transplant centers and other institutions involved in the organ transplant management process. Its second objective is to support the decision-making made by the responsible medical teams involved in transplant centers to process a significant amount of information (organ and corresponding waiting patients' descriptions) so that it would be possible to verify whether there is a compatible recipient on the corresponding waiting lists.

The studies discussed above indicate the appropriateness of adopting multi-agent technology for clinical decision support systems.

3.3 Agent-based Referral Systems

In our search of works conducted to study the possible adoption of agent technology for referral systems at large and referral decision support systems in particular, we have come across only one work [35].

This work presents a study conducted on how to use mobile software agents to facilitate the referral process. It tries to improve the inter-physician interaction that exists in referral communication between outside care providers (PCP's) and two specific hospitals. The agent-based system that has been proposed in this study uses web browser/server to initiate the referral and Java software mobile agents to support the workflow of the referral. This combination is intended to provide a light client implementation that can run on a wide variety of hardware and software platforms found in the office of the PCP. Here, agents are delivered to the PCP as running applications that can perform ongoing queries and alerts at the office of the PCP. Besides, the mobile agents are adapted to support the wide variety of data types that may be used in referral transactions, including reports with complex presentation needs and scanned images. This allows the consultant to specify for the PCP the data that should be attached to the first visit and the PCP is able to receive a reply to the referral as soon as the consultant has seen the patient.

The work focuses only on the referral communication. It does not address the problem of referral decision-making process, which is an important component of a referral process that can affect the overall outcome of a referral system. Thus, the main aim of this research is to study the nature of referral decision problem and investigate the possible ways of adopting multi-agent technology to this problem. The final target is to develop a multi-agent referral decision support framework that can assist physicians in making better referral decisions.

CHAPTER 4 Multi-Agent Referral Decision Support (MARDS) Framework

4.1 Overview

This chapter presents the proposed **M**ulti-**A**gent **R**eferral **D**ecision **S**upport (MRDS) framework aimed at extending the capability of existing e-Referral Systems with an intelligent referral decision support. To ensure cost-effective extension, a three-layered **M**ulti-Agent **e**-**R**eferral (MeR) system framework is proposed. The top layer of the framework, referred to as information system layer, represents any of the existing e-Referral systems designed to improve quality of referral communication. The bottom layer, referred to as communication layer, represents any of the existing distributed messaging middleware that can be employed for inter-agent communication. The key aspect of the system is a multi-agent system layer proposed to provide a referral decision support service for the information system layer. The layer is described in terms of its architectural design and an underlying technique developed for referral-decision support. The multi-agent architecture is designed to support the overall referral decision-making process (referral indication decision, required service identification, and appropriate provider selection). However, the decision support technique focuses on provider selection. The other two are out of the scope of this thesis and would be tasks to be done in the future.

The chapter is organized as follows: section two presents design considerations taken into account while designing the system; section three discusses goals that the MeR system targets to achieve; section four presents an architectural framework of the MeR system; section five presents an architectural design of the MARDS system.

4.2 Design Considerations

4.2.1 Design Assumptions

The following are the main design assumptions considered in designing the MeR system. These assumptions essentially specify the scope of our work.

- **Target Referral System:** the system primarily targets at the context of Ethiopian referral system.

- **Network Infrastructure:** the design of the system assumes an existing network infrastructure (HealthNet) that connects healthcare providers across the country.
- **System Design:** the design of the system focuses on the multi-agent system layer. It assumes that each healthcare provider has an e-Referral system connected to a Hospital Information System (HIS). Besides, the multi-agent system design is limited to an architectural design level. It does not deal with the detail design. However, a detail design and implementation of the core part of the multi-agent system will be dealt with during prototype development.
- **Messaging Middleware:** the system is supposed to use the existing messaging mechanisms (CORBA, RMI, DCOM, HTTP, etc.) for its inter-agent communication.

4.2.2 Referral System Model

As described in the previous chapters, this work targets particularly the Ethiopian referral system. The main reason for this is the learned variations that exist in the referral business process of healthcare systems of different countries. For instance, healthcare providers in some countries make referral to a physician and others to a provider. In addition, the healthcare system of many countries is highly integrated with the insurance system. In such condition, insurance information of patients is considered as an important factor for the referral decision. In other countries, this is not the case. This makes designing a generic system somewhat difficult. Nevertheless, the system design is intended to be easily adapted for the referral system of other countries.

Unfortunately, we have found the referral system of Ethiopia to be not well-defined. It is supposed to operate at a regional level (regional referral systems) in which each region is expected to develop its own referral chain (distribution map) that specifies how patient referrals should flow among providers. However, the referral structure as well as the associated referral process of regions is not well defined. For this reason, we have considered a new referral model for our system. This model is inspired by the idea of the Spanish coordination model [41], which has been adopted by many European countries. Even though the coordination model is designed for national organ transplantation system, we have found its organizational structure and design objectives to be similar to that of referral systems. Hence, we have employed some of its ideas for our referral model.

The new referral model organizes healthcare providers at zone level along with referral coordinators at four stages as shown in Figure 4.1. In this model, the referral process of each healthcare provider is coordinated centrally by the HRC (Healthcare provider Referral Coordinator). Every referring physician in a healthcare provider forwards any indicated referral request to the HRC. The HRC then starts to locate an appropriate provider for the referral, following the predefined hierarchy shown in Figure 4.1 and level of providers (healthcare center, district hospital, regional hospital, specialized hospital).

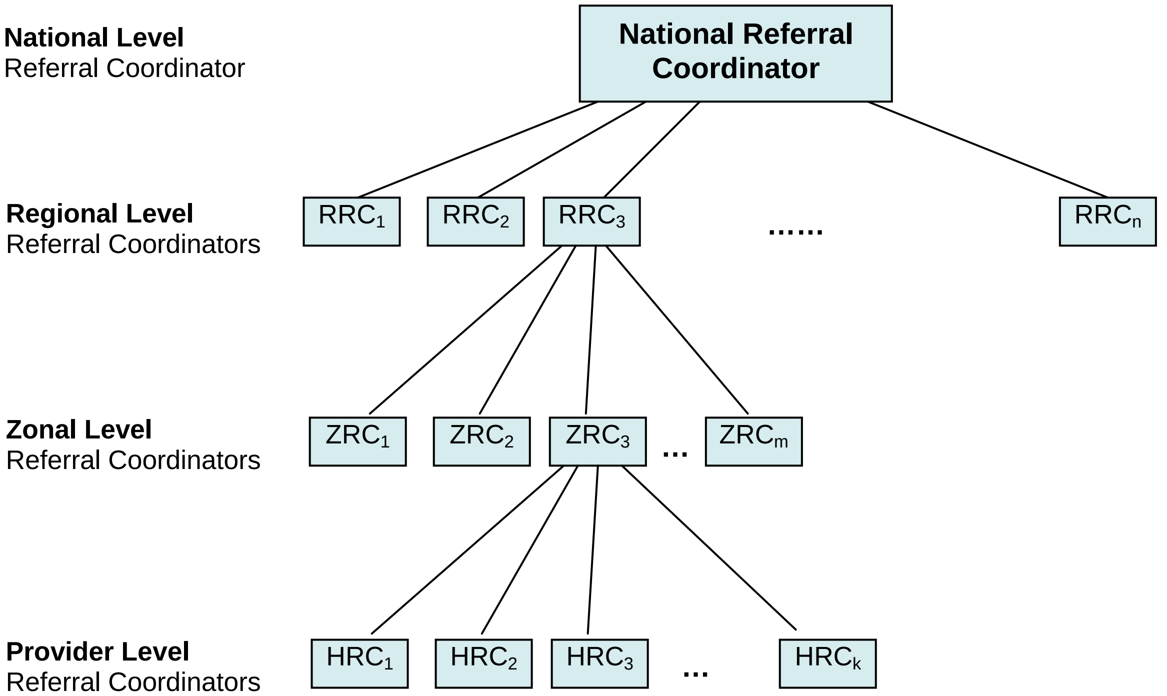


Figure 4.1 Referral system model f or the MeR system

For instance, if the referring provider is a healthcare center, the HRC tries to locate an appropriate nearby district hospital in the same zone that can provide the required service by contacting the **Z**onal **R**eferral **C**oordinator (ZRC). If no such provider is found, the HRC will try to locate a regional hospital in the same zone. If no such provider is found, the search will continue to locate a specialized hospital in the same zone. If still not found, similar searching process will continue in the nearby zone of the same region and zones of nearby regions by contacting the **R**egional **R**eferral **C**oordinator (RRC) and the **N**ational **R**eferral **C**oordinator respectively.

When an appropriate provider is found and selected, the referring HRC will send the referral to the HRC of the selected provider. The referred-to HRC then assigns an appropriate physician for the referral. It also sends referral feedback to the referring HRC after the required services are provided.

The search process is intended to allow finding a healthcare provider at an appropriate level that is closer to the referring healthcare provider.

4.2.3 Design Methodology

In designing the multi-agent layer of the system, a pattern-oriented approach described in [43] is employed. This approach suggests complementing a goal-driven methodology with the application of agent patterns. This is believed to facilitate a goal-driven design process by employing design patterns. In this approach, the design process is carried out both in top-down (by using goal-driven methodology) and bottom-up (by using agent patterns at different design stages) directions in parallel. For the goal-driven approach, the new release of Gaia methodology is adopted for three major reasons. Firstly, the design metaphor (organization metaphor) that is provided by the methodology is found to be convenient to our case since it reduces the conceptual distance between the target domain and the Multi-Agent e-Referral System. Secondly, we have found the design models provided by the methodology to be at an acceptable level of abstraction. Thirdly, we have found the methodology to be easier to learn and use.

The Gaia design process incorporates three phases [44]. The starting point in Gaia process is the analysis phase that aims at collecting and organizing the specification. At the end of this phase, an environmental model, a preliminary roles model, a preliminary interactions model and a set of organizational rules are produced, which are used as a basis for the design of the MAS. The second phase is the architectural design phase that targets at identifying and specifying the overall architecture of the system. This phase produces a MAS architecture together with its completed roles and interactions models. The last phase is the detailed design phase, which aims in defining the agent and service models by making use of the architectural design models.

However, Gaia does not deal with the activities of requirement capturing and modeling, which is an important input for the multi-agent system analysis phase. Besides, the identification of agents is placed in the detail design phase, which we have not found it to be convenient for the architectural design. We believe the identification of agents is an important input to the architectural design. Hence, in designing the architecture of the system, we have followed the approach shown in Figure 4.2 by making a little modification on Gaia.

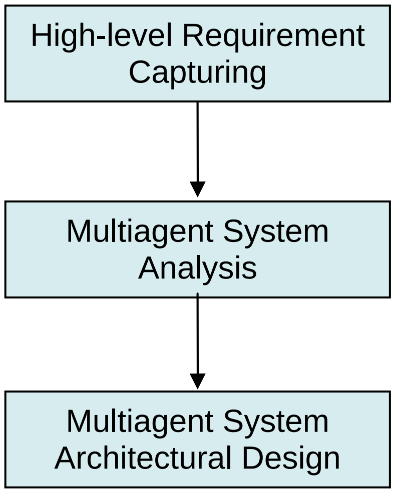


Figure 4.2 Phases of the system design process

High-level Requirement Capturing

In this phase, the high-level system requirements that are specifically important for the architectural design of the system are captured and specified. Here, we have employed the goal-oriented approach [45], since their abstractions closely match those of agent-oriented computing [44]. This approach takes the initial system specification and transforms it into a structured set of system goals. A goal is defined in [46] 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 [46]. Once these goals have been captured and explicitly stated, they are less likely to change than the detailed steps and activities involved in accomplishing them [46]. In capturing system goals of MeR, the following two steps are performed.

- Identification of goals from initial system specification
- Structuring of goals using goal hierarchy diagram

Multi-Agent System Analysis

In this phase, system goals are analyzed with the aim of organizing the system specification for our MAS. Here, the following main analysis steps are performed.

- Subdividing the system into sub organizations
- Identification of environmental entities and resources
- Identification of preliminary roles and interactions
- Identification of preliminary agents from the roles and interactions

- Identification of organizational rules

Multi-Agent System Architectural Design

In this phase, the overall system architecture is designed using the analysis models from the previous phase. In the process of designing the architecture, the following major design steps are carried out.

- Identification of organizational structure
- Completion of preliminary roles and interactions
- Completion of preliminary agents

In identifying agents, interactions and organizational structure, an attempt is made to ensure maximal use of existing design patterns (organizational patterns, social patterns and other agent patterns).

4.3 System Goals

The overall goal of the MeR System is improving the referral process. To achieve this general goal, the system goals (categorized as hard and soft goals) are identified from the initial system specification.

4.3.1 Hard Goals

Hard goals are those whose satisfaction can be established through verification techniques [47, 48]. The hard goals of the system are specified by a goal hierarchy diagram shown in Figure 4.3. Each level of the hierarchy contains goals that are roughly equal in scope and all sub-goals relate functionally to their parent. The overall goal of the system is supporting healthcare providers in improving the referral process to ensure cost-effective and quality patient care. To achieve this general goal, the system should provide a referral decision support and automated referral communication.

In providing the decision support, the system should be able to assist referring providers in determining indication of referral, required services/specialty and selection of appropriate healthcare provider. This would help providers in making quality and cost-effective referral decisions. Regarding the automation of referral communication, the system should be able to automatically generate a referral request; allow referring providers send the request to the selected provider; and enable referred-to providers reply for the request (during consultancy and after consultancy). This would improve the quality of referral communication in terms of time and content.

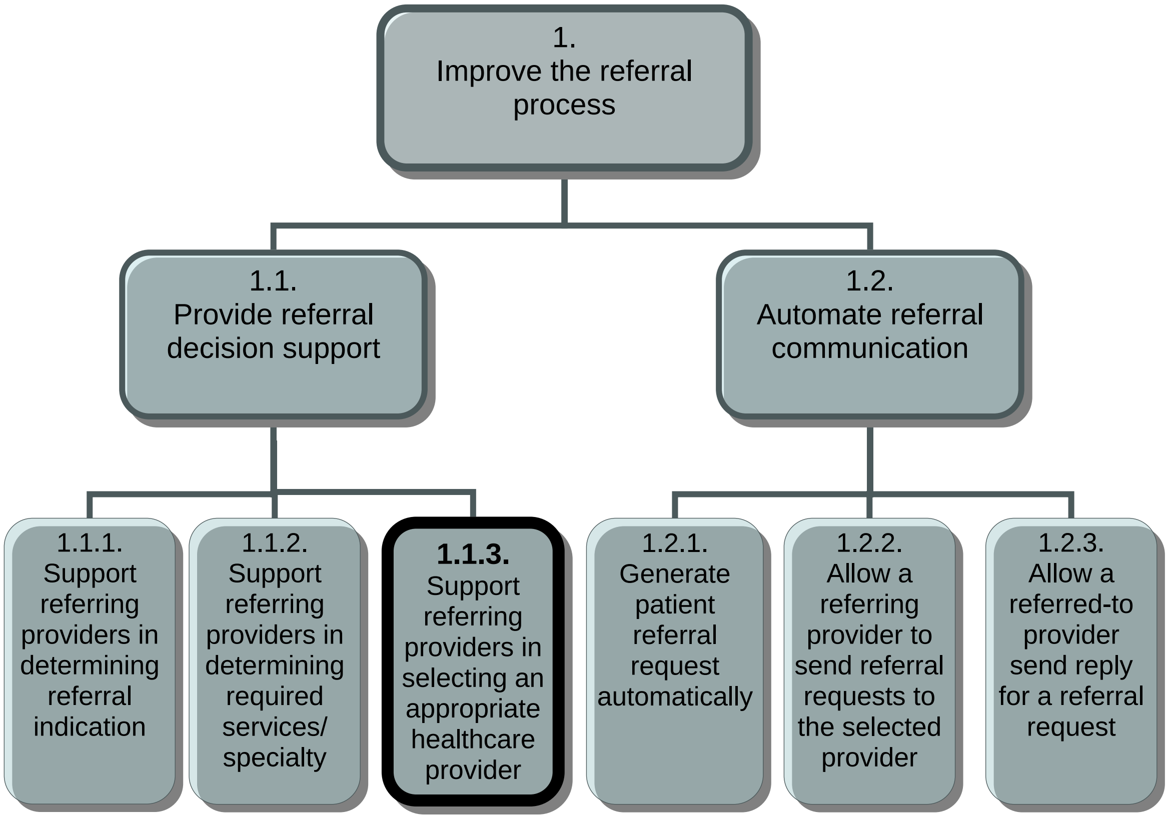


Figure 4.3 Goal Hierarchy Diagram of the MeR

However, our focus in this work is on the referral decision support, specifically on the provider selection. Hence, for goal 1.1.3, we have identified further sub goals as depicted in Figure 4.4. In order to support the referring provider in selecting appropriate provider, the system should collect three categories of decision constraints (patient, referral policy, and provider); and select list of providers that best fit the analyzed constraints by filtering and ranking appropriate providers.

4.3.2 Soft Goals

Soft goals are those whose satisfaction cannot be established in a clear-cut sense [49]. These are especially useful in refining the hard goals [50]. Generally, the Multi-Agent e-Referral System should be designed towards ensuring better care with less cost. Towards achieving this general goal, the following two major categories of soft goals are identified.

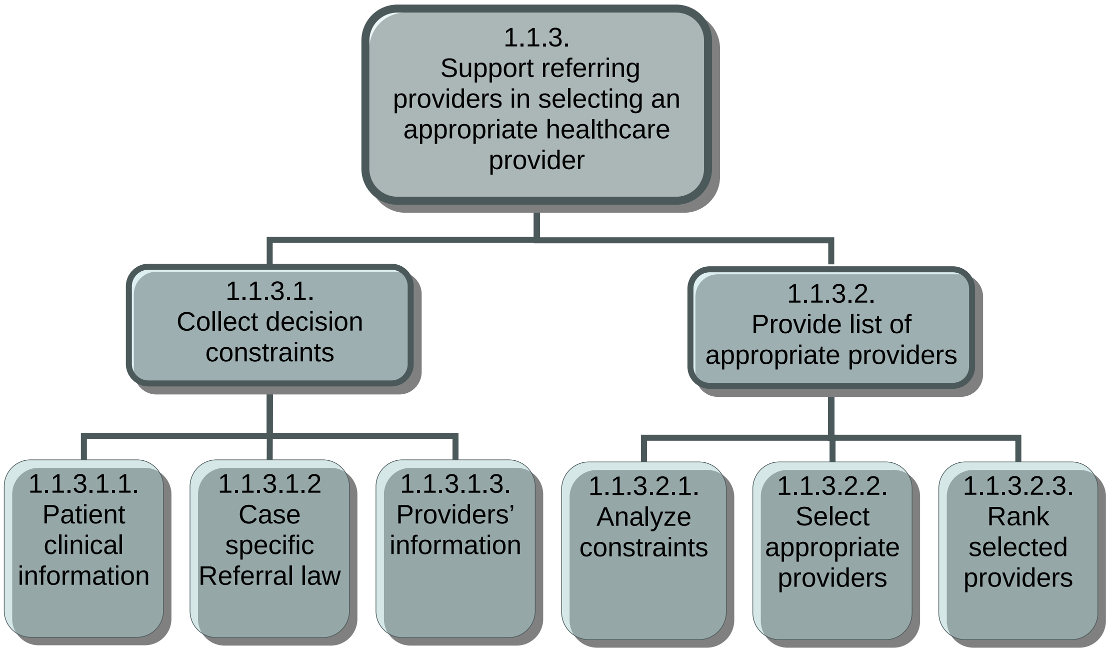


Figure 4.4 Goal Hierarchy Diagram of Sub Goal 1.1.3 (Provider Selection)

4.3.2.1 Ensure a good quality referral decision

Referral decision, as described in chapter 2, is an important aspect of the referral process that can affect the overall outcome of patient care. Hence, the system should provide support to ensure a good quality referral decision by

- Minimizing under-referrals in order to protect inappropriate, cost-ineffective, or even dangerous treatment
- Minimizing over-referrals or unnecessary referrals in order to free consultant resources for treating cases that are more complex
- Identifying the right services
- Sending a patient to an appropriate provider

A detail discussion of sending a patient to an appropriate provider, which is the theme of this thesis work, is given in the next chapter.

4.3.2.2 Ensure a good quality referral communication

As described in chapter 2, good quality referral communication is another vital component for the success of a referral process. Effective transfer of information between providers can improve the quality and efficiency of patient care. Hence, in achieving quality referral communication, the MeR System should be able to:

- Minimize assessment and treatment time of patients

- Improve quality and content of information exchanged
- Minimize intervention of providers in managing the referral communication
- Ensure interoperability between disparate information systems
- Ensure security and privacy of patient data

4.4 MeR System Framework

The main objective of the MeR system is extending the capability of e-Referral systems with intelligent referral decision support. To achieve this, we have chosen a design direction that allows e-Referral systems to be complemented with a new multi-agent system layer for their need of referral decision support. For this reason, the system is designed as a three-layered distributed multi-agent system. The layering approach could simplify the design complexity of the overall system by decomposing it into manageable pieces. More importantly, it allows integration of the MAS with existing e-Referral systems. Figure 4.5 depicts the proposed architectural framework of the MeR System. A general description of each layer is presented below.

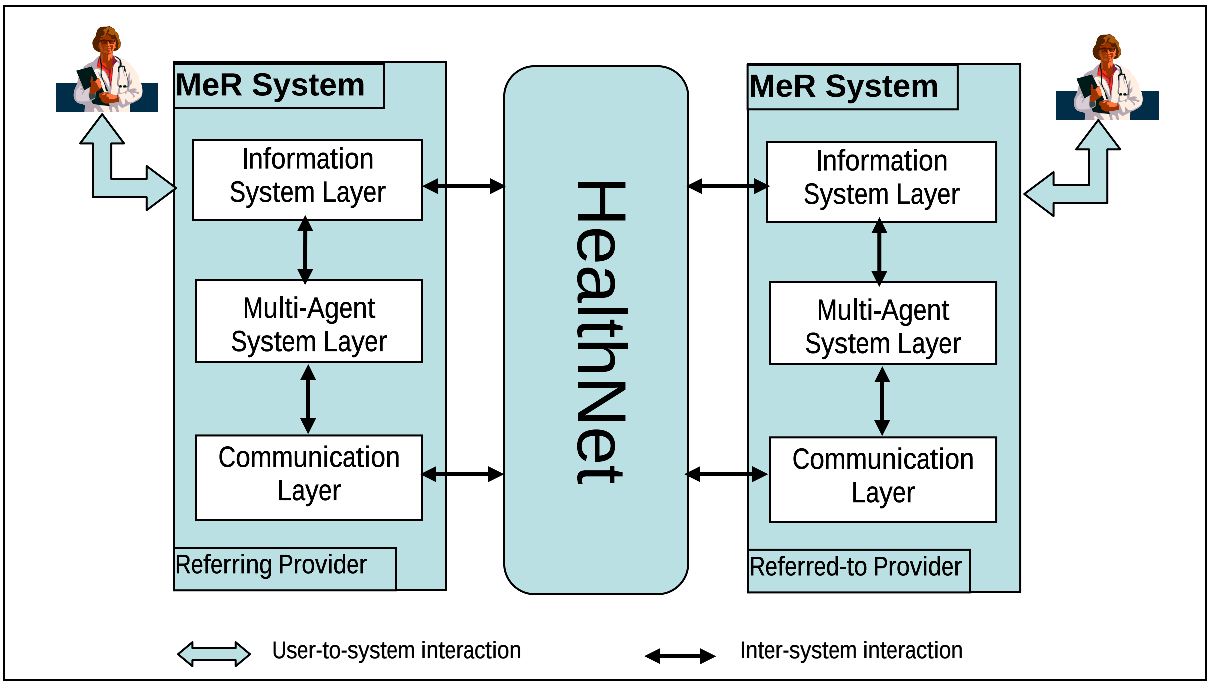


Figure 4.5 Three-layered Architectural Framework of the MeR System

4.4.1 Information System Layer

The information system layer represents an existing e-Referral system that handles e-Transfer of patient referrals between healthcare providers distributed across the HealthNet. With the help of e-Referral system, providers can initiate e-Referral process, send e-Referral request, provide e-Referral reply, track status of ongoing e-Referrals, and audit previous e-Referral transactions. This can facilitate the physical transfer of patients from one healthcare provider to another. However, this should be complemented with referral decision support for the success of the overall referral system.

4.4.2 Multi-Agent System Layer

The multi-agent system layer represents a *distributed problem solving system* that incorporates a group of individual cooperating agents running to provide referral decision support to the information system layer (e-Referral System). The decision support is intended to help referring providers in making an optimal referral decision regarding *the need for referral*, *the required services/specialty* and *the selection of appropriate provider*. In this work, we specifically deal with the study of how to support referring providers in the process of selecting appropriate provider. This would allow referring providers to locate the closest healthcare provider at an appropriate referral hierarchy that can provide the required service. This in turn is intended to improve patient outcomes, minimize transportation time and the associated costs. The architectural framework of this layer is detailed in section 4.5.

4.4.3 Communication Layer

The communication layer provides a messaging mechanism for intra-provider and inter-provider multi-agent communication. Intra-provider multi-agent communication deals with inter-agent communication for agents residing in the same provider. On the other hand, inter-provider communication deals with inter-agent communication for agents located across providers. In this work, this layer assumes to employ any of the existing messaging mechanisms (CORBA, RMI, DCOM, HTTP, etc).

4.4.4 Inter-layer Interaction

The overall inter-layer interaction that should exist between layers goes as follows: when invoked by a referring provider, the information system layer initiates the referral process via its e-Referral system by passing its decision support request to the multi-agent system layer.

Together with the request, it also passes clinical characteristics of the patient under-consideration.

The multi-agent system then starts analyzing the clinical and other relevant data in order to decide whether referral is indicated or not. If it is indicated (if the patient needs referral), the MAS provides its response of referral indication along with the required services/specialty to the information system layer. Otherwise (if the patient does not need referral), it responds the inappropriateness of the referral along with the recommended follow-up service (which serves as a specialist advice). The e-Referral system then provides the recommendation to the referring provider.

The provider may or may not agree with the recommendation. However, we believe the information provided by the system plays an important role in the final decision of the provider. It can contribute in decreasing over-referrals (inappropriate referrals) by providing specialist advice to the primary care physician. Moreover, it can help in minimizing under-referrals by indicating the appropriateness of a referral.

In any case, if the referring provider wants to proceed with the referral, the information system layer invokes the multi-agent system layer for appropriate provider selection by passing the required services/specialty. The MAS then starts locating list of appropriate providers based on the required service/specialty, local and national referral policy, status of providers, and other constraints. Then after filtering and ranking eligible providers, it provides its recommendation to the referring provider via the information system layer. Once a provider is selected, the e-Transfer process between the referring and the referred-to providers proceeds through the e-Referral system.

Agents in the multi-agent layer (intra-provider/inter-provider) communicate with each other through the communication layer that provides messaging service for interacting agents.

4.5 MARDS System Framework

This section discusses the architectural framework of the multi-agent system layer. As mentioned in the previous section, the purpose of this layer is providing a referral decision support to the information system layer. In so doing, it employs several collaborating agents that interact with each other to achieve optimal referral decision. Some of them provide a decision support for referral indication and service identification. Others are dedicated for supporting selection of appropriate provider.

Being motivated by the structure of the target referral system, which involves multiple interacting healthcare providers organized hierarchically, the Multi-Agent Referral Decision Support system is designed as a multi-level hierarchy, which involves multiple autonomous interacting MASs. In this design, each provider is represented by an autonomous MAS that interacts with other MASs based on the hierarchical organization of providers. The internal MAS design of the MARDS system is specified by an intra-provider MAS architecture and the interaction between MASs is described by an inter-provider MARDS system architecture, as detailed below.

4.5.1 Intra-Provider MARDS System Architecture

Figure 4.6 shows the proposed intra-provider MARDS system architecture in which the dotted square encloses agents that belong to the same provider. With the intention of compromising the trade off between the complexity of agents and the inter-agent communication overhead, five types of agents are identified. Each agent is described below in terms of the role it plays and its interaction with other agents

User Interface Agent (UIA): This agent interacts with the user (provider) via the information system layer, receiving user requests and delivering results of the MARDS system. The UIA passes the user's requests to and gets returns from the referral coordinator agent.

Referral Coordinator Agent (RCA): This agent is responsible for coordinating the process of referral decision support. It acts as a *decision support coordinator* from the side of a referring provider, and as a *referral request evaluator* from the side of a referred-to provider. Hence, the RCA should maintain knowledge about the provider (location, services provided, referral level, current availability of services, etc), capabilities of all agents in the local MAS, and the current referral policy.

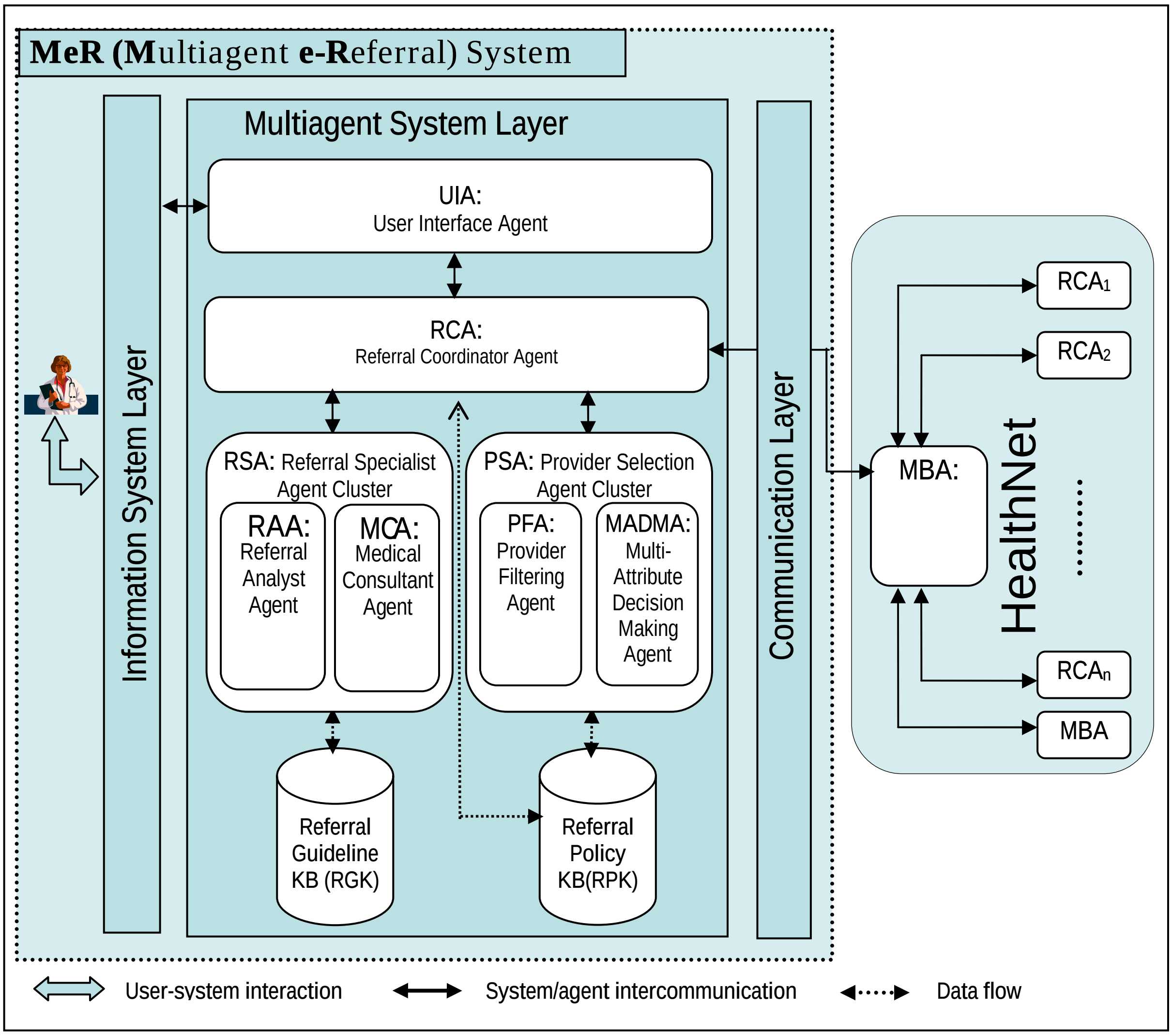


Figure 4.6 Intra-Provider MARDS System Architecture

When acting as a decision support coordinator, it receives decision support request from a referring provider through the UIA, allocates the requested task to an appropriate agent (Referral Specialist Agent or Provider Selection Agent) depending on the request type, and provides the result (recommendation of the assigned agent) to the provider via the UIA. During provider selection, the RCA interacts with the Medical Broker Agent to provide the Provider Selection Agent information about potential providers.

On the other hand, when acting as a referral request evaluator, it delegates the referred-to provider to evaluate and respond to a referral request based on the knowledge about the provider (maintained internally) and referral policy (represented as a knowledgebase). The RCA receives the request from a referring provider through Medical Broker Agent.

Referral Specialist Agent (RSA): This is an agent cluster designed to provide a decision support service for a referring provider regarding the need of referral and required services. It is composed of two key agents: *Referral Analyst Agent (RAA)* and *Medical Consultant Agent (MCA).* The RAA is designed to help providers in determining whether a referral is needed or not. On the other hand, the MCA is intended to provide local medical consultation for Primary Care Physicians (PCPs) when referral is not indicated. To provide this decision support, the RSA employs a Referral Guideline Knowledgebase (RGK).

A Referral guideline serves as a checklist for the Primary Care Physician (PCP) to ensure that the most appropriate treatment is performed prior to a referral. It is meant for common, non-life threatening diagnoses, which describe the tests and treatments a PCP should perform before referring a patient to a specialist [13]. As described in [1], referral guidelines can be developed internally by a healthcare system in cooperation with their specialists or by external vendors. The latter are referred to as proprietary referral guidelines. They are consensus-based, literature-driven protocols that are developed, refined and tested by specialist physicians of a healthcare system. These guidelines can be purchased and utilized by other healthcare systems [13]. Usually, the medical management recommended by these guidelines has been indicated to resolve the illness and eliminates the necessity for specialist referral [13]. For the Ethiopian case, further work is required to study the possible ways of developing a cost-effective referral guideline according to the national healthcare system. Once the guideline is developed, it is implemented using a Referral Guideline Knowledgebase. The RGK is used to store referral guideline knowledge by using a formal explicit knowledge representation language. Since the knowledgebase contains the knowledge of specialists, it is considered as a key resource for the decision making process (regarding need of referral and required services) as well as for local specialist consultation.

The RAA interacts with the RCA and the Referral Guideline Knowledgebase to analyze clinical data of the patient (provided from the information system layer) and determine whether a referral is indicated or not. If a referral is indicated, it recommends required referral services/specialty. Otherwise, the MCA provides a medical management consultation, which describes the tests and treatments a PCP should perform before referring a patient.

Provider Selection Agent (PSA): This is an agent cluster designed to support a referring provider in selecting an appropriate provider by analyzing patient characteristics, referral policy and provider information. It is composed of two key agents: *a Provider Filtering Agent (PFA)* for filtering potential providers by consulting the Referral Policy Knowledgebase (RPK) and *a Multi-Attribute Decision Making Agent (MADMA)* for selecting and ranking final list of providers by employing a multi-attribute decision aid technique.

The PSA collects patient factors from the information system layer through the RCA, information about providers from the Medical Broker Agent via the RCA, case specific policy factors from the RPK. Then it employs PFA and MADMA to analyze the collected decision factors and recommend appropriate providers. A detail discussion of the selection strategy is given in the following chapter.

Medical Broker Agent (MBA): In general, this class of agents maintains knowledge about providers of the system at different levels. RCA of a referring-provider interacts with a **Z**onal **M**edical **B**roker agent (ZMB) to find providers information for the selection decision by the PSA. The ZMB in turn interacts with RCAs, **R**egional **M**edical **B**roker agents (RMBs) and **N**ational **M**edical **B**roker agent (NMB) to find providers information on behalf of the PSA. The method for searching potential providers is discussed in the following chapter.

4.5.2 Inter-Provider MARDS System Architecture

Figure 4.7 shows the proposed inter-provider MARDS system architecture that maps the hierarchical organization of providers described in section 2.2. In this architecture, RCAs, which represent providers of the referral system, are interconnected hierarchically via Medical Broker agents (MBAs) at zonal, regional, and national levels. The architecture incorporates three types of MBAs:

Zonal Medical Broker (ZMB): Each referral zone is represented by a zonal level broker agent that knows about providers (RCAs) in the zone. There are k RCAs in each zone (ZMB), where k is the number of healthcare providers in the zone.

Regional Medical Broker (RMB): Each referral region is represented by a regional level broker agent that has knowledge about referral zones (ZMBs) of the region. There are m ZMBs in each region (RMB), where m is the number of zones in the region.

National Medical Broker (NMB): The national referral system is represented by a national level broker agent that has knowledge about all referral regions (RMBs) of the national referral system. There are n RMBs in the country (NMB), where n is the number of regions in the country. There is only one NMB for the overall system.

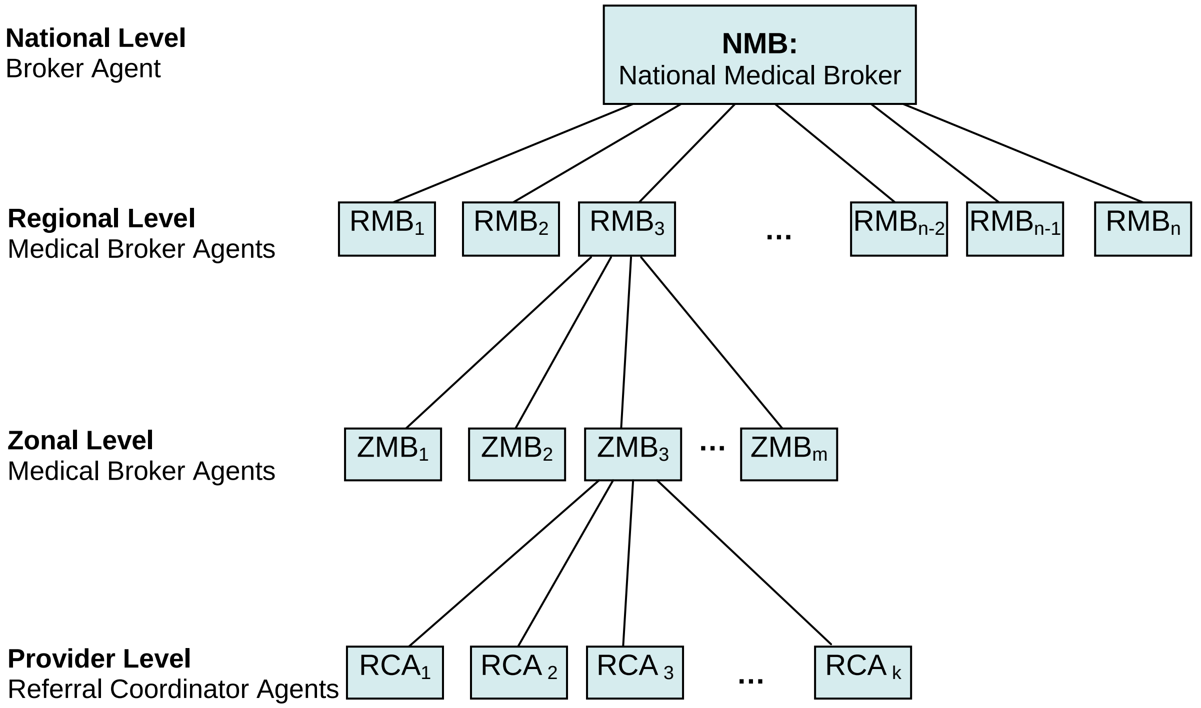


Figure 4.7 Inter-Provider MARDS system Architecture

The inter-provider architecture is designed with the aim of facilitating the search process to locate appropriate providers for patient referrals. The goal of the search process is to allow referring providers find a healthcare provider at an appropriate referral level that is closer to them. This is believed to improve patient outcomes; minimize transport time and the associated costs. The search process is described in the following chapter.

CHAPTER 5 Multi-Criteria Provider Selection (MCPS) Model

5.1 Overview

As described in the previous chapter, the first two aspects of the decision support (referral indication and service identification) can be provided locally by the intra-provider component of the MARDS. However, the third aspect (provider selection) requires communication and coordination among several distributed providers, which causes more complexity than the first two aspects.

This chapter deals with the third aspect of the decision support. It presents the underlying provider selection technique employed by the Multi-Agent Referral Decision Support. Here, a Multi-Criteria Provider Selection (MCPS) model is proposed to aid physicians in making an optimal provider selection. The model employs a three-stepped hierarchical search, a policy-based filtering, and MAUT (Multi-Attribute Utility Theory) based MADM (Multi-Attribute Decision Making) techniques for finding, filtering, and ranking list of appropriate providers, respectively. The main goal of the selection model is to locate the closest provider at an appropriate referral hierarchy. This is believed to improve the overall outcome of patients by providing medical services at an appropriate location, and by minimizing transport time and associated costs. Figure 5.1 depicts the overall approach followed in this work to develop the selection model.

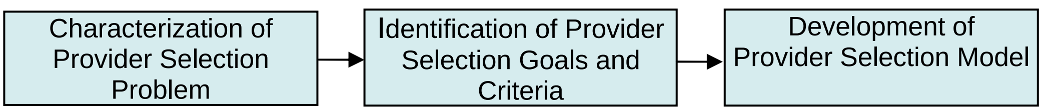


Figure 5.1 Approach for the Development of the Provider Selection Model

The first step in this approach is characterization of the problem of provider selection with respect to the theory and methods of decision aid. This is followed by identification of selection goals and criteria based on the characteristic features of the problem. The final step is development of the selection model based on the defined goals and criteria.

The remaining part of the chapter is organized as follows: section 2 describes characteristic features of provider selection; section 3 discusses goals and criteria of provider selection; section 4 presents the proposed provider selection model; section 5 concludes the chapter.

5.2 Characteristics of Provider Selection

In order to develop a selection model based on some scientific approach, an attempt has been made to study and characterize problem of provider selection in relation to the science of decision-making. For this, literature review has been carried out on the theory and methods of decision aid. This section presents a brief overview of the basic concepts of decision aid theory and methods, and then, it defines problem of provider selection based on these concepts.

5.2.1 Overview of Multi-Criteria Decision Aid Techniques

Decision-making is defined in [51] as the study of identifying and choosing alternatives based on the values and preferences of the decision maker. In making a decision, the implication is that there are alternative choices to be considered, and in such a case, the aim is not only to identify as many of these alternatives as possible but also to choose the one that best fits with the specified goals, objectives, desires and values [51].

A Multi-Criteria Decision Making (MCDM) problem is defined as one that involves some set A of alternatives and a consistent set C of criteria on A which either aims to find [52]:

a) a subset of A that contains the best alternatives,

b) an assignment of the alternatives into predefined categories, or

c) a rank of the alternatives in A from best to worst.

Each one of the objectives defines a different Multi-Criteria Decision Problem, called: (a) choice problem, (b) classification or sorting problem and (c) ranking problem.

On the issue of how to aid decision makers in solving MCDM problems, we come across two schools of thoughts: *the European School and the American School.* Even though there are some distinctions between these two approaches, the overall objective is the same: to help decision makers solve complex decision problems in a systematic, consistent and more productive way [53]. The main concept of each approach is discussed briefly as follows.

The European School (which is adopted by many European researchers) assumes that preferences are not apparent to the decision maker, and therefore the decision support is necessary for structuring the decision situation and for giving insight into the consequences of different weightings in the decision problem [52]. It concentrates on the philosophy of how to help decision makers in making better decisions by developing methods and tools that could help them to understand the *preference model* behind their decisions. This would enable decision makers to find *the way in which the decision process must be handled*. This approach allows decision makers to capture, analyze and understand several points of view that have to be taken into account while solving decision problems. This is called a ***constructivist approach***.

On the other hand, **the American School (**which is mainly developed in USA) takes a more descriptive approach. It supposes that the decision maker has an exact conception about the utility of the scores of the alternative and the weights of the different criteria that will allow him/her to determine the best alternatives. This is done using a utility function, if it can be discovered and described in mathematical terms, or using mechanisms based on comparisons among the different alternatives or options [52, 54].

In addition to the school of thoughts, there are two research areas distinguished in the theory of MCDM: MODM (Multi-Objective Decision Making) and MADM (Multi-Attribute Decision-Making).

MODM analyzes a subset of a continuous solution space, usually restricted by constraints, by locating all efficient solutions, before determining the optimum dependent on the user's preferences [52, 54].

On the other hand, **MADM** focuses on decision problems with discrete (finite) decision space in which alternatives have been predefined in advance [54]. These methods are classified into two distinct families [52]:

Multi-Attribute Utility Theory (MAUT) Methods: these are based on an aggregation approach and are derived from the American School of thought. In this approach, local preferences (at each Criterion's level) are aggregated into a unique (utility, value) function which is then optimized [52, 53]. Some of the methods within this approach include SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution), and AHP (Analytic Hierarchy Process).

Outranking Methods (OM): these are based on order-focused approach and are derived from the European School of thought. As discussed in [52], OMs construct a relation known as an outranking relation, which represents the Decision Maker's preferences. It is assumed that the Decision Maker is not able to define trade-offs between objectives. Hence, no aggregate utility function can be derived and ranking of the alternatives is done based on pair wise comparisons of alternatives. Some examples of OMs are PROMETHEE, ELECTRE, and MACBETH.

Moreover, both MODM and MADM can be classified in different ways. However, we limit ourselves only to two of the classification ways discussed in [52].

Single Decision Maker, Group of Decision Makers: Some of the methods assume a single decision maker and others a group of decision makers. Those methods, which involve more than one decision maker, are included in the research field of Group Decision Making and Negotiation.

Deterministic, Stochastic, Fuzzy Methods: In the deterministic approach, it is considered that the decision-making problem (i.e. the alternatives, criteria, etc.) is *well described* before a decision method is applied. On the other hand, the stochastic or probabilistic case corresponds to a type of modeling in which the criteria are viewed as *random* variables. The case of fuzzy methods consider different types of *uncertainty* and imprecision in some of the elements of the decision making problem.

The following sub section tries to characterize provider selection according to the concepts of decision aid as discussed so far.

5.2.2 Problem of Provider Selection

Provider selection is an important aspect of referral decision that follows decision of referral indication and service identification. It is made based on multi-criteria, and the associated decision aid service is intended to help physicians in choosing the most appropriate provider from a ranked list of alternatives. Hence, provider selection can be considered as *a choice and ranking Multi-Criteria Decision Problem*. Here, the two main challenges that physicians face in the decision making process are:

- Access to distributed knowledge (referral policy and providers information) required to make the selection and
- Computation required to compromise trade-offs among attributes of the available providers and come up with optimal selection

In the previous chapter, it has been discussed that the first challenge can be addressed by employing a Multi-Agent based distributed system design, which can facilitate searching for potential providers. On the other hand, for the second challenge, decision aid techniques can be used. Here, preferences are assumed to be apparent to the physician (existence of well-defined preference model). What is required is, studying the behavior of physicians (selection parameters, relative importance of parameters, etc.) in the process of provider selection so that it would be possible to model and apply it for new selection problems. From this, it can be concluded that provider selection best fits to the *American School of thought.*

Besides, provider alternatives are assumed to be finite and pre-defined, and therefore, selection of providers can be considered as an *MADM problem*. In addition, the decision involves only one decision maker (physician/provider), and hence, the selection strategy is expected to employ a method that assumes a single decision maker. Finally, it is presumed that decision elements (alternatives, criteria, etc.) can be defined before applying a decision method, which implies applying *deterministic* methods for the selection strategy.

In summary, provider selection can be described as a deterministic, choice and ranking MADM (Multiple Attribute Decision Making) problem, characterized by the following main features:

- Well-defined preference model
- Finite, discrete and pre-defined decision elements
- Single decision maker

5.3 Goals and Criteria of Provider Selection

5.3.1 Selection Goals

Provider selection aims at locating the closest provider in an appropriate referral hierarchy. This is intended to improve the overall outcome of patients by providing medical services at an appropriate location, by minimizing transport time and the associated costs. Hence, selecting a provider should in general ensure the following five basic goals:

- Availability of the required medical services and specialty
- Making referral to a provider at an appropriate referral level
- Minimum cost and time of transportation defined in terms of distance between the referring and referred-to providers
- Minimum assessment and treatment time
- Making a referral according to the regional and national referral policies

Some of the above-mentioned goals are conflicting. For instance, ensuring referred-to provider’s referral level may increase distance between providers, which in turn affects cost and time of transportation. In such cases, the decision solution should be able to handle trade offs between goals depending on the type of referral (regular or emergency) as well as the relative importance of goals, and provide optimal provider selection. For instance, for emergency referrals, the main goal should be to minimize the transport and assessment time. Ensuring an appropriate referral hierarchy should not be a priority here, which is an important factor for regular referrals.

5.3.2 Selection Criteria

Based on the specified goals and literature review about eight selection criteria are identified (shown in Figure 5.2) for the initial design of the selection model. The first three are related with patient determinants, the next four with provider determinants, and the last one with system determinants. Each criterion is discussed as follows.

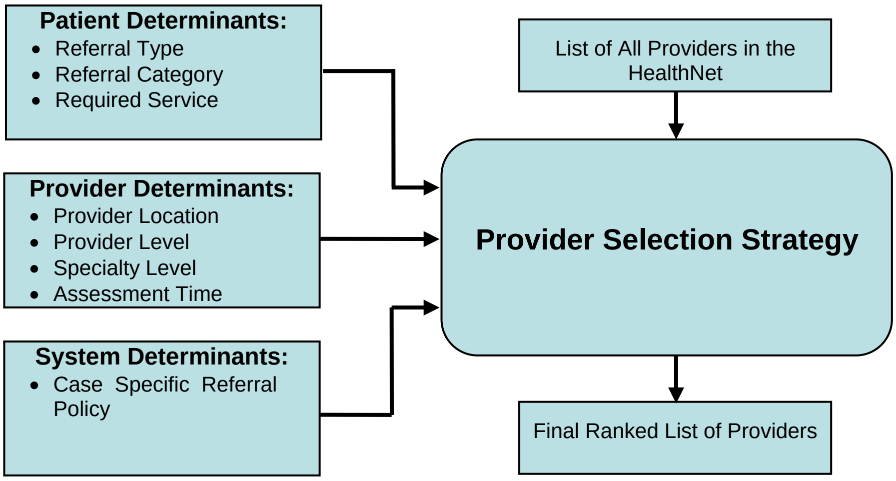


Figure 5.2 Provider Selection Criteria

Referral Type: this criterion is related with patient determinants and it indicates the type of referral required by a referring provider. Its suggested values are Emergency, or Regular. The referred-to provider handles these referral types differently, i.e. it employs different referral policies when responding to the requested referral based on the referral type. Moreover, in choosing an appropriate provider, the referring provider considers different sets of goals based on the referral type.

Referral Category: this criterion is related with patient determinants and it indicates the location at which the referral will take place at the referred-to provider. Its suggested values are Inpatient, or Outpatient. The referred-to provider handles these referral categories differently based on the availability of services and type of referral when responding to a requested referral. Moreover, in choosing an appropriate provider, the referring provider considers different sets of policies for the referral categories.

Required Service: this patient-related criterion describes the type of specialty or service required by the referring provider. Some of the suggested values are LAB (Laboratory), RAD (Radiology), MED (Internal Medicine), PSY (Psychiatry). The referred-to provider makes use of this information while responding to the referral request based on the availability of the requested service or specialty.

Provider Location: this is a provider-related criterion, which describes the location information of providers. One way of describing the location information is using an ordered pair of district, zone and region. For instance, the location of a provider in district 2, zone 2 of region 3 can be represented as [2, 2, 3]. The location information indicates the time and cost estimates of transportation between providers, and it is used by referred-to providers in responding to referral requests and by referring providers when choosing the closest provider. The choice depends on the relative location of the referring provider. For instance, if a referring provider is situated at [2, 2, 3] and we have three potential providers located at [1, 2, 3], [3, 3, 3] and [2, 3, 3], the preferred provider can be the one at [1, 2, 3] since both providers are located at the same zone.

Provider Level: this provider-related criterion describes the referral level of providers in the referral hierarchy. The value of this criterion can be PCP (Primary Care Provider), PRH (Primary Referral Hospital), SRH (Secondary Referral Hospital), or TRH (Tertiary Referral Hospital). This information is used by referring providers when choosing a referring provider at an appropriate referral level, and the choice depends on the level of the referring provider. For instance, if the referring provider is a PCP, appropriate referral level for the referred-to provider may be PRH. However, if the referring provider is PRH, appropriate referral level for the referred-to provider can be SRH.

Specialty Level: this is another provider-related criterion, which describes the level of physician specialty required by referring providers, or available at potential referred-to providers. The suggested values are Health Extension (H-EXT), Nurse (NUR), Health Officer (H-OFF), General Practitioner (GP), Specialist (SP), or Sub-specialist (S-SP). This important indicator is used by referred-to providers to responding to a referral request and by referring providers to choose a provider that can provide a better patient care based on the level of specialty required.

Assessment Time: this is also a provider-related criterion, which describes in how long time a referred patient may get the available service by the referred-to provider. Its values can be described in terms of days, weeks, or months. Together with provider location information, this is an important indicator of assessment and treatment time, and is used by referring providers in choosing a provider that can provide the required services as quick as possible.

Case Specific Referral Policy: this is a system-related criterion, which describes a specific referral policy needed for processing the patient referral at hand. For instance, emergency and regular referrals may not be processed with the same referral policy. Similarly, HIV and Surgical referral cases might not be processed with the same referral policy. In general, this criterion indicates about the policy of making and receiving referrals and it is defined by the healthcare system of the country and/or the regional states. This policy information is used by a referred-to provider while responding to referral requests and by referring providers in considering potential providers for further selection.

In the following section, we will see how the selection criteria are used by the selection model in searching, filtering and choosing an appropriate provider for patient referrals.

5.4 Multi-Criteria Provider Selection Model

This section presents the proposed three-phased Multi-Criteria Provider Selection (MCPS) model. The phase-based model is indicated by the distributed and hierarchical nature of the target referral system as well as the categorized nature of selection determinants. Figure 5.3 depicts the proposed model.

The first phase employs a **three-stepped hierarchical searching strategy** to search potential providers that are suitable for the required service (service-suitable providers) based on clinical factors of the patient. Then, the second phase applies a **policy-based filtering strategy** on the service-suitable providers to shortlist potential providers that are suitable for the required service and referral policy (service-and-policy-suitable providers). Finally, the third phase applies an **MADM method** on the service-and-policy-suitable providers to produce a final ranked list of providers. This list will be provided to the referring physician/provider as a recommendation for a final decision. Each phase is detailed in the following sub sections.

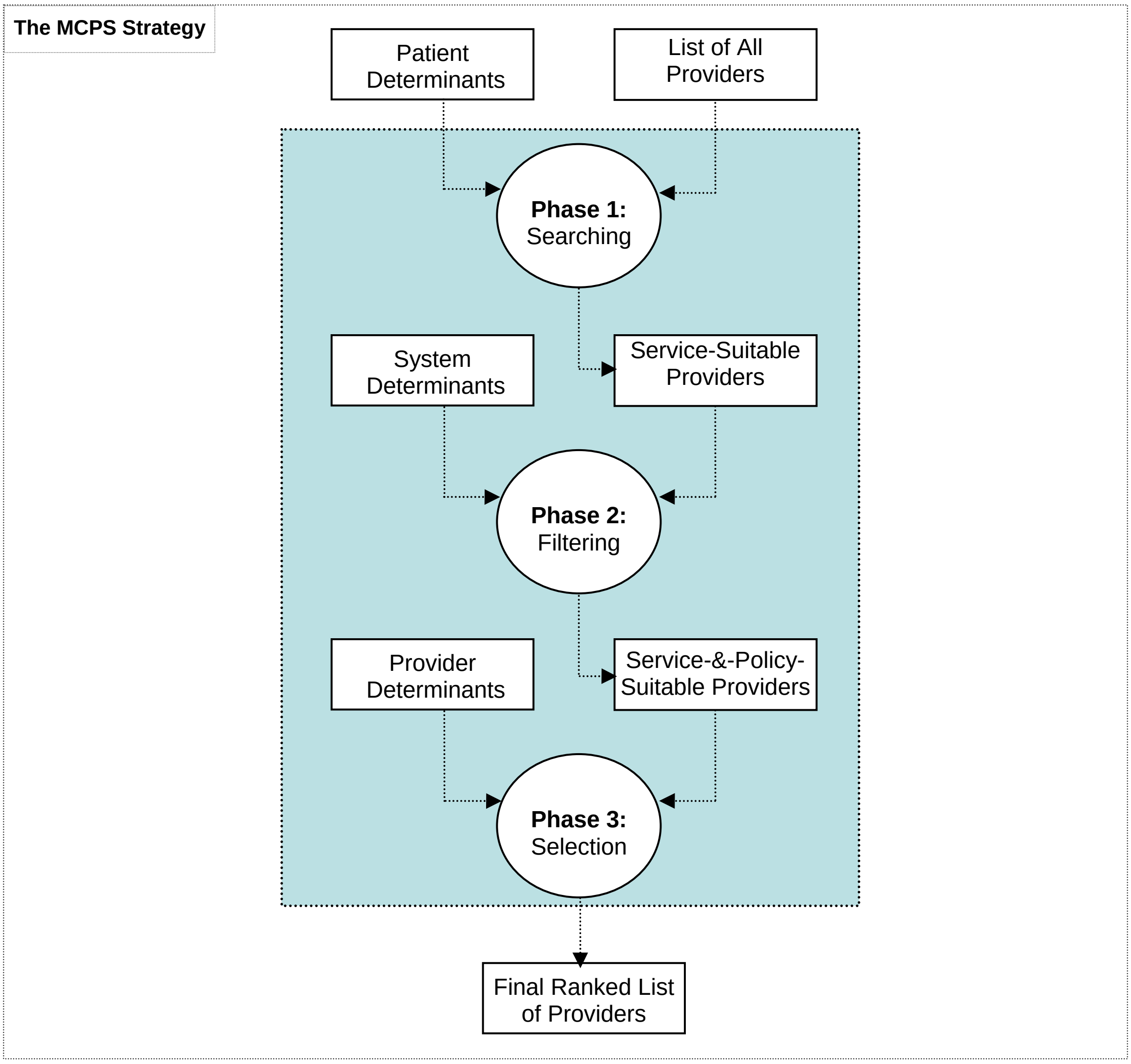


Figure 5.3 The Multi-Criteria Provider Selection (MCPS) Model

Figure 5.8 summarizes the overall sequence of interactions that occur among different components of the model during the selection process.

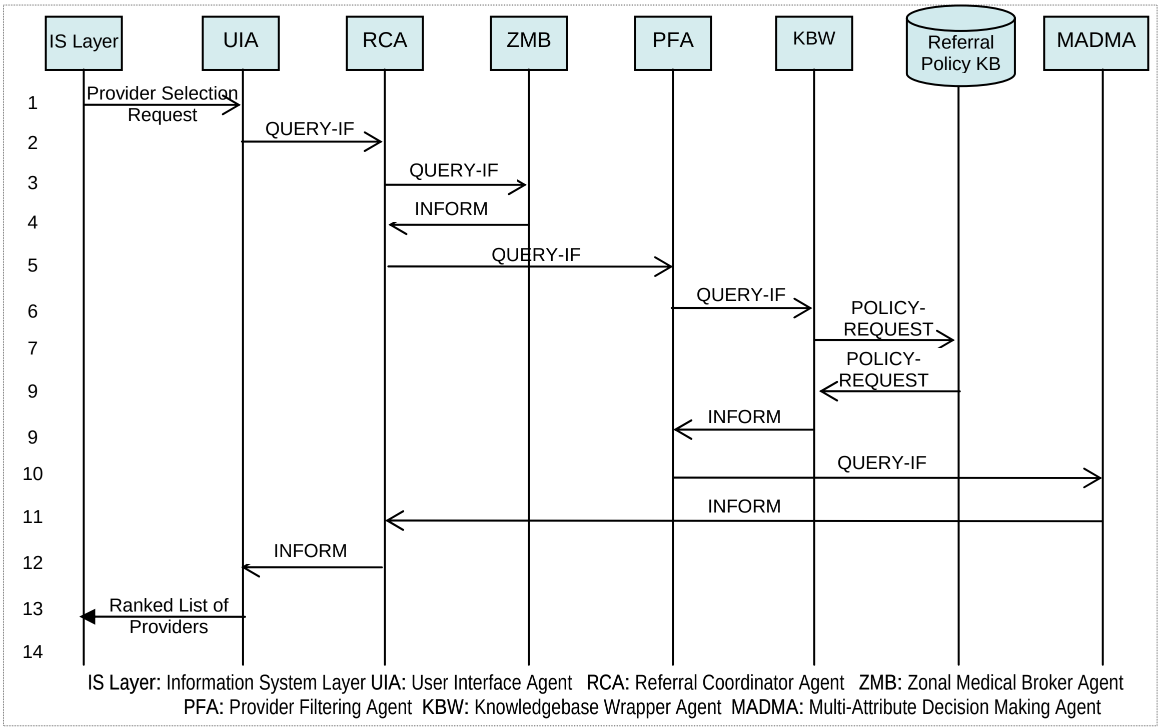


Figure 5.4 Overall Interaction Strategy of the MCPS Model

The process starts when a referring provider makes a request for provider selection, once a decision has been made on referral indication and the required services with the help of the Referral Specialist Agent (RSA). The provider makes the request through the Information System layer. The request is translated into an appropriate ACL format by the UIA and is forwarded to the RCA, which coordinates the overall selection process. In the first phase, the RCA delegates the ZMB to carry out a three-stepped hierarchical (zonal, regional and national) search to find potential providers for the requested referral. The search result is then returned to the RCA, which is list of service-suitable providers. In the second phase, the RCA forwards the list to the PFA to filter it using case specific referral policies to get service-and-policy-suitable list of providers. The PFA accesses the case specific policies from the referral policy knowledgebase through the KBW agent. In the third phase, the PFA forwards the list of service-and-policy-suitable providers to the MADMA for final selection. The MADMA employs a MAUT based MADM method to produce a final ranked list of providers and returns the result to the RCA, which forwards it to the UIA. The UIA translates the result to a format that is convenient to the Information System layer, which then displays it to the requesting physician for final decision.

5.4.1 Phase 1: Searching

By employing a search method, this phase aims at finding list of providers that can provide the required service for an indicated patient referral at hand. Here, the main challenge that the searching method tries to address is lack of provider and policy related knowledge required to make an appropriate selection. This knowledge is found distributed across providers in the system and is dynamic. To deal with this issue, a hierarchical multi-agent referral decision support system is proposed in the previous chapter that can facilitate the searching process. The proposed search method is supposed to be applied on this system and its procedure is detailed as follows.

Step 1: The UIA(User Interface Agent) through the Information System (IS) layer receives a provider selection request and forwards it to the RCA(Referral Coordinator Agent) in an ACL format.

Step 2: The RCA generates a search query (QUERY-IF) and forwards it to the ZMB (Zonal Medical Broker Agent). The search query includes information about the referring provider and the required referral. The content of the QUERY-IF may look like as follows:

REFERRAL-REQUEST: [<REFERRING-PROVIDER>, <REQUIRED-REFERRAL>], where

<REFERRING-PROVIDER>= [<provider_Id=<*pID*>>, <provider_location=<*district, zone, region*>>,
<provider_level=<*level*>>]

<REQUIRED-REFERRAL> = [<referral_type=<*type*>>, <referral_category=<*category*>>
<required_service=<service>>, <specialty_level=<level>>]

Step 3: The ZMB carries out a three-stepped hierarchical search (zonal, regional and national) to search potential providers suitable for the required referral and it returns the search result to the RCA. The hierarchical search is detailed as follows.

Step 3.1: Zonal Search

Figure 5.4 shows the zonal search strategy. The ZMB starts the search from the zone where the referring provider is located. It broadcasts the query received from the referring RCA to all RCAs of the same zone. Each referred-to RCA analyzes the request to check whether it satisfies the referring provider‘s requirements based on the knowledge it has about the provider’s current status and policy of receiving referrals.

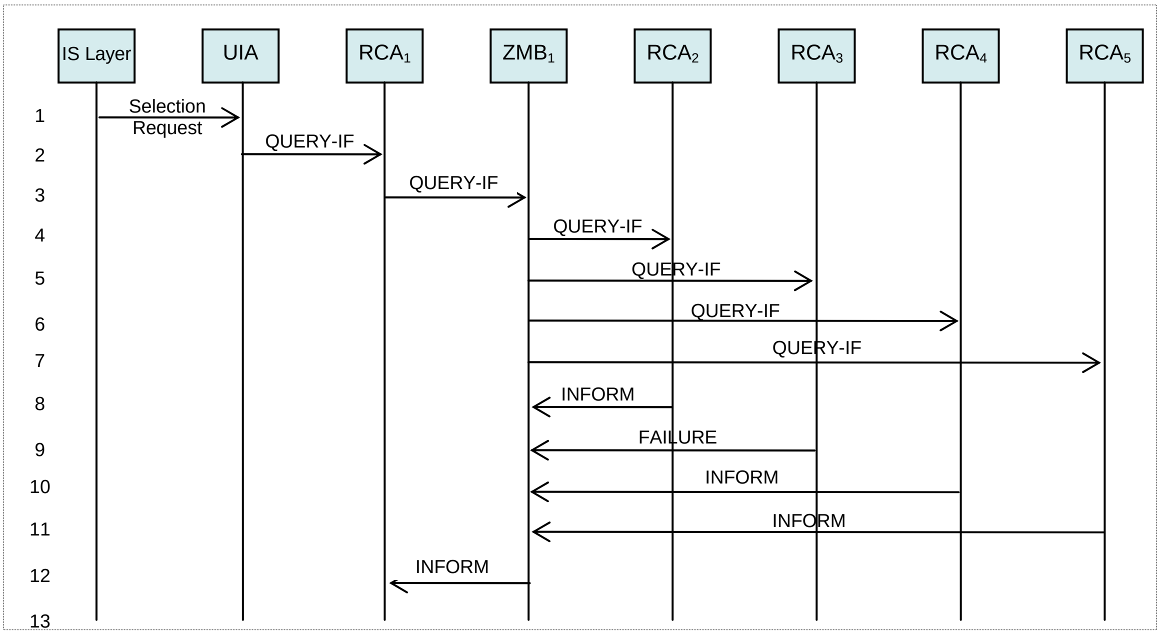


Figure 5.5 Zonal Search Protocol through Zonal Medical Broker Agent

If it does, it returns an INFORM ACL message to the ZMB, otherwise, it returns FAILURE message. The content of the INFORM message may look like as follows:

REFERRAL-REPLY: [<REFERRED-TO-PROVIDER>], where

<REFERRED-TO-PROVIDER>= [<provider_Id=<*pID*>>, <provider_location=<*district, zone, region*>>,
<provider_level=<*level*>>, <specialty_level=<*level*>>,
<assessment_time=<*time*>>]

The ZMB receives all the reply of each referred-to RCA and it compiles an INFORM message consisting of a list of providers with positive answers and sends it to the referring RCA. The content of the INFORM message may look like as follows.

SERVICE-SUITABLE-PROVIDERS: [<provider 1>, < provider 2>, …, < provider N>]

Step 3.2: Regional Search

If the ZMB finds out that none of the providers in the zone can satisfy the requirements of the referring provider, it forwards the query to the RMB (Regional Medical Broker Agent) of the region where the ZMB is located to search providers from the nearest possible zone of the same region. The RMB that knows about the ZMBs of the region forwards the query to the nearest ZMB, which carries out similar search process described in step 3.1. Then the search result will be returned to the ZMB through the RMB. Figure 5.5 shows the regional search strategy.

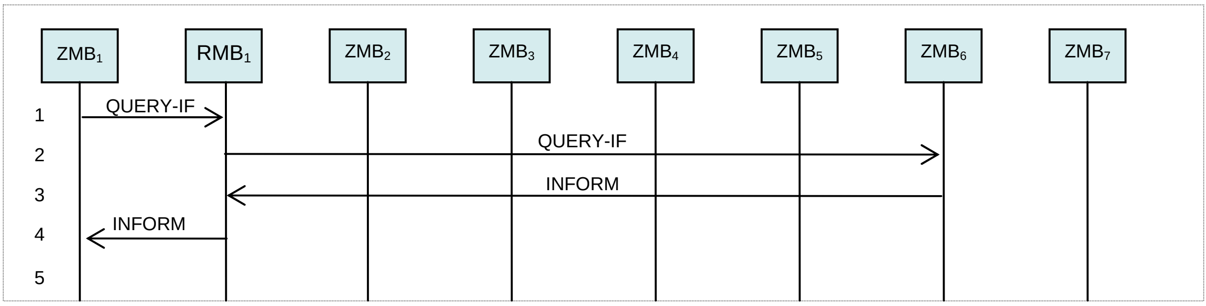


Figure 5.6 Regional Search Protocol through Regional Medical Broker Agent

Step 3.3: National Search

If the RMB cannot find a provider in the region that can satisfy the requirements of the referring provider, it forwards the query to the NMB (National Medical Broker Agent) to search providers from the nearest region. The NMB that knows about the RMBs of the whole nation forwards the query to the nearest RMB, which carries out similar search process described in step 3.2. Then the search result will be returned to the RMB through the NMB. Figure 5.6 shows the national search strategy.

Step 4: The referring RCA receives the search result from the ZMB and it compiles a query message consisting of the referral request and list of service-suitable providers and sends it to the PFA for further filtering. The content of the QUERY-IF message may look like as follows.

FILTER-PROVIDERS: <REFERRAL-REQUEST, SERVICE-SUITABLE-PROVIDERS>

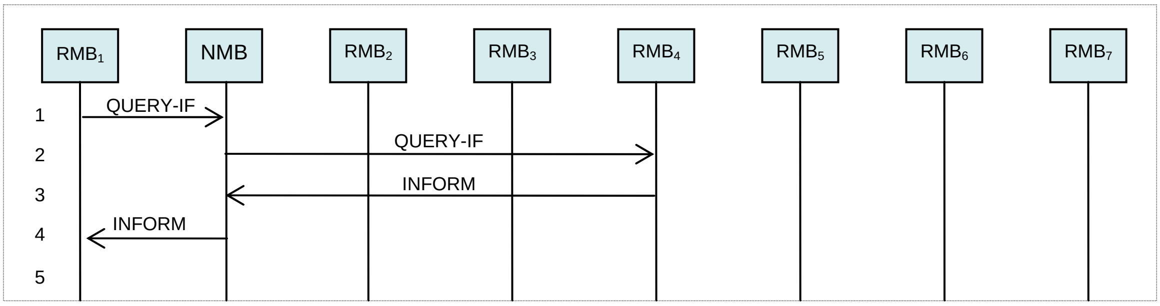


Figure 5.7 National Search Protocol through National Medical Broker Agent

5.4.2 Phase 2: Filtering

In this phase, the PFA (Provider Filtering Agent) applies case specific policy of making referrals to the service-suitable providers in order to filter out service-suitable providers that conform to the referral policy. The aim of this phase is to shortlist potential providers for final ranking and its procedure is detailed as follows.

Step 1: The PFA queries the RPK (Referral Policy Knowledgebase) through the KBW (Knowledgebase Wrapper Agent) for case specific policies based on the parameters in the referral request (referral type, referral category, required service). The content of the query may look like as follows.

POLICY-REQUEST: [<referral_type=<type>>, <referral_category=<category>>, <required_service=<service>>]

Step 2: The RPK processes the query and returns the query result to the PFA through the KBW. The query result consists of case specific policies related with the referral request and it may look like as follows.

POLICY-REPLY: [<policy 1>, <policy 2>, … , <policy k>]

Step 3: The PFA applies each policy to the service-suitable providers to filter out providers that satisfy all the policies, i.e. a provider will be filtered if it satisfies all the case specific policies. The PFA then compiles a query message consisting of service-and-policy-suitable providers and sends it to the MADMA (Multi-Attribute Decision Making Agent) for final ranking. The content of the QUERY-IF message may look like as follows.

SELECT-PROVIDERS: <REFERRAL-REQUEST, SERVICE-POLICY-SUITABLE-PROVIDERS>

Figure 5.7 shows the filtering and selection strategy.

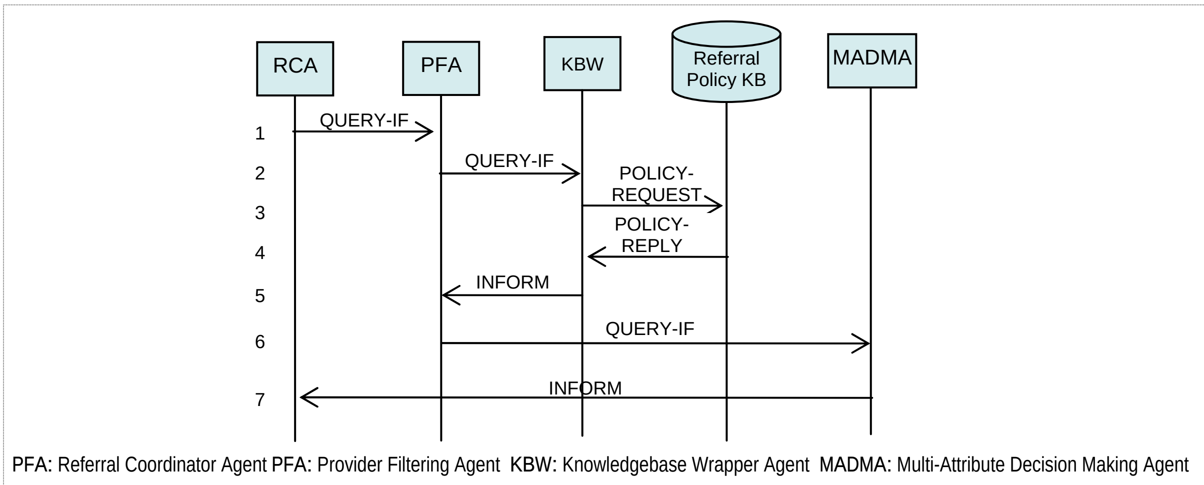


Figure 5.8 Provider Filtering and Selection Strategy

5.4.3 Phase 3: Selection

In this phase, the MADMA implements a decision aid method to rank the service-and-policy suitable list of providers received from the PFA. As described in section 2.2, provider selection is a choice and ranking MADM problem, which can be solved by applying methods that are based on MAUT. In this sub section, we will discuss how MAUT is implemented by the MADMA to provide decision aid service.

MAUT is a systematic method of identifying and analyzing multi-criteria to provide a common basis for arriving at a decision [54]. It is a quantitative comparison method used to combine dissimilar measures of criteria, along with decision makers' preferences, into high-level, aggregated preferences [55]. This method carries out the following three steps to solve a decision problem [57, 58]:

- Construction of decision matrix,
- Computation of global values based on an aggregation function
- Ranking of alternatives based on the aggregated values

Hence, when implementing a particular MAUT method, the MADMA performs the three steps to select and rank alternative providers. Each step is detailed as follows.

Step 1: In this step, the MADMA builds a decision matrix shown in table 5.1 based on the referral request and list of service-and-policy-suitable providers received from the PFA. The decision matrix is composed of n columns of alternative providers (denoted as P_1, P_2, P_3, .., P_n) and m rows of selection criteria (denoted as C_1, C_2, C_3, …, C_m). Each row belongs to a selection criterion and each column describes the performance of an alternative provider. The score P_{ij} describes the *performance* of alternative provider P_j against selection criterion C_i, i.e. $C_i(P_j)$. For each criterion C_i, a weight w_i (between 0 and 1) is assigned that reflects relative importance of the criterion to the decision, and the sum of all weights is one ($\sum w_i = 1$). There are different procedures used to determine the weights of criteria. Among these, the empirical (heuristic) one is usually used. An empirical procedure, the one used in this work, uses the judgment of the decision maker towards the weights of criteria [51, 59].

Table 5.1 Decision Matrix for Provider Selection

Weight	**Selection Criterion**	**Service-and-Policy-Suitable Providers**				
		P_1	P_2	P_3	…	P_n
W_1	C_1	$u_1(P_{11})$	$u_1(P_{12})$	$u_1(P_{13})$	…	$u_1(P_{1n})$
W_2	C_2	$u_2(P_{21})$	$u_2(P_{22})$	$u_2(P_{23})$	…	$u_2(P_{2n})$
W_3	C_3	$u_3(P_{31})$	$u_3(P_{32})$	$u_3(P_{33})$	…	$u_3(P_{3n})$
…	…	…	…	…	…	…
w_m	C_m	$u_m(P_{m1})$	$u_m(P_{m2})$	$u_m(P_{m3})$	…	$u_m(P_{mn})$
Global Value		x_1	x_2	x_3		x_n

In the initial design, based on an empirical procedure and literature review, four selection criteria and two sets of weights have been identified (for detail description of each criterion, see section 3.1.). Table 5.2 shows the proposed four criteria, two sets of weights (one for regular referral and the other for emergency referral), and the suggested performance scores of each criterion. The main reason for having two sets of weights is that the relative importance of each criterion depends on the category of the referral request (regular or emergency). For instance, for emergency referrals, provider location may have the highest relative importance. On the other hand, for regular referrals, provider level may have the highest relative importance. The MADMA uses one of the sets of weights based on the requested type of referral.

Table 5.2 Proposed Selection Criteria and their Relative Importance

Weight (Regular Referrals)	**Weight** (Emergency Referrals)	**Criterion**	**Suggested Performance Scores**
45%	60%	Provider Location	[<district, zone, region>]
15%	5%	Provider Level	[<PCP>, or <PRH>, or <SRH>, or <TRH>]
25%	10%	Specialty Level	[<H-EXT>, or <NUR>, or <H-OFF>, or <GP>, or <SP>, or <SUB-SP>]
15%	25%	Assessment Time	[<days>, or <weeks>, or <months>]

The main idea behind MAUT is the use of *utility functions*, which transform the diverse criteria scores (in terms of scale and range) to one common, dimensionless scale (0 to 1) known as multi-attribute *"utility"* [52]. Every decision criterion, C_i, uses a utility function, u_i (see table 5-1), which converts alternative provider's raw performance score (P_{ij}) to utility score (0 to 1). The key issue here is the determination of the utility functions, which is commonly a difficult issue. Usually these are built from the information provided by domain experts [51].

In the initial design of the selection model, four utility functions for the four criteria have been identified using an empirical procedure. Here, the MADMA uses each utility function to analyze the associated criterion separately and map the performance score of each potential provider to a utility score by comparing the performance score with the corresponding attribute of the referring provider. Table 5-3 depicts the proposed utility functions along with the suggested qualitative and quantitative utility scores. Each utility function is described as follows.

The first utility function u_1 compares provider location of a potential provider with that of the referring provider and maps it to one of the utility scores (country, region, zone, or district) based on the relative location of the potential provider. For instance, if the location of a potential provider is <$district_1$ $zone_2$, $region_3$> and that of the referring provider is <$district_2$, $zone_6$, $region_3$>, a utility score <region> is mapped to indicate that both are located in the same region. If the location of the potential provider is <$district_2$, $zone_3$, $region_4$>, a utility score <country> is mapped to indicate that they are located in different regions.

Table 5.3 Proposed Utility Functions and Corresponding Utility Scores

Criteria	**Utility Function**	**Suggested Qualitative and Quantitative Utility Values**
		Worst value … Best value
Provider Location	u_1	Country, region, zone, district (0.25, 0.50, 0.75,1.0)
Provider Level	u_2	3-L-up, 2-L-up, 1-L-up (0.3, 0.7, 1.0)
Specialty Level	u_3	5-L-up , 4-L-up, 3-L-up, 2-L-up, 1-L-up (0.1, 0.3, 0.5, 0.8, 1.0)
Assessment Time	u_4	very long, long, acceptable, short, very short (0.2, 0.4, 0.6, 0.8, 1.0)

The second utility function u_2 maps referral level of a potential provider to one of the specified utility scores according to the relative difference between referral levels of the two providers. For example, a utility score of 1-L-up (one level up) is mapped to a potential provider with referral level <PRH>, if the referring provider is a <PCP>. A utility score of 2-L-up (two levels up) is mapped for the same referring provider, if the potential provider is a <SRH>.

The third utility function u_3 analyzes the appropriateness of the available specialty level by comparing it with that of the required one and maps it to one of the specified utility scores. For instance, if the required specialty level is <GP> and the available one is <SP>, a utility score 1-L-up is assigned. For the same required specialty level, if the available one is <SUB-SP>, a utility score 2-L-up is mapped.

The fourth utility function u4 analyzes the assessment time based on some predefined range of values and maps it to one of the specified utility scores. For instance, assessment time of 1 to 8 days may be mapped to a utility score of <very short>. Similarly, assessment times of 9 to15 days, 16 to 30 days, and more than 30 days may be mapped to utility scores of <short>, <acceptable>, <long>, and <very long> respectively.

Step 2: In this step, the MADMA computes a global value, x_i, for each alternative provider P_i, which gives a general idea of the utility of the alternative provider by considering all the criteria at the same time. The global value is computed using an aggregation function, U, i.e.

$$x_i = U(P_i), \text{ where } i=1,\ldots,n$$

Different models exist for the aggregation function U. In the initial design, the MADMA is supposed to use SAW (Simple Additive Weighing), which is the simplest and clearest model considered in MAUT [52]. Here, U is an additive combination of weighted utility of the criteria and is expressed as follows;

$$x_i = U(P_i) = \sum w_j * u_i(P_{ij}) \text{ where } j=1,\ldots,m \text{ and } i=1,\ldots,n; \text{ where,}$$

$u_i(P_{ij})$ is the utility score of alternative provider P_i against criteria C_j, w_j is the weight of C_j, $w_j * u_i(P_{ij})$ is the weighted utility score of P_i against C_j, x_i the aggregated utility value of P_i.

Step 3: In this step, the MADMA ranks alternative providers from best to worst based on the utility values obtained in the second step (x_1, x_2, x_3,…,x_n). Here, it is assumed that higher-ranking value means a better performance of the alternative provider. Hence, the provider with the highest-ranking value is supposed to be the best of the alternative providers. The MADMA returns the final ranked list of providers to the RCA (see Figure 5.7), which forwards it to the Information System layer through the UIA. The IS layer displays the result to the physician for final decision. Once the physician selects an appropriate provider, the regular e-Transfer process proceeds through the Information System layer.

CHAPTER 6 Implementation

6.1 Overview

This chapter presents a Multi-Agent Provider Selection System (MPSS) which implements the core part of the MCPS (Multi-Criteria Provider Selection) model. The system serves as a prototype to demonstrate the feasibility of the proposed selection model. In its development process, first an appropriate agent platform is selected, and then major agents and inter-agent communication strategies are designed and implemented in the platform. Finally the system is experimented with limited but relevant data to evaluate the feasibility of the selection strategy.

The chapter is organized as follows: the rest of this section gives an overview of MPSS, about its scope and main features, and the development environment employed to implement the system; section 6.2 describes an architectural and detail design of the system; section 6.3 presents a running example which illustrates the result of the system as applied on a typical referral situation.

6.1.1 Scope of the Prototype

The MPSS implements only the multi-agent layer of the decision support framework. It does not implement the information system and communication layers. The information system layer is simulated by referring and referred-to provider GUIs (Graphic User Interfaces) edited by the user. For the communication layer, messaging components of the selected platform are used.

In its initial design, the MPSS is simulated on a single PC, i.e. agents of the system are implemented and deployed in the same machine. In addition, the system implements two key agent classes: referring and referred-to provider agent classes. The referring provider agent class is designed to simulate roles of RCA (decision coordinator aspect), UIA, ZMB, PFA and MADMA as agent behaviors. By making use of these agent behaviors, the referring provider agent implements the three phases of the selection model in selecting a provider for a given referral. On the other hand, the referred-to coordinator agent class simulates role of RCA to evaluate an incoming referral request and to produce and send a referral reply to the referring provider.

Since the system has been deployed in a single Java-based platform, ontology has not been needed for the required inter-agent communication. Hence, the system has employed an object-based inter-agent communication. Moreover, the Referral Policy Knowledgebase (RPK) has not been implemented. However, sample referral policies are encapsulated within the referring provider agent to be employed during the policy-based filtering phase.

The above discussed design decisions (single PC simulation, agent role overloading, object-based inter-agent communication, and encapsulation of referral policies within agents) have no direct effect on the quality of provider selection produced by the system. The quality of provider selection decision is predominantly affected by the type and nature of selection criteria considered as well as the employed decision aid technique.

6.1.2 Features of the Prototype

The MPSS provides the following basic services:

Provider Information Maintenance: As indicated in section 6.1.1, the Information System (IS) layer is not implemented by MPSS. Hence, this service simulates the IS layer by providing two graphic user interfaces (for referring and referred-to providers) to allow users to edit the basic category of provider information which are important for the provider selection process.

Criteria Weight Maintenance: Relative importance (weight) of criteria is one of the most important factors that can affect the quality of the selection. In addition, setting weights of criteria is a very difficult task which usually employs empirical procedure. For this reason, the system is designed to provide a service for maintaining two categories of weights (for emergency and regular referrals) that allows users to set weight for each selection criteria. This will help to conduct an empirical experiment on the output of the system so that it would be possible to set optimum weights in consultation with domain experts (physicians).

Provider Selection: This is a key service provided by MPSS which implements the three phases of the proposed selection model to allow users to enter a referral request and select an appropriate provider for the required referral. The screen output of the selection request includes referring provider's information, required referral, and the result of each selection phase. This helps in analyzing results of the selection model empirically.

6.1.3 Development Tools

The development tools that have been deployed to implement the Multi-Agent Provider Selection System are:

JADE v. 3.4. (Java Agent Development Framework)

This is the main tool used in the development of the system. It is a Java-based middleware that facilitates the development of multi-agent systems that conform to FIPA specifications. The platform includes [60]:

- A runtime environment where JADE agents can run indefinitely and that must be active on a given host before one or more agents can be executed on that host.
- A library of classes that programmers may use (directly or by customizing them) to develop their agents.
- A set of graphical tools that allows administrating and monitoring the activity of running agents. These tools also help developers in debugging and deploying their system.

Each running instance of the JADE runtime environment is called a **Container** and it can contain several agents. A set of active containers is called a **Platform**. A single special **Main container** must always be active in a platform and all other containers register with it as soon as they start. Figure 6.1 depicts two JADE platforms composed of 3 and 1 container respectively. JADE agents are identified by a unique name and, provided they know each other's name, they can communicate transparently regardless of their actual location: same container (e.g. agents A2 and A3 in Figure 6-1), different containers in the same platform (e.g. A1 and A2) or different platforms (e.g. A4 and A5). In addition to the ability of accepting registrations from other containers, a main container differs from other containers as it holds two special agents: AMS (**A**gent **M**anagement **S**ystem) and DF (**D**irectory **F**acilitator). These agents are automatically started when the main container is launched.

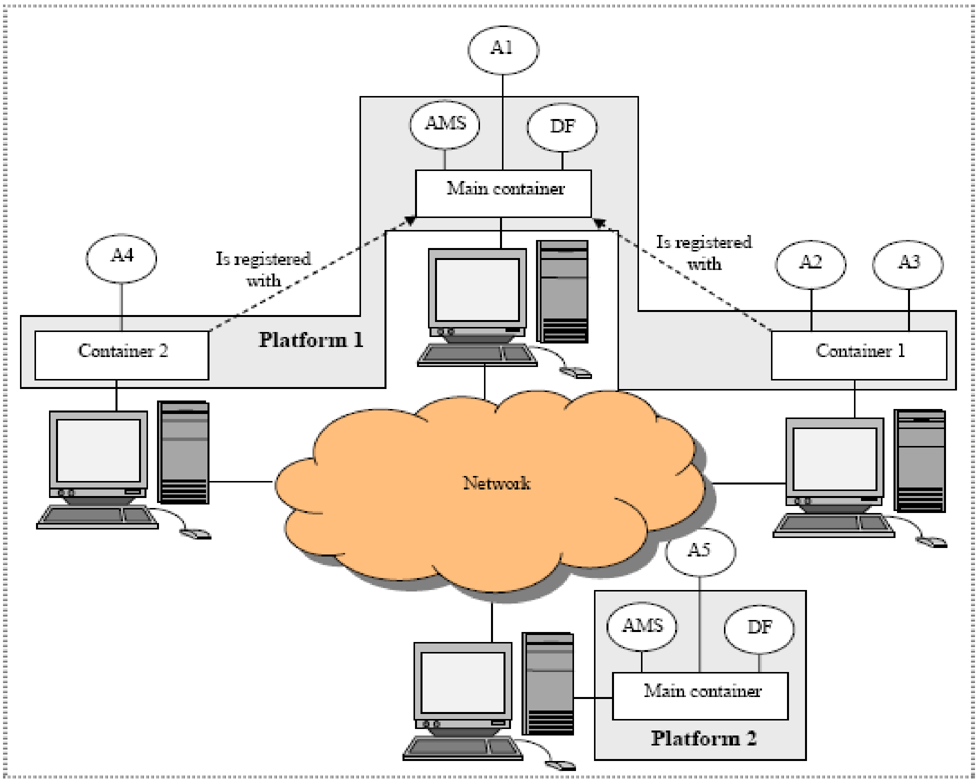


Figure 6.1 JADE Platform

The **AMS** provides a naming service (i.e. it ensures that each agent in the platform has a unique name) and it represents the authority in the platform (for instance, creating/killing agents on remote containers). The **DF** (Directory Facilitator) provides a yellow pages service by means of which an agent can find other agents providing the services it requires in order to achieve its goals.

JavaTM 2 Platform Standard Edition Development Kit (JDKTM)

This kit has been used to create MPSS agents using the Java programming language and JADE library classes.

Netbeans IDE 5.5

This is an integrated development environment (IDE) for writing, compiling, testing, and debugging applications for the Java platform. NetBeans IDE includes a full-featured text editor with syntax highlighting and error checking, visual design tools, and many other features. The MPSS agents are edited using this IDE.

6.2 System Design

The main design objective of MPSS is to experiment feasibility of the selection model, which aims at helping physicians in making a better provider selection. The system design is described in terms of its architectural, detail, and user interface designs.

6.2.1 System Architecture

Figure 6.2 depicts a three-layered architecture of MPSS. A general description of each layer is presented as follows.

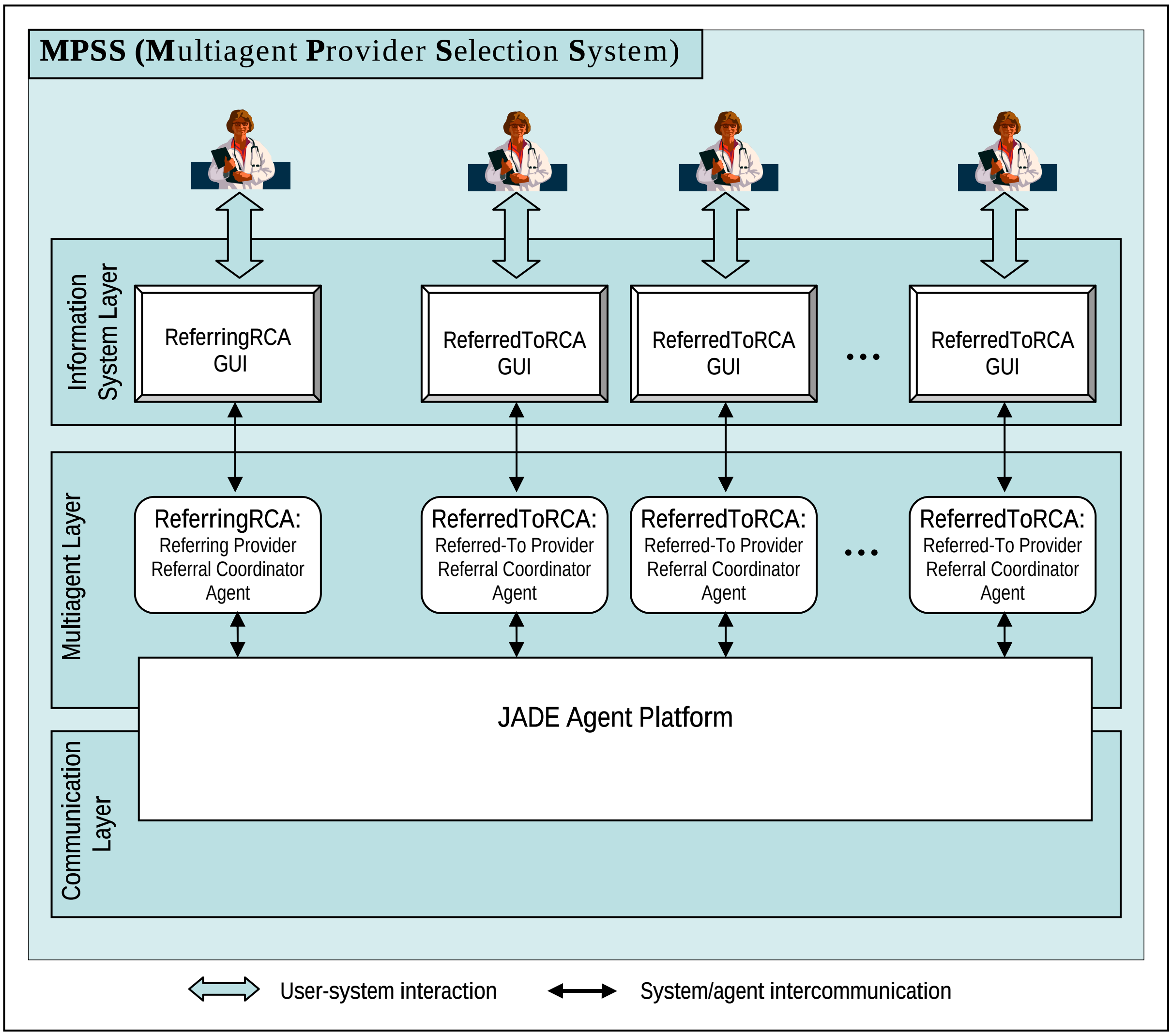


Figure 6.2 MPSS Architecture

6.2.1.1 Information System (IS) Layer

As discussed in section 4.4, this layer represents an e-Referral system that handles e-Transfer of patient referrals between healthcare providers. The e-Referral system is assumed to be connected to HIS (Hospital Information System) of each provider. However, it is beyond the scope of this work to implement the IS layer in the MPSS prototype. Hence, the layer is simulated by two types of GUIs described below.

ReferringRCA GUI: This GUI simulates the IS layer of a referring provider. Through this GUI, a user can edit basic provider information (name, location, and referral level), maintain weights of criteria, or invoke provider selection process.

ReferredToRCA GUI: This GUI is designed to simulate the IS layer of a referred-to provider. Through this GUI, a user can edit basic provider (name, location, and referral level), and service information (service type, specialty level, and assessment time). Each provider is assumed to provide only one service. Design of the GUIs is presented in section 6.2.3.

6.2.1.2 Multi-Agent System Layer

This layer complements the IS layer with provider selection decision support. It is composed of two agent classes deployed in JADE agent platform. Each agent class is described below.

a. ReferringRCA[1]: This is a referring provider agent class, which simulates roles of RCA (decision coordinator aspect), ZMB, PFA and MADMA agents. The main objective of this agent class is selecting an appropriate provider for a given referral. To achieve this objective, it implements three main agent behaviors (discussed below) to simulate roles of the above mentioned agents.

- ***ProviderSearching:*** This is a generic (three-stepped) JADE agent behaviour designed to implement the searching phase of the selection model. It simulates roles of RCA and ZMB to search providers that can offer a required service. In the process, the ReferringRCA first contacts the DF agent of JADE to discover all available providers (ReferredToRCAs). It then broadcasts a referral request query to all ReferredToRCAs. It finally receives replies of each ReferredredToRCA and compiles service-suitable list of providers.
- ***ProviderFiltering:*** This is a one shot JADE agent behaviour designed to implement the filtering phase of the selection model. It simulates role of PFA that performs policy-based filtering in order to shortlist service-and-policy suitable providers. The filtering was supposed to be carried out based on RPK (Referral Policy Knowledgebase). However, implementation of RPK is beyond the scope of this work.

[1] Description of ReferringRCA agent class along with its three behaviors is given in annex a.

Hence, two hard coded sample policies of emergency referrals have been used to simulate the policy based filtering.

- ***ProviderSelection:*** This is also a one shot JADE agent behaviour designed to implement the selection phase of the selection model. It simulates the role of MADMA that employs MAUT decision aid technique to analyze selection constraints and rank final list of appropriate providers. The three steps of MAUT (construction of decision matrix, aggregation of utility values, and ranking of alternative providers) are fully implemented with this behaviour.

b. ReferredToRCA[2]: This is a referred-to agent class, which simulates the role of RCA to evaluate incoming referral requests and to produce and send referral replies to the ReferringRCA. It implements one agent behavior discussed below.

- ***ReferralRequestServer:*** This is a cyclic JADE agent behaviour designed to implement referral request evaluation of the selection model. The evaluation was supposed to be carried out based on RPK (Referral Policy Knowledgebase) and current state of provider (captured and analyzed from the IS layer). However, as mentioned above implementations of RPK and the IS layer are beyond the scope of this work. Hence, to simulate the IS layer, ReferredToRCA GUI has been used. This GUI tracks the current state of the provider regarding available services, specialty level of each service and associated minimum assessment time. On the other hand, some hard coded sample policies about receiving referrals have been used to simulate the policy based request evaluation.

6.2.1.3 Communication Layer

This layer provides a messaging mechanism required by the multi-agent system layer. Since the MPSS is deployed in a single platform, RMI (provided by JADE) has been used for the required inter-agent communication.

6.2.2 Detail Design

This section presents a detail design of the MPSS prototype. The design is described in terms of agent, interaction, and communication models as well as user interface design.

[2] [2] Description of ReferredToRCA agent class along with its behavior is given in annex b

6.2.2.1 Agent Model

An agent model specifies which agent classes are to be defined to play specific roles and how many instances of each class have to be instantiated in the actual system [44]. The agent model of MPSS prototype is depicted in figure 6.3. Description of the MPSS package as well as ReferringRCA and ReferredToRCA agents is found in annex a, b and c respectively.

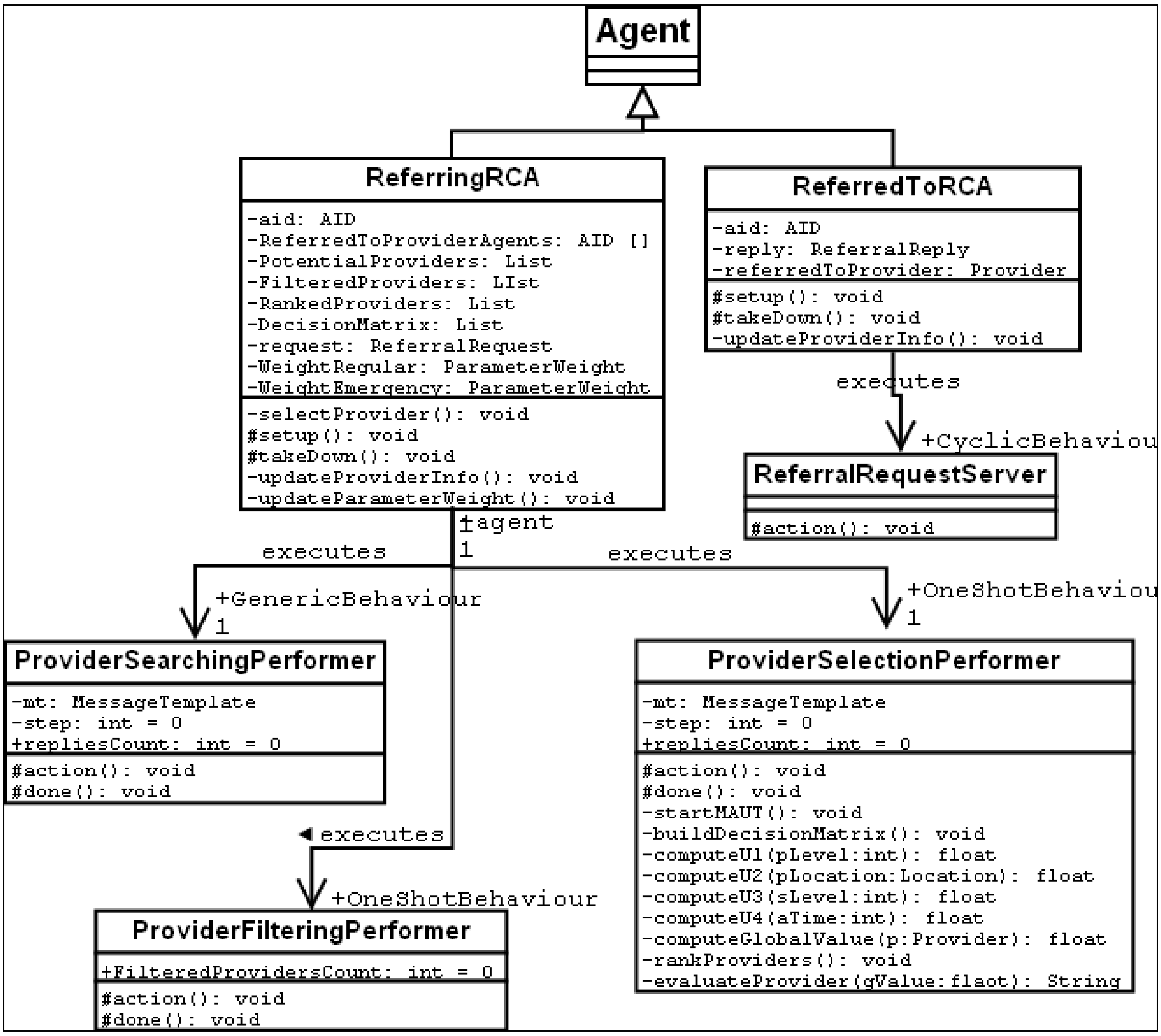


Figure 6.3 Agent Model

6.2.2.2 Interaction Model

An interaction model defines the cooperation that should exist between various agents of a MAS to achieve the desired goal [44]. In MPSS, this has been especially used during the searching phase and it has employed a three-layered inter-agent interaction (see figure 6.4). This interaction uses ***REQUEST*** and ***QUERY-IF*** built-in protocols. The REQUEST interaction protocol is used by the ReferringRCA to discover available providers from the DF agent (which simulates the ZMB agent). When the DF receives a request from the ReferringRCA, it checks if there are currently subscribed providers (ReferredToRCAs) that can provide the requested service. If there are any, it replies an INFORM message containing list of available providers. Otherwise, it replies a FAILURE message. Once available providers are discovered, the ReferringRCA broadcasts a referral request to the providers using QUERY-IF message. Each ReferredToRCA analyzes the request to check whether it satisfies the referring provider‘s requirements based on the knowledge it has about the provider's current status and hard-coded policy of receiving referrals. If it does, it returns an INFORM message to the ZMB, otherwise, it returns FAILURE message.

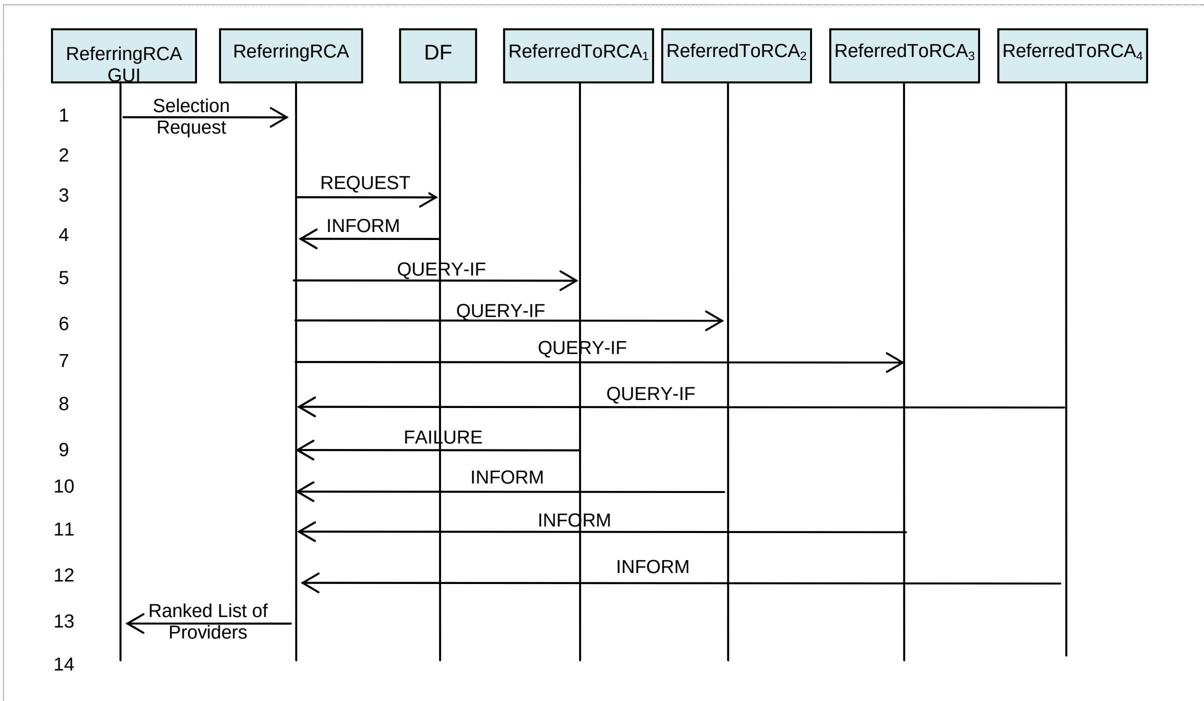


Figure 6.4 Interaction Model

6.2.2.3 Communication Model

A communication model defines the inter-agent communication language, vocabulary, and protocols employed by a MAS to enable agents communicate with each other. Each agent communication language is composed of three layers. The outer layer, referred to as ***ACL*** (Agent Communication Language), defines the outer language that provides the basis for agents to state intentions to other party [63]. The inner layer, referred to as ***Content Language***, defines the actual information about the matter agents trying to communicate. This allows an agent to express its actual application-dependent content to other agents [61]. The innermost layer, referred as to ***Ontology***, specifies the objects, concepts and relationships in a given domain [62].

JADE supports built-in FIPA compliant ACL and Content languages, referred as to **FIPA-ACL** and **FIPA-SL**, respectively. However, we need to define our own vocabulary and semantics for the content of the messages exchanged between our agents. JADE provides three ways of implementing communication between agents.

The first and most elementary way is using ***strings*** to represent the content of messages. This is suitable when the content of messages is atomic data, but not in the case of abstract concepts, objects or structured data. In such cases, the string needs to be parsed to access its various parts. The second way employs Java technology to transmit ***Serialized Java objects*** directly as the content of messages. This is often a convenient method for a local application where all agents are implemented in Java. The third method involves the definition of the ***ontological objects*** to be transferred as extension of predefined classes so that Jade can encode and decode messages in a standard FIPA format. This allows Jade agents to interoperate with other agent systems.

In the case of MPSS, the built-in FIPA-ACL has been used as the outer language. For the concepts and actions of agent messages, since all agents are implements using Java, Serialized Java objects (shown in figure 6.5) have been used.

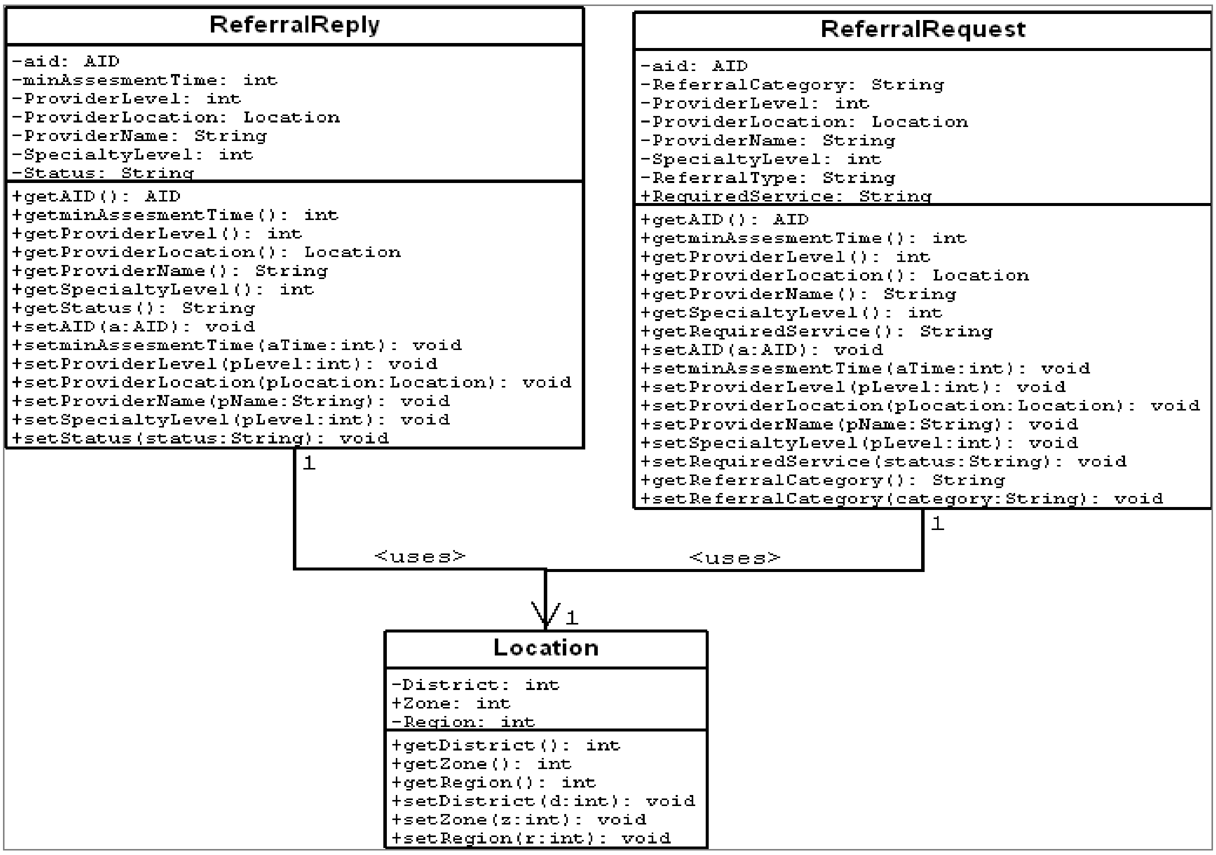


Figure 6.5 Java Communication Objects

6.2.2.4 Interface Design

This section presents the GUIs designed for the MPSS prototype.

a. **ReferringRCA GUI:** Figure 6.6 shows design of the ReferringRCA GUI. As described in section 6.2.1.1, this GUI is designed to simulate the IS layer from a referring provider side. It is used to edit basic provider information, maintain weights of criteria, and invoke provider selection process.

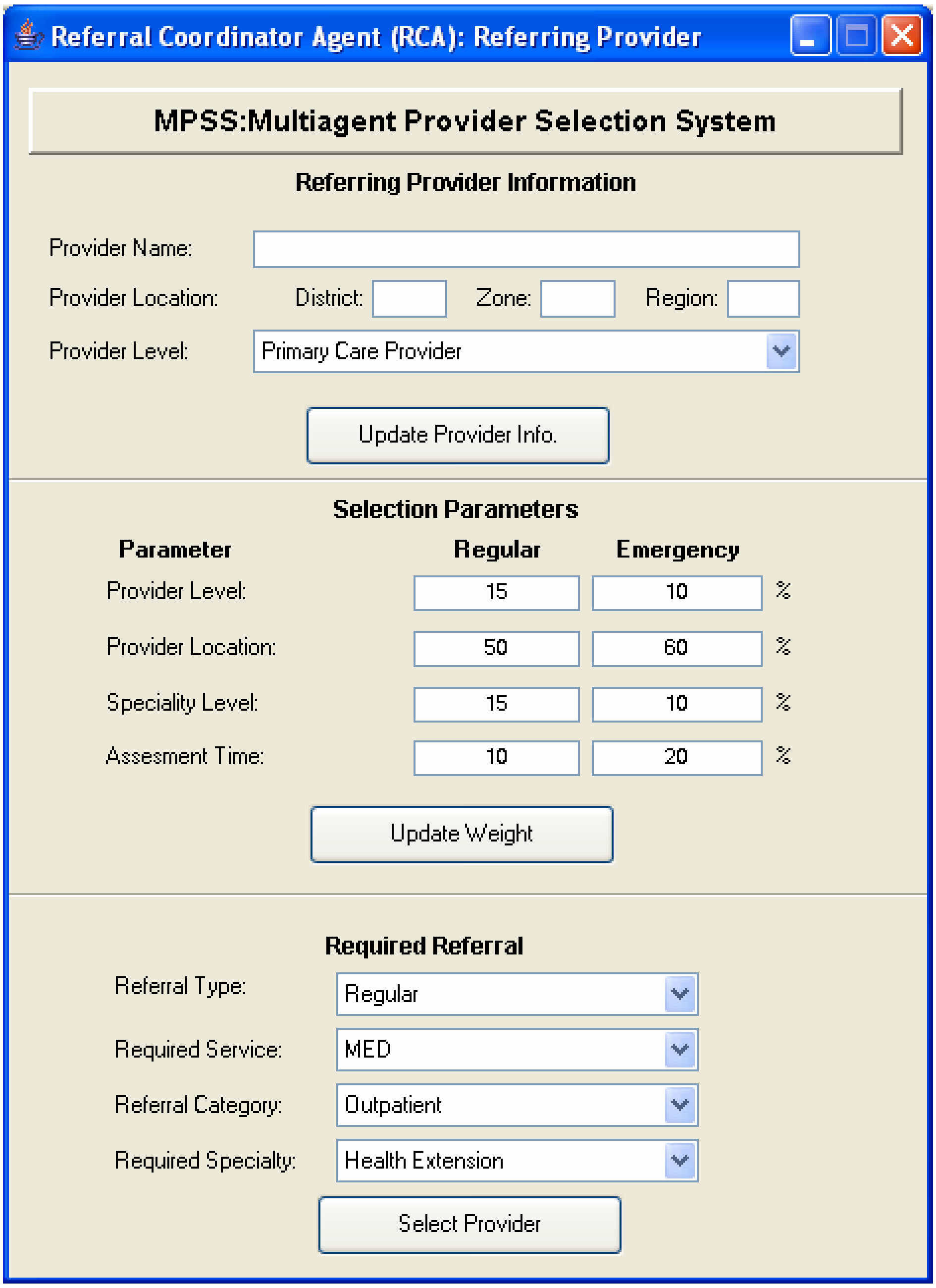


Figure 6.6 Screenshot of ReferringRCA GUI

b. **ReferredToRCA GUI:** Figure 6.7 shows design of the ReferredToRCA GUI. As discussed in section 6.2.1.1, this GUI is designed to simulate the IS layer from a referred-to provider side. It is used to edit basic provider and service information.

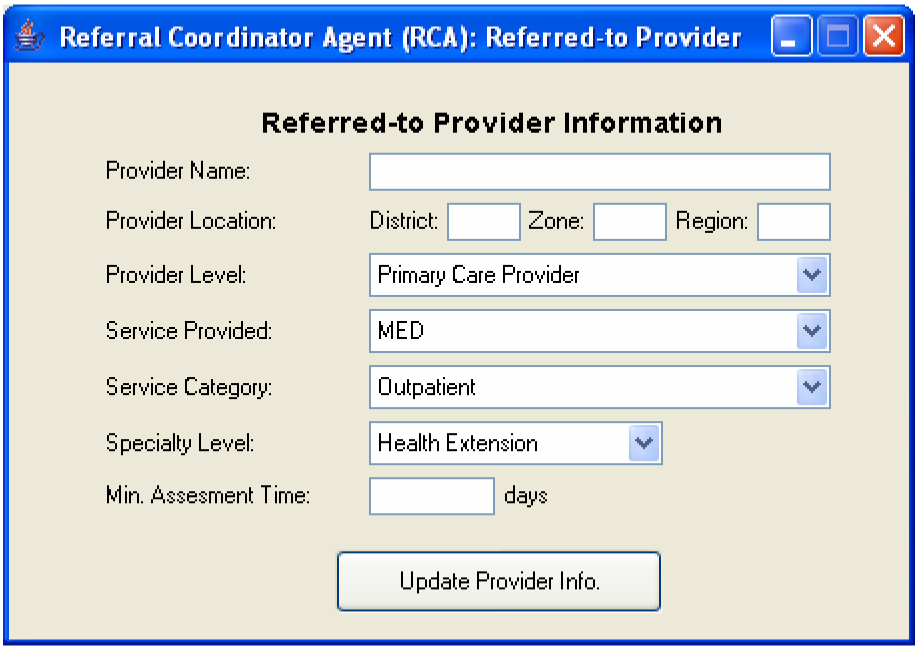


Figure 6.7 Screenshot of ReferredToRCA GUI

6.3 Running Example

6.3.1 Setup

In order to see how the system implements the selection model and investigate its result, we have considered a typical referral situation described by tables 6.1 and 6.2. In this scenario, we have one referring provider (having two referral requests) and seven potential referred-to providers. Each provider is assumed to provide only one service with only one type of specialty level. Moreover, all providers are assumed to provide emergency referrals for the specified service category.

Table 6.1 Referring Provider Information with two referral requests

Referring Provider				Referral Request			
AID	**Provider Name**	**Provider Location**	**Provider Level**	**Referral Type**	**Required Service**	**Referral Category**	**Required Specialty**
Rca	Selam	[2,3,14]	PCP	Regular	MED	Inpatient	GP
				Emergency	MED	Inpatient	GP

Table 6.2 Potential Referred-to Providers Information

AID	Provider Name	Provider Location	Provider Level	Service Provided	Service Category	Specialty Level	Min. Assessment Time
rca1	St Paul	[2,3,14]	TRH	MED	Inpatient	SP	7
rca2	Gullele	[2,3,14]	PCP	MED	Inpatient	H-OFF	1
rca3	Menelik	[4,4,14]	PRH	MED	Inpatient	GP	3
rca4	Yekatit	[2,5,14]	SRH	MED	Inpatient	SUB-SP	5
rca5	Balcha	[4,7,14]	SRH	SUR	Inpatient	SP	1
rca6	Zewditu	[3,3,14]	PRH	MED	Inpatient	GP	3
rca7	R. Desta	[2,3,14]	SRH	MED	Inpatient	GP	3

The referring provider is represented by a ReferringRCA agent (named as rca) and each potential referred-to provider is represented by a separate ReferredToRCA agent (named as rca_i) in a JADE platform. The screenshot in figure 6.8 shows setup of the platform with one referring provider agent(rca), seven referred-to provider agents(rca_1-rca_7) and other built-in agents of JADE (df, ams, etc.).

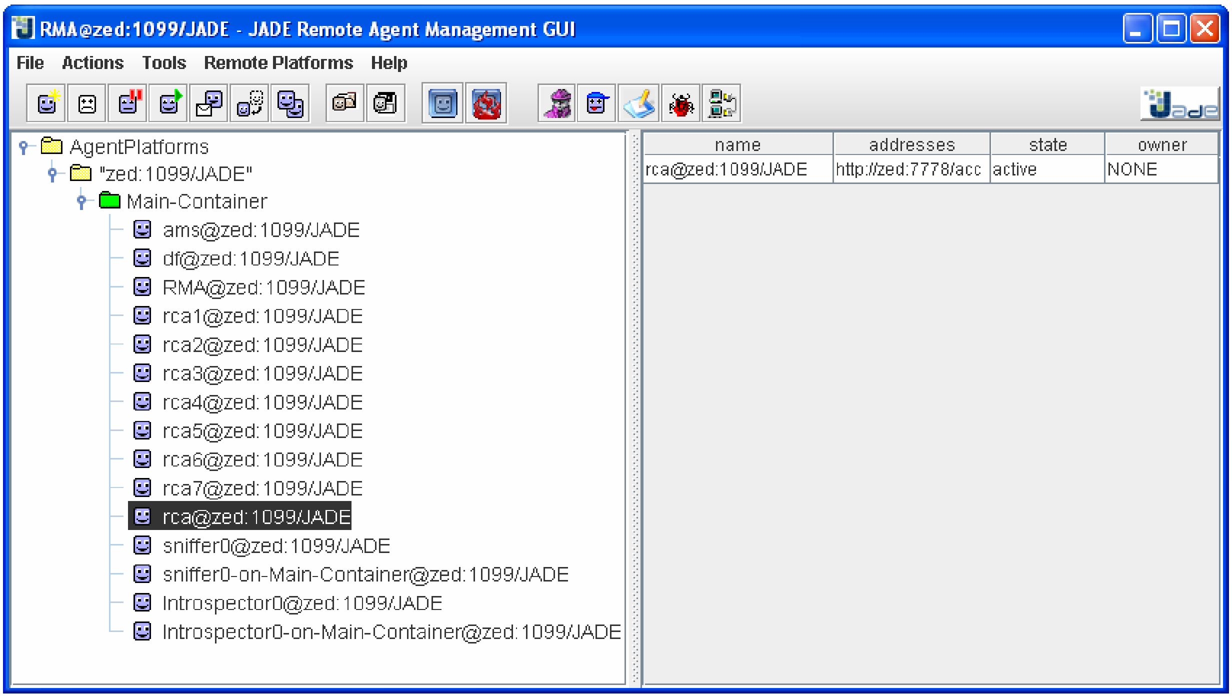


Figure 6.8 Screenshot of the Provider and Built-in Agents Running in JADE Platform

The GUI screenshots of the referring provider agent (rca) and one of the referred-to agents (rca3), which simulate the IS layer of the system, are shown in figures 6.9 and 6.10.

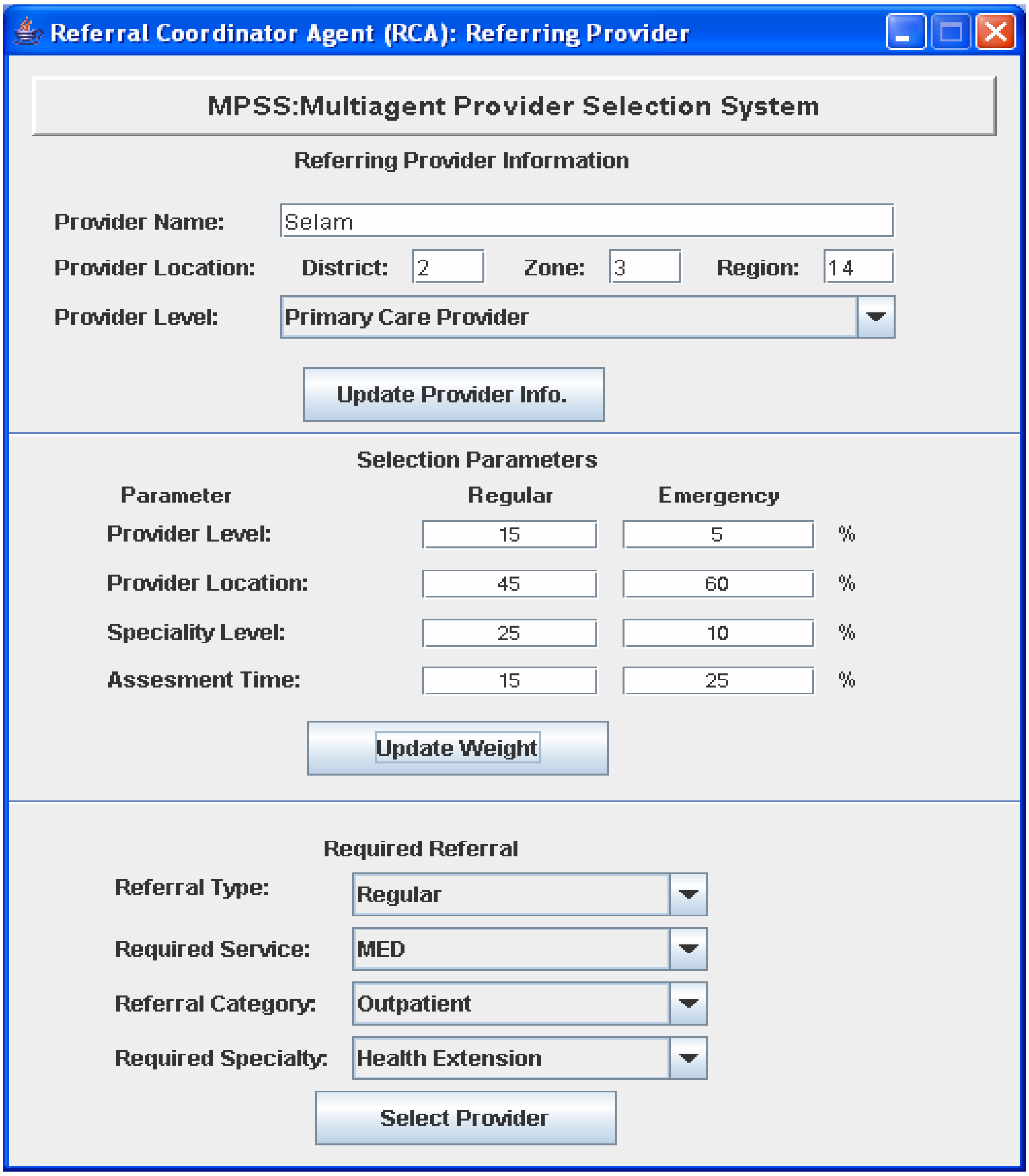


Figure 6.9 GUI of Referring Provider Agent (rca)

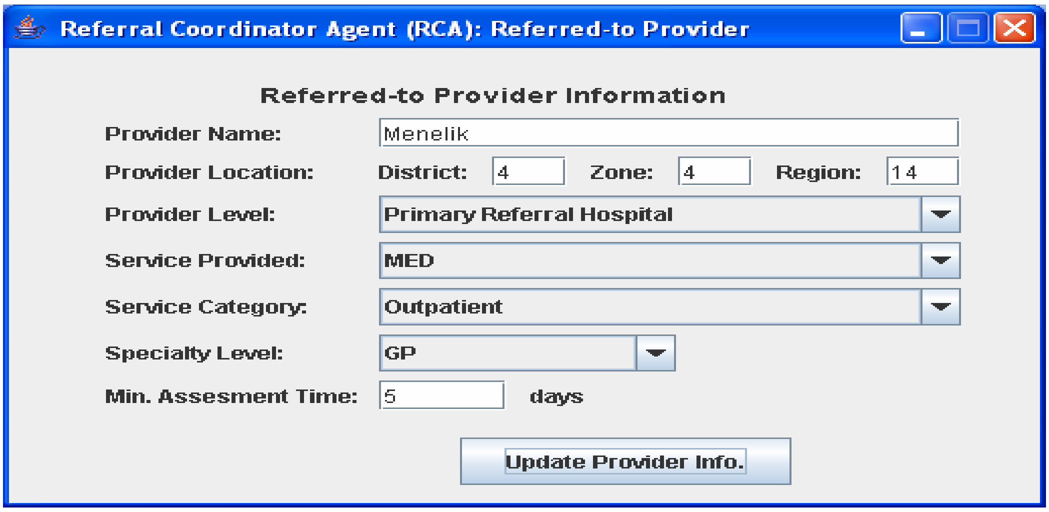


Figure 6.10 Screenshot of the GUI of one of the Referred-to Provider Agents (rca_3)

Suppose a user from the referring provider side has invoked two referral requests (one for regular and the other for emergency) using the ***select provider*** button from the rca GUI after entering the required referral parameters. Each invocation causes the MPSS to launch a new selection process for selecting an appropriate provider for the required referral. To achieve this, the system implements the three phases of the selection model. The output of the two referral requests is described in the following sections.

6.3.2 Output 1 (Regular Referral)

6.3.2.1 Phase 1: Searching

In this phase, the rca employs the ProviderSearchingPerformer behaviour to contact the seven referred-to provider agents (rac1-rca7) via the df agent to search providers that can offer the required service of the requested regular referral. The screenshot of the searching process is illustrated by figure 6.11, as intercepted by the built-in sniffer agent.As shown in the figure, potential providers that can offer the required service are rca1, rca3, rca4, rca6 and rca7. Rca2 refused the request because the required specialty level is not available. On the other hand, rca5 refused the request because the required service is not available.

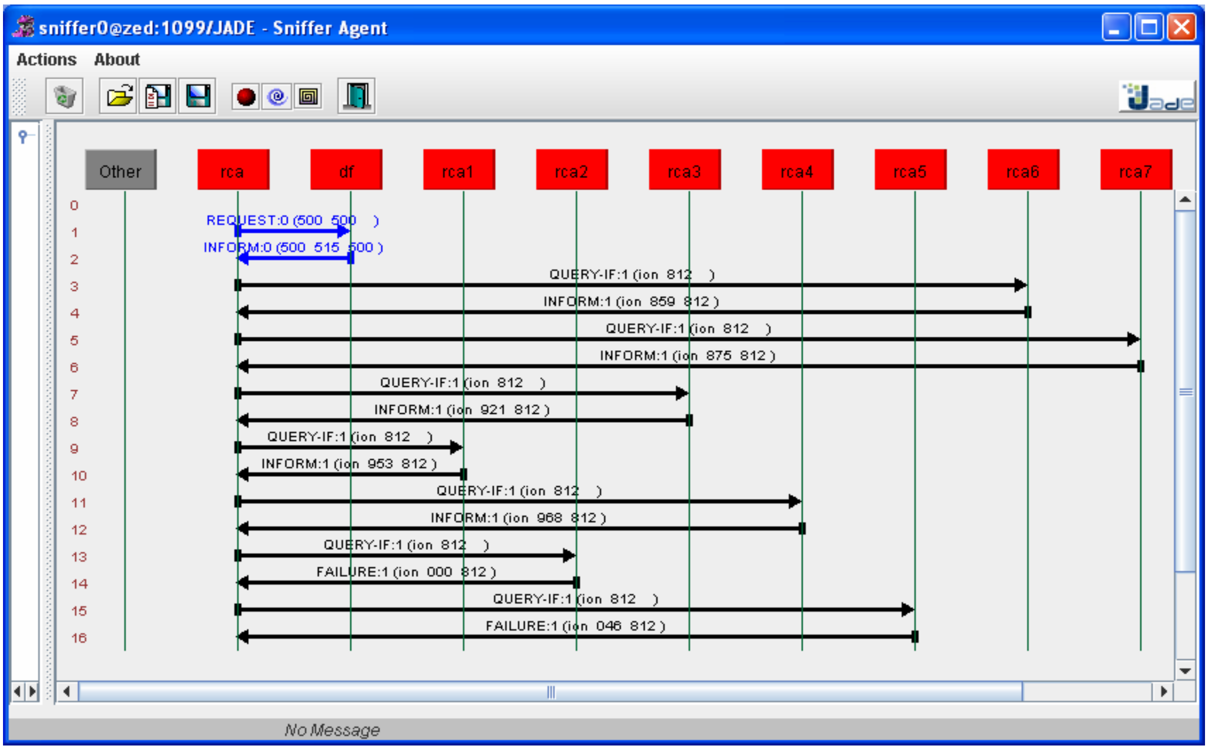
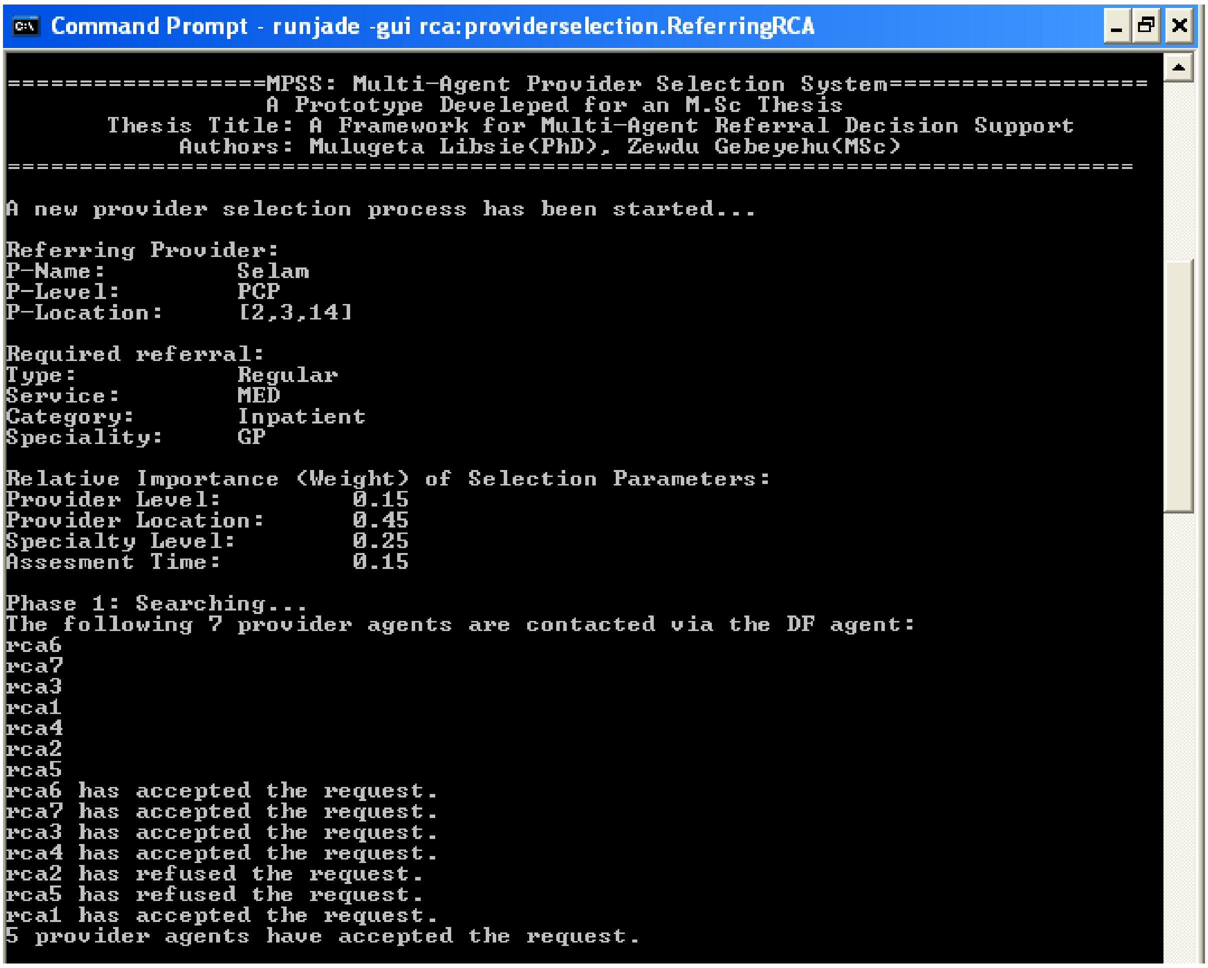


Figure 6.11 Screenshot of the Inter-agent Interaction (regular referral)

Figure 6.12 shows a screenshot of the output of the searching phase. It includes information about the referring provider, the required regular referral, agents contacted during searching and those agents which accepted the request.

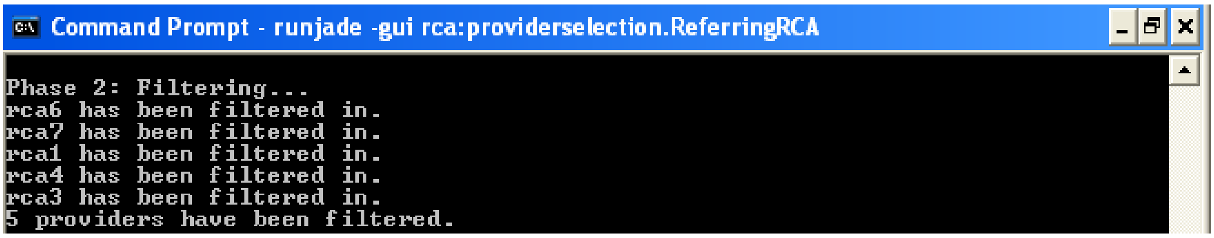


```
Command Prompt - runjade -gui rca:providerselection.ReferringRCA
==================MPSS: Multi-Agent Provider Selection System==================
                    A Prototype Develeped for an M.Sc Thesis
       Thesis Title: A Framework for Multi-Agent Referral Decision Support
            Authors: Mulugeta Libsie(PhD), Zewdu Gebeyehu(MSc)
==============================================================================

A new provider selection process has been started...

Referring Provider:
P-Name:          Selam
P-Level:         PCP
P-Location:      [2,3,14]

Required referral:
Type:            Regular
Service:         MED
Category:        Inpatient
Speciality:      GP

Relative Importance (Weight) of Selection Parameters:
Provider Level:          0.15
Provider Location:       0.45
Specialty Level:         0.25
Assesment Time:          0.15

Phase 1: Searching...
The following 7 provider agents are contacted via the DF agent:
rca6
rca7
rca3
rca1
rca4
rca2
rca5
rca6 has accepted the request.
rca7 has accepted the request.
rca3 has accepted the request.
rca4 has accepted the request.
rca2 has refused the request.
rca5 has refused the request.
rca1 has accepted the request.
5 provider agents have accepted the request.
```

Figure 6.12 Screenshot of the Output of the Searching Phase (regular referral)

6.3.2.2 Phase 2: Filtering

In this phase, the rca uses the ProviderFilteringPerformer behaviour to filter service-and-policy suitable providers based on the hard-coded policies. The screenshot for the output of this phase is shown in figure 6.13. As shown in the figure all service-suitable providers are filtered.

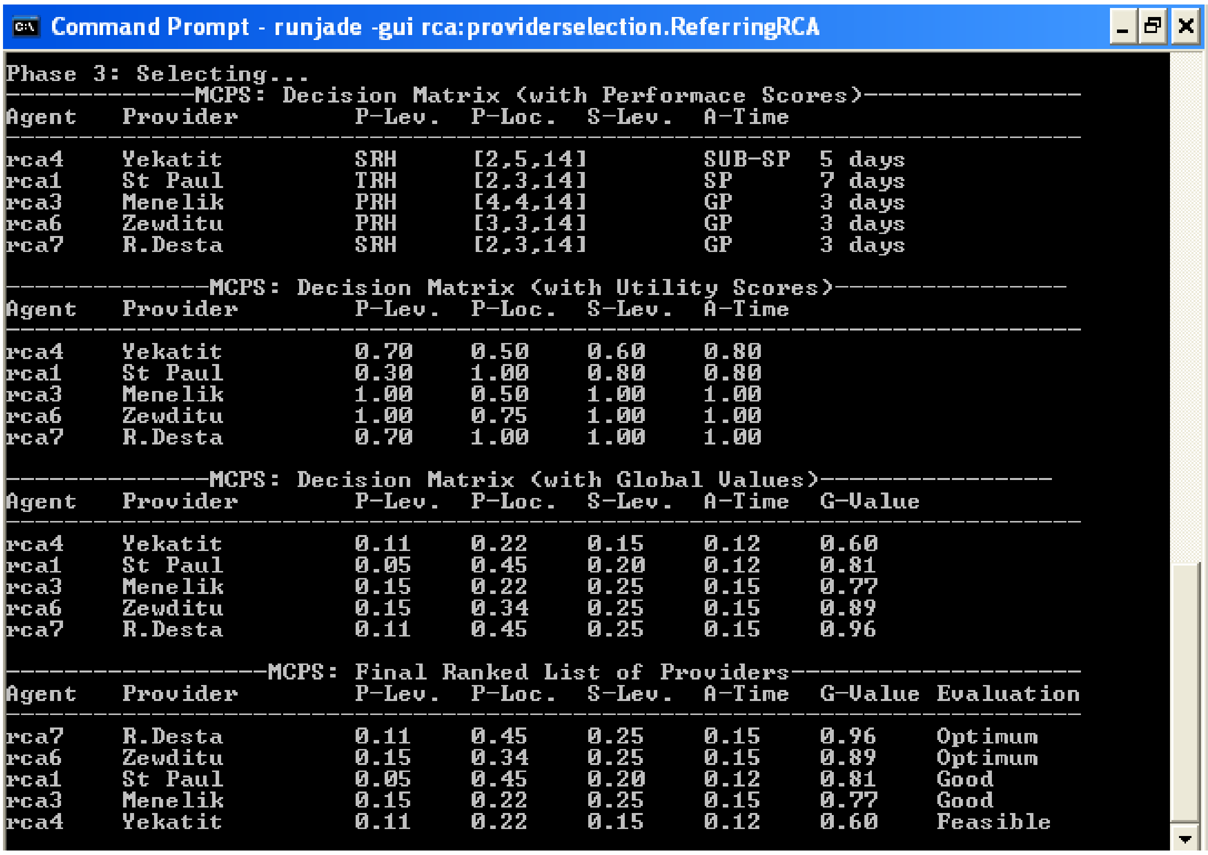


```
Command Prompt - runjade -gui rca:providerselection.ReferringRCA
Phase 2: Filtering...
rca6 has been filtered in.
rca7 has been filtered in.
rca1 has been filtered in.
rca4 has been filtered in.
rca3 has been filtered in.
5 providers have been filtered.
```

Figure 6.13 Screenshot of the Output of the Filtering Phase (regular referral)

6.3.2.3 Phase 3: Selection

In this phase, the rca employs the ProviderSelectionPerformer behaviour that implements the MAUT decision aid technique to produce a ranked list of providers. A screenshot of the output of this phase is shown in figure 6.14. In this output, results of the three steps of MAUT are displayed using four different matrices. The first shows the decision matrix with raw performance scores. The second displays the decision matrix with utility scores after the application of the utility functions.




```
Phase 3: Selecting...
-------------MCPS: Decision Matrix (with Performace Scores)---------------
Agent    Provider        P-Lev.  P-Loc.   S-Lev.  A-Time
--------------------------------------------------------------------------
rca4     Yekatit         SRH     [2,5,14]         SUB-SP  5 days
rca1     St Paul         TRH     [2,3,14]         SP      7 days
rca3     Menelik         PRH     [4,4,14]         GP      3 days
rca6     Zewditu         PRH     [3,3,14]         GP      3 days
rca7     R.Desta         SRH     [2,3,14]         GP      3 days

--------------MCPS: Decision Matrix (with Utility Scores)---------------
Agent    Provider        P-Lev.  P-Loc.   S-Lev.  A-Time
--------------------------------------------------------------------------
rca4     Yekatit         0.70    0.50     0.60    0.80
rca1     St Paul         0.30    1.00     0.80    0.80
rca3     Menelik         1.00    0.50     1.00    1.00
rca6     Zewditu         1.00    0.75     1.00    1.00
rca7     R.Desta         0.70    1.00     1.00    1.00

--------------MCPS: Decision Matrix (with Global Values)----------------
Agent    Provider        P-Lev.  P-Loc.   S-Lev.  A-Time  G-Value
--------------------------------------------------------------------------
rca4     Yekatit         0.11    0.22     0.15    0.12    0.60
rca1     St Paul         0.05    0.45     0.20    0.12    0.81
rca3     Menelik         0.15    0.22     0.25    0.15    0.77
rca6     Zewditu         0.15    0.34     0.25    0.15    0.89
rca7     R.Desta         0.11    0.45     0.25    0.15    0.96

------------------MCPS: Final Ranked List of Providers--------------------
Agent    Provider        P-Lev.  P-Loc.   S-Lev.  A-Time  G-Value Evaluation
--------------------------------------------------------------------------
rca7     R.Desta         0.11    0.45     0.25    0.15    0.96    Optimum
rca6     Zewditu         0.15    0.34     0.25    0.15    0.89    Optimum
rca1     St Paul         0.05    0.45     0.20    0.12    0.81    Good
rca3     Menelik         0.15    0.22     0.25    0.15    0.77    Good
rca4     Yekatit         0.11    0.22     0.15    0.12    0.60    Feasible
```

Figure 6.14 Screenshot of the Output of the Selection Phase (regular referral)

The first two matrices represent output of the first step of MAUT. The third matrix, which represents output of the second step of MAUT, displays global value of each alternative provider after applying the aggregation function, U. The fourth matrix, which represents output of the third step of MAUT, displays the final ranked list of providers along with a general qualitative evaluation of each selection. According to this output, ***Ras Desta*** has been selected by MPSS as an appropriate provider for the required regular referral. This is because during regular referrals, cumulative importance of specialty and provider levels (40%) has almost as equal importance as that of location factor (45%).

6.3.3 Output 2 (Emergency Referral)

6.3.3.1 Phase 1: Searching

The screenshot of the searching process for the required emergency referral is illustrated by figure 6.15, as intercepted by the built-in sniffer agent. As shown in the figure, potential providers that have accepted the request are rca1, rca2, rca3, rca4, rca6 and rca7. The only agent that has refused the request due to unavailability of the required service is rca5. Note that this time around rca2 has accepted the request since during emergency referrals provider and specialty levels are not considered. The only important factor to receive an emergency referral is availability of the required service (this is one of the hard-coded referral policies).

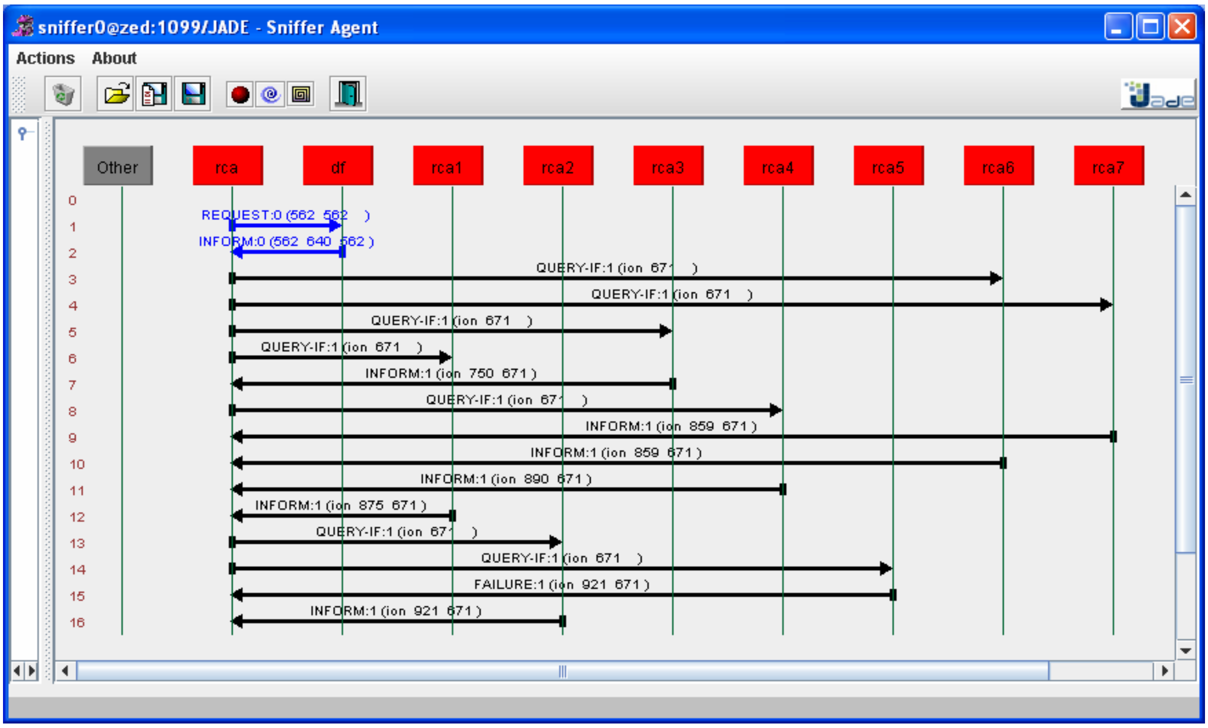
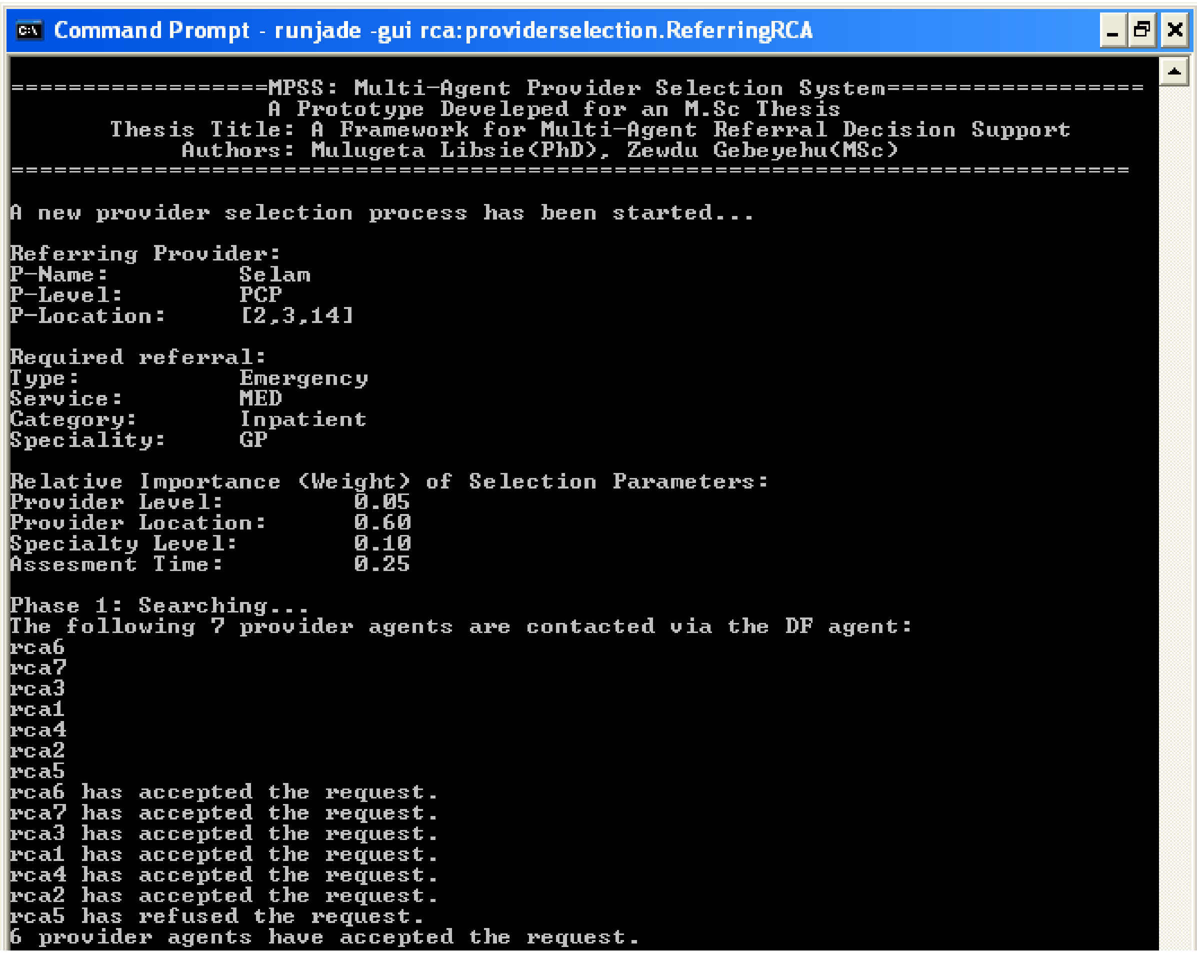


Figure 6.15 Screenshot of the Inter-agent Interaction (emergency referral)

Figure 6.16 shows a screenshot of the output of the searching phase.

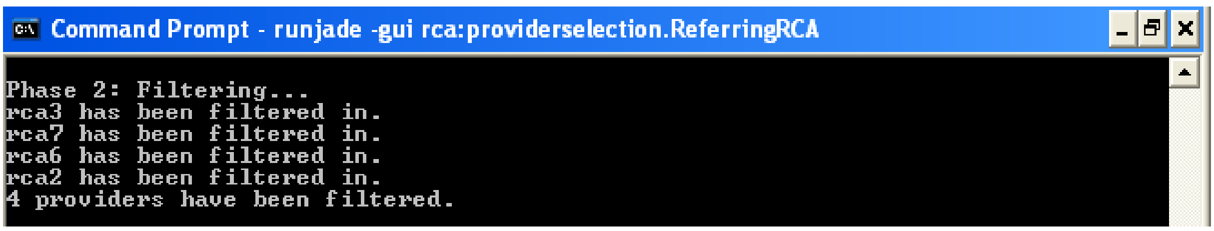


```
Command Prompt - runjade -gui rca:providerselection.ReferringRCA
==================MPSS: Multi-Agent Provider Selection System==================
                  A Prototype Develeped for an M.Sc Thesis
       Thesis Title: A Framework for Multi-Agent Referral Decision Support
            Authors: Mulugeta Libsie(PhD), Zewdu Gebeyehu(MSc)
===============================================================================

A new provider selection process has been started...

Referring Provider:
P-Name:         Selam
P-Level:        PCP
P-Location:     [2,3,14]

Required referral:
Type:           Emergency
Service:        MED
Category:       Inpatient
Speciality:     GP

Relative Importance (Weight) of Selection Parameters:
Provider Level:         0.05
Provider Location:      0.60
Specialty Level:        0.10
Assesment Time:         0.25

Phase 1: Searching...
The following 7 provider agents are contacted via the DF agent:
rca6
rca7
rca3
rca1
rca4
rca2
rca5
rca6 has accepted the request.
rca7 has accepted the request.
rca3 has accepted the request.
rca1 has accepted the request.
rca4 has accepted the request.
rca2 has accepted the request.
rca5 has refused the request.
6 provider agents have accepted the request.
```

Figure 6.16 Screenshot of the Output of the Searching Phase (emergency referral)

6.3.3.2 Phase 2: Filtering

The screenshot for the output of this phase is shown in figure 6.17. As shown in the figure only four service-suitable providers are filtered. Rca1 and rca4 have been filtered out because of their minimum assessment time. For inpatient emergency referrals, the minimum acceptable time is assumed to be 1 to 3 days (this is one of the hard-coded referral policies).

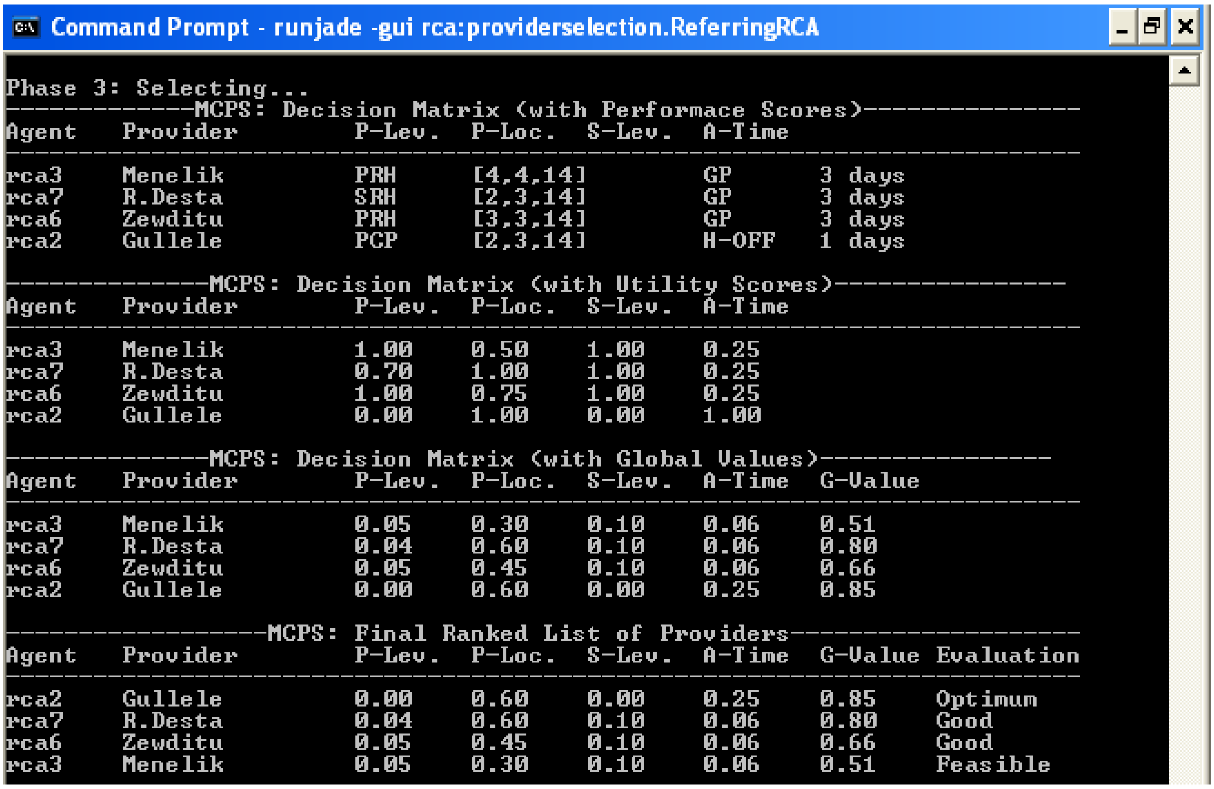


```
Command Prompt - runjade -gui rca:providerselection.ReferringRCA
Phase 2: Filtering...
rca3 has been filtered in.
rca7 has been filtered in.
rca6 has been filtered in.
rca2 has been filtered in.
4 providers have been filtered.
```

Figure 6.17 Screenshot of the Output of the Filtering Phase (emergency referral)

6.3.3.3 Phase 3: Selection

A screenshot of the output of this phase is shown in figure 6.18. In this output, results of the three steps of MAUT are displayed using four different matrices. According to this output, ***Gullele*** has been selected by MPSS as an appropriate provider for the required emergency referral. This is due to the fact that during emergency referrals high importance is given to location and assessment time factors (85%).



```
Command Prompt - runjade -gui rca:providerselection.ReferringRCA

Phase 3: Selecting...
-------------MCPS: Decision Matrix (with Performace Scores)---------------
Agent    Provider         P-Lev.   P-Loc.   S-Lev.   A-Time
--------------------------------------------------------------------------
rca3     Menelik          PRH      [4,4,14]          GP       3 days
rca7     R.Desta          SRH      [2,3,14]          GP       3 days
rca6     Zewditu          PRH      [3,3,14]          GP       3 days
rca2     Gullele          PCP      [2,3,14]          H-OFF    1 days

--------------MCPS: Decision Matrix (with Utility Scores)----------------
Agent    Provider         P-Lev.   P-Loc.   S-Lev.   A-Time
--------------------------------------------------------------------------
rca3     Menelik          1.00     0.50     1.00     0.25
rca7     R.Desta          0.70     1.00     1.00     0.25
rca6     Zewditu          1.00     0.75     1.00     0.25
rca2     Gullele          0.00     1.00     0.00     1.00

--------------MCPS: Decision Matrix (with Global Values)----------------
Agent    Provider         P-Lev.   P-Loc.   S-Lev.   A-Time   G-Value
--------------------------------------------------------------------------
rca3     Menelik          0.05     0.30     0.10     0.06     0.51
rca7     R.Desta          0.04     0.60     0.10     0.06     0.80
rca6     Zewditu          0.05     0.45     0.10     0.06     0.66
rca2     Gullele          0.00     0.60     0.00     0.25     0.85

------------------MCPS: Final Ranked List of Providers--------------------
Agent    Provider         P-Lev.   P-Loc.   S-Lev.   A-Time   G-Value  Evaluation
--------------------------------------------------------------------------
rca2     Gullele          0.00     0.60     0.00     0.25     0.85     Optimum
rca7     R.Desta          0.04     0.60     0.10     0.06     0.80     Good
rca6     Zewditu          0.05     0.45     0.10     0.06     0.66     Good
rca3     Menelik          0.05     0.30     0.10     0.06     0.51     Feasible
```

Figure 6.18 Screenshot of the Output of the Selection Phase (emergency referral)

CHAPTER 7 Conclusion and Future Work

7.1 Discussion

A Medical Referral System is an area of the healthcare domain characterized with diverse organizational and technical challenges. Providing a software solution to the problems of such an area is not an easy task since it requires a coordinated effort of professionals from diverse fields.

This thesis has presented a study conducted on the possibility of adopting multi-agent technology to the problems of referral decision making, which is one of the key aspects of a medical referral system. It proposed a comprehensive Multi-Agent Referral Decision Support (MARDS) framework, which incorporates five types of cooperating agents and two knowledgebases. The aim of the decision support is helping physicians in making better referral decisions. The framework has been designed to support all the three aspects of referral decision. However, a special focus has been made on the provider selection aspect.

To this end, a Multi-Criteria Provider Selection (MCPS) model has been proposed to aid physicians in making better provider selection. The model employs three phases to search, filter and rank appropriate providers. The output of the selection model is a list of ranked providers which is presented to a referring physician for final decision.

The core part of the selection model has been implemented and tested by a Multi-Agent Provider Selection System (MPSS). Even if it requires various refinements and extensive validation and testing, the system has shown the feasibility of the proposed selection model. It has also proved the potential of the employed multi-agent approach to build a distributed software decision support tool that would enable a better provider selection. In general, the result of this work is strongly believed to be one step towards enhancing existing e-Referral systems with intelligent referral decision support.

7.2 Contributions

The following are the main contributions of this research work:

- A three-layered ***M**ulti-Agent **e**-**R**eferral (MeR)* system is proposed with the intention of extending capabilities of the current e-Referral systems with intelligent referral decision support by employing a multi-agent technology. The layering approach is intended to allow cost-effective integration of a referral decision support with existing e-Referral systems. It can also simplify the design complexity of the overall system by decomposing it into manageable pieces.

- A ***M**ulti-**A**gent **R**eferral **D**ecision **S**upport (MARDS)* system framework is developed that can assist physicians in making better referral decisions for cost-effective and better patient care. The framework has two main components. The first component is related with helping physicians in deciding about the need for referral in the presence of clinical uncertainty. This is performed by analyzing patient, physician and healthcare system determinants. If a referral is indicated, the system identifies required services for the referral, based on patient determinates. Otherwise, it recommends a medical management consultation, which describes the tests and treatments a physician should perform before referring a patient. The second component of the decision support is designed to assist physicians in selecting an appropriate provider for an indicated referral.
- A three-phased ***M**ulti-**C**riteria **P**rovider **S**election (MCPS)* model is developed to aid physicians in making an optimal provider selection for patient referrals. The first phase employs a ***three-stepped hierarchical searching strategy*** to find potential providers that are suitable for a required referral based on the clinical factors of the patient. The second phase applies ***a case specific referral policy*** to filter and shortlist potential providers that are suitable for the required service and referral policy. Finally, the third phase applies ***an MADM method*** on the short listed potential providers to generate a final ranked list of providers. This list will be provided to the referring provider as a recommendation for a final decision. This is believed to have its own part in improving the overall healthcare of patients by providing medical services at an appropriate location, and by minimizing transport time and associated costs.

7.3 Future Work

The MARDS framework and the MCPS model proposed in this work will be used as a basis for a number of research and development works towards the realization of an intelligent referral decision support. The planned future works are categorized into three major areas discussed below.

- **Enhancement of the MARDS Framework:** The referral decision support has been developed at a framework level. For this reason, the new proposed referral model has been designed with limited study and experience of the researchers. In addition, the focus of the framework has been on the provider selection aspect of referral decision. The other two aspects have not been dealt with. Hence, further work is needed in the following areas towards enhancing the framework.
  - Further interdisciplinary study is required to come up with a referral model that incorporates all aspects of the target referral system.
  - Additional study is needed on how to design and develop the two knowledgebases (RGK and RPK) employed by the framework.
  - Further work is required to study and develop a decision support technique for the two aspects of a referral decision (referral indication and service identification). The technique is supposed to be employed by the RSA agent class and it has two aspects. The first aspect deals with how to help providers in determining whether a referral is needed or not as well as identification of required services. This will be employed by the RAA component of RSA. The other aspect is concerned on how to provide local medical consultation for Primary Care Physicians (PCPs) when referral is not indicated. This will be employed by the MCA.
  - The other aspect that needs further work is the study required on how to integrate the MARDS framework with the information system layer of MeR system.
- **Refinement of the MCPS Model:** The provider selection model proposed in this thesis still needs some refinement works in the following areas.
  - In the selection model, location of providers is defined in terms of the national political structure (district, zone and region), i.e. geographical location, which indicates actual distance, has not been included. As a result, providers situated in the same political location (district, zone, or region) are considered to have an equal performance score in terms of the location parameter. In addition, during the three-stepped hierarchical searching, providers outside the region being searched but that might be closest to the referring provider are not

considered. Hence, there is a need to improve the proposed searching technique so that actual distance of providers will be considered.

- In developing the model, the study conducted to define the selection parameters is limited. Hence, to improve effectiveness of the selection model, further study is required to adequately define the selection parameters.
- Even though the selection model is designed with an open architecture to employ any MADM technique for choosing and ranking providers, MAUT has been chosen simply for its clarity and simplicity. Thus, further study is required to choose an MADM technique that best fits to the specific requirements of the selection model.
- In the initial design of the selection model, the empirical procedure carried out to define the decision elements is not adequate. This has a significant effect in the quality of the selection result. Hence, further study should be done to come up with optimum assignment of weights, definition of utility and aggregation functions.

- **Improvement of the Prototype:** The current implementation of the selection model (MPSS) requires further work in the following areas.
  - Design and development of system components which have not been included in the current implementation: PFA, MADMA, UIA, ZMB, RMB, NMB agents; complete three-stepped searching technique; referral policy knowledgebase (RPK); knowledgebase wrapper agent (KWR); provider selection ontology.
  - Deployment of the system in a distributed environment and having an extensive testing and validation using adequate sample data.

REFERENCES:

[1]	M. Luck, P. MacBurney, O. Shehory and S.Willmott, “Agent Technoloy Roadmap”, ISBN 085432 8459, AgentLinkII, September 2005
[2]	N. Jennings, “Building Complex Software Systems”, Communications of ACM, June 2001, 44(4):35-41
[3]	A. Moreno, “Medical Applications of Multi-Agent Systems”, Computer Science and Mathematics Department”, University of Rovira, Spain, 2003
[4]	J. Nealon and A. Moreno, “Agent-based applications in health-care”, In John L. Nealon and A. Moreno, editors, Applications of Software Agent Technology in the Health-Care Domain, Whitestein Series in Software Agent Technologies, 2003, pp 3–18, Switzerland
[5]	J. Nealon, A. Moreno, “The Application of Agent Technology to Health-Care”, AgentCities Working Group on Health-Care, 2000
[6]	General Practitioners Committee, “Referral Management: Frequently Asked Questions”, BMA, January 2006
[7]	K. Grumbach, J. Selby, C. Damberg, A. Bindman, C. Quesenberry, A. Truman, C. Uratsu, “Resolving the gatekeeper conundrum: what patients value in primary care and referrals to specialists”, JAMA, 1999, 282:261-266
[8]	T. Gandhi and et al, “Communication Breakdown in the Outpatient Referral Process”, Journal of General Internal Medicine, September 2000, 15(9): 626–631
[9]	B. Sweeney, “Referral System”, BMJ, November 1994, 309:1180-1181
[10]	M. Donohoe, R. Kravitz, D. Wheeler, R. Chandra, A. Chen, and N. Humphries, “Reasons for Outpatient Referrals from Generalists to Specialists”, Journal of General Internal Medicine, May 1999, 14(5): 281–286
[11]	K. Kinchen, L. Cooper, D. Levine, N. Wang, and N. Powe, “Referral of Patients to Specialists: Factors Affecting Choice of Specialist by Primary Care Physicians “, Annals of Family Medicine, 2004, 2:245-252
[12]	O. Kvamme, F. Olesen, M. Samuelson, “Improving the interface between primary and secondary care: a statement from the European Working Party on Quality in Family Practice (EQuiP)”, Qual Health-Care, 2001, 10:33-39.
[13]	Esther Morales, “ Referral Management and Authorization”, Medical Management ‘Signature Series’ by Managed Care Resources, Inc., 1998
[14]	R. Epstein, “Communication between primary care physicians and consultants”, Arch Fam Med., 1995,4:403–9

[15]	D. Sitting, T. Gandhi, M. Franklin, M. Turetsky, A. Sussman, D. Fairchild, D. Bates, A. Komaroff, and J. Tecich, “A computer-based outpatient clinical referral system”, Int. J. Med. Informatics, 1999, 55:149-158,.
[16]	M. Wang, C. Lau, F. Matsen, Y. Kim, “Personal Health Information Management System and its Application in Referral Management”, IEEE Transaction on Infromation Technology in Biomedicine, September 2004, 8: 3
[17]	S. Murphy, T. Ng, D. Sitting, G. Barnett, “Using Web Technology and Java Mobile Software Agents To Manage Outside Referrals” , Poceeding of AMIA Symposium, 1998, 101-105
[18]	W. Michael, “An Introduction to Multi-Agent Systems”, Wiley Ed., 2002
[19]	J. Bradshaw, “Software Agents”, MIT Press, Cambridge, MA, 1997
[20]	O. Chira, “Software Agents”, IDIMS Report, 2003
[21]	S. Katia, ”Multi-Agent Systems”, AI Magazine, 1998, 19(2): 79-92
[22]	G. Weiss, “Multi-Agent Systems: A Modern Approach to Distributed Artificial Intelligence”, MIT Press, 1999
[23]	C. Petrie, “Agent-based Software Engineering”, Agent Oriented Software Engineering Lecture Notes Artificial Intelligence, 2000, 58-76
[24]	N. Jennings, “Agent-based Software Engineering Artificial Intelligence”, 2000, 277-296
[25]	B. Sweeney, “Referral System”, BMJ, November 1994,309:1180-1181
[26]	Wikipedia, “Health-Care and Healthcare delivery”, http://en.wikipedia.org/wiki/Health_care, visited on November, 2006
[27]	Ministry of Health, “Patient Referral Guideline”, Addis Ababa, Ethiopia, 2006
[28]	C. Forrest, P. Nutting, S. Schrader, C. Rohde, B. Starfield, “Primary Care Physician Specialty Referral Decision Making: Patient, Physician, and Health-Care System Determinants”, Medical Decision Making, 2006, 26:76–85

[29]	R. Wootton, K. Harno, J. Reponen , "Organizational aspects of e-referrals", Journal of Telemedicine and Telecare 2003, S2:76-79
[30]	J. Reponen, E. Marttila, H. Paajanen and A.Turula, "Extending a multimedia medical record to a regional service including experiences with electronic referral and discharge letters", 4th International Conference on Successes and Failures Telehealth, 2004, 22-23 July
[31]	P. Harry, S. Lucy, C. Elizabeth, G. Jane, "e-Referral a Better Path to Hospital & Community Service Co-ordination", Service Coordination and e-Referral Project, An initiative funded by the Department of Human Services (DHS, Victoria), 2004
[32]	S. Tracey, "Laying the Foundation for e-Referral", Victorian State-wide Forum on Electronic Referral Summary Report, April 2004
[33]	Z. Ludger, "MEDUSA: A Multi-Agent System for Establishing Electronic healthcare Records", Oldenburg Research and Development Institute for Computer Science Tools and Systems (OFFIS), Oldenburg, Germany, 2005
[34]	J. Fonseca, A. Mora and A. Marques, "MAMIS: Amultiaget Medical Information System", Proceedings of IASTED International Conference on Biomedical Engineering (BioMED), February 2005
[35]	P. Zhang, "Multi-Agent Systems in Diabetic Health-Care: from the perspectives of Activity Theory and Systems Science", PhD Thesis, Blekinge Institute of Technology, 2005, ISSN 1650-2140, ISBN 91-7295-060-9
[36]	A. Moreno, D. Isern, "Accessing distributed health-care services through smart agents", Proceedings of the 4th IEEE International Workshop on Enterprise Networking and Computing in the Health-Care Industry (HealthCom 2002), Nancy, France, 2002, 34-41
[37]	E. Turban, E. Aronson, "Decision Support Systems and Intelligent Systems", Prentice Hall , 6th ed. 2001
[38]	L. John, Models and Managers, "The Concept of a Decision Calculus, Management Science", 1970, 16(8)
[39]	D. Foster, C. McGregor, S. El-Masri , "A Survey of Agent-Based Intelligent Decision Support Systems to Support Clinical Management and Research", D. Foster, C. McGregor, S. El-Masri, www.diee.unica.it/biomed05/pdf/W22-102.pdf, visited on January 2007
[40]	V. Koutkias, I. Chouvardaa, N. Maglaveras, "Multi-Agent System Architecture for Heart Failure Management in a Home Care Environment", IEEE, Computers in Cardiology, 2003, 30:383-386
[41]	A. Valls, A. Moreno, D. S´anchez, "A Multi-Criteria Decision Aid Agent Applied to the Selection of the Best Receiver in a Transplant", 4th. International Conference on Enterprise Information Systems, 2002.
[42]	M. Calisti, P. Funk, S. Biellman, T. Bugnon, "A Multi-Agent System for Organ Transplant Management", in Applications of Software Agent Technology in the Health-Care Domain, eds., A. Moreno and J. Nealon, Whitestein Series in Software Agent Technologies, 2003

[43]	M. Radziah, D. Safaai, A. Hany "Pattern-Oriented Design for Multi-Agent System: A Conceptual Model", Journal of Object Technology, 2007, 6(4)
[44]	F. Zambonelli , N. Jennings , M. Wooldridge, "Developing multi-agent systems: The Gaia Methodology", ACM Transactions on Software Engineering and Methodology (TOSEM), July 2003, 12(3):317-370
[45]	J. Castro, M. Kolp, J. Mylopoulos, "Towards requirements-driven information systems engineering: The tropos project" Information Systems, June 2002 27(6): 365–389
[46]	F. Wood, A. DeLoach, "An Overview of the Multi-Agent Systems Engineering Methodology", The First International Workshop on Agent-Oriented Software Engineering (AOSE2000) , 2000, 207-213
[47]	A. Dardenne, A. van Lamsweerde , S. Fickas, "Goal-Directed Requirements Acquisition", Science of Computer Programming, 1993, 20:3-50
[48]	R. Darimont and A. van Lamsweerde, "Formal Refinement Patterns for Goal-Driven Requirements Elaboration", Proceedings FSE'4 - Fourth ACM SIGSOFT Symposium on the Foundations of Software Engineering, San Francisco, October 1996, 179-190
[49]	J. Mylopoulos, L. Chung, B. Nixon, "Representing and Using Nonfunctional equirements: A Process-Oriented Approach", IEEE Transaction on Software. Engineering, June 1992, 18(6):483-497.
[50]	A. van Lamsweerde, "Goal-Oriented requirements Engineering: A Guided Tour", Proceedings of the 5th International Symposium on Requirements Engineering (RE'01), IEEE CS Press, 2001, 249-261
[51]	R. Harris, "Introduction to Decision Making", http://www.virtualsalt.com/crebook5.htm, visited on February 2007
[52]	A. Valls, "Thesis: ClusDM: A Multiple Criteria Decision Method for Heterogeneous Data Sets", AI Communications, IOS-International Organizations, 2003, 16(2):129-130
[53]	R. Fuller, C. Carlsson, "Fuzzy Multiple Criteria Decision Making: Recent Developments", Fuzzy Sets and Systems, 1996, 78(2):139–153
[54]	J. Geldermann, O. Rentz, "Bridging the Gap between American and European MADM-approaches?", 51st Meeting of the European Working Group Multi-Criteria Aid for Decisions, 30-31 March, 2000
[55]	"Multi-Attribute Utility Theory", http://www2.dmi.columbia.edu/edu/g4050/week11.ppt, visited on January, 2007
[56]	D. Baker, D. Bridges, R. Hunter, G. Johnson, J. Krupa, J. Murphy, K. Sorenson, "Guidebook to Decision-Making Methods", WSRC-IM-2002-00002, Department of Energy, USA, 2002, http://emi-web.inel.gov/Nissmg/Guidebook_2002.pdf, visited on February 2007

[57]	C. Chen, M. Klein, “An Efficient Approach to Solving Fuzzy MADM Problems”, Fuzzy Sets and Systems, 1997, 88:51-67
[58]	M. Henig, J. Buchanan, “Solving MCDM Problems: Process Concepts”, Journal of Multi-Criteria Decision Analysis, 1996, 5:3-21
[59]	M. Janic, A. Reggiani, “An Application of the Multi-Criteria Decision Making Analysis to the Selection of a New Hub Airport”, EJTIR,2002,2(2):113-141
[60]	C. Giovanni, “JADE Tutorial: Jade Programming for Beginners”, TILab S.p.A, Decemebr 2003
[61]	A. Dogac, I. Cingil, “B2B e-Commerce Technology: Frameworks, Standards and Emerging Issues”, Addison Wesley, 2003
[62]	R. A. Bourne, A. Hayzelden, , “Agent Technology for Communications Infrastructure: An Introduction”, John Wiley and Sons, 2000
[63]	T. Pitkäranta, “Software Agents in Semantic Web Environment”, Master´s Thesis, Helsinki University of Technology, 2004

ANNEX A: PACKAGE DESCRIPTION

A.1. Package Components

Class Summary	
Location	Inter-agent Communication Objects
ReferralReply	
ReferralRequest	
ParameterWeight	Internal Objects used within Agents
Provider	
ReferredToProvider	
ReferringProvider	
ReferringRCA	Agent Classes
ReferredToRCA	
ReferringProviderGui	Java GUIs
ReferredToProviderGui	

A.2. Class Hierarchy

- java.lang.Object
  - jade.core.Agent (implements java.lang.Runnable, jade.util.leap.Serializable, jade.core.TimerListener)
    - providerselection.**ReferredToRCA**
    - providerselection.**ReferringRCA**
  - jade.core.behaviours.Behaviour (implements jade.util.leap.Serializable)
    - providerselection.**ReferringRCA.ProviderSearchingPerformer**
    - jade.core.behaviours.SimpleBehaviour
      - jade.core.behaviours.CyclicBehaviour
        - providerselection.**ReferredToRCA.ReferralRequestsServer**
      - jade.core.behaviours.OneShotBehaviour
        - providerselection.**ReferringRCA.ProviderFilteringPerformer**
        - providerselection.**ReferringRCA.ProviderSelectionPerformer**
  - java.awt.Component (implements java.awt.image.ImageObserver, java.awt.MenuContainer, java.io.Serializable)
    - java.awt.Container
      - java.awt.Window (implements javax.accessibility.Accessible)
        - java.awt.Frame (implements java.awt.MenuContainer)
          - javax.swing.JFrame (implements javax.accessibility.Accessible, javax.swing.RootPaneContainer, javax.swing.WindowConstants)
            - providerselection.**ReferredToProviderGui**
            - providerselection.**ReferringProviderGui**
  - providerselection.**Location** (implements java.io.Serializable)
  - providerselection.**ParameterWeight**
  - providerselection.**Provider**
  - providerselection.**ReferralReply** (implements java.io.Serializable)
  - providerselection.**ReferralRequest** (implements java.io.Serializable)
  - providerselection.**ReferredToProvider** (implements java.io.Serializable)
  - providerselection.**ReferringProvider**

ANNEX B: REFERRINGRCA AGENT

B.1. Class ReferringRCA

java.lang.Object
└ jade.core.Agent
 └ **providerselection.ReferringRCA**

All Implemented Interfaces:
jade.core.TimerListener, java.io.Serializable, java.lang.Runnable

public class **ReferringRCA**
extends jade.core.Agent

Nested Class Summary

class	**ReferringRCA.ProviderFilteringPerformer** Inner class ProviderFilteringPerformer.
class	**ReferringRCA.ProviderSearchingPerformer** Inner class ProviderSearchingPerformer.
class	**ReferringRCA.ProviderSelectionPerformer** Inner class ProviderSelectionPerformer.

Nested classes/interfaces inherited from class jade.core.Agent

jade.core.Agent.Interrupted

Field Summary

Fields inherited from class jade.core.Agent

AP_ACTIVE, AP_DELETED, AP_IDLE, AP_INITIATED, AP_MAX, AP_MIN, AP_SUSPENDED, AP_WAITING, D_ACTIVE, D_MAX, D_MIN, D_RETIRED, D_SUSPENDED, D_UNKNOWN

Constructor Summary

ReferringRCA()

Method Summary

void	**buildDecisionMatrix**()
float	**computeGlobalValue**(Provider p)
float	**computeU1**(int pLevel)
float	**computeU2**(Location pLocation)
float	**computeU3**(int sLevel)
float	**computeU4**(int aTime)
java.lang.String	**convertAssesmentTime**(int aTime)
java.lang.String	**convertProviderLevel**(int pLevel)
java.lang.String	**convertProviderLocation**(Location pLocation)
java.lang.String	**convertSpecialtyLevel**(int sLevel)
void	**displayDecisionMatrix**()
void	**displayRankedProviders**()
java.lang.String	**evaluateProvider**(float U)
java.lang.String	**fixDecimal**(float value)
void	**rankProviders**()
void	**selectProvider**(java.lang.String referraltype, java.lang.String referralcategory, java.lang.String requiredservice, int specialtylevel)

Protected void	**setup**()
void	**startMAUT**()
Protected void	**takeDown**()
void	**updateParameterWeight**(float ew1, float ew2, float ew3, float ew4, float rw1, float rw2, float rw3, float rw4)
void	**updateProviderInfo**(java.lang.String providername, int providerdistrict, int providerzone, int providerregion, int providerlevel)

Methods inherited from class jade.core.Agent
addBehaviour, afterClone, afterMove, beforeClone, beforeMove, blockingReceive, blockingReceive, blockingReceive, blockingReceive, changeStateTo, clean, doActivate, doClone, doDelete, doMove, doSuspend, doTimeOut, doWait, doWait, doWake, getAgentState, getAID, getAMS, getArguments, getContainerController, getContentManager, getCurQueueSize, getDefaultDF, getHap, getHelper, getLocalName, getName, getO2AObject, getProperty, getQueueSize, getState, here, notifyChangeBehaviourState, notifyRestarted, postMessage, putBack, putO2AObject, receive, receive, removeBehaviour, restartLater, restore, restoreBufferedState, run, send, setArguments, setEnabledO2ACommunication, setGenerateBehaviourEvents, setQueueSize, waitUntilStarted, write

Methods inherited from class java.lang.Object
clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferringRCA

public **ReferringRCA**()

Method Detail

setup

protected void **setup**()

Overrides:

setup in class jade.core.Agent

---

takeDown

protected void **takeDown**()

Overrides:

takeDown in class jade.core.Agent

---

updateProviderInfo

public void **updateProviderInfo**(java.lang.String providername,
int providerdistrict,
int providerzone,
int providerregion,
int providerlevel)

---

updateParameterWeight

public void **updateParameterWeight**(float ew1,
float ew2,
float ew3,
float ew4,
float rw1,
float rw2,
float rw3,
float rw4)

---

selectProvider

public void **selectProvider**(java.lang.String referraltype,
java.lang.String referralcategory,
java.lang.String requiredservice,
int specialtylevel)

---

startMAUT

public void **startMAUT**()

buildDecisionMatrix

public void **buildDecisionMatrix**()

rankProviders

public void **rankProviders**()

displayDecisionMatrix

public void **displayDecisionMatrix**()

displayRankedProviders

public void **displayRankedProviders**()

computeU1

public float **computeU1**(int pLevel)

computeU2

public float **computeU2**(Location pLocation)

computeU3

public float **computeU3**(int sLevel)

computeU4

public float **computeU4**(int aTime)

computeGlobalValue

public float **computeGlobalValue**(Provider p)

evaluateProvider

public java.lang.String **evaluateProvider**(float U)

convertProviderLevel

public java.lang.String **convertProviderLevel**(int pLevel)

convertProviderLocation

public java.lang.String **convertProviderLocation**(Location pLocation)

convertSpecialtyLevel

public java.lang.String **convertSpecialtyLevel**(int sLevel)

convertAssesmentTime

public java.lang.String **convertAssesmentTime**(int aTime)

fixDecimal

public java.lang.String **fixDecimal**(float value)

B.2. Class ReferringRCA.ProviderSearchingPerformer

java.lang.Object
└─ jade.core.behaviours.Behaviour
  └─ **providerselection.ReferringRCA.ProviderSearchingPerformer**

All Implemented Interfaces:
java.io.Serializable

Enclosing class:
ReferringRCA

---

public class **ReferringRCA.ProviderSearchingPerformer**
extends jade.core.behaviours.Behaviour

Inner class ProviderSearchingPerformer.

Nested Class Summary

Nested classes/interfaces inherited from class jade.core.behaviours.Behaviour
Jade.core.behaviours.Behaviour.RunnableChangedEvent

Field Summary

Fields inherited from class jade.core.behaviours.Behaviour
myAgent, myEvent, NOTIFY_DOWN, NOTIFY_UP, parent, STATE_BLOCKED, STATE_READY, STATE_RUNNING

Constructor Summary

ReferringRCA.ProviderSearchingPerformer()	

Method Summary

void	**action**()
boolean	**done**()

Methods inherited from class jade.core.behaviours.Behaviour
actionWrapper, block, block, getBehaviourName, getDataStore, getExecutionState, getParent, handle, isRunnable, onEnd, onStart, reset, restart, root, setAgent, setBehaviourName, setDataStore, setExecutionState

Methods inherited from class java.lang.Object
clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferringRCA.ProviderSearchingPerformer

public **ReferringRCA.ProviderSearchingPerformer**()

Method Detail

action

public void **action**()

Specified by:
action in class jade.core.behaviours.Behaviour

---

done

public boolean **done**()

Specified by:
done in class jade.core.behaviours.Behaviour

B.3.Class ReferringRCA.ProviderFilteringPerformer

java.lang.Object

└ jade.core.behaviours.Behaviour
  └ jade.core.behaviours.SimpleBehaviour
    └ jade.core.behaviours.OneShotBehaviour
      └ **providerselection.ReferringRCA.ProviderFilteringPerformer**

All Implemented Interfaces:
java.io.Serializable

Enclosing class:
ReferringRCA

---

public class **ReferringRCA.ProviderFilteringPerformer**
extends jade.core.behaviours.OneShotBehaviour

Inner class ProviderFilteringPerformer.

Nested Class Summary

Nested classes/interfaces inherited from class jade.core.behaviours.Behaviour
Jade.core.behaviours.Behaviour.RunnableChangedEvent

Field Summary

Fields inherited from class jade.core.behaviours.Behaviour
myAgent, myEvent, NOTIFY_DOWN, NOTIFY_UP, parent, STATE_BLOCKED, STATE_READY, STATE_RUNNING

Constructor Summary

ReferringRCA.ProviderFilteringPerformer()	

Method Summary

void	**action**()

Methods inherited from class jade.core.behaviours.OneShotBehaviour
Done

Methods inherited from class jade.core.behaviours.SimpleBehaviour
Reset

Methods inherited from class jade.core.behaviours.Behaviour
actionWrapper, block, block, getBehaviourName, getDataStore, getExecutionState, getParent, handle, isRunnable, onEnd, onStart, restart, root, setAgent, setBehaviourName, setDataStore, setExecutionState

Methods inherited from class java.lang.Object
clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferringRCA.ProviderFilteringPerformer

public **ReferringRCA.ProviderFilteringPerformer**()

Method Detail

action

public void **action**()

Specified by:
action in class jade.core.behaviours.Behaviour

B.4.Class ReferringRCA.ProviderSelectionPerformer

java.lang.Object
└ jade.core.behaviours.Behaviour

└ jade.core.behaviours.SimpleBehaviour
  └ jade.core.behaviours.OneShotBehaviour
    └ **providerselection.ReferringRCA.ProviderSelectionPerformer**

All Implemented Interfaces:
java.io.Serializable

Enclosing class:
ReferringRCA

---

public class **ReferringRCA.ProviderSelectionPerformer**
extends jade.core.behaviours.OneShotBehaviour

Inner class ProviderSelectionPerformer.

Nested Class Summary

Nested classes/interfaces inherited from class jade.core.behaviours.Behaviour
Jade.core.behaviours.Behaviour.RunnableChangedEvent

Field Summary

Fields inherited from class jade.core.behaviours.Behaviour
myAgent, myEvent, NOTIFY_DOWN, NOTIFY_UP, parent, STATE_BLOCKED, STATE_READY, STATE_RUNNING

Constructor Summary

ReferringRCA.ProviderSelectionPerformer()

Method Summary

void	**action**()

Methods inherited from class jade.core.behaviours.OneShotBehaviour
Done

Methods inherited from class jade.core.behaviours.SimpleBehaviour
Reset

Methods inherited from class jade.core.behaviours.Behaviour
actionWrapper, block, block, getBehaviourName, getDataStore, getExecutionState, getParent, handle, isRunnable, onEnd, onStart, restart, root, setAgent, setBehaviourName, setDataStore, setExecutionState

Methods inherited from class java.lang.Object
clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferringRCA.ProviderSelectionPerformer

public **ReferringRCA.ProviderSelectionPerformer**()

Method Detail

action

public void **action**()

Specified by:
action in class jade.core.behaviours.Behaviour

ANNEX C: REFERREDTORCA AGENT

C.1. Class ReferredToRCA

java.lang.Object
└ jade.core.Agent
  └ **providerselection.ReferredToRCA**

All Implemented Interfaces:
jade.core.TimerListener, java.io.Serializable, java.lang.Runnable

---

public class **ReferredToRCA**
extends jade.core.Agent

Nested Class Summary

Class	**ReferredToRCA.ReferralRequestsServer** Inner class ReferralRequestsServer.

Nested classes/interfaces inherited from class jade.core.Agent

jade.core.Agent.Interrupted

Field Summary

Fields inherited from class jade.core.Agent

AP_ACTIVE, AP_DELETED, AP_IDLE, AP_INITIATED, AP_MAX, AP_MIN, AP_SUSPENDED, AP_WAITING, D_ACTIVE, D_MAX, D_MIN, D_RETIRED, D_SUSPENDED, D_UNKNOWN

Constructor Summary

ReferredToRCA()

Method Summary

protected void	**setup**()
protected void	**takeDown**()
void	**updateProviderInfo**(java.lang.String providername, int providerdistrict, int providerzone, int providerregion, int providerlevel, java.lang.String serviceprovided, java.lang.String servicecategory, int specialtylevel, int minassesmenttime) This is invoked by the GUI when the user update provider information

Methods inherited from class jade.core.Agent

addBehaviour, afterClone, afterMove, beforeClone, beforeMove, blockingReceive, blockingReceive, blockingReceive, blockingReceive, changeStateTo, clean, doActivate, doClone, doDelete, doMove, doSuspend, doTimeOut, doWait, doWait, doWake, getAgentState, getAID, getAMS, getArguments, getContainerController, getContentManager, getCurQueueSize, getDefaultDF, getHap, getHelper, getLocalName, getName, getO2AObject, getProperty, getQueueSize, getState, here, notifyChangeBehaviourState, notifyRestarted, postMessage, putBack, putO2AObject, receive, receive, removeBehaviour, restartLater, restore, restoreBufferedState, run, send, setArguments, setEnabledO2ACommunication, setGenerateBehaviourEvents, setQueueSize, waitUntilStarted, write

Methods inherited from class java.lang.Object

clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferredToRCA

public **ReferredToRCA**()

Method Detail

setup

protected void **setup**()

Overrides:

setup in class jade.core.Agent

---

takeDown

protected void **takeDown**()

Overrides:

takeDown in class jade.core.Agent

---

updateProviderInfo

public void **updateProviderInfo**(java.lang.String providername,
int providerdistrict,
int providerzone,
int providerregion,
int providerlevel,
java.lang.String serviceprovided,
java.lang.String servicecategory,
int specialtylevel,
int minassesmenttime)

This is invoked by the GUI when the user updates provider information

---

C.2. Class ReferredToRCA.ReferralRequestsServer

java.lang.Object
└ jade.core.behaviours.Behaviour
└ jade.core.behaviours.SimpleBehaviour
└ jade.core.behaviours.CyclicBehaviour
└ **providerselection.ReferredToRCA.ReferralRequestsServer**

All Implemented Interfaces:

java.io.Serializable

Enclosing class: ReferredToRCA

---

public class **ReferredToRCA.ReferralRequestsServer**
extends jade.core.behaviours.CyclicBehaviour

Inner class ReferralRequestsServer.

Nested Class Summary

Nested classes/interfaces inherited from class jade.core.behaviours.Behaviour

jade.core.behaviours.Behaviour.RunnableChangedEvent

Field Summary

Fields inherited from class jade.core.behaviours.Behaviour

myAgent, myEvent, NOTIFY_DOWN, NOTIFY_UP, parent, STATE_BLOCKED, STATE_READY, STATE_RUNNING

Constructor Summary

ReferredToRCA.ReferralRequestsServer()

Method Summary

void	**action**()

Methods inherited from class jade.core.behaviours.CyclicBehaviour

Done

Methods inherited from class jade.core.behaviours.SimpleBehaviour

Reset

Methods inherited from class jade.core.behaviours.Behaviour
actionWrapper, block, block, getBehaviourName, getDataStore, getExecutionState, getParent, handle, isRunnable, onEnd, onStart, restart, root, setAgent, setBehaviourName, setDataStore, setExecutionState

Methods inherited from class java.lang.Object
clone, equals, finalize, getClass, hashCode, notify, notifyAll, toString, wait, wait, wait

Constructor Detail

ReferredToRCA.ReferralRequestsServer

public **ReferredToRCA.ReferralRequestsServer**()

Method Detail

action

public void **action**()

Specified by:

action in class jade.core.behaviours.Behaviour

DECLARATION

The thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for the thesis have been duly acknowledged.

Zewdu Gebeyehu 						Dr. Mulugeta Libsie (Advisor)