KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

OPTIMAL LOCATION OF MOBILE TELECOMMUNICATION MASTS. A CASE STUDY OF CAPE COAST METROPOLITAN AREA

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BY

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B. Sc (Hons.)

Declaration

I hereby declare that this submission is my own work towards Master of Science degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Dedication

This work is dedicated to following personalities: my parents Mr T. E Simpson and Victoria Quansah, my colleagues François Mahama and Mathias Gyamfi, my friends Mr. Kenneth Owuyaw of University of Cape Coast and Clive Ebo Barton-Oduro of Middlesex University, U.K. for their care and support.

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While I share the credit of this Master's thesis with all the above mentioned people, responsibility for any errors, shortcomings or omissions in this project is solely mine.

Abstract

Locating a set of facilities (resources) in order to minimize the cost of satisfying some set of demands (of customers) with respect to some constraints has been under study for a long time. Several location problems have been solved using a number of mathematical models and methods. In this thesis, a determination of optimum location of Mobile Telecommunication masts owned by mobile service providers in the Cape Coast Metropolitan area was under study. The general layout of siting telecommunication mast is based on transmission and receiving conditions. The proliferation of masts across our landscapes nowadays has been in direct response to increased desire for mobile communication services by the public. In order to prevent chaotic building of masts or towers all over the metropolis and to placate the citizenry who are nervous about possible health and environmental impact of these masts, co-location has been widely recommended by industry experts. A number of location strategies such as Centroid Method, Location Break-even Analysis, Factor Rating and Factor Analysis were observed by the researcher. Factor Rating method was adopted to solve this problem. The goal of Factor Rating is for a mobile service provider to be able to carefully derive the maximum benefit that can be used to achieve the company's objectives by considering all relevant factors involved in deciding to site a mast. Following the strict implementation of factor rating method on mast locations in the Cape Coast metropolitan area by five mobile service providers, optimal locations were discovered. Based on findings, propositions which can be inferred include; relocation of existing mast, mounting of additional telecommunication equipments on existing mast, sharing of telecommunication infrastructure, outsourcing of tower and mast management to third party companies, and finally, consideration for co-location by telecom companies.

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CHAPTER 1

INTRODUCTION

This chapter introduces the theory of location and the need for a facility such as mobile telecommunication masts to be optimally located. Outlined in this chapter is a brief background of the area under study, problem statements, objectives, methodology, justification, scope and limitations of the study and general organization of the thesis.

The location of any facility may have a tendency of posing both desirable and undesirable effects. There are many factors that are taking into consideration when locating a facility which may have direct or indirect effect on the settlement where it is located. Location is a branch in operation research which deals with determining the most appropriate site to locate a facility. Amponsah and Darkwa (2007) noted that, in locating a facility, one need to optimize one or more factors and it has to be accurately and mathematically measured. This will serve as scientific basis for a site to be used to locate that facility. One facility that the researcher looks at is Mobile Telecommunication Masts.

With the ever increasing need for broadcasting and telecommunications in this day and age, it has brought in some development in technological innovation and newness in the industrial transformations. The Ministry of Communication Policy Document (2004) pointed out that Ghana has been among the leading countries in Africa in promoting telecommunication developments. According to the document, it has been so because Ghana first opened its basic telecommunications industry to private competition more than a decade ago, and it continues to

be a leader among African nations in the expansion of market entry, the development of new services and business arrangements, and the growth of the telecommunications sector generally.

Støttrup-Andersen (2009) observed that, in most recent times, especially within the last decades, the need for tall structures has accelerated with the requirements for effective communication especially the advent of radio, radar and television. Latest the exponential growth in the use of cellular phones has meant a new era for towers and masts, however smaller in height but larger in number. There are many challenges for the engineers associated with these tall and slender structures. Støttrup-Andersen (2009) acknowledged that several places where mast are sited, a number of factors are taken into consideration.

The overall layout of telecommunication masts and towers is governed by the requirements of transmission and receiving conditions. Moreover, the access and working conditions for installation and service are important issues for the design. The first requirement often leads to relatively tall structures or in mountainous areas a smaller structure on the top of hills or mountains. Both solutions obviously lead to various problems with regard to analysis, design and construction.

1.1 BACKGROUND OF THE STUDY

The background to this study looks at how infrastructural developments have influenced the sighting of telecommunication masts in the Cape Coast Metropolis and the topology of the area under study. It also discusses some key words under study.

Nowadays, a visitor to the town of Cape Coast cannot escape the sight of huge tall metallic slender structures (mast or towers) going up as far as 50 meters in height, and serving a purpose of cell sites for telecommunication companies. New ones are emerging every passing moment.

In an interview with the *Daily Graphic* newspaper, a Deputy Director of Environmental Protection Agency(EPA) explained that "to mount a mast, a telecom operator needs separate permit from Environmental Protection Agency(EPA), metropolitan, municipal and districts assemblies in addition to written neighborhood approval from people living close to the location, where the mast would be erected." (Daily Graphic, Feb1, 2010)

Mobile telephony uses radio waves to transmit data. Phones are transmitters and receivers, typically with a range of a few miles. Ofcom (2011) explained that in order to send or receive calls, a handset must be within range of a transmitter mast. When a call is made within range of a mast, the mast relays the call to a switching centre, either by underground cable or by microwave, which routes it to the correct destination. If the destination is a mobile phone, that too must be in a mast range.

Ofcom (2011) pointed out that, to provide seamless coverage across an area, mobile phone network operators must erect enough masts to be in range of mobile phones most of the time. Each mast can only handle a fixed number of calls, and so multiple masts will need to be clustered in built-up areas.

The terms "mast" and "tower" are often used interchangeably. As noted in Wikipedia (2011), in structural engineering terms, a tower is a self-supporting or cantilevered structure, while a mast

is held up by stays or guys. Broadcast engineers in the UK use the same terminology. In US broadcast engineering, a tower is an antenna structure attached to the ground; whereas a mast is a vertical antenna support mounted on some other structure (which itself may be a tower, a building, or a vehicle). Masts (to use the civil engineering terminology) tend to be cheaper to build but require an extended area surrounding them to accommodate the guy wires. Towers are more commonly used in cities where land is in short supply (Wikipedia, 2011).

Operations Research

Operations Research is a branch of mathematics which represents the study of optimal resource allocation. The goal of Operations research is to provide rational bases for decision making by seeking to understand the structure of complex situations, and to utilize this understanding in any way possible, in order to study and improve system performance (Heger 2006). The research under study looks at a branch of study under operations research which looks at location in general. Amponsah and Darkwa (2007) looked at location problem to be concerning the location of one or more facilities in some space, so as to optimize some specified criteria.

For the purpose of this research, and to ensure consistency, a mast or a tower will be regarded as a tall slender metallic structure which host mobile telecommunication equipments.

1.2 PROBLEM STATEMENT

According to Ghana Statistical Service, Ghana's population now stands at 24,223,431 and out of that number 19,000,000 constituting 70% of the total population owns mobile phones (Business Monitor International report 2010). This means that there should be an increase in siting of moble phone towers across the country. Dowuona (2009) stated in his article and attributed to

National Communication Authority (NCA), that currently there are 3,000 plus telecom towers serving over 13 million mobile phone subscribers and according to experts in the telecommunication industry, the number of towers is woefully inadequate to assure quality service. In as much as it is inadequate, however, the haphazard manner of mast proliferated across the length and breadth of Ghana is a cause for concern. The National Communications Authority (NCA) and the Environmental Protection Agency (EPA) have proposed co-location of telecom towers as a licensing requirement for operators as a way of solving the problem. The government has, indeed, asked the regulators to get tough on operators to voluntarily co-locate; some operators had actually initiated moves towards co-location long before the government's directive, but some have also yet to implement co-location solution.

Problem is how to optimally locate masts. The problem this study seeks solutions to is on how to;

(i) maximize factors that will improve mobile telecommunication services and increase revenue at places where masts are located

(ii) minimize the cost of erecting new masts by reducing clustering of mast at sources

(iii) optimize the location of telecom masts by considering all factors involved. This includes considering co-location possibilities.

1.3 OBJECTIVES

The study seeks to:

(i) review the mobile telecommunication industry In Ghana, assess the growing impact of telecommunication companies in the Cape Coast Metropolis and associated mounting of masts.

(ii) adopt a relative objective model/method to determine an optimal location of a mast belonging to a mobile telecommunication company.

(iii) use the findings to determine the suitability of a co-location possibility. This will in turn help reduce the cost of erecting new mast and reduce clustering of mast at one source.

(iv) make recommendations based on findings. Among recommended points being that, mast owners, independent of telecommunication companies to be tasked to erect masts, so that Mobile telecommunication companies will engage in core business, thereby maximizing revenue

1.4 METHODOLOGY

Algorithm

In adopting factor rating methodology, the following steps will be followed strictly and consistently. These are:

(i) Develop a list of relevant factors.

(ii) Assign a weight to each factor to reflect its relative importance in the company's objectives.

(iii) Develop a scale for each factor

(iv) Have management or related people score each relevant factor, using the scale developed in (c) above.

(v) Multiply the score by the weight assigned to each factor and total the score for each location.

(vi) Make a recommendation based on the maximum point score, considering the result of qualitative approaches as well.

When a decision is sensitive to minor changes, further analysis of either the weighting the point assigned may be appropriate.

Data Sources

Data sources include Cape Coast Municipal Assembly, Environmental Protection Agency (EPA), Mobile communication operators and people living within the Cape Coast Metropolitan area who stay close to telecom masts.

Both primary and secondary sources data was sought to in analyzing the project under study.

1.5 JUSTIFICATION

Masts which serve the purposes of telecommunications have frequency bands within which they operate. They need to be sited at locations which will maximize returns and minimize cost. that will be born at their locations.

Engineers have devised ways within which to utilize reception and maximize returns with the mounting of masts and positioning of various directional antennas on them. Mast Owners or telecom owners need to consider all factors which make siting of mast at a location advantageous to them. Strategically positioning masts will ensure optimum utilization to reap its benefits.

1.6 SCOPE OF THE STUDY

The span of this study bothers on the location of telecommunication masts in the Cape Coast metropolitan area. An overview of telecommunication industry is assessed. A problem of optimally location mast to was assessed. A number of scholarly literature is reviewed. Location of five telecommunication companies in Cape Coast was captured. Facility Location mathematical problem is modeled to aid in optimal location of masts sited at various locations. Factor analysis method was used in data analysis with the aid of a computational tool. Conclusions were made based on findings. Co-location possibility conclusions were drawn based on rated objective factors used. Recommendations have also been made based on conclusions

1.7 LIMITATIONS OF THE STUDY

The researcher was constraint by time factor considering the period allowed for the writing and submission of the dissertation.

The researcher also faced the problem of limited financial and logistical support in the course of writing the dissertation.

The project is limited by the scope of geographical boundary of location under study.

Finally, the research is also limited to only tall slender structures which serve the purpose of mobile telecommunication masts even though there are other structures which may serve other telecommunication purpose such as radio and television.

1.8 ORGANISATION OF THE STUDY

The study is presented in five chapters. Chapter 1 looks at the theoretical framework of the study. Chapter 2 is devoted to the review of literature and related works, whilst Chapter 3 deals with the methodology of the study. Chapter 4 captures the presentation and analysis of data. Finally, Chapter 5 will handle summary of findings, conclusion and recommendations of the study.

1.9 SUMMARY

From the findings of the study, the following summary and conclusions can be made:

The major Telecommunication Operators and Mast Owners should consider all factors that go into erecting a mast or tower. Secondly, by adopting factor rating method, a firm will be able to take a superior strategic decision to locate a facility hence derive the maximum benefit and reduce cost, and eventually achieve the company's objectives. Again, new entrants in the sector will be relieved of initial huge startup cost since they can share already existing telecom infrastructure.

The next chapter reviews and discusses a wealth of scholarly literature on the topic under study.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

The review includes the literature on telecommunication industry as well as mathematical models and theories on facility location problems and how they have been solved.

Knowing the importance of the telecommunication industry, it is not surprising that much literature exists on the history of telecommunication industry. There is a wealth of scholarly debates regarding whether it has been a help or whether it has been of harm to the industry. It can be debated as to which side holds the most truth at the present time. The following will review the current literature available, both on the telecommunications industry in general and telecommunication industry in Ghana. Again, mathematical models associated with it have also been reviewed with emphasis on location optimisation.

2.1 THE TELECOMMUNICATIONS INDUSTRY IN GENERAL

The telecommunications industry is essential and considered a vital part of our everyday lives.

The telecommunication industry has grown rapidly over the last two decades. According to ITU (2009) statistics, from almost a zero base in the early 1980s, mobile telecommunication penetration worldwide in 2002 was estimated at 15.57 mobile phones per 100 people worldwide. European countries were also the first to launch and commercialize mobile cellular networks, with the first mobile cellular subscriptions recorded in Finland as early as 1980, followed soon after by Sweden, Norway, and Denmark.

Mobile cellular has been the most rapidly adopted technology in history. It is expected that the number of mobile phone subscribers globally will rise to billions. Today it is the most popular and widespread personal technology on the planet, with an estimated 4.6 billion subscriptions globally by the end of 2009 (ITU, 2009).

Al-Manthari et al., (2011) proposed a study on Congestion Pricing in Wireless Cellular networks (Mobile telecommunications). The researchers admitted that while the demand for wireless cellular services continues to increase, radio resources such as Mobile communication Masts and other equipments remains an indispensable asset. As a result, network operators have to competently manage these resources in order to increase the efficiency of their Wireless Cellular Networks (WCN) and meet the Quality of Service (QoS) of different users. A key component of Radio Resource Management (RRM) is congestion control. The researcher contended that congestion can severely degrade the performance of WCN and affect the satisfaction of the users and the obtained revenues. Several congestion control techniques have been proposed for WCN. The authors contend that these techniques, however, do not provide incentives to the users to use the wireless network rationally, and hence they cannot solve the problem of congestion. The paper admitted that any congestion control mechanism should promote efficient use of the shared wireless resources by penalizing greedy users to avoid the tragedy of the commons problem The researcher proposed congestion pricing in Wireless Communication Networks as a promising solution that can help alleviate the problem of congestion and generate higher revenues for network operators.

There is currently the need for all stakeholders to see to the provision of necessary policies, infrastructure and equipment which can satisfy the increasing demand for telecommunications services.

Some government agencies and public communities have set up guidelines to regulate the telecom industry. A guidance policy document by a district in the United Kingdom, SNC (2002), presented clear advice and guidance to all those interested in the siting of mobile phone masts in the district of South Northamptonshire. It was issued by the Council, principally for the use of telecommunications operators, but will be an invaluable source of information for the general public interested in the issues involved. The policy guideline sets out measures that must be taken by operators and their agents to minimize the impact of mobile phone masts on the environment and neighbouring residents. The guidelines provides a background to the development of telecommunication systems to date, outline the current legislation and procedures, gives a summary of health issues and finally consider environmental issues associated with telecommunications. This guidance sets out to provide clear advice to all those with an interest in the issues associated with telecommunication masts used for mobile phones and other uses. The scope of the guidelines applies primarily to telecommunication masts and antennae which serve mobile phone and similar communications systems, and other radio communication systems.

The researcher found it prudent to explore these guidelines in order to have better understanding of policy framework regarding telecommunication masts and antennae which serve mobile phone and similar communications systems.

2.2 THE TELECOMMUNICATIONS INDUSTRY IN GHANA

Dowurna (2010), a technology columnist in his numerous articles which appears on Ghanaweb.com, Myjoyonline.com, Graphic Business and Daily Graphic reproduced in his columns some statistics relating to the telecommunications industry in Ghana. Such revelations in his paper are reported below.

Available statistics by Ghana Statistical Service (GSS) reported in 2010 that the telecom industry has been a key driver of economic growth, directly accounting for 7% of investments in Ghana, 10% of government income, and 2% of GDP (Gross Domestic Product). To put that into perspective, the GSS submitted that the service sector, including banking, telecoms and others, constituted the biggest driver of economic growth, and the telecom sector alone, is a key facilitator of the performance of others within the service sector itself, plus it has boosted growth and productivity of workers in all other sectors of the economy. In direct terms, the telecom sector is facilitating communication probably among more than half of Ghana's estimated 24 million plus population. The latest National Communication Authority (NCA) Report on subscriber numbers indicate as at the close of July that there were 19,527,675 mobile subscriptions in the country and 278,221 fixed line subscriptions, which represents 80.3% telephony penetration. Data penetration is 7%, comprising 5% Internet penetration and 2% SMS (text messaging); and data also accounts for 7% operator revenues (Source: Macquarie First South, January 2011 - Data for Africa). But data is growing steadily as players in the industry continue to extend access across country mainly through corporate social responsibility investments into ICT. This means such services are mostly free for the rural dwellers.

Dowurna (2010) explained that whereas fixed broadband internet usage is relatively low, internet access on mobile phones is growing very fast as smartphones and tablets use increase in country. Moreover, with an addition of three submarine fibre optic cables in Ghana namely Glo One, Main One, and WACS (West African Communication Systems)to the already existing SAT-3, data and voice capacity and speeds are going to be phenomenal and services are likely to be cheaper. Sophie Curtis, in an article titled Technology in Ghana: A Blessing or A Curse, acknowledged that "the country's exceptional mobile infrastructure has undoubtedly helped the country to progress leaps and bounds in recent years, making it an attractive target for international investment, adding that ICT could be extremely empowering for people in rural communities – particularly women. Curtis (2011) discovered that "of all the African countries, Ghana is undoubtedly one of the most technologically advanced. Its mobile infrastructure puts much of the developed world to shame, and networking company Alcatel Lucent has even hinted that the company is working with mobile operators in Ghana to launch LTE (Long-Term Evolution), which is the most modern mobile technology." (Retrieved from http://www.techweekeurope.co.uk/comment/technology-in-ghana-a-blessing-or-a-curse-41578)

Nimako and Azumah (2009) conducted a study which sought to assess and analyse customer satisfaction with service delivery of mobile telecommunication networks within Ghana. The researcher's problem was to find out whether customers are satisfied with service delivery of mobile telecommunication networks in Ghana. The researchers targeted a population of individual mobile subscribers and mobile communication companies In their study the authors,, Nimako and Azumah (2009) adopted a Gronroos model of SERVQUAL (Gronroos, 2000) for the study with a reason being that the model is comprehensive and its service quality

dimensionality is justifiably suitable in the context of Mobile Communication Networks in Ghana.

The findings by Nimako and Azumah (2009) pointed out that irrespective of mobile telecom network in Ghana, customer satisfaction is low; neither equal to nor better than desired expectation of the customers. The researcher's findings also indicate that "Technical quality" is the most important dimension, followed by "empathy", "reliability", "economy", "responsiveness", "image", and "assurance", while "tangibles" is found not significantly important to the customers in Ghana's Mobile Telecommunication Networks. Most of the customer-satisfied dimensions were rated less important, while most of the customer-dissatisfied dimensions were rated more important. Furthermore, the researchers found out that Desire and Expectation Disconfirmations collectively and individually explain overall customer satisfaction significantly in Ghana's Mobile Telecommunication Industry. Generally the study finally implores the National Communication Authority and other policy makers to take workable measures to propel Mobile telecommunication networks in Ghana to improve upon their service quality in specific areas.

Burkson (2011) noted in his published article that, Ghana's telecoms sector has enjoyed a financial boost in the last couple of years, with deals across both fixed and mobile platforms bringing some of the biggest operators in the world to the West African state. Mobile telecommunication operators which have found their way in Ghana are Vodafone, MTN, Tigo, Airtel, Expresso and Glomobile.

2.3 THE TELECOMMUNICATIONS INDUSTRY IN CAPE COAST METROPOLIS

Since the study was undertaken in the Cape Coast Metropolis, which is the capital of Central Region, it is useful to have knowledge of important facts about the area of focus, as of the time of this study.

2.3.1 Brief Background of Central Region

The Central Region is one of Ghana's ten administrative regions. It is bordered by the Ashanti and Eastern regions to the north, Western region to the west, Greater Accra region to the east, and to the south by the Atlantic Ocean. The region comprises of 17 districts with Cape Coast Metropolitan being the Central administrative district (CCMA, 2011).

2.3.2 Brief Description of Mobile Telecommunication Companies Which Have Established Their Presence in Cape Coast Metropolis.

There are six major mobile telecommunication network companies in Ghana. Each mobile network operator is associated with brand name. That is, Vodafone of Vodafone Ghana Limited, MTN of Scancom Ghana Limited, TIGO of Millicom Ghana Limited, Airtel of Airtel Ghana Limited, Expresso of Expresso telecom, and Glo of Globacom Limited. All of them have their subsidiary branches in almost all the regions in Ghana. All the six telecommunication companies have established branches in the Cape Coast Metropolitan area. They have contributed to the telecommunication infrastructure in the Cape Coast Metropolis including erection of Telecommunication masts or towers. They have been licensed to offer mobile communication services.

2.4 TELECOMMUNICATION MASTS

According to Støttrup-Andersen (2009), within the last decades the need for tall structures has accelerated with the requirements for effective communication especially the advent of radio, radar and television. He noted also that most recent exponential growth in the use of cellular phones has meant a new era for towers and masts.

O'Flaherty (2001), a legal expert in Telecommunication also had a similar opinion that, the proliferation of towers across our national landscape has been a direct response to increased appetite for radio, television and telephone communications. Masts/Towers serve as points for erecting Microwaves and other telecommunication equipments for wireless communications. They provide a means through which wireless enabled devices can communicate with each other.

In some literature that has been reviewed Telecommunication Masts are also referred to as towers, cell sites or Base Transceiver Station (BTS). They are designed in various forms, shapes and sizes. Mastsanity (2011) describes masts to be like big towers. Wikipedia (2011) explains also that towers are distinguished from masts by their lack of guy-wires.

Zunia (2011) referred to it as a site where antennas and electronic communications equipment are placed to create a cell in a mobile phone network (cellular network). However the term "base station site" might better reflect the increasing co-location of multiple mobile operators, and therefore multiple base stations, at a single site. (Zunia, 2011) pointed out also that depending on

an operator's technology; even a site hosting just a single mobile operator may house multiple base stations, each to serve a different air interface technology.

Støttrup-Andersen (2009) indicated that the overall layout of telecommunication masts and towers is governed by the requirements of transmission and receiving conditions.

Burkson (2011), an expert in Business and Telecommunication wrote in his article that "a sure sign of maturity in the telecom sector is the rush to outsource tower management and ownership to third parties as a means of diversifying revenue and focusing on core activites. It all kicked off in January 2010 when Millicom Ghana (Tigo Ghana) agreed to sell 750 base towers to Helios Towers Ghana (HTG), the deal was the first major sales/leaseback to be completed by major African telecoms operator and an independent tower company on the continent." Other mobile phone Companies followed suite. In Burkson (2011) article, he noted that Vodafone Ghana also signed a ten year deal with Eaton Towers to take over the operations and co-location management of its existing tower infrastructure. The deal is reported to be worth $45 million to Eaton Towers, whose directors are ex-Vodafone employees. MTN rounded off the deals for 2010 with their joint venture deal with American Towers raising $428million for the Mobile operator, Airtel is also actively looking forward to introduce its Tower business for which it is well known in India to the African market, and Ghana looks to be the first country that might benefit from Airtel's experience in tower management.

The National Communications Authority which regulates the telecoms sector has recently called for applications for licenses to build infrastructure, mostly communication towers. Burkson (2011) discussed in his piece the tower business model in India and United States. In India,

mobile companies have to invest massively in tower infrastructure. In order to prevent chaotic building of towers all over the country and to appease the citizenry who are nervous about the radiation effects of these towers, the government has licensed one private basic services operator (BSO) in each state to set up an independent telecom network in the state As noted by (Jhunjhunwala et al., 1998), the inter-state network and international links in India are being operated by the government-owned monopoly operator (Department of Telecommunications, DOT). In the United Sates, towers are built by third parties, with American Towers and Crown Towers being the biggest players in the sector. National Communication Authority of Ghana, have indicated that in the near future only licensed companies will be allowed to build and operate new towers, with the view that the mobile networks will buy space from the newly licensed operators rather than build their own towers (Burkson, 2011).

A number of countries where mobile telecommunication infrastructure has boomed have advocated sharing. These advocacies have been crafted in their telecommunication policy documents.

The Indian National Newspaper, The Hindu (April 12, 2007 edition), wrote a piece attributed to the Telecom Regulatory Authority of India (TRAI) in relation to sharing of telecommunication masts. The article quoted that in a step that could help faster growth of mobile services in rural and remote areas, the Telecom Regulatory Authority of India (TRAI), has recommended sharing of telecom infrastructure among service providers. The regulatory body has emphasised the need for cooperative efforts among telecom service providers with least regulatory intervention, as being followed internationally, for faster rollout and better quality of services.

Another recommendation by TRAI(2007) and forwarded to the Department of Telecommunications (DoT), asked for sharing of both active infrastructure (antenna systems, cables and transmission system) and passive infrastructure (physical sites, towers and power supply). (Hindu, 2007) observed that infrastructure sharing would help in reducing the cost of service provision, enhance competition and make mobile services better and cheaper.

To make such entire process transparent and non-discriminatory, TRAI recommended that the licensees should be required to announce on their website the details of existing as well as future infrastructure installations available for sharing by the other service providers (TRAI, 2007).

TRAI's regulatory policy also indicated that mobile tower design should have the capacity to accommodate at least three service providers to be eligible for subsidy by authorities. In addition, the Regulation policy clearly stated that no subsidy shall be paid if the newly erected tower is not shared. The article in the Hindu (2007) advocated strongly in conclusion that local bodies should grant permission to set up towers in notified sites on condition of sharing by at least three service providers.

LPGN (2007), a Local Planning Guidance on Telecommunication developed by Fintshire Council in UK also advocated that Mast sharing should be considered as a means of reducing or eliminating the need for new masts, but sometimes it may necessitate an existing mast to be increased in height to accommodate more equipment, resulting in greater prominence.

2.4.1 FACTORS CONSIDERED WHEN ERECTING MASTS

Zunia (2011) provided in his paper, some considerations that project engineers take when sitting masts or towers. The site should be large enough for a cell tower—normally (but not always) this

is a parcel double the size of the height of the tower. So if a tower is 100 ft tall, the parcel must be 200' x 200'. Site must have easy and cheap access from a public road. Site must be suitable from a zoning perspective. In many jurisdictions, towers are only allowed on commercially or industrially zoned parcels. Some areas allow towers on agriculturally zoned sites, and most do not allow towers on residentially/ forest land or restricted areas. Sites must not have conditions that would make constructing a tower unduly expensive. These conditions can include wetlands, poor or rocky soil conditions, significant distance to the cell tower site from the main road, lots of trees, possible hazardous waste on the property and high voltage power lines (Zunia, 2011).

Støttrup-Andersen (2009), in his paper, also shared some views in considering a site to locate a mast. They are as follows: directions for the various directional antennas, wind drag on each element of the array and dependent on wind direction, size, weight and disposition of all feeders and cables, the permitted angular rotations in azimuth and elevation of each aerial above which the broadcast signal is significantly reduced; the need for all-weather access to some of the aerials; besides the known antenna and aerial configuration the possible future extension should be defined; atmospheric ice formation on the structure and aerials and its likelihood to occur with high wind; wind drag of the structure itself without ice and with ice if feasible; the degree of security required; the available ground area and access to the site; the geological nature of the site; the overall cost of land, foundations and structure; the cost and implications of future maintenance or structural replacement; any special planning considerations imposed by statutory bodies and finally, the aesthetic appearance of the structure.

2.4.2 LEGAL AND POLICY FRAMEWORKS

In as much as it is necessary for mast to be located in various place for the purposes of telecommunications, there are legal and policy frameworks that owners of masts must adhere to. A telecommunication policy document adopted in the United Kingdom, (SNC, 2002), argues that, in conditions where there is no possibility for overhead lines and underground cables, telecommunication masts are inevitable. Added to that is the need to leverage technology.

In some cases, however, the most convenient and economic technical solution may not be ideal when balanced with possible impact on the environment and possible health concerns. In some countries where mast infrastructure has caught up with them, the governments and other authorities have taken measures to curb the effect of telecom masts. They have set standards and guidelines, and laced measures to regulate mast erections to their laws. This in effect will help to ensure a safer society and a level playing field for all stakeholders. Governmental oversight is vital.

Today, towers or masts are increasing as our communication needs expand due to increasing appetite for mobile phone communication. However, O'Flaherty (2001) cautioned that when a tower collapses or there is an accident, the legal duties and rights of tower owners, engineers who design towers and the contractors who build and service towers come into scrutiny. There must be legal ramifications to the tower industry.

It is in the light of this that the Government of Ghana set up an industry technical committee (ITC) made up of experts from National Communication Authority(NCA) to come out with a report on guidelines for deployment of communication towers in the year 2010.

The mandate of the ITC committee was to:

(i) Provide clear standards and procedures for the installation of towers and also address the issues of environmental sanity

(ii) Formulate a cost effective and efficient mechanism to address administrative and bureaucratic bottlenecks faced by Operator.

(iii) Design a fair and open cost-based fee policy/structure which would ensure that all operators are charged fairly by relevant permitting authorities.

(iv) Facilitate the development of infrastructure to enhance delivery of quality service and also promote the provision of competitive and affordable services nationwide. (ITC Guidelines 2010)

The committee came out with a document that spells out conditions that mast owners must adhere to when siting masts.

Some institutions in Ghana regulate the siting of masts directly or indirectly. They are Environmental Protection Agency (EPA), Inter-Ministerial Committee on Communications (IMC), National Communication Authority (NCA) and Ghana Civil Aviation Authority (GCAA).

The Environmental Protection Agency (EPA) is the leading public body for protecting and improving the environment in Ghana. It is their job to make sure that air, land and water are

properly looked after by everyone in today's society, so that the next generation will inherit a cleaner, healthier world. They have offices across Ghana working on and carrying out Government policy, inspecting and regulating businesses and reacting when there is an emergency such as a pollution incident.

Among the core objectives of EPA is to create awareness to mainstream environment into the development process at the national, regional, district and community levels. Added to that, they must ensure that the implementation of environmental policy and planning are integrated and consistent with the country's desire for effective, long-term maintenance of environmental quality (EPA website, accessed Nov 2011).

The National Communication Authority (NCA) has a legal authority over matters relating to telecommunications in Ghana. The National Communication Act passed in 2008 establishes the National Communications Authority as the central body to license and regulate communications activities and services in the country; and to provide for related purposes (NCA Act, 2008).

The researcher noted that the location of a public facility is a subject that has attracted a lot of attention under Operations Research. The review now looks at location problems which have been successfully tackled by location theorists over the years using mathematical models.

2.5 MATHEMATICAL THEORIES AND MODELS IN ANALYSING FACILITY LOCATION PROBLEMS

Location problems have attracted a lot of interest by mathematical researchers for a long period of time due to its ability to solve numerous problems.

Farahani and Hakmatfar (2009) wrote in their introductory part of their book, “Facility Location, Concepts, Models, Algorithms and case Studies" by emphasizing that the mathematical science of facility location has attracted much attention in discrete and continuous optimisation over nearly last four decades. The authors explained facility location problems as “to locate a set of facilities (resources) to minimise the cost of satisfying some set of demands (of customers) with respect to some set of constraints”. Conducting a review in almost any topic in facility location, according to Schilling et al., (1992) is no small undertaking since academic outlets which publish facility location span a wide range of disciplines. Nevertheless some relevant literature has been covered in this review by the researcher.

Eiselt and Marianov (2011) in their book entitled "Foundations of Location Analysis", gave some good examples location models as locations of trucking terminals, blood banks, ambulances, motels and solid waste transfer points. The authors enumerated additional examples such as points for glaucoma detection, location of new employees in skill space, the location of advertisments in media, selecting a site for plant, or choosing a candidate and many others.

Minimax, Minisum and Covering models are discovered whenever Location Problem arise. There are other hybrid and forms which have been used from which have been discovered and used.

Daskin (1995) explained covering location problems as a problem which tries to determine the number of facilities to cover all demand nodes under center problems. The model introduced under a title p-centre model (minimax problem). The objective this model was to find location of

p facilities so that all demands are covered and the maximum distance between a demand node and the nearest facility is minimised.

Drezner (1995) in his research incorporated five objectives of p-median, p-center, two maximum covering and the minimum variance in order to minimize the maximum percent deviation from the optimum of each of these objectives for a casualty collection point location problem.

Serray and Marianovz (1996) postulated a P-Median problem in a changing network in Barcelona. The authors formulated a p-median-like model to address the issue of locating new facilities when there is uncertainty. Several possible future scenarios with respect to demand and/or the travel times/distance parameters were presented. The authors wanted a strategy of positioning that will do, as well as possible, over the future scenarios. The paper presented a discrete location model formulation to address this P-Median problem under uncertainty. The model was applied to the location of fire stations in Barcelona.

Depending on the problem Eiselt and Marianov(eds.)(2011) research produced a general algorithm which can be used to solve Location Problems. The algorithm is as follows:

$$Min\,\sigma\left(\sum_{i,j} c_{ij}\, y_{ij} + \sum_{i,j} f_j\, x_{ij} + gz\right) \qquad (1,1)$$

$$s.t\ \left(\sum_{,j\epsilon N} y_{ij} = 1\ i = 1,2,\dots n\right) \qquad (1,2)$$

$$y_{ij} \le x_j \quad i = 1,2,\dots n, j = 1,2,\dots m. \qquad (1,3)$$

$$y_{ij} x_j \epsilon \{0,1\}, \quad z \epsilon R^+ \quad i = 1,2,\dots n, j = 1,2,\dots m. \qquad (1,4)$$

Where the variables are;

x: a location variable that equals 1, if a facility is located at node j, and 0 otherwise

y_{ij}: an allocation variable that equals 1 if customer I is assigned to a facility at j and 0 otherwise and

xj: a continuous variable that takes the value of a maximum or minimum distance, depending on the problem to be solved.

The subscripts are

i, j a subscript that indicates customers and potential facility sites, respectively,

N; is the set of nodes. Its definition depends on the problem, and n and m denotes the total number of customers and potential facility locations.

Finally the parameters are:

σ :a parameter that takes value 1 or(-1) , depending on whether the objective is minimized or maximized, and

$c_{ij}, f_j g$: Parameters that depend on the problem being solved.

Depending on the problem Eiselt and Marianov (eds.) (2011) noted that these linear combinations represent maximum, minimum or average distances in investment, transportation, manufacturing costs and assigning demands to facilities and vice versa.

Farahani and Harkmatfar (2010) enumerated certain criteria that can serve as various objective functions to solve Location problems. These include;

(i) Minimizing the total setup cost.

(ii) Minimizing the longest distance from the existing facilities.

(iii) Minimizing fixed cost.

(iv) Minimizing total annual operating cost.

(v) Maximizing service.

(vi) Minimizing average time/ distance travelled.

(vii) Minimizing maximum time/ distance travelled.

(viii) Minimizing the number of located facilities.

(ix) Maximizing responsiveness. (Farahani and Harkmatfar,2010)

A classic example can be attributed to Weber Problem which can be used to solve applications such as locating a single warehouse (Facility) that supplies different amount (weights) of a product to a number of dealers (demands) in such a way that the total transportation cost is minimised, assuming that this cost depends on the distance and amount transported.

Covering Problems of Facility locations have a lot of variations. An instance of this is Location Set Covering problem (LSCP) which was first introduced by Hakimi and formulated as linear programming by Toregas et al in 1971. The aim is to find the maximum number of facilities and their locations, so that all customers are covered, meaning that all customers are further that a preset distance ***D*** of their closest facility.

Amponsah et al., (2010) conducted study of location of ambulance emergency medical service in the Kumasi metropolis in Ghana. The authors modelled the problem as Non-Linear Maximum Expected Covering Location Problem(MEXCLP) implemented by Saydam and Aytug (2003).In their paper the researchers acknowledged that several approaches that have been employed in

solving this very sensitive location problem such as Maximum Availability Location Problem (MALP) developed by Daskin (1982), ReVelle and Hogan (1989). Genetic Algorithms (GA) that uses random key coding was implemented. A formula for renormalization was introduced. Real route distances were used for computation and statistical deviation was introduced in the selection of optimal routes.

Arogundade et al., (2005) conducted a study of fire and emergency service facility location selection in Nigeria. The authors looked at the problem as variant of set covering problem. First, a mathematical model of facility location was introduced and solved by using optimization solver, TORA. Secondly, the balas additive algorithm of branch and bound techniques is used to solve the facility location problem. In analysis the authors discovered that both algorithms indicate the same number of fire stations in different locations. Also the results obtained by applying and implementing balas additive were more explanatory by specifying the names of the locations where the facilities are to be located and the names of the locations to be served by each of the facilities.

Other forms facility location theories, methods and models are models which include Factor Rating Method, Breakeven Analysis, Linear Programming, Centre of Gravity and Factor Analysis. The factor rating method is widely-accepted and used because a broad multiplicity of factors it objectively includes.

Amponsah and Darkwa (2007) again solved a theoretical problem as example to help decide among three sites for the construction of a new oil-processing center by Tema Oil Refinery in

Ghana. Based on factor such as proximity to port facilities, power-source availability and cost, and distance from Tema, the authors were able to locate an appropriate site for the Oil-Processing Refinery. There are other literature reviewed which specifically looks at Location in Telecommunications.

Gourdin et al., (2001) in their study reviewed location problems in telecommunication network design and adopted models for solving such problems. The authors classified the models into three classes as uncapacitated, capacitated and dynamic models. For each class, they discussed the core problem, its generalizations and the solution methods.

Chandrasekaran (2006) discovered in a study that the need for communication networks capable of providing an ever increasing spectrum of services calls for efficient techniques for the analysis, monitoring, evaluation and design of the networks. Analysis is perpetually faced with incomplete and ever increasing user demands and uncertainty about the evolution of the network systems. From the author's point of view, to meet the requirements of users and to provide guarantees on reliability and affordability, system models must be developed to capture the characteristics of the actual network load and yield acceptable precise predictions of performance of the system, in a reasonable amount of time. The author noted Traffic Analysis as a vital component understanding the requirements and capabilities of a network. The past years have seen in numerous traffic models proposed for understanding and analyzing the traffic characteristics of networks. The author noted that there is no single traffic model that can efficiently capture the traffic characteristics of all types of networks, under every possible circumstance. Consequently, the study of traffic models to understand the features of the models

and identify eventually the best traffic model, for a concerned environment has become a crucial and lucrative task. Good traffic modelling, as discovered by the author, is also a basic requirement for accurate capacity planning. The author's report provides an overview of some of the widely used network traffic models, highlighting the core features of the model and traffic characteristics they capture best.

Hakimi (1964) delved into location of this nature in his publication when he wanted to locate switching centres in a communication networks by introducing the 1-median and p-median problems.

Chung et al., (1992) developed a model for designing a full connected/star type network, i.e. all the concentrators are connected to each other and the terminals assigned to a concentrator are directly connected to this concentrator. The authors developed a formulation where the cost function includes the cost of interconnecting connectors. Thus the total cost function is a quadratic. In the final analysis, this formulation is linearised and a dual-based solution procedure and computational results are presented.

Gavish (1983) in a study formulated a problem where terminals are connected to the concentrators via multidrop links which are capacitated concentrators connected to a central unit by point to point links. This results in a star/tree network. The objective function involved establishing the cost of links and installation of concentrators. There were different types of links with different costs and capacities. The author formulated an equation with parameters which was used as constraints. Some constraints stated that for each communication pair of nodes, a

route should be chosen. Other constraints revealed that if a node is the head or the tail of an installed link, then it should receive a concentrator. The author presented a Langragrian Relaxation based solution procedure to solve this nonlinear formulation.

Balakrishnan et al., (1995) conducted a study on the expansion of a telecommunication network. The researchers assumed that there are no concentrators in the network at the beginning of the planning prospect. The problem was to install concentrators and expand the sizes of the links with minimum cost and meet the project demand. They developed a decomposition method based on Langragrian Relaxation and dynamic programming.

Monticone and Funk (1994) considered the problem where a set of communication pairs of terminals are given and are to be connected to each other directly or using exactly two concentrators. The objective of their study was to minimize the cost of establishing these links and the cost of installing concentrators. It was assumed that each communication pair places a unit demand. The authors applied partitioning and reduction techniques to solve the problem.

Pirkul et al., (1988) studied a problem where each network terminal is assigned to two concentrators, one for primary coverage and the second for the secondary or backup coverage. The authors also consider the case where each terminal is required to be assigned k, concentrators. They presented a Lagrangrian Relaxation with primarily and secondary coverage (assignments) constraints dualised. The problem was deduced to an independent knapsack problem for each concentrator. The Langrangain Dual was solved by subgradient optimization

and a heuristic to construct a feasible solution at each iteration of the subgradient optimization given.

Kremling (2007) gave an insight of challenges in the mobile telecommunication industry immediately by bringing to attention network development and optimisation. In his paper he noted that increasing traffic, highly complex and non-optimal network topology can cause major problems. He argued that networks of the future will need a high degree of reliability and at the same time, costs have to be controlled. The author recommended the use of mathematical models based on linear programming to optimise network topology. Constraints that can be imposed in the optimisation include routing restrictions, traffic load, overall reliability, and cost.

From an initial topology, possible alternative routings can evaluated and an optimised topology can be deduced using mathematical models.

Other literature reviewed gave a vivid explanation of some models.

Garson (2009) described Factor Analysis as, a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved, uncorrelated variables called factors. In other words, it is possible, for example, that variations in three or four observed variables mainly reflect the variations in fewer such unobserved variables. Factor analysis searches for such joint variations in response to unobserved latent variables. The observed variables are modelled as linear combinations of the potential factors, plus "error" terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. Factor analysis originated in psychometrics,

and is used in behavioural sciences, social sciences, marketing, product management, operations research, and other applied sciences that deal with large quantities of data.

Factor-rating systems are another most widely used of the general location techniques because they provide a mechanism to combine diverse factors in an easy-to-understand format. Each site is rated against each factor, and a point value is selected from its assigned range. The sums of assigned points for each site are then compared. The site with the most points was selected.

The transportation method is a special linear programming method. It gets its name from its application to problems involving transporting products from several sources to several destinations. The two common objectives of such problems are either (1) minimize the cost of shipping *n* units to *m* destinations or (2) maximize the profit of shipping *n* units to *m* destinations. An example of this problem could be if a company has four factories supplying drugs to warehouses of four major customers and its management wants to determine the minimum-cost per shipping schedule for its monthly output to these customers considering factory supply, warehouse demands, and shipping costs per case for these drugs.

The Centroid method, also referred to as Centre of Gravity method, is a technique for locating single facilities by considering the existing facilities, the distances between them, and the volumes of goods to be shipped. The technique is often used to locate intermediate or distribution warehouses. In its simplest form, this method assumes that inbound and outbound transportation costs are equal, and it does not include special shipping costs for less than full loads. Another major application of the Centroid method today is the location of communication towers in urban areas. Examples include radio, TV, and cell phone towers. In this application the

goal is to find sites that are near clusters of customers, thus ensuring clear radio signals. The Centroid method begins by placing the existing locations on a coordinate grid system. The choice of coordinate systems is entirely arbitrary. The purpose of Center of gravity method is to establish relative distances between locations.

2.6 SUMMARY

The literature under review discussed among the lot, Mobile Telecommunication in general, the telecommunication industry in Ghana, mobile telecommunication companies in the Cape Coast Metropolitan area and telecommunication infrastructure with emphasis on telecommunication masts. The review also looked at mathematical theories and models used in analysing facility location problems. Moreover, it discussed literature on location of network optimisations.

The next chapter discuses the methodology and mathematical models adopted in the study.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This describes the procedures employed in the gathering of the data for the study. This includes the description of the source of data, the target population, methods of data collection, mathematical models and methods algorithm used in data analysis.

3.1 SOURCES OF DATA

The main sources of data for the study were based on both primary and secondary data.

3.1.1 PRIMARY DATA SOURCES

The researcher went to the field to solicit for data/information considered necessary, from the respondents through the administration of open-ended and closed-ended questionnaires, personal interviews and observations.

3.1.2 SECONDARY DATA SOURCES

Some previous scholarly works which include books, articles, journals, newsletters, brochures and other related literature about the topic under study were consulted.

3.2 TARGET POPULATION

The study involved both residents of Cape Coast and Mast owners which include three Mobile Telecom operators and agents who have mast sited in Cape Coast.

The reason for the selection of this target population is that, they constitute the required target group of the case study and as such offer the researcher the opportunity to find the most relevant factors in determining optimal location for mounting of Mobile Telecommunication mast.

3.3 DATA COLLECTION

The researcher employed personal observations, administration of highly structured questionnaires with pre-coded and open-ended questions and interviews to solicit the data from the respondents/target group.

The administration of the questionnaires was done by the researcher himself with the questionnaires being completed by the respondents.

Among data collected included technical guidelines for location of telecommunication masts from the National Communication Authority

3.4 MODEL INSTANCES AND METHODOLOGY USED IN DATA ANALYSIS

In implementing a suitable methodology for analyzing data for facility location of Mobile Telecommunication Masts, researcher assessed some useful mathematical methods and model instances. These are namely, Centre of Gravity (Centroid) method, Break Even Analysis, Factor Analysis and Factor Rating Method.

3.4.1 Center of Gravity

Center of Gravity (Centroid) method is technique for locating single facilities by considering the existing facilities, the distances between them, and the volumes of goods in their movements.

The centroid is found by calculating the X and Y coordinates that result in the minimal cost.

The model is as follows:

$$C_x = \frac{\sum d_{ix} V_i}{\sum V_i} \qquad C_y = \frac{\sum d_{iy} V_i}{\sum V_i}$$

where

C_x = *X* coordinates of the centroid

C_y =*Y* coordinates of the centroid

d_{ix} = X coordinate of the *i*th location

d_{iy} = Y coordinate of the *i*th location

V_i = Volume of goods moved to and from the ith location

3.4.2 Break Even Analysis

The Location break-even analysis is the use of cost-volume analysis to make an economic comparison of location alternative. By identifying fixed and variable cost and graphing them for each location, we can determine which one provides the lowest cost. Location break-even analysis can be done mathematically or graphically. The graphic approach has advantage of providing a range of volumes over which each location is preferable.

The location break-even analysis steps are as follows:

(i) Determine the fixed and variable cost for each location.

(ii) Plot the cost for each location, with cost on the X axis of the graph and the annual volume on the Y axis, and finally,

(iii) Select the location that has the lowest total cost for the expected production.

3.4.3 Factor Analysis

Factor Analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved, uncorrelated variables called factors. In other words, it is possible, for example, that variations in three or four observed variables mainly reflect the variations in fewer such unobserved variables. Factor analysis searches for such joint variations in response to unobserved latent variables. The observed variables are modelled as linear combinations of the potential factors, plus "error" terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. Factor analysis originated in psychometrics, and is used in behavioural sciences, social sciences, marketing, product management, operations research, and other applied sciences that deal with large quantities of data.

Factor analysis model is described

Suppose we have a set of p observable random variables, $x_1, \ldots\ldots x_p$ with means $\mu_1, \ldots\ldots \mu_p$. Suppose for some unknown constants l_{ij} and K unobserved random variables F_j, where $i \in 1, \ldots, p$ and, $j \in 1, \ldots, k$, where, $k < p$, we have

$$x_i - \mu_i = l_{i1}F_1 + \ldots\ldots\ldots\ldots + l_{ik}F_k + \varepsilon_i$$

Here, the $\mathcal{E}_i$ are independently distributed error terms with zero mean and finite variance, which may not be the same for all i. Let $\mathrm{Var}(\mathcal{E}_i) = \psi_i$, so that we have

$$\mathrm{Cov}() = \mathrm{Diag}(\psi_{i1}, \ldots, \psi_p) = \psi \; and \; \mathrm{E}(\varepsilon) = 0$$

In matrix terms, we have

$$x - \mu = LF + \varepsilon.$$

If we have *n* observations, then we will have the dimensions $x_{p\times n}$, $L_{p\times n}$ and $F_{k\times n}$. Each column of x and F denote values for one particular observation, and matrix L does not vary across observations.

Also we will impose the following assumptions on F.

(i) F and ε are independent.

(ii) $\mathrm{E}(F) = 0$

(iii) $\mathrm{Cov}(F) = I$

Any solution of the above set of equations following the constraints for F is defined as the *factors*, and L as the *loading matrix*.

Suppose $\mathrm{Cov}(x - u) = \Sigma$. Then note that from the conditions just imposed on F, we have

$$\mathrm{Cov}(x - \mu) = \mathrm{Cov}(LF + \varepsilon),$$

or

$$\sum = L\mathrm{Cov}(F)L^T + Cov(\varepsilon),$$

or

$$\sum = LL^T + \psi.$$

For any orthogonal matrix Q if we set $L = LQ$ and, $F = Q^T$ the criteria for being factors and factor loadings still hold. Hence a set of factors and factor loadings is identical only up to orthogonal transformations.

3.4.4 Factor-rating method

Factor-rating system is an approach for selecting a facility location by combining a diverse set of factors. Point scales are developed for each criterion. Each potential site is then evaluated on each criterion and the points are combined to calculate a rating for the site.

An advantage of this method is that all necessary factors needed for the location of a facility are considered and objectively included. A major problem with simple point-rating schemes, variation of factor rating is it does not account for the wide range of costs that may occur within each factor. To deal with this problem, it has been suggested that points possible for each factor be derived using a weighting scale based on standard deviations of costs rather than simply total cost amounts. In this way, relative costs can be considered

In implementing Factor rating methodology, the following steps are followed strictly and consistently. That is:

(i) Develop a list of relevant factors.

(ii) Assign a weight to each factor to reflect its relative importance in the company's objectives.

(iii) Develop a scale for each factor

(iv) Have management or related people score each relevant factor, using the scale

developed in iii above.

(v) Multiply the score by the weight assigned to each factor and total the score for each location.

(vi) Make a recommendation based on the maximum point score, considering the result of qualitative approaches as well.

(vii) When a decision is sensitive to minor changes, further analysis of either the weighting or the point assigned are considered.

The researcher settled on Factor Rating method since unlike the other methods discussed, because the Factor Rating is superior since it considers all the necessary factors needed for the location of a facility such as a Mobile Telecommunication Mast.

3.5 MATHEMATICAL TOOL USED

Computational tools such as programmable calculator and Microsoft Excel 2007 was employed in analysis and rating of scores for the various locations considered. Microsoft Excel is a powerful spreadsheet program which can perform complex mathematical computations such as what-if analysis, and generation of graphical data. It was installed on Windows platform Compaq Desktop Computer, with a 1.60GHz Intel processor which has an installed memory of 1GB.

3.6 AREA UNDER STUDY (CAPE COAST METROPOLITAN)

Communities in the Cape Coast Metropolitan area where telecommunication masts are found have been extensively covered in section 2.3

CHAPTER 4

DATA COLLECTION, ANALYSIS AND DISCUSSION

4.0 INTRODUCTION

This chapter is devoted to the presentation and analysis of data gathered. The presentation is done under the following sub-headings; Data Collection, Summary of Data, Formulation of Model Instances And Algorithm, Computational Procedures, Result and discussions.

4.1 TOPOLOGY OF CAPE COAST METROPOLITAN AREA

The Cape Coast Metropolis is bounded on the south by the Gulf of Guinea, west by the Komenda / Edina / Eguafo /Abrem Municipal, east by the Abura/Asebu/Kwamankese District and to the north by the Twifu/Hemang/Lower Denkyira District. The Metropolis covers an area of 122 square kilometers and is the smallest metropolis in the country. It is also the capital of the Central Region. Cape Coast has a population of 82,291 (2000 census). It is well known for its rich cultural history and tourist attractions Cape coast is a world Heritage site due to its rich cultural history, hence attracts a lot of tourists(CCMA, 2011).

Arial Topology of Cape Coast is shown below.

Arial Topology of Cape Coast

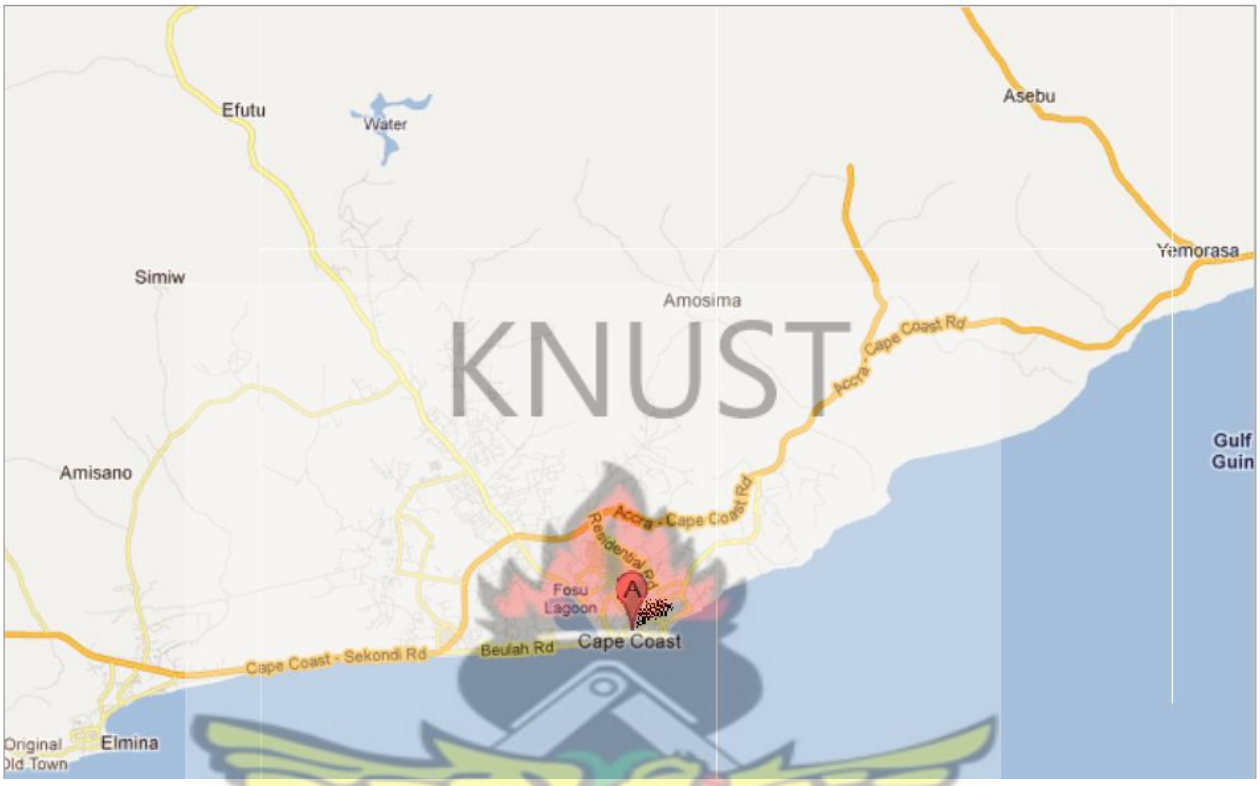


Figure 4.1 Arial Topology of Cape Coast (Source: Google Earth, 2011)

Because of its historic and tourist attractions, the central Government has established numerous infrastructure to enable it function as such. It has benefited from modern infrastructural developments such as good urban road networks, public schools, hospitals and a lot more (CCMA, 2011). Most of the prestigious schools and educational institutions in Ghana can be found in Cape Coast. Due to the influx of people into the place, it has also attracted some investments in the Telecommunication sector. The six major mobile communication operators in Ghana namely MTN, Airtel, Vodafone, Expresso, Tigo and Glomobile have their presence there. The private sector mobile telecommunication companies have contributed immensely to the growth of infrastructure in the town in order to enhance their business operations. In order to

improve and enhance their operations, mobile telecommunication operators have erected telecommunication mast or towers in communities in the metropolis.

Administrative Map of Cape Coast Metropolis

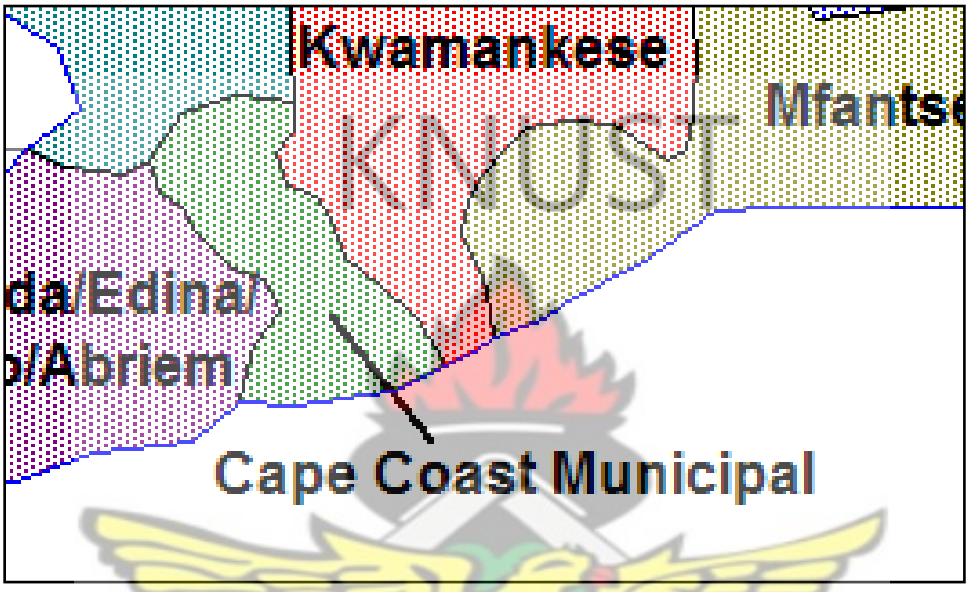


Figure 4.2 Administrative Map of Cape coast Metropolitan showing neighbouring districts (Source: CCMA, 2011)

4.2 DESCRIPTION OF MOBILE TELECOMMUNICATION COMPANIES WHICH HAVE EXTABLISHED IN CAPE COAST METROPOLIS AND SERVICES THEY OFFER.

There are six mobile telecom network companies in Ghana, each operating its own Mobile Telecommunication Network and associated brand name. All of them have their subsidiary branches. These networks are Airtel of Airtel International, Vodaphone of Vodaphone Ghana Limited, TIGO of Millicom Ghana Limited, MTN of Scancom Ghana Limited, Expresso of Expresso Telecom and Glo of Globacom. Telecommunication infrastructure has enabled these

companies to render mobile telecommunication services in the Cape Coast Metropolitan area. The sixth company, Glo, is yet to start operation as of the time of this study.

4.2.1 Airtel Ghana

Airtel, formerly Zain, was re-launched in Ghana in November 2010 as one of the 16 operating countries of Airtel International. Some of the services provided by Airtel include:

(i) Airtel basic service such as credit sharing, caller line identification, call waiting, call holding, voice mail, SMS, per second billing, ring tones, call divert/forwarding, call barring, balance enquiry. Airtel's other services include:

(ii) Airtel money, Me2u, Web2SMS, international Dialing

(iii) Airtel Friendzy

(http://www.africa.airtel.com/wps/wcm/connect/africaairtel/Ghana/Home/About_us)

Airtel Ghana has established their presence in the Cape coast Metropolitan with a well established customer care center and telecommunication masts.

4.2.2 Vodafone Ghana (Vodafone)

Vodafone, formerly Ghana Telecom (GT), is one of the providers of telecommunication services in Ghana. Vodafone provides fixed-line, GSM mobile phone and payphone services. As part of the ADP (1994-2000) reform program, Ghana Telecom (Vodafone) was incorporated on June 16, 1995 as a successor the telecommunications division of Ghana Posts and Telecommunications Corporation (GPTC). This was to enable the telecommunications division to function as a commercially viable entity. The GPTC was established as a public corporation in 1974, and until October 1995, had been responsible for operating the nation's telecommunications and licensing

of telecom services. In 1997, Ghana Telecom was officially privatized to Telecom Malaysia Berhard with full management control. Subsequently the government handed operations of the company to Telenor Management Partner (TMP) till 2007. In 2008, the Government of Ghana sold out of 70% share to Vodafone for the purpose of making the company more profitable. Ghana Telecom's operating license allows it to render the following communications services: Voice telephony, Cellular communication, Telex, Telegraph, Satellite communications, Value added services, Paging, the sale, lease and maintenance of subscriber premise wiring, and Internet connectivity.

Some of the services provided by Vodafone Ghana include:

(i) Vodafone Prepaid include: Call Divert, Call Holding & Waiting, Call Me Back, Caller Line Identity Presentation (CLIP), Community Chat, Conference Call, Family & Friends, Infoshop, International Direct Dial (IDD), i-share Credit Transfer, Onechat, Vodafone GPRS, Prepaid Roaming

(ii) Postpaid: Vodafone Postpaid is the right deal for business executives who make lots of calls and yet do not have the time to always recharge their account.

(iii) Others include: Vodafone call waiting, call transfer, password, itemized billing, last number redial, and phonebook for customers personal data and easy SIM replacement. (www.moc.gov.gh)

Vodafone Ghana has established their presence in the Cape coast Metropolitan with a well established customer care center and telecommunication masts.

4.2.3 Millicom Ghana Ltd (TIGO)

Millicom Ghana Limited, operators of Tigo cellular, is a subsidiary of Millicom International Cellular S.A. ("MIC") UK/Luxembourg, a leading global operator of cellular telephony services with several investments across the world. The company started its operations in 1991 and was the first cellular network operator. Millicom Ghana uses the ETAC System, and it had over 22 000 subscribers in 1998 with a market share of above 70 per cent of the mobile market. The company expanded and in 2002 Millicom Ghana introduced its GSM service under the brand name MOBITEL/Buzz GSM. Buzz GSM with its trendy lifestyle image offered very exciting services to its numerous clientele. Mobitel has, over the years, been able to maintain a fast rate of subscriber and revenue growth and a very high quality of service, acclaimed by most users as being second to none. In 2006, Tigo was launched in Ghana to replace the old national brand *MOBITEL* with a new international brand. Currently Tigo network coverage reaches all the ten regions in Ghana and it is fast expanding to rural areas. Cape Coast is no exception

Some of the services provided by Tigo include:

(i) TiGo basic service such as credit sharing, caller line identification, call waiting, call holding, voice mail, SMS, per second billing, ring tones, call divert/forwarding, call barring, balance enquiry, free itemized billing and conference call.

(ii) TiGo colouring: customised ring tones; My tiGo: ring tones, real tones, wall paper, videos, games, etc.

(iii) My messages: Your web portal for all things SMS! Web SMS, SMS plus, messagealerts, LiveScore.

(iv) My Discussions: Topic Portal is your SMS to web tool for engaging in live feedback discussions, SMS-based survey, SMS or text polls.

(v) Extreme value for unlimited text messaging and talking from 6am to 6pm for GHC 1 or 24 hours for GHC 2..

(vi) Tigo SOS- Tigo SOS provides airtime to prepaid subscribers when they need it most, the objective is to introduce another loyalty tool and also reinforce Tigo's position as an affordable network. Tigo SOS allows Tigo to lend prepaid subs 15Gp airtime when they have less than or equal to 10Gp balance and have been active for more than three months

(vii) Tigo Extreme Value- 3Gp for all Tigo-to-Tigo Calls

(viii) Tigo Cash-Tigo Cash is a new mobile financial services product that allows you to use your mobile phone as a mobile account. Tigo Cash provides you an affordable, fast, convenient and safe way to send and receive money, buy airtime credit, pay for goods and services using a mobile phone anywhere in Ghana. Customers can deposit and withdraw money from their mobile phone with any of our authorized Tigo Cash Agents. Customers are not required to hold a bank account to use the service.

(ix) BE ALIVE is a permanent service on Tigo, which enables you to gain information, advice, daily inspiration and lot's more all in your text message inbox!

Tigo Ghana has established their presence in the Cape Coast Metropolitan area with a well established customer care centre and telecommunication masts.

4.2.4 Scancom Ghana Ltd (MTN)

Scancom Ghana Ltd started operating in October 1996 using GSM 900 technology as spacefone, with 15 sites and equipment from Ericsson. The network provides new services and coverage in

Cape Coast and all the regional capitals in Ghana, with ongoing developments in other towns and cities. The company operated as Areeba and in 2006 it was taken over by Mobile Telecommunication Network Group (MTN) and now its name is MTN Ghana; it has expanded greatly its network coverage. MTN has a wide variety of network services. These services include;

(i) MTN Zone: Y'ello and welcome to MTN Zone, a service that allows users to enjoy discounts up to 100% on MTN-to-MTN calls, all day and all night. With MTN Zone you are automatically moved to a different price plan upon subscription.

(ii) MTN Wireless Office: allows users to browse and use the Internet on your laptop or PC at reduced rates using a GPRS modem and a special Data SIM Card, giving users the freedom to work and have fun everywhere you GO.

(iii) MTN GoLive: uses GPRS (General Packet Radio Service) technology and provides users with a data connection on your mobile phone, and linking it to your laptop. Send and receive e-mail get latest news and information, surf the web, MMS, etc.

(iv) Convenient chip replacement: with SIM SWAP kit wherever users are without visiting an MTN Customer Care Centre.

(v) BlackBerry® solutions from MTN supports push e-mail, mobile, telephone, text messaging, internet faxing, web browsing and other wireless information services. It delivers information over the wireless data networks of mobile phone service companies like MTN. It includes the PIM applications (address book, calendar, to-do list, etc.) as well as telephone capabilities for people on the move.

(vi) Call management services: basic call services like Call Line Identification Presentation, Call Line Identification Restriction, call barring, call waiting and call divert; Call answering services like voicemail, and smart clip.

(vii) Messaging services: MMS, SMS, call back, TX-2-Email, and other services like self-service, you choose (segmented tariff), SG-SSB Sikatext, Phone Banking, DUAL IMSI allowing the use of two MTN numbers on one phone.

(viii) International roaming services and entertainment services to the general public as well as specialized services for different customers such as MTN extraconnect, MTN xtracool, MTN xtraspecial, MTN VIP. (www.mtn.com.gh)

MTN has established their presence in the Cape Coast Metropolitan area with a well established customer care center and telecommunication masts.

4.2.5 Expresso Telecom Limited (Expresso)

Expresso Ghana, formerly, Kasapa, has been in existence since 1995, operating under the name of Celltel; it was the second mobile operator in the country at the time. In 1998, Hutchison Telecom then acquired 80% of the company, improving the analogue infrastructure that was in place at that time. In 2003, the company was re-branded to Kasapa Telecom, the only locally branded telecoms operator in the country, with 9,000 subscribers. Kasapa experienced significant growth and in September 2005, the company made a switch from an analogue network to a CDMA network to further strengthen its market position. In July 2008, Expresso Telecom acquired 100% of the company. Following on from the network expansion and upgrade, in 2010 the company successfully re-branded into Expresso, now providing unrivalled high-quality voice and data services to customers across various market segments.

The company offers mobile, home, and business voice and data service on its 800 MHz CDMA20001X network, expanding throughout Ghana (http: //www.expressotelcom.com/en)

4.2.6 Glo Telecom

Glo Telecom is the sixth telecommunication company to be granted a mobile license to operate in the country, with Glo expected to launch in the first quarter of 2011.

Glo is currently deploying fibre backbone which would ensure voice and data clarity and eliminates bottlenecks usually encountered with pre-expansion technology. The new network elements with multi-media components will be linked to the Glo 1 submarine optic fibre cable thereby providing an opportunity for Ghanaians to establish private call centre operations with attendant economic benefits to the people. (Source: http://www.ibrokerghana.com/news-and-marketinformation/sectors-a-industries/finance/77-glo-ready-for-ghana-operations) Glo telecom has already established their presence in Cape Coast by setting up offices and even though they have not began operations as at the time of this study.

4.3 DATA COLLECTION

The research covered masts belonging to five mobile communication companies which have sited masts in the Cape Coast Metropolis. The companies are Vodafone, Airtel, Tigo, MTN, and Espresso. All site location of masts relevant for this project was visited and assessed. Factors which influenced location of masts were observed.

Coalition of all locations was also got from various Government Agencies. This included Municipal Assembly and Environmental Protection Agency and Mobile Communication

Companies in the Cape Coast Metropolis. Added to that was verification of locations by the Mobile communication companies under the research. Information about the exact location of their mast and factor which were considered relevant for the site were quizzed by the researcher.

4.3.1 SUMMARY OF DATA

The Government of Ghana's Industry Technical Committee (ITC) report entitled "Guidelines for Deployment of Communication Towers" which was drafted by experts from National Communication Authority (NCA) 2010 was under study by the researcher.

Included in the document among others are conditions that towers/mast owners must conform to when erecting masts. The table below spells out the conditions which are legally permissible for siting a mast at a particular area.

Table 4.1: NCA technical guidelines for location of Telecommunication Mast or Towers

Zoning	**Permissible Height**	**Average Plot Size & Protection Area**	**Minimum Set Back Required (in accordance with B**	**Neighbourhood Requirement.**
Residential	<35 meter	Not Less than 20 m x 20 m	Not less(<20m) from base of tower to boundary fence or nearest structure	500 m Radius for group consultation and all immediate neighbours covered.
Commercial	<800meter 120m	Not less than 12.5m x12.5m	Ditto(Roof mast and co-location must be first option)	200m
Industrial	120 meter	Not less than 12.5m x12.5m for shorter mast and 16.5m x 16.5m taller mast	6m from base of tower to boundary fence	100m
Civic & Cultural	<120	20m x 20m	10m from base	100m

			of tower boundary fence	
Mixed Use	<80	20m x 20m	10m from base of tower boundary fence	150m
Educational	Not allowed **on school compounds**(sites*)		At least 150m from the nearest classroom or dormitory structure.	Cosent from school authorities
Health facilities	Not allowed in clinic and poly clinic facilities (sites*)		Well set back from the ward and sensitive equipment facilities	
Aviation Facilities	Not allowed*		Determined by GCAA	

Pre-coded, open-ended questions and interviews to solicit the data from the respondents/target group were performed. Part of the questionnaire management/staff of Mobile Telecommunication Companies was for them to rate locations of their masts based on factors outlined. They were to rate each location on a 1 to 10 point basis factor to reflect its relative importance in relation to the companies objectives.

Owing to adoption of factor rating method, below is a data and factors considered as well as weight ratings.

Table 4.2: Factors considered and their rated weights

Factor	Factor Name	Rating Weight
1	Community Consultation and Desirability	0.3
2	Utility(Electricity and Water Source) availability and cost	0.2
3	Co-location Feasibility	0.2
4	Population density and economic activity	0.3
5	Geological Nature of the Site	0.3
6	Directions for various directional antennas	0.3
7	Future maintenance and expansion	0.2
8	Available ground area and access to the site	0.2

Source: Field Data, November 2011

4.4 FORMULATION OF MODEL INSTANCES, ALGORITHMS AND DATA ANALYSIS

The problem of facility location for Mobile Telecommunication Masts calls for use of various models and methods in order to obtain a solution. A number of models were considered by the researcher which includes Factor rating, Location Break-Even Analysis, and Centeroid Method.

In finding the optimum location of Mobile telecommunication masts for Cape Coast Metropolitan, Factor Rating method was chosen by the researcher.

The problem was modeled as a Facility Location problem.

The method and the algorithm adopted for solving this problem is Factor Rating;

The following steps were followed strictly:

(i) Develop a list of relevant factors.: The factors ranged from market, resources and infrastructure availability. They are Community Consultation and Desirability, Utility(Electricity and Water Source) availability and cost, Co-location Feasibility, Population density and economic activity, Geological Nature of the Site, Directions for various directional antennas, Future maintenance and expansion and finally, Available ground area and access to the site.

(ii) Assign a weight to each factor to reflect its relative importance in the company's objectives: Weight assigned for all factors totaled 2.0 points and are spread across according to the objective for siting masts.

(iii) Develop a scale for each factor: The scale of factors is within the range of 1 to 10 points.

(iv) Have management or related people score each relevant factor, using the scale developed in iii above: This was done in a form of a questionnaire addressed to the manager of the institution involved. In this case it was to the Mobile Communication Companies

(v) Multiply the score by the weight assigned to each factor and total the score for each location: and finally

(vi) Make a recommendation based on the maximum point score, considering the result of qualitative approaches as well.

Mast locations of five mobile telecommunication operators in Cape Coast Metropolis as of ther

time of this study were noted. That is Airtel, Vodafone, Tigo, MTN, and Expresso. Tables below illustrates how data was analyzed using Factor Rating.

4.4.1 MAST LOCATIONS - AIRTEL GHANA, CAPE COAST METROPOLIS

Mobile Phone Masts belonging to Airtel Ghana in the Cape Coast Metropolis have been sited in six (6) locations.

Table 4.3: Mast Locations in the Cape Coast Metropolis, Airtel Ghana

TELECOM MASTS BELONGING TO AIRTEL GHANA IN CAPE COAST				
NO	**COMPANY**	**COMMUNITY**	**LOCATION**	**ALIAS**
1	AIRTEL	KOKOADO	OPPOSITE THE SEA ADJACENT CAPE VARS	A
2	AIRTEL	SEIWIN – NANABA	SEIWIN NEAR CPOLY	B
3	AIRTEL	KWAPROW	NR ACHIMEDES SCH	C
4	AIRTEL	PEDU ESTATE	OPP. PRESBY CHURCH, ALONG REG. HOSPITAL RD.	D
5	AIRTEL	ASHANTI ROAD	SOC. WELFARE REG. OFFICE	E
6	AIRTEL	OLA	BESIDE WOODEX INT. HOSTEL /CNC	F
7	AIRTEL	AMAMOMA	NEAR METHODIST CHURCH BUILDING	G

Source: Field Data, November 2011

Management/Staff of Airtel Ghana Ltd, Cape Coast branch was then given a questionnaire to rate each location on a 1 to 10 point basis.

Table 4.4: Location rating by Management of on a 1-10 point basis, Airtel Ghana

Factor	Factor Name	Rating Weight	Location A	Location B	Location C	Location D	Location E	Location F	Location G
1	Comm. Cons/Desir.	0.3	9	9	10	8	10	7	10
2	Uitility and Cost	0.2	8	5	8	9	9	8	8
3	Co-location Feasibility	0.2	5	6	7	6	5	3	5
4	Pop. Density/Activity	0.3	9	8	9	7	10	7	10
5	Geological Nature	0.3	7	8	8	7	7	10	8
6	Directions for Antenna	0.3	8	8	7	8	10	10	9
7	Future maint &Expan	0.2	7	7	10	6	8	9	7
8	Ground Area Avail.	0.2	8	7	8	10	9	6	8

Source: Field Data, November 2011

Table 4.5: Score rating and Computation of aggregate

				LOCATIONS						
Factor	**Factor Name**	**Rating Weight**	**Ratio of Weight**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
1	Comm. Cons/Desir.	0.3	0.15	1.35	1.35	1.5	1.2	1.5	1.05	1.5
2	Uitility and Cost	0.2	0.1	0.8	0.5	0.8	0.9	0.9	0.8	0.8
3	Co-location Feasibility	0.2	0.1	0.5	0.6	0.7	0.6	0.5	0.3	0.5
4	Pop. Density/Activity	0.3	0.15	1.35	1.2	1.35	1.05	1.5	1.05	1.5
5	Geological Nature	0.3	0.15	1.05	1.2	1.2	1.05	1.05	1.5	1.2
6	Directions for Antennas	0.3	0.15	1.2	1.2	1.05	1.2	1.5	1.5	1.35
7	Future maint &Expan	0.2	0.1	0.7	0.7	1	0.6	0.8	0.9	0.7
8	Ground Area Avail.	0.2	0.1	0.8	0.7	0.8	1	0.9	0.6	0.8
			Total Score	**7.75**	**7.45**	**8.4**	**7.6**	**8.65**	**7.7**	**8.35**

Source: Field Data, November 2011

Clearly from their respective aggregate scores, location E or site E has the highest aggregate. Hence that location may be recommended for sitting of additional telecommunication equipments and probable co-location consideration.

4.4.2 MAST LOCATIONS - VODAFONE GHANA, CAPE COAST METROPOLIS

Mobile Phone Masts belonging to Vodafone in the Cape Coast Metropolis were sited in six(6) locations.

Table 4.6: Mast Locations in the Cape Coast Metropolis, Vodafone.

TELECOM MASTS BELONGING TO VODAFONE IN THE CAPE COAST MUNICIPALITY				
No	**COMPANY**	**COMMUNITY**	**LOCATION**	**ALIAS**
1	VODAFONE	AYEKO AYEKOO	OPPOSITE DANCE P	A
2	VODAFONE	AYEKO AYEKOO	OPPOSITE DANCE P	B
3	VODAFONE	NANABAKROM	NR MOSQUE	C
4	VODAFONE	NANABAKROM	OPPOSITE MUSTARD SEED COMPANY CO. LTD	D
5	VODAFONE	AMAMOMA	NR STERNER STUDENTS HOSTEL	E
6	VODAFONE	EFUTU	OPPOSITE EFFUTU SEC. TEC. SCH	F

Source: Field Data, November 2011

Management of VODAFONE Ghana Ltd, Cape Coast branch was then given a questionnaire to rate each location on a 1 to 10 point basis.

Table 4.7: Location Rating by Management on a 1-10 point basis, VODAFONE Ghana

Factor	Factor Name	Rating Weight	Location A	Location B	Location C	Location D	Location E	Location F
1	Comm. Cons/Desir.	0.3	8	8	9	9	8	5
2	Utility and Cost	0.2	10	10	6	7	10	7
3	Co-location Feasibility	0.2	7	7	8	8	6	7
4	Pop. Density/Activity	0.3	10	10	9	7	10	8
5	Geological Nature	0.3	10	10	9	9	8	10
6	Directions for Antenna	0.3	9	9	10		9	9
7	Future maint &Expan	0.2	8	8	10	9	7	8
8	Ground Area Avail.	0.2	5	5	7	7	8	6

Source: Field Data, November 2011

Table 4.8: Score rating and computation of aggregate

				LOCATIONS-VODAFONE MASTS					
Factor	**Factor Name**	**Rating Weight**	**Ratio of Weight**	**A**	**B**	**C**	**D**	**E**	**F**
1	Comm. Cons/Desir.	0.3	0.15	1.2	1.2	1.35	1.35	1.2	0.75
2	Utility and Cost	0.2	0.1	1	1	0.6	0.7	1	0.7
3	Co-location Feasibility	0.2	0.1	0.7	0.7	0.8	0.8	0.6	0.7
4	Pop. Density/Activity	0.3	0.15	1.5	1.5	1.35	1.05	1.5	1.2
5	Geological Nature	0.3	0.15	1.5	1.5	1.35	1.35	1.2	1.5
6	Directions for Antenna	0.3	0.15	1.35	1.35	1.5	0	1.35	1.35
7	Future maint &Expan	0.2	0.1	0.8	0.8	1	0.9	0.7	0.8
8	Ground Area Avail.	0.2	0.1	0.5	0.5	0.7	0.7	0.8	0.6
			Total Score	**8.55**	**8.55**	**8.65**	**6.85**	**8.35**	**7.6**

Source: Field Data, November 2011

Clearly from their respective aggregate scores, location C or site C would be recommended since it has the highest aggregate. Hence that location may be recommended for sitting of additional telecommunication equipments and probable co-location consideration.

4.4.3 MAST LOCATION- TIGO GHANA LTD, CAPE COAST

Mobile Phone Masts belonging to Tigo, Cape Coast Metropolis are in eleven (11) locations. However the 11th Mast location at Bakaano is yet to be completed as of the time of this study.

Table 4.9: Mast Locations in the Cape Coast Metropolis, Tigo.

No	COMPANY	COMMUNITY	LOCATION	ALIAS
1	TIGO	ASHANTI ROAD	COMM DEVT REG OFFICE,	A
2	TIGO	AKYIM	HOLY CHILD BUNGALOW	B
3	TIGO	EWIM	BEHIND GBC OFFICES	C
4	TIGO	4TH RIDGE	LAGOON VIEW HOSTEL	D
5	TIGO	ANTEM	KINGDOM HALL OF JAH. WITHNESSES	E
6	TIGO	AMISSANO	BESSAKROM	F
7	TIGO	UCC	BEHIND CASFORD HALL	G
8	TIGO	OLA	OLA TRAINING COLLEGE	H
9	TIGO	ESUEKYIR	BEHIND WINNERS CHAPEL	I
10	TIGO	AMAMOMA	NR FLORENCE HOSTEL	J
11*	TIGO	BAKAANO	NR PHILIP QUARQOE	K

(Source: Field Data, November 2011)

Management of TIGO Ghana Ltd, Cape Coast branch was then given a questionnaire to rate each location on a one (1) to ten (10) point basis.

Table 4.10: Location Rating by Management on a 1-10 point basis, Tigo Ghana

			TIGO LOCATIONS										
Factor	Factor Name	Rating Weight	A	B	C	D	E	F	G	H	I	J	K
1	Community Consultalion and Desirability	0.3	9	7	8	6	10	5	8	6	9	10	6
2	Uitility availability and cost	0.2	8	9	6	8	7	7	6	7	7	6	7
3	Co-location Feasibility	0.2	10	10	7	8	5	7	5	5	10	8	8
4	Population density and economic activity	0.3	9	8	4	9	8	8	6	4	10	10	4
5	Geological Nature of the Site	0.3	10	5	8	6	8	10	7	5	5	6	9
6	Directions for various directional antennas	0.3	9	9	6	9	7	8	7	6	6	7	8
7	Future maintenace and expansion	0.2	8	8	8	9	6	8	8	5	9	5	5
8	Available ground area and access to the site	0.2	5	9	10	8	10	6	9	10	6	7	6

Table 4.9: Rated Weights (Source: Field Data; November 2011)

Table 4.11: Score rating and Computation of aggregate

Factor	Factor Name	Rating Weight	Ratio of Weight	A	B	C	D	E	F	G	H	I	J	K
1	Comm. Consult. and Desirability	0.3	0.15	1.35	1.05	1.2	0.9	1.5	0.75	1.2	0.9	1.35	1.5	0.9
2	Uitili. and cost	0.2	0.1	0.8	0.9	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	0.7
3	Co-location Feasi.	0.2	0.1	1	1	0.7	0.8	0.5	0.7	0.5	0.5	1	0.8	0.8
4	Pop.density and economic activity	0.3	0.15	1.35	1.2	0.6	1.35	1.2	1.2	0.9	0.6	1.5	1.5	0.6
5	Geological Nature of the Site	0.3	0.15	1.5	0.75	1.2	0.9	1.2	1.5	1.05	0.75	0.75	0.9	1.35
6	Directions for various directional antennas	0.3	0.15	1.35	1.35	0.9	1.35	1.05	1.2	1.05	0.9	0.9	1.05	1.2
7	Future maintenace and expansion	0.2	0.1	0.8	0.8	0.8	0.9	0.6	0.8	0.8	0.5	0.9	0.5	0.5
8	Available ground area and access to the site	0.2	0.1	0.5	0.9	1	0.8	1	0.6	0.9	1	0.6	0.7	0.6
			Total Score	**8.65**	**7.95**	**7**	**7.8**	**7.75**	**7.45**	**7**	**5.85**	**7.7**	**7.55**	**6.65**

Clearly from their respective aggregate scores, location A or site A would be recommended since it has the highest aggregate. Hence that location may be recommended for sitting of additional telecommunication equipments and probable co-location consideration

4.4.4 MAST LOCATION- MTN GHANA LTD, CAPE COAST

Mobile Phone Masts belonging to MTN, Cape Coast Metropolis are in fourteen (14) locations.

Table 4.12: Mast Locations in Cape Coast, MTN Ghana

No	COMPANY	COMMUNITY	LOCATION	
1	MTN	BAKAANO	PHILIP QUAICOE BASIC SCH	A
2	MTN	ASHANTI ROAD	COMM. DEVT REG. OFFICE	B
3	MTN	EWIM	BEHIND GBC OFFICES	C
4	MTN	4TH RIDGE	LAGOON VIEW HOSTEL	D
5	MTN	ADISADEL ESTATE	SHC OFFICE COMPOUND	E
6	MTN	PEDU NGUABADO	NEAR CAPE TECH	F
7	MTN	ABURA	NEAR OLD CEMETARY	G
8	MTN	EYIFUA	NEAR GNAT HALL	H
9	MTN	KAKOMDO	BEHIND EMPART GAS	I
10	MTN	UCC	BEHIND CASFORD HALL	J
11	MTN	AMAMOMA	OPP. AYENSU PLAZA HOSTEL	K
12	MTN	AMAMOMA	ROUND PALACE HOSTEL	L
13	MTN	AMAMOMA	AFEDZI HOUSE COMPOUND	M
14	MTN	EFUTU	OPP. FUEL STATION	N

Source: Field data, November 2011

Management and related people of MTN Ghana Ltd, Cape Coast branch was then given a questionnaire to rate each location on a 1 to 10 point basis.

Table 4.13: Location Rating by Management on a 1-10 point basis, MTN Ghana.

			MTN LOCATION													
Factor	**Factor Name**	**Rating Weight**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
1	Comm. Consult.& Desirability	0.3	4	10	9	5	10	10	7	9	8	10	6	10	7	9
2	Uitility and cost	0.2	8	8	10	8	7	7	9	8	7	6	7	5	10	8
3	Co-location Feasibility	0.2	10	6	7	6	5	8	8	5	10	8	8	5	8	9
4	Population densit and eco. activity	0.3	9	6	5	8	8	8	8	4	10	6	4	10	9	9
5	Geological Nature of the Site	0.3	5	8	8	9	8	10	5	5	5	6	9	10	10	9
6	Directions for various directional antennas	0.3	5	7	7	10	7	7	6	6	6	8	7	10	6	5
7	Future maintenace and expansion	0.2	10	8	9	5	6	7	8	5	9	9	10	5	9	9
8	Available ground area and access to the site	0.2	5	9	6	10	10	6	5	8	10	8	6	5	9	7

Table 4.14: Score rating and Computation of aggregate

				LOCATIONS- MTN MAST												
Factor	**Factor Name**	**Rating Weight**	**Ratio of Weight**	**A**	**B**	**C**	**D**	**E**	**F**	G	H	I	J	K	L	M	N
1	Community Consult.& and Desirability	0.3	0.15	0.6	1.5	1.35	0.75	1.5	1.5	1.05	1.35	1.2	1.5	0.9	1.5	1.05	1.35
2	Uitility and cost	0.2	0.1	0.8	0.8	1	0.8	0.7	0.7	0.9	0.8	0.7	0.6	0.7	0.5	1	0.8
3	Co-location Feasibility	0.2	0.1	1	0.6	0.7	0.6	0.5	0.8	0.8	0.5	1	0.8	0.8	0.5	0.8	0.9
4	Population density and economic activity	0.3	0.15	1.35	0.9	0.75	1.2	1.2	1.2	1.2	0.6	1.5	0.9	0.6	1.5	1.35	1.35
5	Geological Nature of the Site	0.3	0.15	0.75	1.2	1.2	1.35	1.2	1.5	0.75	0.75	0.75	0.9	1.35	1.5	1.5	1.35
6	Direct.for various directional antennas	0.3	0.15	0.75	1.05	1.05	1.5	1.05	1.05	0.9	0.9	0.9	1.2	1.05	1.5	0.9	0.75
7	Future maint. and expansion	0.2	0.1	1	0.8	0.9	0.5	0.6	0.7	0.8	0.5	0.9	0.9	1	0.5	0.9	0.9
8	Available ground area and access to the site	0.2	0.1	0.5	0.9	0.6	1	1	0.6	0.5	0.8	1	0.8	0.6	0.5	0.9	0.7
	Total Score			**6.75**	**7.75**	**7.55**	**7.7**	**7.75**	**8.05**	**6.9**	**6.2**	**7.95**	**7.6**	**7**	**8**	**8.4**	**8.1**

Clearly from their respective aggregate scores, location M or site M would be recommended since it has the highest aggregate. Hence that location may be recommended for sitting of additional telecommunication equipments and probable co-location consideration

4.4.5 MAST LOCATIONS - EXPRESSO GHANA, CAPE COAST METROPOLITAN

Mobile Phone Masts belonging to Expresso in the Cape Coast Metropolis has been sited in one(1) location.

Table 4.15: Location of Masts belonging to Expresso In the Cape Coast Municipality.

No	COMPANY	COMMUNITY	LOCATION
1	EXPRESSO	IST RIDGE	BEHIND REGIONAL COORD RESIDENCE

Management of Expresso, Cape Coast branch was then given a questionnaire to rate each location on a 1 to 10 point basis.

Table 4.16: Rated Weights and 1 to 10 point table of Factors

Factor	Factor Name	Rating Weight	Location A
1	Community Consultalion and Desirability	0.3	8
2	Uitility availability and cost	0.2	8
3	Co-location Feasibility	0.2	10
4	Population density and economic activity	0.3	9
5	Geological Nature of the Site	0.3	8
6	Directions for various directional antennas	0.3	6
7	Future maintenance and expansion	0.2	8
8	Available ground area and access to the site	0.2	9

Source: Field data, November 2011.

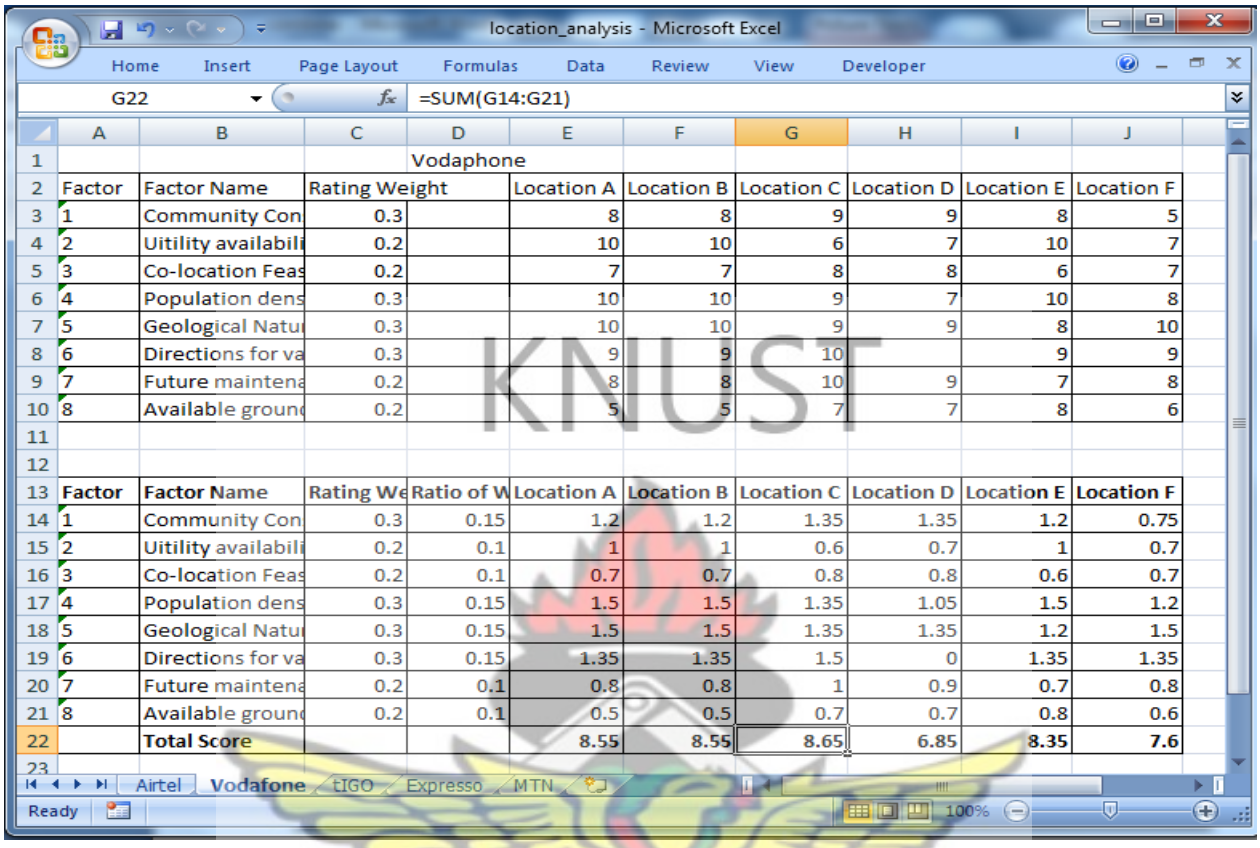
Table 4.17: Score rating and Computation of aggregate

Rating Scores

Factor	Factor Name	Rating Weight	Ratio of Weight	Location A
1	Community Consultation and Desirability	0.3	0.15	1.2
2	Utility availability and cost	0.2	0.1	0.8
3	Co-location Feasibility	0.2	0.1	1
4	Population density and economic activity	0.3	0.15	1.35
5	Geological Nature of the Site	0.3	0.15	1.2
6	Directions for various directional antennas	0.3	0.15	0.9
7	Future maintenance and expansion	0.2	0.1	0.8
8	Available ground area and access to the site	0.2	0.1	0.9
			Total Score	**8.15**

From the aggregate scores, location A or site A, which is the only site would be recommended since it has the highest aggregate. Hence that location may be recommended for sitting of additional telecommunication equipments and probable co-location consideration

Sample Screen Shot Of Software Output



location_analysis - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Developer

G22 =SUM(G14:G21)

	A	B	C	D	E	F	G	H	I	J
1				Vodaphone						
2	Factor	Factor Name	Rating Weight		Location A	Location B	Location C	Location D	Location E	Location F
3	1	Community Con	0.3		8	8	9	9	8	5
4	2	Uitility availabili	0.2		10	10	6	7	10	7
5	3	Co-location Feas	0.2		7	7	8	8	6	7
6	4	Population dens	0.3		10	10	9	7	10	8
7	5	Geological Natu	0.3		10	10	9	9	8	10
8	6	Directions for va	0.3		9	9	10		9	9
9	7	Future maintena	0.2		8	8	10	9	7	8
10	8	Available groun	0.2		5	5	7	7	8	6
11										
12										
13	Factor	Factor Name	Rating We	Ratio of W	Location A	Location B	Location C	Location D	Location E	Location F
14	1	Community Con	0.3	0.15	1.2	1.2	1.35	1.35	1.2	0.75
15	2	Uitility availabili	0.2	0.1	1	1	0.6	0.7	1	0.7
16	3	Co-location Feas	0.2	0.1	0.7	0.7	0.8	0.8	0.6	0.7
17	4	Population dens	0.3	0.15	1.5	1.5	1.35	1.05	1.5	1.2
18	5	Geological Natu	0.3	0.15	1.5	1.5	1.35	1.35	1.2	1.5
19	6	Directions for va	0.3	0.15	1.35	1.35	1.5	0	1.35	1.35
20	7	Future maintena	0.2	0.1	0.8	0.8	1	0.9	0.7	0.8
21	8	Available groun	0.2	0.1	0.5	0.5	0.7	0.7	0.8	0.6
22		**Total Score**			**8.55**	**8.55**	**8.65**	**6.85**	**8.35**	**7.6**
23										

Airtel Vodafone tIGO Expresso MTN

Ready 100%

Figure 4.3 Screenshot of software output

4.5 RESULTS

The results obtained clearly indicate that location E the optimum location for Airtel , Vodafone is location C, Tigo is location A , MTN is location M and that of Expresso is location A. Their corresponding locations have been tabulated below.

Telco	Optimal site	Location Name	Community
AIRTEL	E	SOC. WELFARE REG. OFFICE	ASHANTI ROAD
VODAFONE	C	NR MOSQUE	NANABAKROM
TIGO	A	COMM DEV'T REG OFFICE	ASHANTI ROAD

MTN	M	AFEDZI HOUSE COMPOUND	AMAMOMA
EXPRESSO	A	BEHIND REGIONAL COORD RESIDENCE	IST RIDGE

Result difference or variations are as a result of location difference.

4.6 DISCUSSION

The aim of factor rating method is for a firm to be able to achieve their objectives by taking a total view of all relevant factors which directly or indirectly affect their operations. By so doing a positive strategic decision is eventually arrived and this will in turn minimize cost and maximize returns. A few most convenient reasons for mounting a mast at a particular location may not be ideal when juxtaposed or compared with possible environmental impact as well as other factors combined. Decisions that can be made include relocation of existing mast, mounting of additional telecommunication equipments on existing mast, sharing of telecommunication equipments, investment by third party telecommunication companies such as erection of mast and telecommunication services, and finally, consideration for co-location by telecom owners.

As customers need access to mobile telecommunication services, it will be most beneficial if telecommunication facilities that makes access to these services possible, that is, masts, are sited close to the customers that will be servicing. Investors willing to enter into the telecom sector can easily do so since they can utilize existing infrastructure instead of setting up new infrastructure from the scratch.

The next chapter, that is Chapter 5, spells out conclusions and recommendations based on findings of the study.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter deals with the conclusions and recommendations of the research. The main objective of the study is to analyze and determine the optimum location for sitting a telecommunication mast based on a mast owner's objective of maximizing returns whiles minimizing possible environmental impact of mast by considering relevant factors. Mobile Telecommunication Companies whose masts were sited in the area under study in Cape Coast metropolis were analyzed. Factor rating method was adopted in analysis of data gathered.

5.2 CONCLUSION

The thesis has been adequately treated based on the factor rating methodology the researcher adopted in finding optimum locations for siting Mobile Telecommunication masts in communities in the Cape Coast Metropolitan area.

From the findings of the study, the following conclusions have been made:

(i) Management of telecommunication companies must consider all factors that go into erecting a mast and analyze with a scientific methodology before arriving at a final decision.

(ii) By adopting factor rating method, a will telecommunication company can take positive strategic decision to locate a telecommunication facility based on all relevant factor, hence derive the maximum benefit and reduce cost, and eventually achieve the companies objectives.

(iii) Additionally, new entrants in the sector will be relieved of initial huge startup of being a mobile telecommunication operator since they can share already existing telecom infrastructure.

(iv) Infrastructure sharing would help reduce the cost of service provision hence, make services better and cheaper.

5.3 RECOMMENDATIONS

In view of the findings the researcher recommends the following:

(i) Mast owners who are independent of mobile telecommunication companies must be tasked to erect masts, so that the mobile telecommunication companies can engage in core business, thereby maximizing revenue. Backing must be gotten from the National Communication Authority (NCA).

(ii) New entrants in the sector, as mobile telecommunication operators, must share already existing telecom infrastructure

(iii) Mast owners may adopt this approach in managing their mast locations, be it erecting of new masts which can house as many telecommunication equipment as possible or relocation of existing masts.

(iv) Mobile telecommunication mast/tower design must have the capacity to accommodate at least three service providers.

(v) In as much as the factors used in this study were carefully selected, additional factors may also be considered with weights base on relative objectivity of a researcher.

(vi) In addition other facility location strategy methodologies such as Centre of Gravity method and Break-even method and factor analysis could also be used in future research.

REFERENCES

1. Al-Manthari, B., Nasser, S., and Hassanein, H. (2011). Congestion pricing in wireless cellular networks. IEEE.

2. Amponsah, S. K., Amoako, G., Darkwah, K. F. and Agyeman E (2010) Location of ambulance emergency medical service in the Kumasi metropolis, Ghana. African Journal of Mathematics and Comp. Sc. Research Vol. 4(1), pp. 18-26.

3. Amponsah S. K. and Darkwah F. K. (2007). Operations Research-MATH532. Univ. Press, KNUST, Kumasi.

4. Arogundade, O. T., Akinwale, A. T., Adekoya, A. F. and Aweoludare, G. (2005). A 0-1 Model for fire and emergency service facility location selection: A case study in Nigeria.

5. Balakrishnan, A., Wong, R. T. and Magnanti, T. L. (1995). A Decomposition Algorithm for Local Access Telecommunications Network Expansion Planning. Operations Research (43), 58-76, 1995

6. Balinski, M. L., (1965). Integer programming: Methods, Uses, Computation. Management Science , 253/313.

7. Balakrishnan, C. (2006). Survey of Network Traffic Models,

8. Blazaran, M. and SeyediNezhad (2009). Center Problem : In Farahani R J and Hrkmatfar M(eds)Facility Location:Concepts, Models Algorithmns and Case Studies, Contributions to Management Science Springer-Verlag.

9. Bokpe, S. J. (2010). Checking the spread of phone masts, Telecom Towers Banned. Daily Graphic, February 1 p.1,3.

10. Burkson, S. (2011). Why Isn't Ghana's Telecommunication Industry Getting the Needed Attention despite Oil/Gas Find? Feature Article, available at www.ghanaweb.com

11. COAI(2011) Green Telecommunications - Cellular Operators Association of India(TRAI) Consultation Paper (No 3 of 2011) Technical Note 10.

12. Chandrasekaran, B., Johnson, T. and Smith J W (1992). Task Structure Analysis for Knowledge Modeling. Communications of the ACM , Vol. 33, No. 9, September 1992, pp. 124-136.

13. Cape Coast Metropolitan Assembly(CCMA)(2011). History of Cape Coast Metropolis.

14. Chung S., Myung, Y. and Tcha, D. (1992). Optimal Design of a Distributed network with a Two Level Hierarchical Structure. European Journal of Operations Research.pp105-115.

15. Curtis, S. (2010). Technology in Ghana: A Blessing or A Curse. Retrived from http://www.techweekeurope.co.uk/comment/technology-in-ghana-a-blessing-or-a-curse-41578.

16. Daskin, M. S. (1995), Network and Discrete Locations: Models, algorithms, and applications, John Wiley & Sons, New York. pp 154-191.

17. Dowuona, S. (2009). Radiation from Telecom Mast and our health, GNA, Retrieved July 7, from http: //www.ghanaweb.com/ghanahomepage/newsArchive/artikel.php?id =164901.

18. Dowuona, S. N. N. (2011, October 14) Predators of Ghana's telecom industry - Part I, Myjoyonline.com/Business.

19. Drezner, Z. and Hamacher, H. W., (eds) (2002), Facility Location: Applications and Theory, Springer-Verlag, New York.

20. Drezner, Z. (1995). Dynamic facility location: The progressive p-median problem, Location Science, 3, 1-7.

21. Eiselt, H. A. and Marianov V.(eds.) (2011) Foundations of Location Analysis, International Series in Operations research & Management Science 115, Springer Science Business Media, LLC 2011.

22. Expresso Website (2012) Retrieved Jan 7 2012 from http://www.expressotelecom.com/en/african-presence/ghana.

23. Farahani, R. J. and Hakmatfar, M. (2009). Facility Location Concepts, Models Algorithms and Case Studies, Springer-verlag Berlin Hierdelberg.

24. Galati, M. (2006). Introduction to Operations Research

25. Garson, G (2009). Factor Analysis. From Statnotes: Topics in Multivariate Analysis. Retrieved on April 13, 2009 from http://www2.chass.ncsu.edu/garson/pa765/statnote.htm

26. Gavish, B. (1992). Topological Design of Computer Networks- The overall Design Problem, European Journal of Operations Research pp 149-172.

27. Gavish, B. (1982) Topological Design of Centralized Computer Networks: Formulations and Algorithms, Networks 335-377.

28. GhanaDistricts (2011), Welcome to Cape Coast Metropolitan Retrieved Sept. 22, 2011 from http://capecoast.ghanadistricts.gov.gh/.

29. Goldsworthy, A. (2008). Why Mobile Phone Masts Can Be Dangerous than Phones, Imperial College, London.

30. Gourdin, E., Labbe, M. and Yahan, H. (2002). Telecommunication and Location. In: Drezner Z.

31. Gro¨ nroos, C. (2001), "The perceived service quality concept – a mistake?", Managing Service Quality, Vol. 11 No. 3,pp. 150-2.

32. Hakimi(1964). Optimum Locations of Switching Centers and Absolute Centers and Median of a Graph Operations Research 450-459.

33. Heger, D. A. (2006). An Introduction to Operations Research – Benefits, Methods & Application, Fortuitous Technology Austin, TX, 2006.

34. Hamacher, H. W. (eds) (2009). Facility locations, applications and theory. Springer, Berlin, pp 275 305.

35. ITU (2009) World Telecommunications Regulatory Database.

36. Kremlin, H. (2007). Telecom Day, Challenges in the Mobile Telecommunication Industry, SIAM News, Volume 40, Number 8, Oct.2007.

37. Leeson, D. (2007) Antenna Topics, W6NL/HC8L 2007

38. Local Planning Guidance Note, LPGN.18 (2007). Local Planning Guidance Note No.18 Issue 2 Adopted by Council In 20/2/07. Fintshire Council.

39. Mastsanity (2008). Mast Sanity Quick Guide To Mobile Phone Masts. (Rev,09/11/2008), Registered UK Charity no:1109757. Available at www.mastsanity.org.

40. MOC Policy Document (2004). National Telecommunications Policy: Ministry of Communications MOC/POL-TEL-0001, 2004.

41. Marianov, V. and ReVelle, C. (1996). The queuing maximal availability location problem: A model for the siting of emergency vehicles. European Journal of Operation Research 93, 110.

42. MTN Website (2012) Retrieved Feb 7, 2012 from http://www.mtn.com.gh

43. Ministry of Communication Policy (MOC) (2011) document. Retrieved Nov. 2009 http://www.moc.gov.gh/ on December 30, 2011

44. Monticone, L. C. and Funk, G. (1994). Application of facility location problem to the problem of locating concentrators on an FAA microwave System, Annals of Operations Research 437-454.

45. National Communications Authority Report (2010). Guidelines for the Deployment of Communication Towers, Industrial Technical Committee.

46. Nimako, G. S. and Azumah, F. K.(2009). An assessment and analysis of customer satisfaction with service delivery of Mobile Telecommunication Networks in Ghana- Luleå University of Technology, Sweden Library.

47. OFCOM (2011). Independent Regulator and Competition Authority for UK Communication Industries-Communication Reports, Papers and Reviews. 2011.

48. Office of Communications(2012), UK website www.Ofcom.org.uk

49. O'Flaherty V. F. (2001). The Legal Landscape When a Tower Collapses, Journal of the Missouri Bar Volume 57 - No. 4 - July-August 2001.

50. Pirkul, H. (1987) Efficient Algorithms for the Capacitated Concentrator Location Problem, Computers and Operations Research, 197-208, 1987.

51. Pirkul, H. Narasimhan, S. and De, P. (1988). Locating concentrators for Primary and secondary coverage in a Computer Communication Network. IEEE Transactions on Communications 450-458.

52. Republic of Ghana (2004). National Telecommunications Policy, Ministry of Communications, Accra.

53. ReVelle, C. and Hogan, K. (1989). The maximum availability location problem, Transportation Science, p192.

54. Russell, G. (2010), Mobile Phone Masts Commission, Article on Mobile Phone Masts -Retrieved November 2 2011 from, http://www.politics.co.uk/reference/mobile-phone-masts.

55. Junjhunwala A., Ramamurthi, B. and Gonsalves, T. A. (1998). The Role of Technology in Telecom expansion in India, IEEE Communications Magazine, vol.36, no.11, pp.88-94.

56. Serray, D. and Marianovz, V. (1996). The P-Median Problem in a Changing Network: The Case of Barcelona.

57. Saydam C, Aytug (2003). H Accurate estimation of expected coverage: Revisited. Socio-Econ. Plann. Sci., 37: 69–80.

58. Schilling D A, Jayaraman V, Barkhi R (1992). A review of covering problems in Facility Location, location Science Vol 1 No1 pp 25-55, 1993. Pergamon Press. USA.

59. South Northamptonshire Council SNC (2002), Telecommunications Supplementary Planning Guidance 11102 UK, Adopted November 2002.

60. Støttrup-Andersen, U. (1998). Analysis and Design of Masts and Towers, Structural World Congress, San Francisco.

61. Støttrup-Andersen, U. (2009). Analysis and Construction of Shell and Spatial Structures, , IASS Symposium Sept 2009.

62. Tagoe, M. (2009). *A* handbook for writing research proposals, Ghana Universities Press Accra 2009.

63. Telecommunications Regulatory Authority of India's Press Release dated 12 April, 2007.

64. Telecommunications Regulatory Authority of India- www.trai.gov.in.

65. The Hindu (2007) TRAI Proposes sharing of Telecom infrastructure- Hindu: Online edition of India's National Newspaper (2007, April12) Retrived Jan 2012 from http://www.hindu.com/.

66. Toregas, C., Swain, R., Revelle, C. and Bergman (1988). The location of emergency service facilities. , Operation research Journal of Theoretical and Applied Information Technology pg 1363-1373.

67. Wikipedia (2011). Microwave Transmission.

68. Zunia (2011). The Knowledge Exchange Website.-www.zunia.org

APPENDIX

DETERMINING THE OPTIMAL LOCATION OF MOBILE TELECMMUNICATION MASTS, A CASE STUDY OF CAPE COAST METROPOLITAN AREA

QUESTIONNAIRE FOR STAFF/MANAGEMENT OF MOBILE TELECOMMUNICATION COMPANIES CAPE COAST BRANCH

About this study

This study is being conducted as part of an MSC. Degree in INDUSTRIAL MATHEMATICS.
The aim of this study is to explore the concept of location. This involves delving into factors that influence the location of a facility such as telecommunication mast so as to optimize its benefit and reduce cost. Factors which will be explored by this study are availability of market, resources and infrastructure. The area of study is Cape Coast Metropolitan area.

About this questionnaire

- This questionnaire should take approximately 10 minutes to complete.
- Guidelines for answering questions are typed in italics. Most of questions can be answered my marking the most appropriate answer.
- When in doubt about any aspect of the questionnaire or if you would like more information about it or the study, you can reach me by the phone number 0249403322, 0276363053 or 0207105428.
- When you have completed this questionnaire please return it to the researcher or assist with its collection.

Answers To These Questions Will Be Used For Academic Purpose Only.

APPENDIX A

TELECOM MASTS BELONGING TO ZAIN GHANA IN CAPE COAST

NO	COMPANY	COMMUNITY	LOCATION	ALIAS
1	AIRTEL	KOKOADO	OPPOSITE THE SEA ADJACENT CAPE VARS	A
2	AIRTEL	SEIWIN - NANABA	SEIWIN NEAR CPOLY	B
3	AIRTEL	KWAPROW	NR ACHIMEDES SCH	C
4	AIRTEL	PEDU ESTATE	OPP. PRESBY CHURCH, ALONG REG. HOSPITAL RD.	D
5	AIRTEL	ASHANTI ROAD	SOC. WELFARE REG. OFFICE	E
6	AIRTEL	OLA	BESIDE WOODEX INT. HOSTEL /CNC	F
7	AIRTEL	AMAMOMA	NEAR METHODIST CHURCH BUILDING	G

Please rate each location on a 1 to 10 point basis factor to reflect its relative importance in relation to the company's objectives.

			Less (1 2 3 4 5 6 7 8 9 10)More						
			Location						
FACTOR	**FACTOR NAME**	**RATING WEIGHT**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
1	Community Consultation and Desirability	0.3							
2	Utility(Electricity and Water Source) availability and cost	0.2							
3	Co-location Feasibility	0.2							
4	Population density and economic activity	0.3							
5	Geological Nature of the Site	0.3							
6.	Directions for various directional antennas	0.3							
7	Future maintenance and expansion	0.2							
8	Available ground area and access to the site	0.2							

APPENDIX B

TELECOM MASTS BELONGING TO VODAFONE IN THE CAPE COAST METROPOLITAN AREA

No	COMPANY	COMMUNITY	LOCATION	ALIAS
1	VODAFONE	AYEKO AYEKOO	OPPOSITE DANCE P	A
2	VODAFONE	AYEKO AYEKOO	OPPOSITE DANCE P	B
3	VODAFONE	NANABAKROM	NR MOSQUE	C
4	VODAFONE	NANABAKROM	OPPOSITE MUSTARD SEED COMPANY CO. LTD	D
5	VODAFONE	AMAMOMA	NR STERNER STUDENTS HOSTEL	E
6	VODAFONE	EFUTU	OPPOSITE EFFUTU SEC. TEC. SCH	F

Please rate each location on a 1 to 10 point basis factor to reflect its relative importance in relation to the company's objectives.

			Less (1 2 3 4 5 6 7 8 9 10)More					
			LOCATIONS					
FACTOR	**FACTOR NAME**	**RATING WEIGHT**	**A**	**B**	**C**	**D**	**E**	**F**
1	Community Consultation and Desirability	0.3						
2	Utility(Electricity and Water Source) availability and cost	0.2						
3	Co-location Feasibility	0.2						
4	Population density and economic activity	0.3						
5	Geological Nature of the Site	0.3						
6.	Directions for various directional antennas	0.3						
7	Future maintenance and expansion	0.2						
8	Available ground area and access to the site	0.2						

APPENDIX C

TELECOM MASTS BELONGING TO TIGO IN THE CAPE COAST METROPOLIS

No	COMPANY	COMMUNITY	LOCATION	ALIAS
1	TIGO	ASHANTI ROAD	COMM DEVT REG OFFICE,	A
2	TIGO	AKYIM	HOLY CHILD BUNGALOW	B
3	TIGO	EWIM	BEHIND GBC OFFICES	C
4	TIGO	4TH RIDGE	LAGOON VIEW HOSTEL	D
5	TIGO	ANTEM	KINGDOM HALL OF JAH. WITHNESSES	E
6	TIGO	AMISSANO	BESSAKROM	F
7	TIGO	UCC	BEHIND CASFORD HALL	G
8	TIGO	OLA	OLA TRAINING COLLEGE	H
9	TIGO	ESUEKYIR	BEHIND WINNERS CHAPEL	I
10	TIGO	AMAMOMA	NR FLORENCE HOSTEL	J
11*	TIGO	BAKAANO	NR PHILIP QUARQOE	K

Please rate each location on a 1 to 10 point basis factor to reflect its relative importance in relation to the companies objectives.

			Less (1 2 3 4 5 6 7 8 9 10)More										
			LOCATIONS										
FACTOR	FACTOR NAME	RATING WEIGHT	A	B	C	D	E	F	G	H	I	J	K
1	Community Consultation and Desirability	0.3											
2	Utility(Electricity and Water Source) availability and cost	0.2											
3	Co-location Feasibility	0.2											
4	Population density and economic activity	0.3											
5	Geological Nature of the Site	0.3											
6.	Directions for various directional antennas	0.3											
7	Future maintenance and expansion	0.2											
8	Available ground area and access to the site	0.2											

APPENDIX D

TELECOM MASTS BELONGING TO MTN IN THE CAPE COAST METROPOLIS

No	COMPANY	COMMUNITY	LOCATION	ALIAS
1	MTN	BAKAANO	PHILIP QUAICOE BASIC SCH	A
2	MTN	ASHANTI ROAD	COMM. DEVT REG. OFFICE	B
3	MTN	EWIM	BEHIND GBC OFFICES	C
4	MTN	4TH RIDGE	LAGOON VIEW HOSTEL	D
5	MTN	ADISADEL ESTATE	SHC OFFICE COMPOUND	E
6	MTN	PEDU NGUABADO	NEAR CAPE TECH	F
7	MTN	ABURA	NEAR OLD CEMETARY	G
8	MTN	EYIFUA	NEAR GNAT HALL	H
9	MTN	KAKOMDO	BEHIND EMPART GAS	I
10	MTN	UCC	BEHIND CASFORD HALL	J
11	MTN	AMAMOMA	OPP. AYENSU PLAZA HOSTEL	K
12	MTN	AMAMOMA	ROUND PALACE HOSTEL	L
13	MTN	AMAMOMA	AFEDZI HOUSE COMPOUND	M
14	MTN	EFUTU	OPP. FUEL STATION	N

Please rate each location on a 1 to 10 point basis factor to reflect its relative importance in relation to the companies objectives.

			Less (1 2 3 4 5 6 7 8 9 10)More													
FACTOR	**FACTOR NAME**	**RATING WEIGHT**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
1	Community Consultation and Desirability	0.3														
2	Utility(Electricity and Water Source) availability and cost	0.2														
3	Co-location Feasibility	0.2														
4	Population density and economic activity	0.3														
5	Geological Nature of the Site	0.3														
6.	Directions for various directional antennas	0.3														
7	Future maintenance and expansion	0.2														
8	Available ground area and access to the site	0.2														

APPENDIX E

TELECOM MASTS BELONGING TO EXPRESSO IN THE CAPE COAST METROPOLIS

No	COMPANY	COMMUNITY	LOCATION
1	KASAPA	IST RIDGE	BEHIND REGIONAL COORD RESIDENCE

FACTOR	**FACTOR NAME**	**RATING WEIGHT**	**LOCATION A**
1	Community Consultation and Desirability	0.3	
2	Utility(Electricity and Water Source) availability and cost	0.2	
3	Co-location Feasibility	0.2	
4	Population density and economic activity	0.3	
5	Geological Nature of the Site	0.3	
6.	Directions for various directional antennas	0.3	
7	Future maintenance and expansion	0.2	
8	Available ground area and access to the site	0.2	

This is the end of the questionnaire.
Thank you very much for your cooperation

APPENDIX F

Table F1: NCA technical guidelines for location of Telecommunication mast

Zoning	**Permissible Height**	**Average Plot Size & Protection Area**	**Minimum Set Back Required (in accordance with B**	**Neighbourhood Requirement.**
Residential	<35 meter	Not Less than 20 m x 20 m	Not less(<20m) from base of tower to boundary fence or nearest structure	500 m Radius for group consultation and all immediate neighbours covered.
Commercial	<800meter 120m	Not less than 12.5m x12.5m	Ditto(Roof mast and co-location must be first option)	200m
Industrial	120 meter	Not less than 12.5m x12.5m for shorter mast and 16.5m x 16.5m taller mast	6m from base of tower to boundary fence	100m
Civic & Cultural	<120	20m x 20m	10m from base of tower boundary fence	100m
Mixed Use	<80	20m x 20m	10m from base of tower boundary fence	150m
Educational	Not allowed **on school compounds**(sites*)		At least 150m from the nearest classroom or dormitory structure.	Cosent from school authorities
Health facilities	Not allowed in clinic and poly clinic facilities (sites*)		Well set back from the ward and sensitive equipment facilities	
Aviation Facilities	Not allowed*		Determined by GCAA	