KWAME NKRUMAH UNIVERSITY OF SCIENCE AND

TECHNOLOGY, KUMASI

LOCATION OF ADDITIONAL FIRE STATIONS IN THE KUMASI CITY,USING A BINARY INTEGER PROGRAMMING MODEL

BY

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DECLARATION

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

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DEDICATION

To Mrs. Yaa Amponsah Kuma,my dear wife,and my children Mark Kwabena Sarpong Kuma ,Nana Akua Afriyie Kuma and Joseph Akwasi-Kuma Junior,I dedicate this thesis. I love them very much.

ABSTRACT

With the increasing population of the City of Kumasi from 346336 in 1970 to 2035064 in 2010,the City is gradually expanding thereby increasing the coverage of the Fire Service Stations and consequently diminishing the responsiveness of the fire department. This thesis aims at answering these three questions:(1)Does the City need to build fire stations and how much of the city is currently covered at a standard travel time of 4 minutes?,(2)Which minimum combination of fire stations will cover all Kumasi within 4 minutes?(3)where should the City Authorities have to build new fire stations and in what order? The thesis seeks to increase the number of fire stations so as to save lives and property.A binary integer programming model is therefore used. The results indicated that the City needs more fire stations and that the Kumasi Fire Department will be able to cover all of Kumasi at a 4 minutes travel time with at least 9 fire stations and that they should be built in the following order at these sites:UEW-K(Lat 6.698131,Long -1.686326), Buokrom Estate(Lat 6.739015 ,Long -1.585980)and Bohyen(Lat. 6.7209012,Long. -1.6619288).

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CONTENTS

LIST OF ABBREVIATION

UEW-K .... University of Education Winneba-Kumasi

KMA .... Kumasi Matropolitan Assembly

GSS .... Ghana Statistical Service KCFD ....Kumasi City Fire Department KNUST ....Kwame Nkrumah University of Science and Technology

KATH .... Komfo Anokye Teaching Hospital

RHQ .... Regional Head Quaters

GPS ....Geographic Position System

GNFS ....Ghana National Fire Service GNFRS .... Ghana National Fire Rescue Service

AD ....After the Death of Christ

ED ....Expected Distance ET ....Expected Travel Time NE .... North East NW ....North West SW ....South West

SE ....South East Long ....Longitude

Lat ....Latitude GNA .... Ghana News Agency

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CHAPTER 1

INTRODUCTION

1.1 FIRE

When two molecules meet under the right circumstances, they may exchange electrons in ways that change both molecules into new kinds of molecules. While they do that - reacting to each other they may also release some electrical energy in a form of heat or light. This is what happens when there is a fire. The earliest fires were stars, where or when hydrogen atoms meet under a lot of pressure from gravity, they merge together into helium atoms and let off some extra energy – that is the sunshine we get from our sun. The same kind of thing happens in a forest fire or when we light a candle or a match. Candles are made of hydrocarbon molecules (sometimes oil, sometimes beeswax, sometimes tallow from animal fat), and matches are made from hydrocarbon molecules(wood). When they get hot enough, these hydrocarbon molecules react with oxygen in the air. The heat can come from friction, like when you strike a match or from another fire, like when you hold the match to the candle all from lightning that starts from a forest fire, or from focused sunlight. When the hydrocarbon molecules reach 300 degrees Fahrenheit (150 degrees Celsius), the reaction begins.

During the reaction, the molecules come apart and recombine into carbon dioxide, smoke and water. But the reaction leaves a little energy left over and that is the heat and light of the fire. .Anything made of hydrocarbons like wood, charcoal, alcohol, leaves, people, oil, gas or plastic will burn. A few other things like magnesium will also burn. (www.historyforkids.org/learn/science/fire2.htm) Fire was useful for all kinds of things in the ancient and medieval world, but it was also very dangerous. Because people built their houses of wood, and had thatched roofs, and then built fires inside their houses to cook on and to heat the houses, it was very common for their houses to catch fire and burn down. And because villages had lots of these wooden houses close together, often when one house caught fire, the whole village will burn.

In the ancient world, they didn't have fire departments, so there was nobody to put out a fire once it got started. The Romans tried to make some rules about how close together houses could be, and they made a law that every building had to have buckets of water standing around in case of fire, a lot of people probably didn't follow the rules. Even if they did, a few buckets of water wouldn't be enough to stop a house fire. One example of a very serious fire is the Great Fire of Rome in 66AD. That fire burnt down the whole center of the city of Rome. But even after that fire, the emperors wouldn't let towns organize fire departments, because they were afraid people would use the excuse of a fire department to train soldiers and then lead a revolt against the government. (www.historyforkids.org/learn/science/fire2.htm) Fire fightingconsists of removing one or more of the three elements essential to combustion,fuel, heat and oxygen or of interrupting the combustion chain reaction.NAOED

(2015) . This is mainly done to extinguish fire to limit the damage caused by fires. The modern department with salaried personnel and standardized equipment has become an integral part of municipal administration only late in the 19th century. NAOED (2015). Following many fire outbreaks in most cities in most parts of the world many fire departments have been established in these cities and Kumasi, the garden city of West Africa is no exception.

1.2 BACKGROUND OF STUDY

Kumasi is the second must populous city in Ghana. Because of its strategic location and the fact that it is the capital of Ashanti Region makes it a brisk business and administrative centre and it is also regarded as the commercial capital of Ghana . All that together with a lot of facilities that the city enjoys such as the airport, stadium, universities, hospitals, electricity, pipe – borne water, etc. have caused rural urban migration from most of the surrounding villages and towns far and near. These migrations have increased the population of Kumasi greatly from a population of 346336 in March,1970 to a population of 2035064 in September,2010.GEOHIVE (2015). This increase in the population of permanent residents has immensely contributed to the rapid expansion of the city. As the city is expanding at such a fast rate the area of coverage of the fire service stations becomes very large and diminishes the responsiveness of the fire department. This leads to more damage to life and property whenever there is a fire outbreak at places which are far from the existing fire stations. This rapid growth of the population of Kumasi, which has greatly caused the expansion of the city, has called for the need to locate new fire stations to be added to the existing ones so as to ensure that the entire city is covered by the fire department.

1.2.1 A BRIEF HISTORY OF FIRE FIGHTING AND FIRE STATIONS

The first full time fire station or department, in the western culture, might have been in Rome 2000 years ago. They had people who were selected to roam the city and not only sound the alarm and put out fires but enforce fire codes (sometimes with corporal punishment).These was the “corps of vigiles”. Unfortunately they were not exactly a “paid” department. Augustus Caesar formed this corps from slaves. (www.fireservice.info.com/history.html) . There are many claims to who would be the “first” “modern” “professional” fire brigade or department. Credit for the first “professional fire brigade” is often given to Napoleon Bonaparte. While French emperor, he ordered that a division of French army known as speurs-pompiers be used to protect Paris with 30 manual fire pumps around 1800.But there were people who were paid to provide some form of fire protection or suppression service, in Paris, many years prior to that. In 1699 Francois du Mouriez took interest in a better pump , fire hose and other advancements, provided 12 fire pumps to the city of Paris to become the first “Fire Chief” (director) of des pompes de la ville de Paris in 1716. The French fire brigade was known as “compagnie des Gardes-pompier” the French word for pumper, “pompier (literally the company of pump guards) become the name of the French fire fighters to this day. On March 11, 1733 the French government proclaimed that the service of the fire brigades would be free of charge. Prior to this there was a fee and people often avoid calling in order to avoid being charged.(www.fireservice.info.com/history.html) Edinburgh, Scotland, claims to be the first organized municipal fire brigade in the world, when the Edinburgh Fire Engine Establishment was formed in 1824, led by James Braidwood. London followed in 1832 with the London Fire Engine Establishment. Clicking on a link about James Braidwood proclaims that he “is credited with the development of the modern municipal fire service”. But this ignores the fact that Boston, had a crew who was paid to maintain their one pump and respond to fires as early as 1678 and the fact that London established “fire companies “after the Great fire of London in 1666.But in fairness, James Braidwood probably did contribute some major advances in fire fighting .Prior to him, most fire fighting was done from the streets. He pioneered and developed the strategy of entering and fighting fires from within the structure. One might assume that this advancement was made possible due to the invention of better pumps in 1725 and dependable leather fire hose 1672.(www.fireservice.info.com/history.html)

1.2.2 A BRIEF HISTORY OF GHANA NATIONAL FIRE AND RESCUE SERVICE

The Ghana National Fire and Rescue Service (GNFRS) is an agency under the Ministry of Interior, constituting Ghana's nationwide fire service. It was established as the Ghana National Fire Service (GNFS) with a broad objective of prevention and management of undesired fires and other related matters. (our wikipedia.org/mike/Ghana National Fire and Rescue Service). Before the existence of the fire service, fire was controlled by traditional rulers using the Safe Companies to combat all kinds of fire. As towns developed into municipalities, municipal councils as well as some government agencies with fire hazards formed their own fire brigades.Academy and School (1997)

In 1956, the colonial government employed the services of a fire Advisor, Mr. G. S. Leader to help formulate the policy on fire formation of a National Fire Service which had long been contemplated. In 1963, by an Act of parliament (Act 219 , 1963) the Ghana National Fire Service was formed,Amo-Asante (2012), from the then fragmented railways, Port and Harbours, Kumasi City, Accra and the Sekondi-Takoradi Municipal Fire Brigadiers which hitherto existed as separate entities under government department or municipal councils at that time the following were the responsibilities of GNFS:

- Fighting and extinguishing of Fire.

- The rescue of human beings, animals and property from fires.

- Any other functions which was prescribed or specified by the Minister of Interior. Amo-Asante (2012)

In 1997 by an act of parliament (Act 537, 1997), the service was re-established to expand its functions taking into cognizance modern trend in fire fighting, prevention and safety,Amo-Asante (2012). With this act 537 the GNFS were to perform the following functions as from 1997 to date:

- Organize public fire education programs.

- Create and sustain awareness of the hazard of fire; and.
- Heighten the role of the individual in the prevention of fires.

- Provide technical advice for building plans in respect of machinery and structural layouts to facilitate escape from fire rescue operations and fire management;.

- Inspect and offer technical advice on fire extinguishers;.

- Co-ordinate and advice on the training of personnel in fire fighting department institutions in the country.

- Train and organize fire volunteer squads at community level and.

- Offer rescue and evacuation service to those trapped by fire or in other emergency situations and.

- Undertake any other function incidental to the objective of the service.

(en.wikipedia/wiki/Ghana National Fire Service). The GNFS after its reestablishment in 1997 now has 140 stations across the length and breadth of the country and 18000 employees.

In March 2010, it was announced that the GNFS be named as the Ghana National Fire and Rescue Service. (GNFRS). The new mandate of the service was to operate both fire and ambulance services. GNA (2011)

1.3 PROBLEM STATEMENT

Every so often, when there is a fire outbreak within the Kumasi municipality, the fire fighters response time to salvage the situation is not the best(beyond five minutes) so by the time they get to the scene of fire outbreaks, damage had already been done. This thesis seeks to find out which number of fire stations will Kumasi need, to reduce or minimize the response time.

1.4 OBJECTIVE

The objective of this thesis is:

1. To establish whether or not there is the need for additional fire service stations in Kumasi.

2. To determine the minimum combination of proposed fire service station sites that covers all Kumasi at a four minute travel time.

3. To propose a station priority scheme.

1.5 METHODOLOGY

The methodology used to optimally locate additional fire stations in Kumasi metropolis using a binary integer programming model are outlined below:

- Selection of the area of study

- A map of Kumasi would be collected from the planning department of the KMA
- Data on fire activities would be collected from the fire service department in Kumasi

- The ArcGIS software or google maps would be used to locate towns or points on the map of Kumasi

- The use of latex software and mat lab

- Search on the internet for related literature

- Reading of books from libraries in KNUST

1.6 JUSTIFICATION

When the objectives of this thesis are achieved and implemented it will impact positively on the people in Kumasi and the development of the city as a whole. In the areas of academic/research it is believed that the thesis will add to the existing academic knowledge and enable one to understand the subject matter of fire-fighting or fire service as one of the emergency services in the city.

The social life of the people in the city will be affected positively since with the location or creation of new fire stations, the response time of the department will be better and most of the fire outbreaks will be quenched in no time before it causes damage or harm to the people or loss of human life thereby creating more disable people and orphans in the metropolis.

However the economic activities of the city will also improve since the fire stations quick response to the fire outbreak will enable them quench the fire before they will cause damage to products or goods of most business men and women mostly leading to great loss of money and collapse of their businesses.

Environmental pollutions which comes about due to the fire fumes from the fire outbreaks will drastically reduce with their associated health problems when the responsiveness of the fire service stations improve with the creation of additional fire stations.

1.7 THESIS ORGANISATION

The chapter one of the thesis introduces the thesis with the background of study with the history of fire stations and fire fighting, the Ghana National Fire Service, the Kumasi Fire Service. Within the same chapter one is also the problem statement, the objectives, the methodology, justification and the thesis organization. The chapter two deals with reviewing the related literature on Location Analysis, the problem of fire station allocation and binary integer programming model. The chapter three deals with the methodology. In the fourth chapter are the data collection and analysis. Finally in chapter five is the conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

One of the most essential components of the responsibilities of a municipality is the fire protection services and location of the fire stations and this has been the main factor in providing fire protection coverage. Fire outbreaks that occur within the domain of the fire department are responded to quickly whenever the fire station is placed properly. When a municipality expands, it is very possible that the responsiveness of the fire stations that were meeting the needs of their locations at the time of their construction will diminish. As the fire stations become more distant from a growing percentage of the city, the responsiveness of the fire department as a whole can drop severely. Thus the need therefore arises for the municipality to build new fire stations to maintain minimal response times. Where new fire stations should be constructed so as to minimize the incident response time of the fire department must be determined by the municipality. This thesis addresses the allocation of fire stations for the Kumasi City.

2.1 AN OVERVIEW OF LOCATION ANALYSIS

Location Analysis is a subfield of geography that examines urban-economic systems, with an emphasis on the placement and siting of public and private facilities. But Revelle and Eiselt (2005) defines Location Analysis as the modeling, formulation, and solution of a class of problems concerning the siting of facilities in some given space. They go further to explain that location problems are characterized by these four components:

- Customers, who are located at presumed points or on routes.
- Facilities that will be located
- A space in which customers and facilities are located
- And, a metric that indicates distances or time between customers and facilities.

In formulating a location problem there is an initial distinction, which is the choice of space or region of location. Location problems in general can be viewed as residing either within a d-dimensional real space (planar) or within a network. According to Revelle and Eiselt (2005), a planar location problem was characterized by an infinite solution space and a particular metric by which distance is measured. Problems of location of a network are characterized as follows;

- The solution space consists of points on the network.
- the metric for distance is defined by d_{ij} = the length(or time) of the shortest path from node i to node j . Charles Revelle and Liebman (1970) .

Location problems can be either discrete or continuous. The discrete problems generally restrict the number of eligible points on a network or plane at which a facility can be placed, Walls (2012). Charles Revelle and Liebman (1970) observes that the discrete location problems on a network tend to be formulated as integer programming or combinatorial optimization problems involving zero-one variables. A zero-one variable is a variable that can be either zero or one, Walls (2012). The continuous problems are most of the time planar and tend to be constructed as non-linear optimization problems. Daskin (2008) sub-divided the discrete location models further into median-based models, miscellaneous models and covering-based models. The covering-based models seek to locate facilities so that demand models are within a particular distance or times of the facilities. The idea is that each demands node is "covered" by at least one facility, Walls (2012).

The median-based models are those models that seek to minimize demandweight coverage distance between a facility and its assigned demand nodes. This particular category is generally used with the context of distribution planning where the minimization of transportation cost is desired, Daskin (2008)

The following are some of the examples of discrete location models. The problem of the locating retail stores so that the stores do not compete for the same consumer based while ensuring that a retail store is within a minimum distance to customers. The location of "undesirable" facilities such as land-fills. The objective is to locate the landfill so that it is close enough to be useful while ensuring that the landfill is remote enough so that the undesirable effects of the facility are minimized. The allocation of the fire stations had been generally formulated as a binary integer programming model or a covering-based model.

2.2 THE PROBLEMS OF FIRE STATIONS ALLOCATION

We start with an overview of location research pertaining to emergency response by discussing the fire station allocation problem. According to Chaiken and Larson (1972) urban emergency services have been defined as any system which has the following properties:

- Incidents occur throughout the city which gives rise to calls for service; the time and places of these events cannot be specifically predicted in advance.
- One or more emergency service units are dispatched to the scene of each call received.
- The rapidity with which the units arrive at the scene of the incident has an impact on the actual or perceived quality of service.

There are many services that a municipality provides and they are towing services, fire prevention services, police units and emergency medical services. The notion of fixed or mobile location is what gives the distinction between the difference emergency services. A fire station is a typical example of a fixed location and a police patrol car is also an example of a mobile location.

For an emergency services system, an allocation policy is the collection of the rules and regulations governing the number of units on duty at a given time; the location of each units; the number of personnel assigned to each unit; the priority attached to different types of calls and the order in which the calls are answered; the number of units that respond to the different types of calls; and which particular units respond, Chaiken and Larson (1972).

In determining an allocation policy; there are several methods that can be used. The geography and the land use of a particular region do determine the total number and location of fixed locations.

Industry standards have reinforced the use of geographic factors with respect to fire stations; insurance services offices (iso) in the United States for example offer the following guidance: Items 560 of the fire suppression rating schedule states that "the built-upon areas of the city should have a first-due engine company with one and half miles and a ladder service company within two and half

miles",(http//firechief.iso.com/FCWWeb/mitigation/securedocs/fsrs/ppc400.jsp,2007)

A more meaningful measure of performance is the response time by a unit to an incident. Several features that models of emergency service systems must consider have been described by Chaiken and Larson (1972). The probabilistic variations in demands and service requirements over time is the first and the second is the distributions of incidents and response units over the space of the city.

The greatest component of response time is the travel time. And in modeling response time, there is the need to get an accurate understanding of the relationship between travel distance and travel time. This relationship between travel distance and travel times, for fire trucks was investigated into details by Kolesar and his colleagues. Estimates for response time can be calculated from empirical data. According to Chaiken and Larson (1972),the entire time distribution of an emergency service system should be found, since it is desired to know the probability that travel time exceeds particular limits.

In general the travel time analysis has been limited to a small number of potential facility locations for these discrete locations, the models have focused on determining the travel time properties on all possible combinations of locations or they have used simple algorithms in the search for the optimal site, Walls (2012). The fire station allocation problem will be viewed as an issue of coverage in the following sections. A particular location within a city is said to be covered if at least one fire station site is within T minutes of the location, for a chosen value of T. We introduce the method of set-covering with an example by Hogg.

2.3 THE SITING OF FIRE STATION

The work done by Hogg on the allocation of fire stations is one of the earliest examples of locational analysis. Her work was done for the city of Bristol, England on the problem of determining the number and locations of fire stations. The main objective of her work was to determine the configuration of fire stations that would minimize the potential financial loss incurred by fire within the city of Bristol. Because data on financial loss due to fires was not available, Hogg decided to select a different metric with which to work. She made the assumption that the response time, the time elapsed from the fire brigade receiving an alarm to its arrival at the fire, was directly affected by the location of the fire station. Since limiting the duration of a fire reduces the potential financial loss caused by the fire, Hogg altered the optimization criterion to the minimization of the response time of the fire brigades. Walls (2012).

During the time of the analysis the Bristol city had four fire stations out of operation and six fire stations in operation. There were also nine additional locations which were recommended by the Chief Fire Officer. A fire incident frequency distribution was determined with available data. The Bristol city was then divided into a grid of one kilometer square regions and these regions were assigned a weight based on the number of fires that occurred within them. There were 19 fire stations locations which were plotted into the appropriate grid locations and were then split into 15 sub-areas. These 15 sub-areas had the properties that they would be sufficiently large for the frequency distribution to estimate the incident frequency for the sub-area, follow topographical features, such as rivers and railway line, whenever the features were barriers to movement, and the boundaries between sub-areas were placed along lines of low fire incidence.Walls (2012). Additionally, each possible station site was identified with a particular sub-area, when possible.

Hogg established an $n \times m$ travel time matrix T with n equal to the number of sites assumed to be available to serve m sub-areas .The matrix T represented the time in minutes that was required for the fire tender to travel from the n-sites to the m sub-areas with t_{ij} as the travel time for an appliance(fire tender) at site i to sub-area j . Each sub-area was represented as a point within itself, called the center of gravity for the sub-area in terms of the total number of appliance(fire tenders) journeys to places of fire incidents for the sub-area. The Center of gravity was the road junction nearest to the location of the median appliances journey. The entries in matrix T were estimates from the fire reports and from empirical data obtained by the author.Walls (2012) .

The demand for appliance K to sub - area j was represented by the frequency distribution *f*(*k/j*) .Hogg took into consideration that a sub-area j could have a higher demand for appliances than the fire station i in closest proximity would have available. Thus it was necessary to calculate the response time between all sites i to all of the sub-area j. The number of journeys made from the n- sites to the m sub-area was represented by d_{ij} in the $n \times m$ matrix D. Hogg calculated the total response time on all appliance journey according to this allocation by

$$TD1 = \sum_{i=1}^{n} \sum_{j=1}^{m} t_{ij} d_{ij} \quad (2.1)$$

Now that TD1 had been calculated, Hogg implements a procedure to determine the allocation which gives the least increase in journey time when only n-1 of the n-sites are used. The procedure is repeated until one site remains. An additional procedure was used to determine if the replacement of the set of sites with a rejected site would improve response time. In her work Hogg was trying to determine which configuration of fire stations improved the response time while minimising the financial costs. That is to say that if a comparable solution could be achieved with n-1 instead of n- sites, it would be preferable.Hogg (1968) The solution set achieved gave the travel time properties of different combinations of station sites. The Bristol city administrators were finally left to decide the number and locations of the fire stations.

2.4 BINARY INTEGER PROGRAMMING FORMULATION

In her formulation of the allocation problem, Hogg used a set covering method. This method of set-covering was expanded by the following people,Toregas et al. (1971)

and they also offered an integer program formulation of the fire station allocation problem. By selecting an upper bound for response time ,S , they proceeded with the objective of determining the location for the minimal number of fire stations that allowed the fire department to respond within times. The analysis was constrained by several assumptions:

- The facility locations as were as the user demands can be considered a set of finite points.
- The minimum distance or minimum respond time between user demand and facility point is known.
- The set of user demand point and the set of facility location points consist of the same points.

In formulating a solution to the allocation problem, the first and second assumptions above allowed the problem to be modeled as an integer program. The third assumption is not essential in formulating a solution to the problem according to the authors.

Toregas et al. (1971), defined the set N_i as the set of nodes within S units of time of node i. Since the response time or distance, defined as

$N_i = \{j|d_{ij} \leq S\}$ for $j = 1,2,...,n$ (2.2)

Toregas et al. (1971) , noted that there is a set N_i for each of the n user nodes. Each setN_i contains at least one elements, the node i, which correspond to $d_{ij} = 0$. Toregas and his colleagues then constructed an integer program by defining the decision variable x_{ij} as:

$$x_j = \begin{cases} 0 & \text{if no facility is established at i} \\ 1 & \text{if a facility is established at j} \end{cases} \quad \text{where } j = 1,2,...,n \quad (2.3)$$

They note that x_j is a zero-one integer variable also called the decision variable. The service requirement of a node i can be written as.

$$\sum_{j\epsilon N_i} x_j \geq 1 \qquad (2.4)$$

To fulfill the service requirement, each N_i must be nonempty. It can be recalled that Toregas and his colleagues sought to minimise the number of facilities to be located so they defined the objective z as

$$z = \sum_{j=1}^{n} x_j \qquad (2.5)$$

So the integer program is as follows:

Minimise

$$z = \sum_{j=i}^{n} x_j \qquad (2.6)$$

Subject to:

$$\sum_{j\epsilon N_i}^{max} x_j \geq 1 \qquad , i = 1, 2, ..., n \qquad (2.7)$$

$$x_j = 0 \quad or \quad 1$$

According to Toregas and his colleagues there is only one variable associated with each potential facility node and only one constraint variable for each user node. They also noted that by changing the integer value at a location that particular facility location maybe forced in or out of the solution. To force the location in, the value would be changed to 1 and to force the location out, the value would be changed to 0.

In order to implement the program it is required that for a given value of s, the set N_i have to be determined for all i=1,2,...,n. it is also required that for a distance matrix containing the shortest distance from any node j to any node i be formulated. Once these objects have been found, the program may be solved. It can be recall that the only requirements imposed by Toregas, et al were that the maximum response time or maximum distance, s, be declared and that the response time or distance from any node j to any node i be known. How such a metric should be determined is the questions which need to be answered. Also, with respect to urban emergency fire services what is the nature of the relationship between response time and travel distance? These questions will be examined in the following sections.

2.5 FIRE ENGINE TRAVEL TIME ANALYSIS

Several papers and books have been published on the analysis of fire engine travel time and the relationship between travel time and travel distances. One of such publications was Kolesar and Blum (1973) by Peter Kolesar and Edward H-Blum which presented a square root law to model the expected distance that a fire engine would travel. Kolesar supposed that the expected distance, ED, between the point at which a fire occurred and the nearest fire station was

$$d = \left[\frac{K^2}{N/A}\right]^{1/2}$$

where K is the proportionality constant and N is the given number of fire stations within a particular region or area, A . In Kolesar (1975), this model was expanded and the expanded formula/model for the expected distance, ED, traveled by the nearest responding fire engine to a typical alarm was given by

$$ED = K\left[\frac{A}{n - \lambda ES}\right]^{1/2} \qquad (2.8)$$

Where λ is the expected number of alarms per hour and ES is the expected total service time, in hours, of all the fire engines that's respond to and works at an alarm, A is the area of the region and n is number of fire engines stations in the region. This expanded model suggest that as the number of available engines increase the expected travel distance decreases.

Again in Kolesar (1975) a model for the expected travel time given a particular travel distance ,D, was developed out of the simple reason that, within the constraints of a city , a vehicle does not have sufficient distance to reach a cruising velocity, (the greatest velocity a vehicle is capable of obtaining). So for a very short journey or distance, it is assumed that the vehicle accelerates for the first half and decelerates for the second half. By contract, for a sufficiently large distance where it is possible to obtain a cruising velocity, a vehicle will spend portion of the journey at cruising velocity and by this reasoning Kolesar developed the following model in Kolesar (1975) The model of the expected travel time , ET, is given by

$$ET = \begin{cases} 2\left(\frac{D}{a}\right)^{1/2} & \text{if} \quad D \leq 2d_c \\ \frac{V_c}{a} + \frac{D}{V_c} & \text{if} \quad D > 2d_c \end{cases}$$

(2.9)

where D is the given distance travelled, a is the acceleration, d_c is the distance required to achieve a cruising velocity and V_c is the cruising velocity. Kolesar in Kolesar (1975) arrived at the following approximation of ET by combining the travel time model and the distance model:

$$ET \cong \begin{cases} C_1 \left[\frac{A}{n-\frac{\lambda}{ES}}\right]^{1/4} & , if \quad ED \quad is \quad small \\ C_2 + C_3 \left[\frac{A}{n-\frac{\lambda}{ES}}\right]^{1/2} & , if \quad ED \quad is \quad large \end{cases} \qquad (2.10)$$

The validation of these models yielded that when the distance is over 0.5 miles, then the estimated travel time is approximated to

$$ET = C_2 + C_3 \left[\frac{A}{n - \frac{\lambda}{ES}}\right]^{1/2} \qquad (2.11)$$

It was shown that

$$C_2 = \frac{V_c}{a} \qquad and \qquad C_3 = \frac{K}{V_c} \qquad (2.12)$$

The generalized model for approximating the average travel time for fire engines of the equation (2.8) is of the form

$$ET = \alpha + \beta \left[\frac{A}{n - \frac{\lambda}{ES}}\right]^{\delta} \qquad (2.13)$$

where the parameters α, β *and* δ are values that depend on the physical characteristics of a region.

2.6 GOOGLE MAPS

According to Kolesar (1975), the physical characteristics of a city needs to be known for the estimated travel time to be calculated using the estimated travel time model. The travel time has to be determined in another manner if the physical characteristics are not known. Google maps (www.google.com/maps) serves as an online direction tool that help to provide an estimated travel time between two locations. The only information required is the location of potential fire station sites and the location of district centers of a city. In chapter 3 , google Maps will be used to determine travel times.

CHAPTER 3

METHODOLOGY

3.1 THE LOCATION INTEGER PROGRAMMING MODEL

To determine which combination of potential fire station sites will provide service to all regions within the Kumasi City,we need to create an integer programming model that will allow us to do so.

3.1.1 Presentation of Variables

Let us consider a region R which is divided into n districts.Each district is represented by a singular street(point) within the district called the district center. The set of all district centers are then defined as

$$D = \{d_i\} \quad \text{for} \quad i = 1,2,...,n \qquad (3.1)$$

This set D reduces the region R to a finite collection of points within R. The next is to select m different locations within R as potential fire station sites.These potential fire station sites then form the set

$$F = \{d_i\} \quad \text{for} \quad i = 1,2,...,m \qquad (3.2)$$

Each element in the set F corresponds to the address of a location that has been selected as a possible fire station site. Considering a fire station site say x_j,a decision has to be taken either to use the location for a fire station or not to use the location.This can be likened to that of a switch.When it is on,then it is in use when it is off, then it is not in use.When the location will be used for the fire station site,then it is on and when the location will not be used for the fire station site,then it is off. So x_j is called the decision variable and is defined as

$$x_j = \begin{cases} 1 & \text{,if no facility is established at i} \\ 0 & \text{,otherwise} \end{cases} \qquad (3.3)$$

We define the shortest travel time between district d_i and fire station x_j as t_{ij} and S is also defined as the maximum travel time in minutes.This maximum travel time is the desired upper bound on the travel time between each fire station and each district center, Walls (2012) .The set C_i is also defined as the set of fire stations x_j that are within S minutes of the districts.All three fire stations that cover the district, d_i are within the set C_i

$$C_i = \{x_j \in F | t_{ij} \leq S\}, \quad i = 1,2,...,n \qquad (3.4)$$

If the set $C_i = \emptyset$ then there is no fire station x_j that is within S minutes of district d_i and so we say that district d_i is not covered. The number of C_i^0s corresponds to the number of district centers we have selected for the region R.

3.2 THE INTEGER PROGRAMMING MODEL

Now subject to the constraint that each district center d_i is covered by at least one fire station x_j within the maximum travel time of S minutes, the binary integer programming model seeks to minimize the number of fire stations, so we have

Minimise $\sum_{x_j \in F} x_j$

Subject to : $\sum_{x_j \in C_i} x_j \geq 1$ *for all* $i = 1,2,...,m$ $x_j = 0$ *or* 1 for all $j = 1,2,...,n$

3.2.1 EXAMPLES OF CONSTRUCTING INTEGER PROGRAMMING MODEL

EXAMPLE 1. Let us consider a particular region R where we have only three districts and three potential fire station sites. So the set $D = \{d_1,d_2,d_3\}$ and the set $F = \{x_1,x_2,x_3\}$. The table 3.1 then shows the travel times in minutes between district d_i and station x_j.

For i = 1,...,3, the$C_i'^s$ for $i = 1,...,3$ can then be determined with the maximum

Table 3.1: Travel time of 3 stations

Districts	Station 1	Station 2	Station 3
District 1	3	4	2
District 2	4	5	3
District 3	5	6	4

travel time of 4 minutes. So we have the sets:

$C_i = \{x_j \in F|t_{1j} \leq 4\} = \{x_1,x_2,x_3\}$

$C_i = \{x_j \in F | t_{2j} \leq 4\} = \{x_1, x_3\}$

$C_i = \{x_j \in F | t_{3j} \leq 4\} = \{x_3\}$

And so , District 1 is covered by stations x_1, x_2, and x_3 District 2 is covered by stations x_1 and x_3 , while District 3 is covered by station x_3 .

So the integer programming model can be constructed as

.

$$Minimise \quad \sum_{j=1}^{3} x_j$$

Subjectto:

$$x_1 + x_2 + x_3 \geq 1$$
$$x_1 + x_3 \geq 1$$
$$x_3 \geq 1$$

$x_j = 0$ or 1 for all $j = 1,...,3$

The constraint inequalities can be represented as a system of inequalities $Ax \geq b$

$$\begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix} \geq \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

□ □ □ □ □ □

□ □ □ □ □ □

0 1 X_3 1

The solution is $[0\ 0\ 1]^T$ This means that only the fire station x_3 satisfies all the constraints and thus minimizes the objective function.

Example 2. For the system described above, let us consider the following travel

Table 3.2: Travel time of 3 stations

Districts	Station 1	Station 2	Station 3
District 1	7	8	5
District 2	3	5	4
District 3	6	5	3

times in table 3.2.

With a maximum travel time of 4 minutes the C_i^0s for i=1,...,3 are as follows;

$C_1 = \{x_j \in F | t_{1j} \leq 4\} = \{ \emptyset \}$

$C_2 = \{x_j \in F | t_{2j} \leq 4\} = \{x_1, x_3\}$

$C_3 = \{x_j \in F | t_{3j} \leq 4\} = \{x_3\}$

District 1 is not covered by any of the stations since $C_1 = \emptyset$. But District 2 is covered by the station x_1 and x_3 and District 3 is covered by the station x_3. The integer programming model can be constructed as

Minimise P3j=1 xj Subject to:

$0 \geq 1$

$x_1 + x_3 \geq 1$ $x_3 \geq$

1

$x_j = 0$ or 1 for all $j = 1,...,3$

Since we have $0 \geq 1$ which is logically false , the program cannot be solved. So such an integer program has an infeasible solution. From the first and second examples, it has been made clear that;

- a solution to a model can be determined, if each district is covered by at least one fire station and

- no solution can be found if there is at least one district that is not covered by any of the stations.

Example 3 Now let us consider a region R which has three districts and four potential fire station sites. And so the set $D = \{d_1,d_2,d_3\}$ and the set $F = \{x_1,x_2,x_3\}$. The table 3.3 shows the travel times in minutes between the districts d_i and the fire station x_j. With a minimum travel time of 4 minutes,

Table 3.3: Travel time of 4 stations

Districts	Station 1	Station 2	Station 3	Station 4
District 1	6	2	3	2

District 2	3	4	2	4
District 3	5	6	4	1

the $C_1' s$ for i= 1,... 3 are as follows;

$C_1 = \{x_j \in F | t_{1j} \leq 4\} = \{x_2, x_3, x_4\}$

$C_2 = \{x_j \in F | t_{2j} \leq 4\} = \{x_1, x_2, x_3, x_4\}$

$C_3 = \{x_j \in F | t_{3j} \leq 4\} = \{x_3, x_4\}$

District 1 , District 2 and District 3 are covered by Station x_3 and Station x_4 . The set $C_1' s$ are not empty so the model is expected to have at least one solution.

The integer programming model can be constructed as

Minimise $\sum_{j=1}^{3} x_j$

Subject to: $x_2 + x_3 + x_4 \geq 1$ $x_1 + x_2 + x_3 + x_4 \geq 1$ $x_3 + x_4 \geq 1$ $x_j = 0$ or 1 for all $j = 1,\ldots,3$

The constraint inequalities can be put in the form $Ax \geq b$,

1 1 X_1

1

1 1 1 1

0 1

X_2

1

$1 \times = 1$

X_3

0 1 1

X_4

The model has a solution $[0 \quad 0 \quad 1 \quad 0]^T$. This correspond to building station x_3.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 CONSTRUCTING A MODEL FOR THE KUMASI CITY

In constructing a model for the Kumasi city , it is necessary to determine the location of the potential fire stations sites and to represent the city as a discrete set of district centres. So in my interview of the head of the Kumasi City Fire Station, several years of incident data were obtained with a suggested set of fire station locations.

4.1.1 POTENTIAL FIRE STATION SITES

The Kumasi City has six fire stations in all. The table 4.1 contains the names of the stations, the number of fire tenders and the number of personnel working at each station.

Table 4.1: THE SIX FIRE STATIONS

Name of Station	Place of Station	Number of Fire Tenders	Number of P
RHQ Sub-station	Chirapatre	1	37
City	Adum (KMA)	1	49
KATH	Bantama	1	46
Manhyia	Manhyia	1	43
Magazine	Tafo(near cemetry)	1	38
KNUST	Bomso	1	42

The author met with the head of the city fire station with the objective to collect data on their activities and the fire station sites which they recommend in case there is the need for additional fire station in the metropolis. Several areas such as Bohyen, Buokrom Estate ,Asokwa, between Kwaadaaso and Tanoso and from Magazine to Kronom were recommended by the City Fire Head/Chief as areas that will need fire stations. Out of these five areas Buokrom Estate , Bohyen and besides UEW-Kumasi campus were finally proposed.The table 4.2 also shows the proposed fire station sites with respective GPS coordinates,see also figure 5.1 in appendix B.Also on an inserted sheet in appendix B is a google map of the proposed fire station sites.

Table 4.2: THE PROPOSED FIRE STATION SITES

Station Label	Name of Station	Latitude	Longitude
S1	RHQ Sub-Station	6.64946	-1.58283
S2	City	6.66660	-1.61627
S3	KATH	6.697545	-1.629241
S4	Manhyia	6.7051	-1.6138315
S5	Magazine	6.71834	-1.62320
S6	KNUST	6.674688	-1.571728
S7	Buokrom Estate	6.739015	-1.585980
S8	Bohyen	6.7209012	-1.6619288
S9	UEW-K	6.698131	-1.686326

4.1.2 CREATING IMAGINERY DISTRICTS

The Kumasi City can be divided into several districts. Districts creation is mostly done using the existing road system . But in this work, we would use the longitude -1.627436 as the x-axis and latitude 6.711022 as the y-axis. These particular longitude(x-axis) and latitude(y-axis) divides the city into four quadrants analogous to the cartessian quadrants.These quadrants of the city are labeled counter-clockwise from the origin.The following table 4.3 defines the quadrants.

Table 4.3: Quadrants of Kumasi City

QUADRANTS	REGION
A	Between North and East of origin
B	Between North and West of origin

C	Between West and South of origin
D	Between South and East of origin

We draw several lines parallel to the two major axes on our map obtained(see Figure 5.2 in appendix B) and several enclosed areas(districts) emerge.This process is contained until the entire city of Kumasi is covered and the districts are labeled in the following manner.

For each of the four quadrants, labeling starts at the district adjacent to the origin.This becomes the first district of that quadrant.This is continued horizontally away from the origin and we label each district in a row.For the first quadrant A,labeling is done from West to East and then move to North to the next row.For the second quadrant B,labeling is done from East to West and then move North to the next row. For the third C,labeling is done from East to West and then move South to the next row. The fourth quadrant D, labeling is done from West to East and then move South to the next row.The map(Figure

5.2 in appendix B) shows the results of the labeling scheme.

4.1.3 DIGITIZING THE CREATED DISTRICTS

The districts that have been created can be defined by the set of its corner point vertices. Each of these vertices has its longitude and latitude coordinates. And with the help of google maps, www.maps.google.com, the longitude and latitude coordinates for each vertex of each district can be determined. The longitudelatitude coordinates of the vertices of each district can be recorded on a table.

An example for district A1 is in table 4.4 as follows:

Table 4.4: Coordinates of Vertices of A1

District	Vertex	Longitude	Latitude
A1	NE vertex	-1.592417	6.746127
	NW vertex	-1.627436	6.746127
	SW vertex	-1.627436	6.711022
	SE vertex	-1.592417	6.711022

The vertices are ordered to make sure that they represent enclosed regions (districts), that is why we end with the vertex we started with. Now with a set of longitude-latitude coordinates, defining each district, the boundary equations and inequalities of the lines between the vertices of each district can also be defined.

4.1.4 BOUNDARY EQUATIONS AND INEQUALITIES

Geographic points are expressed in terms of latitude-longitude coordinates, that is the convention.But in this work, we have expressed it in terms of longitude-latitude coordinates so that it matches the convention of the Cartesian coordinates.The longitudes correspond to x-values and the latitudes correspond to y-axis.

Now the equation of the line between the coordinates (x_1,y_1) and (x_2,y_2) is given by

$$\left(\frac{y-y_1}{x-x_1}\right)=\left(\frac{y_2-y_1}{x_2-x_1}\right)$$ where (x , y) is a general point

$$y=\frac{y_2-y_1}{x_2-x_1}\times(x-x_1)+y_1$$

The inequalities of each boundary of a particular district needs to be created, and used in sorting out the incident data obtained from the Kumasi City Fire Department.

Table 4.5: Boundary Equation for District A1

District	Vertex	Equation
A1	North East	
	North West	y= 6.746125
	South West	y= -1.627436
	South East	y= 6.711022
	North East	y= -1.592417

Each boundary equation (for example that of A1 in table 4.5) is associated with a particular cardinal boundary with the inequality that ensures that an enclosed district is captured. The governing factor of the inequality is the sign of the slope.

Walls (2012) .The table 4.6 shows the cardinality-slope relationships.

Table 4.6: Cardinality slope relationship

Cardinality	Positive slope	Negative slope
North	≤	≥
South	≥	≥
East	≥	≤
West	≤	≥

Using district A1 as an example, we have the following inequalities in table 4.7:

4.1.5 THE DISTRICT CENTERS

Reducing the district centers to a single latitude-longitude coordinate gives us a district center. There are three classes of centers, they are the geographic center, the demand center and weighted center .All these centers are to be determined.

Table 4.7: The Inequalities For Boundary of District A1

District	Vertex	Cardinality	Inequalities
A1	North East		
	North West	North	$y \leq 6.746125$
	South West	West	$x \geq -1.627436$
	South East	South	$y \geq 6.711022$
	North East	East	$x \leq -1.592417$

Geographic Centers

The geographic center in this work is defined as the mean of the latitude- longitude coordinates of the district vertices. Since the vertices of each district is known we can calculate the geographic center of each district. The geographic center for district A1 is shown in table 4.8.

Table 4.8: Geographic Center of District A1

District	Vertex	Latitude	Longitude
A1	North East	6.746127	-1.592417
	North West	6.746127	-1.627436

	South West	6.711022	-1.627436
	South East	6.711022	-1.592417
Geographic Center		6.7285745	-1.6099265

The table 5.1 in appendix A shows the geographic centers of all the Districts and figure 5.3 in appendix B shows the map of the geographic districts centers.

Demand Centers

The demand center is defined as the mean of the latitude-longitude coordinates of all the incidents that have occurred within a district over the past several years. From the data of all incidents obtained from the Kumasi Fire Department starting from January 2005 to March 2015. The total demand center for each district can be calculated from the yearly incidents results from the data in table

4.9 .

Table 4.9: Yearly Incidents of Fire outbreaks within Kumasi City

Year	Period	Number of Fire Incidents
2005	Jan-Dec	384
2006	Jan-Dec	335
2007	Jan-Dec	465
2008	Jan-Dec	419
2009	Jan-Dec	423

2010	Jan-Dec	459
2011	Jan-Dec	469
2012	Jan-Dec	527
2013	Jan-Dec	614
2014	Jan-Dec	514
2015	Jan-March	415
Total	10 years	5024

MATLAB is used to calculate the mean of the latitude- longitude within each of the districts. The table 5.2 in appendix A contains the demand centers of all the districts and figure 5.4 in appendix B shows the map of the demand centers. Districts B2 and B3 do not have demand centers since there were no incidents during the 10 year period.

Weighted Centers

A linear combination of the demand and geographic centers gives the weighted center.The weighted center is therefore defined as

$WeightedCenter = (1 - P) * GeoCenter + P * DemandCenter$ (4.1) Where P is the proportionality constant and given by

$$P = \frac{Number \quad of \quad incidents \quad in \quad a \quad district}{total \quad number \quad of \quad incidents \quad in \quad all \quad districts} \quad (4.2)$$

Now with the total number of incidents as 5024 and the number of incidents in each district known, the proportionality constant P can be calculated and the results are as shown in the table 5.3 in appendix A. With the information in the table 5.3, the weighted centers of all the districts can also be calculated. The table 5.4 in appendix A displays them and figure 5.5 in appendix B shows the map.

4.1.6 TRAVEL TIME DETERMINATION

Travel time is defined‘ as the time that a vehicle uses to move from one place to another on the road system. It depends on many variables.Some of the variables are the qualities of the roads,the number of intersections on the road system,the traffic conditions on the road system, etc.Congestion on the road system can lead to longer travel times.Factors that affect traffic include the time of day, the day the week, and the time of the year. The data on travel time when requested from the fire department was not available, so we decided to use the google maps.Google provides direction services with google maps ?. Google maps direction services helps to determine between two locations an estimated driving distance and travel time. So in this work we are using the travel time estimate provided by Google maps as the travel time between each fire station and each district center, The following figure(inserted) displays Google maps calculating the travel time between one fire station S1 and the geographic center of district A1.

The distances between each origin and their destination are measured in miles and the travel times are measured in minutes. Since we have 9 fire station sites and 21 districts the time matrix for each of the geographic center ,the demand center and weighted center has 21 rows and 9 columns, with each row of the matrix corresponding to a specific district and each column corresponding to a specific fire station site. The travel time results for these centers are listed in these three tables in appendix A 5.5,5.6 and 5.7 .

4.2 THE CURRENT COVERAGE OF KUMASI CITY FIRE DEPARTMENT

With the time matrices obtained earlier , this can help us to examine the current coverage of Kumasi City Fire Department. The number of districts that are within four minutes of the existing fire stations, stations S1 to S6 can be determined. The maximum travel time at which these stations cover all the 21 districts can also be determined.

4.2.1 MEAN TRAVEL TIME

The mean travel time between the geographic, demand and weighted centers and the existing six fire stations respectively is what we will consider. The mean travel time for the stations are rounded to the nearest integer value and displayed in the tables 5.8,5.9,5.10 and 5.11 in appendix A. The Mean Travel Times from Stations S1 to S6 to Districts (in minutes) are displayed in tables 5.8 ,5.9, 5.10, and 5.11 in appendix A and are captioned Quadrants A,B,C and D.

4.2.2 CURRENT COVERAGE

A district is said to be covered by a fire station if the travel time between the station and the district is four minutes or less. A district is therefore not covered when the travel time is greater than four minutes. The tables 5.12,5.13,5.14 and 5.15 in appendix A are created to represent covered districts with a value of 1(one) and non-covered districts with a value of 0(zero).These tables 5.12,5.13,5.14 and 5.15 display the districts that are currently covered by stations S1 to S6 of the Kumasi City Fire Department at a 4 minutes travel time.

From the tables 5.12,5.13,5.14 and 5.15 stations S1 and S2 covers districts D8 and D5 respectively. Station S4 covers districts D5 and D1 whilst station S5 covers districts A1 and C1 . Each of the Stations S3 and S6 could not cover one whole district at the 4-minute travel time.

Thus the current coverage at a 4-minute travel time of the Kumasi City Fire Department is 6 districts out of the 21 districts. This implies that approximately 29 percent of the districts are within 4-minutes of the existing fire stations. The maximum travel time at which the six existing fire stations ,S1 to S6 cover all the district can be determined. The tables showing the mean travel time from stations(S1 to S6) to districts can be examined at one increments starting from 5 minutes to 10 minutes so that we calculate the number of districts that stations S1 to S6 cover at each interval.

The number of districts that the six existing fire stations can cover respectively at the maximum travel times 5,6,7,8,9,10 are displayed in the table 5.16 in appendix A. To compare we have included the result for 4-minute travel time. At a maximum travel time of 10 minutes none of the fire stations could cover onethird of the all the 21 districts .Station S5 covered 5 districts followed by both stations S4 and S2 which covered 4 districts followed by station S3, 3 districts followed by station S1, 2 districts and lastly station S6 covered less than 1 district, at the 4 minute maximum standard travel time.

Now assuming no two or more fire stations cover the same district, then for a 4 minute maximum travel time only 6 districts will be covered , but 21 districts needs to be covered. Since this thesis seeks to ensure that the response time is not more than 4 minutes travel time, the analysis is so clear that the City of Kumasi needs more fire stations to be added to the existing six fire stations. According to the Chief Fire Officer at at the City Fire Station near KMA,the response time is actually 6 minutes , 4 minutes travel time plus a 2 minute roll out time. Now the next thing to do is to solve the integer programming model and determine how many additional fire station are needed to maintain the standard of 4 minute maximum response time.

4.3 SOLVING FOR THE INTEGER PROGRAM

Application of binary linear programming can be found in many fields such as scheduling, production planning,networking and etc.Unlike linear programming problems,binary integer programming problem is more difficult to solve since its variables must be a binary number, zero or one.Thus,solving binary integer programming problems efficiently the following approaches can be used,Balas Additive Method,Gomory Cutting Plane Method,bintprog,Reflin et al. (2014). From the third chapter of this thesis the following general binary integer programming model was obtained.

Minimise $\sum_{x_j \in F} x_j$

Subject to: $\sum_{x_j \in C_i} x_j \geq 1$ *forall* $i = 1,2,...,m$ $x_j = 0$ *or* 1 for all $j =$ 1,2,...,n

These are the definitions from which the above integer programming model was obtained: The set of all district centers is $D = \{d_i\}$for $i = 1,...,m$;the set of fire station sites is $F = \{x_j\}$for $j = 1,....,n$; the travel time between district centers d_i and fire station x_j is t_{ij} ; and S is the maximum travel time

; the set $C_i = \{x_j|t_{ij} \leq S\}$ is the set of fire stations sites that cover the district d_i.Now applying the integer programming model to the Kumasi City. We have $F = \{x_j\}$ for j = 1,....,9 ,since we have 9 fire station sites.There are 21 districts so $D = \{d_i\}$ for

$i=1,....,21$. Taking a maximum travel time to be 4 minutes,$S = 4$ and we have $C_i = \{x_j|t_{ij} \leq 4\}$ *for* $i = 1,....,21$.

With these conditions for the Kumasi City, the specific model for the city will be as follows: Minimise $\sum_{x_j=1}^{9} x_j$

Subject to: $\sum_{x_j \in C_i} x_j \geq 1$ *for all* $i = 1,2,...,21$ $x_j = 0$ *or* 1 for all $j = 1,2,...,9$ If each set C_i is considered as a

row vector, we can write the condition $\sum_{x_j \in C_j} x_j$ for all $i = 1,...,21$ as a system of inequalities of the $C_i \tilde{x} \geq 1$ where $\tilde{x}$ is a column vector of the the

$x0js$.

We define the matrix A as

□ □

C_1

□ □

□ □

□ □

□$C2$□ □

□

A = □ □

□ □

□ □

□ ... □

□ □

□ □

□ □

C_{21}

If column vector $\tilde{B}$ is also defined as

$\tilde{B} = [111111111111111111111]^T$,

then we can write the coverage condition as $\tilde{A}x \geq \tilde{B}$. So therefore the model can be represented in the following compact form:

Minimise $\sum_{j=1}^{9} x_j$

Subject to: $\tilde{A}x \geq \tilde{B}$

$x_j = 0$ *or* 1 for all $j = 1,2,...,9$

The form of the model can be translated into MATLAB.

TRANSLATING THE MODEL INTO MATLAB

To solve linear programs in MATLAB there is optimization toolbox that contains functions to help you to do so .The function that solves binary integer programs is called bintprog. The binary integer program must have the following form:

□

□□□□ $\tilde{A}x \leq \tilde{B}$

□□

$\min_x f^T \tilde{x}$ *such that* □ $A_{eq}\tilde{x} = \tilde{B}_{eq}$ (4.3)

□□

□□□□□$\vec{x}$ binary

where f^T is the objective function, MathWorks (2011), A is the inequality constraint matrix, A_{eq} is the equality constraint matrix, $\tilde{B}$ is the inequality constraint vector and $\vec{B}_{eq}$ is the equality constraint vector.

So the integer programming model has to be transformed to fit the bintprog format. The model has the inequality constraint $A\vec{x} \geq \tilde{B}$ whereas the bintprog function requires the inequality constraint $A\vec{x} \leq \tilde{B}$ therefore the inequality constraint of the model must be multiplied by negative one to comply with bintprog.

Thus the MATLAB ready binary integer programming model is

Minimise $\sum_{j=1}^{9} x_j$

Subject to: $-A\vec{x} \geq -\tilde{B}$

$x_j = 0$ *or* 1 for all $j = 1,2,...,9$

The constraint matrix A for all three district centers then needs to be determined. With the time matrix for each district already determined MATLAB can help us to transform these matrices into logical condition. Each cell of a logical matrix is either 1 if it satisfies the logical condition or 0 if the entry does not satisfy the logical condition. We therefore have the following condition: $T_4 = T \leq 4$ where T_4 is a logical matrix and T is the travel time matrix for each of the district centers that is the geographic, demand and weighted centers. The logical matrices tables 5.17, 5.18 and 5.19 in appendix A display the number of fire stations that cover each district and the number of districts that each fire station covers. These logical matrices mentioned show clearly that there are several of the districts that are not covered by the nearest fire stations at the 4-minute maximum travel time. A careful study of these matrices indicates that for the geographic center, the districts that are not covered are A2 and A4 in the first quadrant,B1 and B3 in the second quadrant, only C4 in the third quadrant and D2, D3, D4, D6, D7, D9 and D10 in the fourth quadrant. This is also the same for the demand center and the weighted center. So there as many as seven districts in the fourth quadrant that are not covered at a 4-minute travel time. The nearest fire stations within the fourth quadrant are KNUST fire station and Chirapatre fire station (regional headquarters) but the analysis shows that this fourth quadrant will still need at least one fire station to be added, specifically around the western part of the Chirapatre fire station and the north eastern part of KNUST fire station, for the 4-minute travel time standard to be achieved. To cover A2 and A4 a station can be sited within these two districts. The same applies to B1 and B3 .

In order to help cover the uncovered districts at a 4-minute travel time, the logical matrix for each center types can be adjusted so that none of the matrices contain a row of zeros.So tables 5.20,5.21 and 5.22 in appendix A are the tables of the adjusted logical matrix for each center type.

The bintprog function can now be used to solve the integer program.

EXAMPLES OF SOLVING AN INTEGER PROGRAM USING

bintprog function To

minimise the function

$$f(x) = -9x_1 - 5x_2 - 6x_3 - 4x_4$$

Subject to the constraints:

$$6x_1 + 3x_2 + 5x_3 + 2x_4 \leq 9$$
$$x_3 + x_4 \leq 1$$

$$-x_1 + x_3 \leq 0$$

$$-x_2 + x_4 \leq 0$$

. where x_1, x_2, x_3 and x_4 are binary integers.

This integer program above can be solved in MATLAB by entering the following commands:

$f = [-9; -5; -6; -4]$;

$A = [6\ 3\ 5\ 2; 0\ 0\ 1\ 1; -1\ 0\ 1\ 1; 0\ -1\ 0\ 1]$; $b = [9; 1; 0; 0]$

$x = bintprog(f, A, b)$

$x = [1\ \ 1\ \ 0\ \ 0]^T$

Now for the integer programming model for the Kumasi City,

Minimise $\sum_{j=1}^{9} x_j$

Subject to: $-A\tilde{}x \leq -\tilde{}B$

$x_j = 0$ *or* 1 for all $j = 1,2,...,9$

We enter the following commands in MATLAB to obtain the results in the table below:

f= [1; 1; 1; 1; 1; 1; 1; 1; 1]

B = [1 ;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;;1;11; 1]

$b = -B\ \theta$

$= \quad -A;$

where A is the constraint logical matrix for all the three district centers

$x = bintprog(f, \quad \theta, \quad b)$

(4.4)

This table 5.23(see appendix A) gives the solution of the model of the Kumasi City . A value of 1(one) indicates that , that station is used while a value of 0(zero) indicates otherwise.A station is considered very reliable and it is therefore selected when the solution of each of the three center types indicates a value of 1(one).If the solution of only two of the center types indicates a value of 1(one),we consider the selection of that station to be reliable.The selection of a station is considered to be weak if the solution of only one or none of the center types indicates a value of 1(one).The table then shows the minimum combination of fire stations needed to cover all of the Kumasi City a maximum travel time of 4- minutes.

From the MATLAB results in table 5.23 in appendix A where the logical matrices helped to provide these solutions,the fire stations S1,S2,S3,S4,S5 and S6 have their results indicating 0(zero) for all the three center types. This is the same for stations S7,S8 and S9.This shows that the six existing fire stations are not reliable even though they have already been built.

The unreliable fire stations cannot be closed due to lack of infrastructure and also the huge cost involve in building new ones.We therefore assume that the stations that are already built are not included in the solution since we seek to determine only where new stations should be built while utilizing the existing infrastructure of the fire department.

To improve the system, the logical matrix for each center type was adjusted so that none of the matrices contain a row of zeros. So using the adjusted logical matrix we enter the following commands in MATLAB to obtain new solutions:

f = [1; 1; 1; 1; 1; 1; 1; 1; 1]

B = [1 ;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;;1;1;1; 1]

$b = -B$

$A = -\alpha$

where α is the constraint logical matrix for all the three district centers

$x = bintprog(f, A, \quad B)$

(4.5)

The adjusted logical matrix results obtained in table 5.24(see appendix A) using MATLAB is an improvement of the one from the logical matrix in table 5.23(see appendix A).The table 5.24 results shows that all the nine stations are very reliable since all the three center types indicate a value of 1(one).And therefore the Kumasi City will need a minimum of 9(nine) fire stations to cover it at a maximum travel time of 4 minutes.

STATIONS PRIORITIZATION SCHEME

A priorization of the fire station sites that reduces the maximum travel time required to cover all of the districts after the addition of each new station can be determined.

ADDING THE MOST RELIABLE STATION ONE AT A TIME

The six existing fire stations that currently serve the whole of the Kumasi City are S1,S2,S3,S4,S5 and S6.Three more fire stations S7 ,S8 and S9 have also been proposed in this work to be added to the six stations .Since all the three stations cannot be built at the same time due to lack of funds there is the need to find out the order in which they are to be built so that it will most benefit the City. In table 4.10 and table

4.11, the percentage of coverage of the districts by each fire station before and after the adjustment have been displayed and they will help us very much.

This thesis seeks to determine which of the stations when added to the six Table 4.10: Coverage Before the Adjustment

STATIONS	DISTRICTS COVERED	PERCENTAGE OF COVERAGE
S1	1	4.76
S2	1	4.76
S3	0	4.76
S4	2	9.52
S5	2	9.52
S6	0	4.76
S7	1	4.76
S8	0	4.76
S9	3	14.28
Total	10	47.6

existing ones will improve the system so that the response time of the fire department will be 4 minutes.In table 4.11 Stations S1,S2,S3,S4,S5 and S6 have respectively these percentages of coverage of the districts at a maximum travel time of 4 minutes 9.52,14.28,9.52,14.28,9.52 and 19.04. Stations S7,S8 and S9 also covers respectively these percentages 4.76,9.52 and 14.28.The increase in coverage provided by the addition of stations S7 ,S8 and S9 are shown in table 4.12. From table 4.12, the station S9 increases the coverage to 90.44% .So S9 is selected as the first fire station to be built.The next station to be added to the combination(S1,S2,S3,S4,S5,S6,S9) is also shown in table 4.13.

The second station to be selected and built is the one with the highest percentage of coverage.So station S8 is the next to added since its percentage of coverage is 99.96% . The third station that is to be added must be station S7. This station will increase the coverage to over 100% . Thats is 104.72%. This means that the addition of station S7 will help cover all of Kumasi and beyond. The table 4.14 summarises the implementation(stations priority) scheme

The six existing fire stations cover about 28.57% of the districts created within Kumasi City at a 4 minutes standard travel time before the adjustment of the logical matrix.Now after the adjustment of the logical matrix,the six stations Table 4.11: Coverage After the Adjustment

STATIONS	DISTRICTS COVERED	PERCENTAGE OF COVERAGE
S1	2	9.52
S2	3	14.28
S3	2	9.52
S4	3	14.28
S5	2	9.52
S6	4	19.04
S7	1	4.76
S8	2	9.52
S9	3	14.28
	22	104.72

Table 4.12: INCREASE IN COVERAGE:six stations plus one(% of Districts)

STATIONS	COVERAGE(% of total Districts)

S1,S2,S3,S4,S5,S6	76.16
S1,S2,S3,S4,S5,S6,S7	80.92
S1,S2,S3,S4,S5,S6,S8	85.68
S1,S2,S3,S4,S5,S6,S9	90.44

cover 76.16% .But with the addition of each of these proposed stations S9,S8 and S7,the Kumasi Fire Department is able to cover 104.72% of the districts ,that is the whole of Kumasi and beyond.So station S9 needs to be built first followed by station S8 and then finally by station S7.

Table 4.13: INCREASE IN COVERAGE:six stations plus S9 plus one(% of Districts)

STATIONS	COVERAGE(% of total Districts)
S1,S2,S3,S4,S5,S6,S9	90.44
S1,S2,S3,S4,S5,S6,S9,S7	95.2
S1,S2,S3,S4,S5,S6,S9,S8	99.96

Table 4.14: THE STATIONS IMPLEMENTATION SCHEME AT 4 MINUTES TRAVEL TIME

Number of Stations	Stations	% of Districts Covered
Six	S1,S2,S3,S4,S5,S6	76.16
Seven	S1,S2,S3,S4,S5,S6,S9	90.44
Eight	S1,S2,S3,S4,S5,S6,S9,S8	99.96
Nine	S1,S2,S3,S4,S5,S6,S9,S8,S7	104.72

CHAPTER 5

CONCLUSION

In this thesis there were three main objectives that we set ourselves to achieve,the first was to determine whether or not there is the need for additional fire stations in the Kumasi City, the second was determining the minimum combination of the fire station sites that covers all Kumasi at a four minute travel time and the third was to propose a station priority scheme.

In the fourth chapter of this thesis it has been made clear that the city of Kumasi needs additional fire stations since almost 29% of the districts are within 4 minutes of the existing six fire stations.After the addition of the three(3) proposed stations,the percentage of coverage of the six stations rose to 76.16% and that of the nine(9) stations was 104.72%. Therefore the Kumasi City Fire Department is able to cover all of Kumasi and beyond at a 4 minutes standard travel time.In this same chapter is also the solving of the binary integer programming model,using bintprog which is a function in Matlab optimization toolbox. The solution shows that a minimum of nine(9) fire stations is needed to cover the whole of the Kumasi

City.

To incrementally improve the coverage of the Kumasi City Fire Department a station implementation scheme was made to indicate which stations should be added to the six existing ones. The first station that should be built is station S9,the station site beside UEW-K at latitude 6.698131 and a longitude -1.686326.This station in addition to the six existing ones will cover 90.44% of the districts in Kumasi. Station S8 is the next station to be built at Buokrom Estate at latitude 6.739015 and longitude -1.585980.The addition of S8 increases the coverage of the Fire Department to 99.96%

of the districts.The third station S7 is to be built at Bohyen at latitude 6.7209012 and longitude -1.6619288. This also increases the coverage to 104.72% .

With the additions of the three(3) proposed fire stations the percentage of coverage of the districts has shot from approximately 29% to 104.72% at a 4 minute travel time. So truely the Kumasi City needs additional fire stations, since there has been a significant improvement of the coverage of the 21 districts. As the City grows the coverage of the Fire Department diminishes, so the city must put up plans to provide at least three(3) fire stations, in order to save precious lives and property .

5.0.1 Recommedations

In order to improve on the services of the Kumasi City Fire Department , I would like to recommend the following for the Kumasi City Authorities to implement.

1. Not less than three fire stations should be built to be added to the six existing ones.

2. The stations should be built in this order,station S9 followed by station S8 and then station S7.

3. Each fire station should have at least two fire fighting vehicles.

4. Only one fire fighting vehicles should be seen at each fire station at a time and the other vehicle(s) must always be battle ready positioned at salient points where demands are mostly high within each stations area of operation.

REFERENCES

Academy, F. and School, T. (1997). A brief history of ghana natioal fire service.

Amo-Asante, K. (2012). Location of two fire stations in five sub-metros of the kumasi metropolis. Master's thesis, Kwame Nkrumah University of Science and Technology.

Chaiken, J. M. and Larson, R. C. (1972). *Methods for allocating urban emergency units: A survey*. *Management Science*, volume 19. Abdullah Gul University, Industrial 401. Lecture Material.

Charles Revelle, D. M. and Liebman, J. C. (1970). An analysis of private and public sector location models. *Management Science*, 16(11):692–707.

Daskin, M. S. (2008). What you should know about location model. *Naval Research Logistics(NRL)*, 55(4):283–294.

GEOHIVE (2015). The population of ghana.

GNA (2011). Gnfs to change mandate. *Ghana Business News*.

Hogg, J. M. (1968). The siting of fire stations. *Operations Research Society*, 19:275–287.

Kolesar, P. (1975). A model for predicting average fire engine travel times. *Operations Research*, 24(4):603–613.

Kolesar, P. and Blum, E. H. (1973). *Square root laws for fire engine response distances. Management Science*. Number 1368-1378. INFORMS.

MathWorks (2011). Matlab. *Journal - American Water Works Association*,

Version 7.12.0.0635(r2011a).

NAOED (2015). History of fire fighting. *A Journal of Emergency Dispatch*, 2(5):34–38.

Reflin, E., Octarina, S., Putra Bangun and, C. R. A., and Zulvia, F. (2014). Substituting gomory cutting plane method towards balas algorithm for solving binary linear programming. *Asian Journal of Mathematics and Applications*, 2014(Article ID ama0156):11 pages.

Revelle, C. and Eiselt, H. (2005). Location analysis: A synthesis and survey. *European Journal of Operation Research*, 3(5):23–25.

Toregas, R., S., C., R., and L, B. (1971). The location of emergency service facilities. *Operations Research*, 19(6):1363–1373.

Walls, R. (2012). A binary integer programming model for the optimal location of fire stations: A case study of murray,ky. Master's thesis, Murray State University.

www.google.com/maps

http://firechief.iso.com/FCWeb/mitigation/securedocs/fsrs/ppc400.jsp;2007

www. en.wikipedia/wiki/GhanaNationalFireService

www.fireservice.info.com/history.html

www.historyforkids.org/learn/science/fire2.html

our.wikipedia.org/mike/Ghana.National.Fire.and.Rescue.Service

APPENDIX A

Table 5.1: Geographic Centers

District	Latitude	Longitude
A1	6.7285745	-1.6099265
A2	6.74029675	-1.578083
A3	6.73986875	-1.5467545
A4	6.7585205	-1.6099265
B1	6.740968	-1.6540325
B2	6.7285745	-1.70616175
B3	6.77527275	-1.69781025
C1	6.698698	-1.6540325
C2	6.682172775	-1.70128825
C3	6.6703093	-1.653850775
C4	6.6434743	-1.64953525
D1	6.6987005	-1.6099205
D2	6.6804073	-1.678083
D3	6.6804073	-1.5467545
D4	6.6680998	-1.5251885
D5	6.6886025	-1.6099265

D6	6.7790263	-1.6099265
D7	6.6421023	-1.6099265
D8	6.6434743	-1.578083
D9	6.64614655	-1.5467545
D10	6.6474468	-1.5264466

Table 5.2: Demand Centers

District	Latitude	Longitude
A1	6.721033	-1.601234
A2	6.732035	-1.581215
A3	6.743205	-1.5467545
A4	6.756196	-1.599911
B1	6.715591	-1.635531
B2		
B3		
C1	6.688124	-1.635420
C2	6.686379	-1.700152
C3	6.6666245	-1.641125
C4	6.641241	-1.639901
D1	6.699483	-1.619992
D2	6.660245	-1.575549

D3	6.686379	-1.555299
D4	6.652231	-1.513214
D5	6.687710	-1.609234
D6	6.653014	-1.615423
D7	6.641241	-1.609231
D8	6.648235	-1.5800345
D9	6.640021	-1.555553
D10	6.642021	-1.500192

Table 5.3: District Proportions

District	Number of Incidents	P	1- P
A1	300	0.0597	0.9403
A2	150	0.0299	0.9701
A3	10	0.0020	0.9980
A4	70	0.0139	0.9861
B1	190	0..378	0.9622
B2		0	1
B3		0	1
C1	500	0.0995	0.9005
C2	440	0.0876	0.9124
C3	483	0.0961	0.9039

C4	90	0.0179	0.9821
D1	800	0.1592	0.8408
D2	400	0.0796	0.9204
D3	62	0.0123	0.9877
D4	40	0.0080	0.9920
D5	605	0.1204	0.8796
D6	510	0.1015	0.8985
D7	100	0.0199	0.9801
D8	194	0.0386	0.9614
D9	70	0.0139	0.9861
D10	10	0.0020	0.9980

Table 5.4: Weighted Centers

District	Latitude	Longitude
A1	6.7285	-1.6094
A2	6.7398	-1.5782
A3	6.7398	-1.5468
A4	6.7587	-1.6098
B1	6.7401	-1.6533
B2	6.7286	-1.7062
B3	6.7753	-1.6978

C1	6.6978	-1.6522
C2	6.6824	-1.7012
C3	6.6702	-1.6526
C4	6.6435	-1.6494
D1	6.6991	-1.6115
D2	6.6789	-1.5592
D3	6.6808	-1.5469
D4	6.6677	-1.55251
D5	6.6886	-1.6098
D6	6.7663	-1.6105
D7	6.6421	-1.6099
D8	6.6438	-1.5782
D9	6.6463	-1.5782
D10	6.6474	-1.5264

Table 5.5: GEOGRAPHIC CENTRE TIME MATRIX(minutes)

Districts	S1	S2	S3	S4	S5	S6	S7	S8	S9
A1	31	16	14	10	3	21	19	16	18
A2	24	19	20	13	15	24	8	24	25
A3	28	22	24	16	19	27	4	28	29
A4	25	19	16	15	1	30	21	20	21

B1	24	18	15	18	14	35	29	7	15
B2	28	17	16	17	14	29	30	8	4
B3	30	20	18	20	17	37	31	9	18
C1	17	10	7	9	4	23	22	9	8
C2	22	15	11	15	12	27	28	14	2
C3	25	18	14	18	15	30	31	16	4
C4	26	21	18	22	19	34	35	23	18
D1	14	8	11	1	7	19	15	16	17
D2	18	13	14	7	9	18	17	31	32
D4	20	17	19	19	21	13	19	28	26
D5	11	4	8	4	7	17	19	15	15
D6	9	6	6	13	12	20	28	17	14
D7	14	14	14	20	20	27	36	25	22
D8	4	13	16	18	20	17	33	25	25
D9	14	21	24	24	27	15	28	32	31
D10	15	18	21	21	24	12	25	29	28

Table 5.6: DEMAND CENTER TIME MATRIX(minutes)

Districts	S1	S2	S3	S4	S5	S6	S7	S8	S9
A1	31	16	13	9	3	21	19	16	18
A2	24	19	21	14	15	24	8	24	25

A3	28	21	24	16	19	27	3	28	29
A4	24	19	15	15	11	31	21	20	21
B1	24	18	16	18	14	35	24	8	15
B2	28	17	18	17	14	29	30	8	3
B3	30	20	8	18	17	37	31	9	18
C1	17	9	11	7	4	23	2	10	8
C2	21	15	14	11	12	27	28	14	3
C3	25	18	18	14	15	30	31	16	4
C4	26	20	10	19	19	34	34	23	18
D1	14	9	14	10	7	19	14	16	17
D2	18	12	23	13	9	18	17	18	19
D3	24	21	20	23	23	17	18	31	32
D4	20	17	9	19	20	13	19	28	26
D5	10	4	4	4	6	17	19	15	14
D6	8	4	16	13	12	20	28	17	14
D7	15	14	14	20	20	27	36	25	14
D8	3	13	16	18	20	17	33	24	23
D9	14	20	23	24	27	15	28	32	30
D10	15	18	21	21	23	12	24	29	28

Table 5.7: WEIGHTED CENTER TIME MATRIX(minutes)

District	S1	S2	S3	S4	S5	S6	S7	S8	S9
A1	31	15	12	9	4	21	19	16	18
A2	23	19	21	14	15	24	8	24	25
A3	28	21	15	16	19	27	3	28	29
A4	24	19	16	15	10	31	21	20	21
B1	24	18	18	18	14	34	29	8	15
B2	27	17	18	17	14	29	30	8	3
B3	30	20	9	17	17	37	31	9	18
C1	17	9	11	7	4	23	2	10	8
C2	21	15	14	11	12	27	28	14	3
C3	25	18	18	14	15	30	31	16	4
C4	26	20	10	19	19	34	34	23	17
D1	14	9	14	10	7	19	14	16	17
D2	18	12	23	13	9	18	17	18	19
D3	24	21	20	23	23	17	18	31	32
D4	20	17	9	19	20	12	19	28	20
D5	10	3	4	4	6	17	19	15	14
D6	8	4	16	13	12	20	28	17	14
D7	15	14	15	20	19	27	35	25	22
D8	3	13	16	18	20	17	33	24	23

D9	13	20	23	23	27	15	28	32	29
D10	15	18	20	21	23	12	24	29	28

Table 5.8: Quadrant A

District	S1	S2	S3	S4	S5	S6
A1	31	16	14	10	3	21
A2	24	19	20	13	15	24
A3	28	22	24	16	19	27
A4	25	19	16	15	11	30

Table 5.9: Quadrant B

District	S1	S2	S3	S4	S5	S6
B1	24	18	15	18	14	35
B2	28	17	16	17	14	29
B3	30	20	18	20	17	37

Table 5.10: Quadrant C

District	S1	S2	S3	S4	S5	S6
C1	17	10	7	9	5	23
C2	22	15	11	15	12	27
C3	25	18	14	18	15	30
C4	26	21	18	22	19	34

Table 5.11: Quadrant D

District	S1	S2	S3	S4	S5	S6
D1	14	8	11	1	7	19
D2	18	13	14	7	9	18
D3	24	21	23	20	23	17
D4	20	17	19	19	21	13
D5	11	5	8	4	7	17
D6	9	6	6	13	12	20
D7	15	14	14	20	20	27
D8	4	13	16	18	20	17
D9	14	21	24	24	27	15
D10	15	18	21	21	24	12

Table 5.12: Quadrant A

District	S1	S2	S3	S4	S5	S6
A1	0	0	0	0	1	0
A2	0	0	0	0	0	0
A3	0	0	0	0	0	0
A4	0	0	0	0	0	0

Table 5.13: Quadrant B

District	S1	S2	S3	S4	S5	S6

B1	0	0	0	0	0	0
B2	0	0	0	0	0	0
B3	0	0	0	0	0	0

Table 5.14: Quadrant C

District	S1	S2	S3	S4	S5	S6
C1	0	0	0	0	1	0
C2	0	0	0	0	0	0
C3	0	0	0	0	0	0
C4	0	0	0	0	0	0

Table 5.15: Quadrant D

District	S1	S2	S3	S4	S5	S6
D1	0	0	0	1	0	0
D2	0	0	0	0	0	0
D3	0	0	0	0	0	0
D4	0	0	0	0	0	0
D5	0	1	0	1	0	0
D6	0	0	0	0	0	0
D7	0	0	0	0	0	0
D8	1	0	0	0	0	0

D9	0	0	0	0	0	0
D10	0	0	0	0	0	0

Table 5.16: Number of District covered at 4-10 minutes travel time

Maximum Travel Time	S1	S2	S3	S4	S5	S6	Districts
4	1	1	0	2	2	0	6
5	1	1	0	2	2	0	6
6	1	2	1	2	2	0	8
7	1	2	2	3	4	0	12
8	1	3	3	3	4	0	14
9	2	3	3	4	5	0	17
10	2	4	3	4	5	0	18

Table 5.17:

Districts Covered	1	1	0	2	2	0	1	0	3

GEOGRAPHIC CENTER LOGICAL MATRIX: G– Table 5.18: DEMAND

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
A1	0	0	0	0	1	0	0	0	0	1
A2	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0	0	0	1	0	0	1
A4	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	0	0	0	0	0	0	0
B2	0	0	0	0	0	0	0	0	1	1
B3	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	1	0	0	0	0	1
C2	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	0	0	0	1	1
C4	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	1	0	0	0	0	0	1
D2	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0	0	0
D5	0	1	0	1	0	0	0	0	0	2
D6	0	0	0	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	0	0	0	0
D8	1	0	0	0	0	0	0	0	0	1
D9	0	0	0	0	0	0	0	0	0	0
D10	0	0	0	0	0	0	0	0	0	0
Districts Covered	1	1	0	2	2	0	1	0	3	

CENTER LOGICAL									
Districts Covered	1	1	0	2	2	0	1	0	3

Districts Covered 1 1 0 2 2 0 1 0 3

MATRIX:D_4 Table 5.19: WEIGHTED CENTER LOGICAL MATRIX:W_4

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
A1	0	0	0	0	1	0	0	0	0	1
A2	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0	0	0	1	0	0	1
A4	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	0	0	0	0	0	0	0
B2	0	0	0	0	0	0	0	0	1	1
B3	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	1	0	0	0	0	1
C2	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	0	0	0	1	1
C4	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	1	0	0	0	0	0	1
D2	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0	0	0
D5	0	1	0	1	0	0	0	0	0	2
D6	0	0	0	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	0	0	0	0
D8	1	0	0	0	0	0	0	0	0	1
D9	0	0	0	0	0	0	0	0	0	0
D10	0	0	0	0	0	0	0	0	0	0

Table 5.20: GEOGRAPHIC

Districts Covered	2	3	2	3	2	4	1	2	3

CENTER ADJUSTED									
Districts Covered	2	3	2	3	2	4	1	2	3

LOGICAL									

Districts Covered	2	3	2	3	2	4	1	2	3

MATRIX: AG_4 Table 5.21: DEMAND CENTER ADJUSTED LOGICAL

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
A1	0	0	0	0	1	0	0	0	0	1
A2	0	0	1	0	0	0	0	0	0	1
A3	0	0	0	0	0	0	1	0	0	1
A4	0	0	1	0	0	0	0	0	0	1
B1	0	0	0	0	0	0	0	1	0	1
B2	0	0	0	0	0	0	0	0	1	1
B3	0	0	0	0	0	0	0	1	0	1
C1	0	0	0	0	1	0	0	0	0	1
C2	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	0	0	0	1	1
C4	0	1	0	0	0	0	0	0	0	1
D1	0	0	0	1	0	0	0	0	0	1
D2	0	0	0	1	0	0	0	0	0	1
D3	0	0	0	0	0	1	0	0	0	1
D4	0	0	0	0	0	1	0	0	0	1
D5	0	1	0	1	0	0	0	0	0	2
D6	0	1	0	0	0	0	0	0	0	1
D7	1	0	0	0	0	0	0	0	0	1
D8	1	0	0	0	0	0	0	0	0	1
D9	0	0	0	0	0	1	0	0	0	1
D10	0	0	0	0	0	1	0	0	0	1
Districts Covered	2	3	2	3	2	4	1	2	3	

MATRIX:AD_4 Table 5.22: WEIGHTED CENTER ADJUSTED LOGICAL

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
A1	0	0	0	0	1	0	0	0	0	1
A2	0	0	1	0	0	0	0	0	0	1
A3	0	0	0	0	0	0	1	0	0	1
A4	0	0	1	0	0	0	0	0	0	1
B1	0	0	0	0	0	0	0	1	0	1
B2	0	0	0	0	0	0	0	0	1	1
B3	0	0	0	0	0	0	0	1	0	1
C1	0	0	0	0	1	0	0	0	0	1
C2	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	0	0	0	1	1
C4	0	1	0	0	0	0	0	0	0	1
D1	0	0	0	1	0	0	0	0	0	1
D2	0	0	0	1	0	0	0	0	0	1
D3	0	0	0	0	0	1	0	0	0	1
D4	0	0	0	0	0	1	0	0	0	1
D5	0	1	0	1	0	0	0	0	0	2
D6	0	1	0	0	0	0	0	0	0	1
D7	1	0	0	0	0	0	0	0	0	1
D8	1	0	0	0	0	0	0	0	0	1
D9	0	0	0	0	0	1	0	0	0	1
D10	0	0	0	0	0	1	0	0	0	1
Districts Covered	2	3	2	3	2	4	1	2	3	

MATRIX:AW_4

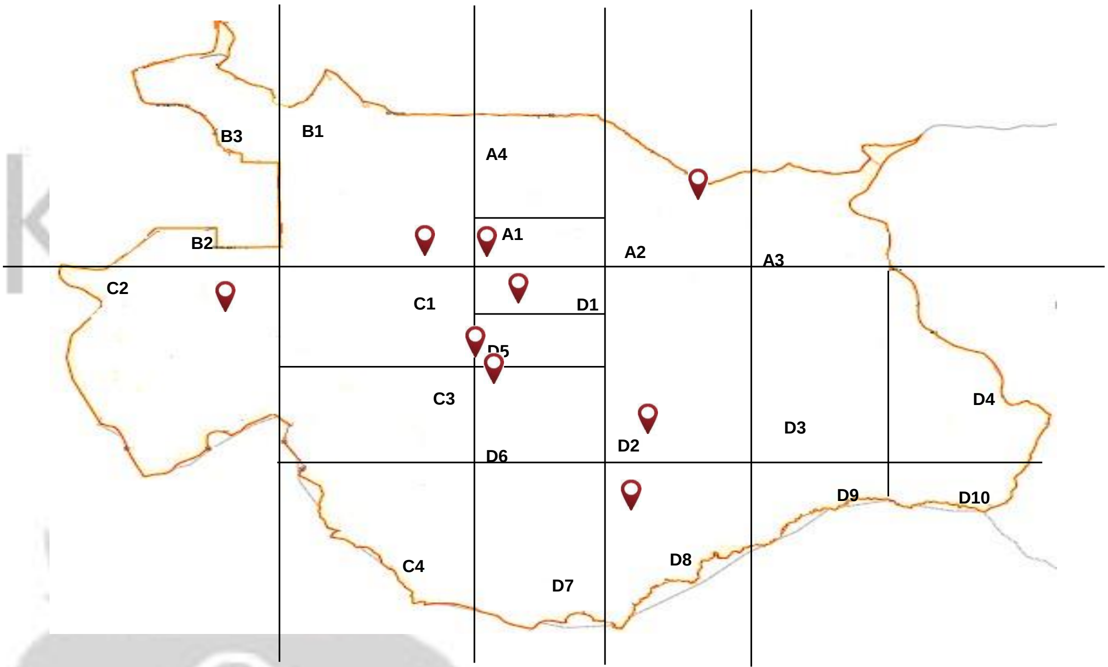
	S1	S2	S3	S4	S5	S6	S7	S8	S9	
A1	0	0	0	0	1	0	0	0	0	1
A2	0	0	1	0	0	0	0	0	0	1
A3	0	0	0	0	0	0	1	0	0	1
A4	0	0	1	0	0	0	0	0	0	1
B1	0	0	0	0	0	0	0	1	0	1
B2	0	0	0	0	0	0	0	0	1	1
B3	0	0	0	0	0	0	0	1	0	1
C1	0	0	0	0	1	0	0	0	0	1
C2	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	0	0	0	1	1
C4	0	1	0	0	0	0	0	0	0	1
D1	0	0	0	1	0	0	0	0	0	1
D2	0	0	0	1	0	0	0	0	0	1
D3	0	0	0	0	0	1	0	0	0	1
D4	0	0	0	0	0	1	0	0	0	1
D5	0	1	0	1	0	0	0	0	0	2
D6	0	1	0	0	0	0	0	0	0	1
D7	1	0	0	0	0	0	0	0	0	1
D8	1	0	0	0	0	0	0	0	0	1
D9	0	0	0	0	0	1	0	0	0	1
D10	0	0	0	0	0	1	0	0	0	1
Districts Covered	2	3	2	3	2	4	1	2	3	

Table 5.23: The MATLAB Results for a maximum travel time of of 4 minutes

STATION	G_4	D_4	W_4
S1	0	0	0
S2	0	0	0
S3	0	0	0
S4	0	0	0
S5	0	0	0
S6	0	0	0
S7	0	0	0
S8	0	0	0
S9	0	0	0
Number of Stations	0	0	0

Table 5.24: The MATLAB Results using the Adjusted logical matrix

STATION	AG_4	AD_4	AW_4
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	1	1	1



S5	1	1	1
S6	1	1	1
S7	1	1	1
S8	1	1	1
S9	1	1	1
Number of Stations	9	9	9

APPENDIX B

THE PROPOSED DISTRICTS CENTRES OF KUMASI CITY

DISTRICT CENTRES.PDF

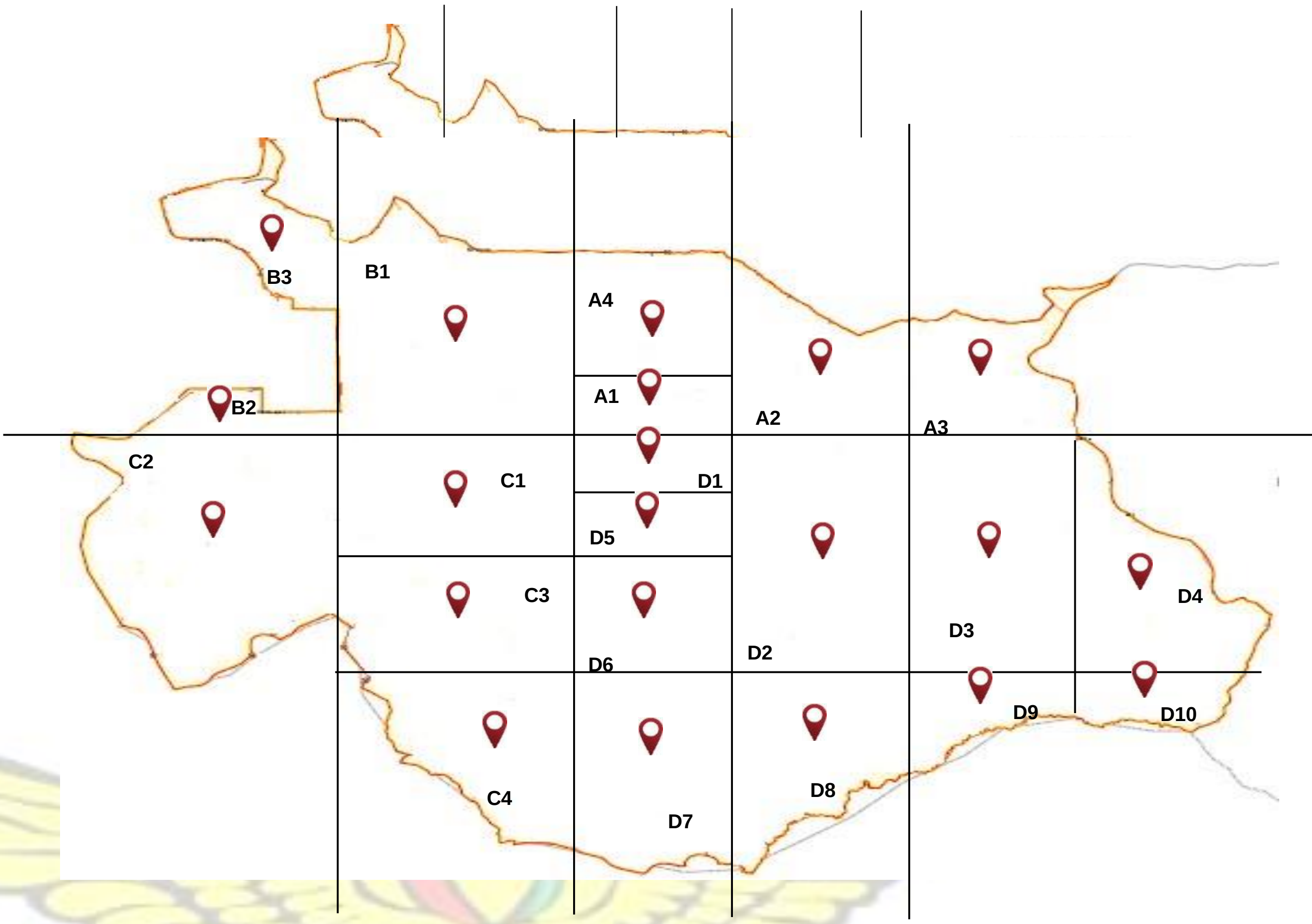


Figure 5.1: A map of the proposed fire stations

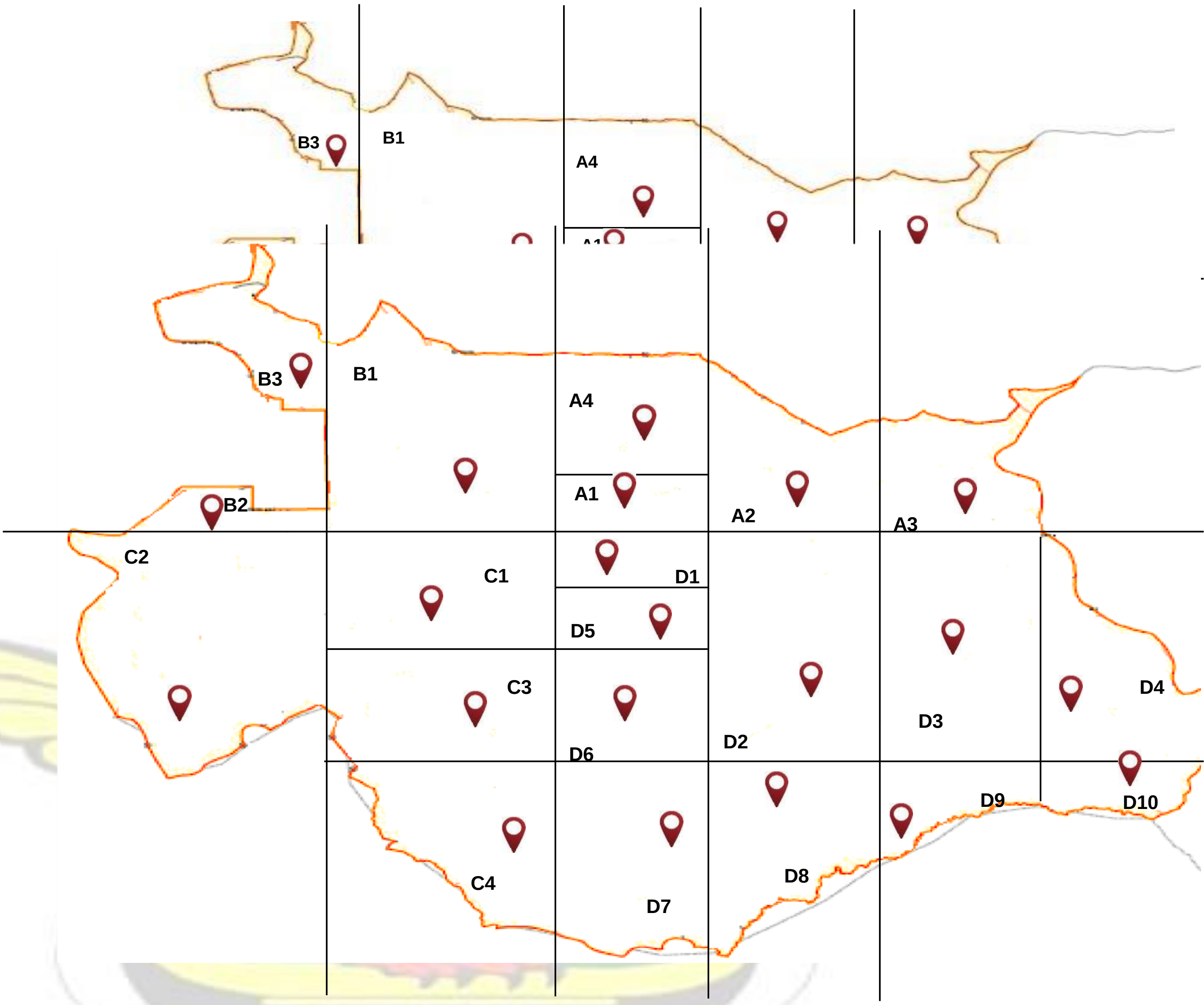
DISTRICTS.PDF

Figure 5.2: A map of the defined district of Kumasi City with labels

THE GEOGRAPHIC DISTRICTS CENTRES OF KUMASI CITY

TRES.PDF

Figure 5.3: A map of the Geographic Districts Centers of Kumasi City



THE DEMAND DISTRICTS CENTRES OF KUMASI CITY

TRES.PDF

Figure 5.4: A map of the Demand Centers

THE WEIGHTED DISTRICTS CENTRES OF KUMASI CITY

TRES.PDF

Figure 5.5: A map of the Weighted District Centers