KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF DISTANCE LEARNING

ASSESSING CUSTOMER PERCEPTION OF THE PERFORMANCE OF TELECOMMUNICATION OPERATORS USING THE ANALYTIC NETWORK PROCESS

BY

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A thesis submitted to the Department of Mathematics,

in partial fulfillment of the requirements for the award of degree of

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science (MSc) and that, to the best of my knowledge, it neither contains any material previously published by another person nor material which has been accepted for the award of any other degree of the University or elsewhere, except where due acknowledgement has been made in the text.

I also declare that, I have wholly undertaken the study reported herein under supervision.

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DEDICATION

This work is first of all dedicated to the Almighty God, who is my source of knowledge and good health.

It is also dedicated to my entire family especially to my mother, Agnes Amoakowaa and my sister, Rita Akwaa for their prayer, encouragement and immense contribution during my course of studies.

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First of all, I am grateful to the Almighty God for my knowledge and good health.

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ABSTRACT

Telecommunication has a significant social, cultural and economic impact on society and it's of no difference in Ghana. The objective of this thesis is to assess the perceived performance of the telecommunication operators in Kumasi, Ghana and rank them. There are five telecommunication operators currently in operation and they are MTN, Tigo, Expresso, Airtel and Vodafone. The performance of the telecommunication operators were assessed according to the following criteria: Total Area of Network coverage, Quality of Network service, Average cost per user, Internet access and speed, Innovation and Contribution to society. These criteria were based on the NCA and the customers' perceptions. The model implemented in solving this multi-criteria decision problem is the Analytic Network Process (ANP) which is one of the best models of the Multi-criteria Decision Making (MCDM) methods because of its property of allowing dependence between its elements. Data collection involved administering an appropriately designed questionnaire to a sample of size one hundred of people who are customers of at least two of the telecommunication operators and also have a fair perception of the performance of all the telecommunication operators in Kumasi. They were also students of Kwame Nkrumah University of Science and Technology who are occupants of the Independence hall of the university.

Upon the completion of the analysis of the problem with ANP, the ranking of the telecommunication operators are as follows from first to last; Vodafone, Airtel, Tigo, Expresso and MTN. Hence Vodafone is the perceived best and MTN, the worst. Also the results showed Contribution to Society to be a more appropriate measure of the perceived performance for the telecommunication operators than the rest a result confirming why network service and network coverage of the various telecommunication operators tend to be not so good on the average.

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INTRODUCTION

1.0 BACKGROUND

The word telecommunication was adapted from the French word télécommunication. It is a compound of the Greek prefix tele- (τηλε-), meaning "far off", and the Latin communicare, meaning "to share". Telecommunication is the transmission of information over significant distances to communicate (The Industry Handbook: The Telecommunications Industry). It allows us to speak, share thoughts and do business with nearly anyone, regardless of where in the world they might be. In earlier times, telecommunications involved the use of visual signals, such as beacons, smoke signals, semaphore telegraphs, signal flags and others. In the modern age of electricity and electronics, telecommunications now includes the use of electrical devices such as telegraphs, telephones, and teleprinters, the use of radio and microwave communications, as well as fiber optics plus the use of the orbiting satellites and the Internet. The telecommunications industry delivers telephone, television, Internet, and other services to customers. The telecommunications industry is divided into four main sectors: wired, wireless, satellite and other telecommunications establishments (The Industry Handbook: The Telecommunications Industry).

Telecommunication has a significant social, cultural and economic impact on modern society. Telecommunications play an important role in the world's economy. The worldwide telecommunication industry's revenue was estimated to be $3.85 trillion in 2008. In cities throughout the world, people use the telephone and the internet to transact their business. With Social impact, Telecommunication played a significant role in social relationships and some have been through the many social networking sites such as Facebook, Twitter, Skype, Hi5 and others.

In cultural terms, telecommunication has increased the public's ability to get access to music, films and news.

The performance of telecommunication operators cannot be overemphasized. This is because telecommunication is the means through which all Social, Economic, Political, Cultural, Trade and Commercial activities are undertaken and therefore the bad or good performance of a country's telecommunication operators affects most activities of a country greatly. As a result, it is very necessary to know how well, the telecommunication operators perform. Due to the poor performance of many of these telecommunication firms, particularly in the developing countries, government have had to intervene through divestiture and privatization (Frempong and Henten, 2004) also for such a reason, was why 70% of Ghana Telecom was sold to Vodafone. The chairman of the National Communications Authority (NCA), Mr. Totobi Quakyi says the recent expression of sheer public dissatisfaction with the quality of service rendered by the telecommunication operators in the country is a clear signal that the Ghanaian consumer can no longer be taken for granted (Clifford, 2010).

The performance of the telecommunication operators can be measured by network coverage, network service and others. The way they perform can also be affected by factors such as Income, equipments, environment and others.

In the European Union, the National Regulatory Authorities (NRA) has been created in order to ensure a successful evolution towards competitive markets, regulate and supervise the relations between incumbents and new comers (Afonso and Scaglioni, 2006).

In Ghana, the organization responsible for licensing, accessing, checking and regulating the activities of the Telecommunication operators in order to get good performance is the National Communications Authority (NCA).

1.1 PROBLEM STATEMENT

The problem of this study is propelled by the need to assess and grade the performance of the telecommunication operators in Ghana with the focus in Kumasi.

There have always been hopes that the performance of the telecommunication operators will meet expectations. However, since 2006, there have been many complaints from Customers about their performance notably with regard to MTN and Ghana Telecom now called Vodafone. A statement released by the NCA in Ghana profusely lamented that, in spite of the appreciable growth and expansion recorded in the industry, "the quality of service is anything but good" (Nimako & Azumah, 2009). Also with six operators serving a population of 22 million, out of which 64 per cent own mobile phone numbers, network problems such as inadequate service coverage, network congestion, network unavailability, high call drop rates, delays in call set up time, error in connections, voice mutation among other public complains have become rampant (Dowuona, 2009).

These events have provoked the study of this problem with an objective and quantitative manner tool such as the Analytic Network Process (ANP).

Applications of ANP to assess the performance of Telecommunication Operators in Ghana have not been reported yet, so this research tries to fill that gap in literature.

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are:

a. To assess the perceived performance of the telecommunication operators in Kumasi using the Analytic Network Process (ANP)
b. To interpret and explain the results of the ANP in view of the current market situation.
c. To make recommendations based on the interpretations of the results to policy

makers, stake holders, the general Public and also for further studies.

1.3 METHODOLOGY

The model for this study will be the ANP model and the codes and analysis will be done with MatLab R2009b.

The ANP model will involve the following processes;

A construction of an ANP network with the criteria and alternatives specified. It will be followed by a collation of data from responses to questionnaires by a sample of customers in which they will assign weights by comparing the criteria with respect to the alternatives and also the alternatives with respect to the criteria. Moreover, the unweighted, weighted and limit supermatrix will be constructed from the Eigenvectors obtained from the pairwise comparison matrices. After this, results obtained from the limit supermatrix will be used to interpret the findings.

The study will make use of a primary source of data for the analysis. Data collection will be done by issuing out an appropriately designed questionnaire to a sample of size one hundred of people who are customers of at least two of the telecommunication operators and also have a fair perception of the performance of all the telecommunication operators in Kumasi. Members of the sample are students of Kwame Nkrumah University of Science and Technology and also occupants of the Independence hall of the university. The questionnaires will be administered by handling it over to them in their rooms, where the questionnaires will be explained to them and then filled or leave it with them and go back in about a week's time for the filled in questionnaires. After having all the hundred filled in questionnaires, an average of them will be taken and then used as the data for the study.

1.4 SIGNIFICANCE OF THE STUDY

The performance of the telecom operators can be good or bad and has a great impact on the social, economic and other activities of a country. As a result, the results of this research will be of significant importance in diverse ways to the business practitioners, policy makers and stake holders.

a. To the management of Ghana's Telecommunication operators, the findings and results of the study will provide a more reliable scientific measure and perspective for describing the level of performance of their company. It will also bring to light the growth or failure of the company due to its performance.

b. To policy makers like government agencies such as the Ministry of Communications and the National Communications Authority, the finding and results of this study will provide insights and a more guide to monitoring the impact of the performance of the telecommunication operators. It will help the Ministry of Communications in Ghana in achieving some of its policy goals, which include; enhancing reliability and efficiency in Provision of Communications services. It will also help the NCA to ensure that the Telecommunication operators achieve the highest level of efficiency in their performance.

c. To the stakeholders like investors, employees, pressure groups, consumer associations and others, the study will provide information that will allow them to provide useful suggestion to the improvement of the performance of the telecommunication operators

1.5 ORGANIZATION OF THESIS

The thesis consists of five chapters.

Chapter 1 is the introduction, which describes the background of the study, statement of the research problem, objectives of the study, methodology, significance of the study, research limitations and organization of the study. Also Chapter 2 comprises the review of related literature. This focuses on the conceptual base of the study. Chapter 3 is concerned with the methodology employed in carrying out the study and Chapter 4 deals with the presentation of results, obtaining solution for the model, interpretation of results, and other findings. Finally, Chapter 5 presents the conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Definition and Brief Historical Perspectives

The word telecommunication was adapted from the French word télécommunication. It was coined in 1904 by the French engineer and novelist Édouard Estaunié. Telecommunication is the transmission of information over significant distances to communicate.

Early telecommunications included smoke signals and drums. Drums were used by natives in Africa and South America, and smoke signals in North America and China. In 1792, a French engineer, Claude Chappe built the first visual telegraphy (semaphore) system between Lille and Paris. However semaphore as a communication system suffered from the need for skilled operators and expensive towers often at intervals of only ten to thirty kilometers. As a result, the last commercial line was abandoned in 1880. An experiment in electrical telegraphy was an 'electrochemical' telegraph created by the German physician, anatomist and inventor Samuel Thomas von Sömmering in 1809. The first commercial electrical telegraph was constructed in England by Sir Charles Wheatstone and Sir William Fothergill Cooke. The first successful transatlantic telegraph cable was completed on 27 July 1866, allowing transatlantic telecommunication for the first time. The conventional telephone was invented by Alexander Graham Bell in 1876, based on his earlier work with harmonic (multi-signal) telegraphs. The first commercial telephone services were set up in 1878 and 1879 on both sides of the Atlantic in the cities of New Haven and London. In 1880, Bell and co-inventor Charles Sumner Tainter conducted the world's first wireless telephone call via modulated lightbeams projected by photophones. Despite this, transatlantic voice communication remained impossible for customers until January 7, 1927 when a connection was established using radio. However no cable connection existed until TAT-1 was inaugurated on September 25, 1956 providing 36 telephone circuits (Wikipedia/History of Telecommunication).

2.1 Brief history of Telecommunications in Ghana

Ghana is located in West Africa, 750km north of the equator on the Gulf of Guinea with an area of about 92,000 square miles. It is between Cote d'ivoire and Togo. The capital, Accra lies on the Greenwich meridian (Nayo, 2001).

Kumasi is the second largest city in Ghana after Accra. It is the capital town of Ashanti Region. It is popularly known as the Garden City.

Kwame Nkrumah University of Science and Technology (KNUST) is the second public university but the first science and technology university to be built in Ghana. Independence hall, Queens hall, Republic hall, University hall, Unity hall and Africa hall are the halls of KNUST with Independence hall being the first hall to be built. Currently, Independence hall houses about a thousand male and female students.

The first telegraph line in Ghana (then known as the Gold Coast) was a ten mile link installed in 1881 between the castle of the colony then governor in Cape Coast and Elimina. The line was then extended to Christianborg Castle near Accra, which became the seat of government. In 1886, telegraph lines were extended to the middle and northern parts of Ghana into the territory of the Ashanti's. Between 1900 and 1901, this new communications technology was used to subdue the Ashanti's in the Yaa Asantewaa war. In 1953, the first automatic telephone exchange with 200 lines was installed in Accra to replace the manual one erected 63 years earlier. Three years later, in 1956, the trunk lines connecting Accra, Kumasi, Takoradi and Tamale were upgraded through the installation of a 48- and 12-channel VHF network. The attainment of independence by Ghana in 1957 brought new dynamism to the country's telecommunications development. A seven-year development plan launched just after independence hastened the completion of a second new automatic exchange in Accra in 1957. By the end of 1963, over 16,000 telephone subscribers and 32,000 rotary-type telephones were in use in Ghana (Allotey and Akorli, 1995).

2.2 Importance of Telecommunication

Before the telecommunication services, it was hard for people to communicate over long distances. They wrote letters to each other. It could take days or even weeks for letters to be delivered and other times, it will not be delivered at all. Then came the telegraph messages and later the telephone (Encarta 2009/Telecommunication). As time went on other telecommunication services such as internet came in and made life simplier.

Some of the important roles of telecommunication are;

a. It is a source of employment for many people. (Boadi & Shaik ,2006).
b. It is a significant source of revenue for both business operators and the government through taxes paid by both the business operators and its customers (Boadi & Shaik, 2006).
c. It is a cheap means of communication since it reduces the cost of travel (Nodh & Nodh, 2007).

Some arguments have been raised against phones use especially mobile phones and some are;

a. It encourages more unwanted calls as a result of being accessible from anywhere in the world. (Nimako & Azumah, 2009).

b. There is a potential cost of using a phone for business, for one's personal use, and the cost can damage the business (Nimako & Azumah, 2009).

c. It is a hazardous to human health such as; fatigue, headache, cancer, infertility in man and other diseases. It causes difficulty in concentration when driving and thus can result in accidents (Google/ 7 disadvantages of cell phones).

2.3 Telecommunication Operators in Ghana

Telecommunication operators are companies or industries that provide telecommunication services to customers.

Alexander Graham Bell and Gardiner Greene Hubbard created the first telephone company, the Bell Telephone Company in the United States, which later evolved into American Telephone & Telegraph (AT&T) (Wikipedia/History of telecommunication).

5 top telecommunication companies in the world according to the number of subscribers as of February, 2010 are;

1. China Mobile - 522 Million 2. Vodafone Group - 333 Million 3. Telefonica - 202 Million 4. AmericaMovil - 201 Million 5. Telenor Group - 172 Million

(Google/ Top 10 largest Telecom operators in world).

Currently, there are six telecommunication operators in Ghana with five operating and the last one, GLO Mobile Ghana, yet to start its operation. The five are MTN, Vodafone-Ghana, Expresso, Airtel and Tigo.

2.3.1 Vodafone Ghana

Vodafone acquired 70% and took-over Ghana Telecom (GT) and its Onetouch subsidiary in 2008 which was the first in Ghana. GT provided fixed lines, GSM mobile phones and payphones. GT was formed out of Ghana Post and Telecommunication Corporation (GPTC) in 1995, which was established in 1974 (Nimako & Azumah, 2009). As at 2009, Vodafone had 1,733,711 subscribers **(** Ajao, 2009). It is the only fixed line operator in the country at the moment

2.3.2 Airtel

Buharti Airtel (Airtel) acquired 75% share from Zain. The second national operator, Western Telesystems Limited (WESTEL), was licensed in 1998 to provide fixed lines. WESTEL was acquired by Kuwait's Mobile Telecommunication Co. (Zain) with 25% holding by Ghana government. As at 2009, Zain had about 1 million subscribers (Ajao, 2009). Airtel provides wireless mobile telecommunication services, internet connection and others (Nimako & Azumah, 2009). Zain launched the first 3.5G network (supports very fast Internet connectivity, video calling etc) in Ghana.

2.3.3 Tigo

Millicom Ghana Limited, operators of Tigo cellular, is a subsidiary of Millicom International cellular S.A. ("MIC") UK/Luxembourg. It is the first cellular network operator in Ghana and started in 1991. In 2002, it introduced its GSM service under the brand name MOBITEL/Buzz GSM. In 2006, the Tigo brand was launched in Ghana to replace MOBITEL brand (Nimako & Azumah, 2009). As at 2009, Tigo had 2,785,714 subscribers (Dowuona, 2009).

2.3.4 MTN Ghana

Scancom Ghana limited started operating in October 1996 using GSM 900 technology as spacefone. The company rebranded to Areeba and in 2006, it was taken over by Mobile Telecommunication Network Group (MTN) and now its name is MTN Ghana. It was the first digital cellular network in Ghana. As at 2009, MTN had 6,592,243 subscribers (Dowuona, 2009). Presently, it has the most subscribers. Some of its services are MTN Zone, International roaming services and others.

2.3.5 Expresso

Celltel started its operation in 1995. Kasapa Telecom Limited, a subsidiary of Hutchison Whampoa Group acquired 80% of Celtel Limited in 1998. The company offers mobile, home, business services and data service on its 800 MHz CDMA2000 1X network (Nimako & Azumah, 2009). As at 2009, Kasapa had 386,732 subscribers (Dowuona, 2009). Expresso Telecom acquired the assets of Kasapa Network in 2010 and it's currently running the company with the brand name Expresso (GNA, 2010).

2.3.6 GLO Mobile Ghana

Glo is a market leader in its home country – Nigeria. Glo revolutionized the telecoms industry in Nigeria with lower tariffs and even more value added services. Though they won a licence to run a cellular network over a year ago, they have not yet started operating (Ajao, 2009).

2.4 Regulatory bodies in Ghana Telecommunication Industry

Regulatory bodies in the past sought to protect players in their respective sectors by creating barriers to market access and restricting trade and new investment, significant changes in regulations as noted in Aryeetey (2002) have occurred in Ghana over the last decade that seek to promote competition and attract investment to Ghana.

Before the Telecommunication Sector Reforms, four regulatory bodies were regulating the activities of GP&T. These are Ministry of Transport and Communications (MOTC), Ministry of Finance (MOF), Ghana Frequency Regulation and Control Board (GFRCB) and GP&T itself. As at 1992, the general performance of GP&T was poor and reflected variedly in low and stagnant telephone penetration rates, poor quality of service and higher international tariffs and also GP&T was acting as a player and a referee at the same time before the reforms. As the telecommunication sector in Ghana underwent privatization, there was the need to assign the regulatory roles to an independent body that will oversee the development of the sector. Consequently, the main regulatory bodies are the NCA and the Ministry of Communication (Ahortor, 2003).

Some of the responsibilities of the NCA are as follows;

a. Issuing of licenses, establishing terms and conditions.
b. Regulation of competition.
c. Tariff regulation consistent with Ministry policies.
d. Consumer protection.

(National Telecommunication Policy, 2004)

Some of the responsibilities of the Ministry of Communication are as follows;

a. The ministry is primarily responsible for the definition and elaboration of Government policy regarding telecommunications.
b. The ministry is responsible for representing the Government of Ghana in all international negotiation and proceedings relating to the country's telecommunication policies.
c. The Ministry shall participate in a consultative capacity in all NCA public regulatory proceedings in an open and transparent manner.

   The ministry shall be responsible for monitoring the development of the telecommunications sector and progress toward achieving the objectives of this policy and also shall issue an Annual Report on telecommunications development in Ghana which identifies trends, issues and concerns in relation to sector goals.

   (National Telecommunication Policy, 2004)

2.5 Performance of Telecommunication Operators in Ghana

The performance of a company is how well the company performs in executing its tasks and obligations or providing services. In the telecommunication industry, their task is to provide those services that have been discussed in page 6. The performance of the telecommunication industry can be good or bad and its effect is great on the economy, society and others. As a result, it is very necessary to know how well, the telecommunication operators perform. A customer is satisfied if the performance of product/service is equal to his/her expectations and he/she is dissatisfied if the product/service performance is perceived to be below his/her expectation. However if expectation exceeds perceived performance, the customer is highly satisfied (Nimako & Azumah, 2009). The way telecommunication operators in Ghana perform can be affected by lots of factors such as; income, equipments, workforce, regulators, competitors, technology and market.

In Ghana, both the government and the general public are of the view that the performance of the players in the sector over the years leaves much to be desired. The operators in the sector continue to blame one another for their non-performance (Ahortor, 2003).

The chairman of the NCA, Mr. Totobi Quakyi made a call at the NCA's inauguration of the industry's forum in Accra saying the recent expression of sheer public dissatisfaction with the quality of service rendered by the telecommunication operators in the country is a clear signal that the Ghanaian consumer can no longer be taken for granted (Clifford, 2010).

With five operators serving a population of 22 million, out of which 64 per cent own mobile phone numbers with network problems such as inadequate service coverage, network congestion, network unavailability, error in connection among other public complains, are rampant. Mr. Mahama noted that, these network problems were of much concern to the public and should attract the attention of the NCA (Dowuona, 2009).

Due to the above reasons, the general performance of the telecommunication operators in Ghana can be perceived as not good.

2.5.2 Measures of Performance of the Telecommunication Industry

A performance indicator or key performance indicator (KPI) is a measure of performance. Such measures are commonly used to help an organization define and evaluate how successful it is (100 KPI's for Telecom Operators). Some of the KPI's are;

- **a.** Total Area of Network Coverage: Network coverage is how far and wide an operator's network covers. The places, the network of an operator covers, are the only places, one can make or receive a call or use other services that, that particular network offers.

b. Quality of Network Service: Network service in areas where an operator's network covers is also necessary for one to use an operator's services properly, in areas where an operator's services are bad; a customer can't use its services properly.
c. Innovation: (Barnett, 1953) defines innovation as "any thought, behavior, or thing that is new because it is qualitatively different from existing forms". 3G, 3.5G and 4G are all technology innovations, which were introduced into the telecom industry. Mobile Phones, conference calls, video calls are also some of the innovations. Others are Mobile Money, MTN Radio, Pay for me and others.
d. Contributions to society: It is how much, an operator contributes to society. It involves social work. "Social work involves giving help and advice to people with serious personal, family or financial problems", (BBC English Dictionary/ Social work). Some include; building schools, clinics and others for a community, helping the poor and the needy in the community and others.
e. Internet Access and Speed: The Internet is a worldwide network of computers that can communicate with each other using the Internet Protocol (IP). The Internet is thus an exchange of messages between computers. Most people use the internet as an alternative for making calls. They use it for a whole lot of things that sometimes calls can't do. Some of the usage of the internet is; searching for information, buying and selling, chatting either with voice or by letters with friends, online studies and others.
f. Average Cost Per User (ACPU): It is a very important indicator in the industry. It is how much an operator charges its customers for the use of its products. Most residential telecom customers prefer lower charges while other customers such as the business customers will pay any amount, either high or low if only, they will be given better and quality products and services.

2.5.3.1 Review of Telecommunication performance literature

Nimako & Azumah (2009) indicate that irrespective of the mobile telecommunication network in Ghana, customers' satisfaction is low; again it concludes that the overall customer satisfaction is different among the mobile telecommunication networks in Ghana

Agyapong (2010) seeks to examine the relationship between service quality and customer satisfaction in the utility industry (telecom) in Ghana. The study adapted the SERVQUAL model as the main framework for analyzing service quality. Multiple regression analysis was used to examine the relationships between service quality variables and customer satisfaction. The results showed that all the service quality items were good predictors of customer satisfaction. For managers, this finding has important implications with regard to brand building strategies. It is imperative for Vodafone (Ghana) and other telecom firms, therefore, to improve customer services by giving customers what they want and at the right time.

Edvarsson et al. (2005) suggest that the perceived service quality is an important determinant of customer satisfaction. They further maintain that perceived quality is formed by customers during their ongoing interactions with product/service providers.

Parasuraman et al. (1988) are also of the view that, the customer is satisfied if the performance of product/service is equal to his/her expectation (positive disconfirmation) and he/she is dissatisfied if the product/service performance is perceived to be below his/her expectation (negative disconfirmation). If performance exceeds expectation, the customer is highly satisfied.

Erginel & Şentürk (2011) suggest that since Customers can easily change their GSM operator after accepting the legal regulation on moving the number to a new operator in Turkey. Fuzzy analytic network process (FANP) is therefore used to rank three Global Systems for Mobile Communications (GSM) operators. Five main criteria are described and also sub-criteria are determined. Because the pairwise comparisons is a linguistic expression, FANP method is preferred to rank the GSM operators in Turkey

All the above papers on telecommunication suggest that the measure of performance of telecommunication is best determined by the customer's satisfaction.

2.5.3.2 Review of Analytic Network Process literature

Taslicali & Ercan (2006) objective is to identify the critical benefits and factors of decision making models in a changing technological environment. In their research; a general idea about decision making models and comparison between the two important models, Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP), are introduced. The research was done by using the information in the literature and expert judgment. This paper can be used by academics as a foundation for further research and development in the area of decision making models. Managers can use this paper for choosing the right decision making method in a variety of constraints, such as time, budget, human resources and others.

Chang (2007) seeks to solve the problem of selecting the most suitable hosts of TV-shopping shows in Taiwan. Starting with interviewing the practitioners and collecting nine criteria for selecting suitable TV-shopping hosts they took the criteria into account in three perspectives. The ANP approach was applied in selecting the most suitable hosts of TV-shopping channels. The model proposed in the paper was argued to be generic, more flexible and comprehensive, and suitable for selecting hosts of TV-shopping channels.

Chen et al. (2005) present a multicriteria decision-making model for lifespan energy efficiency assessment of intelligent buildings (IBs). The decision making model called IBAssessor is developed using an analytic network process (ANP) method and a set of lifespan performance indicators for IBs selected by a new quantitative approach called energy–time consumption index (ETI). In order to improve the quality of decision-making, the authors of this paper make use of previous research achievements including a lifespan sustainable business model, the Asian IB Index, and a number of relevant publications. Practitioners can use the IBAssessor ANP model at different stages of an IB lifespan for either engineering or business oriented assessments. Finally, this paper presents an experimental case study to demonstrate how to use IBAssessor ANP model to solve real-world design tasks.

Demirel and Tüzün (2011) aim is to evaluate the methods for preventing soil erosion through fuzzy ANP. The problem was considered as a multi-criteria decision making problem. Among the main criteria taken into account in the paper are climate, topography, soil, land use, and human activities. This paper also includes some sub-criteria because of the hierarchical structure of the problem. Then, the problem was applied to Turkey and solved by using fuzzy ANP and the methods for preventing soil erosion were evaluated.

Meade and Presley (2002) present analytic network process (ANP) as a potentially valuable method to support the selection of projects in a research and development (R&D) environment. The paper first discusses the requirements of the R&D project selection problem, which requires the allocation of resources to a set of competing and often disparate project proposals. Among the factors complicating this task is the need to make the decision within the framework of an enterprise's strategic objectives and organizational structure while considering and integrating financial and strategic benefits of each project. The paper discusses the use of the ANP, a general form of Saaty's analytic hierarchy process, as a model to evaluate the value of competing R&D project proposals. A generic ANP model developed by the authors, which includes in its decision levels, the actors involved in the decision, the stages of research, categories of metrics, and individual metrics is presented. The paper concludes with a case study describing the implementation of this model at a small high-tech company, including data based on the actual use of the decision making model

Hsu and Hu (2009) use ANP to select suppliers, adding the concept of hazardous substance management

Hsieh et al., (2008) explore customer expectations of service quality in Taiwanese hot spring hotels. ANP is applied to find the weights among the criteria, emphasizing interdependency relationships to increase accuracy of their paper.

Lin et al. (2008) use ANP to find the most optimal dispatching method. They argue that the application of ANP would improve the limitations of AHP, which assumes factors must be mutually independent.

Lee et al. (2009) establish an investment decision model based on the Gordon model. ANP is used to generate the weight of the criteria because of the interrelations and self-feedback relationships among the criteria.

Chen et al. (2010) identify the preferable bank loan quality for reducing non-performing loans (NPL). In combination with the relevant literature and interviews with experts, this study adopts the modified Delphi method and the analytic network process (ANP) to construct an evaluation method and to determine ANP effectiveness. In this study, we apply ANP to construct an evaluation method and introduce four criteria and ten sub-criteria to evaluate six alternative bancassurance alliance models. This paper proves that ANP is an effective tool to provide an accurate solution for the decision maker. The results indicate that executives of banks' decision maker units establish business loan processes to evaluate the emerging industry credit ability model for banking sector

Boran et al. (2008) see the selection of the most suitable personnel among candidates for the vacant positions as an important problem of an organization. Selecting the wrong candidate negatively affects the performance and competitive power of organization. The personnel selection is made mainly upon their performances. There are many methods to measure the performances of personnels. One of the weaknesses of these traditional methods is that they don’t consider the relationship between the criteria used for evaluation. There are, however, relationships, interrelationships and feedbacks between them. In this paper, Analytic Network Process (ANP) method which can be used for selecting the most suitable personnel is used.

Chen and Chen (2010) apply decision-making trial and evaluation laboratory (DEMATEL), fuzzy ANP and TOPSIS to develop a new innovation support system.

Demirtas and Üstün (2008) integrate ANP and multi-objective mixed integer linear programming (MOMILP) to select suppliers and determine their shipment allocations.

Chang et al., (2009) use fuzzy Delphi, ANP and zero one goal programming (ZOGP) to select revitalization strategies for the historic Alishan forest railway.

Liao and Chang (2010) combine ANP with BSC for measuring the managerial performance of TV companies.

Other applications of ANP are: prioritizing and designing rules changes for the game of soccer (Partovi et al., 2002), acquisition of new machine tools in a company (Yurdakul, 2004) and evaluation of alternative fuels for residential heating (Erdogmu et al., 2006).

All the above suggest that the ANP model is a very useful tool for solving multiple-criteria decision making problems.

CHAPTER THREE

METHODOLOGY

3.1 The Analytic Network Process (ANP) Approach

3.1.1 Multi -Criteria Decision Making (MCDM) Models

There are diverse kinds of Multi-Criteria Decision Making (MCDM) models that aid the decision maker to select the best decision for a problem having more than one criterion (i.e., multiple-criteria). Two of the most important methods of the MCDM models are the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). Other methods are Weight Sum Model (WSM), the Weight Product Model (WPM), Elimination and Choice Translating Reality (ELECTRE), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Revised (Multiplicative) AHP (RAHP-MAHP)

3.1.2 The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s.

The AHP reduces a multidimensional problem into a one dimensional one. Decisions are determined by a single number for the best outcome or by a vector of priorities that gives an ordering of the different possible outcomes. We can also combine our judgments or our final choices obtained from a group when we wish to cooperate to agree on a single outcome. Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem (Wikipedia, Analytic Hierarchy Process).

The procedure for using the AHP can be summarized as:

a. Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.

b. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements.

c. Synthesize these judgments to yield a set of overall priorities for the hierarchy.

d. Check the consistency of the judgments.

e. Come to a final decision based on the results of this process.

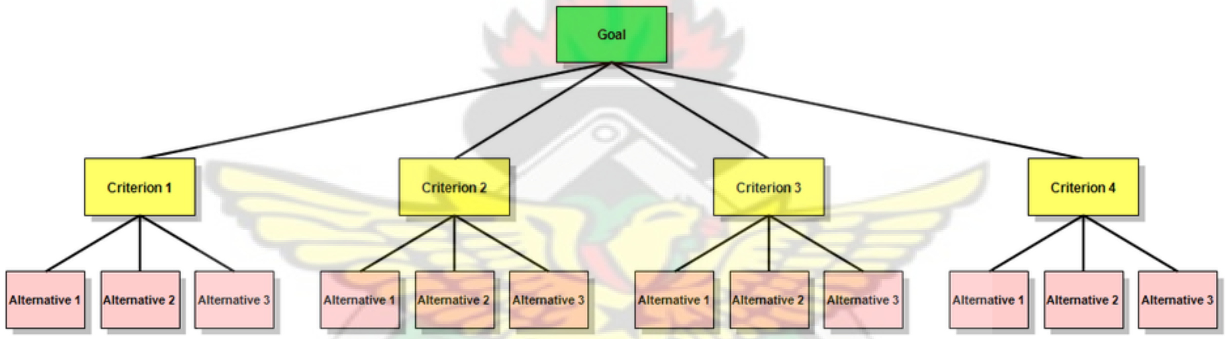

Fig 3.1: A simple AHP structure

Source: (Wikipedia, Analytic Hierarchy Process).

3.1.2.1 Example

For a problem with the goal: Assessing the performance of the Telecommunication Operators in Ghana and MTN, Vodafone-Ghana, Expresso, Airtel and Tigo being its alternatives and its criteria being Network coverage, Network service, Average cost per user, Internet access and speed, Innovation, Contribution to society. Below is how its AHP hierarchy structure will look

An AHP Structure of the Research Problem

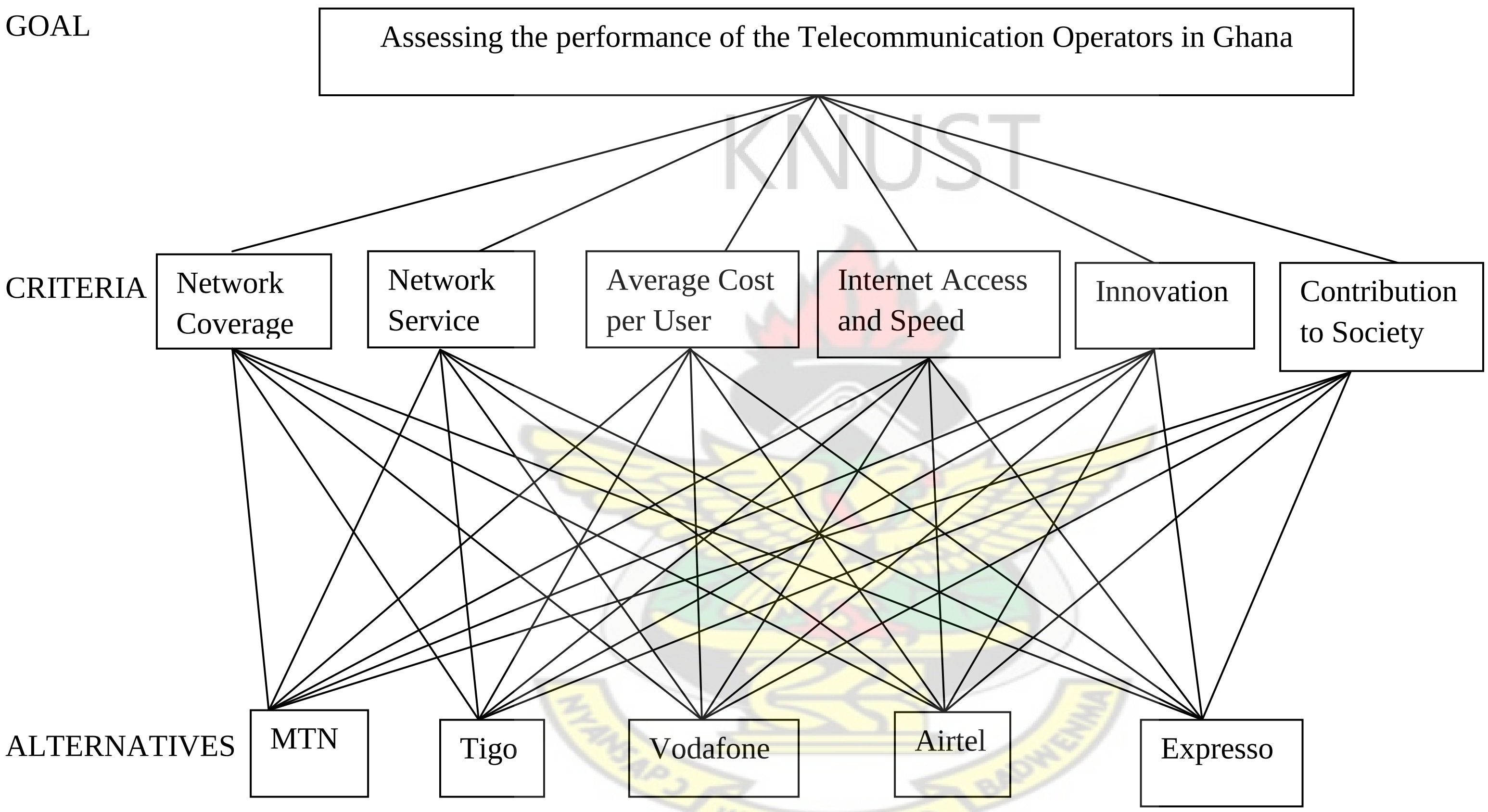

Figure 3.2: An AHP Structure

3.1.2.1.1 Description of the AHP hierarchy structure

There are useful terms for describing the parts of the AHP diagram above. Each box is called a node. A node that is connected to one or more nodes in a level below it is called a parent node. The nodes to which it is connected are called its children. From the AHP diagram above, there is one goal, six criteria and five Alternatives for choosing among them. The goal is to select the most suitable telecommunication operator from a field of the five alternatives and the factors to be considered are the six Criteria.

Some complex decision problems that have involved the application of the AHP include planning, resource allocation, selection among alternatives and forecasting.

3.2 The Analytic Network Process

The Analytic Network Process is a generalization of the Analytic Hierarchy Process (AHP), by considering the dependence between the elements of the hierarchy. It was built on the AHP. It is actually a useful tool for prediction and for representing in a variety of competitors with their surmised interactions and their relative strengths to wield influence in making a decision. In fact the ANP uses a network without the need to specify levels as in hierarchy. The concept of influence is essential in decision making, since influence is a force that creates changes, order, or chaos. That is why when we are in the process of decision making, it is essential to examine all the potential influences and not simply the influences from top to bottom or bottom to top as in the case of hierarchy (Saaty, 2005).

The ANP is a couple of two parts. The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by priority of its control criterion and the results are synthesized through addition for all the control criteria (Saaty, 1999).

3.2.1 Network

It has clusters of elements, with the elements in one cluster being connected to elements in another cluster (outer dependence) or the same cluster (inner dependence). Because of inner dependence, the relationships between same level criteria are not represented hierarchically. It also has sources and sinks. A source node is an origin of paths of influence and a sink node is a destination of paths of influence. The existence of feedback or interdependence indicates there is mutual outer dependence of criteria in two different clusters, which prevents the problem from being modeled hierarchically due to the difficulty in deciding which cluster is higher/lower than the other. A full network can include source nodes; intermediate nodes that fall on paths from source nodes, lie on cycles, or fall on paths to sink nodes; and finally sink nodes. Others contain only source and sink nodes or source and cycle nodes or cycle and sink nodes or only cycle nodes (Saaty, 2005).

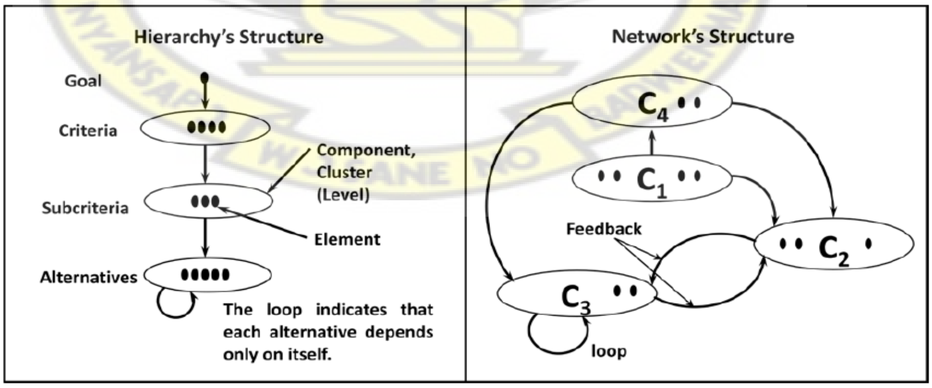

Figure 2. Hierarchy's and network's structures

Fig 3.3: Hierarcy and Network Structure

Source: (Bu-Qammaz, 2007)

3.2.1.1 Under the Network structure

Feedback Network with Components having Inner and Outer Dependence among Their Elements

From Figure 3.3 above, an arc from component C4 to C2 indicates the outer dependence of the elements in C2 on the elements in C4 with respect to a common property and also Loop within a component indicates inner dependence of the elements in that component with respect to a common property (Bu-Qammaz, 2007).

3.2.2 Pairwise comparisons

Prioritization entails seeking judgments in the form of experts' response to questions about the dominance of one element of the hierarchy over another when compared with respect to a specific criterion. A judgment is developed through numerical comparisons between two elements of the model with respect to a common criterion which is known as the control criteron. A pairwise comparison is the process where the decision maker will compare two components at a time with respect to a control/parent criterion based on the nine-point scale according to the Fundamental Scale for Making Judgments. A score of 1 indicates the equality between the two elements whereas score 9 represents the dominance of row element in the matrix over the column element. A reciprocal value is automatically assigned in the opposite position in the matrix (Bu-Qammaz, 2007).

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one activity over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Fig 3.4: The Fundamental Scale for Making Judgments (Saaty, 2005)

Source: (Bu-Qammaz, 2007)

3.2.2.1 Eigenvalues and Eigenvectors

For a square matrix A, we say that λ is an eigenvalue of A if there exists a non-zero vector x such that $Ax=\lambda x$. In this case, x is called an eigenvector corresponding to λ, and the pair (λ, x) is called an eigenpair for A. The dominant eigenvector of a matrix is an eigenvector corresponding to the eigenvalue of largest magnitude of that matrix. Many of the "real world" applications are primarily interested in the dominant eigenpair (λ_{max}, x) (Wikipedia/eigenvectors).

Under ANP, the eigenvector is the priority vector of a consistent matrix. The priority vectors represent the weighted averages of each item giving its preference over the other items under consideration.

3.2.2.1.1 General formula for the solution of the eigenvalues and eigenvectors problem

For a square matrix A and I the identity matrix, det(A-λI) = 0. (det means the determinant of matrix). This equation is called the characteristic equation.

$$A = \begin{bmatrix} a_{1,1} & 0 & \cdots & 0 \\ 0 & a_{2,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & a_{n,n} \end{bmatrix},$$

the characteristic equation then reads

$$\det(A - \lambda I) = \det\left(\begin{bmatrix} a_{1,1} & 0 & \cdots & 0 \\ 0 & a_{2,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & a_{n,n} \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\right)$$

$$= \det \begin{bmatrix} a_{1,1} - \lambda & 0 & \cdots & 0 \\ 0 & a_{2,2} - \lambda & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & a_{n,n} - \lambda \end{bmatrix}$$
$$= (a_{1,1} - \lambda)(a_{2,2} - \lambda)\cdots(a_{n,n} - \lambda) = 0 \quad .$$

The solutions to the characteristic equation are the eigenvalues $\lambda_i = a_{i,i}$ (i = 1, ..., n). For the eigenvectors x_i of A, they are the non-zero solutions of the equations $(A\text{-}\lambda I)x=0$, for the values of λ.

3.2.2.1.2 Worked Example

For a 2x2 matrix A, $A=\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$

det$(A\text{-}\lambda I)=0$

det(A-λI) = det$\begin{bmatrix} 2-\lambda & 1 \\ 1 & 2-\lambda \end{bmatrix}$= 0

Calculating the determinant, this yields the quadratic equation

$\lambda^2 - 4\lambda + 3 = 0$

λ_1=1 and λ_2=3 are the eigenvalues of the matrix A

$(A-\lambda I)x=0$

For λ_1=1

$$\left(\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} - 1\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \left(\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} - \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$x_1+x_2=0$, $x_1= - x_2$ therefore x_1=-1 and x_2= 1

$x=\begin{bmatrix} -1 \\ 1 \end{bmatrix}$ is the eigenvector of the eigenvalue λ_1=1

For λ_2=3

$$\left(\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} - 3\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \left(\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} - \begin{bmatrix} 3 & 0 \\ 0 & 3 \end{bmatrix}\right)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$-x_1 + x_2 = 0$, $x_2 = x_1$ therefore x_1 =1 and x_2 =1

$x=\begin{bmatrix} 1 \\ 1 \end{bmatrix}$ is the eigenvector of the eigenvalue λ_2=3

Since λ_2=3 is the largest eigenvalue of the matrix A, the dominant eigenvector is $x=\begin{bmatrix} 1 \\ 1 \end{bmatrix}$

$Ax=\lambda_{max}\, x$

Since $Ax= \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 3 \\ 3 \end{bmatrix}$ and $\lambda x= 3\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 3 \\ 3 \end{bmatrix}$

Therefore $\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}=3\begin{bmatrix} 1 \\ 1 \end{bmatrix}$

3.2.3 The Control hierarchy

Saaty (2005) has defined the control hierarchy as a hierarchy with criteria, called a control criterion that serves as a basis for making pairwise comparisons about influence. Where the influence could be: economic influence, social influence and others. In general, Saaty (2005) has explained that analysis of priorities in a system can be thought of in terms of a control hierarchy with dependence among its bottom-level subsystem arranged as a network. Where dependence can take place between the clusters and within them. In some intense dependence cases a control network can replace a control hierarchy at the top with dependence among its clusters.

A component or cluster in the ANP is a collection of elements whose function derives from the synergy of their interaction and hence has a higher-order function not found in any single element (Saaty, 2005). Another essential concept is the fact that the criteria in the control hierarchy that are used to compare the clusters are usually the major parent criteria whose sub-criteria are used to compare the elements in the component. The concept of a control hierarchy is critical for the ANP analysis, as it provides dominant criteria for comparing each type of interaction that is intended by the network representation.

Saaty (2005) has defined two different types of control criteria (sub-criteria).

The first is, when a control criterion is directly connected to the structure as the goal of a hierarchy if the structure is a hierarchy, it is called a comparison-"linking" criterion. Alternatively, when a control criterion does not connect directly to the structure but induces comparisons in a network, it is called a comparison-"inducing" criterion (Bu-Qammaz, 2007).

3.2.4 The Supermatrix

Saaty (2005) has explained the supermatrix of a feedback system, to do so, he assumed a system of N clusters or components, where the elements in each cluster interact, have an impact on, or are themselves influenced by some or all of the elements of that cluster or of another cluster with respect to a criterion which govern the interactions of the entire system. Then he suggested assuming that a cluster named *h*, denoted by C_h, h = 1, ..., N, has nk elements, which are denoted by e_{h1}, e_{h2},., e_{hnk} . Through paired comparisons a priority vector is derived, which represents the impact of a given set of elements in a component on another element in the system. Saaty (2005) has explained the situation when an element has no influence on another element, by stating that its influence priority in this case is not derived, yet it is assigned as zero. The pairwise comparison matrices will result in the priority vectors, which are each entered as part of some column of a supermatrix. Saaty (2005) has further explained that, the supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix (Bu-Qammaz, 2007).

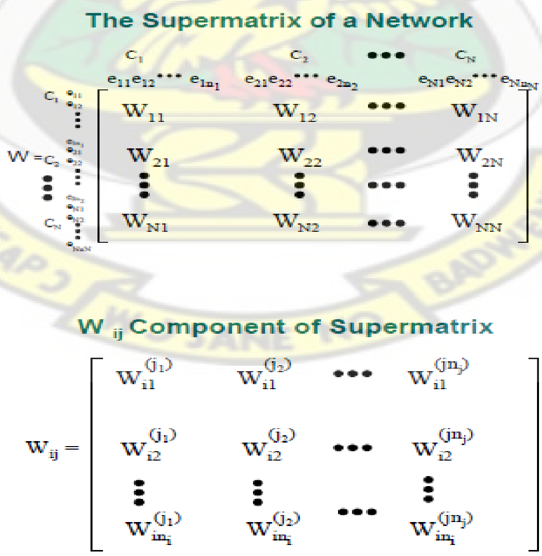

Figure 2 The Supermatrix of a Network and Detail of a Component in it

Fig 3.5: A Supermatrix of a Network

Source: (Bu-Qammaz, 2007)

3.2.5 Markov chains

A Markov chain, named after Andrey Markov, is a discrete-time stochastic process with the Markov property that, given the present state, future states are independent of the past states. Mathematically speaking, a Markov chain is a sequence of random variables X_1, X_2, X_3, … with the Markov property that given the present state X_n, the future state X_{n+1} and past states X_1, X_2, X_3, …, X_{n-1} are independent.

$Pr(X_{n+1} = x|X_n = x_n, X_{n-1} = x_{n-1},\ldots X_1 = x_1) = Pr(X_{n+1} = x|X_n = x_n)$ (Radev,2008)

3.2.5.1 Stochastic matrix

A stochastic matrix (also known as probability matrix, transition matrix, substitution matrix, or Markov matrix) is a matrix used to describe the transitions of a Markov chain.

A right or row stochastic matrix is a square matrix each of whose rows consists of nonnegative real numbers, with each row summing to 1.

A left or column stochastic matrix is a square matrix each of whose columns consist of nonnegative real numbers, with each column summing to 1.

A doubly stochastic matrix is a square matrix where all entries are nonnegative and all rows and all columns sum to 1.

A probability vector is a vector with nonnegative entries that add up to 1

(Wikipedia/stochastic matrix)

3.2.5.1.1 Regular Stochastic Matrix

A stochastic matrix is said to be regular if some power of the matrix has only positive entries.

A markov chain is regular if its stochastic matrix is regular.

$$A=\begin{bmatrix} 0.75 & 0.25 & 0 \\ 0 & 0.5 & 0.5 \\ 0.6 & 0.4 & 0 \end{bmatrix}; \quad A^2=\begin{bmatrix} 0.563 & 0.313 & 0.125 \\ 0.3 & 0.45 & 0.25 \\ 0.45 & 0.35 & 0.2 \end{bmatrix}$$

since all entries in A^2 are positive, matrix A is regular

$$B=\begin{bmatrix}0.5 & 0 & 0.5\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix};\ B^2=\begin{bmatrix}0.25 & 0 & 0.75\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix};\ B^3=\begin{bmatrix}0.125 & 0 & 0.875\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$$

Since B^2, B^3 and further powers of B will have some zero entries, matrix B is therefore not regular.

3.2.5.1.2 Properties of Regular Stochastic Matrix

Let A be a regular stochastic matrix.

1. The powers A^n approach a certain matrix as n gets large. This limiting matrix is called the stable matrix of A.

2. For any initial distribution $[\ ]_0$, $A^n[\ ]_0$ approaches a certain distribution. This limiting distribution is called the stable distribution of A.

3.2.5.1.3 Equilibrium vector or fixed vector of the markov chain

If a markov chain with a stochastic matrix P is regular, then there is a unique vector V such that for any probability vector v and for large values of n, $v.P^n \approx V$.

Vector V is called the Equilibrium vector or fixed vector of the markov chain.

$v.P^n \approx V$, $v.P^n.P \approx V.P$, $v.P^{n+1} \approx V.P$

Since $v.P^n \approx V$ for large values of n, then it's also true for $v.P^{n+1} \approx V$ for large values of n.

Thus, $v.P^n \approx V$ and $v.P^{n+1} \approx VP$, which suggests VP=V

If a markov chain with a regular stochastic matrix P, there exists a probability vector V such that VP=V (Wesley, 2003).

3.2.5.1.4 Worked Example

$$A=\begin{bmatrix}0.6 & 0.2\\0.4 & 0.8\end{bmatrix};\ A^2=\begin{bmatrix}0.44 & 0.28\\0.56 & 0.72\end{bmatrix};\ A^3=\begin{bmatrix}0.376 & 0.312\\0.624 & 0.688\end{bmatrix};\ A^4=\begin{bmatrix}0.3504 & 0.3248\\0.6496 & 0.6752\end{bmatrix}$$

$$A^5=\begin{bmatrix}0.3402 & 0.3299\\0.6598 & 0.6701\end{bmatrix};\ A^6=\begin{bmatrix}0.3361 & 0.3320\\0.6639 & 0.6668\end{bmatrix};\ A^7=\begin{bmatrix}0.3344 & 0.3328\\0.6656 & 0.6672\end{bmatrix}$$

$$A^8=\begin{bmatrix}0.3338 & 0.3331\\0.6662 & 0.6669\end{bmatrix};\ A^9=\begin{bmatrix}0.3335 & 0.3332\\0.6665 & 0.6668\end{bmatrix};\ A^{10}=\begin{bmatrix}0.3334 & 0.3333\\0.6666 & 0.6667\end{bmatrix}$$

It appears matrix A convergence towards having the same values in each row as its power increases. Therefore

$A^{10}=\begin{bmatrix}0.333 & 0.333\\0.667 & 0.667\end{bmatrix}$ is the stable matrix.

Let $\begin{bmatrix}0.25\\0.75\end{bmatrix}$ be the initial distribution, therefore $\begin{bmatrix}0.333 & 0.333\\0.667 & 0.667\end{bmatrix}\begin{bmatrix}0.25\\0.75\end{bmatrix}=\begin{bmatrix}0.333\\0.667\end{bmatrix}$

$\begin{bmatrix}0.333\\0.667\end{bmatrix}$ is therefore the fixed vector or stable distribution of A

3.2.6 Stochasticity of the Supermatrix

After constructing the supermatrix, Saaty (2005) has emphasized that the supermatrix needs to be stochastic to obtain significant limiting priorities. Moreover, initially the supermatrix should be reduced to a matrix before taking the limit, where each of its column sums to unity, which is called a column stochastic matrix. Normally, a supermatrix is not stochastic. The reason is that, its column are made up of several eigenvectors whose entries in normalized form sum to one, and therefore, each column in the supermatrix sums to the number of its nonzero eigenvectors. The clusters are compared according to their impact on each other with respect to the general control criterion, we have been considering, and thus, in case of several control criteria we need to repeat it several times for a decision problem once for each control criterion. This will result in an eigenvector of influence of all the clusters on each cluster. A vector will have zero components when there is no influence. The priority of a component of such eigenvectors used to weight all the elements in the block of the supermatrix that corresponds to the elements of both influencing and the influenced cluster. The outcome is a stochastic supermatrix (Bu-Qammaz, 2007).

3.2.7 The Limit Supermatrix

In the ANP we look for steady state priorities from a limit super matrix known as limit priorities. To obtain the limit we must raise the matrix to powers. Each power of the matrix captures all transitivities of an order that is equal to that power. The limit of these powers, according to Cesaro Summability, is equal to the limit of the sum of all the powers of the matrix. All order transitivities are captured by this series of powers of the matrix.

The outcome of the ANP is nonlinear and rather complex. The limit may not converge unless the matrix is column stochastic (Bu-Qammaz, 2007).

3.2.8 Similarities and Differences between ANP and AHP

AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network. In the AHP, each element in the hierarchy is considered to be independent of all the others but the ANP allows dependence among elements, so it can be used as an effective tool in many real-world cases, since most real-world cases involves interdependence among the items and the alternatives. Both use a system of pairwise comparisons to measure the weights of the components of the structure, and finally to rank the alternatives in the decision (Wikipedia/ Analytic Network Process).

3.3 Types of ANP- Models

The ANP model is one of the best Multi-Criteria Decision Making (MCDM) methods used to solve Multi-Criteria problems because of its several advantages over the other methods especially its property of dependence(outer and inner) between the elements and the clusters. There are several types of the ANP models used for solving the various problems. Below is a list of some of them.

3.3.1 Method 1 - The Fuzzy-ANP model **(1)**

The values of qualitative parameters such as social are transformed into triangular fuzzy numbers and are used to calculate fuzzy values. Furthermore, a scale of 1-9 is used to state the preferences of the decision maker. When comparing criterion *i* with criterion *j*, 1, 3, 5, 7, and 9 indicate equal importance among the compared criteria; moderate importance of *i* over *j*; strong importance of i over j; very strong importance of *i* over *j*; and extreme importance of *i* over *j*, respectively, where $i = 1, 2, \ldots, n$, and $j = 1, 2, \ldots, m$

To evaluate the decision-maker preferences, pair-wise comparison matrices are structured using triangular fuzzy numbers (l,m,u). The $m \times n$ triangular fuzzy matrix can be given as follows:

$$\widetilde{A} = \begin{pmatrix} (a_{11}^l, a_{11}^m, a_{11}^u) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (a_{21}^l, a_{21}^m, a_{21}^u) & (a_{22}^l, a_{22}^m, a_{22}^u) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \vdots & \vdots \\ (a_{m1}^l, a_{m1}^m, a_{m1}^u) & (a_{m2}^l, a_{m2}^m, a_{m2}^u) & \cdots & (a_{mn}^l, a_{mn}^m, a_{mn}^u) \end{pmatrix}$$

The element a_{mn} *represents* the comparison of the component m (row element) with component n (column element). If it is a pair-wise comparison matrix (as shown in Eq. 2), it is assumed that it is reciprocal, and the reciprocal value, i.e. $1/ a_{mn}$, is assigned to the element a_{nm},

$$\widetilde{A} \approx \begin{pmatrix} (1,1,1) & (a^l_{11}, a^m_{11}, a^u_{11}) & \cdots & (a^l_{1n}, a^m_{1n}, a^u_{1n}) \\ \left(\frac{1}{a^u_{11}}, \frac{1}{a^m_{11}}, \frac{1}{a^l_{11}}\right) & (1,1,1) & \cdots & (a^l_{2n}, a^m_{2n}, a^u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{1}{a^u_{1n}}, \frac{1}{a^m_{1n}}, \frac{1}{a^l_{1n}}\right) & \left(\frac{1}{a^u_{2n}}, \frac{1}{a^m_{2n}}, \frac{1}{a^l_{2n}}\right) & \cdots & (1,1,1) \end{pmatrix}$$

$\tilde{A}$ is also a triangular, fuzzy, pair-wise comparison matrix. There are several methods for getting estimates for the fuzzy priorities, w_i, where $w_i = (w_i^{\,l}, w_i^{\,m}, w_i^{\,u})$ and i = 1, 2, …, n, from the judgment matrix, which approximates the fuzzy ratios aij, so that $a_{ij} \approx w_i / {}_j j$. One of these methods, the logarithmic least-squares method is reasonable and effective and is used in this study. Hence, the triangular fuzzy weights representing the relative importance of the criteria, the feedback of the criteria, and the alternatives according to the individual criteria can be calculated. The logarithmic least-squares method for calculating triangular fuzzy weights can be given as follows:

$$\tilde{w}_k = (w_k^l, w_k^m, w_k^u) \quad k = 1, 2, 3, \ldots, n,$$

where

$$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}}, \quad s \in \{l, m, u\}.$$

After identifying the alternatives described as triangular fuzzy numbers, they must be ordered from the best to the worst using one of the ordering methods. The ordering methods transform the fuzzy numbers to crisp numbers by defuzzification. There are different defuzzification methods, such as center of gravity, maximum-membership principle, center of area, weighted average, smallest of maximum and largest of maximum. The center of gravity, center of area, and maximum-membership principle methods have been used herein because they are the most commonly used defuzzification techniques, and their usage is easy. The results are then compared with each other for differences and similarities (Tuzkaya and Önüt, 2008).

3.3.2 Method 2 - The Fuzzy-ANP model **(2)**

The fuzzy sets are defined in terms of membership functions. Membership functions relative to X represent fuzzy subsets of X. The membership function representing a fuzzy set is usually denoted by μ*A*. For an element *x* of X, the value μ*A*(*x*) is called the membership degree of *x* in the fuzzy set. This function assigns to each element x of the universal set X a number μ*A*(*x*) in the unit interval [0,1]. The membership degree μ*A*(*x*) quantifies the grade of membership of the element *x* to the fuzzy set. An element *x* really belongs to A if μ*A*(*x*) = 1 and clearly does not if μ*A*(*x*) = 0.

A triangular fuzzy number can be denoted by three real numbers (*l*, *m*, *u*). The parameters *l*, *m*, and *u* respectively stand for the smallest possible value, the most promising value, and the largest possible value. Its membership function can be defined as

$$(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise}, \end{cases}$$

Research method

Chang's method has been applied in this study. Let X = {x_1, x_2,…., x_n} be an object set, and U = {u_1, u_2,…., u_n} be a goal set. According to Chang's extent – analysis method (1992; 1996), each object is taken and an extent analysis for each goal (g*i*) is performed. Therefore, m extent analysis value for each object can be obtained with the following signs:

$$M_{gi}^{1}, M_{gi}^{2}, \ldots.., M_{gi}^{m}, \quad i = 1,2,\ldots..,n \tag{1}$$

where M_{gi}^{j} (j = 1,2,….*n*) are TFNs. The steps of Chang's extent analysis can be given as in the following:

Step 1: The value of fuzzy synthetic extent with respect to the i[th] object is defined as

$$S_j = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \quad (2)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, perform the fuzzy addition operation of m extent analysis relative to values for a particular matrix such that

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (3)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1}$, perform the fuzzy addition operation of M_{gi}^{j} (j=1,2,…,m) values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_i, \sum_{j=1}^{m} m_i, \sum_{j=1}^{m} u_i \right) \quad (4)$$

and then compute the inverse of the vector in Eq.(4) such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (5)$$

Step 2: The degree of the possibility of $M_2 = (l_2, m_2, u_2) \geq M_1(l_1, m_1, u_1)$ is defined as $V(M_2 \geq M_1)$ $sup_{y \geq x}[\min(u_{M1}(x), u_{M2}(x))]$ and can be equivalently expressed as follows;

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = u_{M_2}(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{else,} \end{cases} \quad (6)$$

where d is the ordinate of the highest intersection point D between $u_{M1}$and u_{M2}. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$. This is given in the figure below

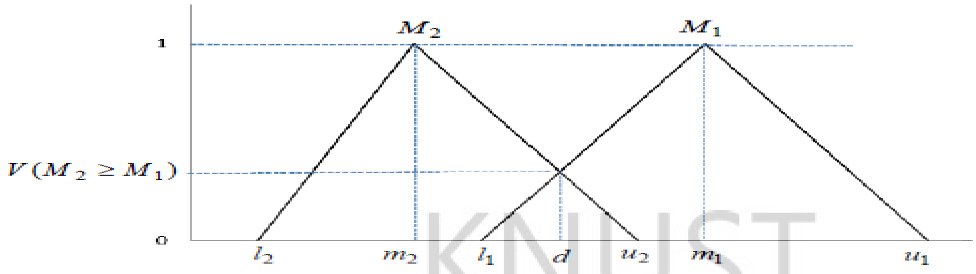

Fig.3.1

Intersection of M_1 and M_2

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i(I = 1, 2, \ldots., k)$ can be defined by

$V(M \geq M_1, M_{2,\ldots.,} M_k) = V[(M \geq M_1)$ ve $(M \geq M_2$ and …. and$(M \geq M_k)] = \min V(M \geq Mi)$, $i = 1,2,\ldots,k$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$. For $k = 1,2,\ldots$, n; $k = i$. Then the weight vector is given by $W' = (d'(A_1), d'(A_2), \ldots., d'(A_n))^T$ where A_i $(i = 1,2,\ldots.,n)$ are n elements.

Step 4: Via normalization, the normalized weight vectors are $W = (d(A_1), d(A_2), \ldots., d(A_n))^T$ where W is a nonfuzzy number (Erginel & Şentürk, 2011).

3.3.3 Method 3 Benefit, Opportunity, Cost and Risk (BOCR) - ANP MODEL (1)

Step 1: Make sure that you understand the decision problem in detail, including its objectives, criteria and subcriteria, actors and their objectives and the possible outcomes of that decision. Give details of influences that determine how that decision may come out.

Step 2: Determine the control criteria and subcriteria in the four control hierarchies, one each for the benefits, opportunities, costs and risks of that decision and obtain their priorities from paired comparison matrices. You may use the same control criteria and perhaps subcriteria for all of the four merits. If a control criterion or subcriterion has a global priority of 3% or less, you may consider carefully eliminating it from further consideration. The software automatically deals only with those criteria or subcriteria that have subnets under them. For benefits and opportunities, ask what gives the most benefits or presents the greatest opportunity to influence fulfillment of that control criterion. For costs and risks, ask what incurs the most cost or faces the greatest risk. Sometimes (very rarely), the comparisons are made simply in terms of benefits, opportunities, costs, and risks by aggregating all the criteria of each BOCR into their merit.

Step 3: Determine a complete set of network clusters (components) and their elements that are relevant to each and every control criterion. To better organize the development of the model as well as you can, number and arrange the clusters and their elements in a convenient way (perhaps in a column). Use the identical label to represent the same cluster and the same elements for all the control criteria.

Step 4: For each control criterion or subcriterion, determine the appropriate subset of clusters of the comprehensive set with their elements and connect them according to their outer and inner dependence influences. An arrow is drawn from a cluster to any cluster whose elements influence it.

Step 5: Determine the approach you want to follow in the analysis of each cluster or element, influencing (the suggested approach) other clusters and elements with respect to a criterion, or being influenced by other clusters and elements. The sense (being influenced or influencing) must apply to all the criteria for the four control hierarchies for the entire decision.

Step 6: For each control criterion, construct the supermatrix by laying out the clusters in the order they are numbered and all the elements in each cluster both vertically on the left and horizontally at the top. Enter in the appropriate position the priorities derived from the paired comparisons as subcolumns of the corresponding column of the supermatrix.

Step 7: Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to (outer dependence) or on elements in their own cluster (inner dependence). In making comparisons, you must always have a criterion in mind. Comparisons of elements according to which element influences a third element more and how strongly more than another element it is compared with are made with a control criterion or subcriterion of the control hierarchy in mind.

Step 8: Perform paired comparisons on the clusters as they influence each cluster to which they are connected with respect to the given control criterion. The derived weights are used to weight the elements of the corresponding column blocks of the supermatrix. Assign a zero when there is no influence. Thus obtain the weighted column stochastic supermatrix.

Step 9: Compute the limit priorities of the stochastic supermatrix according to whether it is irreducible (primitive or imprimitive [cyclic]) or it is reducible with one being a simple or a multiple root and whether the system is cyclic or not. Two kinds of outcomes are possible. In the first, all the columns of the matrix are identical and each gives the relative priorities of the elements from which the priorities of the elements in each cluster are normalized to one. In the second, the limit cycles in blocks and the different limits are summed and averaged and again normalized to one for each cluster. Although the priority vectors are entered in the supermatrix in normalized form, the limit priorities are put in idealized form because the control criteria do not depend on the alternatives.

Step 10: Synthesize the limiting priorities by weighting each idealized limit vector by the weight of its control criterion and adding the resulting vectors for each of the four merits:

Benefits (B), Opportunities (O), Costs (C) and Risks (R). There are now four vectors, one for each of the four merits. An answer involving ratio values of the merits is obtained by forming the ratio B_iO_i / C_iR_i for alternative i from each of the four vectors. The synthesized ideals for all the control criteria under each merit may result in an ideal whose priority is less than one for that merit. Only an alternative that is ideal for all the control criteria under a merit receives the value one after synthesis for that merit. The alternative with the largest ratio is chosen for some decisions. Companies and individuals with limited resources often prefer this type of synthesis.

Step 11: Determine strategic criteria and their priorities to rate the top ranked (ideal) alternative for each of the four merits one at a time. Normalize the four ratings thus obtained and use them to calculate the overall synthesis of the four vectors. For each alternative, subtract the sum of the weighted costs and risks from the sum of the weighted benefits and opportunities.

Step 12: Perform sensitivity analysis on the final outcome. Sensitivity analysis is concerned with "what if" kinds of questions to see if the final answer is stable to changes in the inputs, whether judgments or priorities. How significant the change is can be measured with the Compatibility Index of the original outcome and each new outcome (Saaty, 2005).

3.3.4 Method 4 - (BOCR) - ANP MODEL (2)

Step 1: It consists in developing the structure of the decision-making process. This involves defining its main objective and identifying groups or 'clusters' constituted by various elements ('nodes') that influence the decision and alternatives or options from which to choose. After having chosen which structure is more suitable in the decisional context, whether the simple or the complex Benefits–Opportunities–Costs–Risks (BOCR) one (Saaty, 2005), the relationships between the different elements of the network must be identified. All the elements in the network can be related in different ways since the network can incorporate feedback and complex inter-relationships within and between clusters, thus providing a more accurate modeling of complex settings.

Step 2: It consists of pairwise comparisons, in order to establish the relative importance of the different elements, with respect to a certain component of the network. Comparative or relative judgments are made on pairs of elements to ensure accuracy. In paired comparisons, the smaller element is used as the unit, and the larger element becomes a multiple of that unit with respect to the common property or criterion for which the comparisons are made. It is important to highlight that there are two levels of pairwise comparisons in the ANP: the cluster level, which is more strategic, and the node level, which is more specialized. In pairwise comparisons, a ratio scale of 1–9, that is the Saaty's fundamental scale, is used to compare any two elements. The main eigenvector of each pairwise comparison matrix represents the synthesis of the numerical judgments established at each level of the network (Saaty, 1980).

Step 3: It consists of the progressive formation of three supermatrices: the initial or unweighted one, the weighted one and, finally, the limit one. The unweighted supermatrix contains all the eigenvectors that are derived from the pairwise comparison matrices of the model.

The eigenvector obtained from the cluster-level comparison, with respect to the control criterion, is applied to the initial supermatrix as a cluster weight and the result is the weighted supermatrix. The supermatrix elements allow a resolution to be made of the interdependencies that exist between the elements of the system.

Step 4: It concerns the elicitation of the final priorities. In this step, the weighted supermatrix is raised to a limiting power, as in Equation (1), in order to converge and to obtain, as stated in the Perron–Frobenius theorem, a long-term stable set of weights that represents the final priority vector.

$$\lim_{k \to \infty} W^k$$

In the case of the complex network structure, it is necessary to synthesize the outcome of the alternative priorities for each of the BOCR subnetworks in order to obtain their overall synthesis through the application of different aggregation formulas (Saaty and Vargas, 2006).

Step 5: It consists in carrying out the sensitivity analysis on the final outcome of the model in order to test its robustness.

(Bottero and Ferretti, 2011)

3.3.5 Method 5 – The Eigenvector - ANP Model

Step 1: Model construction and problem structuring

The problem should be stated clearly and decomposed into a rational system, such as a network. The structure can be obtained by soliciting the opinions of the decision makers through brainstorming or other appropriate methods. Firstly, we have to identify the goal or objective of the decision process. This goal will be further decomposed into clusters and elements, criteria and alternatives. Secondly, we have to identify all the relationships between the different parts of the network, in terms of dependence and feed-back.

Step 2: Pair-wise comparison matrices and priority vectors

In ANP, as in AHP, decision elements at each component are compared pair-wise with respect to their importance for their control criterion and the components themselves are also compared pairwise with respect to their contribution to the goal. Decision makers are asked to respond to a series of pair-wise comparisons of two elements or two components in terms of how they contribute to their particular upper-level criterion (Meade and Sarkis, 1999). In addition, if there are interdependencies among elements of a component, pair-wise comparisons are also created. An eigenvector can be obtained for each element to show the influence of other elements on it. The relative importance values are determined on a scale of 1 to 9, where a score of 1 represents equal importance of the two elements and a score of 9 indicates the extreme importance of one element (row component in the matrix) compared to the other element (column component in the matrix) (Meade and Sarkis, 1999). Pairwise comparisons give to the user a basis to reveal his/her preference by comparing two elements. Furthermore, the user has the option of expressing preferences between the two as equally preferred, weakly preferred, strongly preferred, or absolutely preferred, which would be translated into pairwise weights of 1, 3, 5, 7 and 9, respectively, with 2, 4, 6 and 8 as intermediate values. Pairwise comparisons of the elements at each level are conducted with respect to their relative importance towards control criterions or clusters. Pairwise comparisons are performed in two levels, the level of elements and the level of clusters. A reciprocal value is assigned to the inverse comparison; that is, $a_{ij} = 1/ a_{ij}$ where a_{ij} (a_{ji}) denotes the importance of the ith (jth) element compared to the jth (ith) element. As in AHP, pair-wise comparison in ANP is made in the framework of a matrix. A local priority vector to estimate the relative importance associated with the elements (or components) being compared can be derived by solving the following formula: $A.w=\lambda_{max}.w$, Where, A is the matrix of pair-wise comparison, w is the eigenvector, and λ_{max} is the largest eigenvalue of A. Saaty (1980) proposes several algorithms for approximating *w*. In this paper, the following three-step procedure is used to synthesize priorities (Saaty, 1980; Meade and Presley, 2002).

a) Sum the values in each column of the pair-wise comparison matrix.

b) Divide each element in a column by the sum of its respective column. The resultant matrix is referred to as the normalized pairwise comparison matrix.

c) Sum the elements in each row of the normalized pair-wise comparison matrix, and divide the sum by the *n* elements in the row. These final numbers provide an estimate of the relative priorities for the elements being compared with respect to their upper-level criterion.

Priority vectors must be derived for all comparison matrices.

Step 3: Super-matrix formation

The super-matrix concept is similar to the Markov chain process (Saaty, 1996). To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix known as a super-matrix. A supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two nodes (components or clusters) in a system (Meade and Sarkis, 1999). Let the components of a decision system be C_k, k=1, 2,…,n and let each component k have m_k elements, denoted by e_{k1}, e_{k2},….., e_{km}

The local priority vectors obtained in Step 2 are grouped and located in appropriate positions in a super-matrix based on the flow of influence from a component to another component, or from a component to itself, as in the loop.

$$W_k = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & 0 & 0 \\ 0 & w_{32} & I \end{bmatrix} \quad (3)$$

Where W_{21} is a vector that represents the impact of the goal on the criteria; W_{32} is a matrix that represents the impact of criteria on each of the alternatives; *I* is the identity matrix; and entries of zero correspond to those elements that have no influence. The (2, 2) entry of W_n given by W_{22} would indicate the interdependency, and the super-matrix would be as follows (Saaty, 1996):

$$W_n = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & w_{22} & 0 \\ 0 & w_{32} & I \end{bmatrix}$$

Note that any zero in the super-matrix can be replaced by a matrix if there is an interrelationship of the elements in a component or between two components. Since there usually is interdependence among clusters in a network, the columns of a super-matrix usually sum to more than 1. The super-matrix must first be transformed to make it stochastic; that is, each column of the matrix sums to unity. An approach recommended by Saaty (1996) is to determine the relative importance of the clusters in the super-matrix with the column cluster (block) as the controlling component (Meade and Sarkis, 1999). That is, the row components with nonzero entries for their blocks in that column block are compared according to their impact on the component of that column block (Saaty, 1996). Through pair-wise comparison of the row components with respect to the column component, an eigenvector can be obtained for each column block. For each column block, the first entry of the respective eigenvector is multiplied by all the elements in the first block of that column, the second by all the elements in the second block of that column, and so on. In this way, the block in each column of the super-matrix is weighted. The result is known as the weighted super-matrix, which is stochastic. Raising a matrix to powers gives the long-term relative influences of the elements on each other. To achieve convergence on the importance weights, the weighted super-matrix is raised to the power of $2k + 1$, where k is an arbitrarily large number. This new matrix, called the limit super-matrix (Saaty, 1996), has the same form as the weighted super-matrix, but all the columns are the same. By normalizing each block of the super-matrix, the final priorities of all the elements in the matrix can be obtained.

Step 4: Selection of best alternatives

If the super-matrix formed in Step 3 covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized super-matrix. On the other hand, if a super-matrix comprises only components that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be the one selected (Chen, Lin & Lu, 2010).

3.4 Proposed ANP-model and Approach

Alternatives: They are the elements that are to be assessed. In this thesis, they are the telecommunication operators in Ghana and they are MTN, Vodafone-Ghana, Expresso, Airtel and Tigo.

Criteria: Criteria are what the alternatives are going to be assessed by. In this thesis, they are some of the measures of performance (KPI) of telecommunication operators and they are Network coverage, Network service, Average cost per user, Internet access and speed, Innovation and Contribution to society. These criteria were actually gotten by considering the NCA and the customer's perception of the criteria for assessing the performance of the telecommunication operators.

Actors: They are the decision makers. They are the assessors of a research problem. This thesis will involve only one actor and it is the customers of the telecommunication operators who are students of Kwame Nkrumah University of Science and Technology and occupants of Independence hall of the University. Moreover, should be a customer of at least two of the telecommunication operators and also have a fair perception of the performance of all the telecommunication operators in Kumasi.

The method 5 of the ANP-models listed above is what will be used for the solution of this research problem. Below are the steps and approach of the application of the ANP-model to solve this research problem.

The Eigenvector - ANP Model

Step 1: Model construction and problem structuring

In this research, the alternatives are MTN, Vodafone-Ghana, Expresso, Airtel and Tigo (Telecommunication operators in Ghana) and the criteria are Network coverage, Network service, Average cost per user, Internet access and speed, Innovation, Contribution to society (measures of performance (KPI) of the telecommunication operators). The clusters will contain the alternatives and the criteria. To construct the network, influences between and within clusters will be showed by arrows connecting each other (inner and outer dependence)

Step 2: Pair-wise comparison matrices and priority vectors

In this step, a series of pairwise comparison is made by the customers. It will be done by designing a questionnaire which will be given to a sample of hundred customers who are students of Kwame Nkrumah University of Science and Technology and also occupants of the Independence hall of the university. They should at least be customers of two of the telecommunication operators and also have a fair perception of the performance of all the telecommunication operators in Kumasi. They will then assign weights by comparing the alternatives with respect to each of the criteria and the criteria with respect to each of the alternatives. The measurement of customer's opinions is based on the relative importance; a scale of 1-9 is used to compare two options. In this a score of 1 indicates the two options under comparison have equal importance, while a score of 9 indicates the overwhelming dominance of the row component over the column component and reciprocal value is assigned to its inverse comparison.

As in AHP, pair-wise comparison in ANP is made in the framework of a matrix. A local priority vector to estimate the relative importance associated with the elements (or components) being compared can be derived by solving the following formula: $A.w=\lambda_{max}.w$**,** where, A is the matrix of pair-wise comparison, w is the eigenvector, and λ_{max} is the largest eigenvalue of A. Saaty (1980) proposes several algorithms for approximating *w*. In this paper, the following three-step procedure is used to synthesize priorities (Saaty, 1980; Meade and Presley, 2002).

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The super-matrix concept is similar to the Markov chain process (Saaty, 1996). To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix known as a super-matrix. A supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two nodes (components or clusters) in a system (Meade and Sarkis, 1999). Let the components of a decision system be C_k, k=1, 2,…,n and let each component k have m_k elements, denoted by e_{k1}, e_{k2},…..,e_{km}

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Note that any zero in the super-matrix can be replaced by a matrix if there is an interrelationship of the elements in a component or between two components. Since there usually is interdependence among clusters in a network, the columns of a super-matrix usually sum to more than 1. The super-matrix must first be transformed to make it stochastic; that is, each column of the matrix sums to unity. An approach recommended by Saaty (1996) is to determine the relative importance of the clusters in the super-matrix with the column cluster (block) as the controlling component (Meade and Sarkis, 1999). That is, the row components with nonzero entries for their blocks in that column block are compared according to their impact on the component of that column block (Saaty, 1996). Through pair-wise comparison of the row components with respect to the column component, an eigenvector can be obtained for each column block. For each column block, the first entry of the respective eigenvector is multiplied by all the elements in the first block of that column, the second by all the elements in the second block of that column, and so on. In this way, the block in each column of the super-matrix is weighted. The result is known as the weighted super-matrix, which is stochastic. Raising a matrix to powers gives the long-term relative influences of the elements on each other. To achieve convergence on the importance weights, the weighted super-matrix is raised to the power of $2k + 1$, where k is an arbitrarily large number. This new matrix, called the limit super-matrix (Saaty, 1996), has the same form as the weighted super-matrix, but all the columns are the same. By normalizing each block of the super-matrix, the final priorities of all the elements in the matrix can be obtained.

Step4: Selection of best alternatives

If the super-matrix formed in Step 3 covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized super-matrix. On the other hand, if a super-matrix comprises only components that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be the one selected.

The codes and analysis will be done with MatLab R2009b.

CHAPTER FOUR

DATA ANALYSIS AND RESULTS

4.0 Introduction

In this chapter, the proposed ANP model in chapter 3 with MatLab R2009b will be used to analysis the data obtained. From the analysis, the results of the study will be gotten.

4.1 Step 1: Model construction and problem structuring

Below is a description and construction of a network structure of the ANP model of this study.

The alternatives for the ANP model were taken as the various telecommunication operators in Ghana namely MTN, Vodafone, Expresso, Airtel, and Tigo.

The six (6) relevant Criteria for the model being measures of performance of the telecommunication operators (KPIs) were taken as Network coverage, Network service, Average cost per user, Internet access and speed, Innovation and Contribution to society

Description of the ANP network structure

The network structure below contains inner and outer dependence arcs within and between its elements and clusters.

a. The inner dependence arc connected to the alternatives cluster shows that all the telecommunication operators depend on each other in order for each to perform well (they serve as competitors for each other).

b. There are lots of arcs from one cluster to another. Firstly, the arc from network service to internet access and speed indicates the outer dependence of internet access and speed on network service. This is because without the network service in an area, you won't be able to use the internet service and therefore explains that internet access and speed depends on network service for it to function. Also the arc from the network coverage to innovation shows the outer dependence of innovation on network coverage, it is because innovations brought by the telecommunication operators can only be used where there is network coverage. It is also the same for the arc from the network service to innovation.

   Also the arc from network service to average cost per user shows the outer dependence of average cost per user on network service. It is because, without a network service, a customer can't experience the cost of using the products of an operator. It is also the same for the arc from network coverage to average cost per user.

c. There exists interdependence between the Alternatives cluster and the Criteria clusters. It shows that they both depend on each other because without the KPI, the telecommunication operators can't perform well and also if the telecommunication operators didn't exist there will be nothing like network service, network coverage and the other KPI's. There is also an inter independence between network coverage and network service. The reason is because in an area where there is network coverage but there is no network service, the products of that telecommunication operator can't be used and vice versa. As a result, they influence each other and therefore the reason for the interdependence.

An ANP Structure of the Research Problem

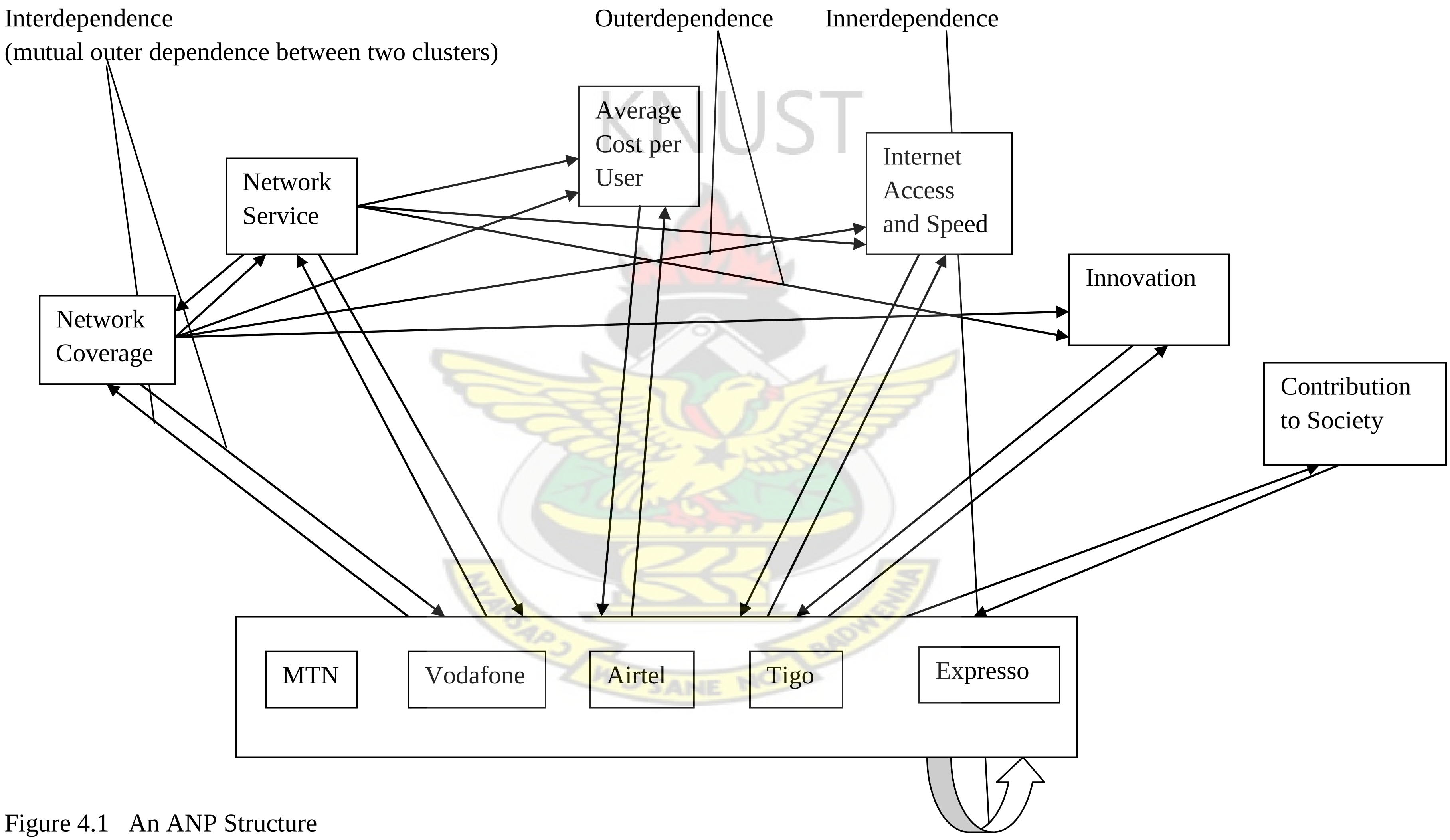

Figure 4.1 An ANP Structure

4.2 Step 2: Pairwise comparison matrices and priority vectors

The actor or decision maker for this study is the customers of the telecommunication operators who are students of Kwame Nkrumah University of Science and Technology and also occupants of Independence hall of the University. Moreover, should be a customer of at least two of the telecommunication operators and also have a fair perception of the performance of all the telecommunication operators in Kumasi.

A sample of hundred questionnaires were given to a random sample of them to fill and they filled by comparing the alternatives with respect to each of the criterion and also the criteria with respect to each of the alternatives. In all, the matrices in each questionnaire were eleven since the questionnaire were many; an average of each of the weights assigned was taken and put in new matrices. The dominant eigenvectors of each of the eleven matrices (the averaged matrices) are then worked for.

4.2.1 Pairwise comparisons of the telecommunication operators (alternatives) with respect to the measures of their performance (criteria)

Table 4.1 Pairwise comparison of the telecommunication operators with respect to network coverage

NETWORK COVERAGE	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	6.000	3.500	4.500	7.500	0.363
Tigo.	0.188	1.000	2.071	4.125	7.000	0.179
Airtel	0.583	3.625	1.000	4.125	6.000	0.220
MTN	0.563	2.063	2.063	1.000	4.063	0.167
Expresso	0.134	0.146	0.222	4.056	1.000	0.071

The above Table 4.1 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to network coverage with its $\lambda_{\max}$ (largest eigenvalue) = 10.0769

Table 4.2 Pairwise comparison of the telecommunication operators with respect to network service

NETWORK SERVICE	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	6.500	3.500	6.500	2.563	0.301
Tigo.	0.163	1.000	0.238	4.500	0.196	0.065
Airtel	3.500	5.000	1.000	4.125	2.071	0.256
MTN	0.163	0.563	2.063	1.000	0.156	0.063
Expresso	4.100	5.500	3.625	7.000	1.000	0.315

The above Table 4.2 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to network service with its $\lambda_{\max}$ (largest eigenvalue) = 9.9268.

Table 4.3 Pairwise comparison of the telecommunication operators with respect to average cost per user

AVERAGE COST PER USER	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	0.238	0.583	6.500	3.063	0.145
Tigo.	5.000	1.000	1.071	6.500	2.750	0.238
Airtel	3.500	3.750	1.000	6.500	4.083	0.326
MTN	0.163	0.155	0.155	1.000	0.143	0.022
Expresso	4.083	1.100	3.063	7.000	1.000	0.268

The above Table 4.3 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to average cost per user with its $\lambda_{\max}$ (largest eigenvalue) = 8.867

Table 4.4 Pairwise comparison of the telecommunication operators with respect to internet access and speed

INTERNET ACCESS AND SPEED	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	7.500	7.000	5.000	7.500	0.480
Tigo.	0.134	1.000	0.171	3.063	3.167	0.103
Airtel	0.146	6.000	1.000	3.750	4.000	0.189
MTN	0.313	4.083	1.071	1.000	1.571	0.129
Expresso	0.134	1.583	0.571	3.667	1.000	0.099

The above Table 4.4 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to internet access and speed with its λ_{max} (largest eigenvalue) = 8.7082.

Table 4.5 Pairwise comparison of the telecommunication operators with respect to innovation

INNOVATION	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	0.583	4.167	4.250	5.500	0.280
Tigo.	3.500	1.000	3.500	3.250	4.500	0.330
Airtel	1.563	0.583	1.000	2.750	4.000	0.190
MTN	1.063	1.083	1.100	1.000	2.000	0.153
Expresso	0.229	0.250	0.333	0.500	1.000	0.047

The above Table 4.5 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to innovation with its λ_{max} (largest eigenvalue) = 7.5801.

Table 4.6 Pairwise comparison of the telecommunication operators with respect to contribution to society

CONTRIBUTION TO SOCIETY	Vodafone	Tigo	Airtel	MTN	Expresso	Eigenvector
Vodafone	1.000	6.000	4.583	6.500	8.000	0.391
Tigo.	0.222	1.000	2.583	2.667	5.000	0.154
Airtel	3.056	3.100	1.000	3.125	7.000	0.304
MTN	0.181	1.600	2.083	1.000	5.000	0.128
Expresso	0.127	0.200	0.146	0.208	1.000	0.023

The above Table 4.6 is a pairwise comparison matrix of the telecommunication operators in Ghana with respect to contribution to society with its λ_{max} (largest eigenvalue) = 8.9589.

4.2.2 Pairwise comparisons of the measures of their performance (criteria) with respect to the telecommunication operators (alternatives)

Table 4.7 Pairwise comparison of the measures of their performance with respect to Vodafone

VODAFONE	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society	Eigenvector
Network coverage	1.000	0.583	0.333	2.000	1.563	0.139	0.069
Network service	3.500	1.000	5.000	1.500	2.563	1.063	0.190
Average cost per user	4.000	0.313	1.000	1.563	1.563	0.306	0.098
Internet access and speed	0.667	0.750	4.167	1.000	1.071	0.306	0.092
Innovation	4.167	4.100	4.167	3.750	1.000	0.306	0.200
Contribution to society	7.500	4.250	5.500	5.500	5.500	1.000	0.353

The above Table 4.7 is a Pairwise comparison matrix of the measures of performance with respect to Vodafone with its λ_{max} (largest eigenvalue) = 10.5988.

Table 4.8 Pairwise comparison of the measures of their performance with respect to Tigo

TIGO	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society	Eigenvector
Network Coverage	1.000	4.000	2.667	2.000	0.208	1.556	0.152
Network service	0.333	1.000	1.125	2.500	0.292	1.583	0.094
Average cost per user	1.600	2.250	1.000	2.250	0.625	2.625	0.144
Internet access and speed	0.667	0.625	1.125	1.000	0.250	2.600	0.088
Innovation	5.000	3.500	2.500	4.000	1.000	3.100	0.264
Contribution to society	4.667	3.167	2.100	2.600	2.583	1.000	0.259

The above Table 4.8 is a Pairwise comparison matrix of the measures of performance with respect to Tigo with its $\lambda_{\max}$ (largest eigenvalue) = 10.6724.

Table 4.9 Pairwise comparison of the measures of their performance with respect to Airtel

AIRTEL	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society	Eigenvector
Network coverage	1.000	0.500	1.563	0.196	1.100	0.171	0.061
Network service	2.000	1.000	4.500	1.000	1.100	3.600	0.204
Average cost per user	4.167	0.321	1.000	2.500	1.600	0.171	0.114
Internet access and speed	5.500	1.000	0.625	1.000	1.600	0.171	0.116
Innovation	2.750	2.750	2.667	2.667	1.000	1.600	0.196
Contribution to society	6.000	2.571	6.000	6.000	2.667	1.000	0.309

The above Table 4.9 is a Pairwise comparison matrix of the measures of performance with respect to Airtel with its $\lambda_{\max}$ (largest eigenvalue) = 10.1643.

Table 4.10 Pairwise comparison of the measures of their performance with respect to MTN

MTN	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society	Eigenvector
Network coverage	1.000	5.500	4.500	1.250	0.183	0.183	0.123
Network service	0.196	1.000	0.292	0.625	0.183	0.183	0.041
Average cost per user	0.250	3.500	1.000	0.225	0.183	0.183	0.060
Internet access and speed	1.250	2.500	4.500	1.000	0.183	0.183	0.102
Innovation	5.500	5.500	5.500	5.500	1.000	2.000	0.378
Contribution to society	5.500	5.500	5.500	5.500	0.500	1.000	0.296

The above Table 4.10 is a Pairwise comparison matrix of the measures of performance with respect to MTN with its $\lambda_{\max}$ (largest eigenvalue) = 7.0026

Table 4.11 Pairwise comparison of the measures of their performance with respect to Expresso

EXPRESSO	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society	Eigenvector
Network coverage	1.000	0.416	0.350	0.299	1.750	2.250	0.103
Network service	2.500	1.000	0.267	2.500	1.750	2.250	0.171
Average cost per user	3.500	4.000	1.000	2.500	1.750	2.250	0.272
Internet access and speed	5.500	0.416	0.416	1.000	1.750	2.250	0.170
Innovation	1.167	1.167	1.167	1.167	1.000	2.500	0.158
Contribution to society	1.125	1.125	1.125	1.125	0.625	1.000	0.127

The above Table 4.11 is a Pairwise comparison matrix of the measures of performance with respect to Expresso with its $\lambda_{\max}$ (largest eigenvalue) = 8.4624.

4.3 Step 3: Construction of the Super-matrix

There are three different forms of the supermatrix. They are the unweighted supermatrix, the weighted supermatrix and the limit supermatrix.

To obtain the supermatrix, the eigenvectors of each of the eleven matrices are entered into the appropriate columns of a matrix and is known as the initial supermatrix. And this is how it is done; each eigenvector is entered into the column that bears the name that, either the alternatives or criteria are being compared with respect to. After filling in the columns, one assigns zeros to all the spaces without values. The zeros represent no relationship between the components involved.

The initial supermatrix can either be an unweighted supermatrix or a weighted supermatrix.

If the sum of each of the columns of the supermatrix is one, it is known as a weighted supermatrix and if it is not one, it is known as an unweighted supermatrix. It must therefore be transformed into a stochastic matrix also known as a weighted supermatrix in which each column sums to unity or one before it can be transformed into a limit supermatrix. The unweighted supermatrix is made stochastic or weighted by an approach recommended by Saaty (1996), which is to determine the relative importance of the clusters in the super-matrix with the column cluster (block) as the controlling component (Meade and Sarkis, 1999). That is, the row components with nonzero entries for their blocks in that column block are compared according to their impact on the component of that column block (Saaty, 1996). Through pair-wise comparison of the row components with respect to the column component, an eigenvector can be obtained for each column block. For each column block, the first entry of the respective eigenvector is multiplied by all the elements in the first block of that column, the second by all the elements in the second block of that column, and so on. In this way, the block in each column of the super-matrix is weighted.

After obtaining the weighted supermatix, one can then transform it into a limit supermatrix. This is done by raising the weighted supermatix to the power of $2k + 1$, where k is an arbitrarily large number which will make the matrix sequence converge; that is the non-zero numbers in each particular row will be the same with respect to a particular number of decimal places. If the initial supermatrix obtained after entering the eigenvectors in the matrix is stochastic or a weighted supermatrix, then one needs not to do anything to it and can therefore be transformed directly into a limit supermatrix.

Table 4.12 Initial supermatrix

	Vodafone	Tigo	Airtel	MTN	Expresso	Network Coverage	Network Sevice	Average Cost per User	Internet Access and Speed	Innovation	Contribution to Society
Vodafone	0.000	0.000	0.000	0.000	0.000	0.363	0.301	0.145	0.480	0.280	0.391
Tigo	0.000	0.000	0.000	0.000	0.000	0.179	0.065	0.238	0.103	0.330	0.154
Airtel	0.000	0.000	0.000	0.000	0.000	0.220	0.256	0.326	0.189	0.190	0.304
MTN	0.000	0.000	0.000	0.000	0.000	0.167	0.063	0.022	0.129	0.153	0.128
Expresso	0.000	0.000	0.000	0.000	0.000	0.071	0.315	0.268	0.099	0.047	0.023
Network Coverage	0.069	0.152	0.061	0.123	0.103	0.000	0.000	0.000	0.000	0.000	0.000
Network Service	0.190	0.094	0.204	0.041	0.171	0.000	0.000	0.000	0.000	0.000	0.000
Average Cost per User	0.098	0.144	0.114	0.060	0.272	0.000	0.000	0.000	0.000	0.000	0.000
Internet Access and Speed	0.092	0.088	0.116	0.102	0.170	0.000	0.000	0.000	0.000	0.000	0.000
Innovation	0.200	0.264	0.196	0.378	0.158	0.000	0.000	0.000	0.000	0.000	0.000
Contribution to Society	0.353	0.259	0.309	0.296	0.127	0.000	0.000	0.000	0.000	0.000	0.000

The above is an initial supermatrix table. Since it is stochastic and therefore a weighted supermatrix, it should be transformed directly into a limit supermatrix.

Table 4.13 Limit supermatrix

	Vodafone	Tigo	Airtel	MTN	Expresso	Network Coverage	Network Sevice	Average Cost per User	Internet Access and Speed	Innovation	Contribution to Society
Vodafone	0.000	0.000	0.000	0.000	0.000	0.377	0.377	0.377	0.377	0.377	0.377
Tigo	0.000	0.000	0.000	0.000	0.000	0.193	0.193	0.193	0.193	0.193	0.193
Airtel	0.000	0.000	0.000	0.000	0.000	0.261	0.261	0.261	0.261	0.261	0.261
MTN	0.000	0.000	0.000	0.000	0.000	0.117	0.117	0.117	0.117	0.117	0.117
Expresso	0.000	0.000	0.000	0.000	0.000	0.121	0.121	0.121	0.121	0.121	0.121
Network Coverage	0.095	0.095	0.095	0.095	0.095	0.000	0.000	0.000	0.000	0.000	0.000
Network Service	0.161	0.161	0.161	0.161	0.161	0.000	0.000	0.000	0.000	0.000	0.000
Average Cost per User	0.131	0.131	0.131	0.131	0.131	0.000	0.000	0.000	0.000	0.000	0.000
Internet Access and Speed	0.111	0.111	0.111	0.111	0.111	0.000	0.000	0.000	0.000	0.000	0.000
Innovation	0.233	0.233	0.233	0.233	0.233	0.000	0.000	0.000	0.000	0.000	0.000
Contribution to Society	0.300	0.300	0.300	0.300	0.300	0.000	0.000	0.000	0.000	0.000	0.000

The above is a limit supermatrix, it was transformed from the weighted supermatrix by raising the latter to the power 71.

4.4 Step 4: Selection of best alternatives

In the first five rows of the limit supermatrix, the limiting priorities of the five alternative network operators are seen; they are 0.377, 0.193, 0.261, 0.117 and 0.121 for Vodafone, Tigo Airtel, MTN and Expresso respectively. As a result of this, Vodafone can be said to be perceived by customers to be a better performing network operator than the rest because of its highest value. Also in the last six rows, the limiting priorities of the six measures of performance of the network operators are seen; they are 0.095, 0.161, 0.131, 0.111, 0.233 and 0.300 for Network Coverage, Network Service, Average Cost per User, Internet Access and Speed, Innovation and Contribution to Society respectively. As a result of this, Contribution to Society can be said to be a more appropriate measure of perceived performance for the telecommunication operators than the rest because of its highest value.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the summary and recommendation of the results of the research. The results shows the grading of the telecommunication operators with respect to their performance and also the grading of the measures of performance with respect to which of them, the operators are paying more attention to, all according to the perception of the customers.

5.1 Summary of Findings

The findings from table 4.14 (the limit supermatrix) show that the priorities in decreasing order are 0.377, O.261, 0.193, 0.121, 0.117 for Vodafone, Airtel, Tigo, Expresso and MTN respectively. This means that from the perception of customers in Kumasi with respect to the measures of performance, Vodafone is performing better than all the other operators, followed by Airtel, Tigo, Expresso, the least being MTN. Also the same table shows the priorities in increasing order as 0.095, 0.111, 0.131, 0.161, 0.233 and 0.300 for Network Coverage, Internet Access and Speed, Average Cost per User, Network Service, Innovation and Contribution to Society respectively. This in turn means that, of all the measures of performance; contribution to society is what customers perceive as best indicator of performance priority of the operators followed by innovation, network service, Average Cost per User, Internet Access and Speed with the least being network coverage.

This study therefore appears to confirm widely held perceptions reflecting the complaints of many customers on most platforms that MTN (also ironically the most subscribed) is one of the less performing telecommunication operators in Ghana and also that network service and network coverage of the various telecommunication operators tend to be not so good on the average.

5.3 Recommendation

In general, the ANP model has been a useful tool elsewhere and has as borne out by this research also been of immense help in assessing the perceived performance of telecommunication operators in Kumasi.

From my findings, I recommend that;

Firstly, the NCA should prompt the telecommunication operators to concentrate more on making the network service better in order to avoid all the unnecessary problems associated with their services.

Moreover, the table 4.14 (the limit supermatrix) shows the ranking of the telecommunication operators in respect of perceived performance in accordance with the specified criteria, Stakeholders, individuals should therefore be guided and prudent in the choice of a telecommunication operator.

Also, the telecommunication operators lagging behind can also be guided to work harder and improve on their performance.

Finally, since the study only covers Kumasi, further studies should be made to cover other regions or the whole nation or even the sub-region in order to have a more cross-sectional view of the perception of customers on the performance of the relevant telecommunication operators.

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APPENDICES

APPENDIX A

MatLab Code to calculate the Eigenvectors of the pairwise comparison matrices

i)Pairwise comparisons of the telecommunication operators (alternatives) with respect to the measures of their performance (criteria)

Ai) %let a be the pairwise comparison matrix for the alternatives

```
[m,n]=size(a);
```

Aii) %summation of elements in each column of matrix a

```
%sumcol1=sum of colum 1

sumcol1=0

for  i=1:m

sumcol1=sumcol1+a(i,1)

end
```

```
%sumcol2=sum of colum 2
sumcol2=0;
for  i=1:m
sumcol2=sumcol2+a(i,2)
end
%sumcol3=sum of column 3
sumcol3=0;
for  i=1:m
sumcol3=sumcol3+a(i,3)
end
%sumcol4=sum of column 4
sumcol4=0;
for  i=1:m
sumcol4=sumcol4+a(i,4)
end
```

```
%sumcol5=sum of column 5

sumcol5=0;

for  i=1:m

sumcol5=sumcol5+a(i,5)

end
```

Aiii) %division of elements in a column by the sum of its respective column

```
%column 1

for  i=1:m

a(i,1)./sumcol1

end

%column 2

for  i=1:m

a(i,2)./sumcol2

end
```

```
%column 3

for  i=1:m

a(i,3)./sumcol3

end

%column 4

for  i=1:m

a(i,4)./sumcol4

end

%column 5

for  i=1:m

a(i,5)./sumcol5

end

%a1=matrix formed after division of elements in a column by the sum of its respective column
```

Aiv) %summation of elements in each row of matrix a1

```
%sumrow1= sum of row 1

sumrow1=0;

for  j=1:5

sumrow1=sumrow1+a1(1,j)

end

%sumrow2=sum of row2

sumrow2=0;

for  j=1:5

sumrow2=sumrow2+a1(2,j)

end

%sumrow3=sum of row3

sumrow3=0;

for  j=1:5

sumrow3=sumrow3+a1(3,j)

end
```

```
%sumrow4=sum of row4

sumrow4=0;

for  j=1:5

sumrow4=sumrow4+a1(4,j)

end

%sumrow5=sum of row 5

sumrow5=0;

for  j=1:5

sumrow5=sumrow5+a1(5,j)

end

%a2=matrix formed after summation of elements in each row of matrix a1
```

Av) %division of each element in matrix a2 by the number of elements in the row of matrix a1

```
for  i=1:m

a2(i,1)./m

end
```

ii) Pairwise comparisons of the measures of their performance (criteria) with respect to the telecommunication operators (alternatives)

Bi) %let b be the pairwise comparison matrix for the criteria

```
[m,n]=size(b);
```

Bii) %summation of elements in each column of matrix b

```
%sumcol1=sum of column 1

sumcol1=0;

for  i=1:m

sumcol1=sumcol1+b(i,1)

end

%sumcol2=sum of column 2

sumcol2=0;

for  i=1:m

sumcol2=sumcol2+b(i,2)

end
```

```
%sumcol3=sum of column 3

sumcol3=0;

for  i=1:m

sumcol3=sumcol3+b(i,3)

end

%sumcol4=sum of column 4

sumcol4=0;

for  i=1:m

sumcol4=sumcol4+b(i,4)

end

%sumcol5=sum of column 5

sumcol5=0;

for  i=1:m

sumcol5=sumcol5+b(i,5)

end
```

```
%sumcol6=sum of column 6

sumcol6=0;

for  i=1:m

sumcol6=sumcol6+b(i,6)

end
```

Biii) %division of elements in a column by the sum of its respective column

```
%column 1

for  i=1:m

b(i,1)./sumcol1

end

%column 2

for  i=1:m

b(i,2)./sumcol2

end
```

```
%column 3

for  i=1:m

b(i,3)./sumcol3

end

%column 4

for  i=1:m

b(i,4)./sumcol4

end

%column 5

for  i=1:m

b(i,5)./sumcol5

end

%column 6

for  i=1:m

b(i,6)./sumcol6

end

%b1=matrix formed after division of elements in a column by the sum of its respective column
```

Biv) %summation of elements in each row of matrix b1

```
%sumrow1= sum of row 1

sumrow1=0;

for  j=1:n

sumrow1=sumrow1+b1(1,j)

end

%sumrow2=sum of row2

sumrow2=0;

for  j=1:n

sumrow2=sumrow2+b1(2,j)

end

%sumrow3=sum of row3

sumrow3=0;

for  j=1:n

sumrow3=sumrow3+b1(3,j)

end
```

```
%sumrow4=sum of row4

sumrow4=0;

for  j=1:n

sumrow4=sumrow4+b1(4,j)

end

%sumrow5=sum of row 5

sumrow5=0;

for  j=1:n

sumrow5=sumrow5+b1(5,j)

end

%sumrow6=sum of row 6

sumrow6=0;

for  j=1:n

sumrow6=sumrow6+b1(6,j)

end

%b2=matrix formed after summation of elements in each row of matrix b1
```

Bv) %division of each element in matrix a2 by the number of elements in the row of matrix a1

```
for  i=1:m

b2(i,1)./m

end
```

APPENDIX B

QUESTIONNAIRE FOR CUSTOMERS OF TELECOMMUNICATION OPERATORS

Dear telecommunication operator's customer, this questionnaire is designed to collect information about how you feel and perceive about the performance of the various telecommunication operators in Kumasi, Ghana.

Your response will be treated confidential and used for only academic purposes. I am a Master of Science student of Kwame Nkrumah University of Science and Technology.

Please tick (√) the appropriate box for your answer

Note the Following

Telecommunication operators (Alternatives) =

[a. MTN b. Vodafone c. Expresso d. Airtel e. Tigo]

Measures of performance of the telecommunication operators (Criteria) =

[a. Total Area of Network Coverage b. Quality of Network Service c. Innovation

d. Contributions to society e. Internet Access and Speed f. Average Revenue per User]

The Fundamental Scale for Making Judgments (Saaty, 2005)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one activity over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Note: A score of 1 indicates the equality between the two elements whereas score 9 represents the dominance of row element in the matrix over the column element. A reciprocal value is automatically assigned in the opposite position in the matrix (NB: it means in comparing, the column element always has a value of 1).

Respondents Identification

1. Gender a. Male ( ) b. Female ( )
2. Age Group(years) a. below 20 ( ) b.20-29 ( ) c. 30-39 ( ) d. 40-49 ( ) e. above 50 ( )
3. Year a. First Year ( ) b. Second Year ( ) c. Third Year ( ) d. Fourth Year ( )

Pairwise comparisons of the telecommunication operators (alternatives) with respect to the measures of their performance (criteria)

Table 4.1: Pairwise comparisons of the telecommunication operators with respect to network coverage

NETWORK COVERAGE	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Table 4.2: Pairwise comparisons of the telecommunication operators with respect to network service

NETWORK SERVICE	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Table 4.3: Pairwise comparisons of the telecommunication operators with respect to average cost per user

AVERAGE COST PER USER	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Table 4.4: Pairwise comparisons of the telecommunication operators with respect to internet access and speed

INTERNET ACCESS AND SPEED	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Table 4.5 Pairwise comparisons of the telecommunication operators with respect to innovation

INNOVATION	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Table 4.6: Pairwise comparisons of the telecommunication operators with respect to contribution to society

CONTRIBUTION TO SOCIETY	Vodafone	Tigo	Airtel	MTN	Expresso
Vodafone	1				
Tigo.		1			
Airtel			1		
MTN				1	
Expresso					1

Pairwise comparisons of the measures of their performance (criteria) with respect to the telecommunication operators (alternatives)

Table 4.7: Pairwise comparisons of the measures of their performance with respect to Vodafone

VODAFONE	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society
Network coverage	1					
Network service		1				
Average cost per user			1			
Internet access and speed				1		
Innovation					1	
Contribution to society						1

Table 4.8: Pairwise comparisons of the measures of their performance with respect to Tigo

TIGO	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society
Network coverage	1					
Network service		1				
Average cost per user			1			
Internet access and speed				1		
Innovation					1	
Contribution to society						1

Table 4.9: Pairwise comparisons of the measures of their performance with respect to Airtel

AIRTEL	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society
Network coverage	1					
Network service		1				
Average cost per user			1			
Internet access and speed				1		
Innovation					1	
Contribution to society						1

Table 4.10: Pairwise comparisons of the measures of their performance with respect to MTN

MTN	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society
Network coverage	1					
Network service		1				
Average cost per user			1			
Internet access and speed				1		
Innovation					1	
Contribution to society						1

Table 4.11: Pairwise comparisons of the measures of their performance with respect to Expresso

EXPRESSO	Network coverage	Network service	Average cost per user	Internet access and speed	Innovation	Contribution to society
Network coverage	1					
Network service		1				
Average cost per user			1			
Internet access and speed				1		
Innovation					1	
Contribution to society						1