MODELLING VIRTUAL ENTERPRISES USING A MULTI-AGENT SYSTEMS APPROACH: CASE OF CONSTRUCTION INDUSTRY IN KENYA

George Wamamu Musumba

Registration Number: C341-0001/2012

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Computer Science

January 2016

DECLARATION

I declare that this is my original work and that it has not wholly, or in part, been presented in Dedan Kimathi University of Technology, any other University or any institution of higher learning for the award of a PhD degree, that to the best of my knowledge and belief, the thesis contains no material previously published or written by any other person except where due reference is made in the thesis itself.

George Wamamu Musumba

Signature: ______________________ Date: 23/07/2016

Supervisors:

This thesis is the candidate's original work and has been prepared with our guidance and assistance. It has been submitted with our approval as the official University supervisors.

1. Prof. Henry O. Nyongesa

Department of Computer Science, University of The Western Cape

Signature: .... Date: 24/07/2016

2. Dr. Patrick W. Kanyi

Department of Information Technology, United States International University-Africa

Signature: .... Date: 25/07/2016

ABSTRACT

Disparate enterprises can pool together their core competencies to form a temporary organization in order to exploit a market opportunity. This inter-organizational collaboration of enterprises is commonly referred to as a virtual enterprise (VE). The success of any VE is dependent on the partner members' performance and influence of the partner attributes on its performance. These members and their attributes need to be carefully evaluated. The competitive advantage of any VE is jeopardized by the time it takes to set it up when the information available about the partners is insufficient.

Extensive research on the evaluation and selection of partners has been done, but only a few studies have considered evaluation and selection of partners for VEs in the construction industry. Little research has been done in evaluating the factors that affect the VE performance. This research evaluates and selects partners representing ten construction companies to carry out project tasks for a large building in Nairobi. Each partner has business, technical and management expertise.

Qualitative and quantitative research methods were used in this study. The qualitative method comprised interviews (with the stakeholders). Subsequently, quantitative methods, namely, Fuzzy Analytical Hierarchy Process (FAHP) and Reduced Group Fuzzy Analytical Hierarchy Process (RGFAHP), Multi-Criteria Decision Making (MCDM) algorithms, were applied. A technique called Partners Selection and Performance Evaluation Technique (PaSPET) is proposed. The technique combines fuzzy approximate reasoning with conventional Analytical Hierarchy Process algorithm, designed to deal with imprecise evaluators' judgement.

A Multi-Agent Systems (MAS) approach was chosen to simulate VEs. A MAS is a computerized system composed of multiple interacting intelligent agents within an environment. Prior evidence of MAS to facilitate formation of VEs is lacking. Results, however, show that the chosen techniques are both efficient and effective. In particular, RGFAHP reduces the number of pairwise comparisons required when a large number of attributes are to be compared. Validation of the system, carried out by stakeholder evaluation, show that the approach is approximately 87% accurate in evaluation and selection of partners and partners' performance evaluation.

Keywords: Multi Criteria Decision Making Model (MCDMM), Analytical Hierarchy Process (AHP), Fuzzy AHP (FAHP), Reduced Group FAHP (RGFAHP), Partners Evaluation and Selection Problem (PESP), Multi-Agent Systems (MAS)

DEDICATION

This thesis is dedicated to my spouse, Pauline Nafula and daughter Linda for their unwavering support. They were patient with me throughout the research period. God bless them.

ACKNOWLEDGEMENT

I wish to acknowledge my supervisors, Prof. Henry Nyongesa and Dr. Patrick Kanyi for guiding me through this research. Their valuable contributions made this work to be successful. They dedicated their time to this work. They enabled me get organizations that were used as case studies. They guided my research, reviewed my documentations and made corrections. I acknowledge my colleague Benjamin Otieno who was my research assistant. I also acknowledge Dedan Kimathi University of Technology management for facilitating my supervisors and providing necessary support for this research. Finally I thank my Pastor, Rev. Solomon Mwalili for the spiritual guidance throughout the research period.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

ABM-Agent Based Modelling

AHP-Analytical Hierarchy Process

ANP-Analytical Network Process

BORAQS-Board of Registration of Architects and Quantity Surveyors

BS-Business Strength

CC-Cultural Compatibility

CD-Cost of Development

CI-Consistency Index

CM-Contract Modification

CoR-Consistency Ratio

CR-Collaboration Record

DAI-Distributed Agent Intelligence

DS-Development Speed

EB-Equipment Breakdown

EBK-Engineers Board of Kenya

ELECTRE-Elimination Et Choice Translation Reality

EMCA-Environment Management and Coordination Authority

FAHP-Fuzzy Analytical Hierarchy Process

FIPA-Foundation for Intelligence Physical Agents

FS-Financial Security

IEEE- Institute of Electrical and Electronics Engineers

IQn-Interview Question

IT-Information Technology

JADE-Java Agent Development Environment

KNBS-Kenya National Bureau of Statistics

MA-Management Ability

MAS-Multi Agent System

MCDA: Multi-criteria Decision-Analysis

MCDM: Multi-criteria Decision-Making

MCDMM: Multi-criteria Decision-Making Model

MR-Market Rate

MRQn-Main Research Question

NCA-National Construction Authority

NEMA-National Environment Management Authority

PaSPET: Partner Selection and Performance Evaluation Technique

PC-Price Change

PCM-Pairwise Comparison Matrix

PE-Personnel Experience

PESP-Partner Evaluation and Selection Problem

PR-Personnel Rate

PV-Priority Vector

PW-Priority Weight

RGFAHP-Reduced Group Fuzzy Analytical Hierarchy Process

RI-Random Index

RJ-Repeat/Rework Job

RQ- Required Quality

RQn-Research Question

SAW-Simple Additive Weighting

SL-Site Location

SP-Strategic Position

TC-Transport Cost

TFN-Triangular Fuzzy Number

TOPSIS-Technique for Order Preference by Similarity to Ideal Solution

UML-Unified Modelling Language

VE-Virtual Enterprise

WSA-Weighted Sum Algorithm

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview

Recently, large, medium and small sized enterprises are teaming up to enhance their competitiveness in the market-place and adapt to the rapid changes of technological innovation. Organizations enhance their competitive ability in the market-place by creating effective relationships with others. A Virtual Enterprise (VE) is a temporary organization that pools together different member enterprise core competencies (Crispim & de Sousa, 2009). VEs offer new opportunities (for developing products) to companies operating within an environment with a growing number of participants, such as, contractors, service providers, agencies and others. A typical application area for the VE paradigm is in industrial manufacturing. Nowadays, most manufacturing processes are not carried out on a single line. Companies tend to focus on their core competencies and join efforts with others, in order to fulfill the requirements of new products and associated services demanded by the market. In a VE, every enterprise is just a node that adds some value to the process. Although most classic examples of cooperative networked organizations can be found in some particular business domains such as the automotive industry, this tendency is spreading to many other areas including the food and agribusiness industry (Camarinha-Matos et al., 1997), electronics (Azevedo et al., 1998) and civil engineering (Zarli & Poyet, 1999).

Similar to manufacturing industries, the need to remain competitive in the market also forces service provider companies to seek alliances outside their core competencies when additional skills / resources are needed to fulfill business opportunities. For instance, travel agencies typically offer aggregated or value-added-services composed of components supplied by a number of different organizations. To "book a complete journey plan", services may include several means of traveling, several hotel bookings, car rentals and leisure tour bookings. A networked cooperation must exist among the many different organizations (Afsarmanesh & Camarinha-Matos, 2000) to enable collaboration.

1.2 Classification of Virtual Enterprises

Attempts have been made to classify VEs based on a number of factors on their formation. Camarinha-Matos et al. (1998) classified VEs according to three dimensions: (1) Time, (2) Topology and (3) Structure. The time dimension refers to the duration or lifespan of the organization. VEs are created for both short and long term purposes. The formation of short-term enterprises is designed to take advantage of time-dependent client demands that appear for a short period or a single business cycle. In long-term VEs, the life of the enterprise extends for several business cycles. In this case, the VEs focus on establishing strategic bonds amongst its members. The relationship among member partners may survive, even if the initial customer problem has been solved. They can reassemble their core capabilities to satisfy new customer needs in different projects.

The topology dimension considers the membership of a VE. A VE can be either open or closed. Closed memberships are static since partner companies remain in the VE for several business cycles. Open memberships, on the other hand, are dynamic since there is a constant renewal of the membership. Partner companies join or, and leave the VE based on factors such as the need for the capabilities of a partner, the stage of the business cycle and scale of the project (Tolle, 2004). For example, it is possible to bring into the VE a member for its research and development competencies for a given product. Once the research and development phase is completed, the VE may not require these competencies anymore, but may require the capabilities of another member to manufacture a product on a large scale. In this dynamic process, each member shares both risks and benefits regardless of the stage of the product development process where its core competencies are needed. The structural dimension deals with the different management structures of VE. The three most common forms are star-like, democratic alliances and federations. The distinguishing factor of these structures is the partners' level of independence with respect to the collaboration of the VE members.

The star-like structure is characterized by the dominant role of one of the members. Usually, the dominant member establishes the protocols for information and communication exchange within the VE. Automobile and Agribusiness alliances usually manage their supply chains in this manner (Tolle, 2004; Camarinha-Matos &

Afsarmanesh, 2005). Normally one member owns the project and invites others to participate. The democratic alliances, on the other hand, work in a more collaborative and egalitarian environment where each member keeps its autonomy. The decision making process is based more on consensus than on the relative power of the member enterprises. Members are brought into the alliance because of the mutual complementation of their core capabilities (Tolle, 2004; Camarinha-Matos & Afsarmanesh, 2005). Federated alliances are an extension of collaborative alliances based on the need for a common management of resources and skills. This structure is more likely to be implemented, after member enterprises have been successful in democratic alliance. This kind of alliance is however, seldom seen in industry where alliances are implemented (Tolle, 2004; Camarinha-Matos & Afsarmanesh, 2005).

Combinations of the above three dimensions will result in a viable VE. The most challenging combination is the one characterized by a short duration span, an open membership, and a federated management structure. In this case, the partners are constantly joining and leaving the VE. In addition, all the partners equally influence the management of the organization. This combination is what can be considered a VE in its purest form. It is known, however, that this configuration of VE has a poor success rate. To improve this poor success rate VE may evolve from an open to a closed membership and create what is defined as a " web" of VEs (Tolle, 2004). In the "web", member enterprises register with their core competencies, which are verified using some criteria. A web coordinator (Tolle, 2004), who can be any member partner, is central to the web. The web coordinator brings together all partners' core competencies in the VE.

1.3 Lifecycle of Virtual Enterprises

The lifecycle of a VE is divided into three phases (Guerra, 2006): (1) Formation, (2) Management and (3) Dissolution. The formation phase establishes the goal and the objectives of the VE, according to the product demand. It also identifies the functional requirements that organization needs to fulfill. After the functional requirements are known, the core capabilities needed by VE are determined. Several companies may have these core capabilities, but only few of them are selected as members of the organization. This process is defined as the partner evaluation and selection process. Once the partner evaluation and selection process is finished, the VE enters its management phase. The management phase focuses on how to achieve the goals and objectives of the VE. In the management phase, members collaborate and integrate their core competencies to satisfy the functional requirements, identified in the formation phase. The performance of partners is also evaluated in this phase. Finally, once the product demand is met, the VE dissolves, and its members find other value-adding chains, where their core capabilities can be used. The dissolution phase deals with ending the relationship among partners and eventually the evaluation of the results of the collaborative work.

1.4 Building and Construction Industry in Kenya

Kenya has a well-developed building and construction industry with quality engineering, building and architectural design services. The construction industry is a key sector in Kenya economy and has consistently posted the second highest growth (Kenya Economic Update, 2013). The industry also offers direct employment to a significant proportion of the labour force spread throughout the country. The Kenya construction industry grew by 5.5% in 2013 compared to 4.8% a year earlier (Kenya Economic Survey, 2014). The growth was abated by an increase in the value of building plans approved in the housing sector, which rose by 34.2% to Kenya shillings (KSh) 243.1 billion from KSh 181.1 billion in 2012. This was partly attributed to increased activity in the real estate to cater for rising demand for housing due to rapid population growth in urban areas. This sector has attracted a lot of interests from local and foreign investors as seen from the massive projects that have either been completed, are undergoing implementation or are scheduled to take off (World Bank Report [WBR], 2012; Kenya National Bureau of Statistics [KNBS] Report, 2013).

Table 1.1 below presents a detailed analysis of selected key economic indicators in Building and Construction from 2009 to 2013. Wage employment in the sector grew by 12.2 per cent from 116.1 thousand persons in 2012 to 130.3 thousand persons in 2013 while employment level in the public sector rose by 5.2 per cent from 17.4 thousand persons in 2012 to 18.3 thousand persons in 2013. Similarly, private sector employment increased by 13.5 per cent from 98.7 thousand persons in 2012 to 112 thousand persons in 2013. The index of reported private building works completed in major towns rose to 401.2 in 2013 from 381.2 recorded in 2012. The index of reported public building works completed in main towns increased from 86.9 in 2012 to 103.7 in 2013 as a result of several housing projects completed by National Housing Corporation (NHC) and Housing Finance across the country. Cement consumption increased by 6.9 per cent in 2013 to 4,266.5 thousand tonnes compared to 3.1 per cent increase in 2012. The demand was driven by increased construction projects undertaken during the year under review.

Table 1.1 Selected Key Economic Indicators in Building and Construction, 2009 – 2013 (KNBS, 2014)

Indicator/Year	2009	2010	2011	2012	2013
Index of reported private building work completed in major towns	**134.5**	**202.5**	**313.7**	**381.2**	**401.2**
Index of reported public building work completed in major towns	**22.6**	**31.7**	**48.2**	**86.9**	**103.7**
Index of government expenditure on roads	**312.9**	**265.4**	**397.0**	**447.3**	**385.2**
Index of Employment	**153.2**	**165.7**	**175.7**	**192.2**	**215.7**
Cement consumption ('000 tonnes)	**2671.2**	**3104.8**	**3870.9**	**3991.2**	**4266.5**
Private Employment ('000)	**73.0**	**81.4**	**88.8**	**98.7**	**112.0**
Public Employment ('000)	**19.5**	**18.7**	**17.3**	**17.4**	**18.3**
Loans and Advances from Commercial Banks to the sector (KSh Millions)	**30414.0**	**32637.0**	**50805.0**	**69183.0**	**70770.0**

During the review period, commercial bank loans and advances to the building and construction sector rose by 2.3 per cent in 2013 to KSh 70.8 billion mainly due to increased financing of real estate development.

The construction sector in Kenya is regulated by among other bodies the Engineers Board of Kenya (EBK), a statutory body established under Section 3(1) of the Engineers Act 2011, the Board of Registration of Architects and Quantity Surveyors

(BORAQS), established by Cap 525, the Physical Planners Act of Cap 286, the Public Procurement and Disposal Act 2005, the Public Health Act of Cap 242 and the National Environmental Management Authority (NEMA) established by Environment Management and Coordination Act (EMCA) number 8 of 1999. EBK is mandated with the responsibility of regulating standards in the engineering profession and building capacity for individual engineers and engineering firms. EBK also registers engineers and engineering firms and regulates their conduct for improved performance of the engineering profession. BORAQS registers and regulates architects and quantity surveyors while NEMA was established to deal with all environmental issues and concerns. Each of the Boards or Authorities describes the roles and responsibilities of the respective professionals it governs or regulates. Some of them specify the necessary training and qualification required of the professionals who are registered under the respective Acts. The supervisory and quality control level of the building construction industry involves Engineers, (under EBK), Architects and Quantity Surveyors (under BORAQS), Environmental audit experts (under NEMA) among others. Finally, National Construction Authority (NCA) established by the National Construction Authority Act number 41 of 2011 is mandated to streamline, overhaul and regulate the construction industry in Kenya and establish a code of conduct for contractors. The construction sector has proven to be very important in the Kenya economy and studies that will improve the sector are necessary and timely.

A construction project is implemented by a team of professionals and an alliance of companies. Alliance of companies is formed by consultants who evaluate contractors for specific project tasks. Consultants are hired by the client to manage the project on their behalf. To facilitate hiring of consultants and procuring other services, the Kenyan government has provided standard tender documents through Public Procurement and Oversight Authority (Public Procurement and Oversight Authority [PPOA], 2007).

1.5 The Problem Definition

The trend where enterprises outsource competencies is getting replaced by strategic alliances, where enterprises work together towards a common goal and share responsibilities as well as their profits. This calls for new ways of organizing work and the technological support that allows flexibility. A crucial competitive factor of a VE, is its ability to form an end-user focused team which can be jeopardized if the right team is not formed. The construction sector's potential contribution to growth of the economy can be enhanced given recent increased expenditure on infrastructure development, if the challenges facing the sector are effectively addressed. Delayed completion of projects (Patroba, 2012), frequent collapse of buildings (Charagu, 2013), use of inappropriate specifications and manuals, incompetent design, lack of ethics, poor supervision, use of inappropriate materials, poor coordination and management of contractors (Mambo, 2010), poor construction procedures (Kenya Engineers Report on Projects [KERP], 2006) are among the challenges facing the sector. These can be attributed to poor choice of partners for the tasks due to insufficient information available about partners and lack of facilitation techniques.

This lack of information can be attributed to the sources of information. Project initiators normally use company profiles to evaluate partners (Charagu, 2013). Information from company profiles is often insufficient and decisions made out of insufficient information are subjective. Furthermore, the choices made by project initiators do not take into account that human judgements during partner evaluation and selection are imprecise. This can lead to selection of undeserving partners because partner attributes can change during and / or after the evaluation and selection process, with the possibility of having the qualified partners being unqualified.

Partners' evaluation and selection process reliability can be enhanced if decision making techniques that are able to deal with subjective information (Mikhailov, 2003; Covella & Olsina, 2006) are employed. Analytic Hierarchy Process (Saaty, 1980), Elimination EtChoix Traduisant la REalite´ (Roy, 1991), Technique for Order Preference by Similarity to Ideal Solution (Lai et al., 1994), Data Envelopment Analysis (Cook et al., 2014), Neural Networks, Weighted Linear Models, Linear Programming, Mathematical Programming (Aruldoss et al., 2013) are among multi criteria decision making techniques. However, they cannot be used with subjective information.

Incorporating fuzzy logic (Zadeh, 1963) in decision making techniques can address the partners' evaluation and selection process reliability issue. This study proposes a framework that incorporates fuzzy logic in AHP (a multi criteria decision making technique) to be used by project initiators to effectively evaluate and select right partners for tasks and evaluate / predict the partners' performance, even when information available about the partners is insufficient.

1.6 Research Questions

This research focused on modelling VEs in the construction sector with a focus in Kenya. The broad objective of this study was to propose a framework that would be used by project initiators to effectively evaluate and select the right partners for tasks using subjective information as provided in the partners' company profiles. The framework would encompass partners represented as agents, which once selected, would form a team that would collaborate to complete tasks. In order to achieve the objective, other tasks included determination of the system components of the VE, determination and design of the techniques for evaluation and selection of partners. Another task was the design of MAS environment where partners would interact. Finally, simulation of the framework would be carried out for partners in the construction sector in Kenya. The following is a summary of research questions.

The main research question was:
MRQn: How can VE be modelled in the construction industry?

In answering the above main research question, a set of secondary research questions were defined. These set of research questions were as follows:

RQn1: What are the systemic components for modelling VEs?
RQn2: How is the formation and evaluation VEs achieved?
RQn3: How can multi agent systems support the modelling of VEs?
RQn4: How can a VE model be implemented for the construction industry?

The following section explains these research questions.

RQn1: The systemic components would be identified by evaluators and corroborated with literature review. These would be used as the evaluation and selection criteria and sub-criteria for partners. They would also include the VE phases.

RQn2: Various multi-criteria decision making models (MCDMMs) would be reviewed to identify the ones where the evaluators' uncertainty judgements could be taken care of while selecting partners and evaluating their performance.

RQn3: Multi-agent systems (MAS) techniques would be reviewed. Partners would be represented as agents and evaluated using company profiles. Virtual Enterprises (VEs) as MAS would be discussed. A MAS tool would be used to develop a prototype as a proof of concept.

RQn4: Data would be collected from Kenyan contractors and professionals from the construction sector. The problem would be structured in the construction sector context. MCDM algorithms would be used to select and evaluate partners. A framework would be proposed as a solution to modelling VEs in the construction sector.

1.7 Chapter Summary

This chapter has presented the VE definition, types and lifecycle. A Virtual Enterprise (VE) is a temporary organization that pools together different member enterprise core competencies. VEs are classified according to three dimensions: (1) Time, (2) Topology, and (3) Structure. The lifecycle of a VE is divided into three phases: (1) Formation, (2) Management, and (3) Dissolution.

Kenya has a well-developed building and construction industry with quality engineering, building and architectural design services. The construction industry is a key sector in Kenya economy and has consistently posted the second highest growth. The industry also offers direct employment to a significant proportion of the labour force spread throughout the country. The construction sector's potential contribution to growth of the economy can be enhanced given recent increased expenditure on infrastructure development, if the challenges facing the sector are effectively addressed. Research questions were also presented.

A summary of the next chapters is as follows: In chapter two, a review of previous works is presented. A VE conceptual model and partner evaluation and selection problem is analyzed and a solution for the problem is proposed. In chapter three, research methodology is presented. Research design is also outlined. Chapter four discusses MAS for modelling VEs. Chapter five presents partner evaluation and selection as a multi-criteria decision making problem. Experimentation and simulation of VEs is done in chapter six while chapter seven presents interpretation of results and research conclusion.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Due to frequently changing demands from customers, global competition and technological advances, it has been stated that the next generation of advanced production technologies will rely on cooperation and collaboration of enterprise (business) partners to share expertise, costs and risks (Hsieh & Lin, 2014). The changing customer demands require that enterprises mobilize their resources to quickly develop a product to meet these demands. This can be achieved if enterprises in competition work together to deliver the product instead of each trying to deliver it. Each of them brings their expertise into the collaboration. This collaboration where each enterprise brings in its core competency is referred to as a virtual enterprise (VE).

The formation phase of a VE can be divided into four steps (Tolle, 2004; Afsarmanesh & Camarinha-Matos, 2005; Guerra, 2006). These steps are: (1) Identification of the problem, (2) Identification of the core competencies required to develop a solution to the problem, (3) The evaluation and selection of the partner companies capable of delivering the required core capabilities and (4) Integrating the core capabilities of the partners. Among these steps, the partner evaluation and selection step is the most crucial one and is the main focus of this study. The first two steps are problem specific. The integration phase identifies the functional requirements for VE after identifying the required partners' core competencies.

2.2 Evaluation and Selection of Partners

The evaluation and selection of partners for any type of collaborative relationship has been usually based on factors such as location and cost associated with the services, or habits (Guerra, 2006). This is changing because enterprises can seek for partners who are not closely located as long as they have the competencies required for a given task in a project. The distance between the partners can be brokered by use of information and communication technologies. Due to the dynamic nature of VEs, the evaluation and selection process becomes critical for their success. Despite being critical to the success of the VE, the partner evaluation and selection problem has not received much attention in the construction industry. Most authors acknowledge the importance of the partner selection, but quietly avoid dealing with the problem. They concentrate on the evaluation of the collaboration (Wildeman, 1998) instead of how to make it work. Making the collaboration work means focusing on the evaluation and selection of the best partners for the enterprise (Camarinha-Matos & Cardoso, 1999). There exist only a few research works dealing with this subject.

Wildeman (1998) divides the selection process into the partner and the collaboration phases. Each phase focuses on different aspect of the prospective partners. The partner phase concentrates on the analysis of the partner as an individual and autonomous unit. The collaboration phase, on the other hand, centers on the analysis of the relationship between partners. Each phase uses a different set of selection criteria. In a VE initiation stage, the partner's credentials consideration receives 70% of the attention, leaving the rest to the analysis of the collaboration. Once the preliminary assessment of the partner has been performed, the focus is shifted to the evaluation of the collaboration. At this point analysis of the collaboration gets 70% of the attention.

Using Plug and Play (PnP) principles, Gosain (1998) proposed a partners' integration scheme that can be used to deal with variable membership. Plug and Play defines three major protocols: cool, warm and hot (Fisher, 1995). The cool protocol means that the computer needs to be turned off before inserting the hardware. In VEs, a cool protocol is similar to an initial stage or start-up phase where the members are starting to integrate. The warm protocol deals with situations, in which the computer is on, but most of the software are closed. In VEs, the warm protocol occurs when the partners have been working together and the VE is in the phase of improving the performance and reducing cost (Wildeman, 1998). The hot protocol allows for the computer to remain on and majority of the software are not closed. This resembles deployment of VEs where the members have been working together and have a close understanding of each other and VE tries to reduce cost through a better economy of scale (Wildeman, 1998).

In the PRODNET project, Camarinha-Matos and Cardoso (1999) present a framework for partner selection and describe the functionalities, but do not discuss techniques to deal with the changing partner requirements and partner uncertainty during evaluation. This can be addressed by introducing fuzzy logic (Zadeh, 1963) in selection techniques. Gunasekaran (1998) studied the partner selection problem for VE in supply chain management and pointed out that, mathematical models and optimization methods are still a challenge which affects the choice of their application. The partner selection problem is also studied under project management in the cooperation relationship of sub-projects contracted by partners (Wang et al., 2001). In Brucker (1999), the partner selection is embedded in the project scheduling problem. However, these studies do not consider that VEs as market driven organizations, may require members with varying attributes and that evaluators' judgements may be subjective. Therefore, the evaluation and selection process has to be performed considering evaluators' subjective opinions occasioned by impreciseness of evaluation parameters. A more realistic approach is to assign weights to partners that are not exact but that are fuzzy.

A number of researchers have studied selection criteria specific to VE. There is little evidence of research that has tried to identify evaluation and selection criteria specific to VEs in the construction industry. This section reviews partner evaluation and selection criteria from other domains that can be considered helpful to the construction sector. The formation of a VE takes advantage of the core competencies of each member of the organization (Goldman et al., 1995; Sieber, 1998; Tolle, 2004). These core competencies are dependent on the project tasks. The selection criteria consider these core competencies. If partners' core competencies match the core competencies defined for the selection problem, ranking is done to determine the best partner for each task. Core competencies are the requirements that must be fulfilled by potential partners to qualify for consideration. Zhang et al. (1997), Chen et al. (1998) and Camarinha-Matos and Cardoso (1999) used cost, quality, capacity, and delivery time as selection criteria for partner companies. XueNing et al. (2000) added customer services and financial stability to the list.

The selection of partners in collaborative relationships has been addressed in (Bronder & Pritzl, 1992; Bailey et al., 1998; Huang & Mak, 2000). Bronder and Pritzl (1992) propose to select partners in collaboration alliances according to complementarity, strategic and cultural compatibility. The complementarity criteria evaluate, among other factors, the complementation in core capabilities, the potential for increasing shareholders value, risks, and mutual gains. The strategic compatibility takes into account the strategic goals and the lifespan of the alliance. A cultural profile of the partners can be used to evaluate their cultural compatibility. The profile considers the attitude of the partners towards the workforce and issues such as quality, cost, innovation, technology and customer orientation. Technical capabilities and collaboration history is not explicit. Bailey et al. (1998) conducted a survey to identify the parameters used by companies in different industrial fields in order to select partners. They identify as the most important criteria: technical capabilities, matching aims, cultural compatibility, development speed, strategic position, management ability, security, collaborative record, business strength and cost of the development. These criteria were also ranked according to how managers consider them during the selection process. In this case, it seems that the size of the partner company was not considered important.

Huang and Mak (2000) propose a set of selection criteria to be used during the early involvement of suppliers in the development process of new products. The selection criteria consider financial, business and technical factors. Financial factors evaluate the financial position of the partners. The technical factors take into account quality, price, reliability, as well as process and design capabilities. The business factors deal with the flexibility of the partner, its reputation, communication mechanism, and the closeness of relationship between partners. Wildeman (1998) identified a more comprehensive set of selection criteria used in the partner selection and collaboration phases. The partner selection phase considers the following criteria: complementary skills, market position, financial position, management philosophy and size. The collaboration phase evaluates the “chemistry” between managers, complementarity, culture, trust, commitment, financial position and openness. This study also provides the relative importance of each criterion. The study, however, fails to discuss ranking of these selection criteria. Each of these criteria, have relative importance during the evaluation and selection process. The American Society of Mechanical Engineers (ASME) conducted surveys to identify the selection criteria used in collaboration and found commitment to quality and reputation as the two most important criteria used in the partner selection process (ASME, 1997). The factor considered least important was the matching of corporate cultures. Other factors in between these two extremes are the previous collaborative record, the resources of the partners, price, confidentiality, as well as general and value-adding capabilities.

Sari et al. (2008) proposes the following partner selection criteria; the task price, caution price (in terms of risk or commitment), task completion probability (representing delivery time) and the partners' performance. Cost is a major factor which influences the partner selection. A partner's bid involving higher cost is liable to be rejected on economic ground. The total task quantity also influences the overall price. Level of commitment is measured in terms of a caution cost which is the cost that the partner must pay to the VE if the partner decides to give up before the assigned task is finished and is secured in the form of letter of credit. Thus, the higher this value is, the more preferable for the VE. Another key construct in the selection of partners is the risk issue related to cooperating with new and unknown or less familiar partners. Inclusion of new partners possessing the competencies required in a specific situation is seen by many as one of the major challenges related to VEs (Wu et al., 1999).

Risk/uncertainty related to co-operating with new partners in a global environment should also be considered in partner selection process. For example, Petroni and Braglia (2000) concluded that the relative importance assigned to a partner attribute was primarily based on the type of risk involved in a specific project. One of the key issues in forming and succeeding of the VE is the matter of trust. Trust is also a key requirement in order to make information and knowledge-sharing within these types of collaborative work. Partner performance is a trust building element. Purdy and Safayeni (2000) suggested that management would generally be willing to pay 4% to 6% higher than the lowest acceptable bid if product performance is superior.

Bailey et al. (1998) studied the selection criteria in collaborative relationships. Wildeman (1998), on the other hand, identified the selection criteria used in instances of VEs. However, Sari et al. (2008) considered variability of selection criterion and performance while evaluating partners. Bailey et al. (1998) conducted a survey to identify the criteria used to select partners in industrial fields such as electronics, aerospace, biotechnology, as well as design and manufacturing. They identify as the most important criteria: (1) Technical capabilities, (2) Cultural compatibility, (3) Development speed, (4) Strategic position, (5) Management ability, (6) Security, (7) Collaborative record, (8) Business strength and (9) Cost of the development. These criteria were ranked according to how managers consider them during the selection process.

Wildeman (1998) also carried out a survey to identify selection criteria. The work proposed to divide the partner selection process into two phases: (1) Evaluation of the partners and (2) Evaluation of the collaboration. This approach is based on the understanding that a successful collaborative project starts with the right partners. In summary, the approach starts by considering the components of the system before analyzing how the components will fit and work together. The partner phase focuses on the analysis of partners as individual and autonomous units. Thus, if partners are not in a sound situation on their own, it is almost impossible to succeed within the collaboration. The collaboration phase analyzes the relationship among partners. It takes into account 'soft' or management related issues that are not the core competencies of the partners. Factors such as management style, and corporate culture should be considered during the evaluation of the collaboration. The criteria identified for the evaluation of partners are: (1) Complementary core capabilities (skills), (2) Market position, (3) Partner's financial position, (4) Management philosophy, and (5) Size of the partner's organization. The market position evaluates the possibility of gaining access to new markets through partners. The management philosophy is used to evaluate a potential fit among the partners. It takes into account issues such as management style, openness to cooperation and consistency in decision-making. The criteria utilized for the evaluation of the collaboration are: (1) Chemistry, (2) Complementarity, (3) Culture, (4) Trust, (5) Commitment, (6) Financial position of the collaboration, and (7) Openness.

In contrast to the selection criteria for the partner phase, the criteria used in the collaboration phase are qualitative and subjective. It can be seen that these criteria deal with 'soft' issues that are both difficult to evaluate and subjective. Chemistry takes into account the relationship between managers. The complementarity of core capabilities evaluated in the partner phase, can now be extended to consider management and ‘soft’ issues between the partners. Culture considers the corporate backgrounds of the partners. Openness takes into consideration the management attitude towards change and new ideas as well as towards collaboration. It should be noted that the relative importance of both phases varies. During the preliminary evaluation of the partners, the focus is on the partners. Wildeman (1998) proposed to assign 70% of the importance to the criteria for evaluating partners while 30% importance is assigned to "soft" issues in the collaboration phase.

A critical analysis of Bailey et al. (1998) and Wildeman (1998) work reveal that collaborative record (Bailey et al., 1998) and trust (Wildeman, 1998) are considered equivalent criteria. These two criteria are not equal; however, they are strongly related, since trust is achieved by establishing collaborative relationships. Furthermore, business strength (Bailey et al., 1998) has no equivalent in the Wildeman (1998)'s set. Chemistry, complementarity, commitment and openness can be evaluated by combining several criteria.

To gain a more comprehensive understanding of the criteria used for partner selection, the scope of some of the selection criteria originally proposed by Bailey et al. (1998) is expanded to include the findings of Wildeman (1998) and Sari et al. (2008). To that extent, the financial security criterion is now considered in evaluating both the partners and the collaboration in a VE. The collaborative record also takes into account trust, performance and reliability among partners. In addition, business strength takes into account the chemistry between interacting managers, how the partners complement each other's goals and objectives (complementarity) and their commitment to the VE. The business strength criterion is also used to evaluate the openness of partners. Partners' commitment to the VE takes into account risks and / or uncertainty of having partners in the collaboration.

It should be noted that the size of the company and its location are not considered as selection criteria. Location is made irrelevant partly by the use of information and communication technologies. The size of the company is not included because of three important reasons. First, Goldman et al. (1995) considers the size of the partner to be irrelevant to formation of VE. Second, it has been found that in rapidly changing market sectors such as biotechnology and computer industry, the small companies are the leading companies in forming VEs (Campbell, 1998). Third, VEs are used by smaller companies as a means to increase their apparent size since they can present themselves to customers as larger organizations. It can be stated that partner enterprises in a VE require three domains namely business, technical and management (Bailey et al., 1998; Wildeman, 1998). Business domain deals with all financial and market related issues to grow the enterprise. Technical domain involves technological requirements for the smooth running of the business. Management domain considers all human resource related issues in the organizations.

2.2.1 The Partners' Evaluation and Selection Problem

The partners' evaluation and selection problem can be formulated using 'the switching principle' (Mowshowitz, 1999), which separates the abstract requirements of the tasks from their satisfiers. Switching is the dynamic assignment of satisfiers to the abstract requirements in such a way that the strategic goals of the VE are met. The abstract requirements are the needs of the tasks and the satisfiers are the resources required to meet those needs. In this problem, the tasks identified during problem analysis are the abstract requirements, and the partners are the satisfiers of those tasks. In principle, the problem can be interpreted as an assignment problem and represented using a bipartite graph, as shown in Figure 2.1.

A bipartite graph is a graph whose vertices can be divided into two independent sets, for example, U for Partners and V for tasks, such that every edge (u, v) connects a vertex from U to V and (v, u) from V to U. There is no edge that connects vertices of same set. In Figure 2.1, the tasks are represented on the right and the partner companies on the left. It represents a pool of potential partners and the project tasks. That is, many partners can have the competencies needed for several tasks and one task can be implemented by more than one partner (one-to-many type of relationships). This evaluation and selection problem can be simplified by considering each task independently, as shown in Figure 2.2 where one task can be implemented by more than one partner and the best partner company has to be selected.

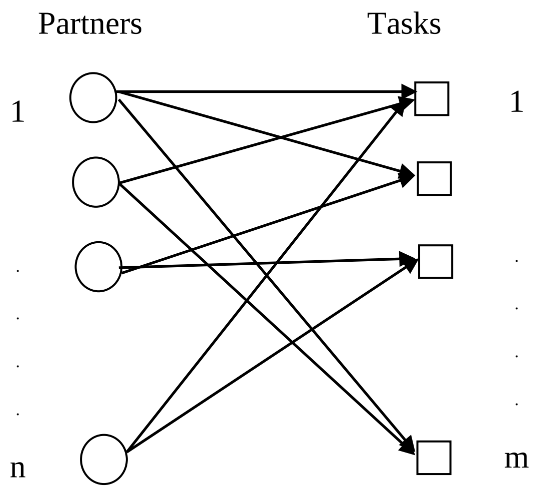


Figure 2.1 Task Assignment

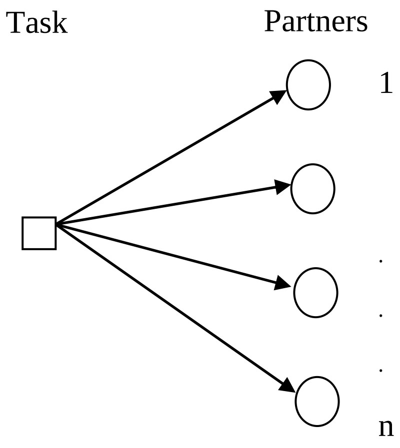


Figure 2.2 Partners' Selection

Partner evaluation and selection problem (PESP) can be represented mathematically as:

$$\gamma\ (t) = f\ (Z(h), S(p), P(m), T) \qquad (2.1)$$

where:

$\gamma(t)$: partner evaluation and selection problem.

$Z(h)$: a set of tasks of the project,

$Z(h) = \{z_1, z_2, \ldots z_m\},\ _{m \geq 1}.$

$S(p)$: a set of selection criteria for assigning tasks to partner companies,

$S(p) = \{s_1, s_2, \ldots s_n\},\ _{n \geq 1}.$

$P(m)$: a set of prospective partner companies that satisfies the selection criteria, s_p and project tasks, z_h.

$P(m) = \{p_1, p_2, \ldots p_m\},\ _{m \geq 1}.$

T= expected completion time.

The PESP for the project is formulated as follows:

"Which partner companies p_m (m>1) are capable of performing the task z_h(h>1) according to the selection criteria s_p(p>1) for expected completion time T?" This

requires the determination of the number of companies that are qualified to carry out tasks.

The same problem for a single task is formulated as follows:

"Which partner company p_m is capable of performing the task z_h according to the selection criteria s_p for expected completion time T?" This requires the determination of a company that is qualified to carry out a task.

The term P(m) in Equation 2.1 refers to a pool of partner companies that, at least, have the core capabilities needed by the VE to complete the project task. They can satisfy one or more tasks. The tasks Z(h) refer to the different technologies or domains in which the partner companies have expertise. For a building construction project, the tasks include, among others, electrical, mechanical plumbing, structural, interior design and land-scaping. Each of these tasks requires different technologies and / or specializations and requires different resources. A different set of selection criteria S(p), may be specified for each task or domain. For example, a structural engineering task may require a partner with technical, management and business skills. Business skills may include financial security, business strength among others. The selection criteria S(p), are the parameters used to evaluate how partner companies meet the specifications of the tasks. The specifications may include the design, construction or management specifications needed to perform the task. In addition to the technical specifications, other specifications such as cost and quality can be added. In general, the partners' evaluation and selection problem is a multi-criteria and multi-objective decision making problem.

2.3 Construction Project as a Virtual Enterprise

Projects in the construction sector are implemented by multiple partners. A client hires an architect / consultant who makes designs for the project and engages other consultants to carry the various tasks. For example, in a building construction project, the main consultant who is normally the architect, contracts civil/structural, electrical, mechanical, plumbing, interior design and land-scaping engineers. They work as a team to accomplish the tasks. The main consultant selects the best engineer / engineering firm among many who have similar qualifications. These companies coordinate among each other.

Civil engineering firm implements the structural works which include among others, earth works, form work, reinforcement, concreting, masonry, roofing and plastering. Electrical engineering firm carries out connections to power supply, wiring, fittings and conduits. Mechanical engineering firm carries out fixing sleeves, fittings among others. Plumbing firm does pipe works, connections to external works among others. Land-scaping firm carries out earth works, planting, constructing fountain among others. Interior design firm does partitioning, paint works, furnishing and decorations.

2.3.1 Virtual Enterprise Performance Evaluation

In the construction industry, time overruns and cost overruns are major performance issues (Kaming et al., 1997; Choudhury & Phatak, 2004; Olawale & Sun, 2010). For a successful construction project, time and cost efficiency is important. If partners accomplish their tasks in good time and at reasonable costs, then the overall project will be considered efficacious. This section reviews the causes of time and cost overruns of construction projects. Available literature on this subject, examines the time and cost overruns of projects, without indicating how partner activities influence these time and cost overruns.

2.3.1.1 Time overruns and causes

Time overruns is defined as the extension of time beyond planned completion dates traceable to the contractors (Kaming et al., 1997). Chan (2001) and Choudhury and Phatak (2004) defined time overruns as the difference between the actual completion time and the estimated completion time. Delays in projects are those that cause the project completion date to be delayed (Al-Gahtani & Mohan, 2007). Factors related to time overruns vary with types of project, location, size and scope of project. Kaming et al. (1997) identified 5 causes of time overruns through a questionnaire survey in Indonesian high rise construction projects. These were: design changes, poor labour productivity, lack of adequate planning, shortage of materials and inaccuracy of material estimates. Kaming et al. (1997) do not explicitly state, if contract modification, lack of personnel experience and sometimes quality requirements, lead to more time spent in executing the project. Chan and Kumaraswamy (1997) reported five principle causes of time overruns, perceived among contractors, clients and consultants in Hong Kong construction projects. They included: poor site management and supervision, unforeseen ground conditions, delay in decision making, client initiated variations and design changes.

Frimpong et al. (2003) carried out a questionnaire survey in Ghana groundwater construction projects and ranked 26 factors responsible for project delays and cost overruns. The factors included, among others, planning and scheduling deficiencies, delays in work approval, inspection and testing of work, frequent breakdowns of construction plant and equipment, escalation of material prices, slow decision-making and difficulties in obtaining construction materials at official current prices. Kendall's coefficient of concordance (Cheng et al., 2010) was used to test the degree of agreement between owners, contractors and consultants and concluded that there was insignificant degree of disagreement. The five most important factors as agreed by owners, contractors and consultants as main causes of time and cost overruns were: monthly payment difficulties from agencies, poor contractor management, material procurement, poor technical performances and escalation of material prices.

Aibinu and Jagboro (2002) examined the effects of delay on the delivery of construction projects in Nigeria. Acceleration of site activities coupled with improved owner's project management procedures and inclusion of an appropriate contingency allowance in the pre-contract estimates were recommended as a means of minimizing the adverse effects of construction delays. These recommendations do not envisage scenarios where contractors, owners or consultants would require modifying the project requirements due to new development or unforeseen requirements, which may not have been factored in pre-contract estimates.

In addition, personnel experience which is critical in any construction project is not factored. Odeh and Battaineh (2002) studied the causes of construction delay at traditional contracts in Jordan. The study illustrated that labour productivity was the most important delay factor according to contractors. Inadequate contractor's experience, however, was the most important delay factor to consultants. Koushki et al. (2005) also identified estimates of time overruns and their causes. The three main causes of time overruns are changing orders, owner's financial constraints and owner's ignorance in construction issues. Both studies exclude the quality requirement of the project as a factor which may delay the project completion time.

Doloi et al. (2012) identified the key factors impacting delay in the Indian construction industry. They established the critical attributes for developing prediction models for the impact of these factors on delay. Regression modelling and factor analysis were used to examine the significance of the delay factors. The most critical factors of construction delay were identified as lack of commitment, inefficient site management, poor coordination in site, improper planning, lack of clarity in scope of project, lack of communication from factor analysis. The regression model indicated slow decision making from owners, poor labour productivity and architects' reluctance to change and / or rework mistakes in construction were the reasons that affected the overall delay of the project. These factors were also evidenced by Mambo (2010) in addition to accessibility to the project's site especially when the site is located in towns.

Shanmugapriya and Subramanian (2013) investigated the significant factors influencing time overruns in Indian construction projects. They observed 76 factors of time overruns and grouped them in to 12 major groups. Hierarchical assessment of factors was carried out to determine ranking of the factors based on the significance. This was based on Relative Importance Index (RII), calculated for each group of respondents i.e. contractors, consultants and owners and overall respondents. Their survey showed that top the 5 most significant factors of time overruns ranked by overall respondents were, change in material market rate (attributable to various reasons such as change in materials price in the market or unavailability of materials in the market), contract modification (the modification of the contract would lead to the project delay due to the addition of new work and replacement to the project requirements), higher level of quality requirement (to produce a higher quality product, requires more than the estimated time), project location (difficult to transport materials and equipment to a site) and placing overall responsibility on inexperienced personnel (takes more time on a project compared to the experienced ones).

Considering time overruns, this study observes that that most important factors applicable in Kenya are contract modification, required quality, personnel experience and site location. Contract modification entails everything to do with changes occasioned by either, project owners, contractors or consultants. Required quality is about the decisions by project owners demanding that project is executed with highest standards possible, which requires that more time is used to achieve the same. For personnel, the more experienced the contractors, consultants and other officers, the less time it takes to complete a project and vice versa. Finally, the location of the project determines the accessibility of personnel and materials to the site, affecting the project completion time. Among these factors, the ones that affect partners' performance are contract modification, required quality of the product and personnel experience. Site location is often beyond partners' control.

2.3.1.2 Cost overruns and causes

Cost overrun is defined as excess of actual cost over budget. Cost overrun is also called cost escalation, cost increase, or budget overrun. Choudhury and Phatak (2004) defined the cost overrun as the difference between the original cost estimate and actual construction cost on completion of a construction project. In a study of infrastructure projects in Nigeria (Omoregie & Radford, 2006), it was found that the major factors of cost overruns were fluctuations in prices, financing and payments made for completed works, inefficient contract management, delays in schedule, changes in site condition, inaccurate estimates, shortages of materials, delay in imported materials, additional works, changes in design, subcontractors and nominated suppliers, adverse weather conditions, non-adherence to contract conditions, mistakes and disagreements in contract condition and fraudulent practices. Similarly, in Vietnam, Le-Hoai et al. (2008) found that the top 5 significant factors causing cost overruns in large construction projects are inadequate site management and supervision, lack of project management support, owner's financial difficulties, contractors' financial difficulties and changes in design.

A study on UK's construction industry, Olawale and Sun (2010) identified 21 major factors causing cost overruns as changes in design, risk and uncertainty associated with projects, inaccurate evaluation of projects time and cost, non-performance of subcontractors, complexity of works, conflict between project parties, disagreements in contract documentation, contract and specification interpretation disagreement, inflation of prices, financing and payment, lack of proper training and experience of project manager, low skilled manpower, unpredictable weather condition, dependency on imported materials, lack of appropriate software, unstable interest rate, fluctuation of currency/exchange rate, weak regulation and control, projects fraud and corruption and unstable government policies.

Shanmugapriya and Subramanian (2013) investigated the significant factors influencing cost overruns in Indian construction projects. They observed 54 factors of cost overruns and grouped them in to 8 major groups. Hierarchical assessment of factors was carried out to determine ranking of the factors based on level of significance. It was assessed based on Relative Importance Index (RII) value, calculated for each group of respondents i.e. contractors, consultants and owners and also the overall respondents. The survey showed that the top 5 most significant factors of cost overruns ranked by overall respondents are high transportation cost (attributed to the long distance of the site from the market and high rent of the vehicles), change in material specification (change in the contract causes change in material specification which affects material costs) and escalation of material price, frequent breakdown of construction plants and equipment, rework (rework of sections of the project increases the cost).

The following factors can be enumerated as the main ones causing cost overruns: repeat job, personnel charges rate change, market rate change, material price change, equipment breakdown and change in transport cost. Among these factors, repeat job and change in charge rate are within partners' control while the rest are beyond partners' control but affects the overall project performance. Factors within partners' control should be managed well to attain cost effectiveness.

2.4 Multi Criteria Decision Making Models

The partner selection process can be considered as a Multi-Criteria Decision-Making Modelling (MCDMM) process, characterized by a substantial degree of uncertainty and subjectivity due to limited information about potential partners. Several multi-criteria decision making models have been proposed, including Analytic Hierarchy Process (AHP) (Saaty, 1980), Elimination EtChoix Traduisant la REalite´ (ELECTRE) (Roy, 1991), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Lai et al., 1994), Neural Networks (NN), Weighted Linear Models (WLM), Linear Programming (LP), Mathematical Programming (MP) (Aruldoss et al., 2013), Data Envelopment Analysis (DEA) (Cook et al., 2014).

Although several effective techniques and models have been utilized for evaluating partners, there is little work incorporating variability measures into the evaluation process (Chou et al., 2008; Chatterjee & Mukherjee, 2010). The integration of evaluation and selection criteria attributes variability into the decision making process, and the identification of effective alternative choices provides the VE initiator with flexibility in the final evaluation and selection process (Sari et al., 2008).

Zhang et al. (1997) considered a weighted sum algorithm (WSA) for the selection of partners. In decision theory, the WSA is the simplest Multi Criteria Decision Analysis (MCDA) method for evaluating a number of alternatives in terms of a number of decision criteria. In general, suppose that a given MCDA problem is defined on *m* alternatives and *n* decision criteria. Furthermore, assuming that all the criteria are benefit criteria, that is, the higher the values are, the better it is. Suppose that W_j denotes the relative weight of criterion C_j and a_{ij} is the performance value of alternative A_i when it is evaluated in terms of criterion C_j. Then, the total (i.e. when all the criteria are considered simultaneously) importance of alternative A_i, denoted as $A_i^{WSA\text{-}score}$, is defined as follows:

$$A_i^{WSA\text{-}score} = \sum_{j=1}^{n} W_j a_{ij} \text{ for } i=1, 2, 3,.., m \qquad (1.1)$$

The problem with this method is that, it is applicable only when all the data are expressed in the same unit. Another problem here is in attaching weighting coefficients to each of the objectives. The weighting coefficients do not necessarily correspond directly to the relative importance of the objectives or allow tradeoffs between the objectives to be expressed.

Data Envelopment Analysis (DEA) **(**Sherman & Zhu, 2013; Cook et al., 2014**)** is a Linear Programming based technique for the analysis of efficiency of organizations with multiple inputs and outputs. Its merits are: (1) Multiple inputs and outputs can be handled and (2) Comparisons are directly against peers. The demerits are: (1) Measurement error can cause significant problems, (2) Absolute efficiency cannot be measured, (3) Statistical tests are not applicable and (4) Large problems can be demanding.

Elimination EtChoix Traduisant la REalite´ (ELECTRE) (Roy, 1991) is a MCDM method which allows decision makers to select the best choice with most advantage and least conflict in the function of various criteria. The ELECTRE method is used for choosing the best action from a given set of actions. Different versions of ELECTRE have been developed including ELECTRE I, II, III, IV and TRI. All methods are based on the same fundamental concepts but differ both operationally and according to the type of the decision problem. Specifically, ELECTRE I, is intended for selection problems, ELECTRE TRI for assignment problems and ELECTRE II, III and IV for ranking problems. The main idea is the proper utilization of "outranking relations". ELECTRE creates the possibility to model a decision process by using coordination indices. These indices are concordance and discordance matrices. The decision maker uses concordance and discordance indices to analyze outranking relations among different alternatives and to choose the best alternative using the crisp data. This method is time consuming.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method (Lai et al., 1994) assumes that each criterion has a tendency of monotonically increasing or decreasing utility which leads to easily defining the positive and the negative ideal solutions. To evaluate the relative closeness of the alternatives to the ideal solution, a Euclidean distance approach is proposed. A series of comparisons of these relative distances will provide the preference order of the alternatives. The TOPSIS method first converts the various criteria dimensions into non-dimensional criteria similar to ELECTRE method (Nikoomaram et al., 2009). The concept of TOPSIS is that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). This method is used for ranking purposes and to get the best performance in multi criteria decision making. The method, however, is time consuming and does not consider variability in attributes.

Sha and Che (2005) and Ip et al. (2004) used more elaborate approaches for the evaluation and selection of partners. The former utilized a 0-1 integer programming with a non-analytical function and a branch and bound algorithm. The latter implemented Genetic Algorithms. These decision making models use optimization rules for performing partner evaluation and selection. Optimization rules involve finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones. Optimization is limited by the lack of full information, and the lack of time to evaluate what information is available (Ling et al., 2010). Unconstrained optimization involves finding the optimum to some decision problem in which there are no constraints while constrained optimization involves finding the optimum to some decision problem in which the decision-maker faces constraints (e.g. constraints of money, time, capacity or energy).

Although these algorithms do rank all the available alternatives, they are unable to take into account the requirements of the VE as a whole that may require that alternative attributes are varied to take into account partner or project changes. Given a pool of partner companies, these methods rank the partners according to their satisfaction of the evaluation and selection criteria without considering the tendencies of the decision makers to be imprecise when making judgements about partner abilities to perform a task. To account for this impreciseness, there is need for incorporating techniques that can address the imprecise judgements from evaluators. Covella and Olsina (2006) suggested the use of fuzzy logic to deal with impreciseness (subjectivity) of the evaluators.

Many research studies have analyzed and solved multi-criteria decision making problems using multi-level analysis of alternatives. Analytical Hierarchy Process (AHP) (Saaty, 1980) is a MCDM algorithm that uses pairwise comparisons of alternatives to derive weights of importance from a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives depending on the problem. In cases where the comparisons are not perfectly consistent, AHP provides an uncomplicated method for improving the consistency of the comparisons, by using the Eigenvalue method and consistency checking method (Saaty, 1980). The hierarchical structure fits well with the structure of partner evaluation and selection problem. Cheng et al. (1999) identified the shortcomings of AHP as follows: (i) It is used in nearly crisp (exact) decision applications, (ii) Does not take into account any uncertainty associated when mapping human judgement to a number scale, (iii) The subjective assessment of decision makers, and change of scale have great influence on the AHP outcome. Furthermore, Wang et al. (2008) found out that the increase in the number of characteristics geometrically increases the number of pairwise comparisons by $O(n^{2}/_{2})$ which can lead to inconsistency or failure of the algorithm. Furthermore, AHP cannot solve non-linear models (Cheng et al., 1999).

Another weakness of AHP identified by Mikhailov (2003) is that it cannot be used when judgements are considered to be uncertain. In practice, human evaluation can sometimes be vague. The factors that contribute to ambiguity/fuzzy/uncertainty of judgements are: (i) lack of sufficient information about the problem domain, (ii) incomplete information, (iii) lack of methods for data validation, (iv) changing nature of the problem, (v) lack of appropriate scale. Mikhailov (2003) argues that the best way to solve uncertain judgement is to express it in terms of fuzzy sets or fuzzy numbers (Mikhailov, 2003). In an attempt to address the shortcomings of AHP, Mikhailov (2003) introduced fuzzy logic in AHP. Fuzzy logic (Zadeh, 1963) deals with a continuum of variables and best addresses uncertainty and vagueness in input variables, in order to make rational decisions under such conditions. Fuzzy logic is derived from fuzzy set theory that has proven advantages within fuzzy, imprecise and uncertain decision situations and is an abstraction of human reasoning in its use of approximate information and uncertainty to generate decisions (Zadeh, 1965). It implements grouping of data with boundaries that are not sharply defined. Fuzzy logic is considered the best method compared to deterministic approaches, algorithmic approaches, probabilistic approaches and machine learning (Ahmad et al., 2004) for problems that users are not certain of the value of parameters to use.

Fuzzy AHP (Mikhailov, 2003) being an extension of conventional AHP, comprises the steps of conventional AHP, with fuzzy logic, namely: (i) structuring the problem into hierarchy; (ii) computing the pairwise comparison matrix to obtain the weight or priority vector and (iii) computing the global prioritization weight. Structuring of the problem into hierarchy involves decomposing the problem into objectives, sub-objectives and alternative solutions. AHP analyses how the alternative solutions satisfy the sub-objectives and how sub-objectives influence objectives of the problem. This is done by computing priority weights for alternatives in all levels of the hierarchy.

Different approaches have been proposed by researchers to compute the prioritization of weights. The approaches differ according to whether they are applied to crisp preference values or fuzzy preference values. Examples of the approaches for computing crisp preference values are: (i) the Eigenvalue method (Saaty, 1980) (ii) distance functions (Golany & Kress, 1993) (iii) least squares (Golany & Kress, 1993) (iv) weighted least squares (Golany & Kress, 1993), (v) logarithmic least squares (Wang et al., 2008), (vi) logarithmic least squares with absolute values (Wang et al., 2008), and (vii) the goal programming method (Wang et al., 2008). Examples of the approaches used for computing fuzzy preference values (Wang & Fu, 1997) are: (i) extent analysis (ii) fuzzy preference programming (iii) fuzzy goal programming.

The following is a brief description of each of the weight prioritization methods. For crisp preference values, the Eigenvalue method computes the average of the normalized reciprocal pairwise comparison matrix at all levels of the hierarchy. Normalization of the pairwise matrix is computed by dividing the matrix column value with the matrix column total. The normalized values in each matrix column, is averaged for each row in the matrix. The averages are the priority vectors which are then normalized to find priority weights. The distance functions are computed on all set of ratio-scale matrices and then for given inconsistent ratio-scale matrix, the minimum distance between each ratio-scale values and the desired output is computed. For least squares method, the minimum of the results of the squares of the output of the distance method is computed. In the linear programming method, summations of the differences of the ratio-scale matrix values and the desired weights are computed.

For fuzzy preference values, extent analysis is computed by the extent of each pairwise comparison fuzzy values. Fuzzy numbers can be triangular if they are three or trapezoidal if they are four. Extent analysis is calculated by finding the degree of possibility that any of the numbers is the correct evaluation value. Wang and Chin (2008) used extent analysis to compute priorities for fuzzy judgements. Mikhailov (2003) applied fuzzy preference programming method for fuzzy judgements to address the weakness of other methods in applying fuzzy AHP, namely: (i) all methods derive priorities from fuzzy comparison matrices, (ii) fuzzy priorities obtained lead to the final fuzzy scores results, which are also fuzzy, (iii) ranking can be done by using different methods in the defuzzification of the final fuzzy scores, although this can result in giving different outcomes (Bortolan & Degani, 1985).

Srdjevic (2005) proposes a combined method for prioritization which combines methods from the traditional AHP and Fuzzy AHP. In this method, Extent analysis was not included. Chang (1996) proposed that priority weight can be computed using the basic theory of extent analysis in Fuzzy AHP. Mikhailov (2003) stated that the fuzzy extent analysis method has problems especially because of its use of the arithmetic mean method to compute fuzzy priorities. Zhu et al. (1999) introduced an improved approach of Fuzzy AHP (with extent analysis). The fuzzy extent analysis method has been applied in other research studies. For example, Bozdag et al. (2003) applied Fuzzy AHP (with extent analysis) in selecting computer integrated manufacturing systems. Kwog and Bai (2002) also used Fuzzy AHP (with extent analysis) and noted that it was effective in solving multi-criteria evaluation problems. Wang and Chin (2008), however, suggest that the use of extent analysis can lead to incorrect decisions.

Leung and Cao (2000) gives a good outline of consistency checking and ranking done when using fuzzy AHP. They question research done with Fuzzy AHP without testing consistency. On the other hand, Saaty and Tran (2007) also question research done using methods that fuzzify AHP. Their stance is that all judgements before being fuzzified are already fuzzy and that fuzzification might make the results even more inconsistent. However, Leung and Cao (2000) argue that the procedure in computing the consistency of evaluators' judgements may provide answers to their doubts on consistency. Mikhailov (2003) provides a method for deriving fuzzy priorities when using Fuzzy AHP without requiring calculation for aggregation and ranking procedures. This approach is best used in non-linear equations approach by computing priorities without calculating fuzzy comparisons; it addresses the doubts raised by Saaty and Tran (2007). This study also concurs with Triantaphyllou et al. (1997) that multi-criteria decision methods are controversial and that there is no unique theory accepted by all in the field.

2.4.1 Partners' Evaluation and Selection as an MCDM Problem

Figure 2.3 shows a general representation of a decision-making problem. This representation considers the decision-making problems as systems (Changkong & Haimes, 1983). A system is a set of parts or components that works together to achieve certain goals. A system interacts with the environment in two forms: inputs and outputs. The inputs are usually the conditions in the environment where a system exists and the stimuli that cause a reaction from the system. The outputs are consequences of the inputs being processed by the system.

In the partner evaluation and selection problem, the inputs are the evaluation and selection criteria. These criteria are established in the objectives and attributes unit of the decision-making system. The triggering signal is the purpose for decision making. This is the evaluation and selection of a team of partners who will collaborate to provide a solution to the customer needs. The output of the problem is the ranking of alternatives (potential partner companies) according to their satisfaction of the evaluation and selection criteria.

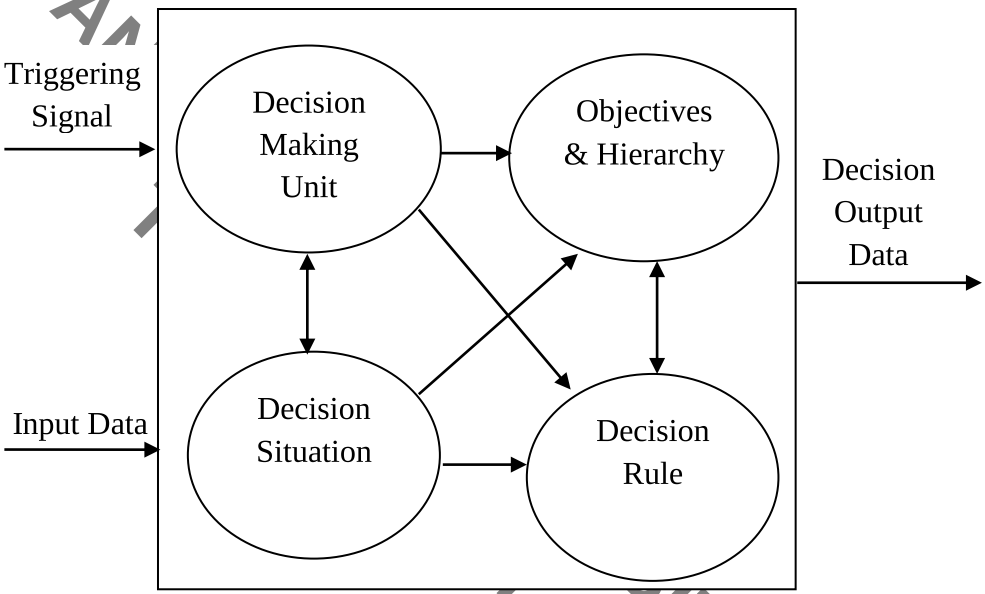


Figure 2.3 A General Representation of a Decision-Making System

According to Changkong and Haimes (1983) and Yu (1985), the components of a decision-making problem are: (1) a decision-making unit, (2) a set of objectives/tasks and their hierarchy, (3) the decision situation, and (4) the decision rule.

The following sections discuss these components in the context of VEs in the construction sector.

The Decision-Making unit processes the information from all other sub-components. It takes as inputs the other components of the system. This unit is likened to the project initiator who gets the clients' problem, decomposes it into objectives, sets the criteria and selects the best partners according to how they satisfy the criteria. The inputs are the project requirements and the output is the selected team of partner companies.

The set of objectives and their hierarchy helps to formulate the decision problem precisely. The objectives are the tasks that when implemented by the partners, the problem is solved. These objectives are achieved by partners and they provide a reference for evaluating the performance of a given partner. A hierarchy, on the other hand, is a result of a well-defined set of objectives and selection criteria. The hierarchy organizes the objectives and selection criteria from general to specifics. The highest level of the hierarchy contains the most general objective and selection criteria. At the lowest level of the hierarchy, the criteria become more specific and narrow in scope. This transformation from broad objective to specific selection criteria is a result of dividing broad and complex objective and selection criteria into sub-criteria. In a hierarchy, the sub-criteria at lower levels contribute to satisfy the criteria of the next higher level.

The decision situation component defines the structure of the problem and the decision environment in multi-criteria decision-making problems. The decision situation requires a complete characterization of the boundaries (or scope) and the basic components of the problem. The decision situation component produces a decision, and for this study, the selected partners. The scope and type of inputs of the decision situation vary, according to the magnitude of the construction project. In the simplest case, the scope of a decision situation has three elements: a set of available partners, a set of objectives and selection criteria and sub-criteria that are used as decision variables, and a description of the current state in the environment in which the decision is made. The inputs, in this case, are the values of attributes for each potential partner. In addition, the VE initiator is the only element in the decision-making unit.

Decision situation units are problem specific. Partner evaluation and selection problems in the construction sector, for example, may vary depending on its complexity. The input to the decision unit is the set of credential of the potential partners, the attributes are the selection criteria used for selecting partners and the decision variable is used to select partners according to the ranking obtained in the decision rule unit. The alternatives are the potential partners. The state of the decision environment is the formation of a VE.

The Decision Rule deals with making a selection from a set of potential partners. The selection of the "best" partner implies a certain order, ranking, or preference, based on the selection criteria or rules. In general, these criteria evaluate performance and satisfaction of tasks. The Decision Rule unit is a set of rules used to evaluate or rank a set of available partners.

2.5 Agent-based Modelling

Agent-based computing (Wooldridge, 1998; Jennings, 1999) is a scientific domain which is large and widely spread. An agent could even be a representation of an interacting social component of a large system used to explore emergent global behaviour in a simulation (Gilbert & Troitzsch, 2005; Niazi & Hussain, 2011).

Agent design and simulation go hand in hand but in completely different ways in different sub-domains of agent-based computing. On one hand, there are studies whose aims are to design various types of agents where the role of simulation is closely linked to validation of the future operation of actual or physical agents (Bellifemine et al., 2001). On the other, there are studies, whose goal is not agent-design but rather the agent-design is a means of developing simulations that may lead to better understanding of global or emergent phenomena associated with complex adaptive systems (Macal & North, 2007; Naizi & Hussain, 2011).

The area of agent-based modelling can be related to a wide spectrum of research such as agent methodologies and agent theories. The agent-based models seem to be driven by agent theories, such as the work on teams and teamwork. Another approach takes object-oriented modelling techniques, such as UML, and proposes extensions to it to model agent properties. This research follows approaches inspired by organizational modelling and business process modelling, where autonomous entities within an enterprise are considered. Tan et al. (2013), proposed a framework for service enterprise workflow simulation with multi-agents cooperation. This was to address the lack of flexibility and scalability as exhibited in the generic method for service business workflow simulation based on the discrete event queuing theory.

While Agents and MAS from the AI perspective are not less important in any way, agent-based modelling (ABM) and simulation paradigm has even been termed a revolution in the esteemed journal Proceedings of the National Academy of Sciences (Bankes, 2002). ABM has found parallel applications in numerous domains as diverse as the Social Sciences (Epstein & Axtell, 1996) to Biological Sciences (Siddiqa et al., 2009; Mukhopadhyay et al., 2010) to Environmental modelling (Niazi et al., 2010; Xiaofei, 2010). It is even prevalent in the modelling of business systems (Aoyama, 2010) and recently in the modelling of computational systems such as in Wireless Sensors (Niazi & Hussain, 2010) and ad-hoc Networks (Niazi & Hussain, 2009).

Several authors have proposed software agents and distributed artificial intelligence (DAI) as a means of supporting dynamic organizational forms such as VEs. Levitt et al. (2001), propose an ABM approach to project-oriented organizations engaged in knowledge work. The participants of a VE are considered as agents whose autonomous behaviour needs to be coordinated. In Bernus and Baltrusch (2002) and Bernus et al. (2003), agents are proposed as a means of supporting the control and decision framework of a VE.

A methodological framework for the design of inter-enterprise cooperation, within the context of a VE, was proposed by Tata and Boughzala (2003). They proposed three models of integration: by data, where agents share data, by processes where agents synchronize their actions and processes, and by knowledge where agents use and share knowledge to perform some common processes. They describe how coordination can be achieved by such integration. Agent-based models for VEs, where the focus is on the formation and operation of VEs, are not widely reported in the literature. However, several architectures, such as proposed in Camarinha-Matos et al. (2005) address the VE formation phase. Other works have been published on the application of multi agent systems (MAS) and market-oriented negotiation mechanisms for the VE formation (Camarinha-Matos & Afsarmanesh, 2001). An early example by Rocha and Oliveira (1999) assumes a virtual market place where enterprises, represented by agents that are geographically distributed and possibly not known in advance, can meet each other and cooperate in order to achieve a common business goal.

Camarinha-Matos et al. (2005) proposed an architecture to model the electronic market. In addition to agents representing the enterprises, there is a market agent-coordinator or broker that initiates the VE formation when a business opportunity occurs. A multi-round contract-net protocol is followed and the most favorable bids are selected based on a multi criteria mechanism and constraint-based negotiation. Utility values are associated with each of these criteria and a linear combination of attribute values, weighted by their utility values is used. Multiple negotiation rounds can take place. At the end of each round, bidder agents receive indication whether their bids are wining or loosing plus a rough qualitative justification, allowing them to change the parameters of their bids.

Similar work is found in Li et al. (2000) where detailed analysis of goal decomposition, leading to a hierarchy of VE goals, is done. In addition to the enterprise agents and VE coordinator agent (broker), an information server agent is introduced to keep public information related to common organizational and operational rules, market environment, enterprises and products / services provided, etc. The need for a common ontology to support the communication among agents is explicitly introduced and a multi-attribute, constraint-based negotiation / selection process is implemented. The work by Shen and Norrie (1998) identifies the need for yellow pages' agents that are responsible to accept messages for registering services (similar to the information agent server).

The research in Web Services (Field & Hoffner, 2002) is another area where relevant models for VE can be found. In a Web Services-oriented view of a VE, the partners provide services to, or consume services from each other. Other techniques that have been proposed for evaluation and selection of partners in a VE include multi-attribute optimization techniques (Petersen & Divitini, 2002; Jarimo et al., 2005) and mathematical approaches (Bittencourt & Rabelo, 2005).

2.6 Chapter Summary

This chapter has discussed the three critical issues that this study addressed. They include (1) Partner evaluation and selection for VEs, (2) Partner evaluation and selection as a MCDM problem and (3) Modelling of VEs using MAS approach. VE has a lifecycle of formation, management and dissolution. The formation phase of a

VE can be divided in four steps (Tolle, 2004; Afsarmanesh & Camarinha-Matos, 2005; Guerra, 2006). These steps are: (1) Identification of the problem; (2) Identification of the core competencies required to develop a solution to the problem; (3) The selection of the partner companies capable of delivering the required core capabilities; and (4) The formation of the VE by integrating the core capabilities of the partners.

Partner evaluation and selection process comprises the partner phase and collaboration phase Wildeman (1998). The following selection criteria were identified by Wildeman (1998): Technical capability (TC), financial security (FS), management ability (MA), strategic position (SP), development speed (DS), cost of development (CD) for the partner phase while for the collaboration phase, the following criteria were discussed: Cultural compatibility (CC), collaborative record (CR), business strength (BS). Bailey et al. (1998) proposed complementary skills, partner's financial position, management philosophy, market position, size for partnership phase while for the collaboration phase the following criteria were proposed: Culture, financial position (collaboration), trust, chemistry, complementarity, commitment and openness. All other selection criteria from other authors were combined into one of these. VEs, just like any other enterprise has three domains, thus Business, Technical and Management. Partners' selection criteria can be classified into these domains. The use of time and cost for evaluating partner performance was also reviewed.

MCDMs include AHP, Fuzzy AHP, mathematical programming, linear weighted models, data envelopment analysis and neural networks. AHP and Fuzzy AHP are applicable in multi-attribute problems. There are priority weighting techniques for crisps and fuzzy decision values. Partner Evaluation and Selection Problem can be designed as a MCDM system and decomposed into decision unit, objectives and their hierarchy, decision situation and decision rules. The input to the system, are the selection criteria and the output of the system is the selected team of partners.

There are a number of ABM techniques and there is very little evidence of MAS in partner evaluation and selection in the construction industry. Projects in the construction sector are implemented by multiple partners. A client hires an architect / consultant who make designs for the project and engages other consultants to carry the various tasks. For example, modelling a building construction project, involves representing the main consultant who is normally the architect as an agent. Each contractor like civil/structural, electrical, mechanical, plumbing, interior design and land-scaping engineers are also represented as agents. These agents collaborate to accomplish the tasks. The main agent selects the best agent for each task. They coordinate among each other. In implementing the MAS environment, the partners are modelled as dynamic software agents. These agents are capable of modifying their attributes to suit the specified project requirements. These agents interact among themselves and report progress of their tasks.

Next chapter presents research methodology.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

The research methodology was mixed, employing a combination of theoretical and empirical work. Literature review provided the theoretical part while the industrial case scenarios provided the empirical part. This combination seemed suitable as the theoretical approach helped consider a holistic view of VEs and the empirical approach ensured that the ideas that were developed based on the theoretical approach were applicable in the construction industry.

Using mixed research methods brings out both qualitative and quantitative aspects of the topic under study. In this study, qualitative evaluation methods were used during data collection because of their usefulness in providing detailed information and rich description of phenomena in a short time.

Using a combined research approach, the disadvantages of each of the methods used can be minimized and their advantages maximized. Dubé and Paré (2003) argue that a “multi-method approach to research involves several data collection techniques, such as interviews and documentation, organized to provide multiple but dissimilar data sets regarding the same phenomena”. Further, mixed methods are used when researchers want to avoid "being carried away by vivid, but false, impressions in qualitative data, and it can bolster findings when it corroborates those findings from qualitative evidence”. Table 3.1 summarizes the merits and demerits of research methods employed in this study.

Table 3.1 Pros and Cons of the proposed research methods

Method	**Advantages**	**Disadvantages**
Focus group interview	Interviews are conducted in an interactive group setting. It allows the researcher to study people in a more natural setting than in a one-to-one interview (Myers & Newman, 2007)	The researcher, who is a facilitator, can influence the outcome of the research. Time consuming (Johnson & Onwuegbuzie, 2004)
Questionnaire	Provide data to a researcher from all users and / or evaluators (Gable, 1994)	Not as flexible as an interview where researcher can discover new problems and thus derive new insights (Gable, 1994)
Data analysis using methods such as statistical analysis and Code Mapping	Some methods like code mapping, iteratively analyses and categorizes qualitative data which can then be easily converted to quantitative data for quantitative data analysis (Glaser & Strauss, 1967; Meriam, 1988; Creswell, 1994). Constant comparative analysis occurs as the data are compared and categories and their properties emerge or are integrated together (Glaser & Strauss, 1967). Findings can be corroborated using triangulation.	Some methods such as code mapping do not give indication of data significance. Quantitative data analysis techniques are not explicitly applied.

Method	**Advantages**	**Disadvantages**
Decision Making Algorithms such as Analytical Hierarchy Process (AHP), Fuzzy AHP and Reduced Group Fuzzy AHP	Some methods are considered to be more objective and verifiable (Yaghini et al., 2009) while some methods allows the use of both quantitative and qualitative data. In addition, some methods have the capability of handling uncertainty of user evaluation judgement.	In AHP, the subjectivity associated with the quantitative data is ignored. In cases where subjectivity can be handled by the algorithm, careful consideration must be given to the use of the algorithm because the change of scale, membership function and the inference method can result in a different outcome.

According to Johnson and Onwuegbuzie (2004) the following are the advantages of mixed methods: (1) Words, pictures, and narrative can be used to add meaning and precision to numbers and vice versa, (2) Includes the strength of both quantitative and qualitative methods, (3) Does not confine a researcher to a single research method thus, allows a range of research questions and answers, (4) Since it allows multiple research methods, the strength of one method can be used to overcome the weakness of the other methods. The conclusion can be provided through convergence of findings from a chain of logical evidence, (5) Reveals some insights and understanding of phenomena that might be either missed or difficult to find when only a single method is used, (6) Increases the credibility and the generalizability of the research results and the use of mixed methods from qualitative and quantitative research produces comprehensive knowledge necessary to inform theory and practice, (7) An algorithm that can handle both qualitative and quantitative evaluation judgements, allows the inclusion of many views in the evaluation process. In addition, a combination of methodologies allow broader consultation when evaluating partners for a particular construction project.

3.2 Research Design

The following steps were followed to realize this research:

Step 1: Literature review, conducting interviews and administering questionnaires. The purpose of this step was to identify the main researchable issues in the construction industry. The main issues identified were partner evaluation and selection, partner performance evaluation and partner collaborations. Partners would act as agents of their sponsor companies. To model these activities, a MAS approach would be appropriate.

Step 2: Literature review on the VE life cycle. This was to determine the process of problem identification, definition of selection criteria, partner evaluation and selection methods, collaborations and partner performance evaluations.

Step 3: Literature review on decision making models and their application to the partner evaluation and selection problem. This process helped identify MCDMs that could deal with imprecise human decision making situations.

Step 4: Conceptual and architectural design of a MCDM framework.

Step 5: Implementation of a MCDM architecture for partner evaluation and selection problem.

Step 6: Conceptual and architectural design of a MAS for modelling VE.

Step 7: Implementation of an architectural modelling environment for VE for the construction industry.

Step 8: Simulation of a generic construction industry VE.

Step 9: Data collection from case study construction projects through interviews (appendix B) and questionnaires (appendix C). Focus group interviews and evaluation tools were used to collect data from participants.

Step 10: Data analysis and extraction of simulation parameters from case studies' data. The analysis of qualitative data was done by finding patterns in the collected data, as suggested by Seidel (1998). In analyzing the data and identifying patterns, themes and subcategories were developed. Sub categories were arrived at by analyzing the data further. Additionally, triangulation was used to increase the reliability of research findings. In this regard, interview questions and research questionnaires were developed. Interview and questionnaires' questions were tied to research questions.

Triangulation of the interviews with questionnaires as well as triangulation of the interviews with one another rendered a holistic understanding of the research questions and generally converging conclusions. As Fielding and Fielding (1986) state, "Triangulation puts the researcher in a frame of mind to regard his or her own material critically, to test it, to identify its weaknesses, to identify where to test further doing something different". Internal validity, external validity, reliability, and objectivity that are traditionally addressed in quantitative studies could not be addressed well in qualitative research (Lincoln, 2001). However, credibility, dependability and confirmability were achieved by triangulation while transferability was achieved by clear research process. Multiple sources of data collection as well as multiple voices (of contractors, consultants and architects) were used to triangulate the data.

Step 11: Integration of MCDM and MAS models of VE in the construction and their simulation.

Step 12: Analysis of simulation results.

Step 13: Presentation of simulation results.

3.3 Survey Study

Representatives from ten (10) construction companies based in Nairobi, Kenya were invited for a focus group interview. Most construction companies in Kenya have their offices in Nairobi, the Capital City. These companies were selected by purposive sampling (Van & Maree, 1999) from the National Construction Authority (NCA) database. NCA is the body mandated to regulate construction industry in Kenya. The purposive sampling procedure was used because of the difficulty in getting these participants. The participants were given a consent form to complete before taking part in the research to adhere to the ethical standards set for this study (appendix A). The objective of the study was explained to them. Interview questions were formulated based on literature.

Nairobi town had more than a half of the total contractors in Kenya. Due to this, contractors from Nairobi town were selected for this research. These contractors were classified as shown in Table 3.2 below:

Table 3.2 Categories of contractors for Nairobi city (NCA Database as at November, 2012).

Class of contractors	**Total number**
Building works	**1709**
Civil Engineering Services	**1752**
Electrical Engineering Services	**1011**
Mechanical Engineering Services	**306**
Architects	**541**

Some contractors have many specializations. Representatives from building works, civil engineering services, mechanical engineering services, electrical engineering services and architects were interviewed.

3.4 Instrument Design and Pilot Testing

Results of the interview, answering RQn1 were used to design an evaluation tool (questionnaire) to answer RQn2. The applicability and validity of the questionnaire for the collection of quantitative data was evaluated and discussed with experienced quantitative data analysis experts. A pilot study was conducted at the proposed development of an office block for Kenya Commercial Bank Ltd (KCB) staff retirement benefits scheme and KCB staff pension fund construction site in Nairobi (appendix E). This was an ongoing multi-billion construction project with many contractors implementing different tasks of the project. Five contractors were identified through the main consultant and after explanation on the objective of this study; they were given the evaluation tool to use to evaluate partners in their sections. After the process, they gave feedback on the applicability and validity of the evaluation tool in rating partners. They also suggested changes that would make the evaluation tool applicable.

3.5 Data Collection and Preparation

Data was collected between November 2012 and August 2013. Ten construction companies with ongoing construction projects within and in the environs Nairobi city were identified from the NCA database by purposive sampling (Van & Maree, 1999). Each organization was given twenty questionnaires (appendix C). A total of 83 responses (response rate of 41.5%) were collected. Taking into consideration the length and complexity of the questionnaire, this response rate compares well above other surveys such as ASME (1997), Bailey et al. (1998), and Culley et al. (1999) that obtained 17%, 31%, and 23.6% response rate respectively. These respondents were given profiles of five companies (appendix D). They used the companies' profiles information to evaluate each company according to how they satisfied a selection criterion for a particular task in the construction project. Respondents of questionnaires were required to indicate the level importance of one selection criterion over another in implementing the task, the level importance of a sub-criterion over another in satisfying a criterion and how preferable a company (partner) was over another in satisfying a sub-criterion (appendix C).

The data from focus group interview was largely qualitative while data from questionnaires were largely quantitative. Techniques to analyze both qualitative and quantitative data were employed. Analyzed data was used to evaluate and select partners. Merriam (1988) and Creswell (1994) recommend simultaneous data collection and analysis for generating categories. As data were being categorized, the responses were compared within categories and between categories (constant comparative analysis) (Glaser & Strauss, 1967). Constant comparative analysis occurs as the data are compared and categories and their properties emerge or are integrated together. Code mapping is the process of identifying and categorizing data (Seidel et al., 1988). Data from focus group interviews was categorized into evaluation and selection criteria and sub-criteria.

3.6 Multi Criteria Decision Making Techniques

Multi-criteria decision making algorithms were applied to the values assigned to selection criteria and sub criteria by evaluators to select the best partners for each task and evaluate their performance. This approach is sequential multi-level technique.

While selecting the best partners for a particular task in the construction project, the partners' attributes are analyzed and weights assigned. Multi criteria decision making algorithms are used to derive relative weights of partners and checking consistency of evaluators' judgements. Analytical Hierarchy Process (AHP) is an analytical algorithm for data in hierarchical structure. It can be used as an analysis as well as a multi-criteria decision making technique. Multi-level partners' evaluation and selection process is implemented in four cycles.

First Cycle: Use of AHP - The objective of this cycle is to evaluate the importance of selection criteria, sub-criteria and partners using crisp numerical values. AHP is useful in determining evaluation preferences by a group of evaluators, however, its weakness include giving unreliable results when evaluator judgement is uncertain. Thus, in order to deal with uncertainty during evaluation there is a need for an algorithm, which can cope with this reality.

Second Cycle: Use of Fuzzy AHP (FAHP) - The objective of this cycle is to extend AHP (using fuzzy logic) which is applicable for managing "certain" evaluation judgements, and to imitate the way humans' reason and judge. Human reasoning and judgement during the partner evaluation and selection is subjective and can be said to be "uncertain". Thus, algorithms that can deal with the uncertainty of human judgements will be an improvement on AHP. Fuzzy logic combined with the AHP algorithm can compensate for the weakness of AHP. The algorithm is implemented and the outcomes of the FAHP and AHP are compared. FAHP does not discard priority weights with low numerical values. However, FAHP is complex and time consuming. It has so many steps.

Third Cycle: Use of Reduced Group Fuzzy AHP (RGFAHP) - To handle the time and space complexity of FAHP, RGFAHP is proposed. This method has characteristics of both AHP and FAHP. The method is proposed to address AHP's weakness of inability to analyze imprecise data and FAHP's weakness of having so many steps to arrive at the final results. RGFAHP use imprecise data unlike traditional AHP and has fewer steps than FAHP.

Fourth cycle: Implementation of partner evaluation and selection and partner performance evaluation (prediction). A prototype is developed based on MCDM algorithms and is used to simulate data from six different case study groups as a proof of concept.

3.7 Chapter Summary

In this chapter various research methods employed in this study are presented. Mixed research methodology is adopted where literature review provide theoretical part while industrial case scenarios provide the empirical aspect. By using mixed research methods, the disadvantages of some are minimized while maximizing their advantages. Advantages of mixed methods include among others: includes the strength of both quantitative and qualitative methods and does not confine a researcher to a single research method.

Research design entail: literature review on VE life cycle and decision making models; conceptual and architectural design of a MCDM framework; implementation of a MCDM architecture for PESP; conceptual and architectural design of a MAS; implementation of an architectural modelling environment; Simulation of a generic VE for construction projects, data collection from case studies; data analysis and extraction of simulation parameters; integration of MCDM and MAS; analysis and presentation of simulation results.

Data collection techniques include focus group interviews and questionnaires. Data analysis is done using code mapping and statistical techniques. Decision making algorithms include AHP, FAHP and RGFAHP. Triangulation enables data validation.

In the next chapter, Multi-Agent Systems of Modelling VEs is discussed.

CHAPTER FOUR

4.0 MULTI AGENT SYSTEMS MODELLING OF VIRTUAL ENTERPRISES

4.1 Introduction

In artificial intelligence research, agent-based systems technology has been hailed as a new paradigm for conceptualizing, designing, and implementing software systems. Agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. Increasingly, however, applications require multiple agents that can work together. A multi-agent system (MAS) is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver. Multi-agent techniques are used to address the issues of complex enterprises and solutions through intelligent behaviours, such as cooperation, competition, and coordination in a set of autonomous agents under a dynamic distribution-oriented open environment (John & Heavey, 2006). MAS features are suitable for the representation of entities in enterprise environments (Niu et al., 2011).

MAS consist of agents and their environment. Typically MAS research refers to software agents. However, the agents in a MAS could equally well be robots (Kaminka, 2004), humans or human teams. A MAS may contain combined human-agent teams. Agents can be divided into different types ranging from simple to complex. Some categories suggested in Kubera et al. (2010) to define these types include:

- Passive agents or agent without goals (like obstacle, apple or key in any simple simulation),
- Active agents with simple goals (like birds in flocking, or wolf–sheep in prey-predator model),
- Cognitive agents, which contain complex calculations.

Agent environments can be organized according to various properties like: accessibility (depending on the possibility of gathering complete information about the environment), determinism (if an action performed in the environment causes a definite effect), dynamics (how many entities influence the environment at the moment), discreteness (whether the number of possible actions in the environment is finite), episodicity (whether agent actions at certain time periods influence other periods) (Russell et al., 2003), and dimensionality (whether spatial characteristics are important factors of the environment and the agent considers space in its decision making) (Salamon & Tomas, 2011). Agent actions in the environment are typically mediated via an appropriate middleware. This middleware offers a first-class design abstraction for MAS, providing means to govern resource access and agent coordination (Weyns et al., 2007).

MAS can manifest self-organization as well as self-steering and other control paradigms with related complex behaviours even when the individual strategies of all their agents are simple. Many MASs are implemented in computer simulations, stepping the system through discrete "time steps". The MAS components communicate typically using a weighted request matrix and a weighted response matrix.

A challenge-response-contract scheme is common in MAS systems, where

First, a "Who can?" question is distributed.

Only the relevant components respond: "I can, at this price".

Finally, a contract is set up, usually in several more short communication steps between sides, also considering other components, evolving "contracts", and the restriction sets of the component algorithms.

Another paradigm commonly used with MAS systems is the pheromone, where components "leave" information for other components "next in line" or "in the vicinity". These "pheromones" may "evaporate" with time, that is their values may decrease (or increase) with time. MAS also referred to as "self-organized systems", tend to find the best solution for their problems "without intervention". There is high similarity here to physical phenomena, such as energy minimizing, where physical objects tend to reach the lowest energy possible within the physically constrained world. For example: many of the cars entering a metropolis in the morning will be available for leaving that same metropolis in the evening.

The main feature which is achieved when developing MAS, is flexibility, since a MAS can be added to, modified and reconstructed, without the need for detailed rewriting of the application (Rzevski & Skobelev, 2014). The systems also tend to prevent propagation of faults, self-recover and be fault tolerant, mainly due to the redundancy of components. While ad hoc MAS are often created from scratch by researchers and developers, some frameworks have arisen that implement common standards (such as the FIPA agent system platforms and communication languages). These frameworks save developers time and also aid in the standardization of MAS development. One such developmental framework for robotics is given in (Ahmed et al., 2007).

MAS are applied in the real world to graphical applications such as computer games. Agent systems have been used in films (Film showcase, 2012). They are also used for coordinated defense systems. Other applications include transportation (Xiao-Feng et al., 2012), logistics (Máhr et al., 2010), graphics, GIS as well as in many other fields. It is widely being advocated for use in networking and mobile technologies, to achieve automatic and dynamic load balancing, high scalability, and self-healing networks.

A MAS has the following advantages over a single agent or centralized approach (Kubera et al., 2010):

- A MAS distributes computational resources and capabilities across a network of interconnected agents. Whereas a centralized system may be plagued by resource limitations, performance bottlenecks, or critical failures, a MAS is decentralized and thus does not suffer from the "single point of failure" problem associated with centralized systems. These computational resources resemble contractors in the construction industry who have their own companies that can bid for tenders, compete with others and execute the tasks.

- A MAS allows for the interconnection and interoperation of multiple existing legacy systems. By building an agent wrapper around such systems, they can be incorporated into an agent society.
- A MAS models problems in terms of autonomous interacting component-agents, which is proving to be a more natural way of representing task allocation, team planning, user preferences, open environments, and so on. Contractors interact with each other during the course of the project.

- A MAS efficiently retrieves, filters, and globally coordinates information from sources that are spatially distributed. This is a good attribute as it enables partners' information for example any design changes to be communicated to others who then make adjustments if necessary.

- A MAS provides solutions in situations where expertise is spatially and temporally distributed. The experts in the construction industry may be distributed in terms of operating offices but are represented in the projects.
- A MAS enhances overall system performance, specifically along the dimensions of computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility, and reuse.

4.2 Virtual Enterprises and Multi-Agents Systems

Petersen and Matskin (2003) present characteristics of VEs as follows:

a) *Partnership of enterprises that collaborate:* or a strategic alliance, where the enterprises are aligned not just at the activities level, but also at the level of their business goals. Such an alliance requires trust, commitment and a mutual interest among the partners to achieve their goals. The partners achieve their goals through collaboration.
b) *Temporary network of enterprises with a limited lifetime*: where two or more independent enterprises get together to exploit a particular market opportunity or to meet a specific customer demand. Such a network will work together and collaborate until they meet the customer's demands and then disintegrate. Thus, they have a limited lifetime.
c) *Communication and information flow:* supported by Information

Technology, where there is a lot of emphasis on the importance of enhanced intra- and inter- enterprise communication and the flow of information among the enterprises. There is a need to improve the social and cultural skills in an enterprise. Most of the definitions of VEs emphasize the importance of Information Technology for the existence of both of these entities. This characteristic is important to VEs since to achieve collaboration among the partners, they have to communicate and exchange information.

d) *Sharing of skills, costs and markets:* where the partners of a VE share their skills by having each enterprise focus on their areas of specialization. The trend to move away from outsourcing is replaced by enterprises forming a collaboration where they can share complementary competencies. This also encourages enterprises to focus their attention on their core competency. Similarly, costs and markets are also shared by enterprises. So rather than competing with peer enterprises, a strategic alliance is formed to share the market, skills, costs, risks and profits.

e) *Goal-oriented and commitment-based:* This characteristic is a consequence of some of the other characteristics described above. For example, if a VE is formed to meet a specific customer demand within a limited amount of time, the VE will have to work in a goal-oriented manner to meet that demand. Similarly, if the enterprises in a VE share their costs, they each have to make a commitment to meet their goals in order to succeed.

One of the requirements of technologies supporting VEs is coordination functionalities such as distributed resource management and scheduling (Camarinha-Matos & Afsarmanesh, 1997). Klein (1996) defines the need for coordination or collaborative processes when the task to be performed by a single entity is too large. VEs are formed in such situations, where the partners of a VE will perform the task(s) through collaborative processes. Klein (1996) suggests flexible coordination approaches in organizations such as explicit representation of their goals. Agents being goal-oriented or pro-active, thus, become an appropriate means of supporting coordination.

The distributed nature of agents does not require the co-location of the partners of a VE. VEs are formed by several partners agreeing to collaborate and share skills and information. Thus, the role of negotiation in a VE is central to the formation of a VE as well as the operation and success of a VE. The short lifespan of the VE means that the partners that participate in one VE may also be negotiating on a contract with another VE. By delegating agents to do this job, the partners have the time to do the actual work required in the VE. The ability to delegate responsibilities to agents and agents being reusable components make them suitable means of representing the partners in a VE.

VEs are composed of partners that collaborate, yet they may also be competing. This raises an interesting notion about agents. While agents are goal-directed and pursue their own goals, they are also capable of behaving cooperatively. Cooperative behaviour of agents is necessary to achieve a common goal with other agents, through collaboration. Sandholm (1997) defines self-interested agents as agents that act to maximize individual profit while cooperative agents will act to maximize social welfare, i.e. for the good of the VE. An interesting distinction between self-interested or competitive and cooperative agents, in the context of electronic commerce, was given by Guttman and Maes (1998). They define competitive negotiation between two parties as resolving a conflict over a single mutually exclusive goal whereas cooperative negotiation is when two parties negotiate over multiple independent, but non-mutually exclusive goals. For example, if a VE initiator and a partner negotiate over the price of work, it can be considered as competitive negotiation, whereas if they negotiate over the price as well as the delivery date and the time period when the work will be conducted, this can be considered as cooperative negotiation. These are a reflection of activities of partners in the construction industry.

There are a number of characteristics in the VE domain that make it a suitable application area for MAS (Camarinha-Matos & Afsarmanesh, 2005). Examples of such characteristics include:

- A VE is composed of distributed, heterogeneous and autonomous components, a situation easily mapped into MAS. In the same manner, partners in the construction industry are diverse in nature. They possess different traits, abilities and strengths.

- Coordination and distributed problem solving also tackled by MAS are critical problems in VE management.

- Decision making with incomplete information, and involvement of network members as autonomous entities, that although willing to cooperate in order to reach a common goal might be competitors regarding other business goals.

- The effective execution and supervision of distributed business processes requires quick reactions from enterprise members. Computer networks being the preferred media for communication, there is a need for each company having a "representative" in (or "listening" to) the network. This can be supported by agents.

- Recent developments in VE are changing the focus from information modelling and exchange to role modelling, addressing aspects of distribution of responsibilities, capabilities and knowledge.

- The phase of VE formation in which it is necessary to select partners and distribute tasks, shows market characteristics and negotiation needs that have been research issues in MAS.

- A VE consortium is a dynamic organization that might require re-configuration e.g. replacement of partners, changes in partners' roles, etc, for which a flexible modelling paradigm is necessary.

- VE supporting functionalities need to interact with the "local" environment (legacy applications and humans).

- The scalability property of MAS seems particularly adequate to support dynamic VEs in which different levels of cooperation with different sets of partners might be established at different phases. On the other hand, each enterprise might itself be seen as composed of a network of semi-autonomous entities.

- More flexibility than in a client-server model is required to support dynamic change of roles of the VE members.

- Continuous evolution of business models, technologies, organizational paradigms, and market conditions require effective support for evolution and a high level of modularity of the infrastructures.

- New forms of teamwork, namely cooperative concurrent engineering, are emerging in the context of VEs.

- Finally, there is a need to handle the requirements of autonomy versus cooperative behaviour for which federated MAS approaches provide a balanced solution.

Consider a case of a building construction project that requires investments of massive financial and human resources where many tasks are identified. These tasks' requirements are defined and a call for suitable partners is made. Each potential partner is autonomous in terms of decision making and resource management. These partner companies have their profiles that describe what they are in terms of past projects completed, financial strengths, professionalism and all factors they deem fit. These companies are selected to do a task. Once selected, they interact with others in the project. They can also make adjustments in the tasks and inform the coordinator of the change. They deploy their competencies, which is a conglomeration of all their skilled staff and resources. These partners exhibit the characters of agents which include: social ability, autonomy and pro-activeness. A MAS environment is applicable in modelling VEs for the construction sector. Partners are represented using software agents and all interactions are achieved through agents' communication protocols. Java Agent Development Environment (JADE), a MAS tool is used in this study to develop a prototype for VE simulation (appendix F).

4.3 Multi Agents Systems Approach

In order to support the rapid formation of VEs in the construction industry, a model prototype is important. Figure 4.1 shows the different entities and / or components of the model and their relationships. A VE in the construction sector has a goal (or a set of goals) that is / are achieved by a set of tasks that are performed by partners who are agents. A task requires a certain set of skills. The agent that performs the tasks meets the skills' requirement. The agents are described by a set of attributes and these attributes form the basis for the evaluation of the agent as a partner in the VE and during the evaluation and selection process.

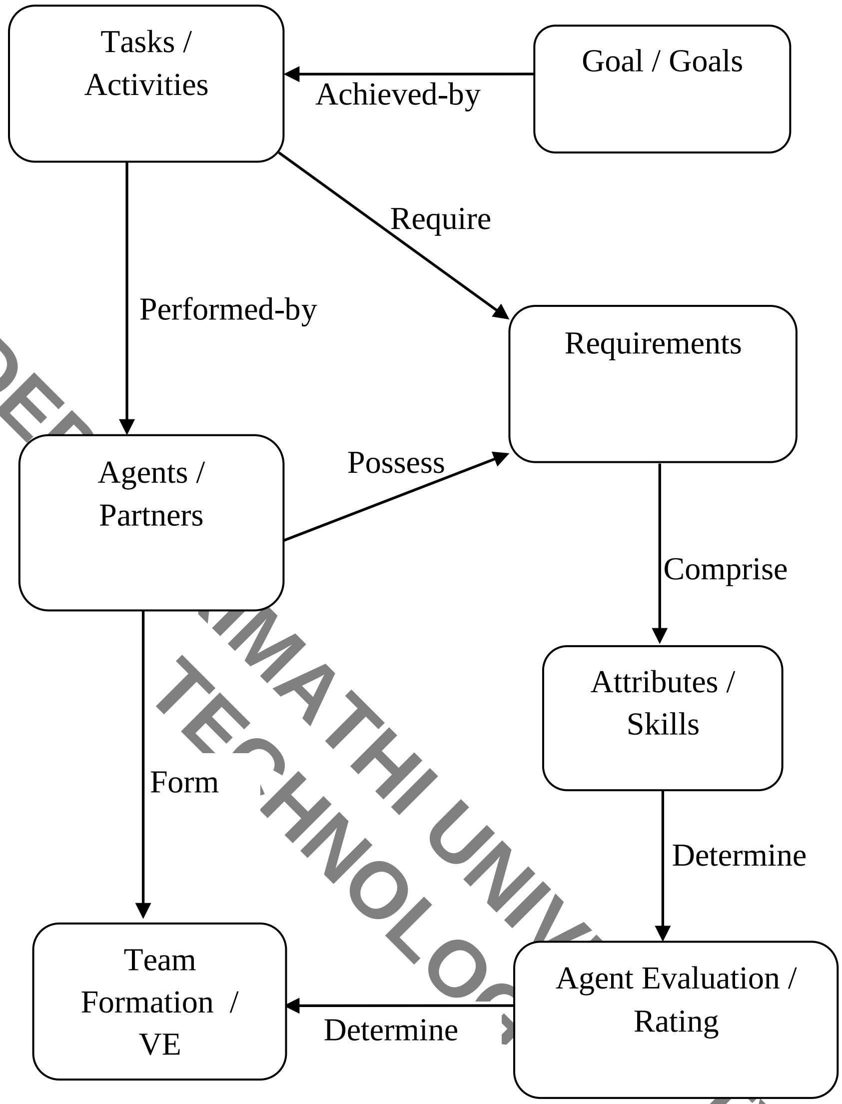


Figure 4.1 Agent entities' and relationships during virtual enterprise formation

Agents possess attributes and skills that they are evaluated from. The outcome of the evaluation determines the team of partners selected. In order to model VE, agents' tasks of a building construction project as shown in Table 4.1 is designed. The tasks are labeled with alphabetical letters A, B, C, D and E. The tasks are electrical, mechanical plumbing, structural, interior design and land-scaping works. Each task has sub tasks. In a project, the tasks are executed in some order. Sub tasks of one task can precede or succeed others in another task. This order of sub tasks requires coordination of partners.

Table 4.1 Building Construction Project Tasks

Building Construction Project Tasks			
Task Label	**Task**	**Sub Tasks**	**Task Predecessors**
A	Electrical works	A1- Conduits	C1,C2,C5
		A2- Wiring	A1,C7
		A3- Fittings	A2,C7,D1,D2
		A4-Connection to power supply	A3
B	Mechanical Plumbing works	B1- Pointing/fixing sleeves	C1,C2,C5
		B2- Pipe works	B1,C4,C5,
		B3- Fittings	B2,C7
		B4- Connection to external works	B3
C	Structural Engineering works	C1- Earth works	None
		C2- Form work	C1
		C3- Fixing Reinforcement	C2
		C4- Concreting	C3,A1,B1
		C5- Masonry-walls	C4,
		C6- Roof works	C5
		C7- Plaster works	C6,A1,A3,B1,B2,B3
D	Interior Design works	D1- Partitioning	C7
		D2-Paint works	D1
		D3- Furnishing	D2
		D4- Decorations	D3
E	Land-Scaping works	E1- Earth works	A4,B4,D4
		E2- Planting	E1
		E3- Constructing fountain	E2
		E4-Pipe work	E3

In Table 4.1, in electrical works, sub task conduits is preceded by earth works, form works and masonry walls while sub task wiring is preceded by sub tasks conduits and plaster works. The same descriptions apply to other tasks. Figure 4.2 represents agents' coordination of activities for a housing construction project.

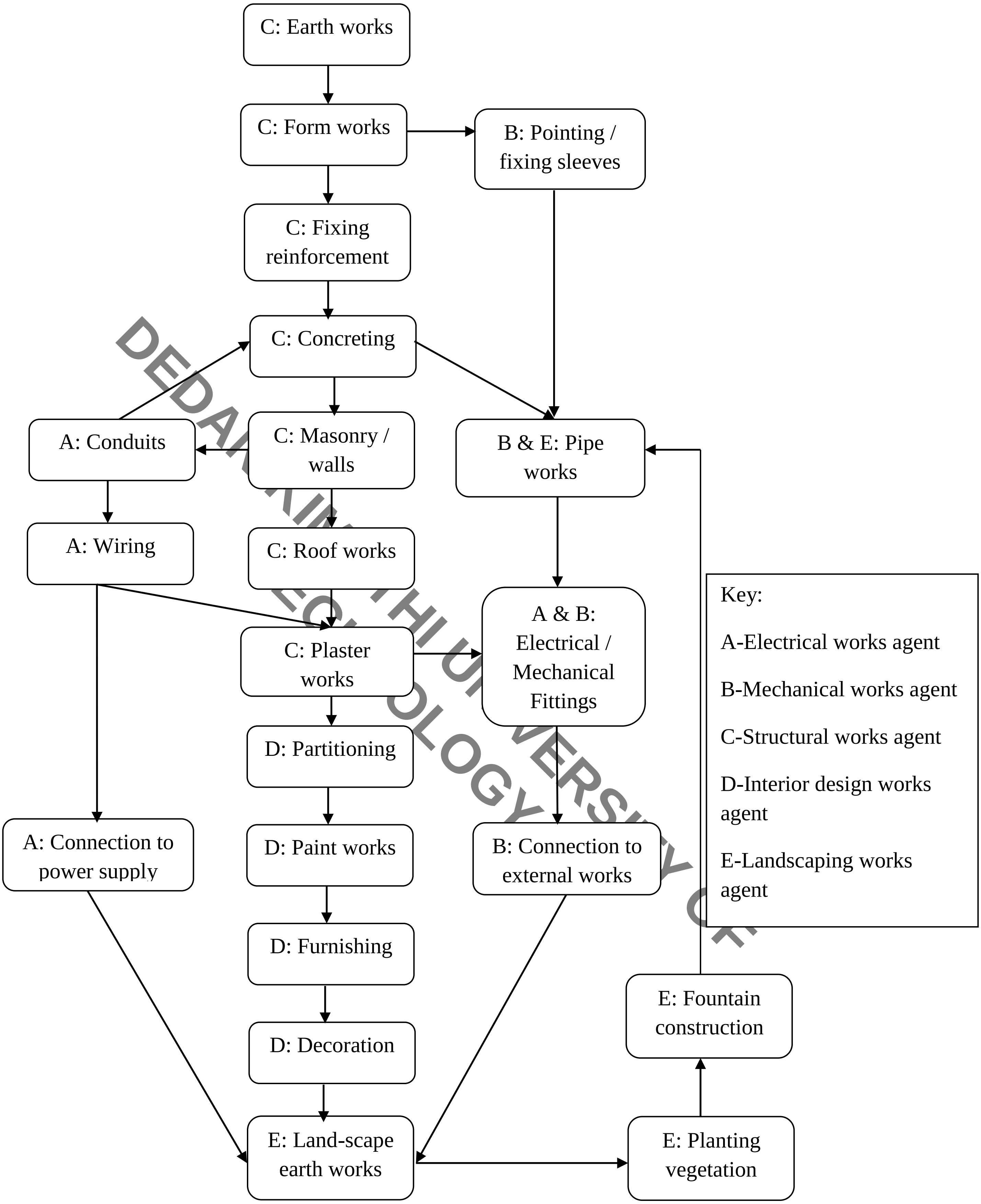


Figure 4.2 Multi Agents Systems Coordination in a housing construction project

The figure shows the flow of activities and agents interactions that ensures that tasks that require prerequisite sub tasks are facilitated.

4.4 Chapter Summary

This chapter has presented MAS. Agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. A MAS being a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver is applicable to VEs. Multi-agent techniques are used to address the issues of complex enterprises and solutions through intelligent behaviours, such as cooperation, competition, and coordination in a set of autonomous agents under a dynamic distribution-oriented open environment. VEs can be modelled as MAS because they are partnership of enterprises that collaborate; temporary network of enterprises with a limited lifetime; share skills, costs and markets; goal-oriented and based on commitment. A building construction project is decomposed into tasks and sub tasks. Each task is assigned to an agent (partner). Agents coordinate to ensure the project is completed according to specifications.

In the next chapter, partner evaluation and selection is discussed as a multi criteria decision making problem.

CHAPTER FIVE

5.0 PARTNER EVALUATION AND SELECTION: AN MCDM PROBLEM

5.1 Introduction

In this chapter, Multi Criteria Decision Making Techniques applied in this study are discussed. These are group decision making techniques where decision a group of evaluators provide data.

5.2 Multi Criteria Decision Making Algorithms

5.2.1 The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) (Saaty, 1980) is a method for modelling unstructured decision-making problems. Unstructured decision making problems are those in which there is not a clear arrangement of the components of the problems. In the construction industry, the partner evaluation and selection problem is unstructured. AHP is a multi-criteria decision-making (MCDM) method that uses pairwise comparisons of alternatives to derive weights of importance from a multi-level hierarchical structure of objectives, criteria, sub-criteria and partners. In cases where the comparisons are not perfectly consistent, AHP provides an uncomplicated method for improving the consistency of the comparisons, by using the Eigenvalue method and consistency checking method. The hierarchical structure fits well with the hierarchical structure of a partner evaluation and selection problem.

As shown in Figure 5.1, AHP algorithm has the following steps: i) Define the unstructured problem and state clearly the goal/objectives and outcomes; ii) Decompose the complex problem into a hierarchical structure of alternatives; iii) Employ pairwise comparisons of alternatives and form pair-wise comparison matrices; iv) Use the Eigenvalue method to estimate the relative weights; v) Check the consistency of decision judgements; vi) Aggregate the relative weights to obtain the overall rating for alternatives.

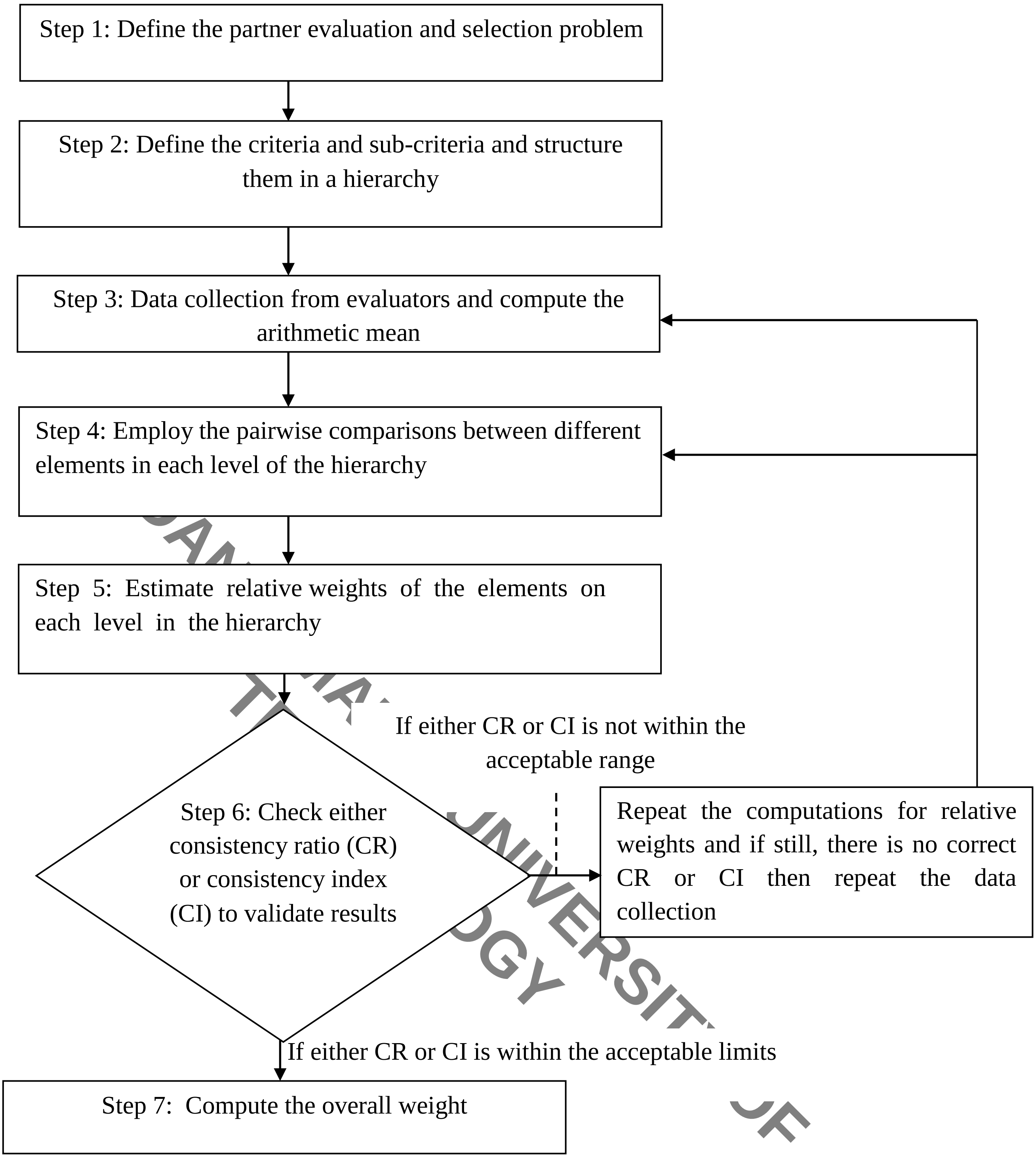


Figure 5.1 Analytical Hierarchy Process

These steps of the algorithm can be summarized into three (Vila & Beccue, 1995). Firstly, the problem is decomposed into a number of hierarchical levels. Secondly, data is collected from evaluators, arithmetic mean computed on the values and pairwise comparison matrices are formed. This step reduces the complexity of the multi-criteria multi-decision to a simple set of pairwise comparisons. A rating scale is used to indicate the level of importance / preference of one alternative over another, instead of comparing all alternatives simultaneously. The third step is called synthesization. It is where the overall weights of alternatives in all levels of the hierarchy are obtained.

To summarize, assume you have a hierarchical structure as shown in Figure 5.2 of *m* alternatives with respect to a specific objective, which must be evaluated using *n* criteria, denoted C_i(i=1, 2, ...n).

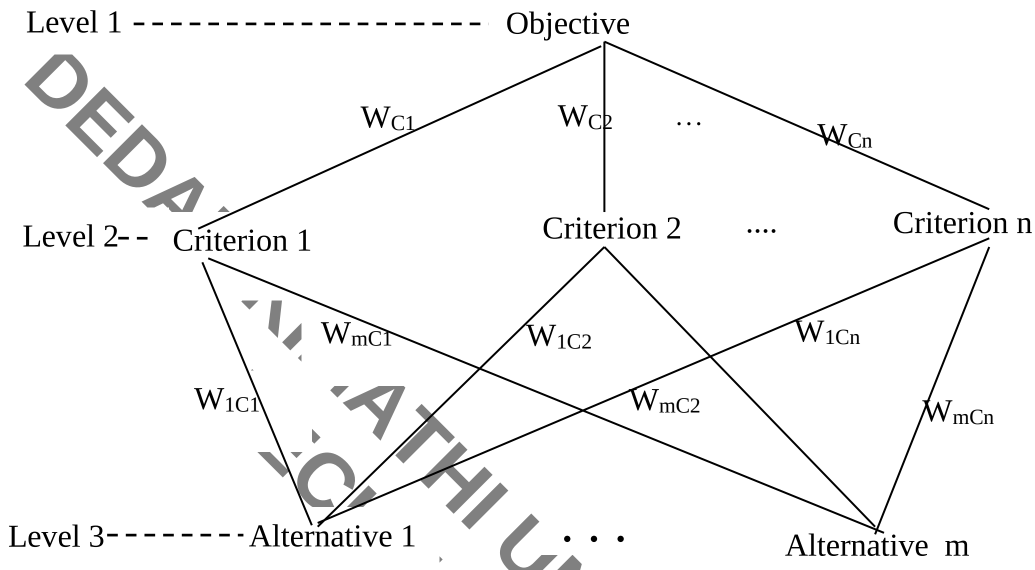


Figure 5.2 A simple hierarchical structure

Let the weight of criterion C_i with respect to the objective be W_{Ci}. Let the relative weight of alternative k $(1\leq k\leq m)$ with respect to criterion C_i be W_{KCi}. The overall weights, denoted P_i $(1\leq i\leq m)$ of m alternatives with respect to the objective are given by equation 5.1.

$$(P_1 \ldots P_m) = (W_{C1}\ W_{C2} \ldots W_{Cn}) \times \begin{pmatrix} W_{1C1} \ldots W_{mC1} \\ W_{1C2} \ldots W_{mC2} \\ \ldots \\ W_{1Cn} \ldots W_{mCn} \end{pmatrix} \quad (5.1)$$

It is important to note that W_{Ci} $(1\leq i\leq n)$ are the relative (local) weights of criteria C*i* while W_{KCi} are relative weights of alternatives, in this case, the partners. These relative weights are computed for elements at level 1 of the hierarchical structure, then at levels 2, 3 to the last level.

The following are steps for computing relative (local) weights AHP (Saaty, 1980).

Step 1: First, local weights (weights at a specific level) of alternatives at each level of the hierarchy are calculated. The higher the weight, the better (or preferable) the alternative is. Assessment of local weights is performed through pairwise comparison of the alternatives (alternatives in this case refers to elements for comparison at each level e.g. partners, sub criteria, criteria etc), using the Saaty nine-point scale (Table 5.1). The values of alternatives to be compared are assigned by evaluators using some chosen method. This results in so called, pairwise comparison matrices (PCM) of alternatives at a level in the hierarchy. For example, considering Figure 5.1, local weights of criteria C_i with respect to the objective are computed at level 1 because the criteria are at level 1 of the hierarchy.

Table 5.1 Saaty Scale (Saaty, 1980)

Definition	**Intensity of importance**
Equal importance	1
Moderate importance over one another	3
Essential or strong importance	5
Very strong or demonstrated importance	7
Absolute importance	9
Intermediate values between adjacent scales	2, 4, 6, 8

At level 2, local weights of alternatives (or sub criteria or partners) with respect to criteria C_i are computed. This is because evaluators compare and assign evaluation values to alternatives according to how they satisfy criteria C*i*. Saaty (1980) proposes that alternatives can be assigned a crisp (exact) value to show how important the alternative is viz a viz others according to how evaluators rate them. For example alternative 1 weighed against alternative 2 may have numerical value 9 (which means alternative 1 is absolutely important than 2), the numerical value of alternative 1 weighed against alternative 3 can be 5 (alternative 1 is strongly or essentially important than 3) while the numerical value of alternative 2 weighed against alternative 3 may be 7 (alternative 2 has very strong or demonstrated importance than 3). Saaty (1980) proposes the Eigenvalue method to compute pairwise comparison matrices. Each alternative weighed against itself is of equal importance (1).

At any level of the hierarchy the comparisons form a square matrix. Let the square matrix of m x n (m = = n) where the rows of the square matrix are denoted *i*(i=1 to m) and columns are denoted *j* (j=1 to n).

Let E be the elements of pairwise comparison matrix for alternative *i* over *j*.

$$E = e_{ij} \text{ (elements of the pairwise comparison matrix)} \qquad (5.2)$$

The elements of the pairwise comparison matrix are computed using equation 5.3.

$$e_{ij} = e_i / e_j \qquad (5.3)$$

where *i* and *j* are rows and columns of the pairwise comparison matrix respectively, and e_i is the value of element in row *i* while e_j is the value of element in column *j*. Suppose, the problem is decomposed into three levels, say, objective, criteria and alternatives, then the first pairwise comparison matrix is obtained by comparison of criteria with respect to the objective and the second pairwise comparison matrices are obtained by comparison of alternatives with respect to a criterion which results in matrices equivalent to the number of criteria. Suppose, there are *n* criteria for the objective (i.e. Criterion 1, Criterion 2 to Criterion n) with preference (numerical) values C_1, C_2 to C_n. Applying equation 5.3, the resulting pairwise comparison matrix is shown in Table 5.2.

Table 5.2 Pairwise Comparison Matrix for the Objective

Objective	Criterion1	Criterion 2	...	Criterion n
Criterion 1	$^{C1}/_{C1}=e_{11}$	$^{C1}/_{C2}=e_{12}$	...	$^{C1}/_{Cn}=e_{1n}$
Criterion 2	$^{C2}/_{c1}=e_{21}$	$^{C2}/_{C2}=e_{22}$	...	$^{C2}/_{Cn}=e_{2n}$
...	...	...	...	...
Criterion n	$^{Cn}/_{C1}=e_{n1}$	$^{Cn}/_{C2}=e_{n2}$	...	$^{Cn}/_{Cn}=e_{nn}$

If for each criterion, there are *m* alternatives that need to be selected, then *i* pairwise comparison matrices for *m* alternatives are computed with respect to each criterion *i* as shown in Table 5.3.

Table 5.3 Pairwise Comparison Matrix for alternative *k* with respect to criterion *i*

Criterion *i*	Alternative *1*	Alternative *2*	...	Alternative *m*
Alternative *1*	$^{CA1}/_{CA1}$	$^{CA1}/_{CA2}$	...	$^{CA1}/_{CAm}$
Alternative 2	$^{CA2}/_{CA1}$	$^{CA2}/_{CA2}$	...	$^{CA2}/_{CAm}$
.....	...	...	...	...
Alternative *m*	$^{CAm}/_{CA1}$	$^{CAm}/_{CA2}$	...	$^{CAm}/_{CAm}$

Note: C_{Ai} is the numerical value of alternative *i*.

After obtaining the pairwise comparison matrices, the next step is to normalize the matrices and then obtain the principal eigenvector. Obtaining the principal eigenvector is discussed later. This process is done for all levels. Then overall composite weights for *m* alternatives are computed. Normalization is obtained first by computing the total of each column *j* in pairwise comparison matrix (Saaty, 1980) and then values in each field in column *j* is divided by the sums of all fields in column *j* (referred to as column total in this study). The column total is expressed as($\sum_{i=1}^{n} eij$). Table 5.4 illustrates the computation of the pairwise comparison matrix column total.

Table 5.4 Sum of the Pairwise Comparison Matrix columns

Objective	Criterion1	Criterion 2	...	Criterion n
Criterion 1	$^{C1}/_{C1}=e_{11}$	$^{C1}/_{C2}=e_{12}$	...	$^{C1}/_{Cn}=e_{1n}$
Criterion 2	$^{C2}/_{c1}=e_{21}$	$^{C2}/_{C2}=e_{22}$	...	$^{C2}/_{Cn}=e_{2n}$
...	...	...	...	...
Criterion n	$^{Cn}/_{C1}=e_{n1}$	$^{Cn}/_{C2}=e_{n2}$	...	$^{Cn}/_{Cn}=e_{nn}$
Sum=$\sum_{i=1}^{n} eij$	$c1_T = \sum_{i=1,j=1}^{m} eij$	$c2_T=\sum_{i=1,j=2}^{m} eij$	...	$cn_T=\sum_{i=1,j=n}^{m} eij$

Normalization is given by the following expression:

$$e_{ij}n= \frac{eij}{\sum_{i=1}^{n} eij}\ , i, j=1, 2,\ldots n \qquad (5.4)$$

where $e_{ij}n$ is the normalized element, e_{ij} is the element in the column and $\sum_{i=1}^{n} eij$ is the total of the column. Table 5.5 illustrates calculation of normalized pairwise comparison matrix for criteria with respect to objective. After normalization, the sum of each column *j* of the matrix is equal to 1.

$$\sum_{i=1}^{n} eij= 1 \qquad (5.5)$$

In order to get the priority vector (V_i) for the criteria *i*, compute the average of each row of the normalized PCM (assume the normalized matrix is e'ij). Therefore,

$$V_i = \frac{1}{n}\sum_{j=1}^{n} e'ij,\ i=1 \text{ to } n \qquad (5.6)$$

This process is done for the other matrices in order to obtain the priority vector for the alternatives at each level of the hierarchy.

Table 5.5 Normalized PCM for objective and Priority Vectors for Criteria

Objective	Criterion 1	Criterion 2	…	Criterion N	Average (Priority Vector)
Criterion 1	$\frac{e11}{\sum_{i=1,j=1}^{m} eij}=e_{11}n$	$\frac{e12}{\sum_{i=1,j=2}^{m} eij}=e_{12}n$	…	$\frac{a1n}{\sum_{i=1,j=n}^{m} aij}=e_{1n}n$	$V_1=\frac{e11n+e12n+\ldots+e1nn}{3}$
Criterion 2	$\frac{e21}{\sum_{i=1,j=1}^{m} eij}=e_{21}n$	$\frac{e22}{\sum_{i=1,j=2}^{m} eij}=e_{22}n$	…	$\frac{e2n}{\sum_{i=1,j=n}^{m} eij}=e_{2n}n$	$V_2=\frac{e21n+e22n+\ldots+e2nn}{3}$
…	…	…	…	…	…
Criterion n	$\frac{en1}{\sum_{i=1,j=1}^{m} eij}=e_{n1}n$	$\frac{en2}{\sum_{i=1,j=2}^{m} eij}=e_{n2}n$	…	$\frac{enn}{\sum_{i=1,j=n}^{m} eij}=e_{nn}n$	$V_n=\frac{en1n+en2n+\ldots+ennn}{3}$
Sum	1	1	…	1	

To compute the local weights of alternative *i* $(1 \le i \le m)$ at any level of the hierarchy with respect to criterion C_i, use equation 5.7.

$$LW_i = \frac{PVi}{\sum PV} \qquad (5.7)$$

Where LW_i is the local weight of the ith alternative, PVi is the priority vector value of ith alternative and PV is the sum of the priority vector values of all alternatives at a level in the hierarchy. The maximum Eigen vector, λ_{max} is calculated by multiplying the column total in Table 5.7 and Priority Vectors in Table 5.8 according to equation 5.8 then,

$$\lambda_{max} = c1_T*V_1 + c2_T*V_2+...+ cn_T*V_n \tag{5.8}$$

where λ_{max} is the approximate maximum Eigenvalue for the pairwise comparison matrix.

Step 2: Next step is checking the consistency of evaluations' data. Because human being judgements are associated with inconsistency, Saaty (1980) suggested consistency checking after the priority vectors have been computed. Consistency checking is done to avoid contradictions or differences or conflicts of the evaluator judgement. Proving consistency of the evaluation judgements of different evaluators is important in order to visualize the trend of data if they are pointing in the right direction (i.e. association of the dataset). To measure the deviation from consistency AHP method uses the Consistency Index (Saaty, 1980).

Let CI be the consistency index,

$$CI = \frac{\lambda max - n}{n-1} \tag{5.9}$$

where λ_{max} is the larger Eigenvalue and n is the order of the matrix.

The Consistency Ratio (CR) (Teknomo, 2006) is defined as the ratio between the Consistency Index (CI) and Random Index (Saaty 1980). The random index (RI_n) for any n x n square matrix is given as a constant value, as shown in Table 5.6. Each pairwise comparison is checked against a predetermined consistency index. Even though it is impossible to come up with perfect consistency, Saaty (1980) established a threshold value of 0.10, which he determined to be an acceptable consistency ratio.

Table 5.6 Random Index (adapted from Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Let CR be the consistency ratio. Let RI be the random index, then

$$CR = \frac{CI}{RI} \qquad (5.10)$$

If CI = 0 then E is consistent; otherwise,

If CR ≤ 0.1 then E is consistent enough,

If CR ≥ 0.1 then E is seriously inconsistent,

where E are elements in the pairwise comparison matrix

Step 3: Computing global weights. This is the step whereby the relative importance of each element within the level (local weights) is merged/multiplied with the relative importance of each element in the parent level. This gives the global weights for each alternative. This is done using equation 5.1. For a three level hierarchy of objective, criteria and alternatives, the global weight of each alternative is calculated as shown in Equation 5.10 which is equivalent to equation 5.1.

$$P_{WI} = AC \ x \ (CO)^T \qquad (5.11)$$

Where: P_{WI}: Global (overall) weight of alternative *i*, *AC*: Local weights of the criteria with respect to the objective, and *CO*: Local weight of the alternatives with respect to criteria. Finally, the alternative with the highest weight value is selected.

Cheng et al. (1999) identified the following shortcomings of AHP; (i) It is used in nearly crisp decision applications; (ii) Deals with unbalanced scale of judgements (1 up to 9); (iii) Does not take into account any uncertainty associated when mapping human judgement to a number scale; (iv) The ranking of AHP is imprecise or inexact; (v) The subjective assessment of decision makers, and change of scale have great influence on the AHP outcome. Furthermore, Wang et al. (2008) found that the increase in the number of characteristics geometrically increases the number of pairwise comparisons by $O(n^2/_2)$ which can lead to inconsistency or failure of the algorithm. Also, AHP cannot solve non-linear models (Cheng et al., 1999).

In view of these AHP weaknesses, Fuzzy AHP that addresses these challenges is discussed in the following sections.

5.2.2 Fuzzy Analytical Hierarchy Process

Fuzzy theory has proven advantages for dealing with imprecise and uncertain decision situations and models human reasoning in its use of approximate information (Zadeh, 1965). Fuzzy set theory implements grouping of data with boundaries that are not distinctly defined. In conventional AHP, the pairwise comparison is established using a nine-point scale which indicates the human preferences between alternatives (Cheng et al., 1999). The discrete scale of AHP has the advantage of ease of use but, it cannot handle the uncertainty associated with the mapping of evaluators' preferences to a number (Kwong & Bai, 2002). The evaluators' judgements are normally vague and difficult to represent in terms of exact numbers but could best be given as interval judgements than fixed value judgements. Different types of fuzzy numbers (triangular or trapezoidal) are used to decide the priority of one decision variable over other (Buckely, 1985; Dubois et al., 2000). A triangular fuzzy number (TFN), Ñ is given by $a \leq b \leq c$ where b, a, and c are the most likely, the lower bounds and upper bounds decision values, respectively (Buckely, 1985; Dubois et al., 2000). The triangular fuzzy numbers (TFNs) Ñ are linear piece-wise membership functions, $\mu_n(x)$ of the form;

$$\mu_n(x) = \begin{cases} (x-a) / (b-a), & a \leq x \leq b \\ (c-x) / (c-b), & b \leq x \leq c \\ 0, & \text{Otherwise} \end{cases}$$

$$\text{where } \infty < a \leq b \leq x \leq c < \infty$$

Figure 5.3 shows a fuzzy number, which is characterized by a membership function. It differs from traditional set which defines an element as either belongs or does not belong to a set (i.e. 0 and 1). The fuzzy triangular membership function gives the foundation for defining other types of membership functions such as general triangular function, right-angled triangular function and trapezoidal function. For example when $a=b$ for a right-angled triangular membership function such as (*1*, *1*, *3*) (Buckley, 1985).

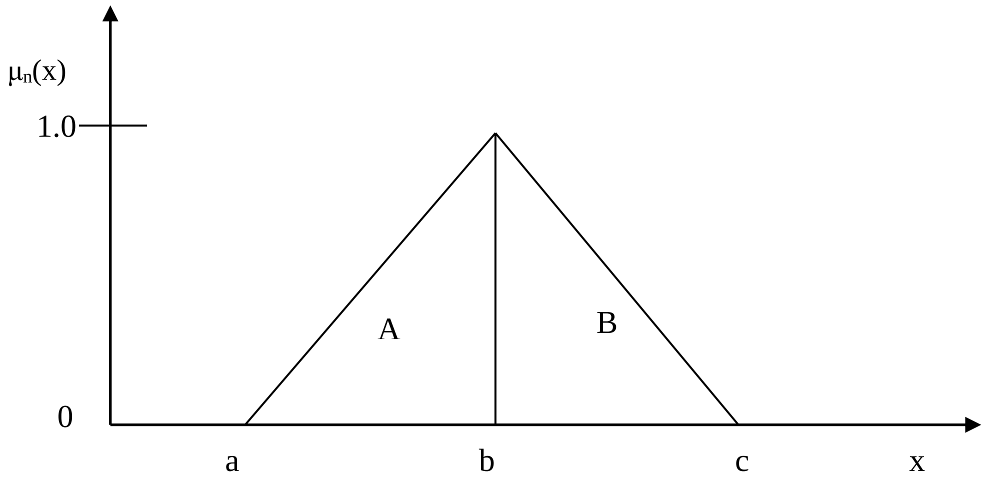


Figure 5.3 Fuzzy triangular numbers membership

When Saaty's nine scale values are converted into fuzzy numbers and the values used in AHP, the resulting algorithm is Fuzzy AHP (FAHP). There are many types of FAHP algorithms such as: FAHP (with extent analysis) (Chang, 1996; Zhu et al., 1999; Mikhailov, 2003), Fuzzy goal programming (Wang & Fu, 1997; Wang & Chin, 2008) and fuzzy preference programming (Bozdag et al., 2003). This study adopts the FAHP (with extent analysis) algorithm.

5.2.2.1 Fuzzy AHP (with extent analysis) Algorithm

This study proposes an algorithm specifically for partner evaluation and selection in the construction sector (Figure 5.4) that incorporates the concept of fuzzy extent analysis in AHP. The proposed FAHP (with extent analysis) algorithm has three steps, which is similar to conventional AHP except that in each step, fuzzy theory is introduced. Fuzzy extent analysis is used to obtain partners' selection criteria relative importance and partner performance preferences (Zhu et al., 1999). Thus, the computation of fuzzy extent analysis results in fuzzy weights.

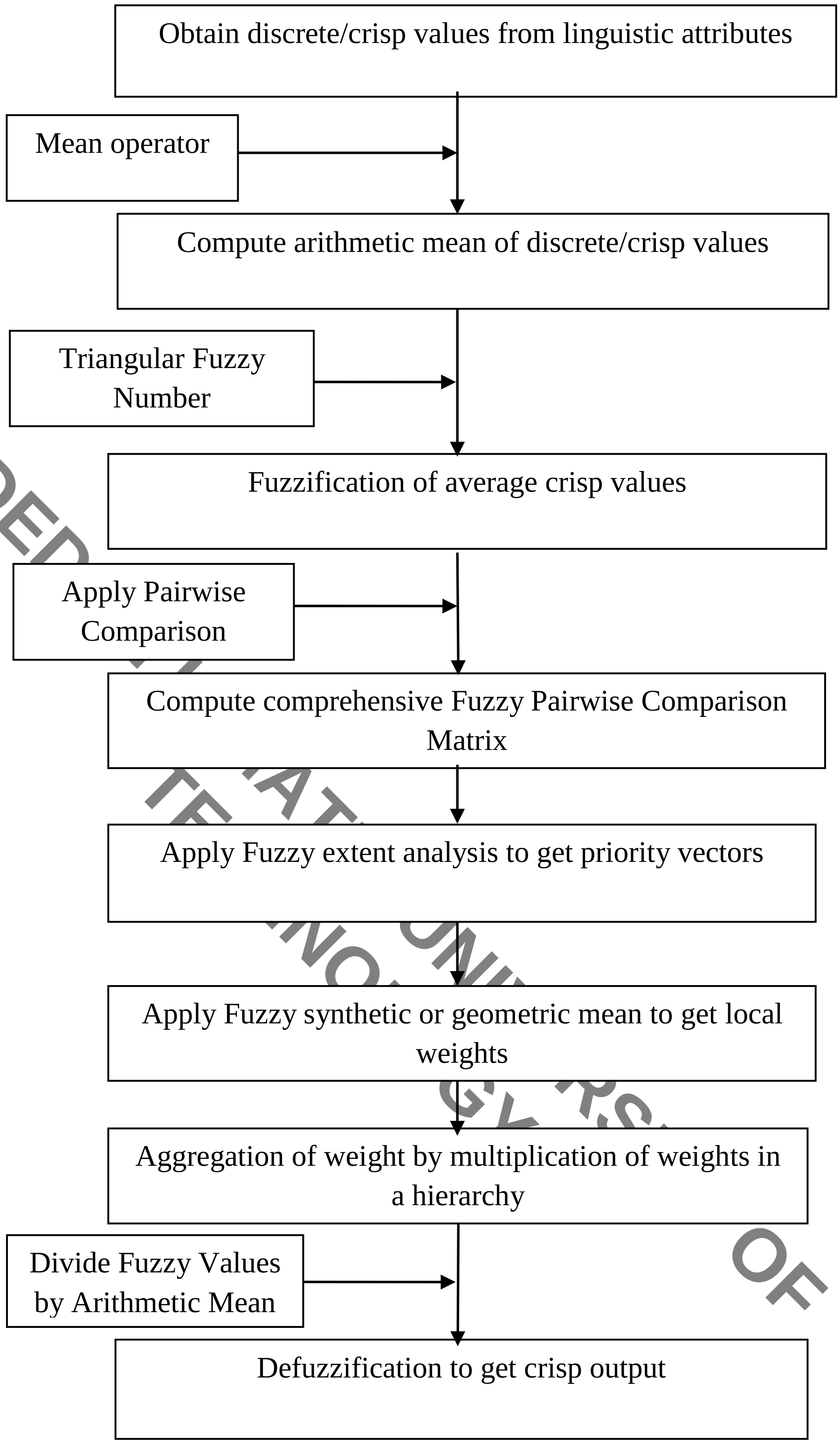


Figure 5.4 Proposed Fuzzy AHP (with extent analysis)

Steps of the proposed Fuzzy AHP algorithm for this study are as follows:

1. Obtain preference values / level of importance of alternatives (appendix C). This is done by choosing the linguistic attributes e.g. the statement “Indicate how important

each of the following criterion is when your company is selecting partners for structural engineering works in a building construction project" needs an evaluator to choose one answer from (extremely important, very important, important, weakly important and not at all important) to answer.

2. The chosen linguistic attributes are converted into numerical crisp values using Table 5.7. In the partner evaluation tool, alphabetical symbols (A, B, C, D, E) with matching nominal scales (extremely important, very important, important, weakly important and not at all important) are provided. These are converted to Saaty (1980) scale.

Table 5.7 Crisp Scale

Alphabetical symbol	**A**	**B**	**C**	**D**	**E**
Nominal	Extremely important	Very important	Important	Weakly important	Not at all important
Ordinal scale	5	4	3	2	1
Saaty scale	9	7	5	3	1
Ratio scale	10	8	6	4	1

3. Once the linguistic opinions are converted to numerical values, computation of the arithmetic mean of the numerical values is done and the averages of crisp values are converted to fuzzy scale using Table 5.8 and Figure 5.5.

Table 5.8 Conversion of nominal or crisp to fuzzy scale

Alphabetical Symbol	**A**	**B**	**C**	**D**	**E**
Nominal scale	Extremely important	Very important	Important	Weakly important	Not at all important
Crisp number	1	3	5	7	9
Fuzzy Membership function	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

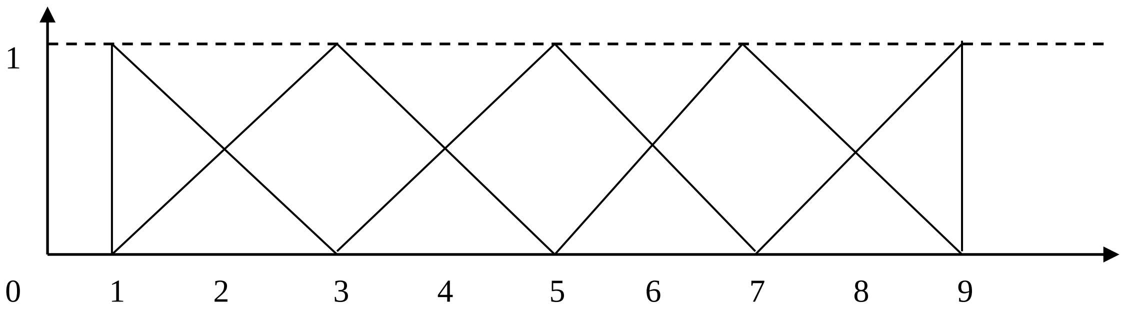


Figure 5.5 Fuzzy Membership for Table 5.8

The linguistic symbols obtained from evaluators can be converted directly to TFNs and their arithmetic mean computed. The use of weight mean operator helps to get the collective opinion of all participants. This is done to all lower bound, middle and upper bound triangular fuzzy values. The outcomes of this step are comprehensive fuzzy opinions.

4. Compute the pairwise comparisons matrices of the values of alternatives. This step gives the fuzzy pairwise comparison matrix in form of triangular fuzzy number *(l, m, u).* The pairwise comparison judgement matrix gives the preference of one alternative (A_i) over the other (A_j), and is given by $A_{ij} = \frac{Ai}{Aj}$ for i, j =1, 2, 3,...n.

5. Apply the fuzzy extent analysis to the pairwise comparison matrix. The basic procedures for fuzzy extent are adopted from Zhu et al. (1999) thus,

Let X = {x_1, x_2, x_3 ….x_n} be an object set (for this study object set is either the objective, criteria, or sub-criteria) and

G = {g_1, g_2, g_3, …g_n} be a goal defined for each level in the hierarchical structure. Thus, G can change depending on the level of the hierarchy.

M extent analysis on each object is taken

$$\acute{M}^1_{gi}, \acute{M}^2_{gi}, \acute{M}^3_{gi}, \ldots\ldots \acute{M}^m_{gi}, \quad i=1, 2, 3, \ldots\ldots, n \qquad (5.13)$$

where $\acute{M}^j_{gi}$ (j=1, 2, 3,…., m) are triangular fuzzy numbers (TFNs).

There are three procedures as explained in the following section for finding extent analysis of objects.

6.1 *First procedure*: The fuzzy synthetic extent value (S) with respect to the ith object is defined as,

$$S_i = \sum_{j=1}^{m} \acute{M}_{gi}^{j} * \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \acute{M}_{gi}^{j}\right]^{-1} \qquad (5.14)$$

*The symbol * in equation 5.14 is a multiplication operator*

To obtain $\sum_{j=1}^{m} \acute{M}_{gi}^{j}$, perform the normalized fuzzy addition operation of *m* extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} \acute{M}_{gi}^{j} = \left(\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj\right) \qquad (5.15)$$

where *l* is the lower limit (bound) value, *m* is the most promising value and *u* is the upper limit (bound) value. Table 5.9 is an example of a fuzzy pairwise comparison matrix.

Let *Ob1* represent object *1*, *Ob2* represent object *2* to *Obn* representing object *n*. Additionally, let *Obil* denote the lower TFN value, *Obim* denote the middle TFN value while *Obiu* denote the upper TFN value of the ith object. Therefore for *Ob1* in column 1, $\sum_{j=1}^{n} l1$ is found by getting the sum of $(\frac{Ob1l}{Ob1l}, \frac{Ob2l}{Ob1l}, ..., \frac{Obnl}{Ob1l})$, $\sum_{j=1}^{n} m1$ is found by getting the sum of $(\frac{Ob1m}{Ob1m}, \frac{Ob2m}{Ob1m}, ..., \frac{Obnm}{Ob1m})$ while $\sum_{i=1}^{n} u1$ is found by getting the sum of $(\frac{Ob1u}{Ob1u}, \frac{Ob2u}{Ob1u}, ..., \frac{Obnu}{Ob1u})$. The same process is repeated for columns 2, 3 to n for objects 2, 3 to n. Table 5.9 is then normalized in the same way it is done in conventional AHP. This is done by dividing each fuzzy number in a column with its respective sum of the column. That is lower bound elements are divided by the sum of lower bound elements. Likewise the same is done to middle and upper bound elements.

Table 5.9 Fuzzy Pairwise Comparison Matrix

Objective	***Object 1 (Ob1)***	***Object 2 (Ob2)***	**…**	***Object n (Obn)***
Object 1	$\frac{Ob1l}{Ob1l}, \frac{Ob1m}{Ob1m}, \frac{Ob1u}{Ob1u}$	$\frac{Ob1l}{Ob2l}, \frac{Ob1m}{Ob2m}, \frac{Ob1u}{Ob2u}$	**…**	$\frac{Ob1l}{Obnl}, \frac{Ob1m}{Obnm}, \frac{Ob1u}{Obnu}$
Object 2	$\frac{Ob2l}{Ob1l}, \frac{Ob2m}{Ob1m}, \frac{Ob2u}{Ob1u}$	$\frac{Ob2l}{Ob2l}, \frac{Ob2m}{Ob2m}, \frac{Ob2u}{Ob2u}$	**…**	$\frac{Ob2l}{Obnl}, \frac{Ob2m}{Obnm}, \frac{Ob2u}{Obnu}$
…	**…**	**…**	**…**	**…**
Object n	$\frac{Obnl}{Ob1l}, \frac{Obnm}{Ob1m}, \frac{Obnu}{Ob1u}$	$\frac{Obnl}{Ob2l}, \frac{Obnm}{Ob2m}, \frac{Obnu}{Ob2u}$	**…**	$\frac{Obnl}{Obnl}, \frac{Obnm}{Obnm}, \frac{Obnu}{Obnu}$
Sum	$\sum_{i=1}^{n} l1, \sum_{i=1}^{n} m1, \sum_{i=1}^{n} u1$	$\sum_{i=1}^{n} l2, \sum_{i=1}^{n} m2, \sum_{i=1}^{n} u2$	**…**	$\sum_{i=1}^{n} ln, \sum_{i=1}^{n} mn, \sum_{i=1}^{n} un$

Let us use $nl_{1,1}$, $nm_{1,1}$ and $nu_{1,1}$ to denote normalized values for column 1 in row 1, $nl_{1,1}$, $nm_{1,1}$ and $nu_{1,1}$ for column 2 in row 1 and $nl_{1,1}$, $nm_{1,1}$ and $nu_{1,1}$ for column 3 in row 1. If similar notations are applied to other rows and fuzzy addition of the rows of the normalized values is done, then results are as shown in Table 5.10.

Table 5.10 Fuzzy Addition of Normalized Pairwise Comparison Matrix

	Object 1 (Ob1)	**Object 2 (Ob2)**	**...**	**Object n (Obn)**	**Fuzzy Addition to obtain** $\sum_{j=1}^{m} \acute{M}_{gi}^{j}$
Object 1 (Ob1)	$nl_{1,1}$, $nm_{1,1}$, $nu_{1,1}$	$nl_{1,2}$, $nm_{1,2}$, $nu_{1,2}$	**...**	$nl_{1,n}$, $nm_{1,n}$, $nu_{1,n}$	$\sum_{j=1}^{m} l1$, $\sum_{j=1}^{m} m1$, $\sum_{j=1}^{m} u1$
Object 2 (Ob2)	$nl_{2,1}$, $nm_{2,1}$, $nu_{2,1}$	$nl_{2,2}$, $nm_{2,2}$, $nu_{2,2}$	**...**	$nl_{2,n}$, $nm_{2,n}$, $nu_{2,n}$	$\sum_{j=1}^{m} l2$, $\sum_{j=1}^{m} m2$, $\sum_{j=1}^{m} u2$
...	**...**	**...**	**...**	**...**	**...**
Object n (Obn)	$nl_{n,1}$, $nm_{n,1}$, $nu_{n,1}$	$nl_{n,2}$, $nm_{n,2}$, $nu_{n,2}$	**...**	$nl_{n,n}$, $nm_{n,n}$, $nu_{n,n}$	$\sum_{j=1}^{m} ln$, $\sum_{j=1}^{m} mn$, $\sum_{j=1}^{m} un$
$\sum_{i=1}^{n}\sum_{j=1}^{m} \acute{M}_{gi}^{j}$					$\sum_{i=1}^{n} li$, $\sum_{i=1}^{n} mi$, $\sum_{i=1}^{n} ui$

Values in the fourth column of the first row are obtained as follows:

$\sum_{j=1}^{m} l1 = nl_{1,1} + nl_{1,2} + \ldots + nl_{1,n}$,

$\sum_{j=1}^{m} m1 = nm_{1,1} + nm_{1,2} + \ldots + nm_{1,n,}$,

$\sum_{j=1}^{m} u1 = nu_{1,1} + nu_{1,2} + \ldots + nu_{1,n.}$

Similarly, values in the second row are obtained as:

$\sum_{j=1}^{m} l2 = nl_{2,1} + nl_{2,2} + \ldots + nl_{2,n}$,

$\sum_{j=1}^{m} m2 = nm_{2,1} + nm_{2,2} + \ldots + nm_{2,n}$,

$\sum_{j=1}^{m} u2 = nu_{2,1} + nu_{2,2} + \ldots + nu_{2,n},$

while values in the last row are obtained as:

$\sum_{j=1}^{m} ln = nl_{n,1} + nl_{n,2} + \ldots + nl_{n,n},$

$\sum_{j=1}^{m} mn = nm_{n,1} + nm_{n,2} + \ldots + nm_{n,n},$

$\sum_{j=1}^{m} un = nu_{n,1} + nu_{n,2} + \ldots + nu_{n,n}.$

To obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} \acute{M}_{gi}^{j}\right]$, perform the fuzzy addition operation of

M_{gi}^{j} (j=1, 2,….m) values such that;

$$\sum_{i=1}^{n}\sum_{j=1}^{m} \acute{M}_{gi}^{j} = \left(\sum_{i=1}^{n} li,\ \sum_{l=1}^{n} mi,\ \sum_{l=1}^{n} ui\right) \qquad (5.16)$$

where;

$\sum_{i=1}^{n} li = \sum_{j=1}^{m} l1 + \sum_{j=1}^{m} l2 + \ldots + \sum_{j=1}^{m} ln,$

$\sum_{i=1}^{n} mi = \sum_{j=1}^{m} m1 + \sum_{j=1}^{m} m2 + \sum_{j=1}^{m} mn,$ and

$\sum_{i=1}^{n} ui = \sum_{j=1}^{m} u1 + \sum_{j=1}^{m} u2 + \ldots + \sum_{j=1}^{m} un$

The inverse of the vector above is then computed, such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} \acute{M}_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} ui}, \frac{1}{\sum_{i=1}^{n} mi}, \frac{1}{\sum_{i=1}^{n} li}\right) \qquad (5.17)$$

Note: Inverse of a fuzzy number N (l, m, u) is N^{-1} ($^1/_l$, $^1/_m$, $^1/_u$)

Thus equation 5.14 then becomes:

$$\left(\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj\right) * \left(\frac{1}{\sum_{i=1}^{n} ui}, \frac{1}{\sum_{i=1}^{n} mi}, \frac{1}{\sum_{i=1}^{n} li}\right)$$

Recall that if an inverse of a fuzzy number N^{-1} ($^1/_l$, $^1/_m$, $^1/_u$), the value to be multiplied is given in reversed order thus ($^1/_u$, $^1/_m$, $^1/_l$).

The outcome of the first procedure extent values of each alternative which are still fuzzy in nature. These are referred to as blocks of fuzzy extent values. Block 1 is for alternative 1, block 2 for alternative 2 and so on.

6.2 *Second procedure: Layer simple sequencing (Defuzzification of extent analysis values)*

There are two alternatives that can be used to implement this procedure. The first procedure is the original Fuzzy AHP technique. The second procedure is a proposed modification to the Fuzzy AHP.

6.2.1 Alternative one-Fuzzy Synthetic Method.

Fuzzy synthetic method (Mikhailov, 2003) compares each block (alternative) pair by pair towards the overall goal. This gives the sequencing weight vector, V_i, for each block. The same procedure is done when finding the local weights for all levels in the hierarchy. Bozdag et al. (2003) stated that given two triangular fuzzy numbers $\dot{F}_1(l_1, m_1, u_1)$ and $\dot{F}_2\ (l_2, m_2, u_2)$, the degree (D) of possibility that $\dot{F}_1\ (l_1, m_1, u_1) \geq \dot{F}_2\ (l_2, m_2, u_2)$ is defined as,

$$D\ (\dot{F}_1 \geq \dot{F}_2) = \begin{cases} 1, & if\ m_1 \geq m_2 \\ 0, & if\ u_1 \leq l_2 \\ \frac{l1-u2}{(m2-u2)-(m1-l1)}, & otherwise \end{cases} \qquad (5.18)$$

To explain equation 5.18, we consider two fuzzy numbers $\dot{F}_1 = (l_1, m_1, u_1)$ and $\dot{F}_2 = (l_2, m_2, u_2)$. For a sensible comparison between these two fuzzy numbers, it should be investigated both the degree of possibility that $\dot{F}_1$ is bigger than or equal to $\dot{F}_2$ and the degree of possibility that $\dot{F}_1$ is smaller than or equal to $\dot{F}_2$. Let $D\ (\dot{F}_1 \geq \dot{F}_2)$ denote the degree of possibility that $\dot{F}_1$ is bigger than or equal to $\dot{F}_2$. We have three possible cases for $D(\dot{F}_1 \geq \dot{F}_2)$:

Case 1: If $m_1 \geq m_2$, then we have $D(\dot{F}_1 \geq \dot{F}_2)=1$.

Case 1: If $u_1 \leq l_2$, then we have $D(\dot{F}_1 \geq \dot{F}_2)=0$.

Case 3: For all other possible cases the corresponding degree of possibility is given

by $D(\dot{F}_1 \geq \dot{F}_2) = \frac{l1-u2}{(m2-u2)-(m1-l1)}$

For a logical comparison, Chang (1996) uses the degree of possibility that a fuzzy number $\dot{F}i$ is to be greater than *k* fuzzy numbers. This term can be written as follows:

$$D(\dot{F}_i \geq \dot{F}_1,... \dot{F}_n) = (D(\dot{F}_i \geq \dot{F}_1) \wedge (\dot{F}_i \geq \dot{F}_2) \wedge,... D(\dot{F}_i \geq \dot{F}_n)) \qquad (5.19)$$

The principle of fuzzy number comparison (Chang, 1996) states that the degree of possibility that a fuzzy number F_i is greater than or equal to a set of fuzzy numbers is equal to the minimum degree of possibility among these values. This is stated as:

$$D(\dot{F}_i \geq \dot{F}_1,... \dot{F}_n) = \min (D(\dot{F}_i \geq \dot{F}_j \mid j=1,2,3..., n)) \qquad (5.20)$$

Consider the synthetic extent values S_i found from matrix of (n x n), then the degree of possibility of the i[th] alternative is given by: $\min(D(S_i \geq S_j \mid j=1,\ldots,n; j \neq i)$

6.2.2 Alternative two: Geometric Mean Method (Modified Fuzzy AHP)

For each block, a geometric mean of the fuzzy extent values is computed. This gives the priority vector, V_i, for each block. The same procedure is done when finding the local weights for all levels in the hierarchy. For both alternatives, the non-normalized priority vector for *n* elements becomes:

$$Pv_i' = (h'_1, h'_2.., h'_n)^T \quad i=1, 2, ...n \qquad (5.21)$$

where h_i' is the priority vector value for each of the n alternatives.

6.3 Third procedure: Normalizing the sequencing vector obtained in the second procedure. The local weight is found by normalizing the components of this vector using integral value (Liou & Wang, 1992; Bozdag et al., 2003) approach. This approach can be used in computing a wide of range of defuzzification values between 0 and 1 which is similar to the fuzzy state of reasoning of the evaluators.

$$PV_i = h'_i / \sum_{i=1}^{n} h'i: PV = (h_1, h_2.., h_n)^T. \qquad (5.22)$$

This becomes the local weight of alternatives in each level of the hierarchy. Global weights for partners are derived by multiplying local weights in lower hierarchy to local weights in the parent elements in the hierarchy using equation 5.1. The partner with the highest weight is selected. This method is time consuming. RGFAHP can handle fuzzy values of evaluation and take a lesser time.

5.2.3 Reduced Group Fuzzy AHP

This new algorithm has both features for AHP and FAHP. First, obtain evaluation comparison judgements of different alternatives in crisp values, as it is done in AHP. Then crisp values are fuzzified using triangular fuzzy number as it is done in FAHP. The arithmetic average of the fuzzified evaluators' opinions is found and a fuzzy pairwise comparison matrix is formed. From literature, this is based on Group Decision Making Algorithm (Tang & Zhang, 2007). The steps of the RGFAHP are illustrated in Figure 5.6 below.

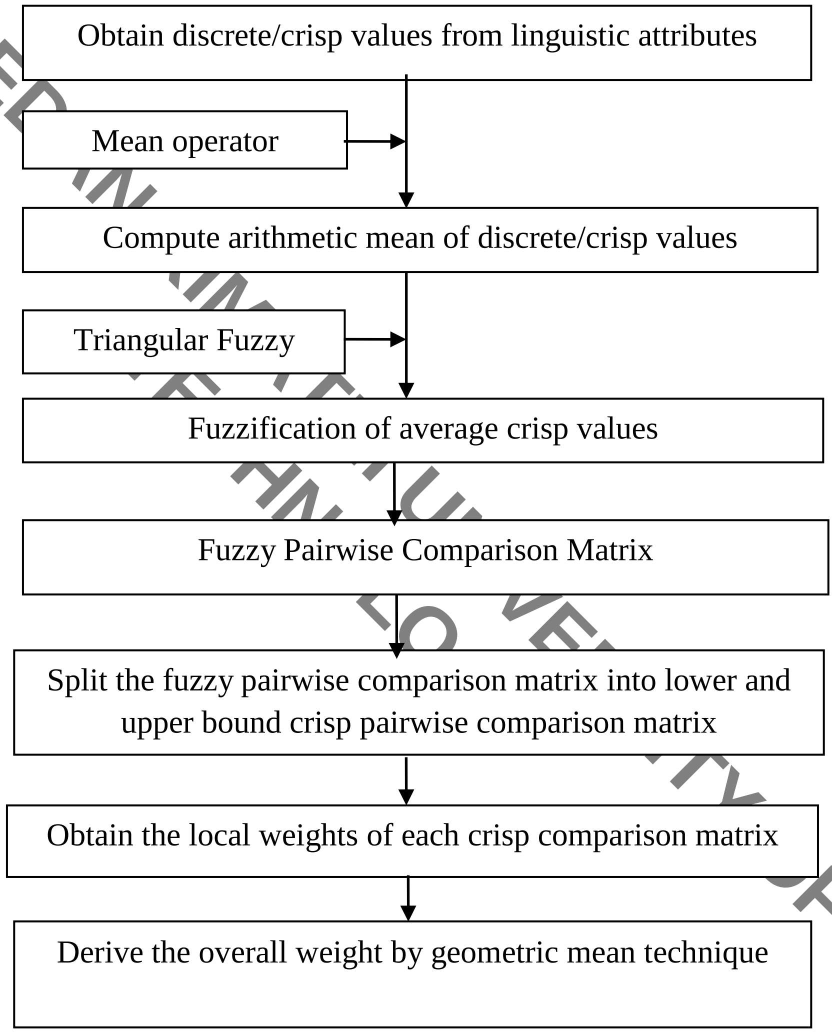


Figure 5.6 Reduced Group Fuzzy AHP

Steps of the proposed Reduced Group Fuzzy AHP algorithm are as follows:

1. Obtain preference values / level of importance of alternatives (appendix C). This is done by choosing the linguistic attributes e.g. the statement “Indicate how important

each of the following criterion is when your company is selecting partners for structural engineering works in a building construction project" needs an evaluator to choose one answer from (extremely important, very important, important, weakly important and not at all important) to answer.

2. The chosen linguistic attributes are converted into numerical crisp values using Table 5.7. In the partner evaluation tool, alphabetical symbols (A, B, C, D, E) with matching nominal scales (extremely important, very important, important, weakly important and not at all important) are provided. These are converted to Saaty (1980) scale.

3. Once the linguistic opinions are converted to numerical values, computation of the arithmetic mean of the numerical values is done and the average of crisp values, are converted to fuzzy using Table 5.8 and Figure 5.5. The linguistic symbols obtained from evaluators can also be converted directly to TFNs and their arithmetic mean computed. The use of weight mean operator helps to get the collective opinion of all participants. This is done to all lower bound, middle and upper bound triangular fuzzy values. The outcomes of this step are comprehensive fuzzy opinions.

4. Compute the pairwise comparisons matrices of the values of alternatives. This step gives the fuzzy pairwise comparison matrix in form of triangular fuzzy number *(l, m, u).* The pairwise comparison judgement matrix gives the preference of one alternative (A_i) over the other (A_j), and is given by $A_{ij} = {}^{A_i}/_{A_j}$ for i, j =1, 2, 3,...n.

5. The fuzzy comparison matrix is split into two parts. The lower bound values are used to form lower PCM while upper bound values form upper PCM. These PCMs have crisp values, therefore, AHP approach is used to derive priority vectors after confirming the evaluators' consistency using Saaty (1980)'s method. Priority vector of lower PCM is combined with upper PCM using geometric mean. The elements of the pairwise comparison matrices are computed using equation 5.3. After obtaining the pairwise comparison matrices, the next step is to normalize the matrices and then obtain the principal eigenvectors. This process is done for all levels.

6. Computing global weights. This is the step whereby the relative importance of each element within the level (local weights) is merged/multiplied with the relative importance of each element in the parent level. This gives the global weights for

each alternative. This is done using equation 5.1. For a three level hierarchy of objective, criteria and alternatives, the final overall weight of each alternative is calculated as shown in Equation 5.11 which is equivalent to equation 5.1.

5.3 Chapter Summary

This chapter has discussed MCDM techniques applied in this study. The AHP (Saaty, 1980) is a method for modelling unstructured decision-making problems. It is an MCDM method that uses pairwise comparisons of alternatives to derive weights of importance from a multi-level hierarchical structure of objectives, criteria, sub-criteria and partners. In cases where the comparisons are not perfectly consistent, it provides an uncomplicated method for improving the consistency of the comparisons, by using the Eigenvalue method and consistency checking method. The hierarchical structure fits well with the hierarchical structure of a partner evaluation and selection problem.

Fuzzy theory has proven advantages for dealing with imprecise and uncertain decision situations and models human reasoning in its use of approximate information. Fuzzy set theory implements grouping of data with boundaries that are not distinctly defined. The evaluators' judgements are normally vague and difficult to represent in terms of exact numbers but could best be given as interval judgements than fixed value judgements. Different types of fuzzy numbers (triangular or trapezoidal) are used to decide the priority of one decision variable over other.

RGFAHP algorithm has both features for AHP and FAHP. Evaluation comparison judgements of different alternatives in crisp values are obtained as done in AHP. The crisp values are fuzzified using TFN as done in FAHP. The average of the fuzzified evaluators' opinions is computed and a fuzzy pairwise comparison matrix is formed.

In the next chapter, experimentation and simulation of VEs is discussed.

CHAPTER SIX

6.0 EXPERIMENTATION AND SIMULATION

6.1 Introduction

Analysis of focus group interview responses was performed using code mapping (mapping of data to clusters) which categorizes the responses from evaluators according to selected themes. The results of the analysis informed the design of the evaluation tool (questionnaire). Evaluators use the evaluation tool to indicate their preference / importance of selection criteria and sub-criteria in evaluating and selecting partners. Partners are then weighed against each other using their profiles according to how they satisfy a specific sub-criterion. To determine the accuracy of these techniques, data is obtained from six case study groups. The mean of their opinions are subjected to the MCDM techniques. MCDM techniques are used to simulate different knowledge based scenarios by evaluators from the six case studies. Partner performance evaluation criteria are used to predict partners' performance.

6.2 Partners Evaluation and Selection Factors

First, determination of evaluation and selection criteria is done followed by determination of partner performance evaluation criteria. To determine partner evaluation and selection criteria, data from focus group (experts) interviews were categorized. Categories include: Technical capability (TC), development speed (DS), cost of development (CD), Information Technology (IT), financial security (FS), business strength (BS), strategic position (SP), collaboration record (CR), cultural compatibility (CC) and management ability (MA). Specific categories were then put in general categories. Technical skills comprised TC, DS, CD and IT while FS, BS, SP and CR, CC, MB were categorized as Business Skills and Management Skills respectively. Constant comparative analysis aided in identifying patterns and categories.

At the lowest level, TC comprised the following factors: capacity, customer services, value-adding capabilities, skills, experience, complementation in core capabilities; DS comprised delivery time, development speed, task completion probability; CD comprised price/cost, task price; IT comprised design capabilities, communication techniques while FS comprised financial position, credit worthiness, risk, uncertainty, caution price; BS comprised commitment to quality, partner flexibility, reputation, communication mechanism, market position, size of company, reliability, partner resources, security; SP comprised partner performance, location, strategic goals; CR comprised previous collaboration experience, ability to work as a team, relationship between staff; CC comprised matching of corporate cultures, trust, confidentiality. Finally, MA comprised management style, openness.

The following section explains the sub criteria considered. Technical capabilities, requires that partners should have relevant types of skills and experience for the task. Development speed, assesses the capability of a partner to complete tasks within project timelines. Financial security, is important because it reveals the financial strength of the partner. The partner deposits some amount of money before project commencement. Collaborative record, determines the ability of the partner to work in a team. This is done by examining the successful projects the partner has been part of. Business strength, examines the necessary equipment and qualified staff of the partner. Cost of development, determines the ability of the partner to implement a task within the project budget. Corporate cultural compatibility, examines staff management style in the previous projects and corporate culture of the partner. Strategic position, is about the partnerships with other firms like financiers during previous projects. Management ability, indicates how the partner relates with staff and handles staff issues. Use of Information Technology, determines the partner's ability to use software for designs, finance and staff management issues.

Miles and Huberman (1994) suggested that initial clustering be conducted to find conditions among the participants, as a method of pointing to regularities in the setting. As Bogdan and Biklin (1982) explained, "certain words, phrases, patterns of behaviour, subject's ways of thinking repeat and stand out". These categorizations of evaluation and selection factors can be represented in a hierarchical structure. The hierarchy shown in Figure 6.1 represents a decision problem for a specific task. This hierarchy is composed of four levels: objective, criteria, sub-criteria and partners. The overall objective of the problem is the task of partner evaluation and selection, the criteria for evaluating and selecting partners are technical, management and business, sub-criteria for each criterion are defined and the partners to be considered.

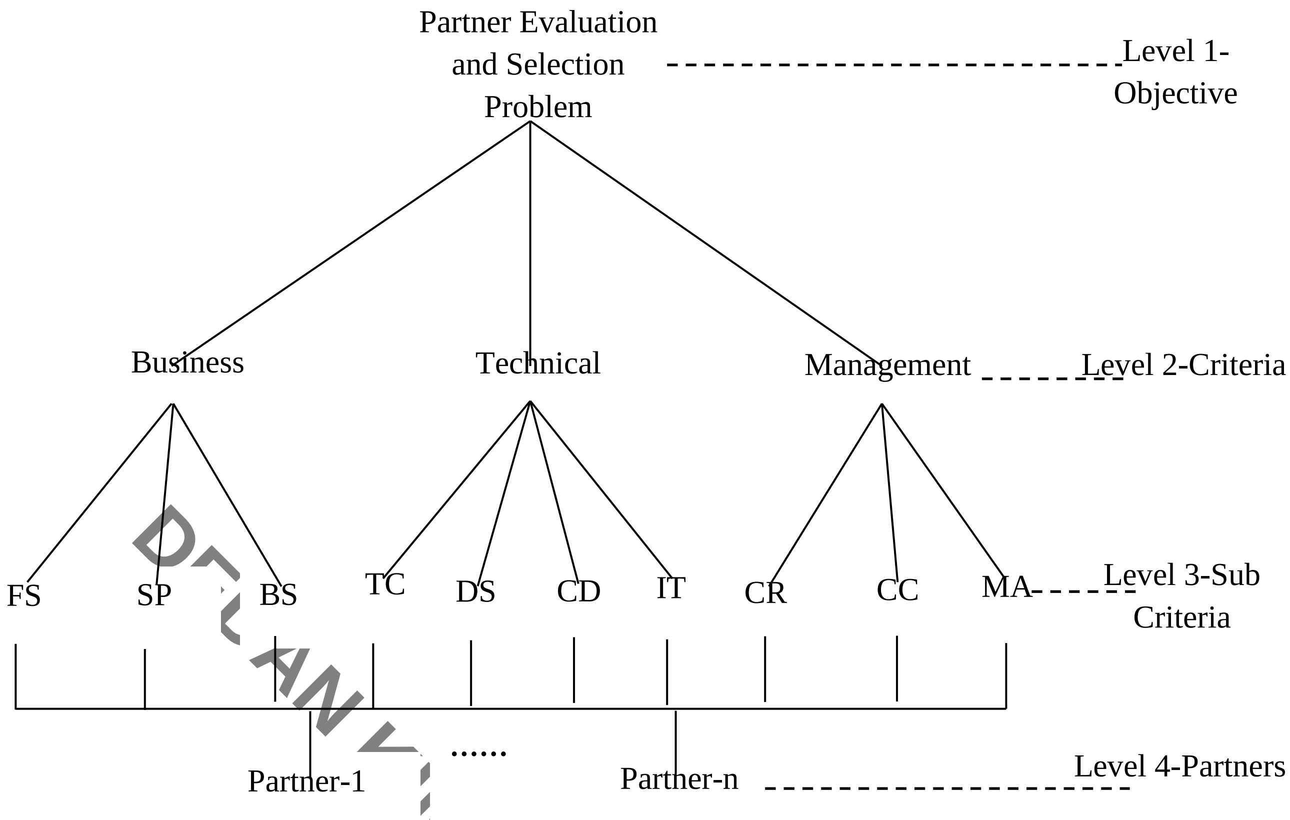


Figure 6.1 Hierarchical Structure of the Partner Evaluation and Selection Problem

At level 1, objective of the problem is defined as provided by the project owner. The objective in this case is the partner evaluation and selection problem of a construction project.

At level 2, the evaluation and selection criteria are defined. The problem can be solved if the right criteria are defined. The potential partners are selected based on these criteria.

At level 3, the evaluation and selection sub-criteria are defined. For each criterion, sub-criteria are defined. Preference values of partners are dependent on how they satisfy the sub-criteria.

At level 4, potential partners' profiles are provided. Partners are weighed against each other depending on how they satisfy a given sub-criterion.

At each level local weights are computed and the overall weights of partners are calculated.

6.3 Experimentation

MCDM algorithms are applied to data from evaluators. The results of each algorithm are discussed. Evaluation tool required categorical responses. Numerical values were allocated to these categorical responses. Responses of all evaluators were categorized. There are two methods for computing combined group decisions in AHP, FAHP and RGFAHP: (i) using either the arithmetic mean or the geometric mean of individual respondents' judgements and (ii) using either the arithmetic mean or the geometric mean of the individually calculated relative weights (Forman & Peniwati, 1998). The first method is used if the group of the respondents acts as a unit while the second method is used if the group acts as a combination of individuals. The first method was used in this study.

6.3.1 Application of AHP Algorithm

The results derived when applying AHP, gives the relative weights for each criterion, sub-criterion and partners. The averages of evaluators' opinions after conversion from linguistic to Saaty scale for each criterion in Figure 6.1 were obtained as 9, 7, 7 for business, technical and management criterion respectively. These values could vary for a different set of evaluators. AHP checks the consistency of the evaluations and as long as the values are consistent, they are considered valid and reliable. The pairwise comparison matrix (PCM) for the level is derived as follows.

Table 6.1 Pairwise Comparison Matrix for Level 2 in Figure 6.1

Criteria	Business	Technical	Management
Business	1.000	1.286	1.286
Technical	0.778	1.000	1.000
Management	0.778	1.000	1.000
Sum	2.556	3.286	3.286

Divide numerical value of one criterion by the value of another criterion. Business skills criterion against itself is 9/9=1, business skills against technical skills is 9/7= 1.286. Same applies to business and management skills criteria. These are the values in the upper diagonal of Table 6.1. Values in the lower diagonal of the Table are the reciprocals of the respective values in the upper diagonal. Technical criterion against business criterion is the reciprocal of business criterion against technical criterion which is 1/1.286=0.778. Values in Table 6.1 are then normalized by dividing the values of each field in a column by the sum of the values in the specific column. This results in values in Table 6.2.

Table 6.2 Normalized PCM, Priority Vector and Local Weights for Criteria

Criteria	Business	Technical	Management	Priority Vector	Local Weights
Business	0.391	0.391	0.391	0.391	0.391
Technical	0.304	0.304	0.304	0.304	0.304
Management	0.304	0.304	0.304	0.304	0.304

For instance normalized value for business against business, field 1 of column 1, is 1/2.55=0.391 and normalized value for technical against business, field 2, column 1, is 0.778/2.556=0.304. Then averages of normalized values in each row are derived which are the priority vector. Average of row 1 of Table 6.2 which is for business criterion is 0.391. Then arithmetic mean for technical and management criteria are 0.304. To derive the local weights for each criterion, normalize the priority vector values by finding the quotient of each vector value by the sum of the vector values. For example local weight for business criterion is:

0.391/(0.391+0.304+0.304)= 0.391.

To determine if the data collected from evaluators were consistent, maximum approximate Eigen value, λ_{max}, is calculated by finding the sum of the products of priority vector values of criterion in Table 6.2 and respective totals of the column of PCM values for the respective criterion in Table 6.1. In this case λ_{max} = 2.556 x 0.391 + 3.286 x 0.304 + 3.286 x 0.304 = 3.000. Saaty (1980) suggests that Consistency Index (CI) of a matrix of order n is $\frac{\lambda max - n}{n-1}$ and values are consistent if CI $\leq$ 0.1. In this case, n=3 and CI = $\frac{3-3}{2}$ = 0. This process is repeated for level 3 and 4 to find local weights for sub criteria and partners.

The averages of partners' evaluators' opinions after conversion from linguistic to Saaty scale for Business sub criteria; financial security (FS), business strength (BS) and strategic position (SP) were 9, 5, 3 respectively; Technical sub criteria, technical capability (TC), development speed (DS), cost of development (CD) and information technology (IT) were 9, 5, 7 and 3 respectively and Management sub criteria, collaboration record (CR), cultural compatibility (CC) and management ability (MA) were 9, 3 and 5 respectively. Tables 6.3 to 6.5 show the local weights of each sub criteria. In addition, they show the largest Eigenvalue, Consistency Index (CI) and the Consistency Ratio (CR) of each pairwise comparison matrix. The results show that all the pairwise comparison matrices have a CR smaller than 0.1 and therefore are considered consistent. The Local weights for each matrix identify the most important alternative.

Table 6.3 Local Weights for Business Criterion

Sub criterion	SP	FS	BS	Local Weights
SP	1.00	0.33	5.00	0.170
FS	3.00	1.00	1.80	0.527
BS	1.70	0.60	1.00	0.303

λ_{max} = 2.99, CI =0.001, CR = 0.0

In the Business criterion, Financial Security has the highest weight of 0.527.

Table 6.4 Local Weights for Technical Criterion

Sub criterion	TC	DS	CD	IT	Local Weights
TC	1.00	1.80	1.30	3.00	0.379
DS	0.55	1.00	0.71	1.70	0.214
CD	0.77	1.40	1.00	2.33	0.286
IT	0.33	0.60	0.43	1.00	0.121

λ_{max} = 3.95, CI = 0.016, CR = 0.018

In the Technical criterion, Technical Capability ranks first with a local weight of 0.379.

Table 6.5 Local Weights for Management Criterion

Management Criterion	CC	MA	CR	Local Weights
CC	1.00	0.60	0.33	0.186
MA	1.70	1.00	0.55	0.321
CR	3.00	1.20	1.00	0.494

λ_{max} = 2.890, CI = 0.055, CR = 0.095

In the Management criterion, Collaborative Record (CR) ranks first with a value of 0.494.

Global weights are derived by merging/multiplying local weights of alternatives at lower levels in the hierarchy by local weights of alternatives in the parent levels in the hierarchy. Thus global weights for the business, technical and management criteria were calculated as shown in Tables 6.6 to 6.8.

Table 6.6 Global Weights for Business Criterion

Criterion	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**
Business	0.391	FS	0.527	0.206
		SP	0.170	0.066
		BS	0.303	0.118

Global weight for FS is derived as 0.527 x 0.391 = 0.206, SP, 0.170 x 0.391 = 0.066 and 0.303 x 0.391 = 0.118 for BS. The same is done for Technical and Management criteria as shown in Tables 6.7 and 6.8.

Table 6.7 Global Weights for Technical Criterion

Criterion	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**
Technical	0.304	TC	0.379	0.115
		DS	0.214	0.065
		CD	0.286	0.087
		IT	0.121	0.037

Table 6.8 Global Weights for Management Criterion

Criterion	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**
Management	0.304	CR	0.496	0.151
		CC	0.188	0.057
		MA	0.316	0.096

Evaluators give their preference values of partners for a specific sub criterion. In this case, Table 6.9 shows the relative weights of partners for FS.

Table 6.9 PCM and Local Weights for Partners Financial Security Sub-criterion

FS	P1	P2	P3	P4	P5	Local Weights
P1	1.000	0.200	0.333	0.125	0.150	0.333
P2	5.000	1.000	4.000	3.000	7.000	0.167
P3	3.000	0.250	1.000	0.200	9.000	0.233
P4	8.000	0.112	3.000	1.000	0.500	0.112
P5	6.667	0.143	0.111	2.250	1.000	0.155

For each sub criterion, partners 1 to 5 were evaluated. The local weights for all factors at all levels applied to Figure 6.1 yields Figure 6.2. Table 6.10 below summarizes the results of this process.

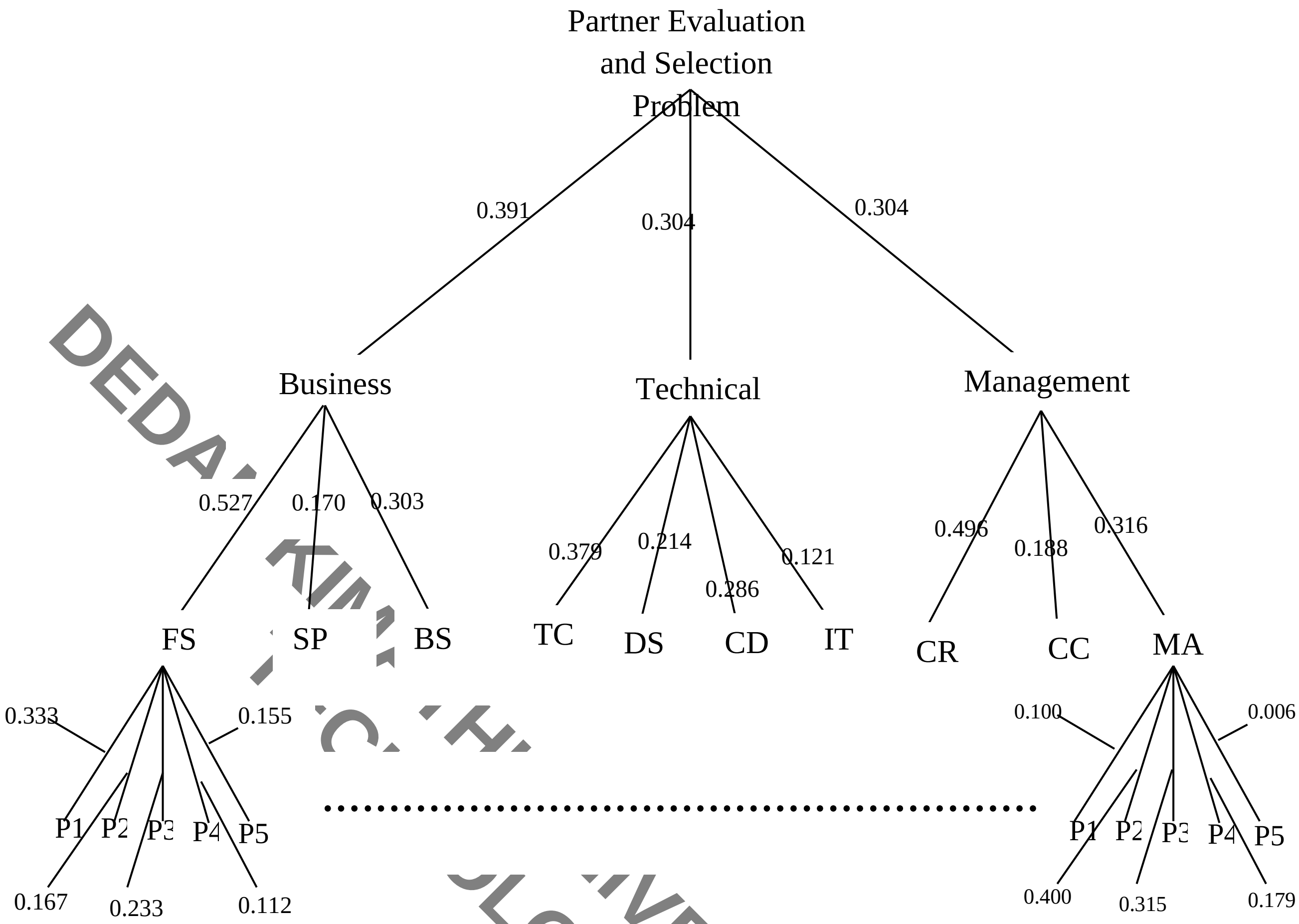


Figure 6.2 Computations of Partners Relative Weights in AHP

Table 6.10 Results of Evaluation using AHP

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.391	FS	0.527	0.206	0.333	0.167	0.233	0.112	0.155
		SP	0.170	0.066	0.433	0.167	0.111	0.101	0.188
		BS	0.303	0.118	0.285	0.143	0.333	0.154	0.085
Technical	0.304	TC	0.379	0.115	0.188	0.250	0.167	0.274	0.121
		DS	0.214	0.065	0.129	0.375	0.115	0.122	0.259
		CD	0.286	0.087	0.250	0.150	0.368	0.211	0.021
		IT	0.121	0.037	0.133	0.267	0.267	0.194	0.139
Management	0.304	CR	0.496	0.151	0.367	0.333	0.211	0.022	0.067
		CC	0.188	0.057	0.200	0.100	0.066	0.289	0.345
		MA	0.316	0.096	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.264	0.233	0.229	0.150	0.122
				Total	0.998				
				Error	0.002				

To calculate the overall weights for partners (referred to as Priority Weight, PW), the global weights for each sub-criterion in each criterion is multiplied by the local weights of each partner according to a sub-criterion. After this, the sum of the products (partner local weights multiplied by sub-criterion global weights) of each partner is computed. This is illustrated in the following section.

$$\begin{bmatrix} 0.333 & \cdots & 0.155 \\ \vdots & \ddots & \vdots \\ 0.100 & \cdots & 0.006 \end{bmatrix} \text{ x } \begin{Vmatrix} 0.206 \\ \vdots \\ 0.096 \end{Vmatrix} = \begin{Vmatrix} 0.264 \\ \vdots \\ 0.122 \end{Vmatrix}$$

Global weight (GW) for FS is derived by multiplying local weight of Business criterion by local weight of FS, which is 0.391 x 0.527 = 0.206; GW for TC is 0.304 x 0.379=0.115. Likewise GW for CC is 0.304 x 0.188=0.057. Finally Priority Weight (PW) for partners is derived by finding the sum of products of global weights of each sub criterion and the local weight of the partner in the sub criterion. For instance PW for partner 1 is 0.206 x 0.333 + 0.066 x 0.433 + 0.118 x 0.285 +0.155 x 0.188 + 0.065 x 0.129 + 0.087 x 0.250 + 0.037 x 0.133 + 0.151 x 0.367 + 0.057 x 0.200 + 0.096 x 0.100 = 0.264. PWs for partners 2 to 5 are derived in the same way. If all is perfect the sum of the weights for partners should be 1. From Table 6.10 the sum is 0.998 with an error of 0.002. The PWs of Partner 1 through 5 was 0.264, 0.233, 0.229, 0.150 and 0.122 respectively. Partner 1 has the highest weight and is consequently selected.

6.3.2 Application of Fuzzy AHP (with extent analysis)

This algorithm addresses the problem of using crisp values during evaluation and selection of partners. For example, an evaluator might feel that technical skills of a partner are more important than management skills but cannot tell exactly by how much. This data can be represented a range of values (fuzzy/continuous). Averages of evaluators' opinions for Business, Technical and Management criteria were 9, 7 and 7 respectively. These crisp values were fuzzified using triangular fuzzy numbers resulting into (7, 9, 9) for business criterion, (5, 7, 9) for technical criterion and (5, 7, 9) for management criterion. A fuzzy pairwise comparison matrix was formed as shown in the Table 6.11.

Table 6.11 Fuzzy PCM for Partner Evaluation and Selection Criteria

Criteria	Business	Technical	Management
Business	**1, 1, 1**	**7/5, 9/7, 9/9**	**7/5, 9/7, 9/9**
Technical	**9/9, 7/9, 5/7**	**1, 1, 1**	**1, 1, 1**
Management	**9/9, 7/9, 5/7**	**1, 1, 1**	**1, 1, 1**
Sum	**3, 2.556, 2.428**	**3.4, 3.286, 3**	**3.4, 3.286, 3**

Values in field 1, column 1 for business against itself is (1,1,1) which is found by dividing lower bound value by lower bound value, middle value by middle value and upper bound value by upper bound value (7/7, 9/9, 9/9). Values in field 3, column 1, is found by dividing (7, 9, 9) by (5, 7, 9). Other field values are derived in the same manner. The sum of each column is found by adding lower bound values together, middle values together and upper bound values together. That is sum of column 1 is

(1+1+1=3), (1+7/9+7/9=2.556) and (1+5/7+5/7=2.428). Sums of columns 2 and 3 are found in the same manner.

To calculate the extent analysis on the Fuzzy PCM, the following steps were followed.

First, the Fuzzy PCM was normalized by applying equation 5.16. Table 6.12 shows the normalized fuzzy pairwise comparison matrix of the selection criteria.

Table 6.12 Normalized Fuzzy Pairwise Comparison Matrix for Criteria

Criteria	Business	Technical	Management	Fuzzy Addition
Business	**0.333, 0.391, 0.412**	**0.412, 0.391, 0.333**	**0.412, 0.391, 0.333**	**1.157, 1.173, 1.078**
Technical	**0.333, 0.304, 0.294**	**0.294, 0.304, 0.333**	**0.294, 0.304, 0.333**	**0.921, 0.912, 0.960**
Management	**0.333, 0.304, 0.294**	**0.294, 0.304, 0.333**	**0.294, 0.304, 0.333**	**0.921, 0.912, 0.960**
Sum				**2.999, 2.997, 2.998**
Inverse of sum				**0.333, 0.334, 0.334**

Fuzzy addition in the last column of the first row is achieved as follows:

0.333+0.412+0.412=1.157; 0.391+0.391+0.391=1.173; 0.412+0.333+0.333=1.078

Other rows were determined using the same procedure.

Sum of the fuzzy additions in the second last row is found as

1.157+0.921+0.921=2.999; 1.173+0.912+0.912=2.997; 1.078+0.960+0.960=2.998

The inverse of the sums of fuzzy additions in last row was found by dividing one (1) by the sum of the fuzzy additions. In this case inverses are:

$\frac{1}{2.999} = 0.333, \frac{1}{2.997} = 0.334, \frac{1}{2.998} = 0.334$

Extent analysis values are found by multiplying the normalized fuzzy addition of each criterion by the inverse of the sums of the normalized fuzzy addition. This is achieved using equation 5.20.

1.157x0.334, 1.173x0.334, 1.078x0.333 = 0.386, 0.392, 0.359

0.921x0.334, 0.912x0.334, 0.960x0.333 = 0.308, 0.305, 0.320

0.921x0.334, 0.912x0.334, 0.960x0.333 = 0.308, 0.305, 0.320

The local weights of each criterion are derived by finding the geometric mean of the fuzzy extent values as shown in Table 6.13.

Table 6.13 Fuzzy Local Weight for the Selection Criteria

Criteria	Fuzzy Local Weight	Defuzzified Weights
Business	0.386, 0.392, 0.359	0.379
Technical	0.308, 0.305, 0.320	0.311
Management	0.308, 0.305, 0.320	0.311

The last column of the matrix is determined by finding geometric mean of the fuzzy weights. Thus, for the first row: $(0.386 \times 0.392 \times 0.359)^{1/3} = 0.379$.

The same procedure was done to find the local weights for second and third levels of the hierarchy. Table 6.14 shows the local weights for Business sub criteria.

Table 6.14 Local Weight for Business Sub criteria

Sub criteria	**Local Weight**	**Defuzzified weights**
Financial Strength	0.436 0.382 0.423	0.413
Strategic Position	0.290 0.315 0.305	0.303
Business Strength	0.240 0.302 0.308	0.282

The same procedure is done when finding the priority vectors and local weights for all levels in the hierarchy. Global weights are derived like in AHP. Table 6.15 shows the outcome when data from evaluators were subjected to Fuzzy AHP.

To calculate the Priority Weight (PW) of partners, the global weights for each sub-criterion in each criterion is multiplied by the local weights of each partner according to a sub-criterion. After this, the sum of the products (partner local weights multiplied by sub-criterion global weights) of each partner is computed. This is illustrated in the following section.

$$\begin{bmatrix} 0.333 & \cdots & 0.155 \\ \vdots & \ddots & \vdots \\ 0.100 & \cdots & 0.006 \end{bmatrix} \text{ x } \begin{Vmatrix} 0.157 \\ \vdots \\ 0.072 \end{Vmatrix} = \begin{Vmatrix} 0.264 \\ \vdots \\ 0.140 \end{Vmatrix}$$

Table 6.15 Results of Evaluation using FAHP

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.379	FS	0.413	0.157	0.333	0.167	0.233	0.112	0.155
		SP	0.303	0.115	0.433	0.167	0.111	0.101	0.188
		BS	0.282	0.107	0.285	0.143	0.333	0.154	0.085
Technical	0.311	TC	0.288	0.090	0.188	0.250	0.167	0.274	0.121
		DS	0.200	0.062	0.129	0.375	0.115	0.122	0.259
		CD	0.140	0.044	0.250	0.150	0.368	0.211	0.021
		IT	0.371	0.115	0.133	0.267	0.267	0.194	0.139
Management	0.311	CR	0.488	0.152	0.367	0.333	0.211	0.022	0.067
		CC	0.280	0.087	0.200	0.100	0.066	0.289	0.345
		MA	0.231	0.072	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.264	0.231	0.214	0.151	0.140
				Total	1.000				
				Error	0				

Global weight (GW) for SP is derived by multiplying local weight of Business criterion by local weight of SP, which is 0.379 x 0.303 = 0.115, GW for CD is 0.311 x

0.140=0.044. Likewise GW for MA is 0.311 x 0.231=0.072. Finally PW for partners is derived by finding the sum of products of global weights of each sub criterion and the local weight of the partner in the sub criterion. For instance PW for partner 2 is 0.157 x 0.167 + 0.115 x 0.167 + 0.107 x 0.143 +0.090 x 0.250 + 0.062 x 0.375 + 0.044 x 0.150 + 0.115 x 0.267 + 0.152 x 0.333 + 0.087 x 0.100 + 0.072 x 0.400 = 0.231. PWs for partners 1, 3 to 5 are derived in the same way. If all was perfect the sum of the weights for partners should be 1. From Table 6.15, the sum is 1.0 with an error of 0. The PWs of partners 1 through 5 were 0.264, 0.231, 0.214, 0.151 and 0.140 respectively. Partner 1 has the highest weight and is consequently selected.

6.3.3 Application of Reduced Group Fuzzy AHP

Data collected from evaluators was converted from crisp values to fuzzy/continuous values. It was done for all levels of the hierarchy. The arithmetic mean values for Business, Technical and Management criteria by evaluators were (9, 7, 7) respectively. These crisp values were fuzzified using triangular fuzzy numbers to get (7, 9, 9) for business criterion, (5, 7, 9) for technical criterion and (5, 7, 9) for management criterion. A fuzzy pairwise comparison matrix was formed as shown in Table 6.16 below.

Table 6.16 Fuzzy Pairwise Comparison Matrix for Partner Selection Criteria

Partner Selection	Business criterion	Technical criterion	Management criterion
Business criterion	1, 1, 3	7/5, 9/7, 9/9	7/5, 9/7, 9/9
Technical criterion		1, 1, 3	1, 1, 3
Management criterion			1, 1, 3

Then the fuzzy pairwise comparison matrix is divided into two matrices consisting of lower and upper bound elements as shown in Tables 6.17 and 6.18.

Table 6.17 Lower Bound PCM for Selection Criteria

Criteria	Business	Technical	Management
Business	1.00	1.40	1.40
Technical	0.714	1.00	1.00
Management	0.714	1.00	1.00

Table 6.18 Upper Bound PCM for Selection Criteria

Criteria	Business	Technical	Management
Business	3.00	1.00	1.00
Technical	1.00	3.00	3.00
Management	1.00	0.33	3.00

After that the local weight of each pairwise comparison matrix is done like in the conventional AHP. Table 6.19 shows the local weights for the lower and upper bound elements.

Table 6.19 Local and Global Weights for Selection Criteria

Criteria	Lower Local Weight	Upper Local Weight	Overall Weight (Geometric Mean)
Business	0.412	0.325	0.366
Technical	0.294	0.441	0.360
Management	0.294	0.235	0.263

After obtaining the results for the local weights of the lower and upper elements then the final step is to combine two respective local weights (for the lower and upper element) in order to get the overall weights for alternatives. The same procedure was applied to all levels of hierarchy. Table 6.20 below shows the overall outcome of the RGFAHP.

Table 6.20 Results of Evaluations using RGFAHP

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.366	FS	0.417	0.153	0.333	0.167	0.233	0.112	0.155
		SP	0.302	0.111	0.433	0.167	0.111	0.101	0.188
		BS	0.253	0.093	0.285	0.143	0.333	0.154	0.085
Technical	0.360	TC	0.312	0.112	0.188	0.250	0.167	0.274	0.121
		DS	0.211	0.076	0.129	0.375	0.115	0.122	0.259
		CD	0.126	0.045	0.250	0.150	0.368	0.211	0.021
		IT	0.351	0.126	0.133	0.267	0.267	0.194	0.139
Management	0.263	CR	0.449	0.118	0.367	0.333	0.211	0.022	0.067
		CC	0.298	0.078	0.200	0.100	0.066	0.289	0.345
		MA	0.254	0.067	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.254	0.230	0.207	0.153	0.143
				Total	0.987				
				Error	0.013				

To calculate the Priority Weights (PW) of partners, the global weights for each sub-criterion in each criterion is multiplied by the local weights of each partner according to a sub-criterion. After this, the sum of the products (partner local weights multiplied by sub-criterion global weights) of each partner is computed. This is illustrated in the following section.

$$\begin{bmatrix} 0.333 & \cdots & 0.155 \\ \vdots & \ddots & \vdots \\ 0.100 & \cdots & 0.006 \end{bmatrix} \text{ x } \left\| \begin{matrix} 0.153 \\ \vdots \\ 0.067 \end{matrix} \right\| = \left\| \begin{matrix} 0.254 \\ \vdots \\ 0.143 \end{matrix} \right\|$$

Global weight (GW) for BS is derived by multiplying local weight of Business criterion by local weight of BS, which is 0.366 x 0.176 = 0.064, GW for DS is 0.360 x 0.211=0.076. Likewise GW for CR is 0.263 x 0.499=0.118. Finally PW for partners is derived by finding the sum of products of global weights of each sub criterion and the local weight of the partner in the sub criterion. For instance PW for partner 1 is 0.191 x 0.333 + 0.111 x 0.433 + 0.064 x 0.285 +0.112 x 0.118 + 0.076 x 0.129 + 0.045 x 0.250 + 0.126 x 0.133 + 0.118 x 0.367 + 0.078 x 0.200 + 0.067 x 0.100 = 0.254. PWs for partners 1, 3 to 5 are derived in the same way. If all was perfect the sum of the weights for partners should be 1. From Table 6.20 the sum is 0.987 with an error of 0.013. The PWs of Partners 1 through 5 was 0.254, 0.230, 0.207, 0.153 and 0.143 respectively. Partner 1 has the highest weight value and is consequently selected.

6.3.4 Comparison of Algorithms

Table 6.21 shows the results of the evaluation of partners using the three algorithms.

Table 6.21 Comparison of Outcomes of algorithms

Method	**P1**	**P2**	**P3**	**P4**	**P5**	**Total**	**Error**
AHP	0.264	0.233	0.229	0.150	0.122	0.998	0.002
FAHP	0.264	0.231	0.214	0.151	0.140	1.00	0
RGFAHP	0.254	0.230	0.206	0.153	0.143	0.987	0.013

Ideally, in any algorithm that ranks alternatives, the sum of the PWs of alternatives should be 1. If this is not the case, then the algorithm has not performed optimally therefore resulting in errors. The higher the error the worse the algorithm's performance becomes. Since the consistency ratio correlate to the judgemental errors in pairwise comparisons (Karlsson et al., 1998), it can be concluded that these mean errors correspond to the consistency ratio (Saaty, 1980).

The three algorithms ranked all the partners in the following order, P1, P2, P3, P4 and P5 with P1 with the highest weight and P5 having the lowest weight. FAHP (with extent analysis) has the least error of zero (0), conventional AHP has an error of 0.002 while RGFAHP has the most error of 0.013. In order to verify the results of these algorithms, sources of data was varied from additional five cases of evaluators. Table 6.22 shows the results of case one (1).

Table 6.22 Case 1 Results of Algorithms

Method	P1	P2	P3	P4	P5	Total	Error
AHP	0.261	0.231	0.229	0.153	0.123	0.997	0.003
FAHP	0.266	0.232	0.214	0.141	0.143	0.996	0.004
RGFAHP	0.251	0.232	0.206	0.145	0.154	0.988	0.012

For case 1, P1, P2, P3, P5 and P4 have priority weights in that order with P1 with the highest and P4 with the least. However, this slightly differs from AHP where P4 has a higher weight than P5. AHP has the least error of 0.003 while FAHP and RGFAHP have errors of 0.004 and 0.012 respectively . Table 6.23 shows the results of case two (2).

Table 6.23 Case 2 Results of Algorithms

Method	P1	P2	P3	P4	P5	Total	Error
AHP	0.256	0.229	0.229	0.153	0.122	0.989	0.011
FAHP	0.261	0.236	0.214	0.131	0.153	0.995	0.005
RGFAHP	0.253	0.223	0.206	0.145	0.154	0.981	0.019

For case 2, P1, P2, P3, P5 and P4 have priority weights in that order with P1 with the highest and P4 with the least. However, this slightly differs from AHP where P4 has a higher weight than P5. FAHP is the most accurate with the least error of 0.005 while RGFAHP is the least accurate with the highest error of 0.019. Table 6.24 shows the results of case three (3).

Table 6.24 Case 3 Results of Algorithms

Method	P1	P2	P3	P4	P5	Total	Error
AHP	0.263	0.244	0.229	0.143	0.119	0.998	0.002
FAHP	0.262	0.232	0.214	0.141	0.148	0.997	0.003
RGFAHP	0.251	0.232	0.206	0.154	0.143	0.986	0.014

For case 3, P1, P2, P3, P4 and P5 have priority weights in that order with P1 with the highest and P5 with the least. However, this slightly differs from FAHP where P5 has a higher weight than P4. AHP is the most accurate with the least error of 0.002 while RGFAHP is the least accurate with the highest error of 0.014. Table 6.25 shows the results of case four (4).

Table 6.25 Case 4 Results of Algorithms

Method	P1	P2	P3	P4	P5	Total	Error
AHP	0.263	0.233	0.227	0.151	0.122	0.996	0.004
FAHP	0.268	0.234	0.212	0.143	0.143	1	0
RGFAHP	0.253	0.234	0.202	0.152	0.149	0.990	0.010

For case 4, P1, P2, P3, P4 and P5 have priority weights in that order with P1 with the highest and P5 with the least. However, P4 and P5 have similar weights in FAHP. FAHP is the most accurate with the least error of 0 while RGFAHP is the least accurate with the highest error of 0.010. Table 6.26 shows the results of case five (5).

Table 6.26 Case 5 Results of Algorithms

Method	P1	P2	P3	P4	P5	Total	Error
AHP	0.228	0.258	0.226	0.150	0.126	0.988	0.012
FAHP	0.224	0.256	0.222	0.161	0.133	0.996	0.004
RGFAHP	0.251	0.252	0.206	0.134	0.145	0.988	0.012

For case 5, P2, P1, P3, P4 and P5 have priority weights in that order with P2 with the highest and P5 with the least. FAHP is the most accurate with the least error of 0.004 while AHP and RGFAHP are least accurate with equal errors of 0.012. The arithmetic mean total and errors of the algorithms are shown in Table 6.27.

Table 6.27 Arithmetic Mean Total and Error

Method	Case 1	Case 2	Case 3	Case 4	Case 5	Total	Mean Total	Mean Error
AHP	0.997	0.989	0.998	0.996	0.988	4.968	0.9936	0.0064
FAHP	0.996	0.995	0.997	1	0.996	4.984	0.9968	0.0032
RGFAHP	0.988	0.981	0.986	0.99	0.988	4.933	0.9866	0.0134

From these comparisons, it can be stated that FAHP is relatively more accurate with a mean error of 0.0032 followed by conventional AHP with a mean error of 0.0064 and RGFAHP which has a mean error of 0.0134. A closer examination at these outcomes, partners' relative weights for each criterion in each algorithm is presented in chart 1.

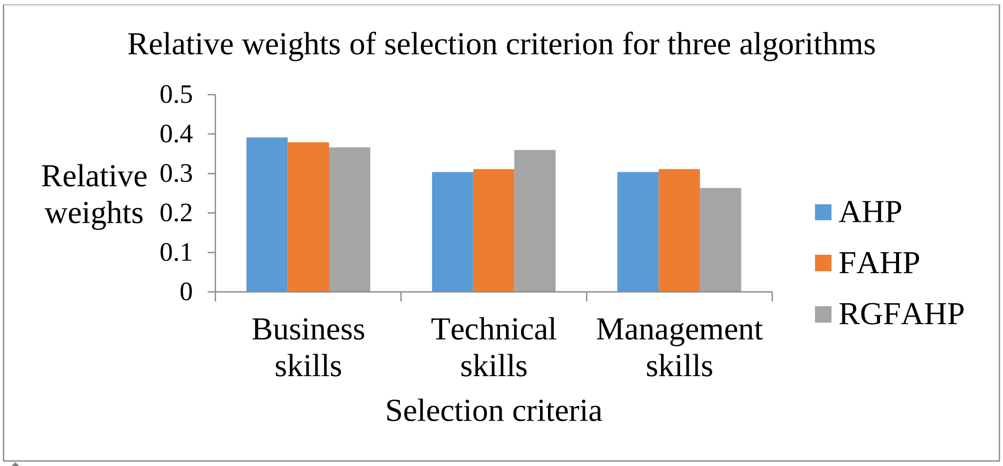


Chart 1: Relative weights of selection criterion for three algorithms

As shown above, business skills criterion had relatively higher weights than the rest. AHP outweighed FAHP and RGFAHP in business skills criterion. RGFAHP outweighed AHP and FAHP in Technical skills criterion while FAHP did better than AHP and RGFAHP in Management skills criterion. Evaluators for this cases could use AHP if business skills were the most important selection sub criteria; employ RGFAHP if technical skills sub criteria were more important than others while they could work with FAHP (with extent analysis) if management skills were the most important selection sub criteria for partners.

The three algorithms are effective but FAHP (with extent analysis) and RGFAHP outweigh conventional AHP in terms of generality. This is because FAHP (with extent analysis) and RGFAHP can be used when evaluators' judgements are either exact or fuzzy. RGFAHP outweigh FAHP (with extent analysis) because it has fewer steps. In addition RGFAHP has characteristics of both AHP and FAHP (with extent analysis). Apart from the correctness, simplicity and generality of the algorithm, other aspects which can be used to differentiate between the algorithms are time and space complexities. Time complexity refers to time in which the algorithm runs. It is determined by finding the upper bound on the execution time (Chang, 1996). Chang (1996) found FAHP (for n criteria) has the time complexity of n(n+6) and AHP has a time complexity equal to $\frac{n(n-1)}{2}$. RGFAHP has a time complexity between that of AHP and FAHP but twice that of AHP which is n(n-1). AHP algorithm can be extended to be used in a situation where the evaluators have imprecise information about evaluation judgements. Fuzzy logic can be incorporated in AHP to address the uncertainty of users' judgements during the evaluation of partners. These algorithms gave approximately similar results in all the cases.

6.4 Simulations of Partners Evaluation and Selection

Relative weights for Business, Technical and Management skills criteria were fixed and used to simulate different scenarios when the weights were interchanged. Table 6.28 shows the results for the first scenario. In this case business criterion was assigned weight of 0.41, with 0.36 and 0.23 assigned to technical and management criteria respectively. The computed results are shown in appendix G, where Business, Technical and Management criteria relative weights were fixed and then interchanged.

Table 6.28 Partner Evaluation & Selection: Business (0.41), Technical (0.36) & Management (0.23)

Algorithm	P1	P2	P3	P4	P5
AHP	0.262	0.227	0.230	0.155	0.123
FAHP	0.264	0.231	0.214	0.151	0.140
RGFAHP	0.257	0.225	0.210	0.154	0.141

As shown in chart 2, in all the algorithms, P1 was the best partner. P2 had the highest weight using FAHP while it had similar weights when AHP and RGFAHP were used. P3, P4 and P5 had varied relative weights for AHP, FAHP and RGFAHP.

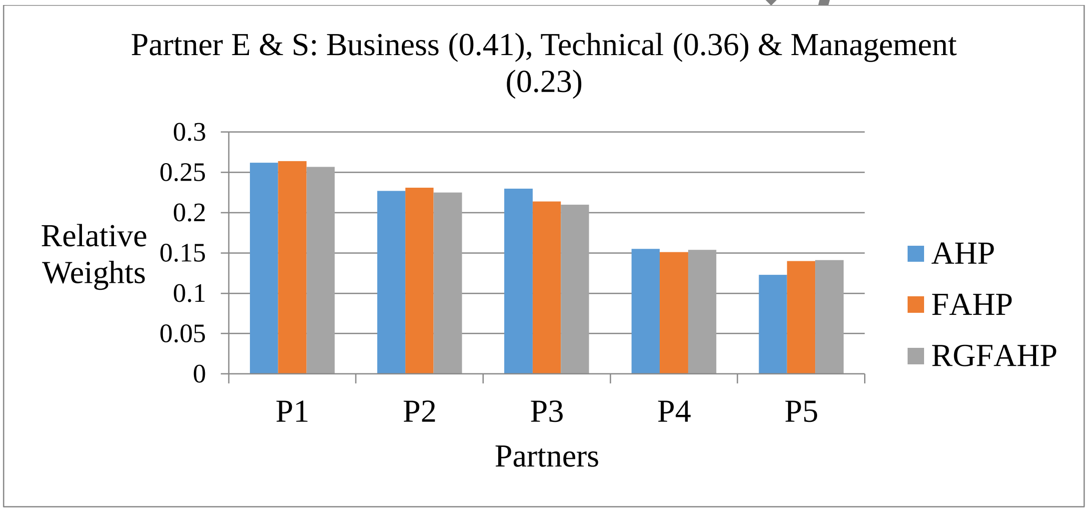


Chart 2: Partner Evaluation & Selection with emphasis on Business criterion

Results in Table 6.29 were found when business, technical and management criteria were assigned relative weights of 0.23, 0.41 and 0.36 respectively.

Table 6.29 Partner Evaluation & Selection: Business (0.23), Technical (0.41) & Management (0.36)

Algorithm	P1	P2	P3	P4	P5
AHP	0.244	0.251	0.226	0.160	0.119
FAHP	0.241	0.248	0.212	0.159	0.138
RGFAHP	0.236	0.247	0.208	0.162	0.140

As shown in chart 3, in all the algorithms, P2 was the best. P1 had the highest weight using AHP while it had close weights when FAHP and RGFAHP were employed. P3, P4 and P5 had varied relative weights for AHP, FAHP and RGFAHP.

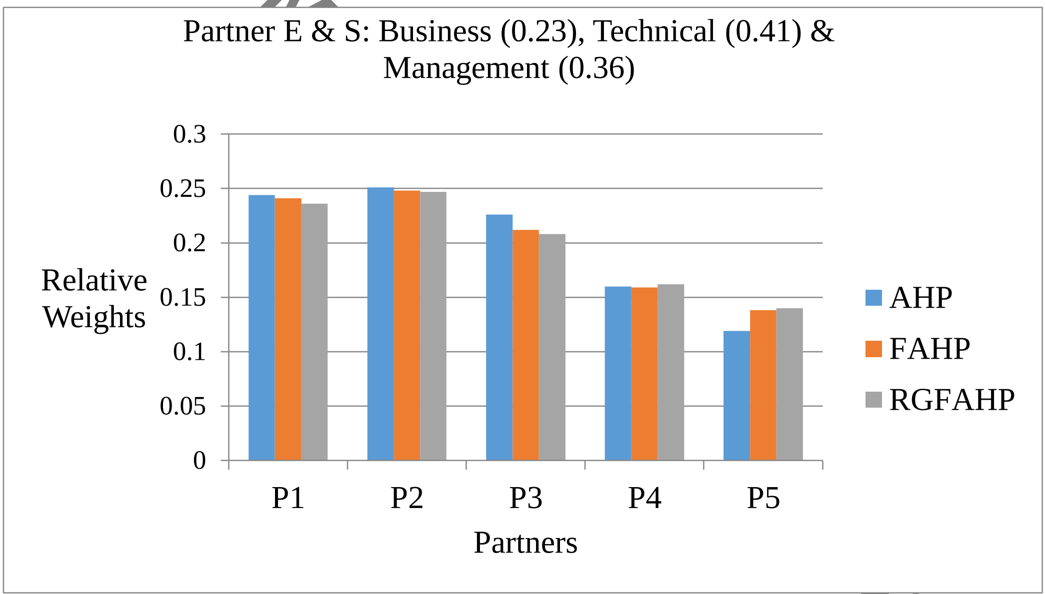


Chart 3: Partner Evaluation and Selection with emphasis on Technical criterion

Results in Table 6.30 were found when business, technical and management criteria were assigned relative weights of 0.36, 0.23 and 0.41 respectively.

Table 6.30 Partner Evaluation & Selection: Business (0.36), Technical (0.23) & Management (0.41)

Algorithm	P1	P2	P3	P4	P5
AHP	0.267	0.243	0.228	0.143	0.119
FAHP	0.270	0.235	0.212	0.145	0.138
RGFAHP	0.263	0.234	0.207	0.147	0.140

As shown in chart 4, in all the algorithms, P1 was the best. P2 had the highest weight using AHP while had similar weights when FAHP and RGFAHP were used. P3, P4 and P5 had varied relative weights for AHP, FAHP and RGFAHP.

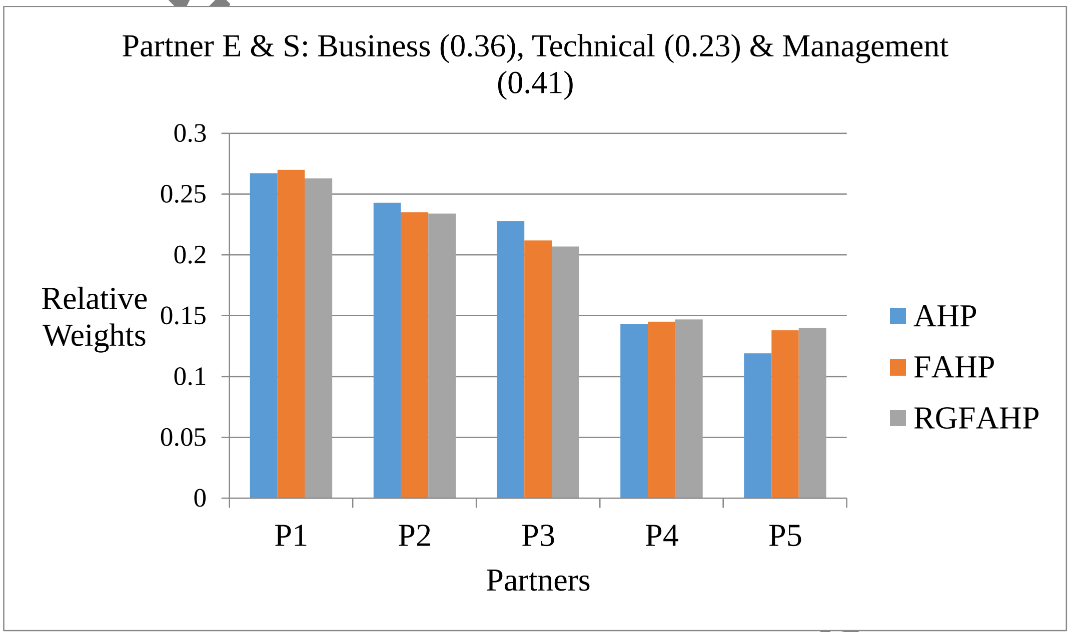


Chart 4: Partner Evaluation and Selection with emphasis on Management criterion

From these outcomes, it is indicated that when different relative weights were assigned to evaluation and selection criteria, different evaluations were found. It can be stated that if different categories of evaluators (business, technical or management knowledge based) are used, they will give different evaluations depending on their specializations. Depending on the skill set of evaluators, AHP, FAHP and RGFAHP would give different outcomes. The ideal situation would be if different skills set are combined during evaluations. It can be stated that varying evaluators while maintaining the evaluation parameters and partners, give different results.

6.5 Partner Performance Evaluation

In order to evaluate performance of partners, the following steps are applicable to achieve the best possible performance, while satisfying the objectives of the enterprise (Petersen & Matskin, 2003; Tolle, 2004).

1) Identification of the performance evaluation criteria,
2) Selection of the performance evaluation method,
3) Performance prediction and
4) Performance monitoring.

First, the criteria for evaluating partners' performance are determined. They represent the desired level of performance of the VE. The second step requires the selection of the performance evaluation method to be used for evaluating performance of partner companies. Third, the partners' performance is predicted and the final step is partners' performance monitoring. This study deals with the first three steps. Partners' performance monitoring is a continuous process.

Performance evaluation criteria from evaluators were categorized. Specific categories identified were: Contract modification (CM), quality requirement (RQ), site location accessibility (SL), personnel experience (PE), change in material market rate (MR), material price change (PC), equipment breakdown (EB), rework/repeat job (RJ), change in transport cost (TC) and change in personnel charge rate (PR). These categories were further classified into two general categories, time and cost. Time as a general category comprised CM, RQ, SL and PE. These factors could affect the expected project completion time while clusters like MR, PC, PC, RJ, TC and PR could affect the project cost.

Second, partners' performance evaluation techniques were identified. AHP, FAHP and RGFAHP methods were used because performance evaluation problem can be hierarchically structured. Figure 6.3 shows the hierarchy used for this process. Time and cost were identified as evaluation criteria. This hierarchical representation allows determination of the influence of lower levels elements of the hierarchy on the higher level elements. For example, how a change in material cost affect the overall project cost and how contract modification influence the time the project takes to complete.

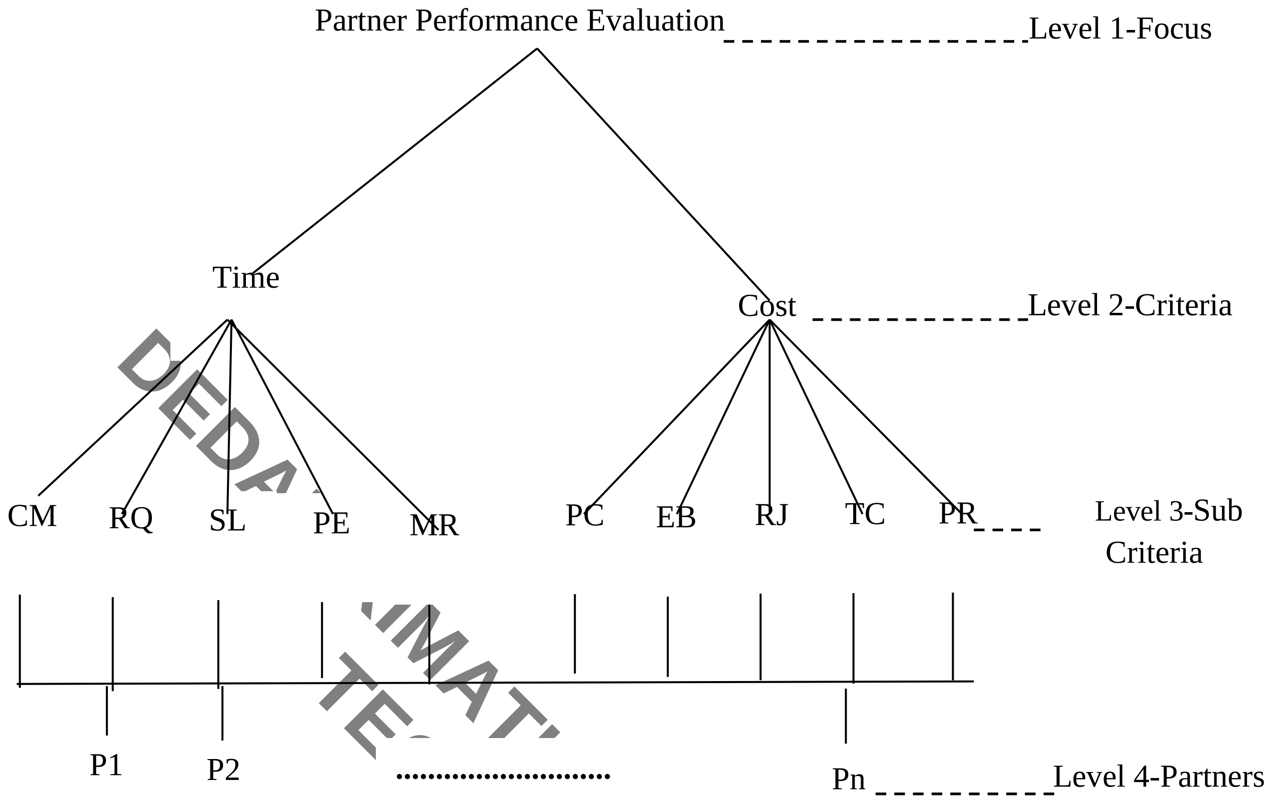


Figure 6.3 Hierarchy of the Partner Performance Evaluation

Third, to predict the partners’ performance, evaluators' results using AHP, FAHP and RGFAHP are established. Aggregated / average crisp rating of time and cost by evaluators were 9 and 7 respectively. If another set of evaluators were invited, possibly another set of different values would be found. The following section describes the use of AHP in the evaluation. In Table 6.31, the values of the comparison matrix of time criterion against itself is $^{9}/_{9}$ which is 1, while time criterion weighed against cost criterion is $^{9}/_{7}$ = 1.29. In the same manner the weight of cost criterion against time criterion is $^{7}/_{9}$ = 0.78.

Table 6.31 PCM for Performance Evaluation Criteria

Performance criteria	Time	Cost	Local Weight
Time	**1**	**1.29**	**0.56**
Cost	**0.78**	**1**	**0.44**
Sum	**1.78**	**2.29**	**1.00**

Table 6.31 is normalized and local weights of time and cost criteria are 0.56 and 0.44 respectively. Time factor has the highest weight attributable to the fact that, change in project completion time affects the cost of the project. It can be stated that varying completion time consequently affects the total cost of the project. The aggregated responses for the time criterion sub-criteria from evaluators were 9, 7, 3, 7, 5 for CM, RQ, SL, PE and MR respectively. Normalized Reciprocal PCM and priority vector and local weights for time sub criteria are as in Table 6.32.

Table 6.32 Normalized Reciprocal PCM for Time Sub Criteria and Local Weights

Sub criteria	CM	RQ	SL	PE	MR	Priority Vector	Local Weight
CM	0.29	0.29	0.39	0.22	0.29	0.296	0.296
RQ	0.23	0.23	0.30	0.23	0.37	0.272	0.272
SL	0.10	0.14	0.13	0.10	0.07	0.108	0.108
PE	0.23	0.18	0.04	0.17	0.11	0.146	0.146
MR	0.16	0.16	0.13	0.28	0.16	0.178	0.178

λ_{max} = 0.296 x 3.45 + 0.272 x 4.38 + 0.108 x 7.66 + 0.146 x 5.96 + 0.178 x 6.27 = 5.026

CI = $\frac{(5.026-5)}{4}$ = 0.006 and CR = $\frac{CI}{RI}$ = $\frac{0.006}{1.12}$ = 0.005 < 0.1 (i.e. consistent).

Similarly, the aggregated responses for the cost criterion sub-criteria were 9, 3, 7, 7, 5 for PC, EB, RJ, TC and PR respectively. These values are subjective and could change when a different set of evaluators were used. Their normalized PCM and local weights are shown in Table 6.33.

Table 6.33 Normalized Reciprocal PCM for Cost Sub Criteria and Local Weights

Sub criteria	PC	EB	RJ	TC	PR	Priority Vector	Local Weight
PC	0.30	0.49	0.19	0.22	0.29	0.298	0.299
EB	0.10	0.16	0.35	0.23	0.37	0.242	0.242
RJ	0.13	0.10	0.15	0.10	0.07	0.110	0.110
TC	0.30	0.13	0.05	0.17	0.11	0.152	0.152
PR	0.17	0.12	0.25	0.28	0.16	0.196	0.196

λ_{max} = 0.298 x 3.32 + 0.242 x 6.09 + 0.110 x 6.62 + 0.152 x 5.96 + 0.196 x 6.27 = 5.32618

CI = $\frac{(5.326-5)}{4}$ = 0.082 and CR = $\frac{CI}{RI}$ = $\frac{0.082}{1.12}$ = 0.071 < 0.1.

Global weights for each sub criteria are shown Table 6.34.

Table 6.34 Performance Evaluation Criteria using AHP

Criteria	Local weight	Sub-criteria	Local weight	Global weight
Time	0.56	Contract Modification (CM)	0.296	0.166
		Level of Required Quality (RQ)	0.272	0.152
		Site Location Accessibility (SL)	0.108	0.060
		Personnel Experience (PE)	0.146	0.082
		Material Market Rate Change (MR)	0.178	0.100
Cost	0.44	Market Price Change (PC)	0.299	0.132
		Equipment Breakdown (EB)	0.242	0.106
		Rework / Repeat Job (RJ)	0.110	0.048
		Transport Cost Change (TC)	0.152	0.067
		Personnel Charge Rate Change (PR)	0.196	0.086

This study suggests that finding the product of "priority weights of partners in the partner evaluation and selection phase" and "global weights of partners' performance evaluation sub criteria (for example global weight for sub criterion "repeat job")" and computing their geometric mean can give a good indication of (approximately predict expected) partners' performance. This process helps predict expected approximate partners' performance. The process is repeated for FAHP and RGFAHP techniques evaluation values. The study also suggests that expected partners' performance can be computed based on each performance sub criterion. This is because different partners can perform differently on each performance sub criterion, resulting in different overall performance (i.e. when performances of partners on all performance sub criteria are combined).

This research further proposes the use of sub criteria that only directly affect partners. Those that are within partners' control (i.e. contract modification, required quality, personnel experience and repeat job with global weights of 0.166, 0.152, 0.082 and 0.048 respectively). Sub criteria like site location accessibility, market rate change, material price change, equipment breakdown and change in transport cost are beyond partners' control but affect the overall project performance.

For the partners' performance criteria proposed, they are relevant in the following ways: For contract modification, it is expected that a partner that does least modification performs better (lesser time and cost) than the one with most modifications. Likewise, best performing partner on required quality sub criteria, is the one which produces the highest quality product. In addition, partner with the highest personnel experience is expected to perform better (will take lesser time and cost) than others with lesser experience even as partners that do least repeat jobs would perform better (take lesser time and cost) than those that do most repeat jobs. CM sub criterion has the highest weight and therefore the most important sub criterion.

The following section describes the expected outcomes of partners' performance on CM sub criterion, depending on the simulations' results of partners' evaluation and selection when the criteria values were fixed to 0.41, 0.36 and 0.23 for business, technical and management criteria respectively. Further outcomes are when the values were interchanged. Different scenarios of partners' evaluation and selection and the expected partners' performances are shown. The partners' performance evaluation for CM sub criterion is computed using AHP as shown in Table 6.35.

Table 6.35 AHP Partners Performance for CM for B(0.41), T(0.36), M(0.23)

Partner	**Priority Weight**	**CM sub-criterion global weight**	**Geometric Mean**
Partner 1	**0.262**		**0.209**
Partner 2	**0.227**		**0.194**
Partner 3	**0.230**	**0.166**	**0.195**
Partner 4	**0.155**		**0.160**
Partner 5	**0.123**		**0.143**

where B is business, T is technical and M is management criteria respectively.

The value in the last column of row 1 is attained as $(0.262 \times 0.166)^{1/2} = 0.209$. Other values in the last column are achieved in the same way. This process is repeated to all the performance evaluation sub-criteria and geometric mean weights are computed for all partners. The results are shown in chart 5.

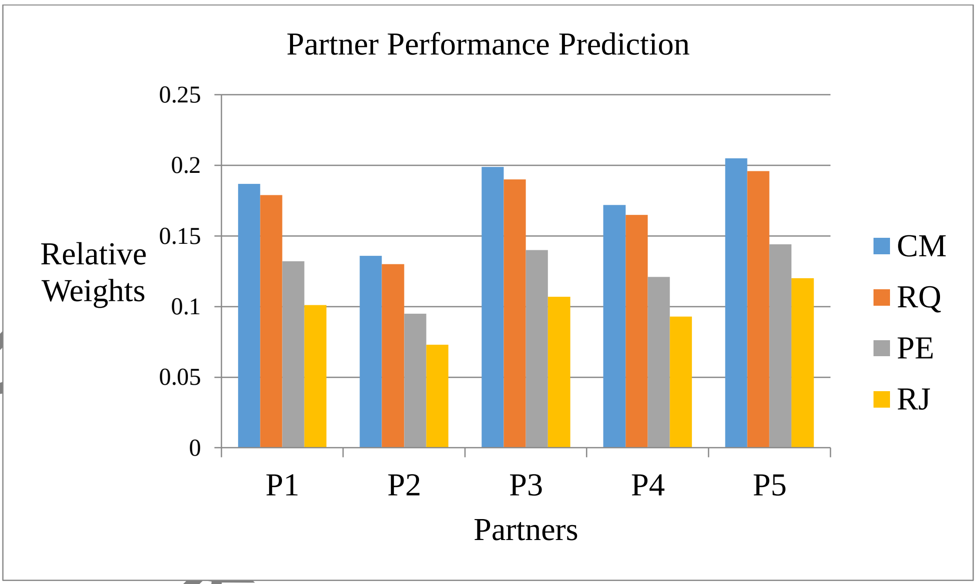


Chart 5: Partner Performance Prediction

As shown in chart 5, Partners P3 and P5 would perform better than P1, P2 and P4 on CM sub-criterion. They would make the least modification with P5 making the least or no modification. Partners P1, P3 and P5 would perform better than P2 and P4 on required quality. Their work would be of the highest quality. P5 and P3 would outweigh others in repeat job. They would have the least repetitions of work. All partners would perform comparatively equal in personnel experience. Different partners would perform differently per sub-criterion. There would be no one dominant partner in all the cases.

Partners' performance for different scenarios using AHP, FAHP and RGFAHP techniques when relative weights for partners' evaluation and selection criteria were fixed and interchanged were simulated. The first scenario was when the relative weights for business, technical and management criteria were 0.41, 0.36 and 0.23 respectively, the relative weights of partners for the performance evaluation sub criterion, CM is as shown in Table 6.36. Computations partners' performance is shown in appendix H.

Table 6.36 CM Partner Performance: Business (0.41), Technical (0.36) & Management (0.23)

Algorithm	P1	P2	P3	P4	P5
AHP	0.209	0.194	0.195	0.160	0.143
FAHP	0.198	0.185	0.178	0.149	0.144
RGFAHP	0.189	0.177	0.171	0.146	0.140

As shown in chart 6, for all the algorithms P1 would perform better than others. AHP has the highest performance values for CM. P2 and P3 have almost similar performance predictions, followed by P4 and P5.

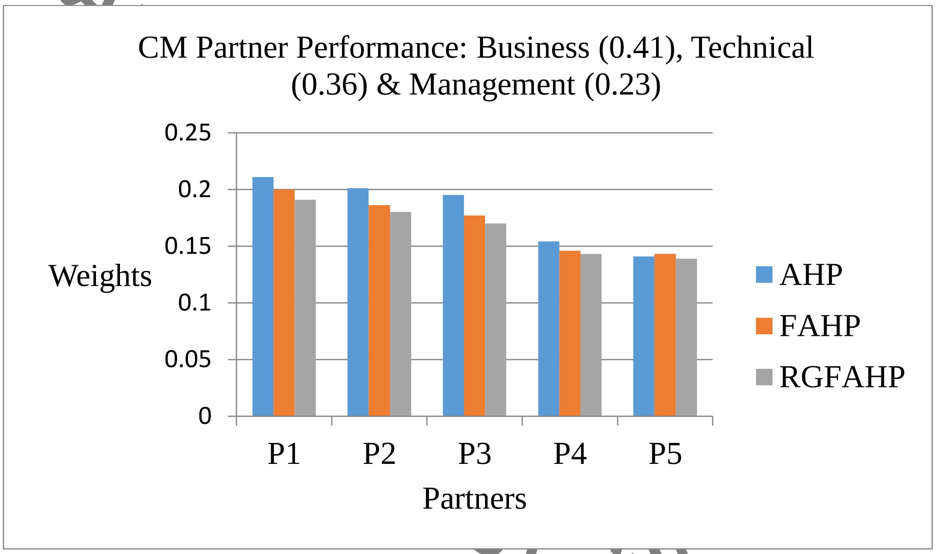


Chart 6: CM partner performance with emphasis on Business criterion

The order of significance in performance prediction in this scenario is AHP, FAHP and RGFAHP.

The second scenario was when the relative weights for business, technical and management criteria were 0.23, 0.41 and 0.36 respectively, the relative weights of partners for the performance evaluation sub criterion, CM is as shown in Table 6.37.

Table 6.37 CM Partner Performance: Business (0.23), Technical (0.41) & Management (0.36)

Algorithm	P1	P2	P3	P4	P5
AHP	0.201	0.204	0.194	0.163	0.141
FAHP	0.189	0.192	0.177	0.153	0.143
RGFAHP	0.181	0.185	0.170	0.150	0.139

As shown in chart 7, in all the algorithms P1 would perform better than others. AHP has the highest performance values for CM. P2 and P3 have almost similar performance predictions, followed by P4 and P5.

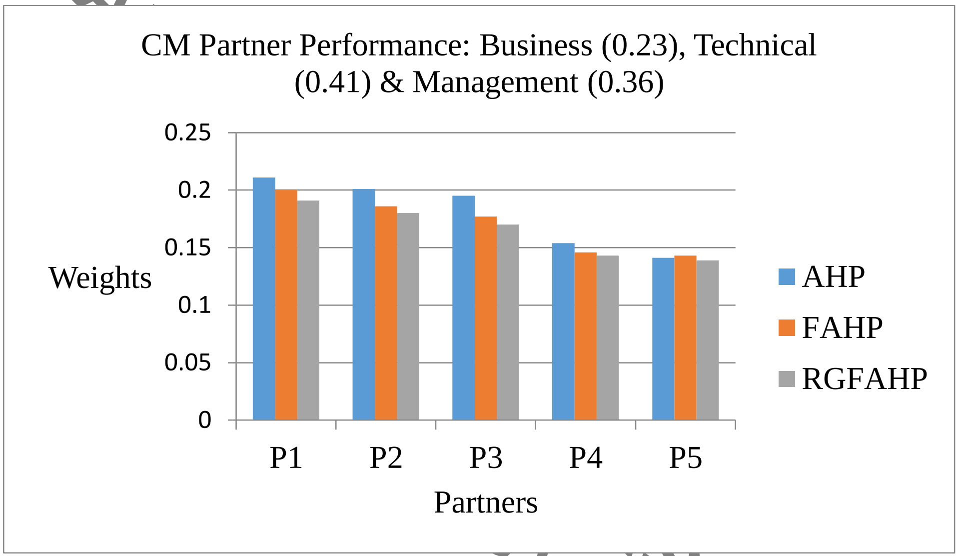


Chart 7: CM partner performance with emphasis on Technical criterion

The order of significance in performance prediction in this scenario is AHP, FAHP and RGFAHP.

The third scenario was when the relative weights for business, technical and management criteria were 0.36, 0.23 and 0.41 respectively, the relative weights of partners for the performance evaluation sub criterion, CM is as shown in Table 6.38.

Table 6.38 CM Partner Performance: Business (0.36), Technical (0.23) & Management (0.41)

Algorithm	P1	P2	P3	P4	P5
AHP	0.211	0.201	0.195	0.154	0.141
FAHP	0.200	0.186	0.177	0.146	0.143
RGFAHP	0.191	0.180	0.170	0.143	0.139

As shown in chart 8, in all the algorithms P1 would perform better than others. AHP has the highest performance values for CM. P2 and P3 have almost similar performance predictions, followed by P4 and P5.

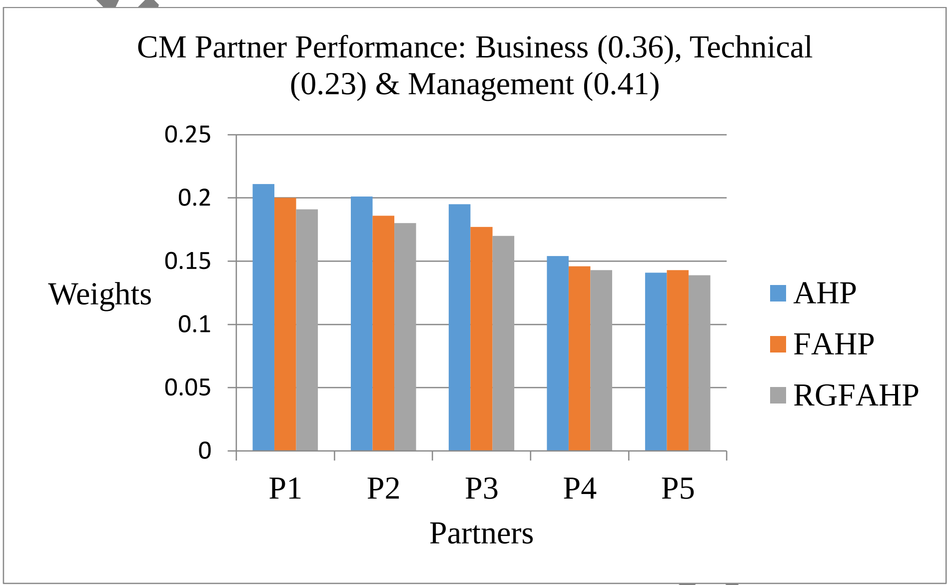


Chart 8: CM partner performance with emphasis on Management criterion

The order of significance in performance prediction in this scenario is AHP, FAHP and RGFAHP.

6.6 Chapter Summary

Analysis of focus group interview responses is performed. The results of the analysis inform the evaluation tool design. Evaluators use the evaluation tool to indicate their preference / importance of alternatives i.e. criteria, sub criteria and partners. To determine the accuracy of these techniques, data is obtained from six case study groups. MCDM techniques are used to simulate different knowledge based scenarios by evaluators from the six case studies. Partner performance evaluation criteria are used to predict partners' performance.

The three algorithms are effective but FAHP (with extent analysis) and RGFAHP outweigh conventional AHP in terms of generality. RGFAHP outweigh FAHP (with extent analysis) because it has fewer steps. In addition RGFAHP has characteristics of both AHP and FAHP (with extent analysis). When different relative weights are assigned to evaluation and selection criteria, different evaluations are found. Using different categories of evaluators (business, technical or management knowledge based), give different evaluations. Depending on the skill set of evaluators, AHP, FAHP and RGFAHP give different outcomes.

Priority weights of partners are used with global weights performance sub criteria to predict partners' performance. Factors that are within the control of partners are used to evaluate them. Performance prediction (evaluation) is done for each partner in each sub-criterion. It is evident that different partners would perform differently in each sub-criterion.

In the next chapter, research discussions and conclusions are presented.

CHAPTER SEVEN

7.0 DISCUSSIONS AND CONCLUSION

7.1 Introduction

This chapter presents the research findings, their interpretation, discussions and conclusion. A framework for partner evaluation and selection and partners' performance evaluation is also proposed. In this study, gaps in the knowledge regarding the evaluation and selection of partners in the construction industry according to selection criteria and sub-criteria were identified as lack of research dealing with the uncertainty of evaluators' judgements during the evaluation and selection process. An algorithm was developed that can be used to assist VE initiators to evaluate and select partners that would be best for a specific construction project. The flowcharts of the algorithms of AHP (Figure 5.1), Fuzzy AHP (Figure 5.4) and Reduced Group Fuzzy AHP (Figure 5.6) give precise prescriptions of the steps of the techniques that can be incorporated in the design and development of new techniques for evaluating and selecting partners, and evaluating partners' performance.

To ensure plausibility, credibility, consistency and transferability of knowledge of this study, the comments, criticism, suggestions and advice received from seminars, conferences and journal peer reviewers were incorporated in the development of the algorithms which in turn improved the results. Parts of the thesis have been presented in conferences, workshops and published in peer reviewed journals.

7.1.1 Problem Restatement

A crucial competitive factor of a VE, is its ability to form an end-user focused team which can be jeopardized if the right team is not formed. The construction sector's potential contribution to the economic growth can be enhanced by effectively addressing the challenges facing the sector. The challenges facing the sector can be attributed to poor choice of partners for the tasks due to insufficient information available about partners and lack of facilitation techniques. This lack of information can be attributed to the use of company profiles as sources of information. Information from company profiles is often insufficient and decisions made out insufficient information are subjective. Furthermore, the choices made by project initiators do not take into account that human judgements during partner evaluation and selection are imprecise. Partners' evaluation and selection process reliability can be enhanced if decision making techniques capable of dealing with subjective information are employed. This study proposed a framework that can be used by project initiators to effectively evaluate and select right partners for tasks and evaluate / predict the partners' performance.

The lifecycle of a VE include: Formation, management, and dissolution. The formation phase establishes the goal and the objectives of the VE, according to the product demand. It also identifies the functional requirements that organization needs to fulfill. After the functional requirements are known, the core capabilities needed by VE are determined. Once the VE formation is finished, the VE enters its management phase. The management phase focuses on how to achieve the goals and objectives of the VE. In the management phase, members collaborate and integrate their core competencies to satisfy the functional requirements, identified in the formation phase. The performance of partners is also evaluated in this phase. Finally, once the product demand is met, the VE dissolves, and its members find other value-adding chains, where their core capabilities can be used. The dissolution phase deals with ending the relationship among partners and eventually the evaluation of the results of the collaborative work.

The formation phase of a VE can be divided into four steps. These steps are: (1) Identification of the problem, (2) Identification of the core competencies required to develop a solution to the problem, (3) The evaluation and selection of the partner companies capable of delivering the required core capabilities and (4) Integrating the core capabilities of the partners. Among these steps, the partner selection step is the most crucial one and was the main focus of this study.

The partner evaluation and selection process can be considered as a Multi-Criteria Decision-Making Modelling (MCDMM) process, characterized by a substantial degree of uncertainty and subjectivity due to limited information about potential partners. Several MCDMMs have been proposed, including AHP, FAHP and RGFAHP. Others MCDMs are: ELECTRE, TOPSIS, DEA, NN, WLM, LP and MP. This study has employed AHP, FAHP and RGFAHP and their findings are presented in the following sections.

7.1.2 Findings of the Implementation of AHP

A key issue of the process was to determine the suitability of the AHP algorithm in the evaluation and selection of potential partners. In the evaluation and selection, qualitative methods (focus group interviews) were complimented by quantitative methods (questionnaires). It has been shown that AHP is suitable for evaluating and selecting partners because of its accuracy and flexibility in making a logical, consistent and informed decision. AHP deals with crisp values of evaluation and selection judgements. However, human judgements are imprecise, uncertain and fuzzy (Mikhailov & Tsvetinov, 2004). Furthermore, when the number of evaluation and selection criteria considered increases, the number of pairwise comparisons increases geometrically. This can lead to inconsistencies or even that the AHP algorithm fails completely. FAHP can address this problem and is proposed as an alternative method for imprecise problems or problems with more criteria.

Using AHP in the VE partner evaluation and selection is suitable because it simplifies a complex problem by breaking it up into smaller steps that help in visualizing the problem. In Figure 6.1, the eight steps of the AHP are discussed. The steps are: defining the goals and outcomes of the problem; decomposing the problem into a hierarchical structure; computing pairwise comparisons; employing the Eigenvalue method to estimate relative weights; checking consistency and finally combining the relative weights to obtain the overall rating for the alternatives. Business skills, technical skills and management skills were considered as the most important factors for evaluating and selecting partners. The subjective evaluation and selection was consistent for the sub-criteria identified for business, technical and management criteria. The evaluation and selection was shown to be consistent since the computed consistency indices, for all pairwise comparisons, were less than 10% thus confirming that all evaluators who participated were consistent in their judgement. Involving all stakeholders in the evaluation and selection of partners had the added advantage of greater acceptance of the technique. FAHP and RGFAHP were then implemented to see whether they could address the weakness of AHP.

7.1.3 Findings of the Implementation of FAHP and RGFAHP

Using FAHP (with extent analysis) and RGFAHP, it has been shown how preference and consensus can be attained if a group decision-making process is used in the partner evaluation and selection problem. They differ from the traditional AHP method, which uses preferences and consensus generated from crisp values to evaluate and select partners. The level of accuracy of the prioritization outcome when FAHP (with extent analysis) was used was averagely 99.34% while RGFAHP was 98.63%. It can be stated that FAHP (with extent analysis) and RGFAHP can be incorporated in the design and development of new techniques for the VE partner evaluation and selection.

FAHP (with extent analysis) and RGFAHP have those advantages of conventional AHP (Sanga & Venter, 2009), which are: They are flexible, they integrate deductive approaches, they acknowledge interdependence of alternatives (selection criteria and sub-criteria), they have hierarchical structure, measure intangibles, track logical consistency, give an overall estimation, consider relative weights and improves judgements.

7.2 Research Questions Revisited

This research focused on modelling VEs in the construction sector with a focus in Kenya. The broad objective of this study was to propose a framework that would be used by project initiators to effectively evaluate and select the right partners for tasks using subjective information as provided in the partners' company profiles. The framework would encompass partners represented as agents, which once selected, would form a team that would collaborate to complete tasks. In order to achieve the objective, other tasks included determination of the VE system components, determination and design of the techniques for evaluation and selection of partners. Another task was the design of MAS environment where partners would interact. Finally, simulation of the framework would be carried out for partners in the construction sector. The following is a re-statement of research questions.

Several research questions as highlighted in the following section were posed.

RQn1: What are the systemic components for modelling VEs?

RQn2: How is the formation and evaluation VEs achieved?

RQn3: How can multi agent systems support the modelling of VEs?

RQn4: How can a VE model be implemented for the construction industry?

Systemic components of modelling VEs: The systemic components were identified by evaluators and corroborated with literature review. These have been used as the evaluation and selection criteria and sub-criteria for partners. They also include the VE phases (which are formation, management and dissolution). It was shown how subjective partner evaluation measurement can be translated from linguistic descriptions to discrete values, which in turn were extended into continuous values. This was done using fuzzy logic. Fuzzy values were used in the technique to reflect the uncertain judgement of evaluators.

Formation and Evaluation of VEs: Various MCDMMs were reviewed and AHP approach was adopted. AHP was extended by introducing fuzziness. FAHP (with extent analysis) was used to evaluate partners. The evaluators' uncertainty judgements were taken care of with this method. RGFAHP was proposed and implemented. This combined the advantages of both AHP and FAHP and had fewer steps than FAHP. Partners were selected and their performance evaluated. Findings of these algorithms are discussed in sections 7.1.2 and 7.1.3.

MAS support in modelling VEs: MAS techniques were reviewed. Partners were represented as agents and evaluated using company profiles. VEs as MAS were discussed. Project tasks were defined and the coordination of activities and information flow was described. JADE, a MAS tool was used to develop the prototype (appendix I) as a proof of concept. Inter-agent communications enabled the VE initiator to interact with potential partner agents. Evaluations were carried out using evaluator agents and the best partners per task were selected. By delegating the evaluation and selection process to agents, the users could use the time to do the real work. This reduced time and cost of evaluating and selecting partners and evaluating their performance.

Implementation of VE model in the construction industry: Data used was collected from Kenyan contractors and professionals from the construction sector. The problem structuring considered partner selection criteria and sub-criteria. The selection criteria were divided into three as per the information from the focus group interview. They were business, technical and management criteria. The business criterion had the following sub-criteria: Financial strength, strategic position and business strength. Technical criterion had the following sub-criteria: technical capability, development speed, cost of development and use of information technology while management criterion had the following sub-criteria: Management ability, collaboration record and cultural compatibility. This information was used to create a hierarchical structure of the problem. Preference values for partners and level of importance of criteria and sub criteria were given by evaluators. MCDM algorithms were used to select and evaluate the alternatives. A partners' evaluation and selection framework which is discussed in the following section was proposed as a solution to modelling VEs in the construction sector.

7.3 Partners' Evaluation and Selection Framework Formulation

The stepwise procedures for the formulation of the partners' evaluation and selection framework (referred to as framework henceforth), which incorporate FAHP (with extent analysis) and RGFAHP algorithms that can handle uncertainty of evaluators' judgements, are presented. The application of the framework in the collected data resulted into the following findings. In the first cycle, using conventional AHP, it was found that, Partner 1 was the most preferable. In the second cycle, when FAHP (with extent analysis) was applied, partner 2 outweighed others in technical skills. The novel property of the FAHP (with extent analysis) and RGFAHP is that they can give computational results with expression of the degree of uncertainty (i.e. pessimistic, moderate or optimistic).

In chapter 2, the gaps in the existing works were identified. In order to fill the gaps in current knowledge, potential partners were evaluated and selected in terms of their suitability to do structural engineering works in a building construction project. The evaluation used the subjective partner selection criteria from both qualitative and quantitative methods to collect the data. During VE partner evaluation and selection, a framework was designed to enhance decision making in situation where there is insufficient information, ambiguity, fuzziness and vagueness. In order to work towards development of the final framework, all the processes involved in the research study were combined. The final design of the framework consists of many steps (Figure 7.1). The framework can be expanded to include the steps for AHP, FAHP (with extent analysis) and RGFAHP.

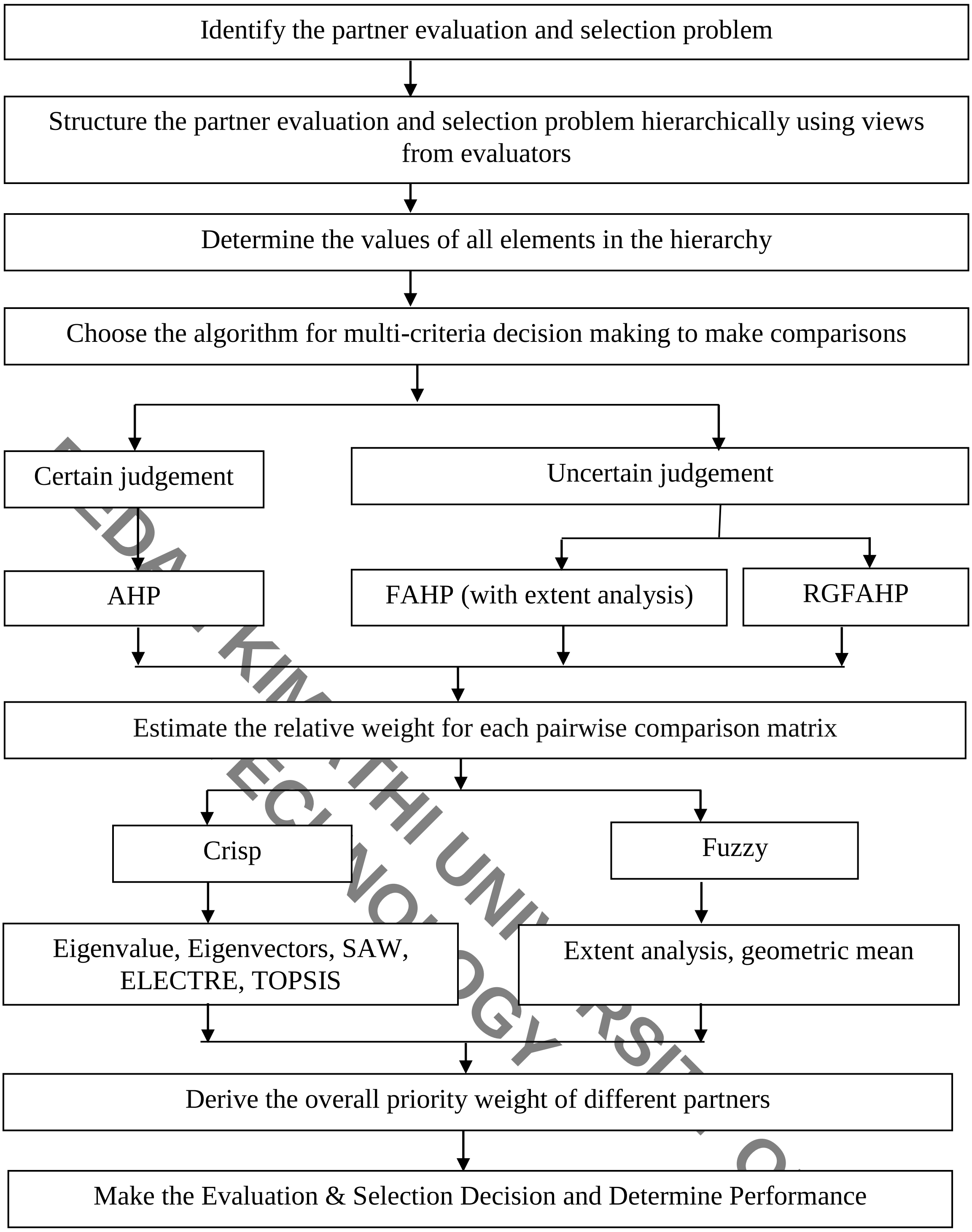


Figure 7.1 Partners' evaluation and selection framework

The steps for these algorithms are shown in Figure 7.1. The framework can be enlarged to include the steps of other algorithms such as simple additive weighting (SAW); a technique for order preference by similarity to ideal solution (TOPSIS) and elimination et choice translation reality (ELECTRE) (Chou et al., 2008).

7.4 Knowledge Contribution

The research contributes to the development of new techniques for addressing consensus and judgement for group evaluation and selection of partners and partners' performance in the construction industry. It provides a link between decision theory and computer science. Using the developed algorithms / techniques, the best partner for a specific task in a construction project can be selected, chosen or predicted and their performance determined.

The research undertaken by researchers and scholars interested in developing techniques which mimic the way evaluation judgements are done by humans, show that use of real time multi-criteria decision making algorithm and fuzzy models is the future of this research field (Bonissone et al., 2009). The traditional solutions using classical set theory have proved not to be conforming to reality, the way human beings rate partner during evaluation. Instead of having only two choices of instances (for example, 0 or 1, true or false, yes or no), human beings rate events or phenomena in many ways (for example, yes, may be, no). The use of fuzzy logic can address the uncertainty, incompleteness of information, randomness of ideas and imprecision of phenomena. Wu (2009) researched multi-criteria decision-making (MCDM) "under uncertainties", in particular the linguistic uncertainties. He proposed the incorporation of fuzzy logic in AHP algorithm. This thesis addressed some solutions identified in the thesis of Wu (2009) as area for future study. Wu (2009) concurs with Saaty and Tran (2007) who oppose the FAHP algorithm because the algorithm capture first the certain and crisp judgements, the captured judgements are then fuzzified to be used in the algorithm. According to them, it is possible and more reasonable to obtain these uncertain judgements directly from the evaluators. This research has shown that linguistic judgements can be fuzzified, that is: It does not need fuzzify crisp numbers obtained directly from evaluators, instead the evaluators, can provide the pairwise comparison in linguistic terms. These can then be modelled using fuzzy logic.

This study sought to evaluate and select partners for tasks in the construction projects. Research has shown the importance of using multiple evaluators in the evaluation and selection of partners. This is important for the project sustainability in terms of the evaluators being able to work as a team.

According to Ramesh et al. (2004), one of the areas of Computer Science research that receives little research attention is in terms of research approaches on the use of evaluative methodologies. This thesis addresses this area, which has got insufficient emphasis.

Three algorithms for the partners' evaluation and selection were developed and applied to the data collected in four cycles. Each cycle addressed some gaps in current knowledge identified as research questions. Those areas that needed further intervention in the next cycle of each algorithm were determined. For example, the inability of AHP (in the first cycle) to handle uncertain evaluator judgement during partner evaluation and selection were addressed by the development of the FAHP (with extent analysis) and RGFAHP (in the second and third cycle respectively). In the fourth cycle, a simulation model was developed using the three algorithms and used with collected data and arbitrary data to simulate different scenarios. Thus, the cyclic intervention in addressing the partners' evaluation and selection problem confirms the completeness of the thesis.

There is a great need for the development of techniques for solving evaluation and selection problems (Chang & Dillon, 2006; Chang et al., 2008). The computer societies of academics, scholars and researchers have come up with new approaches to address this problem. These new approaches are published in the IEEE computational intelligence journal and IEEE computational intelligence magazine (Bonissone et al., 2009). In a recent publication in IEEE's computational magazine the MCDM and fuzzy modelling have been identified by researchers as methods to solve hard science problems (if it can well be incorporated into decision support system). This study has answered part of this problem.

7.5 Assumptions of the Study

This study assumed that the sample used for data collection represented the professionals and contractors in the sector. Another assumption was that the questionnaires, interviews used as data collection instruments, collected valid and reliable data. This was ascertained after designing the instruments and discussing them with quantity and quality data analysis experts and with supervisors. Respondents were assumed to answer questions correctly and honestly. Cases chosen were fair representation of other cases in the sector. Finally, Nairobi County represented other counties in the country. This was ascertained when most professionals and contractors had their offices in Nairobi.

7.6 Limitation of the Study

Finding participants for focus group interviews and questionnaires was difficult because of their busy schedules, data collection methods were susceptible to bias and some of the developed algorithms accepted only exact values.

More than one method for data collection (triangulation) was used to address the problem of the limited number of participants. Code mapping data analysis technique enabled categorization of qualitative data from focus group interviews. Cyclic data modelling helped to get more insight about the research problem. Biasness from the instruments used in data collection was mitigated by using more than one data collection method (triangulation). By means of consistency checking it was possible to evaluate if the evaluator judgement given during evaluation and selection of partners, was not contradictory. The limitation of the some of the algorithms (i.e. AHP) to accept only crisp value was controlled through the integration of fuzzy logic and AHP (i.e. FAHP).

Another limitation concerned the data collection methods that were inherently susceptible to bias. The strategies to control this limitation were:

(i) More than one method was used during data collection. Triangulation helped to extend the limited scope of the study.

(ii) The use of focus group interviews helped the researcher to uncover information, which would not have been possible with other data collection methods.

(iii) The AHP algorithm has the capability of checking the consistency of an evaluator's judgement. This was used as a technique to control which sets of data to use. If there was inconsistency of the evaluation judgement then either the evaluation process or calculation of consistency checking was to be repeated.

(iv) The first three cycles of the data analysis and modelling, using AHP, FAHP (with extent analysis) and RGFAHP, helped to get more clues about the partner evaluation and selection problem (PESP) which could not be revealed if only single algorithm was implemented.

(v) The applicability and validity of the questionnaire for the collection of quantitative data was evaluated and discussed with experienced quantitative analysis experts and issues of concern were rectified before the methods were in the study.

(vi) Fuzzy logic addressed the problem of uncertainty or imprecise evaluators' judgements hence the use of only crisp values was not the case.

7.7 Directions for Future Research

An avenue for future study is to consider how the results of this study could be used for partner evaluation and selection problems in general. That research should be carried out to determine the applicability of this model to other industries and other research fields.

More simulations should done using the model for varying scenarios to determine its weaknesses and recommendations for its improvement. In this regard, views of all professionals in the construction industry should be considered to develop the model. This will increase acceptability of the model in the industry.

The limitations of FAHP (with extent analysis) and RGFAHP should probably be addressed in future research. Examples of limitations are: (i) checking if FAHP (with extent analysis) and RGFAHP preserve the consistency of the evaluator‘s judgement; and (ii) whether FAHP (with extent analysis) and RGFAHP ignore the dependence between the elements at the same level of the hierarchy, as is the case with AHP.

A study should be done to determine how the incorporation of the Analytical Network Process (ANP) in this algorithm can address weaknesses of FAHP (with extent analysis) and RGFAHP. Further study is required to check if the developed technique from this study can be generalized.

7.8 Trustworthiness of the results

Apart from the simulations, case study results were verified by stakeholders in the construction sector (appendix J). As a proof of concept, a VE prototype was developed and deployed for seven construction companies. Six of the companies were part of the case study organizations (one from each case study) while the seventh one was not part of the case study firms. All the seven companies used the model to form a VE and predict VE partner's performance. All the seven companies were in agreement with the results.

Triangulation of the interviews with questionnaires as well as triangulation of the interviews with one another rendered converging conclusions. The applicability and validity of the questionnaire for the collection of quantitative data was evaluated and discussed with experienced quantitative data analysis experts. A pilot study was conducted as discussed in chapter three where participants gave feedback on the applicability and validity of the evaluation tool in rating partners in addition to suggesting changes that would make the evaluation tool applicable.

7.9 Conclusion

Chapter one presents the VE definition, types and lifecycle. It introduces construction industry in Kenya, its significance to the economy and its challenges. A VE conceptual model and a solution to the partner evaluation and selection problem is proposed. Chapter two discusses the three critical issues that that this study addresses. They include (1) partner evaluation and selection for VEs, (2) partner evaluation and selection as a MCDM problem, and (3) Modelling of VEs using MAS approach.

Chapter three presents the research methods employed in this study showing their merits and demerits. Mixed research methodology is adopted where literature review provides theoretical part while industrial case scenarios provide the empirical aspect. Data collection techniques include focus group interviews and questionnaires. Data analysis is done using code mapping and statistical techniques. Decision making algorithms are AHP, FAHP and RGFAHP. Triangulation enables data validation.

Chapter four introduces agents as sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. Multi-agent techniques are used to address the issues of complex enterprises and solutions through intelligent behaviours, such as cooperation, competition, and coordination in a set of autonomous agents under a dynamic distribution-oriented open environment.

Chapter five discusses MCDM techniques applied in this study. The AHP is a method for modelling unstructured decision-making problems. FAHP introduces fuzzy logic in AHP and enables modelling unstructured decision making problems with imprecise values. RGFAHP is a new algorithm that has both features for AHP and FAHP.

In chapter six, analysis of focus group interview responses is performed. The results of the analysis inform the evaluation tool design. Evaluators use the evaluation tool to indicate their preference / importance of alternatives i.e. criteria, sub criteria and partners. To determine the accuracy of these techniques, data is obtained from six case study groups. MCDM techniques are used to simulate different knowledge based scenarios by evaluators from the six case studies. Partner performance evaluation criteria are used to predict partners' performance.

In chapter seven, the interpretations of the results is presented. In the first cycle, the implementation of AHP is done. The weakness of AHP necessitate developing an algorithm to handle uncertain judgements of users. This is the reason that FAHP (with extent analysis) and RGFAHP are implemented in the second and third cycles respectively. All these cyclic interventions are done to answer the research questions. Systemic components for modelling and Evaluation of VEs are identified. VE partner selection and performance evaluation is done. A MAS prototype is developed and framework formulated to aid evaluators in evaluation of partners according to defined criteria and sub-criteria. This framework allows the evaluation of partners' selection criteria and sub-criteria that are of interest to stakeholders in a specific construction project. In addition, it incorporates algorithms which compute prioritization of evaluator judgements when the evaluation situation is either certain or uncertain. This has been shown using FAHP (with extent analysis) and RGFAHP. The combination of these algorithms is termed as Partner Selection and Performance Evaluation Technique (PaSPET).

Finally, this thesis shows that the evaluation and selection of partners and performance evaluation of partners for tasks in the construction industry can be improved by providing a technique / framework / guideline / roadmap, which can aid / guide evaluators in the evaluation and selection of partners and partners' performance evaluations which is time and cost effective.

REFERENCES

1. Afsarmanesh, H., & Camarinha-Matos, L. M. (2000). Future smart-organizations: a virtual tourism enterprise. In Web Information Systems Engineering, 2000. Proceedings of the First International Conference on Web Information Systems Engineering. IEEE Computer Society Press, ISBN 0-7695-0577-5, Hong Kong, 1, 456-461.
2. Afsarmanesh, H., & Camarinha-Matos, L. M. (2005). A framework for management of virtual organization breeding environments. In Collaborative networks and their breeding environments. Springer, US, 35-48.
3. Ahmad, A., Basir, O., & Hassanein, K. (2004). Adaptive user interfaces for intelligent e-learning: issues and trends. In Proceedings of the fourth international conference on electronic business (ICEB 2004). Beijing, 925-934.
4. Ahmed, S., Karsiti, M., & Agustiawan, H. (2007). A development framework for collaborative robots using feedback control.
5. Aibinu, A. A., & Jagboro, G. O. (2002). The effects of construction delays on project delivery in Nigerian construction industry. International Journal of Project Management, 20(8), 593-599.
6. Al-Gahtani, K., & Mohan S. (2007). Total float management for delay analysis. Journal of Cost Engineering, 49(2), 32-37.
7. Aoyama, H. (2010). Econophysics and companies: statistical life and death in complex business networks. New York: Cambridge University Press.
8. Aruldoss, M., Lakshmi, T. M., & Venkatesan, V. P. (2013). A survey on multi criteria decision making methods and its applications. American Journal of Information Systems, 1(1), 31-43.
9. Azevedo, A. L., Sousa, J. P., Bastos, J. A., & Toscano, C. (1998). A distributed order promise and planning system for the virtual enterprise. In Globalization of Manufacturing in the Digital Communications Era of the 21st Century. Springer US, 69-80.
10. Bailey, W. J., Masson, R., & Raeside, R. (1998). Choosing successful technology development partners: a best-practice model. International Journal of Technology Management, 15 (1-2), 124-138.

11. Bankes, S. C. (2002). Agent-based modelling: A revolution? National Academic Sciences, 99, 7199-7200.
12. Bauer, B., Muller, J. P. , & Odell, J. (2001). Agent UML: A Formalism for Specifying Multi-agent Interaction. In Ciancarini and Wooldridge, M.J, editors, Proceedings of Agent-oriented Software Engineering. Springer-Verlag, 91-103.
13. Bellifemine, F., Poggi, A., & Rimassa, G. (2001). Developing multi-agent systems with JADE. Intelligent Agents VII Agent Theories Architectures and Languages, 42-47.
14. Bernus, P., & Baltrusch, R. (2002). Better Models for Agile Virtual Enterprises-The Enterprise and its Constituents as Hybrid Agents. In Karvonen, I. et. al, editor, Global Engineering and Manufacturing in Enterprise Networks
15. Bernus, P., Baltrusch, R., Tolle, M., & Vesterager, J. (2003). Better Models for Agile Virtual Enterprises-the Enterprise and its Constituents as Hybrid Agents. In VTT SYMPOSIUM, 224, 91-110.
16. Bittencourt, F., & Rabelo, R. J. (2005). A systematic approach for VE partners selection using the SCOR model and the AHP method. In Collaborative networks and their breeding environments, Sixth IFIP Working Conference on Virtual Enterprises PRO-VE. Springer US, 99-108.
17. Bogdan, R., & Biklin, S. (1982). Qualitative research for education: An introduction to theory and methods. Boston, MA: Allyn and Bacon.
18. Bonissone, P., Subbu, R., & Lizzi, J. (2009). Multi Criteria Decision Making (MCDM): A Framework for Research and Applications. IEEE Computational Intelligence Magazine, 4(3), 48-61.
19. Bortolan, G., & Degani, R. (1985). A review of some methods for ranking fuzzy subsets. Fuzzy Sets and Systems, 15(1), 1-19.
20. Bozdag, C., Kahraman, C., & Ruan, D. (2003). Fuzzy group decision making for selection among computer integrated manufacturing systems. Computers in Industry, 51(1), 13-29.

21. Bronder, C., & Pritzl, R. (1992). Developing strategic alliances: a conceptual framework for successful co-operation. European Management Journal, 10, 412-421.
22. Brucker, P. (1999). Resource-constrained project scheduling: notation, classification, models and methods. European Journal for Operation Research, 112, 3-41
23. Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy sets and systems*, 17(3), 233-247.
24. Camarinha-Matos, L. M., Carelli, R., Pellicer, J., & Martin, M. (1997). Towards the virtual enterprise in food industry. In Re-Engineering for Sustainable Industrial Production. Springer US, 73-84.
25. Camarinha-Matos, L. M., & Afsarmanesh, H. (1997). Virtual Enterprises: Life-cycle Supporting Tools and Technologies. In Molina, A, Sanchez, J, and Kusiak, A, editors, Hand book of Lifecycle Engineering: Concepts, Tools and Techniques, Chapman & Hall.
26. Camarinha-Matos, L. M., & Cardoso, T. (1999). Selection of partners for a virtual enterprise. In Infrastructures for Virtual Enterprises, networking industrial enterprises. Springer US, 259-278.
27. Camarinha-Matos, L. M., & Afsarmanesh, H. (2001). Virtual enterprise modelling and support infrastructures: applying multi-agent system approaches. In Multi-agent systems and applications. Springer Berlin Heidelberg, 335-364.
28. Camarinha-Matos, L. M., Silveri, I., Afsarmanesh, H., & Oliveira, A. I. (2005). Towards a framework for creation of dynamic virtual organizations. In Collaborative networks and their breeding environments. Springer US, 69-80.
29. Camarinha-Matos, L. M., & Afsarmanesh, H. (2008). On reference models for collaborative networked organizations. International Journal of Production Research. 46(9), 2453-2469.
30. Campbell, A. (1998). The agile enterprise: assessing the technology management issues. International Journal of Technology Management. 15(1-2), 82-95

31. Chan, A. P. C. (2001).Time cost relationship of public sector projects in Malaysia, International Journal of project Management. 19(4), 223-229.
32. Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research. 95, 649–655.
33. Changkong, V., & Haimes, Y. (1983) Multi-objective Decision Making. North-Holland Series in System Science and Engineering, Elsevier Science.
34. Charagu, S. N (2013). Collapsing Building Structures in Kenya. In Proceedings of the 20th Engineers International conference. Tom Mboya Labour College, Kisumu, Kenya.
35. Chan, D. W, & Kumaraswamy, M. M. (1996). An evaluation of construction time performance in the building industry. Building and Environment, 31(6), 569-578.
36. Chang, D.Y. (1996). Applications of The Extent Analysis Method on Fuzzy AHP. European Journal of Operational Research, 95(3), 649-655.
37. Chatterjee, D., & Mukherjee, B. (2010). Study of fuzzy AHP model to search the criterion in the evaluation of best technical institutions: A Case Study. International Journal of Engineering Science and Technology, 2(7), 2499-2510
38. Chen, Y. M., Liao, C. C., & Prasad, B. (1998). A Systematic Approach of Virtual Enterprising Through Knowledge Management Techniques. Concurrent Engineering: Research and Applications, 6(3).
39. Cheng, C., Yang, K. L., & Hwang, C. (1999). Evaluating attack helicopters by AHP based on linguistic variables weight. European Journal of Operational research, 116(2), 423 -435
40. Cheng, C., Liu, Y. Z., & Wang, R. D. (2010). The test for Kendall's coefficient of concordance W conducted by SPSS (J). Journal of Taishan Medical College, 7, 001.
41. Cheng, J., Proverbs, D. G, & Oduoza, C. F. (2006). The satisfaction levels of UK construction Clients based on the performance of consultants. Engineering, Construction Architectural Management, 13(6), 567–583.

42. Chou, S. Y., Chang, Y. N., & Shen, C. Y. (2008). A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. European Journal of Operational Research, 189(1), 132-145.

43. Choudhury, I., & Phatak, O. (2004). Correlates of time overrun in commercial construction. In ASC proceeding of 4th Annual Conference, Brigham Young University-provo-Utah, 8-10.

44. Cook, W. D., Tone, K., & Zhu, J. (2014) Data envelopment analysis: Prior to choosing a model, OMEGA, 44, 1-4.

45. Covella, G. J., & Olsina, L. A. (2006). Assessing quality in use in a consistent way. In Proceedings of the 6th international Conference on Web Engineering. Palo Alto, California, USA: ACM Press, New York, NY, 1-8.

46. Creswell, J. (1994). Research design: Qualitative and quantitative approaches. Thousand Oaks, CA: SAGE.

47. Crispim, J. A., & Pinho de Sousa, J. (2009). Partner selection in virtual enterprises: a multi-criteria decision support approach. International Journal of Production Research, 47(17), 4791-4812.

48. Crotty, M. (1998). The foundations of social research: Meaning and perspective in the research process. London: Sage.

49. Culley, S. J., Boston, O. P., McMahon, C. A. (1999). Suppliers in New Product Development: Their Information and Integration. Journal of Engineering Design, 10(1), 59-75.

50. Davison, R. N. (2002). Ethics and research methods. In System Sciences, 2002. HICSS. Proceedings of the 35th Annual Hawaii International Conference on System Sciences (Hicss'02). IEEE Computer Society, Washington DC, 8, 3439-3445.

51. Doloi, H, Sawhney, A., & Lyer, K. C. (2012). Structural equation model for investigating factors affecting delay in Indian construction projects. Journal of Construction Management and Economics, 30, 869-884.

52. Dubé, L., & Paré, G. (2003). Rigor in information systems positivist case research: current practices, trends, and recommendations. MIS quarterly, 597-636.
53. Dubois, D., Kerre, E., Mesiar, R., & Prade, H. (2000). Fuzzy interval analysis. In *Fundamentals of fuzzy sets.* Springer US, 483-581.
54. Epstein, J., & Axtell, R. (1996). Growing artificial societies: MIT press Cambridge, MA.
55. Eversheim, W., Bauernhansl, T., Bremer, C., Molina, A., Schuth, S., & Walz, M. (1998). Configuration of virtual enterprises based on a framework for global virtual business. In Organizational Virtualness-VoNet-Workshop, 77-83.
56. Fielding, N., & Fielding, J. (1986). Linking data. Newbury Park, CA: Sage Publications.
57. Field, S., & Hoffner, Y. (2002). In Search of the Right Partner, in Collaborative Business Ecosystems and Virtual Enterprises, L. M. Camarinha-Matos (Ed.), Kluwer Academic Publishers, 55-62.
58. Film showcase. MASSIVE. http://www. massivesoftware.com/film. (Retrieved April 2012).
59. Fischer, K., Müller, J., Hemmig, I., & Scheer, A. W. (1996). Intelligent Agents in Virtual Enterprises. In Proceedings of First International Conference and Exhibition on the Practical Applications of Intelligent Agents and Multi-Agent Technology (PAAM-96). London, U.K, 205–204.
60. Fisher, L. (1995). Win 32 Application Support for Plug and Play.
61. Forman, E., & Peniwati, K. (1998). Aggregating individual judgements and priorities with the analytic hierarchy process. European Journal of Operational Research, 108(1), 165-169.
62. Foundation for Intelligent Physical Agents. Specifications. (1999). Available at http://www.fipa.org.
63. Fox, M. S., Barbuceanu, M., & Gruninger, M. (1996). An organization ontology for enterprise modelling: preliminary concepts for linking structures and behaviour. Computers in Industry, 29(1), 123–134.
64. Friedman-Hill, E. J. (1998). Java Expert System Shell.

Available at http://herzberg.ca.sandia.gov/jess.

65. Frimpong, Y., Oluwoye, J., & Crawford, L. (2003). Causes of delays and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. International Journal of Project Management, 21, 321-326.
66. Gable, G. G. (1994). Integrating case study and survey research methods: an example in information systems. European Journal of Information Systems, 3(2), 112-126.
67. Gilbert, N., & Troitzsch, K. G. (2005). Simulation for the social Scientist (Second ed.): McGraw Hill Education.
68. Glaser, B. G., & Strauss, A. (1967). The discovery of grounded theory: Strategies for qualitative research. Chicago: Aldine.
69. Golany, B., & Kress, M. (1993). A multi-criteria evaluation of methods for obtaining weights from ratio-scale matrices. European Journal of Operational Research, 69(2), 210-220.
70. Goldman, S., Nagel, R. N., & Preiss, K. (1995). Agile competitors and virtual Organizations: strategies for enriching the customer, Van Nostrand Reinhold, New York.
71. Gosain, S. (1998). Applying Plug-and-Play Design Philosophy to Virtual Organizing. Institut für Wirtschaftsinformatik der Universittät Bern (Hrsg.): Newsletter, 2(4), 12-19. (www.virtualorganization.net)
72. Gray, C. F., & Larson, E. W. (2000). Project management-The managerial process. McGraw-Hill
73. Guerra, M. A. P. (2006). Analysis and design of virtual enterprises. Doctoral dissertation, University of Saskatchewan.
74. Gunasekaran, A. (1998). Agile manufacturing: enablers and an implementation framework. International Journal of Production Research, 36(5), 1223–1247
75. Gupta, P., Gupta, R., & Netzer, T. (2009). Building India: Accelerating Infrastructure Projects Infrastructure Practice. Report prepared by Mckinsey & Company Inc. Mumbai, India.
76. Guttman, R. H., & Maes, P. (1998). Cooperative vs. competitive multi-agent negotiations in retail electronic commerce. In Cooperative Information Agents

II Learning, Mobility and Electronic Commerce for Information Discovery on the Internet. Springer Berlin Heidelberg, 135-147.

77. Hersh, M. A., & Tucker, W. D. (2005). Ethics and Mono-disciplinarily: Positivism, Informed Consent and Informed Participation. In Proceeding of the 16th IFAC World Congress. Prague, Czech Republic.
78. Hsieh, F. S., & Lin, J. B. (2014). A dynamic scheme for scheduling complex tasks in manufacturing systems based on collaboration of agents. Applied Intelligence, 41(2),366-382.
79. Huang, G. Q., & Mak, K. L. (2000). WebBid: A web based framework to support early supplier involvement in the new product development. Robotics and Computer Integrated Manufacturing, 16, 169-179.
80. Ip, W. H., Huang, M., Yung, K. L., & Wang, D. (2003). Genetic algorithm solution for a risk-based partner selection problem in a virtual enterprise. Computers and Operations Research, 30(2), 213-231.
81. Jarimo, T., Ljubic, P., Salkari, I., Bohanec, M., Lavrac, N., Znidarsic, M., & Hodik, J. (2005). Hierarchical multi-attribute decision support approach to virtual organization creation. Springer US, 135-142.
82. Jennings, N. (1999). Agent-based computing: Promise and perils. In Proceedings of the 16th International Joint Conference on Artificial Intelligence (IJCAI-99), Stockholm, Sweden.
83. John, R., & Heavey, C. (2006). Process modelling for simulation. Computers in Industry, 57(5), 437–450.
84. Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. Educational Researcher, 33(7), 14-26.
85. Kabir, G., & Hasin, M. A. A. (2013). Integrating modified Delphi method with fuzzy AHP for optimal power substation location selection. International Journal of Multi-criteria Decision Making, 3(4), 381–398.
86. Kabir, G., & Sumi, R. S. (2014). Hazardous waste transportation firm selection using fuzzy analytic hierarchy and PROMETHEE methods. International Journal of Shipping and Trans-port Logistics.

87. Kaming, P. F., Olomolaiye, P. O., Holt, G. D., & Harris, F.C. (1997). Factors influencing construction time and cost overruns on high-rise projects in Indonesia. Journal of Construction management and Economics, 15(1), 83-94.
88. Kaminka, G. A. (2004). Robots are Agents, Too! AgentLink News, 16–17.
89. Karlsson, J., Wohlin, C., & Regnell, B. (1998). An evaluation of methods for prioritizing software requirements. Information and Software Technology, 39(14-25), 939-947.
90. Kenya Institute for Public Policy Research and Analysis (KIPPRA): Kenya Economic Report 2013. Available at http://www.kippra.org/downloads/Kenya Economic Report 2013.pdf (Retrieved July 2013).
91. Kenya Economic Survey 2013. Available at http://www.vision2030.go.ke/cms/vds/Kenya_Economic_Survey_2013.pdf (Retrieved July 2013)
92. Kenya Economic Survey Report Highlights (2014). Ministry of Devolution and Planning.
93. Kenya Economic Update: World Bank Report (2012). Devolution without Disruption: Pathways to a Successful New Kenya. Nairobi.
94. Kenya National Bureau of Statistics (2013). Economic Survey. Nairobi: Government Printer
95. Kenya Engineers Reports on projects (KERP, 2006). Ministry of Public works. Available at: http://www.publicworks.go.ke. (Retrieved January 2013)
96. Klein, M. (1996). Challenges and Directions for EI: A Distributed AI Perspective. In Bernus, P., & Nemes, L., editors, Modelling and Methodologies for Enterprise Integration, Chapman and Hall, 319–332.
97. Kluber, R. (1998). A Framework for Virtual Organizing. Journal for Organizational Virtualness, Proceedings of the VoNet-Workshop, Bern, Switzerland, 93-106. (www.virtual-organization.net)
98. Knabe, T., Schillo, M., & Fischer, K. (2002). Improvements to the FIPA contract net protocol for performance increase and cascading applications. In

International Workshop for Multi-Agent Interoperability at the German Conference on AI (KI-2002).

99. Koushki, P. A, Rashid A. L, Khalid & Kartam, N. (2005). Delays and cost increases in the construction of private residential projects in Kuwait. Journal of Construction Management and Economics, 23(3), 285-294.

100. Kraemer, H. C. (1976). The small sample non-null properties of Kendall's coefficient of concordance for normal populations. Journal of the American Statistical Association, 71(355), 608-613.

101. Kubera, Y., Mathieu, P., & Picault, S. (2010). Everything can be Agent! In Proceedings of the ninth International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS). Toronto, Canada, 1547–1548

102. Kwong, C., & Bai, H. (2002). A fuzzy AHP approach to the determination of importance weights of customer requirements in quality function deployment. Journal of Intelligent Manufacturing, 13(5), 367–377.

103. Labrou, Y., & Finin, T. (1998). Semantics and Conversations for an Agent Communication Language. In Huhns, M. N., & Singh, M. P., editors, Readings in Agents, Morgan Kaufmann, 235–242

104. Lai, Y. J., Liu, T. Y., & Hwang, C. L. (1994). Topsis for MODM. European Journal of Operational Research, 6(3), 486-500

105. Leung, L. C., & Cao, D. (2000). On consistency and ranking of alternatives in fuzzy AHP. European Journal of Operational Research, 124(1), 102-113.

106. Levitt, R. E., Jin, Y., Oralkan, G. A., Kunz, J. C., & Christiansen, T. R. (2001). Computational Enterprise Models: Towards Analysis Tools for Designing Organizations. In Olsen, G. M., Malone, T. W., & Smith, J. B, editors, Coordination Theory and Collaboration Technology, Lawrence Erlbaum Associates, Publishers, 623–649.

107. Le-Hoai, L., DaiLee, Y., & Lee, J. Y. (2008). Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. KSCE journal of civil engineering, 12(6), 367-377.

108. Li, Y., Huang, B. Q., Liu, W. H., Wu, C., & Gou, H. M. (2000). Multi-agent system for partner selection of virtual enterprises. In Proceedings of 16th IFIP World Computer Congress. Beijing, China, 21-25.

109. Lincoln, Y. S. (2001). Varieties of validity: Quality in qualitative research. Higher Education-New York-Agathon Press Incorporated, 16, 25-72

110. Ling, Y., Gu, Y., & Wei, G. Y. (2010). Dynamic alliance partner selection in the Top-k problem optimization algorithm. Computer Integrated Manufacturing, 16(3), 650-657

111. Liou, T. S., & Wang, M. J. (1992). Ranking fuzzy numbers with integral value. Fuzzy Sets and Systems, 50, 247–255.

112. Macal, C. M., & North, M. J. (2007). Agent-based modelling and simulation: desktop ABMS. In Proceedings of the 39th conference on Winter simulation: 40 years! The best is yet to come, Washington D.C.

113. Máhr, T. S., Srour, J., De Weerdt, M., & Zuidwijk, R. (2010). Can agents measure up? A comparative study of an agent-based and on-line optimization approach for a drayage problem with uncertainty. Transportation Research Part C: Emerging Technologies 18: 99. doi:10.1016/j.trc.2009.04.018.

114. Mambo, S. (2010). Why Engineering Structures Fail. Journal of the institution of Engineers of Kenya, 31(2), 28-29.

115. Merriam, S. (1988). Case study research in education. San Francisco, CA: Jossey-Bass.

116. Microsoft Windows and Plug and Play Framework Architecture (1994).

117. Mikhailov, L. (2003). Deriving priorities from fuzzy pairwise comparison judgements. Fuzzy Sets and Systems, 134(3), 365-385.

118. Mikhailov, L., & Tsvetinov, P. (2004). Evaluation of services using a fuzzy analytic process. Applied Soft Computing, 5(1), 23-33.

119. Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis: An expanded source book. Thousand Oaks, CA: Sage Publications.

120. Mowshowitz, A. (1999). The Switching Principle in Virtual Organizations. Proceedings of the 2nd VoNet-Workshop, Zurich, Switzerland, September 23-24, 9-20. (www.virtual-organization.net)

121. Mukhopadhyay, R., Costes, S. V., Bazarov, A. V., Hines, W. C., Barcellos-Hoff, M. H., & Yaswen, P. (2010). Promotion of variant human mammary epithelial cell outgrowth by ionizing radiation: an agent-based model supported by in vitro studies. Breast Cancer Research, 12(1).

122. Myers, M. D., & Newman, M. (2007). The qualitative interview in IS research: Examining the craft. Information and organization, 17(1), 2-26.

123. Nayak, N., Bhaskaran, K., & Das, R. (2001). Virtual Enterprises. Building Blocks for Dynamic e-Business, In Proceedings of the Workshop on Information Technology for Virtual Enterprises. IEEE Computer Society, 80–87.

124. Niehaves, B. (2005). Epistemological Perspectives on Multi-Method Information Systems Research, Thirteenth European Conference on Information Systems, Regensburg, Germany

125. Niazi, M., & Hussain, A. (2009). Agent based Tools for Modelling and Simulation of Self-Organization in Peer-to-Peer, Ad-Hoc and other Complex Networks. IEEE Communications Magazine, 47(3), 163 - 173.

126. Niazi, M., & Hussain, A. (2010). A Novel Agent-Based Simulation Framework for Sensing in Complex Adaptive Environments (In-Press). IEEE Sensors Journal, 11(1), doi:10.1109/JSEN.2010.2068044.

127. Niazi, M., Siddique, Q., Hussain, A., & Kolberg, M. (2010). Verification and Validation of an Agent-Based Forest Fire Simulation Model. Paper presented at the SCS Spring Simulation Conference, Orlando, FL, USA.

128. Niazi, M. A., & Hussain, A. (2011). A Novel Agent-Based Simulation Framework for Sensing in Complex Adaptive Environments. Sensors Journal, IEEE, 11(2), 404-412.

129. National Construction Authority registered contractors database. Available at: http://www.nca.go.ke/index.php/contractors-center/search-registered-contractors. (Retrieved November 2012)

130. Nikoomaram, H., Mohammadi, M., Taghipourian, M. J., & Taghipourian, Y. (2009). Training performance evaluation of administration sciences instructors

by fuzzy MCDM approach. Contemporary Engineer Science, Tehran, Iran, 2, 559-75.

131. Niu, N., Jin, M., & Cheng, J. R. C. (2011). A case study of exploiting enterprise resource planning requirements. Enterprise Information Systems, 5(2), 183-206.

132. Odeh, A. A., & Battaineh, H. T. (2002). Causes of construction delay: traditional contracts. International Journal of Project Management, 20(1), 67-73.

133. Olawale, Y. A., & Sun, M. (2010). Cost and time control of construction projects: inhibiting factors and mitigating measures in practice. Construction Management Economic, 28, 509-526

134. Oliveira, E., & Rocha, A. P. (2000). Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organization Formation Process. In European Perspectives on Agent Mediated Electronic Commerce, Springer-Verlag.

135. Omoregie, A., & Radford, D. (2006). Infrastructure delays and cost escalation: Causes and effects in Nigeria. In Proceedings of the 6th International Conference on Postgraduate Research, Netherlands.

136. Ota, K., Taira, N., & Miyagi, H. (2008). Group Decision-Making Model in Fuzzy AHP Based on Variable Axis Method. IEEJ Transactions on Electronics, Information and Systems, 128(2), 303-312.

137. Patroba, H. (2012). China in Kenya: Addressing Counterfeit Goods and Construction Imbalance in Kenya.

138. Petersen, S. A., Rao, J., & Tveit, A. (2002).Virtual Enterprises: Challenges in Selecting and Integrating Computational and Human Resources. In Burg, B., Dale, J., Finin, T., Nakashima, H., Padgham, L., Sierra, C., & Willmott, S, editors, Agent cities: Challenges in Open Agent Environments, Springer-Verlag, (in print process), LNCS.

139. Petersen, S. A., & Divitini, M. (2002). Using agents to support the selection of virtual enterprise teams, Fourth International Bi-conference Workshop on Agent-oriented Information Systems (AOIS) at AAMAS, Bologne, Italy

140. Petersen, S. A., & Matskin, M. (2003). Agent interaction protocols for the

selection of partners for virtual enterprises, in V. Marik et al. (Eds.) Multi-agent Systems and Applications III, 3rd International Central and Eastern European Conference on Multi-agent Systems, CEEMAS, Prague: Springer-Verlag.

141. Petroni, A., & Braglia, M. (2000). Vendor selection using principal component analysis. Journal of supply chain management, 36(1), 63-69.

142. Purdy, L., & Safayeni, F. (2000). Strategies for supplier evaluation: A framework for potential advantages and limitations. IEEE Transactions on Engineering Management, 47(4), 435-443.

143. Ramesh, V, Robert Glass, L, Vessey, Iris. (2004). Research in computer science: An empirical study, Journal of Systems and Software, 70(1-2), 165-176.

144. Rocha, A., & Oliveira, E. (1999). An electronic market architecture for the formation of virtual enterprises, in Infrastructures for Virtual Enterprises, Kluwer, Boston.

145. Rocha, A. P., & Oliveira, E. (2001). Electronic Institutions as a framework for Agents' Negotiation and mutual Commitment. In Progress in Artificial Intelligence (Proceedings of Tenth EPIA), Springer Berlin Heidelberg, LNAI 2258, 232-245.

146. Roy, B. (1991). The outranking approach and the foundations of ELECTRE methods. Theory and decision, 31(1), 49-73.

147. Rzevski, G., & Skobelev, P. (2014). Managing Complexity. Wit Press

148. Russell, Stuart J., & Norvig, P. (2003). Artificial Intelligence: A Modern Approach (2nd ed.), Upper Saddle River, New Jersey: Prentice Hall, ISBN 0-13-790395-2

149. Saaty, T. (1980). The analytic hierarchy process: Planning, priority setting, resource allocation. New York: McGraw-Hill International.

150. Saaty, T. L., & Tran, L. T. (2007). On the invalidity of fuzzifying numerical judgements in the Analytic Hierarchy Process. Mathematical and Computer Modelling, Decision Making with the Analytic Hierarchy Process and the Analytic Network Process, 46(7-8), 962-975.

151. Salamon & Tomas. (2011). Design of Agent-Based Models. Repin: Bruckner Publishing. ISBN 978-80-904661-1-1, 22.

152. Sandholm, T. W., & Lesser, V. (1997). Coalitions among Computationally Bounded Agents. Artificial Intelligence, Special issue on Economic Principles of Multi-agent Systems, 94(1), 99-137.

153. Sanga, C., & Venter, I. M. (2009). Is a multi-criteria evaluation tool reserved for experts? The Electronic Journal of Information Systems Evaluation (EJISE), 12(2), 165-176.

154. Sanga, C. (2010). A Technique for the Evaluation of Free and Open Source E-Learning Systems. Doctoral dissertation, University of the Western Cape.

155. Sari, B, Sen, D. T, & Kilic, S. E. (2007). Formation of dynamic virtual enterprises and enterprise networks. The International Journal of Advanced Manufacturing Technology, 34(11-12), 1246-1262.

156. Sari, B., Sen, T., & Kilic, S. E. (2008). Ahp model for the selection of partner companies in virtual enterprises. The International Journal of Advanced Manufacturing Technology, 38(3-4), 367-376.

157. Seidel, J. V. (1998). Qualitative data analysis. Available in the Ethnograph v5 user‘s manual: www.qualisresearch.com. (Retrieved September 2012).

158. Seidel, J., Kjoiseth, R., & Seymour, E. (1988). The ethnograph: A user's guide (Version 4.0). Amhurst, MA: Qualis Research Associates.

159. Sen, C. G., & Cinar, G. (2010). Evaluation and pre-allocation of operators with multiple skills: A combined fuzzy AHP and max–min approach. Expert Systems with Applications, 37, 2043– 2053.

160. Sha, D. Y., & Che, Z. H. (2005). Virtual integration with a multi-criteria partner selection model for the multi-echelon manufacturing system. International Journal of Advanced Manufacturing Technology, 25(7-8), 793-802.

161. Shanmugapriya S., & Subramanian K. (2013). Investigation of Significant Factors Influencing Time and Cost Overruns in Indian Construction Projects.

International Journal of Emerging Technology and Advanced Engineering, 3(10).

162. Shen, W., & Norrie, D. H. (1998). An agent-based approach for distributed manufacturing and supply chain management, in Globalization of Manufacturing in the Digital Communications Era of the 21st Century: Jacucci, G. (ed.), Kluwer, Boston.

163. Sherman, H. D., & Zhu, J. (2013). Analyzing performance in service organizations, Sloan Management Review, 54(4), 37-42.

164. Siddiqa, A., Niazi, M. A, Mustafa, F., Bokhari, H., Hussain, A., & Akram, N. (2009). A new hybrid agent-based modelling & simulation decision support system for breast cancer data analysis. International Conference on In Information and Communication Technologies, 134-139.

165. Sieber, P. (1998). Organization Virtualness. The Case of Small IT Companies. Journal of Organizational Virtualness, Bern, Switzerland, 107-122.

166. Srdjevic, B. (2005). Combining different prioritization methods in the analytic hierarchy process synthesis. Computers and Operations Research, 32(7), 1897-1919

167. Stewart, G., Manz, C., Sims, H. (1999). Team Work and Group Dynamics, New York, 139-140

168. Swan, P., Skitmore, M., & Earl, G. (2000). Selecting a suitable procurement method for a building project. Journal for Construction Management and Economics, 16(2), 221-33.

169. Tata, S., & Boughzala, I. (2003). Modelling Contribution for Virtual Enterprise Support. In Proceedings of the 12th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE 2003). Linz, Austria.

170. Tan, W., Xu, W., Yang, F., Xu, L., & Jiang, C. (2013). A framework for service enterprise workflow simulation with multi-agents cooperation. Enterprise Information Systems, 7(4), 523-542.

171. Tang, H., & Zhang, J. (2007). Study on Fuzzy AHP Group Decision-Making Method Based on Set-Valued Statistics. FSKD, 3, 689-693.

172. Teknomo, K. (2006). Analytic hierarchy process (AHP) tutorial. Available at http://people.revoledu.com/kardi/tutorial/ahp/ (Retrieved June 2013).

173. The JADE Project Home Page (2000). Available at http://sharon.cselt.it/projects/jade.

174. The Outsourcing of Engineering Functions and Services, American Society of Mechanical Engineers (ASME), (1997).

175. The Standard Tender Documents, issued by Public Procurement and Oversight Authority in January, 2007. Available at http://ppoa.go.ke/downloads/standard-tender-documents

176. Tolle, M. (2004). Management and engineering of virtual enterprises. Doctoral dissertation, Technical University of DenmarkDanmarks Tekniske Universitet, Department of Management EngineeringInstitut for Planlægning, Innovation og Ledelse.

177. Tolle, M., & Vesterager, J. (2002). VEM: Virtual Enterprise Methodology. In VTT Symposium (Valtion Teknillinen Tutkimuskeskus. Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN, Julkaisija Utgivare Publisher, Finland, 53-70.

178. Tolle, M. & Bernus, P. (2003). Reference models supporting enterprise networks and virtual enterprises, International Journal of Networking and Virtual Organizations, 2(1), 2-15.

179. Triantaphyllou, E., Kovalerchuk, B., Mann Jr. L., & Knapp, G. (1997). Determining the most important criteria in maintenance decision making. Journal of Quality in Maintenance Engineering, 3(1), 16-28.

180. Van Vuuren, D., & Maree, A. (1999). Survey methods in market and media research. Research in practice: Applied methods for the social sciences, 269-286.

181. Vila, J., & Beccue, B. (1995). Effect of visualization on the decision maker when using analytic hierarchy process. In System Sciences, 1995.

Proceedings of the 28th Hawaii International Conference on System Sciences, hicss. IEEE, 4, 992-1001.

182. Wang, H. F., & Fu, C. C. (1997). A generalization of fuzzy goal programming with preemptive structure. Computers and Operations Research, 24(9), 819-828.

183. Wang, D., Yung, K. L., & Ip, W. H. (2001). A heuristic genetic algorithm for subcontractor selection in a global manufacturing environment. Applications and Reviews, IEEE Transactions on Systems, Manufacturing, and Cybernetics, Part C, 31(2), 189-198.

184. Wang, Y. M., Luo, Y., & Hua, Z. (2007). On the extent analysis method for fuzzy AHP and its applications. European Journal of Operational Research, 186, 735–747.

185. Wang, Y. M., & Chin, K. S. (2008). A linear goal programming priority method for fuzzy analytic hierarchy process and its applications in new product screening. International Journal of Approximate Reasoning, 49(2), 451-465.

186. Wassenaar, A. (1999). Understanding and Designing Virtual Organization Form. Virtual-organization.net Newsletter, 3(1), 6-18.

Available at www.virtual-organization.net

187. Weyns, D., Omicini, A., & Odell, J. (2007). Environment as a first-class abstraction in multi-agent systems (PDF). Autonomous Agents and Multiagent Systems, 14(1), 5–30. doi:10.1007/s10458-006-0012-0. (Retrieved May 2013).

188. Wildeman, L. (1998). Alliances and networks: the next generation. International Journal of Technology Management, 15(1-2), 96-108.

189. Wilson, B. (1984). Systems: Concepts, Methodologies and Applications. Wiley, Chichester.

190. Winstanley, G. (1991). The Engineering Domain and Systems. Artificial Intelligence in Engineering. Eds. G. Winstanley. John Wiley and Sons Ltd.

191. Wong, P. S. P., & Cheung, S. O. (2005). Structural equation model trust and partnering success. Journal of Engineering and Management, 21(2), 70-80.

192. Wooldridge, M. (1998). Agent-based computing. Interoperable Communication Networks, 1, 71-98.
193. World Bank Report (2012). Doing Business Report, available at http://www.doingbusiness.org/data.
194. World Bank Report (2013). Accelerating growth and poverty reduction in the new Kenya. Kenya Economic update, 8.
195. Wu, D. (2009). Intelligent systems for decision support. University of Southern California. http : // www-scf.usc.edu / ~dongruiw / files / PhD_Dissertation_WU.pdf (Retrieved May 2013)
196. Wu, N. Q., Mao N., & Qian Y. M. (1999). An approach to partner selection in agile manufacturing. Journal of Intelligent Manufacturing, 10(6), 519–548
197. Xiaofei, D. (2010). A Study on Simulation of Forest Fire Spread Based on a Multi-Agent Model. Anhui Agricultural Science Bulletin.
198. Xiao-Feng X., Smith, S., & Barlow, G. (2012). Schedule-driven coordination for real-time traffic network control. International Conference on Automated Planning and Scheduling (ICAPS), Sao Paulo, Brazil, 323-331.
199. XueNing, C., Tso, S. K., Zhang, W. J., & Li, Q. (2000). Partners' selection for virtual enterprises. In Proceedings of the 3rd World Congress on Intelligent Control and Automation. IEEE, Hefei, China, 1, 164-168.
200. Yaghini, M., Bourouni, A., & Amiri, R. H. (2009). A Framework for Selection of Information Systems Development Methodologies, Computer and Information Science, 2(1), 3-11
201. Yu, P. L. (1985). Multiple-Criteria Decision Making: Concepts, Techniques and Extensions. Plenum Press, New York.
202. Zadeh, L. (1963). Optimality and Non-Scalar-Valued Performance Criteria. IEEE Transactions on Automatic Control, 8, 59–60
203. Zadeh, L. (1965). Fuzzy sets, Information and Control, 8(3), 338-353.
204. Zadeh, L. (1983). The role of fuzzy logic in the management of uncertainty in expert systems. Fuzzy Sets and Systems, 11(1-3), 197-198.
205. Zhang, W. J., Liu, X., & Van Luttervelt, C. A. (1997). A New Methodology and Computer Aid for Manufacturing System Design with Special Reference to Partner Factories Selection in Virtual Enterprises. Proceedings of the

International Conference of World Manufacturing Congress. New Zealand, 61-66.

206. Zarli, A., & Poyet, P. (1999). A framework for distributed information management in the virtual enterprise: The VEGA project. In Infrastructures for Virtual Enterprises. Springer US, 293-306.

207. Zhu, K., Jing, Y., & Chang, D. (1999). A discussion on extent analysis method and applications of fuzzy AHP. European Journal of Operational Research, 116, 450-456.

208. Zimmaermann R., Winkler, S., & Bodendorf, F. (2006). Supply chain event management with software agents. In: S. Kirn, O. Herzog, P. Lockemann, O. Spaniol (Eds.), Multiagent Engineering-Theory and Applications in Enterprises. Springer, Berlin-Heidelberg, 157-175.

APPENDICES

Appendix A: Ethical Consideration

Procedure for ethical clearance: Ethical approval was sought from Dedan Kimathi University of Technology, Board of Graduate School Research Ethics Committee before commencement of the research activities in the year 2012.

Procurement of consent and voluntary participation: The participants were invited to participate in the research by means of a consent form, which explained the objective of the research. It gave the assurance to the participants that all information provided will be treated as confidential. The participants signed the consent form indicating that they are willing to participate. In the consent form, each participant was informed that s/he has a right to withdraw at any time, thus participation was voluntarily without any kind of coercion or deception (Davidson, 2002; Hersh & Tucker, 2005).

Participant confidentiality agreement: In order to ensure privacy and confidentiality, the collected data were kept in a secure place and destroyed at the end of research study, each questionnaire was numbered and did not identify any participant. The results from the study were published in conference and journal without revealing particulars of the participants.

Humanitarian Considerations: Risk and Benefits: The data collection methods in this study did not risk or interfere with the mental or physical integrity of the participants. The participants were informed about the objective of the research; they had sufficient and appropriate information in order to make informed decisions (Hersh & Tucker, 2005).

Consent Form

The main objective of this study is to develop a framework for modelling virtual enterprises (VEs) in the construction industry. The formation phase of VEs entails selection and evaluation of potential partners when the decision maker’s judgements are uncertain. The development of such framework will be useful for construction industries when selecting and evaluating partners' performance according to specific selection and evaluation criteria and sub-criteria. Construction industries have a challenge of selecting partners and evaluating their performance with certainty. This research aims at working toward this end.

I, ________________________________, understand that my participation in this research is solely for the collection of data to model virtual enterprises in the construction industry in general and I agree to participate. I understand that all information that I will provide will be kept confidential, and that my identity will not be revealed in any publication resulting from the research (unless I choose to give permission). Moreover, all recorded interviews and its transcripts plus data from questionnaires will be destroyed after they have been analyzed. I am also free to withdraw from the research at any time.

For further information, please do not hesitate to contact:

George Musumba

Department of Computer Science

Dedan Kimathi University of Technology

P.O. Box 657-10100, Nyeri, Kenya

Email: george.musumba@dkut.ac.ke

Appendix B: Interview Questions

This interview is part of a PhD research study at Dedan Kimathi University of Technology. The objective of the study is to develop a framework for modelling virtual enterprises (VEs) in the construction industry. VE is a collaboration of companies in developing a product for the market.

Your participation is entirely voluntary and your responses will be kept confidential. Thank you very much for participating in this interview.

George Musumba E-mail: george.musumba@dkut.ac.ke

QUESTIONS

1. Which business skills or factors do you consider when evaluating potential partners for a task? ____
2. Which technical skills or factors do you consider when evaluating potential partners for a task?____

3. Which management skills or factors do you consider when evaluating potential partners for a task?______________________________________

Appendix C: Research Questionnaire

Dear respondent,

This questionnaire is for a research study in the construction industry as part of a PhD research study at Dedan Kimathi University of Technology, Kenya. The objective of the study is to develop a framework for modelling virtual enterprises (VEs) in the construction industry. VE is a collaboration of companies in developing a product for the market. Your participation is entirely voluntary and your responses will be kept confidential. Thank you very much for completing this questionnaire.

Indicate your choice with a tick (√) on the label provided. For the purpose of this study the term "collaboration" is defined as participation in a construction project between organizations (contractors) that operate under a different management.

Section A-Partners Evaluation and Selection Criteria

1. Indicate how important each of the following criterion is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Business Skills		A	B	C	D	E
Technical Skills		A	B	C	D	E
Management Skills		A	B	C	D	E

2. Considering Business Skills Criterion; indicate how important each of the following sub-criterion, is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub-Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Business Strength (BS)		A	B	C	D	E
Financial Security (FS)		A	B	C	D	E
Strategic Position (SP)		A	B	C	D	E

3. Considering Technical Skills Criterion; indicate how important each of the following sub-criterion, is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub-Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Technical Capabilities (TC)		A	B	C	D	E
Development Speed (DS)		A	B	C	D	E
Cost of Development (CD)		A	B	C	D	E
Information Technology (IT)		A	B	C	D	E

4. Considering Management Skills Criterion; indicate how important each of the following sub-criterion, is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub-Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Collaboration Record (CR)		A	B	C	D	E
Cultural Compatibility (CC)		A	B	C	D	E
Management Ability (MA)		A	B	C	D	E

Section B-Partner Performance Evaluation

5. Indicate how important is each of the following criterion in measuring partner performance in the project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Time		A	B	C	D	E
Cost		A	B	C	D	E

6. Indicate how important each of the following sub-criterion in affecting expected project delivery time is. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub criterion		Extremely	Very	Important	Weakly	Not at all

		important	important		important	important
Contract modification (few or many) (CM)		A	B	C	D	E
Level of quality requirement (High, Medium, Low) (RQ)		A	B	C	D	E
Site location (Easy to access or not easy to access all the time) (SL)		A	B	C	D	E
Experience of personnel (PE)		A	B	C	D	E
Material market rate (Increase or decrease) (MR)		A	B	C	D	E

7. Indicate how important each of the following sub-criterion in affecting expected project cost is. Use the symbols “A to E” with A being “Extremely important” and E being “Not at all important”. Choose the symbol which best indicates your choice.

Sub criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Material price escalation (PC)		A	B	C	D	E
Breakdown of equipment (EB)		A	B	C	D	E
Rework of sections (RJ)		A	B	C	D	E
Transport cost variation (TC)		A	B	C	D	E
Change in personnel charge rate (PR)		A	B	C	D	E

Section C-Partner Selection

Use the company profiles of companies P1, P2, P3, P4 and P5 provided at the end of this questionnaire. Indicate how preferable is each company against each other according to partner selection sub-criterion to perform a task in a building construction project. Use the symbols “A to E” with A being “Extremely preferable” and E being “Not at all preferable”. Choose the symbol which best indicates your choice.

Sub-Criterion		Extremely preferable	Strongly preferable	Preferable	Weakly preferable	Not at all preferable
		P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5
Technical capabilities (Have relevant types of skills)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Development speed (Completes tasks within project timelines)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Financial security (Amount of money deposited before project		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E

commencement)						
Collaborative record (Have successfully been part of large projects)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Business strength (Have necessary equipment and qualified staff)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Cost of development (The projected task cost within the project budget)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Corporate cultural compatibility (Staff management style in the previous projects)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Strategic position (Partnership with other firms like financiers)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Management ability (Handles staff issues amicably)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Use of Information Technology (Use software for designs, finance and staff issues management)		A A A A A	B B B B B	C C C C C	D D D D D	E E E E E

Appendix D: Partner Company Profiles

P1: China ZhongXing Construction Company Ltd

China ZhongXing Construction Company Ltd is an incorporated limited liability construction company. The company has an office in Nairobi, Off Ngong Road; plot number L.R 209/7718. The company contracts projects in the industrial sector, public and private sector housing development, roads, bridges, water, electricity, steel structures and major civil works, gardens, parks and sports stadia. The company has from time to time contracted projects in joint ventures with other major construction companies and corporations on specific projects. It is backed by extensive innovative and advanced construction technology and equipment. It has experienced management and competent technical staff. Most of the staff have been working in East Africa and have experience in local construction technology and materials, statutory and local authority requirements.

Major projects completed

- Proposed Ezra Sanctuary on plot L.R No. 13401, Karen, Nairobi
- Proposed Data Centre on plot L.R. No. 120891/9 Enterprise Road, Nairobi.
- Proposed office development for African Population and Health Research Centre on plot L.R No. 2951/462, Kitisuru, Nairobi
- Proposed Eden Beach Hotel on plot L.R. No. MN/1/3595 on Beach road, Mombasa
- And other 17 projects spread in Nairobi, Nakuru and Mombasa counties.
- More than 25 references from business associates and clients are available.

P2: M. R. Shah Construction (K) Ltd

M.R. Shah Construction (K) Ltd is a registered Category A contracting firm for building and civil engineering works established in 1977. The company has an office in Nairobi, Museum Hill Centre, Museum Hill road. To date the firm is proud to have completed 11 high-rise office blocks in Kenya with 9 buildings in the capital city of Nairobi, 1 in Mombasa and 1 in the Kisii town. All building contracts awarded to the firm have been successfully completed to clients' and consultants satisfaction. Building contracts completed so far, include projects for parastatals, ministry of roads and public works, co-operative societies, educational and financial institutions, health institutions and private clients. The firm has over 40 years of experience in the building construction industry with a well established reputation and capability of undertaking construction contracts of all types and size. M.R. Shah Construction (K) Ltd employs experienced technical, supervisory and administrative staff with a workforce of skilled tradesmen and labourers. When required, the services of other professionals in the construction trade are also employed. Moreover, the directors are actively involved in the full time management of the business to ensure building projects are completed on time and within budget. Its success and integrity can be attributed to vast experience, strong work ethic, quality of construction work and the strong relationship with its clients.

Major projects completed

- Extension of textile mill for United Textile Industries Ltd at KSh. 75 millions

- Commodities storage warehouses for Rupshi Meghji & Bros at KSh 65 millions
- Reinforced Concrete Grain Silos for Jambo Flour Mills at KSh 50 millions
- Farmers Housing for National Irrigation Board at KSh. 85 millions
- And other 50 projects spread in major towns of Kenya.
- More than 15 references from business associates and clients are available

P3: Next Generation Construction Limited (NeGeCoL)

NeGeCoL is a structural engineering firm with headquarters in Nairobi, Kenya. It specializes in the state of the art structural works. It authors designs and implements them. It has 120 technical staff who are directly involved in structural projects either as technical staff or supervisors. It implements commercial projects like office buildings, parking bays, garages, retail centres, hotels, recreation facilities, schools, financial institutions, laboratories, warehouses, factories, medical office buildings, and housing schemes. NeGeCoL finances its projects and recovers the cost from the financiers. It has an average annual financial return of over KSh. 4500,000,000. NeGeCoL boasts of offering among others structural engineering services to many multi-storey buildings in major towns in East Africa.

Projects completed

- Office fit-out for export processing zone at Britak Centre upper hill Nairobi at a cost of KSh. 15 millions
- Bank of Baroda headquarters, Koinange street, Nairobi at a cost of KSh. 45 millions
- Completion of wet laboratories, University of Nairobi, Chiromo campus at a cost of KSh. 90 millions
- Post Bank House refurbishment works of mezzanine floor and ground floor at a cost of KSh. 14 millions
- And other 61 projects spread in major towns of Kenya.
- More than 30 references from business associates and clients are available

P4: Mecoy Consultants Ltd

Mecoy Consultants is a visionary firm. It employs experienced professionals in the field of Mechanical Engineering, Electrical Engineering and Information Technology. It employs and train citizen staff, actively encourages continuing professional development and provides industrial training to degree course students. The firm has an office in Nairobi, PCEA-Jitegemee Flats, Block G, Jubavu Road, Hurlingham. It has a professional indemnity insurance cover with UAP at KSh 4 millions. Much of the business is carried out using state of art methods and techniques. Since inception Mecoy has provided wide range of consultancy services ranging from single buildings through campuses to urban infrastructure developments in addition to number of refurbishments projects. It adopts holistic approach to building projects and generally towards the built environment which among other things recognizes the complex interrelationships between light, heat and sound in aesthetically pleasing environment. Mecoy works in multi-disciplinary teams with other specialist consultants to balance functional and practical engineering solutions with costs. The firm has considerable experience in general electrical, mechanical and information technology services for buildings. Detailed projects planning, design and execution has included utility services intake and distribution, lighting power and electronic system including fire, security, voice and data services, heating, ventilation and air conditioning, building management system, wet services, fire protection services and vertical transportation (lift) services.

Major projects completed

- World Vision International Kenya, Headquarters at a cost of KSh. 150 millions
- Rehabilitation of Kenya Meat Commission at a cost of KSh. 450 millions
- Cooperative Bank Branch, along Digo Road, Mombasa, Kenya at a cost of KSh. 50 millions
- Proposed new co-operative bank branch, kajiado branch at a cost of Ksh. 50 millions
- And other 101 projects spread in major towns of Kenya.
- More than 120 references from business associates and clients are available

P5: Civil Engineering Consultancy Limited (CECL)

Civil Engineering Consultancy Limited (CECL) is a full service structural/civil engineering consulting firm with headquarters located in Nairobi, Kenya. It offers comprehensive design services to architects, project owners, developers and contractors. Its staff have extensive experience with all types of commercial projects including office buildings, parking garages, retail centres, hotels, recreation facilities, schools, financial institutions, laboratories, warehouses, factories, medical office buildings, and housing schemes. CECL also offers unique design services in the areas of renovation/rehabilitation, preservation of historical structures, due diligence reports for all types of building structures, and other special projects. Professional services offered by CECL include complete preparation of structural/civil construction drawings, specification writing, cost estimating and value engineering for both new construction and the rehabilitation of existing facilities. The staffs routinely review and coordinate the work of the full design team, including the work of the architect, mechanical and electrical engineers. CECL has an average annual financial return of over KSh. 550,000,000.00. CECL boasts of providing structural engineering services to major international airports in East Africa.

Appendix E: A Building Construction Project

A client has the following project. The project initiator defines the requirements of each of these tasks and sends invitation to registered potential partners. The project cost as shown in Table E.1 is approximately Kenya shillings 1882591302.00 and is supposed to be implemented in 36 months.

Table E.1 Proposed development of KCB staff retirement benefits scheme 2006 and pension fund

Main Research Case Project Information		
Project	**Proposed Development of an Office Block for KCB Staff Retirement Benefits Scheme 2006 and KCB Staff Pension Fund.**	
Main Consultant	**Pinnacle Projects Limited**	
project Location	**LR Number: 209/12396**	
Project Highlights	**Contract Sum**	**KSh 1882591302.00**
	Contract duration	**156 Weeks**
	Site handover	**15th November, 2010**
	Ground breaking	**6th December, 2010**
	Completion date	**31st December, 2013**
Project Design Team	**Developer**	**KCB Staff Retirement Benefits Scheme 2006 and Staff Pension Fund**
	Project Manager	**Pinnacle Projects Ltd**
	Architect	**Planning Systems Services Ltd**
	Quantity Surveyor	**Armstrong and Duncan**
	Civil & Structural Engineer	**Base Plan Associates**
	M & E Engineer	**EAMS Ltd**
	Main Contractor	**China WU YI Company Ltd**
	Plumbing Sub contractor	**Allied Plumbers**
	Electrical Sub contractor	**Mehta Electricals**
	Structured Cabling GIBM Sub contractor	**Forecast Electronics**
	Mechanical Ventilation Sub	**Universal Engineering**

	contractor	
Construction Team	**Waste Water Treatment Sub contractor**	**Clear Edge**
	Security Installations Sub contractor	**HFI International**
	Generator (Diesel) Sub contractor	**TBD**
	UPS & Voltage Regulator Sub contractor	**TBD**
	Facade Sub contractor	**China WU YI Company Ltd**
	Lifts & Escalators Sub contractor	**China WU YI Company Ltd**
	Steel Staircase Sub contractor	**David Engineering**
	Toilets cubicles	**Island Homes**
	Tenant	**Kenya Commercial Bank Ltd (KCB)**
Consultant Team	**Consultants**	**China WU YI Ltd**
	Consultants	**Mehta Electrical Ltd**
	Consultants	**Universal Engineering Systems**
	Consultants	**David Engineering**
Design Team	**Designers**	**Pinnacle Projects Ltd**
	Designers	**Armstrong & Duncan**
	Designers	**Planning Systems Services Ltd**
	Designers	**Base Plan Associates**
	Designers	**EAMs**
	Designers	**COW**
	Residents Engineer	**Civil Engineering Construction Ltd**

The project is decomposed into six tasks thus T1-Structural works, T2-Plumbing works, T3-Electrical works, T4-Mechanical works, T5-Land-scaping works and T6-Interior design works as shown in Table E.2 below

Table E.2 Tasks and skills requirements for building construction project

Task No	Task Name	Task Descriptions	Task Skills requirements
T1	Structural works	Earth works, form work, reinforcement, concreting, masonry, roofing and plastering	Civil Eng cert, Civil Eng Test, Civil Eng project
T2	Plumbing works	Pipe works, connection to external works.	Plumb cert, Plumb Test, Plumb project
T3	Electrical works	Conduits, wiring, fittings, connections to power supply	Elec. Eng cert, Elec. Eng Test, Elec. Eng project
T4	Mechanical works	Fixing sleeves, fittings,	Mech. Eng cert, Mech. Eng Test, Mech. Eng project
T5	Land-scaping works	Earth works, planting, constructing fountain and pipe works	Lscape cert, Lscape Test, Lscape project
T6	Interior design works	Partitioning, paint works, furnishing, decoration	Interior des cert, Interior des Test, Interior des project

Appendix F: Multi-Agent Systems

Introduction: In order to support the formation of VEs in the construction industry, a MAS software tool is important.

Agent Communication Protocol: An Agent Communication Protocol (ACP) describes the sequence of communication between two agents and the contents of the messages exchanged (Foundation for Intelligent Physical Agents [FIPA], 2002; Labrou & Finin, 1998). ACP for VE formation and selection of partners can be compared to the basic auction protocols (Bauer et al., 2001) and the Contract Net

Protocols (Knabe et al., 2002). During the formation phase of a VE, the Potential Partners and the VE Initiator communicate, for example, the VE Initiator initiates (announces) the VE in to potential partners. The Potential Partners disclose their interests and competencies (in the form of bid proposals whose contents correspond to the requirements expressed in the VE announcement). The VE initiator evaluates the bids based on some criteria and goes ahead with classifying the Potential Partners according to their characteristics and interests in relation to the VE characteristics and goals. A contract is awarded to the appropriate team of partner(s).

Java Agent Development Environment: Java Agent Development Environment (JADE) is a software framework for writing agent based applications in compliance with the FIPA (Friedman-Hill, 1998) specifications for inter-operable intelligent multi-agent systems. FIPA is an international non-profit association of companies and organizations sharing the effort to produce specifications for generic agent technologies. FIPA does not just promote a technology but a set of general technologies for different application areas that developers can integrate to make complex systems with a high degree of interoperability. JADE is an Open Source project, and the complete system can be downloaded from JADE Home Page (The JADE Project, 2000). The goal of JADE is to simplify development while ensuring standard compliance through a comprehensive set of system services and agents. To achieve such a goal, JADE offers the following list of features to the agent programmer:

- FIPA-compliant Agent Platform, which includes the AMS (Agent Management System), the default DF (Directory Facilitator), and the ACC (Agent Communication Channel). All these three agents are automatically activated at the agent platform start-up.
- Distributed agent platform. The agent platform can be split on several hosts. Only one Java application, and therefore only one Java Virtual Machine, is executed on each host. Agents are implemented as one Java thread and Java events are used for effective and lightweight communication between agents on the same host. Parallel tasks can be still executed by one agent, and JADE schedules these tasks in a cooperative way.
- A number of FIPA-compliant additional DFs (Directory Facilitator) can be

started at runtime in order to build multi-domain environments, where a domain is a logical set of agents, whose services are advertised through a common facilitator.

- Java API to send/receive messages to/from other agents; ACL messages are represented as ordinary Java objects.
- FIPA97-compliantI IOP protocol to connect different agent platforms.
- Light weight transport of ACL messages inside the same agent platform, as messages are transferred encoded as Java objects, rather than strings, in order to avoid marshalling and un-marshalling procedures.
- Library of FIPA interaction protocols ready to be used.
- Graphical user interface to manage several agents and agent platforms from the same agent.

JADE is a mature software development tool. JADE is a middleware that enables fast and reliable implementation of Multi-Agent distributed systems and which can be integrated with artificial intelligence (AI) tools. JADE can arguably be considered the most popular software agent platform available today.

Appendix G: Simulation of Partner Evaluation and Selection

The following section illustrates the outcomes of simulating partners' evaluation and selection when the values for business, technical and management criteria were fixed and interchanged using AHP, FAHP and RGFAHP techniques. Table G.1 shows the results of AHP when business, technical and management criteria values were fixed to 0.41, 0.36 and 0.23 respectively. Tables G.2 and G.3, show the results of AHP the values were interchanged to 0.36, 0.23, 0.41 and 0.23, 0.41, 0.36 for business, technical and management criteria respectively.

Table G.1 Results of AHP-High importance placed on business knowledge.

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.41	FS	0.527	0.216	0.333	0.167	0.233	0.112	0.155
		SP	0.170	0.070	0.433	0.167	0.111	0.101	0.188
		BT	0.303	0.124	0.285	0.143	0.333	0.154	0.085
Technical	0.36	TC	0.379	0.136	0.188	0.250	0.167	0.274	0.121
		DS	0.214	0.077	0.129	0.375	0.115	0.122	0.259
		CD	0.286	0.103	0.250	0.150	0.368	0.211	0.021
		IT	0.121	0.044	0.133	0.267	0.267	0.194	0.139
Management	0.23	CR	0.496	0.114	0.367	0.333	0.211	0.022	0.067
		CC	0.188	0.043	0.200	0.100	0.066	0.289	0.345
		MB	0.316	0.073	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.262	0.227	0.230	0.155	0.123
				Total	0.997				
				Error	0.003				

The PWs of Partners 1 to 5 were 0.262, 0.227, 0.230, 0.155 and 0.123 respectively with an error of 0.003.

Table G.2 Results of AHP-High importance placed on technical knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.23	FS	0.527	0.121	0.333	0.167	0.233	0.112	0.155
		SP	0.170	0.039	0.433	0.167	0.111	0.101	0.188
		BT	0.303	0.070	0.285	0.143	0.333	0.154	0.085
Technical	0.41	TC	0.379	0.155	0.188	0.250	0.167	0.274	0.121
		DS	0.214	0.088	0.129	0.375	0.115	0.122	0.259
		CD	0.286	0.117	0.250	0.150	0.368	0.211	0.021
		IT	0.121	0.050	0.133	0.267	0.267	0.194	0.139
Management	0.36	CR	0.496	0.179	0.367	0.333	0.211	0.022	0.067
		CC	0.188	0.068	0.200	0.100	0.066	0.289	0.345
		MB	0.316	0.114	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.244	0.251	0.226	0.160	0.119
				Total	1.000				
				Error	0				

The PWs of Partners 1 to 5 were 0.244, 0.251, 0.226, 0.160 and 0.119 respectively with an error of 0.

Table G.3 Results of AHP-High importance placed on management knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.36	FS	0.527	0.190	0.333	0.167	0.233	0.112	0.155
		SP	0.170	0.061	0.433	0.167	0.111	0.101	0.188
		BT	0.303	0.109	0.285	0.143	0.333	0.154	0.085
Technical	0.23	TC	0.379	0.087	0.188	0.250	0.167	0.274	0.121
		DS	0.214	0.049	0.129	0.375	0.115	0.122	0.259
		CD	0.286	0.066	0.250	0.150	0.368	0.211	0.021
		IT	0.121	0.028	0.133	0.267	0.267	0.194	0.139
Management	0.41	CR	0.496	0.203	0.367	0.333	0.211	0.022	0.067
		CC	0.188	0.077	0.200	0.100	0.066	0.289	0.345
		MB	0.316	0.130	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.267	0.243	0.228	0.143	0.119
				Total	1.000				
				Error	0				

The PWs of Partners 1 to 5 were 0.267, 0.243, 0.228, 0.143 and 0.119 respectively with an error of 0.

Table G.4 shows the results of FAHP when business, technical and management criteria values were fixed to 0.41, 0.36 and 0.23 respectively. Tables G.5 and G.6, show the results of FAHP the values were interchanged to 0.36, 0.23, 0.41 and 0.23, 0.41, 0.36 for business, technical and management criteria respectively.

Table G.4 Results of FAHP-High importance placed on business knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.41	FS	0.413	0.169	0.333	0.167	0.233	0.112	0.155
		SP	0.303	0.124	0.433	0.167	0.111	0.101	0.188
		BT	0.282	0.116	0.285	0.143	0.333	0.154	0.085
Technical	0.36	TC	0.288	0.104	0.188	0.250	0.167	0.274	0.121
		DS	0.200	0.072	0.129	0.375	0.115	0.122	0.259
		CD	0.140	0.050	0.250	0.150	0.368	0.211	0.021
		IT	0.371	0.134	0.133	0.267	0.267	0.194	0.139
Management	0.23	CR	0.488	0.112	0.367	0.333	0.211	0.022	0.067
		CC	0.280	0.064	0.200	0.100	0.066	0.289	0.345
		MB	0.231	0.053	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.264	0.231	0.214	0.151	0.140
				Total	1.000				
				Error	0				

The PWs of Partners 1 to 5 were 0.264, 0.231, 0.214, 0.151 and 0.140 respectively with an error of 0.

Table G.5 Results of FAHP-High importance placed on technical knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.23	FS	0.413	0.095	0.333	0.167	0.233	0.112	0.155
		SP	0.303	0.070	0.433	0.167	0.111	0.101	0.188
		BT	0.282	0.065	0.285	0.143	0.333	0.154	0.085
Technical	0.41	TC	0.288	0.118	0.188	0.250	0.167	0.274	0.121
		DS	0.200	0.082	0.129	0.375	0.115	0.122	0.259
		CD	0.140	0.057	0.250	0.150	0.368	0.211	0.021
		IT	0.371	0.152	0.133	0.267	0.267	0.194	0.139
Management	0.36	CR	0.488	0.176	0.367	0.333	0.211	0.022	0.067
		CC	0.280	0.101	0.200	0.100	0.066	0.289	0.345
		MB	0.231	0.083	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.241	0.248	0.212	0.159	0.138
				Total	0.998				
				Error	0.002				

The PWs of Partners 1 to 5 were 0.241, 0.248, 0.212, 0.159 and 0.138 respectively with an error of 0.002.

Table G.6 Results of FAHP-High importance placed on Management knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.36	FS	0.413	0.149	0.333	0.167	0.233	0.112	0.155
		SP	0.303	0.109	0.433	0.167	0.111	0.101	0.188
		BT	0.282	0.102	0.285	0.143	0.333	0.154	0.085
Technical	0.23	TC	0.288	0.066	0.188	0.250	0.167	0.274	0.121
		DS	0.200	0.046	0.129	0.375	0.115	0.122	0.259
		CD	0.140	0.032	0.250	0.150	0.368	0.211	0.021
		IT	0.371	0.085	0.133	0.267	0.267	0.194	0.139
Management	0.41	CR	0.488	0.200	0.367	0.333	0.211	0.022	0.067
		CC	0.280	0.115	0.200	0.100	0.066	0.289	0.345
		MB	0.231	0.095	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.270	0.235	0.212	0.145	0.138
				Total	1.000				
				Error	0				

The PWs of Partners 1 to 5 were 0.270, 0.235, 0.212, 0.145 and 0.138 respectively with an error of 0. Table G.7 shows the results of AHP when business, technical and management criteria values were fixed to 0.41, 0.36 and 0.23 respectively. Tables G.8 and G.9, show the results of AHP the values were interchanged to 0.36, 0.23, 0.41 and 0.23, 0.41, 0.36 for business, technical and management criteria respectively.

Table G.7 Results of RGFAHP-High importance placed on business knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.41	FS	0.417	0.171	0.333	0.167	0.233	0.112	0.155
		SP	0.302	0.124	0.433	0.167	0.111	0.101	0.188
		BT	0.253	0.104	0.285	0.143	0.333	0.154	0.085
Technical	0.36	TC	0.312	0.112	0.188	0.250	0.167	0.274	0.121
		DS	0.211	0.076	0.129	0.375	0.115	0.122	0.259
		CD	0.126	0.045	0.250	0.150	0.368	0.211	0.021
		IT	0.351	0.126	0.133	0.267	0.267	0.194	0.139
Management	0.23	CR	0.449	0.103	0.367	0.333	0.211	0.022	0.067
		CC	0.298	0.069	0.200	0.100	0.066	0.289	0.345
		MB	0.254	0.058	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.257	0.225	0.210	0.154	0.141
				Total	0.987				
				Error	0.013				

The PWs of Partners 1 to 5 were 0.257, 0.225, 0.210, 0.154 and 0.141 respectively with an error of 0.013.

Table G.8 Results of RGFAHP-High importance placed on technical knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.23	FS	0.417	0.096	0.333	0.167	0.233	0.112	0.155
		SP	0.302	0.069	0.433	0.167	0.111	0.101	0.188
		BT	0.253	0.058	0.285	0.143	0.333	0.154	0.085
Technical	0.41	TC	0.312	0.128	0.188	0.250	0.167	0.274	0.121
		DS	0.211	0.086	0.129	0.375	0.115	0.122	0.259
		CD	0.126	0.052	0.250	0.150	0.368	0.211	0.021
		IT	0.351	0.144	0.133	0.267	0.267	0.194	0.139
Management	0.36	CR	0.449	0.162	0.367	0.333	0.211	0.022	0.067
		CC	0.298	0.107	0.200	0.100	0.066	0.289	0.345
		MB	0.254	0.091	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.236	0.247	0.208	0.162	0.140
				Total	0.993				
				Error	0.007				

The PWs of Partners 1 to 5 were 0.236, 0.247, 0.208, 0.162 and 0.140 respectively with an error of 0.007.

Table G.9 Results of RGFAHP-High importance placed on management knowledge

Criteria	**Local weight**	**Sub-criteria**	**Local weight**	**Global weight**	**P1**	**P2**	**P3**	**P4**	**P5**
Business	0.36	FS	0.417	0.150	0.333	0.167	0.233	0.112	0.155
		SP	0.302	0.109	0.433	0.167	0.111	0.101	0.188
		BT	0.253	0.091	0.285	0.143	0.333	0.154	0.085
Technical	0.23	TC	0.312	0.072	0.188	0.250	0.167	0.274	0.121
		DS	0.211	0.049	0.129	0.375	0.115	0.122	0.259
		CD	0.126	0.029	0.250	0.150	0.368	0.211	0.021
		IT	0.351	0.081	0.133	0.267	0.267	0.194	0.139
Management	0.41	CR	0.449	0.184	0.367	0.333	0.211	0.022	0.067
		CC	0.298	0.122	0.200	0.100	0.066	0.289	0.345
		MB	0.254	0.104	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.263	0.234	0.207	0.147	0.140
				Total	0.991				
				Error	0.009				

The PWs of Partners 1 to 5 were 0.263, 0.234, 0.207, 0.147 and 0.140 respectively with an error of 0.009.

Appendix H: Simulation of Partner Performance Evaluation

This section illustrates the results of simulations of partners' performance on contract modification sub criterion when the values of business, technical and management sub criteria were fixed and interchanged for AHP, FAHP and RGFAHP techniques.

Table H.1 AHP Partners Performance Computation for CM for B(0.41), T(0.36), M(0.23)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.262	0.166	0.209
Partner 2	0.227		0.194
Partner 3	0.230		0.195
Partner 4	0.155		0.160
Partner 5	0.123		0.143

Where CM is contract modification, B is business criterion, T is technical criterion and

M is management criterion.

Table H.2 AHP Partners Performance Computation for CM for B(0.23), T(0.41), M(0.36)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.244	0.166	0.201
Partner 2	0.251		0.204
Partner 3	0.226		0.194
Partner 4	0.160		0.163
Partner 5	0.119		0.141

Table H.3 AHP Partners Performance Computation for CM for B(0.36), T(0.23), M(0.41)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.267	0.166	0.211
Partner 2	0.243		0.201
Partner 3	0.228		0.195
Partner 4	0.143		0.154
Partner 5	0.119		0.141

Before applying FAHP, global weights of the performance sub criteria are computed as shown in Table H.4.

Table H.4 Performance Evaluation Criteria using FAHP

Criteria	Local weight	Sub-criteria	Local weight	Global weight
Time	0.526	Contract Modification (CM)	0.282	0.148
		Level of Required Quality (RQ)	0.262	0.138
		Site Location Accessibility (SL)	0.128	0.067
		Personnel Experience (PE)	0.190	0.100
		Material Market Rate Change (MR)	0.121	0.064
Cost	0.452	Market Price Change (PC)	0.288	0.130
		Equipment Breakdown (EB)	0.262	0.118
		Rework / Repeat Job (RJ)	0.140	0.063
		Transport Cost Change (TC)	0.122	0.055
		Personnel Charge Rate Change (PR)	0.176	0.080

Table H.5 FAHP Partners Performance Computation for CM for B(0.41), T(0.36), M(0.23)

Partner	**Relative Weight**	**Evaluation Criterion Weight**	**Geometric Mean**
Partner 1	0.264	0.148	0.198
Partner 2	0.231		0.185
Partner 3	0.214		0.178
Partner 4	0.151		0.149
Partner 5	0.140		0.144

Table H.6 FAHP Partners Performance Computation for CM for B(0.23), T(0.41), M(0.36)

Partner	**Relative Weight**	**Evaluation Criterion Weight**	**Geometric Mean**
Partner 1	0.241	0.148	0.189
Partner 2	0.248		0.192
Partner 3	0.212		0.177
Partner 4	0.159		0.153
Partner 5	0.138		0.143

Table H.7 FAHP Partners Performance Computation for CM for B(0.36), T(0.23), M(0.41)

Partner	**Relative Weight**	**Evaluation Criterion Weight**	**Geometric Mean**
Partner 1	0.270	0.148	0.200
Partner 2	0.235		0.186
Partner 3	0.212		0.177
Partner 4	0.145		0.146
Partner 5	0.138		0.143

Before applying RGFAHP, global weights of the performance sub criteria are computed as shown in Table H.8.

Table H.8 Performance Evaluation Criteria using RGFAHP

Criteria	Local weight	Sub-criteria	Local weight	Global weight
Time	0.518	Contract Modification (CM)	0.269	0.139
		Level of Required Quality (RQ)	0.251	0.130
		Site Location Accessibility (SL)	0.136	0.070
		Personnel Experience (PE)	0.154	0.080
		Material Market Rate Change (MR)	0.183	0.095
Cost	0.464	Market Price Change (PC)	0.245	0.114
		Equipment Breakdown (EB)	0.226	0.105
		Rework / Repeat Job (RJ)	0.187	0.087
		Transport Cost Change (TC)	0.142	0.066
		Personnel Charge Rate Change (PR)	0.176	0.082

Table H.9 RGFAHP Partners Performance Computation for CM for B(0.41), T(0.36), M(0.23)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.257	0.139	0.189
Partner 2	0.225		0.177
Partner 3	0.210		0.171
Partner 4	0.154		0.146
Partner 5	0.141		0.140

Table H. 10 RGFAHP Partners Performance Computation for CM for B(0.23), T(0.41), M(0.36)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.236	0.139	0.181
Partner 2	0.247		0.185
Partner 3	0.208		0.170
Partner 4	0.162		0.150
Partner 5	0.140		0.139

Table H.11 RGFAHP Partners Performance Computation for CM for B(0.36), T(0.23), M(0.41)

Partner	Relative Weight	Evaluation Criterion Weight	Geometric Mean
Partner 1	0.263	0.139	0.191
Partner 2	0.234		0.180
Partner 3	0.207		0.170
Partner 4	0.147		0.143
Partner 5	0.140		0.139

Appendix I: Virtual Enterprise Prototype for Simulation

A prototype was developed using Java Agent Development Environment (JADE) as a proof of concept. The project is divided into tasks. For each task, the best partner (with the highest relative weight) is selected for each task using a multi attribute weighting technique. In the prototype, partner evaluator module (Figure I.1), takes the aggregated evaluators' values as input, and using a multi criteria decision making algorithm, gives as an output, a ranked list partners.

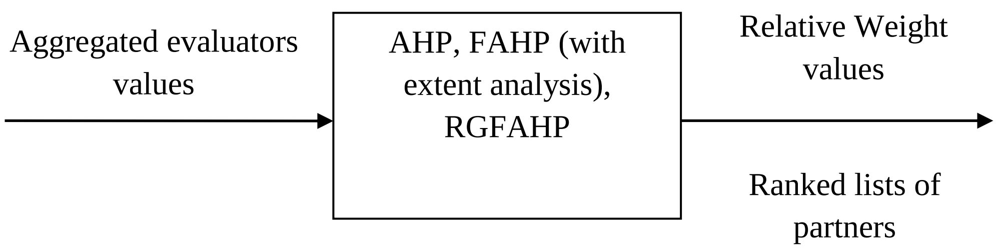


Figure I.1 Partner Evaluator

In the prototype projects tasks are referred to as roles and partners are represented as agents. Partners are selected for a role. The evaluator module use MCDM technique on the preference values to compute relative weights for the agents.

Inter-agents communications during VE formation (Figures I.2 and I.3) follows these steps. First, the Project task requirements are sent by VE initiator agent to all say *m* agents as a call for proposals. Second, the agents compare the task requirements with their profile details. From *m* agents, *i* agents can match the requirements while *j* do not. The *i* agents then propose their bids with their profiles.

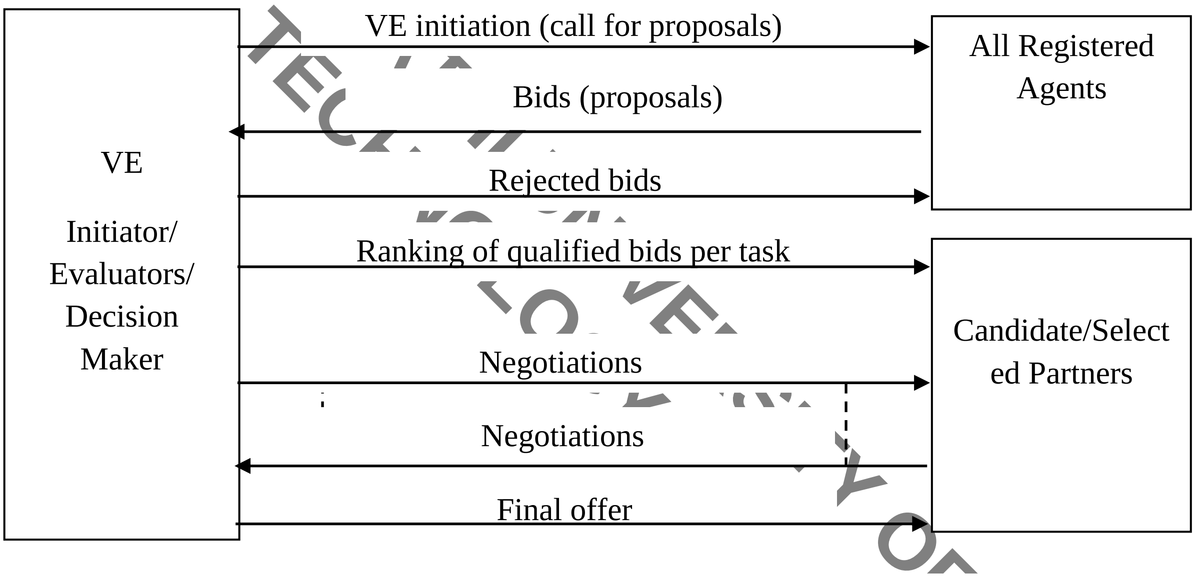


Figure I.2 Inter-agents communication during VE formation

Evaluator agents for each task examine the *i* agents' profiles viz a viz task requirements and assign their opinions. They also assign importance values to selection criteria and sub criteria. Decision maker (DM) agent converts the evaluator opinions into numerical values and computes the arithmetic means for all alternatives. The DM agent applies an MCDM algorithm to the arithmetic means of alternatives to derive their local relative weights. From the local relative weights, the DM computes the global weights for partner agents and sends the details of the partner agents with the highest relative weight in each task (proposed VE agents) to the VE initiator agent. The VE initiator agent sends invitation messages to the proposed VE agents. Negotiations between the VE initiator agent and the VE proposed agents takes place if they is need to adjust some of the requirements by either party. If there is no consensus in the negotiations, some of the proposed agents decline the offer and the initiator agent sends invitation messages to the second best agent for the affected task.

Agent communication languages (ACL) are special communication languages through which agents interact with each other. A message in JADE is implemented as an object of the jade.lang.acl.ACLMessage class that provides get and set methods for accessing all fields specified by the ACL format. All performatives (communicative acts) defined in the FIPA specifications are mapped as constants in the ACLMessage class. Sending a message to another agent involves filling out the fields of an ACLMessage object and then calling the *send* method of the Agent class.

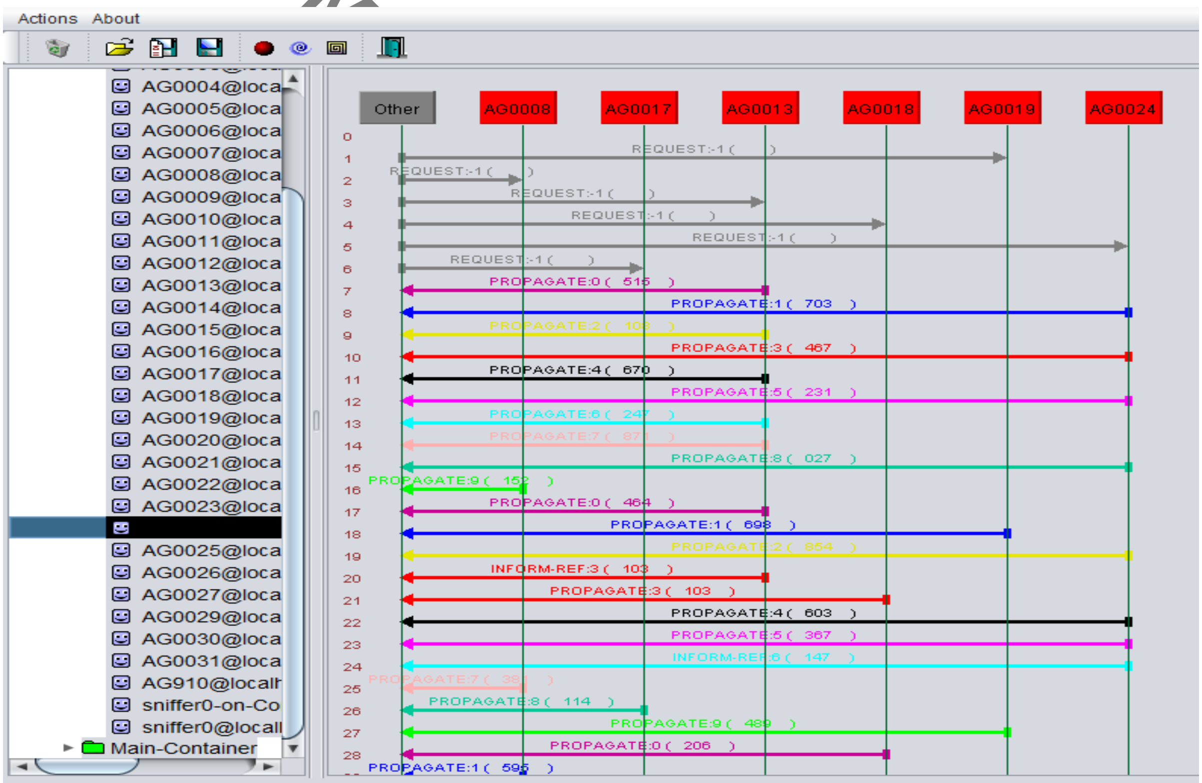


Figure I.3 Inter-agent messages propagation

ACL performatives defined by FIPA have well-defined formal semantics that are exploited to make an agent automatically take proper decisions when a message is received. A serialized Java object (project) is sent to all available or active agents including itself. To allow flexibility in the prototype, this study used thirty (30) static agents. For each role (Figure I.4), potential partners were considered for selection in each task. The project objectives, selection criteria and sub criteria were determined by the initiator agent. Each of the agents provides their profiles. Evaluators use the profiles to give their preferences of the agents for each role. The best agent for each role then forms a team. Agents with the highest weight are ranked on top. As shown in Figure I.5, for structural engineering task, partners ranked from the highest score of 0.174 by partner 24 to the lowest score of 0.141 by partner 15, with partners 27, 29, 3 and 12 ranked in that order in descending order. Partner 28 is the project initiator and coordinator.

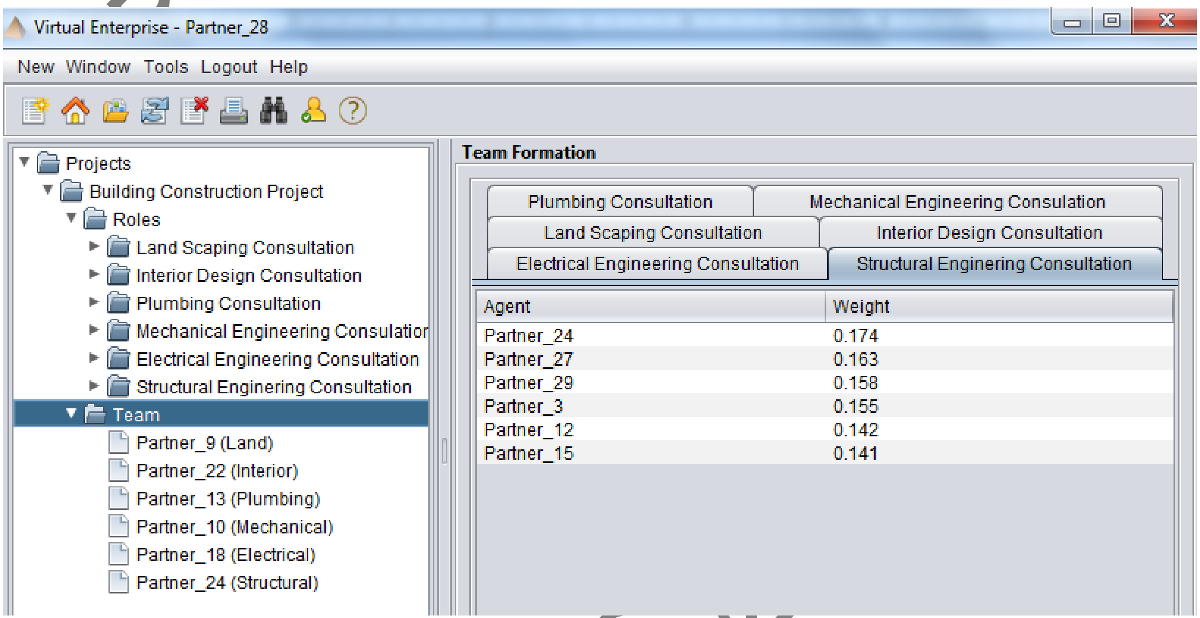
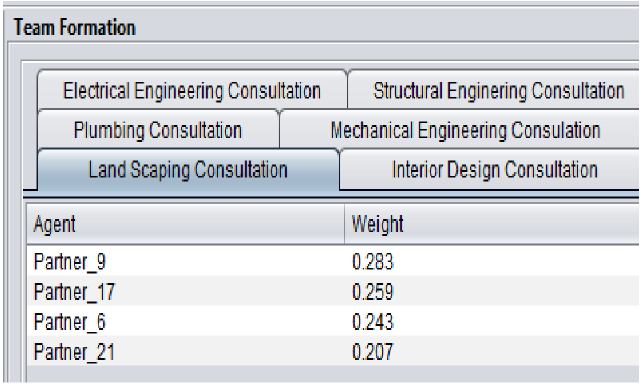
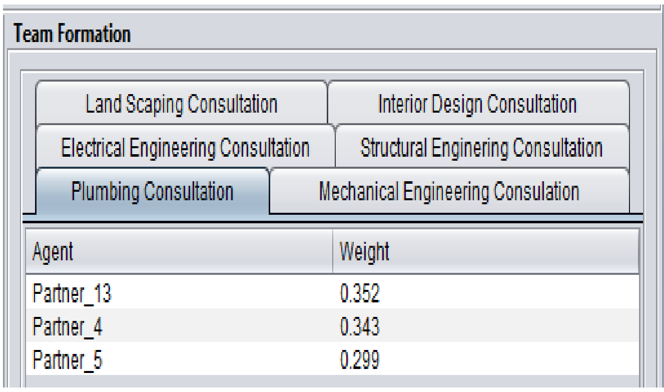


Figure I.4 Output of selected team for building construction

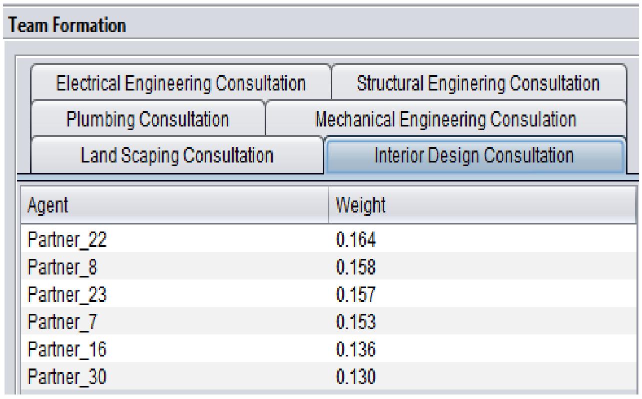
The model can allow multiple projects to be created simultaneously. Other roles in the project include plumbing, mechanical, interior design and electrical engineering works. Figures I.5 and I.6, show the weighting of partners for other tasks (Land-scaping, interior design, plumbing and electrical engineering). The output values presented would vary if the set of evaluators are varied. Also changing the skills set of evaluators, changes the output.



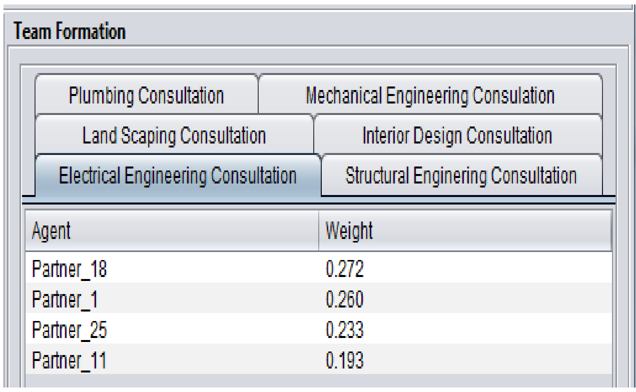
Partner Weighting for Land scaping task



Partner Weighting for Plumbing task



Partner Weighting for Interior design task



Partner Weighting for Electrical Engineering task

Figure I.5 Partner Weighting for Land scaping & Interior design tasks

Figure I.6 Partner Weighting for Plumbing & Electrical Engineering tasks

Appendix J: Feed Back

J.1 Feedback from Civil Engineering Consultancy Limited (CECL)

This company was part of case study organizations

CASE STUDY FEED BACK FORM

BUSINESS TO BUSINESS COLLABORATIONS (VIRTUAL ENTERPRISES)

INTRODUCTION

We are carrying out research on collaborations by organizations. This is informed by the fact that many organizations are collaborating with a view of developing a superior product faster and taking advantage of economies of scales and exploiting diversity in expertise from partners. We have developed a software model to facilitate organizations in their collaboration. This questionnaire is for collecting feedback from organizations that have used the model. We request you to provide us with your assessment of the model. We undertake to use this information for research purposes only. You can highlight an option using RED colour

SECTION A: GENERAL INFORMATION

1.0 Name of your organization (Optional)....CIVIL ENGINEERING CONSULTANCY LTD

1.1 Which best describes your organization type?

- [ ] Public
- [x] Construction
- [ ] Wholesale & Retail
- [ ] Transport & Communication
- [ ] Financial
- [ ] Manufacturing
- [ ] Software
- [ ] Others (Specify)....................................

1.2 What is your designation in the organization?

MANAGING DIRECTOR

SECTION B: COLLABORATIONS [Tick where appropriate]

2.0 How has the model facilitated your enterprise in carrying out the following activities in collaborations?

a) Initiating a new project [x] Yes [ ] No

Comment.......ADEQUATELY TACKLES ALL THE NECESSARY REQUIREMENTS FOR INITIATING A NEW PROJECT

b) Organizing candidate partner enterprises into roles [x] Yes [ ] No

Comment.......GIVES OPTION OF DEFINING ROLES

c) Negotiation with candidate partners ☑ Yes ☐ No

Comment: ITS ONLINE APPLICATION MAKES NEGOTIATION EASY & TIMELY BECAUSE IT IS REAL TIME. ANY CHANGES IN NEGOTIATED FIGURES ARE INSTANTLY UPDATED AND RANKING DONE

d) Selecting a team ☑ Yes ☐ No

Comment: FROM AN INBUILT DATA BASE; THIS MAKES THE PROCESS EASY AND MORE OBJECTIVE

e) Assigning tasks ☑ Yes ☐ No

Comment: BASED ON AN INBUILT DATA BASE ~~DATA~~ TASKS ARE ASSIGNED DEPENDING ON QUALIFICATIONS

f) Monitoring progress per role ☑ Yes ☐ No

Comment: ONCE EACH PARTY IN THE COLLABORATION UPDATES THEIR BIT, ~~AN~~ PROGRESS CAN BE MONITORED CENTRALLY. POWERFUL BECAUSE AVOID NEED FOR MEETINGS TO GATHER INFO. ON PROGRESS

g) Monitoring overall progress ☑ Yes ☐ No

Comment: FOR COMPLEX PROJECTS, THIS IS VERY ADVANTAGEOUS BECAUSE THE INDIVIDUAL TASKS CAN BE VERY MANY

SECTION C: SOFTWARE APPLICATION TO FACILITATE COLLABORATIONS

[Tick where appropriate]

3.0 Which of these attributes / features / characteristics / functionalities were proposed and the model enables?

- ☑ Fair representation from participating organizations
- ☑ Participants can be mobile (can collaborate remotely)
- ☐ Social media techniques are incorporated

- [x] Maintain individual organizations' autonomy
- [ ] Use of software agents to represent organization
- [x] Use of remote access techniques
- [x] Document processing and sharing
- [x] Messaging techniques
- [x] Desktop sharing
- [x] Specification generation
- [x] Remote progresss updates and monitoring
- [ ] Other(Specify)..

....

3.1 How can model be used in project management?

TEAM FORMATION, MONITORING PROGRESS, MANAGING DESIGN PROCESS, ~~[illegible]~~ MANAGING CHANGES IN DESIGN

3.2 How do you compare following activities in terms of duration and efficiency?

a) Team formation

i) Without the model........5/10........

ii) With the model........9/10........

b) Collaboration

i) Without the model........4/10........

ii) With the model........9/10........

SECTION D: ADDITIONAL COMMENTS AND FURTHER CONTACT INFORMATION

4.1 If you wish to make any suggestions or comments about the design and implementation of the model, please do so in this section

....

4.2 Apart from your organization, which other firm (s) do you recommend to use this model?

PROJECT MANAGEMENT FIRMS, CONTRACTORS, CONSULTANTS, SUPPLIERS

4.2 We would greatly appreciate it if you could allow us to send you a report on the model.

Can we send you a report? [x] Yes [ ] No

4.3 Please provide your contact information. Under no circumstances will this information be shared with a third party without your consent.

Email ---- musiomi2005@gmail.com ----

Phone ---- 0724675559 ----

Address...... Box 22483-00100 NAIROBI ......

Signature...... [signature] ......Date...... 20/03/2014 ......

J.2 Industrial Commercial and Development Corporation

This company was not part of case study organizations.

SECTION A: GENERAL INFORMATION

1.1 Name of your organization (Optional)

Industrial Commercial and Development Corporation (ICDC)

1.2 Which of the following describe(s) your organization type?

☒ *Public* ☐ Construction ☐ Wholesale & Retail

☐ Transport & Communication ☒ *Financial* ☐ Manufacturing

☐ Software ☐ Others (Specify)…………………………….

1.3 What is your designation in the organization?

...........Systems Analyst.........

SECTION B: COLLABORATIONS [Tick where appropriate]

2.0 How has (can) the model facilitated (facilitate) your enterprise in carrying out the following activities in collaborations?

a) Initiating a new project ☒ *Yes* ☐ No

Comment……*ICDC is engaged in a number of equity and real estate projects. These projects have multiple players and the model can be best used by ICDC as an initiator so as to co-ordinate the various players.*

b) Organizing candidate partner enterprises into tasks (roles) ☒ *Yes* ☐ No

Comment……*In the real estate/construction projects, ICDC can make use of the model to organize the various partner enterprises.*

c) Negotiation with candidate partners to adjust their attributes ☐ *Yes* ☒ No

Comment……*It would be hard for ICDC to use the model to do negotiating since currently we use the public procurement laws which have a special way to treat negotiations.*

d) *Selecting a team* ☒ *Yes* ☐ No

Comment……*The team selection in the model can perfectly fit in the evaluation criteria we use to select service providers/team players in our projects.*

e) Assigning tasks ☒ *Yes* ☐ No

Comment……*Since teams are selected to carry out specific tasks, the model can as well be used to assign the tasks.*

f) Monitoring progress per task (role) ☒ *Yes* ☐ No

Comment……*Currently we use MS Project to monitor tasks. The limitations in MS Project that can be covered by this model are the real time collaboration and reporting by teams in remote locations.*

g) Monitoring overall progress ☒ Yes ☐ No

Comment……*Same as above*

SECTION C: SOFTWARE APPLICATION TO FACILITATE COLLABORATIONS

[Tick where appropriate]

3.0 Which of these attributes / features / characteristics / functionalities were proposed and has been implemented in the model?

☐ Fair representation from participating organizations

☒ *Participants can be mobile (can collaborate remotely)*

☐ Social media techniques are incorporated

☒ *Maintain individual organizations' autonomy*

☒ *Use of software agents to represent organization*

☒ *Use of remote access techniques*

☐ Document processing and sharing

☒ *Messaging techniques*

☐ Desktop sharing

☒ *Specification generation*

☒ *Remote progresss updates and monitoring*

☐ Others (Specify)……………………………………………

3.1 How can model be used in project management?

The strength of the model is in remote representation of collaborating entities. The ability to track the progress of the project and the sharing of project progress updates.

3.2 How do you compare following activities in terms of duration and efficiency? [Use the scale 0…10]

a) Team formation: i) Without the model-4…ii) With the model…*8*…

b) Collaboration: i) Without the model..*3*…ii) With the model…..*8*….

SECTION D: ADDITIONAL COMMENTS AND FURTHER CONTACT INFORMATION

4.1 If you wish to make any suggestions or comments about the design and implementation of the model, please do so in this section

Incorporate security features and moderation of the project progress.

4.2 Apart from your organization, which other firm (s) do you recommend to (or you suggest can) use this model?.................……………………………………………..

4.2 We would greatly appreciate it if you could allow us to send you a report on the model. Can we send you a report? ☒ *Yes* ☐ No

4.3 Please provide your contact information. Under no circumstances will this information be shared with a third party without your consent.

Email *otienobenjamin@gmail.com*

Phone *0733 365 384*

Address *P.O. Box 45519 – 00100 Nairobi*.

Signature…  Date…*16th Sep 2014*