LOCATION OF SEMI-OBNOXIOUS FACILITY AND THE TRANSPORTATION OF SOLID WASTE IN THE NORTHERN REGION OF GHANA. CASE STUDY: ZOOMLION GHANA LIMITED.

BY

ALHASSAN ABDUL-BARIK (BSc. Computer Science)

PG 5069610

A Thesis Submitted to the Department of Mathematics, Kwame Nkrumah University of Science and Technology in Partial Fulfillment of the Requirements for the Degree

Of

MASTER OF PHILOSOPHY

COLLEGE OF SCIENCE

JUNE, 2012

DECLARATION

I, Alhassan Abdul-Barik hereby declare that this thesis "Location of Semi-Obnoxious Facility and the Transportation of Solid Waste in the Northern Region of Ghana. Case Study: Zoomlion Ghana Limited", consists entirely of my own work produced from research undertaken under supervision and that no part of it has been published or presented for another degree elsewhere, except for the permissible references from other sources, which have been duly acknowledged.

Alhassan Abdul-Barik (PG 5069610) ---------- ----------

Signature **Date**

Certify by:

Dr. S. K. Amponsah ---------- ----------

Signature **Date**

Certified by:

Mr. K. F. Darkwah ---------- ----------

Signature **Date**

DEDICATION

This thesis is dedicated to the Almighty God for giving me life and sustenance. It is also dedicated to my mother, Madam Imoro Fulera for her unflinching love, care, and support always.

ABSTRACT

Waste includes all items that people no longer have any use for, which they either intend to get rid of or have already discarded. Additionally, wastes are such items which people are require to discard, for example by law because of their hazardous properties. The United Nations and other agencies estimate worldwide annual waste production at more than 1 billion tons, and some estimates go as high as 1.3 billion (European Environment Agency, 2009). There are a number of different options available for the management of waste of which landfilling or disposal even though should be the last resort is however largely practiced in Africa and the West. Waste management in Ghana is by mainly identifying dumping sites, instituting vantage collection points and conveying the waste to the various dumping site(s). When the urban roads in northern Ghana are constructed, and collection points of waste are properly sited then the waste management company can now efficiently convey waste to the dump sites on time. This will eventually provoke the conscience of the people about the need for environmental cleanliness and healthy living conditions. There can then be a paradigm shift of waste management by merely moving from collection to dumping sites in Northern Region to management of waste by re-use, minimization and prevention, and recycling. The thesis therefore looks at scientific methods of dump-site location (method of factor-rating for facility location) using secondary data from Zoomlion Ghana Limited. The Floyd-Warshall's algorithm is used specifically for the shortest path of transporting the waste from the various collection points to the dump-site. Matlab is the programming language used for the analysis which shows that, Gbalahi is the best site for the location of the semi-obnoxious facility (dump-site) by Zoomlion Ghana Limited, and that taking a detour or transit to the dump-site in most cases constitutes a shorter path than a direct path.

ACKNOWLEDGEMENT

Despite the difficulty involved in duly appreciating the efforts and contributions of all and sundry to the success of this thesis, I will still have to recognise the contributions of some individuals.

Whether in prosperity or adversity, comfort or troubles, man needs Divine Assistance. All thanks and praises be to God Almighty.

I say thank you to my parents for their continual diverse support from childhood till now. Without them I would not have been in this world.

I also thank my supervisor, Dr. S. K. Amponsah for his scholarly support and constructive criticism that has led to the success of this thesis. He has made the pursuance of a master's degree a loving one and not a frustration as others do.

The contribution of friends and family members cannot be over emphasised. My sincere thanks go to Prof. S. K. Nokoe, Dr. K. A. Gbolagade, Mr. Iddrisu N. Muniru, Mr. Issah Nantogmah, Mr. Abdulai Teddy, Mr.and Mrs. Alhassan Amin, Mr. Alhassan Suale, Mr. Alhassan Sayibu, Mr. Baba Seidu, Mr. Alhassan Yakubu, Mr. and Mrs. Saeed Majeed F., Mr. Addae Stephen, Mr. Anas Tawhir, Sheikh Mohammed Al-Habib Daud Mustapha, Sheikh Alhassan Kailan. To all the above mentioned, the good Lord richly bless you.

TABLE OF CONTENTS

Content **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

U.S.A	United States of America
EPA	Environmental Protection Agency
UN	United Nations
EU	European Union
WEEE	Waste from Electrical and Electronic Equipment
IT	Information Technology
BMW	Biodegradable Municipal Waste
ELV	End-of-Life Vehicles
EPR	Extended Producer Responsibility
PPP	Polluter Pays Principle
NESPoCC	National Environmental Sanitation Policy Coordinating Council
NSP	National Sanitation Policy
ESS	Environmental Sanitation Service
MMDA	Metropolitan Municipal and District Assemblies
WMD	Waste Management Departments
EHSD	Environmental Health and Sanitation Departments
EIA	Environmental Impact Assessment

GAEC	Ghana Atomic Energy Commission
RPB	Radiation Protection Board
PNDC Law	Provisional National Defence Council Law
LI	Legislative Instrument
DACF	District Assemblies Common Fund
HIPC	Highly Indebted Poor Countries
PDF	Portable Data Format
MATLAB	Matrix Laboratory
DC	Discrete Constraint or Distance Constrain
EMFLP	Euclidean Multi-Facility Location Problem
LAP	Location-Allocation Problem
AS/RS	Automated Storage and Retrieval System
CSP	Constrained Shortest-path Problem
AHP	Analytic Hierarchy Approach
APSP	All-Pairs Shortest Path Problem
FPTAS	Fully Polynomial Time Approximation Scheme
EA	Evolutionary Algorithms
MSPP	Multi-objective or Single Parametric Problem
SPEA2	Second Shortest Path Evolutionary Algorithms

PCGA	Pareto Converging Genetic Algorithm
MinCSP	Minimum-Covering/Shortest-Path
NSGA	Non-dominated Sorting Genetic Algorithm
GA	Genetic Algorithm
ESPPRC	Elementary Shortest-Path Problem with Resource Constraints
VRPTW	Vehicle-Routing Problem with Time Windows
FORTRAN	Formula Translator
GIS	Geographic Information Systems

CHAPTER 1

1.0 INTRODUCTION

The research involves management of waste by landfilling, which is by far the predominant waste management option in most countries. Here, we find the best site for dumping the waste, and then find suitable routes or shortest paths for conveying the waste to the dump site.

1.1 BACKGROUND OF THE STUDY

Waste includes all items that people no longer have any use for, which they either intend to get rid of or have already discarded. Additionally, wastes are such items which people are require to discard, for example by law because of their hazardous properties. Many items can be considered as waste e.g., household rubbish, sewage sludge, wastes from manufacturing activities, packaging items, discarded cars, old televisions, garden waste, old paint containers etc. Thus all our daily activities can give rise to a large variety of different wastes arising from different sources (European Environment Agency, 2009).

The United States of America manages to produce a quarter of the world's waste despite the fact that its population of three hundred (300) million is less than 5% of the world's population, according to 2005 estimates. The United States accumulates at least two hundred and thirty-six (236) million tonnes per year of municipal solid waste alone, according to the United States Environmental Protection Agency. The United Nations and other agencies estimate worldwide annual waste production at more than 1 billion tonnes, and some estimates go as high as 1.3 billion tonnes (European Environment Agency, 2009).

1.1.1 GLOBAL WASTE AND WASTE MANAGEMENT

Over 1.8 billion tonnes of waste are generated each year in Europe. This equals to 3.5 tonnes per person. This is mainly made up of waste coming from households, commercial activities (e.g., shops, restaurants, hospitals etc.), industry (e.g, pharmaceutical companies, clothes manufacturers etc.), agriculture (e.g., slurry), construction and demolition projects, mining and quarrying activities and from the generation of energy. With such vast quantities of waste being produced, it is of vital importance that it is managed in such a way that it does not cause any harm to either human health or to the environment.

There are a number of different options available for the treatment and management of waste including prevention, minimisation, re-use, recycling, energy recovery and disposal. Under European Union policy, landfilling is seen as the last resort and should only be used when all the other options have been exhausted, i.e., only material that cannot be prevented, re-used, recycled or otherwise treated should be landfilled. Nonetheless there are other types of waste that are produced which are minor, but can be very hazardous (European Environment Agency, 2009).

1.1.2 TYPES OF WASTE

There are various ways by which waste can be classified, depending on whether it is biodegradable or non-biodegradable, toxic or nontoxic, and the composition. However, the categorisation is largely by composition. The categorisation by composition includes;

1.1.3 MUNICIPAL WASTE (including Household and Commercial)

Municipal waste is generated by households, commercial activities and other sources whose activities are similar to those of households and commercial enterprises. It does not include other waste arising e.g., from mining, industrial or construction and demolition processes.

Municipal waste is made up of residual waste, bulky waste, secondary materials from separate collection (e.g., paper and glass), household hazardous waste, street sweepings and litter collections. It is made up of materials such as paper, cardboard, metals, textiles, organics (food and garden waste) and wood (European Environment Agency, 2009).

1.1.4 INDUSTRIAL WASTE (including manufacturing)

Manufacturing industry waste comprises many different waste streams arising from a wide range of industrial processes. Some of the largest waste generating industrial sectors in Western and Central Europe include the production of basic metals, food, beverage and tobacco products, wood and wood products and paper and paper products.

The manufacturing industry has a central role to play in the prevention and reduction of waste as the products that they manufacture today become the wastes of tomorrow (European Environment Agency, 2009).

1.1.5 HAZARDOUS WASTE

Hazardous waste arises from a wide range of different sources including households, commercial activities and industry. Wastes are classified as being hazardous depending on whether they exhibit particular characteristics.

The main disposal route for hazardous waste is landfill, incineration and physical or chemical treatment. On the recovery side, a significant proportion of hazardous waste is recycled or

burned as a fuel. Hazardous waste is typically the subject of special legislation and requires special management arrangements to ensure that hazardous waste is kept separate from and treated differently to non-hazardous waste (European Environment Agency, 2009).

1.1.6 CONSTRUCTION AND DEMOLITION WASTE

Construction and demolition waste is made up of two individual components (construction waste and demolition waste). It arises from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance. In some countries even materials from land levelling are regarded as construction and demolition waste. It is made up of numerous materials including concrete, bricks, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled in one way or another (European Environment Agency, 2009).

1.1.7 WASTE FROM ELECTRICAL AND ELECTRONIC EQUIPMENT

Waste from electrical and electronic equipment (commonly referred to as WEEE) consists of end of life products and comprises of a range of electrical and electronic items such as: Refrigerators, Information Technology and Telecommunication equipment, Freezers, Electrical and electronic tools, Washing machines, Medical equipment Toasters, Monitoring and control instruments, Hairdriers, Automatic dispensers, Televisions, etc. Thus, sources are all users of electrical and electronic equipment from householders to all kinds of commercial and industrial activities (European Environment Agency, 2009).

1.1.8 BIODEGRADABLE MUNICIPAL WASTE

Biodegradable Municipal Waste (BMW) is waste from households and commercial activities that is capable of undergoing biological decomposition. Food waste and garden waste, paper and cardboard are all classified as biodegradable municipal waste.

A range of options are used to treat BMW. Alternatives to landfill include composting, mechanical-biological pre-treatment recycling and incineration (European Environment Agency, 2009).

1.1.9 END-OF-LIFE VEHICLES (ELVs) AND TYRES

End-of-life vehicles are defined as cars that hold up to a maximum of eight passengers in addition to the driver, and trucks and lorries that are used to carry goods up to a maximum mass of 3.5 tonnes. Thus their sources range from households to commercial and industrial uses.

Cars are composed of numerous different materials. Approximately 75% of the weight of a car is made up of steel and aluminium, most of which is recycled. Other materials present include lead, mercury, cadmium and hexavalent chromium, in addition to other dangerous substances including anti-freeze, brake fluid and oils that, if not properly managed, may cause significant environmental pollution. The remainder is composed of plastic which is recycled, incinerated or landfilled (European Environment Agency, 2009).

1.1.10 AGRICULTURAL WASTE

Agricultural waste is composed of organic wastes (animal excreta in the form of slurries and farmyard manures, spent mushroom compost, soiled water and silage effluent) and waste such as plastic, scrap machinery, fencing, pesticides, waste oils and veterinary medicines (European Environment Agency, 2009).

1.1.11 WASTE TREATMENT AND MANAGEMENT CONCEPTS

There are a number of concepts about waste management which vary in their usage between countries or regions. Some of the most general, widely used concepts include;

Extended producer responsibility: Extended Producer Responsibility (EPR) is a strategy designed to promote the integration of all costs associated with products throughout their life cycle (including end-of-life disposal costs) into the market price of the product. Extended producer responsibility is meant to impose accountability over the entire lifecycle of products and packaging introduced to the market. This means that firms which manufacture, import and/or sell products are required to be responsible for the products after their useful life as well as during manufacture.

Polluter pays principle: the Polluter Pays Principle is a concept principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the waste.

Education and awareness: Education and awareness in the area of waste and waste management is increasingly important from a global perspective of resource management. The Talloires Declaration is a declaration for sustainability concerned about the unprecedented scale and speed of environmental pollution and degradation, and the depletion of natural resources. Local, regional, and global air pollution; accumulation and distribution of toxic wastes; destruction and depletion of forests, soil, and water; depletion of the ozone layer and emission of "green house" gases threaten the survival of humans and thousands of other living species, the integrity of the earth and its biodiversity, the security of nations, and the heritage of future generations.

Prevention and Minimisation: Prevention means eliminating or reducing the quantity of waste which is produced in the first place, thus reducing the quantity of waste which must be

managed. Prevention can take the form of reducing the quantities of materials used in a process or reducing the quantity of harmful materials which may be contained in a product. Prevention can also include the reuse of products. Prevention is the most desirable waste management option as it eliminates the need for handling, transporting, recycling or disposal of waste. It provides the highest level of environmental protection by optimising the use of resources and by removing a potential source of pollution.

Minimisation includes any process or activity that avoids, reduces or eliminates waste at its source or results in re-use or recycling. It can be difficult to draw a clear distinction between the terms "Prevention" and "Minimisation".

Waste prevention and minimisation measures can be applied at all stages in the life-cycle of a product including the production process, the marketing, distribution, or utilisation stages, up to discarding the product at the end-of life stage.

Re-Use: Re-use means the use of a product on more than one occasion, either for the same purpose or for a different purpose, without the need for reprocessing. Re-use avoids discarding a material to a waste stream when its initial use has concluded. It is preferable that a product be re-used in the same state e.g., returnable plastic pallets, using an empty glass jar for storing items and using second hand clothes.

Recycling: Recycling involves the treatment or reprocessing of a discarded waste material to make it suitable for subsequent re-use, either for its original form or for other purposes. It includes recycling of organic wastes but excludes energy recovery. Recycling benefits the environment by reducing the use of virgin materials (European Environment Agency, 2009).

1.1.12 WASTE AND WASTE MANAGEMENT IN GHANA

With regards to decision making, a coordinating council, the National Environmental Sanitation Policy Coordinating Council (NESPoCC) has been put in place since January 2000 to expedite the implementation of the National Sanitation Policy. The national laws, specifically the Criminal Code (Act 29), 1960, and Revised Bye-laws of all the 110 MMDA's have enough laws to support the Environmental Sanitation Service delivery and enforce the compliance of sanitation rules. It is however noted that these laws are not deterrent enough and logistical problems make MMDA's impotent in ensuring clean, safe and healthy environment (Sanitation2004-Ghana).

1.1.13 SOLID WASTE

General waste management in Ghana is the responsibility of the Ministry of Local Government and Rural Development, which supervises the decentralized Metropolitan, Municipal and District Assemblies (MMDAs). However, regulatory authority is vested in the Environmental Protection Agency (EPA) under the auspices of the Ministry of Environment and Science. The Metropolitan, Municipal and District Assemblies are responsible for the collection and final disposal of solid waste through their Waste Management Departments (WMDs) and their Environmental Health and Sanitation Departments.

The only guidelines, which indirectly discourage unsustainable practices and promote sustainable consumption and production, are those on the Environmental Impact Assessment (Sanitation2004-Ghana).

1.1.14 HAZARDOUS WASTE

With respect to Hazardous waste management, there are currently no clearly distinguishable methods for the disposal of hazardous waste. However, the Environmental Protection Agency (EPA) is responsible for the provision of guidelines for such wastes. A Draft Hazardous Waste Control bill is currently before cabinet for consideration (Sanitation2004-Ghana).

1.1.15 RADIOACTIVE WASTE

The Ghana Atomic Energy Commission, recognizing the need to establish the basic requirement for the protection of people against undue radiation exposure from unsafe practices established the Radiation Protection Board (RPB) in 1993 through amendments to the Atomic Energy Act, (Act 204) of 1963 and PNDC Law 308. These Laws have been further strengthened by regulations and Legislative Instrument, (LI 1559 of 1993). The Radiation Protection Board as the sole regulatory authority was mandated to establish an inventory of radiation sources in the country and evolve protection and safety strategies for the control of the radiation sources and safe disposal of radioactive waste. No person, body or institution shall generate or manage waste without a valid license from the Radiation Protection Board (Sanitation2004-Ghana)

1.1.16 FINANCING OF WASTE MANAGEMENT IN GHANA

There are funds from the central Government in the form of District Assemblies Common Fund for sanitation purposes. The main sources of funding for environmental sanitation services are from the national budgetary allocation and bi-lateral and multilateral donor support from World Bank. Funds are also made available to the Districts from the HIPC

inflows while MMDAs are expected to use a sizeable portion of their locally generated revenue to handle their own municipal waste (Sanitation2004-Ghana)

1.1.17 WASTE MANAGEMENT IN NORTHERN REGION

Tamale is the northern regional capital. Residents of the surrounding savannah area are chiefly engaged in the activities of cattle raising, farming, and cotton growing. The city, which is a road hub and trade center, contains cotton- and shea-nut-processing industries, and handicrafts, especially baskets, are made here. Tamale was founded in the early 1900s by the British as an administrative center for the Northern Territories protectorate of the Gold Coast. The 2000 population estimates for the Northern Region is One Million Eight Hundred and Fifty-four Thousand, Nine Hundred and Ninety-four (2010 PHC, Statistical Service)

Waste management in Northern Ghana is mainly by identifying strategic points, collecting the waste and dumping the waste at the waste dump-site or sometimes just landfills. There are six waste management companies in northern Ghana, of which Zoomlion Ghana Limited is the registered and most efficient waste management company (www.zoomlionghana.com). Figure 1.1 and Figure1.2 shows the map of Northern Region and Ghana respectively.

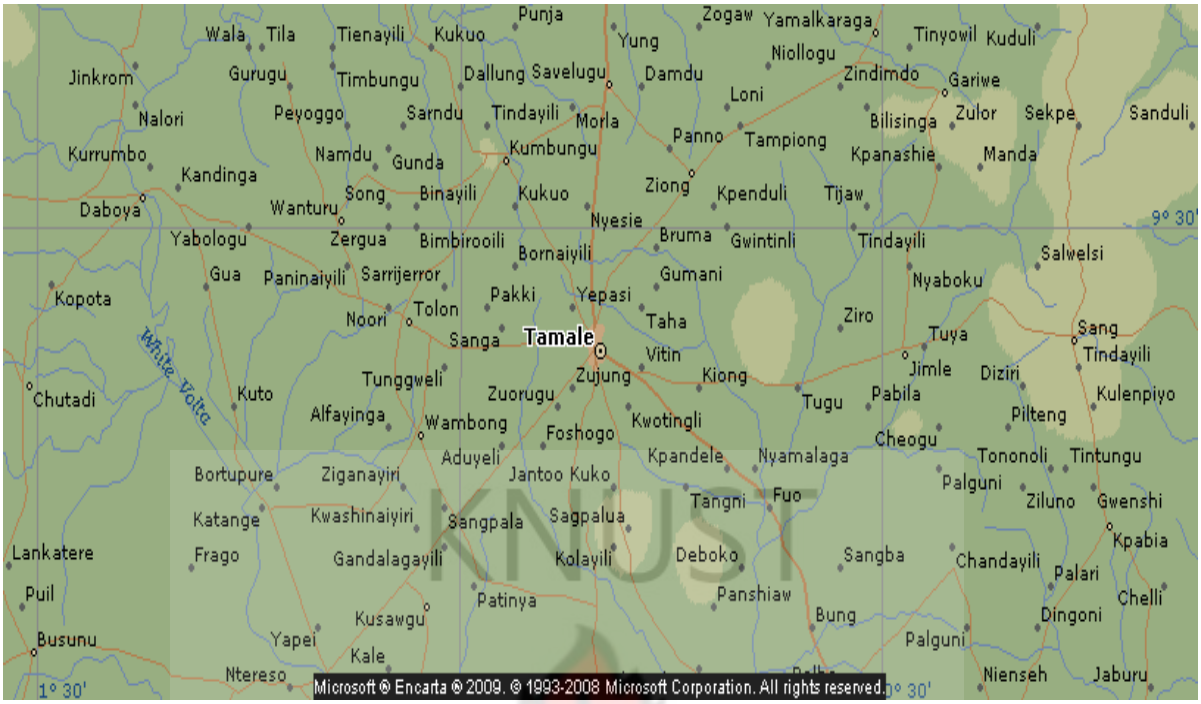


FIGURE 1.1 MAP OF NORTHERN REGION SOURCE; Microsoft Encarta 2009.

1993-2008 Microsoft Corporation

FIGURE 1.2 MAP OF GHANA SOURCE; Microsoft Encarta 2009. 1993-2008

Microsoft Corporation

1.1.18 PROFILE OF ZOOMLION GHANA LIMITED

Zoomlion Ghana Limited is a giant in waste management as well as environmental sanitation business in Ghana and Africa as a whole. The Company was formed under the company's Act with registration number CA22256 in January 2006.The Company which was formed in 2006 as Zoomlion Ghana Limited with a few members of staff has now grown over the past four years with eight (8) subsidiaries.

Zoomlion also operates in other African countries such as Togo, Angola and Guinea while negotiations are far advanced for the company to start operations in other African countries such as Nigeria, Sierra Leone and Liberia (www.zoomlionghana.com).

1.2 PROBLEM STATEMENT

Waste and waste management is now an issue of global concern, multifaceted in dimension that can only be dealt with holistically. Waste management in Ghana is by mainly identifying dump-sites, instituting vantage collection points and conveying the waste to the various dump-sites. Zoomlion Ghana Limited aims to be at the forefront of the environmental sanitation services industry, by the introduction and utilization of simple but modern technologies and methods of waste management at affordable and competitive rates. It is therefore important to identify the best dump-site, and the best route for conveying the waste.

1.3 OBJECTIVES OF THE STUDY

The objectives of the study are:

(i) to find ways of exploring methods of waste dump-site(s) location as against cost incurred, time, and risk factor in order to make efficient and convenient waste and waste management.

(ii) to find the shortest ways or routes in transporting or conveying the waste to the various dumping site(s).

(iii) to minimise cost by reducing distance of travel or fuel consumed in transportation of the waste to the dump-site.

(iv) to find scientific method with an analytical and objective basis for decision making by management board of Zoomlion Ghana Limited.

(v) to find a method which serves as a learning material for libraries and on the internet for students and other researchers in to a similar field in the near future.

1.4 JUSTIFICATION OF THE STUDY

The relevance of this thesis is to come out with a long lasting programme or model for a comprehensive waste management planning policy to be implemented in a short term project and long term project in the Northern Region by Zoomlion Ghana Limited and other waste management expert companies in Ghana.

When the urban roads in northern Ghana are constructed, and collection points of waste are properly sited at vantage points then the waste management company can now efficiently convey waste to the various dump sites on time. This will eventually provoke the conscience of the people about the need for environmental cleanliness and healthy living conditions.

There can then be a paradigm shift of waste management by merely moving the waste from collection points to dumping sites in Northern Region to management of waste by reuse, minimization and prevention, and recycling.

This will also bring an enormous economic benefit to Zoomlion Ghana Limited in particular and Ghana in general by availing us resources from the reuse and recycling of waste.

Unemployment will also be curtailed since the plants for re-use and recycling will require more hands on board.

1.5 METHODOLOGY OF THE STUDY

Zoomlion Ghana Limited has the focus of efficient waste management so as to maximize profit and reduce cost by proper dump-site(s) location, and vantage collection points to enable prompt movement of waste to dump-sites. It is to be at the forefront of the environmental sanitation services industry, by the introduction and utilization of simple but modern technologies and methods of waste management at affordable and competitive rates.

For the success of this thesis, secondary data will be collected from Zoomlion Ghana Limited, and the method of factor-rating for site location will be used to analyse the data for the best of dump-site location. The Floyd-Warshall's algorithm will be specifically used for the shortest path of transporting the waste from the various collection points to the dump-site(s). Resources used in this research are required books and largely the internet. The programming language used is matlab.

1.6 LIMITATIONS OF THE STUDY

The limitations of the study include;

(i) Resource availability, the availability of genuine software programs without limitations, books or Portable Data Format (pdfs) that are supposed to be purchase before assess, and the

having to pay subscription fees before being a member of a Scientific Journal in order to assess information.

(ii) Time, the time frame within which the research is supposed to be carried out if not limited but highly challenging to be accomplished.

1.7 ORGANIZATION OF THE STUDY

The thesis consists of five chapters. Chapter 1 sheds light on the introduction, problem statement, objectives of the study, justification, methodology and structure of the thesis. Chapter 2 reviews pertinent literature on location of dump-site and transportation of waste. Chapter 3 contains the method used to carry out this research. Chapter 4 presents data collection and analysis. Chapter 5, the final chapter focuses on the conclusions and recommendations of the study.

1.8 SUMMARY

Landfilling is by far the dominant way by which waste is managed in Africa, and in most countries. It is therefore of significance that, we find the best site for dumping the waste, and efficient routes by which the waste can be conveyed. This is achieved by using the factor-rating method for the Semi-obnoxious facility location (dump-site), and the all-pairs shortest path problem for the shortest path for conveying the waste to the dump-site.

In the next chapter, we shall put forward pertinent literature in the field of location of dump-site and transportation.

CHAPTER 2

REVIEW OF LITERATURE

2.0 INTRODUCTION

The thesis focuses on how to locate a Semi-obnoxious facility (dump-site) using the 'Factor-rating Method, and then conveying the waste from vantage collection points to the dump-site using the 'Shortest path problem', specifically the Floyd-Warshall's method. Hence the literature will be on facility location, specifically the 'factor-rating method', and then on 'All-pairs shortest path method'.

2.1 LITERATURE REVIEW ON LOCATION PROBLEM

Goldman (1975) appears to be the first to discuss the fact that, while facilities are to provide service, it may not be desirable to place certain ones too close to demand points. For example, a franchiser company may wish to exclude from location consideration those areas within certain distances of some obnoxious "demand" points. Among the factors that may be considered objectionable are high crime rates, high property taxes or rents, and the difficulty of utilizing existing distribution channels effectively. In the problems that involve obnoxious facilities, each demand point may decide on the objectionability of a facility along with the specification of the minimum separation from the demand point. For example, a safety-conscious community would oppose construction of nuclear power plants or missile silos nearby, for fear of being exposed to radiation or hazardous materials these facilities might produce. (Recent accidents at Three Mile Island, Pennsylvania and Damascus, Arkansas have well demonstrated the existence of such hazards.) Dump-sites for chemical waste or collected refuse may be opposed in a similar manner. (Recall the wide publicity of the dumping incident at Love Canal, New York.)

Church and Meadows (1979) relaxed both of the simplifications, allowing all points of the network to be potential sites and maximal distance, to vary with demand points. With this, though, they established that there exists at least one optimal solution to the problem that consists entirely of network intersection points, which are composed of the centers and boundary points of the neighborhoods defined using the (DC). This enabled the authors to treat the problem as a discrete problem.

Francis and Cabot (1972) proved that the objective function is convex, and it is strictly convex if for i = 1,..., n, the set Si = { j: wij >0 } is non-empty and the points of Si are non-collinear. Furthermore, they have shown that the optimal solution of problem EMFLP exists and lies in the convex hull of the existing facilities.

Weiszfeld (1980) proposed that, the discrete demand multi-facility location problem (MFLOC) is a problem of optimally locating **n** new service facilities to serve the demand at **m** existing customer locations or facilities. The general lp distance model for this problem can be stated as follows:

$$\text{Minimise} \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}\, l_p\left(X_i, P_j\right) + \sum_{i=1}^{n-1}\sum_{k=i+1}^{n} V_{ik}\, l_p\left(X_i, X_k\right)$$

where,

wij is a non-negative parameter that represents the annual cost of separating new facility i and existing facility j by a unit distance.

The multi-facility problem basically suffers from the non-differentiability of the objective function. These points of non-differentiability of the objective function occur not only when new and existing facility locations coincide, but also occur on linear subspaces where the new facilities themselves coincide. In addition, since the objective function is not strictly convex, multiple minimisers of the problem are results in which iterative schemes might tend to converge.

Rosen and Xue (1992b) developed an algorithm which, from any initial point, generates a sequence of points that converges to the closed convex set of optimal solutions to the Problem (EMFLP). Since in some multi-facility location problems, the optimal solution coincides with one of the existing facilities, researchers have derived necessary and sufficient conditions for optimality to avoid the non-differentiability difficulty of the objective function associated with such a coincidence.

Eyster and White (1973) proposed that if the facility-customer separation penalty is defined to be proportional to the square of the Euclidean distance, then the resulting problem is called a squared-Euclidean distance problem. The problem was separable in the x and y variables. Indeed, some special applications have been cited by Eyster and White for this class of problems. It was obvious that the function that is to be minimized is strictly convex, and unlike the Euclidean distance case, it has continuous first partial derivatives with respect to x and y. Consequently, the optimal solution of both the single and the multi-facility problems is unique and can be obtained by simple calculus techniques. However, for the multi-facility case, one needs to solve two systems of n linear equations in n variables.

Love and Morris (1975) solved the uncapacitated case of this problem by proposing a two-stage procedure. In the first stage of their procedure, they used a set reduction algorithm to reduce the set of all possible optimal locations of the new facilities. The resulting problem was equivalent to a p-median problem on a weighted connected graph. Consequently, in the second stage, they used a technique for solving the p-median problem to obtain an optimal location and allocation solution.

Bongartz et al., (1994) developed a methodology to solve the general lp distance LAP. The method relaxed the {0,1} constraints on the allocations, and simultaneously, solves for both the locations and the allocations. The algorithm involved both a step to compute a good starting solution and a specialized line search procedure that retains the feasibility of the

allocation and recognizes the discontinuity of the first derivative along the search direction. A set of necessary and sufficient conditions for the local minima of the relaxed problem are then given, which in turns leads to an efficient algorithm involving the use of an active set strategy and orthogonal projections.

Shi, (2010) motivated by a real project for a sophisticated automated storage and retrieval system (AS/RS), studying the problem of generating K shortest paths that are required to satisfy a set of constraints. Proposed a structural branching procedure that decomposes the problem into at most K|N| sub problems, where |N| is the number of nodes in the network. By using a Network Modification procedure, each sub problem can be transformed into a constrained shortest path problem (CSP). When these constraints satisfy a so called separable property, the sub problem can be further simplified. Based on this branching procedure, a specific algorithm was proposed for an application where resource and loop less constraints have to be respected. Numerical results show that their algorithm is very efficient and robust.

Sherali and Adams (1984) presented the location of n facilities on a set of n potential sites in a one-to-one fashion and the allocation of the products to customers. They transformed the problem to a fixed-charge location problem with assignment side constraints and developed an efficient Lagrangian relaxation, enumeration and decomposition composite algorithm.

Hakimi (1965) focused on the p-center problem, which was also introduced first by Hakimi, is to find the facility locations such that the maximum of weighted distances between demand points and their respective nearest facilities is minimized. It is well known that the center model is useful especially for the location of emergency facilities such as ambulance stations and firehouses. Analogous to the relationship between maxian and median problems, one can conceive of the p-anti-center problem as the maximin version of the p-center problem. Again, the presence of some type of obnoxiousness may require the use of such an objective. Finally, in the absence of demand points, the maximin version of the p-defense problem

would be relevant in dispersing the facilities so as to maximize the minimum distance between any pair of them. This type of problem is called the p-dispersion problem.

Dearing et al., (1976) put forward that, for any combination of Distance Constraint (DC) considered, we say that the DC is consistent if there exists a location vector that satisfies the DC. Dearing et al. (1976) observed that some network location problems with upper bounded DC are convex optimization problems if and only if the underlying network is a tree. In such cases then, many standard results of convexity can be applied. The facilities in Dearing et al., (1976), however, may also be regarded as distinct, providing distinct kinds of service to demand points.

Khumawala (1973) was the first to propose simple heuristic procedures for the discrete version He proposed to apply two slightly different methods and take the better of the two solutions. His first method involves the computation of the minimum cost savings, in terms of weighted distance, that can be attained by opening each facility. The facility with the least minimum savings is then closed. The process continues until the required p facilities are opened. The second method differs from the first only in the way the cost savings are computed.

Lowe (1978) finally, in regard to multi-criteria problems with DC, Lowe dealt with more than one objective to place a single facility on a tree network. Let hi(x), i = 1, . . ., k, be k noncommensurable functions of location variable x. The problem considered in (Lowe 1978) was to:

$$\text{minimise } \{h_i : X \in Q_i \text{ and } X \in G\}$$

where Qi is a nonempty set on which hi(x) is minimized. Such Q, may be specified by distance constraints of uncapacitated type. Thus, the problem is Multi-objective uncapacitated. Lowe considered the case where Q = {Qi: i = 1, . . . , k} defines a convex set,

for which he developed a method for finding the efficient set of solutions. Partial results were also given for the case where Q does not define a convex set.

Church and Meadows (1977, 1979) observed that network intersection points should be useful in analyzing certain covering and median problems with either of the two types of Distance Constraints. In regard to the constrained minimax or maximin problems, the approach of initially solving the related covering (or anti-covering) problem should provide greater insight, with useful information, into the original problem. For some combinations of DC, however, solving this related problem itself would constitute the main part of the solution effort. Suppose p* is the minimum number of facilities found for a covering problem and p is the actual number of facilities that must be placed. Obviously, p* < p is the only case for which additional consideration must be given. The aim is to locate (p - p*) redundant facilities most effectively in accordance with the problem objective, subject to the DC. Similarly, if p* is the maximum number of facilities that can be placed on the network, the case for p < p* needs additional attention. The question in this case would be how to choose p out of p* possible locations most effectively, without violating the DC. The development of such a procedure for each problem type may be worthwhile.

Francis et al., (1992), Love et al., (1988), proposed the minisum location problem. In particular, the objective is the sum of two weighted sums, one of which is equivalent to the Weber problem and the other is a weighted sum of square roots of some function of the distance metric. The solution procedures for finding the optimal joint decisions and the total cost functions can be done quite efficiently. This facilitates the use of the models to evaluate alternative system designs.

Geoffrion (1978) solved location problems employing a wide range of objective criterion and methodology used in the decision analysis, for instance Geoffrion, includes decomposition, mixed integer linear programming, simulation and heuristics that may be used in analyzing

location problems. He notes that a suitable methodology for supporting managerial decisions should be computationally efficient, lead to an optimal solution, and be capable of further testing.

Zahedi, (1996), put forward one analytical approach often suggested for solving such a complex problem is the AHP (Analytic Hierarchy Approach process), it is a highly flexible decision methodology that can be applied in a wide variety of situations. It is typically used in a decision-making situation involving selecting one or more alternatives from several candidate locations on the basis of multiple decision criteria of a competing or conflicting nature. Particularly important, the decision criteria may hold a different degree of adequacy or level of importance in the eyes of the decision-makers.

McGinnis and White, (1992) proposed a technique in which a two-dimensional Tchebychev space can be converted to rectilinear space. Therein, the authors solve the two dimensional minimax location problems with Tchebychev distances. The authors detailed the relationship between rectilinear and Tchebychev distances, with the help of the diamond-covering problem with its center at the origin. This diamond is rotated about the z-axis by 45 degrees to form a square with its center at the origin. Thus the corresponding points are obtained using the following conversion equation.

$$Q(x,y) = (x,y)\begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} = (x+y, -x+y) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The inverse transformation can be found by:

$$Q(u',v') = (u,v)\begin{bmatrix} 1/2 & 1/2 \\ -1/2 & 1/2 \end{bmatrix} = (u-v, u+v) \ldots\ldots\ldots\ldots\ldots (4)$$

By using these transformations, it was found that the rectilinear distance between any two vertices of the diamond was the same as the Tchebychev distance between any two vertices of the square.

Gass and Witzgall (2004) used linear programming techniques to approximate the Tchebychev Minimax Criterion that is utilized in finding a circle that is the closest to a given set of points. This is useful in problems in location theory and also in the quality control of shapes such as drilled holes, spheres, etc.

2.2 ALL-PAIRS SH1`ORTEST PATH PROBLEM

Gorgy et al., (2004a,b, 2005b) presented in this problem, a weighted directed (acyclic) graph whose edge weights can change in an arbitrary manner, and the decision maker has to pick in each round a path between two given vertices, such that the weight of this path (the sum of the weights of its composing edges) be as small as possible. Efficient solutions, with time and space complexity proportional to the number of edges rather than to the number of paths (the latter typically being exponential in the number of edges), have been given in the full information case, where in each round the weights of all the edges are revealed after a path has been chosen.

Gelenbe et al., (2004, 2001), proposed a model of the label-efficient bandit problem for shortest paths is motivated by an application to a particular packet switched network model. This model, called the cognitive packet network, was introduced by Gelenbe et al., (2004, 2001). In these networks a particular type of packets, called smart packets, are used to explore the network (e.g., the delay of the chosen path). These packets do not carry any useful data; they are merely used for exploring the network. The other types of packets are the data packets, which do not collect any information about their paths. The task of the decision maker is to send packets from the source to the destination over routes with minimum average transmission delay (or packet loss). In this scenario, smart packets are used to query the delay (or loss) of the chosen path. However, as these packets do not transport information, there is a tradeoff between the number of queries and the usage of the

network. If data packets are on the average α times larger than smart packets (note that typically α >> 1) and ε is the proportion of time instances when smart packets are used to explore the network, then ε/(ε +α(1- ε)) is the proportion of the bandwidth sacrificed for well informed routing decisions.

Pangilinan and Janssens (2007) showed that, a set of problems exist wherein the number of Pareto-optimal solutions is exponential which implies that any deterministic algorithm that attempts to solve it is also exponential in terms of runtime complexity at least in the worst case. But some labelling algorithm studies, dispute this exponential behaviour. They show that the number of efficient paths is not exponential in practice.

Tsaggouris and Zaroliagis,(2006) explained that, while some researchers focus on exhaustive solutions or on improvements thereof, other researchers are more concerned with better runtime solutions. The authors presented an improved fully polynomial time approximation scheme (FPTAS) for the multi-criteria shortest path problem and a new generic method for obtaining FPTAS to any multi-objective optimization problem with non-linear objectives. They show how their results can be used to obtain efficient approximate solutions to the multiple constrained path problems and to the non-additive shortest path problem. Their algorithm builds upon an iterative process that extends and merges sets of node labels representing paths which departs from earlier methods using rounding and scaling techniques on the input edge costs. The algorithm resembles the Bellman-Ford method but implements the label sets as arrays of polynomial size by relaxing the requirements for strict Pareto optimality.

Granat and Guerriero, (2003) introduced an interactive procedure for the MSPP based on a reference point labelling algorithm. The algorithm converts the multi-objective problem into a parametric single-objective problem whereby the efficient paths are found. The algorithm was tested on grid and random networks and its performance was measured

based on execution time. They conclude that an interactive method, from their experimental results, is encouraging and does not require the generation of the whole Pareto-optimal set (which avoids the intractability problem). Likewise, they suggested an interactive method that incorporates an efficient k-shortest path algorithm in identifying Pareto-optimal paths in a bi-objective shortest path problem. The algorithm was tested against other MSPP algorithms on 39 network instances. They conclude that their k-shortest path algorithm performs better in terms of execution time.

From a different perspective, evolutionary algorithms (EAs) have been extensively analyzed in single objective optimization problems but only a few researchers have applied EAs to the multi-objective shortest path problem either as the main problem or as a sub-problem in relation to route planning, traffic and transport design, information systems and communications network design.

Zitzler and Thiele (1989) explained that, the Second Shortest Path Evolutionary Algorithms (SPEA2) is regarded as one of the better elitist multi-objective evolutionary algorithms. It has three favourable characteristics. First, SPEA2 features an excellent fitness assignment strategy that accounts for an individual's strength in terms of the individuals that it dominates and the strength of its dominators. Second, SPEA2 incorporates a density estimation technique which discriminates individuals efficiently, and third, it has an archive truncation method that prevents boundary solutions from elimination. The algorithm is summarized below.

Input: N, the population size $\bar{N}$

$\bar{N}$, the archive size

T, the maximum number of generations

Output: A, the non-dominated set of solutions

Step 1: Initialization. Generate an initial population P_o and

Create the empty archive (external set) $\overline{P_o} = \emptyset$. Set t=0.

Step 2: Fitness assignment: Compute the fitness values of individuals in $\mathbf{P}_t$ and $\overline{P_t}$.

Strength of an individual **i**

$$S(\mathbf{i}) = |\{ \mathbf{j} \mid \mathbf{j} \in P_t + \overline{P_t} \wedge \mathbf{i} \propto \mathbf{j}\}| \quad (1)$$

where $|\ .\ |$ denotes the cardinality of a set, + stands for multi-set union and the symbol $\propto$ corresponds to the Pareto dominance relation extended to individuals.

$$\text{Raw fitness } R(i) = \sum_{j \in P_{t+\overline{P_t}} j \propto i} S(j) \quad (2)$$

For each individual **i** the distances (in objective space) to all individuals **j** in the archive and in the population are calculated and stored in a list. After sorting the list in increasing order, the k-th element gives the distance sought, denoted as σ_i^k. Two (2) is added to the denominator to ensure that its value is greater than zero and D(**i**) < 1.

Density $$D(i) = \frac{1}{\sigma_i^k + 2} \quad ; k = \sqrt{N + \overline{N}} \quad (3)$$

Fitness $$F(i) = R(i) + D(i) \quad (4)$$

Step 3: Environmental Selection. Copy all non-dominated individuals in P_t and $\overline{P_t}$ to + $\overline{P_{t+1}}$. If size of $\overline{P_{t+1}}$ exceeds $\overline{N}$ then reduce $\overline{P_{t+1}}$. by means of the truncation operator, otherwise if size of $\overline{P_{t+1}}1$ is less than $\overline{N}$ then fill $\overline{P_{t+1}}$ with dominated individuals in P_t and $\overline{P_t}$.

Step 4: Termination. If t ≥ T or another stopping criterion is satisfied then set A is the set of decision vectors represented by the nondominated individuals in ill$\overline{P_{t+1}}$. Stop.

Step 5: Mating selection. Perform binary tournament selection with replacement on ill $\overline{P_{t+1}}$ in order to fill the mating pool.

Step 6: Variation. Apply recombination and mutation operators to the mating pool and set Pt+1 to the resulting population. Increment generation counter (t = t +1) and go to Step 2.

Line B., and David P. (2011), stated that shortest path problems appear as sub problems in numerous optimization problems. In most papers concerning multiple objective shortest path problems, additive of the objective is a de-facto assumption, but in many real-life situations objectives and criteria, can be non-additive. The purpose of the project is to give a general framework for dominance tests for problems involving a number of non-additive criteria. These dominance tests can help to eliminate paths in a dynamic programming framework when using multiple objectives. Results on real-life multi-objective problems containing non-additive criteria are reported. We show that in many cases the framework can be used to efficiently reduce the number of generated paths.

Dimitri, and Tsitsiklis, (1991) provided a stochastic version of the classical shortest path problem whereby for each node of a graph, must choose a probability distribution over the set of successor nodes so as to reach a certain destination node with minimum expected cost. The costs of transition between successive nodes can be positive as well as negative. It proved natural generalizations of the standard results for the deterministic shortest path problem, and extended the corresponding theory for undiscounted finite state Markovian decision problems by removing the usual restriction that costs are either all non negative or all non positive.

Ramaswamy, and Orlin, (2003) addressed sensitivity analysis questions concerning the shortest path problem and the maximum capacity path problem in an undirected network. For both problems, the maximum and minimum weights that each edge can have so that a given path remains optimal were determined. For both problems, show how to determine these maximum and minimum values for all edges in O (m + K log K) time, where m is the number of edges in the network, and K is the number of edges on the given optimal path.

Ernesto Queirós, and Vieira Martins, (2003) said that multi-criteria shortest path problems have not been treated intensively in the specialized literature, despite their potential applications. In fact, a single objective function may not be sufficient to characterize a

practical problem completely. For instance, in a road network several parameters (as time, cost, distance, etc.) can be assigned to each arc. Clearly, the shortest path may be too expensive to be used. Nevertheless the decision-maker must be able to choose some solution, possibly not the best for all the criteria.

Kumar, and Banerjee, (2003) presented an algorithm for multi-criteria network design (shortest paths and spanning trees) with two objectives of optimizing network delay and cost subject to satisfaction of reliability and flow constraints. They tested an evolutionary algorithm approach, Pareto Converging Genetic Algorithm (PCGA), to design different sized networks and found that EAs scale better in larger networks than two traditional approaches namely branch exchange heuristics and exhaustive search. They conclude that the primary advantage of EAs to solve multi-objective optimization problems is their diversity of solutions generated in polynomial time.

Current, and ReVelle, (2007) presented a multi-objective nature of many network design and routing problems, there has been a tremendous increase in multi-objective network modeling in recent years. In this article we introduce one such model, the minimum-covering/shortest-path (MinCSP) problem, and formulate several variations of the problem. The MinCSP problem is a two-objective path problem: minimization of the total population negatively impacted by the path and minimization of the total path length. A population is considered to be negatively impacted by the path if the path comes within some predetermined distance of the population. Consequently, the MinCSP problem extends the concept of coverage from facility location modeling to network design. Additionally, several existing solution methods for the problem are briefly discussed and potential applications presented.

Tajdin, and Mahdavi, (2010) presented a novel approach for computing a shortest path in a mixed fuzzy network, network having various fuzzy arc lengths. First, we develop a new technique for the addition of various fuzzy numbers in a path using cuts. Then, we present a

dynamic programming method for finding a shortest path in the network. For this, we apply a recently proposed distance function for comparison of fuzzy numbers. Four examples are worked out to illustrate the applicability of the proposed approach as compared to two other methods in the literature as well as demonstrate the novel feature offered by our algorithm to find a fuzzy shortest path in mixed fuzzy networks with various settings for the fuzzy arc lengths.

Jing-Rung Yu, and Wei, (2007) proposed a simple linear multiple objective programming to deal with the fuzzy shortest path problem. Their proposed approach does not need to declare 0-1 variables to solve the fuzzy shortest path problem because it meets the requirements of the network linear programming constraints. Therefore, the linear programming relaxation can be used to arrive at an integer solution without using the Branch and Bound technique, and the complexity of our proposed method can be reduced. A compromising non-dominated integer optimal solution, the fuzzy shortest path, can be obtained easily without adding extra constraints. This approach not only can obtain a fuzzy shortest path but also can reduce the complexity of solving the basic fuzzy shortest path problem without using 0-1 variables. Three examples with trapezoidal and triangular fuzzy numbers in arc length are used to demonstrate the proposed method in more details.

Chitra, and Subbaraj, (2010) proposed that the shortest path routing problem is a multi-objective nonlinear optimization problem with constraints. This problem has been addressed by considering Quality of service parameters, delay and cost objectives separately or as a weighted sum of both objectives. Multi-objective evolutionary algorithms can find multiple pareto-optimal solutions in one single run and this ability makes them attractive for solving problems with multiple and conflicting objectives. This paper uses an elitist multi-objective evolutionary algorithm based on the Non-dominated Sorting Genetic Algorithm (NSGA), for solving the dynamic shortest path routing problem in computer networks. A priority-based

encoding scheme is proposed for population initialization. Elitism ensures that the best solution does not deteriorate in the next generations. Results for a sample test network have been presented to demonstrate the capabilities of the proposed approach to generate well-distributed pareto-optimal solutions of dynamic routing problem in one single run. The results obtained by NSGA are compared with single objective weighting factor method for which Genetic Algorithm (GA) was applied.

Hassan, and Mohsen, (1992) introduced a method for reducing acyclic networks with knapsack constraints is discussed. The method is applicable for acyclic network with each arc having time and length as attributes. It is based on identification and removal of arcs and nodes that render a path infeasible which the method accomplishes by doubly traversing the network. The model has a modest computational requirement enhancing its usage in the solution of constrained shortest path problem.

Endelman, and Silberg, (2004) put forward that protein function can be tuned using laboratory evolution, in which one rapidly searches through a library of proteins for the properties of interest. In site-directed recombination, n crossovers are chosen in an alignment of p parents to define a set of p (n + 1) peptide fragments. These fragments are then assembled combinatorial to create a library of p^{n+1} protein. They developed a computational algorithm to enrich these libraries in folded proteins while maintaining an appropriate level of diversity for evolution. For a given set of parents, our algorithm selects crossovers that minimize the average energy of the library, subject to constraints on the length of each fragment. This problem is equivalent to finding the shortest path between nodes in a network, for which the global minimum can be found efficiently. Our algorithm has a running time of $O(N^3p^2 + N^2n)$ for a protein of length N. Adjusting the constraints on fragment length generates a set of optimized libraries with varying degrees of diversity. By comparing these

optima for different sets of parents, we rapidly determine which parents yield the lowest energy libraries.

Nagoorgani, and Begam, (2010) showed that shortest path problems are essential for the optimal routing control of data networks. A fuzzy shortest-path problems on a network in which a trapezoidal fuzzy number instead of a real number is assigned to each edge and introduce an order relation among trapezoidal numbers. Here a novel method for ranking of fuzzy numbers is proposed. The Fuzzy shortest path length method is proposed to find the fuzzy shortest length and the fuzzy similarity measure is used. At last, some numerical examples are given to illustrate this method.

Irnich, and Villeneuve, (2006) stated that the elementary shortest-path problem with resource constraints (ESPPRC) is a widely used modeling tool in formulating vehicle-routing and crew-scheduling applications. The ESPPRC often occurs as a sub problem of an enclosing problem, where it is used to generate implicitly the set of all feasible routes or schedules, as in the column-generation formulation of the vehicle-routing problem with time windows (VRPTW). As the ESPPRC problem is NP-hard in the strong sense, classical solution approaches are based on the corresponding non elementary shortest-path problem with resource constraints (SPPRC), which can be solved using a pseudo-polynomial labelling algorithm. While solving the enclosing problem by branch and price, this sub problem relaxation leads to weak lower bounds and sometimes impractically large branch-and-bound trees. A compromise between solving ESPPRC and SPPRC is to forbid cycles of small length. In the SPPRC with k-cycle elimination (SPPRC-k-cyc), paths with cycles are allowed only if cycles have length at least (k+1). The case k=2 forbids sequences of the form (i –j–i) and has been successfully used to reduce internality gaps. We propose a new definition of the dominance rule among labels for dealing with arbitrary values of k ≥2. The numerical experiments on the linear relaxation of some hard VRPTW instances from Solomon's

benchmark show that k-cycle elimination with k ≥3 can substantially improve the lower bounds of vehicle-routing problems with side constraints. The new algorithm has proven to be a key ingredient for getting exact integer solutions for well-known hard problems from the literature.

Nepal and Kali, (2009) proposed an algorithm for an upgrading arc median shortest path problem for a transportation network. The problem is to identify a set of non dominated paths that minimizes both upgrading cost and overall travel time of the entire network. These two objectives are realistic for transportation network problems, but of a conflicting and non compensatory nature. In addition, unlike upgrading cost which is the sum of the arc costs on the path, overall travel time of the entire network cannot be expressed as a sum of arc travel times on the path. The proposed solution approach to the problem is based on heuristic labelling and exhaustive search techniques, in criteria space and solution space, respectively. The first approach labels each node in terms of upgrading cost, and deletes cyclic and infeasible paths in criteria space. The latter calculates the overall travel time of the entire network for each feasible path, deletes dominated paths on the basis of the objective vector and identifies a set of Pareto optimal paths in the solution space. The computational study, using two small-scale transportation networks, has demonstrated that the algorithm proposed herein is able to efficiently identify a set of non dominated median shortest paths, based on two conflicting and non compensatory objectives.

Hartel, and Glaser, (1996) stated that the resource constrained shortest path problem is an NP-hard problem for which many ingenious algorithms have been developed. These algorithms are usually implemented in FORTRAN or another imperative programming language. We have implemented some of the simpler algorithms in a lazy functional language. Benefits accrue in the software engineering of the implementations. Our implementations have been applied to a standard benchmark of data files, which is available

from the Operational Research Library of Imperial College, London. The performance of the lazy functional implementations, even with the comparatively simple algorithms that we have used, is competitive with a reference FORTRAN implementation.

Fagerholt, and Heimdal, (2000) presents the problem of determining the estimated time of arrival (ETA) at the destination port for a ship located at sea. This problem is formulated as a shortest path problem with obstacles, where the obstacles are modelled by polygons representing the coastlines. An efficient solution algorithm is proposed to solve the problem. Instead of generating a complete visibility graph and solving the problem as an ordinary shortest path problem, the algorithm constructs arcs to the ship node during the solution process only when needed. This greatly enhances the algorithmic performance. Computational results based on test problems from an actual dry-bulk shipping operation are provided. The proposed algorithm is implemented in a decision support system for the planning of ship operations and it has successfully been applied on several real life problems.

Nie, and Yu, (2009) studied the problem of finding a priori shortest paths to guarantee a given likelihood of arriving on-time in a stochastic network. Such "reliable" paths help travelers better plan their trips to prepare for the risk of running late in the face of stochastic travel times. Optimal solutions to the problem can be obtained from local-reliable paths, which are a set of non-dominated paths under first-order stochastic dominance. The authors showed that, Bellman's principle of optimality can be applied to construct local-reliable paths. Acyclicity of local-reliable paths is established and used for proving finite convergence of solution procedures. The connection between the a priori path problem and the corresponding adaptive routing problem is also revealed. A label-correcting algorithm is proposed and its complexity is analyzed. A pseudo-polynomial approximation is proposed based on extreme-dominance. An extension that allows travel time distribution functions to vary over time is also discussed. They showed that the time-dependent problem is

decomposable with respect to arrival times and therefore can be solved as easily as its static counterpart. Numerical results are provided using typical transportation networks.

Crichigno and Baran, (2004) demonstrated similar representations (spanning trees) to Kumar's for a multicast algorithm. The basic difference between both algorithms is the latter adopts the Strength Pareto Evolutionary Algorithm (SPEA) in generating efficient solutions to the multicast routing problem. A contemporary report shows the behaviour of an elitist genetic algorithm as applied to the MSPP in the field of geographic information systems (GIS). The experiment compares the runtime performance (execution time) of the EA against a modified version of Dijkstra's algorithm on several artificial and real road networks. The results show that the EA competes well with the modified Dijkstra approach in terms of execution time and that the EA converges quickly to the Pareto-optimal paths adaptation.

2.3 SUMMARY

In this chapter, we have presented relevant literature on facility location (single or multi-facility location), as well as literature on All-pairs shortest path problem. In the next chapter for the success of this thesis we will look at the methodology employed. We present the various methodologies including the Factor-rating method, Centre of gravity method, break-even analysis method, Method of All-pairs shortest path problem. We shall put forward the proposed method for solving the Semi-obnoxious facility location problem as well as the conveying of the waste to the dump-site.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 INTRODUCTION

The thesis involves locating a semi-obnoxious facility (waste dump-site) for the disposal of waste using the factor-rating method for facility location. Waste collected from vantage collection points are then transported or conveyed to the dump-site. The All-pairs Shortest Path Problem (specifically the Floyd-Warshall's Method) is employed in this regard.

3.1 FACILITY LOCATION

Facility location problems have occupied an important place in operations research since the early 1960's. They investigate where to physically locate a set of facilities so as to optimize a given function subject to a set of constraints.

Facility location models are used in a wide variety of applications. Examples include locating warehouses within a supply chain to minimize the average travel time to the markets, locating hazardous material sites to minimize exposure to the public, locating railroad stations to minimize the variability of delivery schedules, locating automatic teller machines to best serve the bank's customers, and locating a coastal search and rescue station to minimize the maximum response time to maritime accidents (Hale, and Moberg, 2003). We shall discuss the various types of facility location problems.

3.1.1 TYPES OF FACILITY LOCATION PROBLEMS

Discrete facility location problem: it is a location problem where the sets of demand points and potential facility locations are finite.

Continuous facility location problem: it is a location problem in a general space endowed with some metric, example, ℓp norm. Facilities can be located anywhere in the given space.

Network facility location problem: it is a location problem which is confined to the links and nodes of an underlying network.

Stochastic facility location problem: it is a location problem where some parameters, example, demand or travel time, are uncertain.

We can furthermore classify a model as capacitated as opposed to uncapacitated where the former term refers to the upper bound on the number of clients (or demand) that a facility can serve. Models are called dynamic (as opposed to static) if the time element is explicitly represented (Wesolowsky, 1973).

Once a firm has decided to open a new facility or relocate an existing facility, it must be decided where that facility should be located. Facility location problem involves the evaluation of various sites for a new facility. There are several factors that influence the Facility Location Decision including: Labour availability and cost, Labour Skills, Materials availability, quality and cost, Land cost; Energy cost and availability, Water availability, cost, and quality, Environmental regulations, Cultural issues, etc.

3.2 METHODS FOR SOLVING FACILITY LOCATION

There are many analytical techniques that can be used in facility location decision. Some of these are: Factor Rating, Cost-Profit-Volume analysis (Break-Even Analysis), Center of Gravity Method, and Transportation and Simulation Models.

3.2.1 THE FACTOR RATING METHOD

Factor-rating systems are perhaps the most widely used of the general location techniques because it provides a mechanism to combine diverse factors in an easy-to-understand format. A major problem with simple point-rating schemes is that they do not account for the wide range of costs that may occur within each factor. To deal with the problem of just using

nominal cost, 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.

The Factor Rating Method

(i) In factor rating method, first identify the Most Important Factors in evaluating alternative sites for the new facility.

(ii) Then, assign a weight between 0 and 100 to each of these factors.

(iii) Each alternative location will then be rated based on these factor weights.

(iv) The most weighted alternative is selected as the best alternative (Comerford C., Kovar D., and Keehan M., 2004).

3.2.2 COST-PROFIT-VOLUME ANALYSIS (BREAK-EVEN ANALYSIS)

The location break-even analysis is the use of cost-volume analysis to make an economic comparism 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 method employs three steps. These are;

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

(ii) Plot the cost for each location, with Cost on the vertical axis and the Annual volume on the horizontal axis of the graph.

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

When the fixed and variable costs for each site differ, Cost-profit-volume analysis can be used to identify the location with the lowest cost (Comerford C., Kovar D., and Keehan M., 2004).

3.2.3 CENTRE OF GRAVITY METHOD

The center-of-gravity technique can be used when multiple suppliers or customer bases exist at different geographic locations, and it is economically sensible to locate centrally to service all of them. In general, transportation costs are a function of distance, weight, and time. The center-of-gravity technique is a quantitative method for locating a facility, such as a warehouse, at the center of movement in a geographic area, based on weight and distance.

The center of gravity method is used to find a location that Minimizes the Sum of Transportation Cost in between new facility and old facilities. Transportation cost is assumed to be a linear function of the Number of Units Shipped and the Traveling Distance.

The location of the firm's existing facilities are converted into x and y coordinates.

The following center of gravity equations are then used for calculating the x and y coordinates for the new facility:

$$C_x = \frac{\sum_{i-1}^{n} X_i V_i}{\sum_{i-1}^{n} V_i} \qquad and \qquad C_y = \frac{\sum_{i-1}^{n} Y_i V_i}{\sum_{i-1}^{n} V_i}$$

Where,

Cx : is the x coordinate for new location, Cy:, is the y coordinate for new location

Xi:, is the x coordinate of existing ith location yi:, is the y coordinate of existing ith location

i:, is the index for existing locations, and n: total number of existing locations. (Comerford C., Kovar D., and Keehan M., 2004).

3.2.4 THE TRANSPORTATION MODEL

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.

A special form of linear programming, that is Transportation Model, can be used to compare the total transportation cost associated with each alternative site.

The transportation model technique can be used to determine how many units should be shipped from each plant to each warehouse To Minimize Total Transportation Cost (Comerford C., Kovar D., and Keehan M., 2004).

3.2.5 SIMULATION MODELS

Firms often consider many variables and factors when they choose a facility location, which are often difficult to estimate and they also change in time. In these kinds of Dynamic Situations, Simulation may be the best modeling technique. Simulation models allow managers to examine a range of Scenarios and are well suited to open-ended problems. However, the determination of the parameters in a simulation is also a challenging task. Also, developing a simulation model may take considerable time and effort. (Comerford C., Kovar D., and Keehan M., 2004)

3.3 THE SHORTEST PATH PROBLEMS

The all-pairs shortest path problem can be considered the mother of all routing problems. It aims to compute the shortest path from each vertex v to every other. Using standard single-source algorithms, you can expect to get a naive implementation of O(n^3) if you use Dijkstra for example that is running a O(n^2) process n times. Likewise, if you use the Bellman-Ford-Moore algorithm on a dense graph, it will take about O(n^4), but handle negative arc-lengths as well.

Storing all the paths explicitly can be very memory expensive indeed, as you need one spanning tree for each vertex. This is often impractical in terms of memory consumption, so these are usually considered as all-pairs shortest distance problems, which aim to find just the distance from each to each node to another.

The result of this operation is an n * n matrix, which stores estimated distances to each node. This has many problems when the matrix gets too big, as the algorithm will scale very poorly.

Shortest path problems are the most fundamental and most commonly encountered problems in the study of transportation, communication, and computer networks. There are many types of shortest paths problems. For example we may be interested in determining the shortest path (i.e the most economical path or fastest path or minimum-fuel consumption path) from one specified node in the network to another specified node; or we may need to find shortest paths from a specific node to all the other nodes. Shortest paths between all pairs of nodes in a network are required in some problems. It is also possible to find the shortest path from one given node to another given node that passes through certain specified intermediate nodes. In some applications, one requires not only the shortest path but also the second and third shortest paths. There are instances when the actual shortest path is not required but only the shortest distance is required. The two most important shortest path problems are;

(i) How to determine shortest path distance (a shortest path) from a specific node S to another specific node T, and

(ii) How to determine shortest distances (and paths) from every node to every other node in the network (S. K. Amponsah, 2009)

3.4 TYPES OF SHORTEST PATH PROBLEM

Shortest paths are classified based on the graph or network. This could be directed or undirected, closed or not closed, and finally whether the weights of the edges are positive or negative.

3.4.1 SINGLE-SOURCE SHORTEST PATH PROBLEM

We look at finding the shortest paths in a weighted graph, based on several algorithms on Dynamic Programming. Given a weighted, directed graph G, a start node S and a destination node T, the S-T shortest path problem is to output the shortest path from S to T. The single-source shortest path problem is to find shortest paths from S to every node in G. The (algorithmically equivalent) single-sink shortest path problem is to find shortest paths from every node in G to T.

We will allow for negative-weight edges, but will assume no negative-weight cycles (else the shortest path can wrap around such a cycle infinitely often and has length negative infinity). As shorthand, if there is an edge of length ℓ from i to j and also an edge of length ℓ from j to i, we will often just draw them together as a single undirected edge. So, all such edges must have positive weight (S. K. Amponsah, 2009).

3.4.2 DIJKSTRA'S ALGORITHM

The Dijkstra's algorithm is one of the algorithms for finding the shortest path problem. We then will see how the basic approach of this algorithm can be used to solve other problems including finding maximum bottleneck paths and the minimum spanning tree (MST) problem. We will then expand on the minimum spanning tree problem, giving one more algorithm, Kruskal's algorithm, which to implement efficiently requires a good data structure

for something called the **union-find** problem. We consider the Dijkstra's algorithm for shortest paths when no edges have negative weight.

For a single-source shortest path problem, given a graph G, and a start node **s**, we want to find the shortest path from **s** to all other nodes in G. These shortest paths can all be described by a tree called the shortest path tree from start node **s**. A Shortest Path Tree in G from start node **s** is a tree (directed outward from **s** if G is a directed graph) such that the shortest path in G from **s** to any destination vertex **t** is the path from **s** to **t** in the tree.

We present the Dijktra's Algorithm Method.

It should be noted that distance between nodes can also be referred to as weight.

Step 1: Assign the permanent label 0 to the starting vertex.

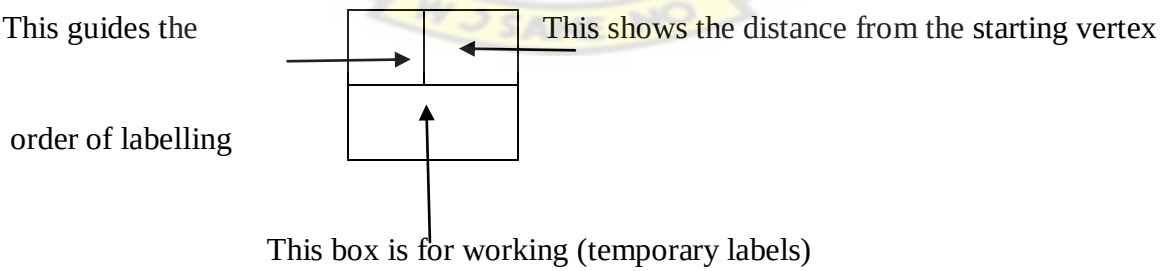
Step2: Assign temporary labels to all the vertices that are connected directly to the most recently permanent labelled vertex.

Step3: Choose the vertex with the smallest temporary label and assign a permanent label to that vertex.

Step4: Repeat step 2 and 3 until all vertices have permanent labels.

Step5: Find the shortest path by tracing back through the network.

It is important to notice that, recording the order in which permanent labels are assigned to the vertices is an essential part of the algorithm.

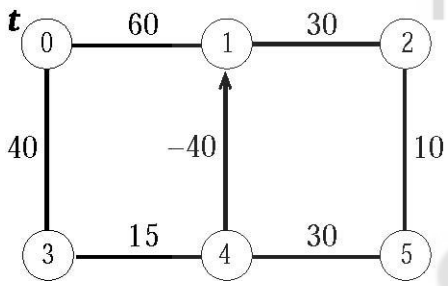


The algorithm gradually changes all temporary labels into permanent ones (Comerford C., Kovar D., and Keehan M., 2004).

3.4.3 BELLMAN–FORD ALGORITHM

Bellman (1953) is credited for inventing Dynamic Programming, and even if the technique can be said to exist inside some algorithms before him, he was the first to distill it as an important technique.

We consider a Dynamic Programming algorithm called the Bellman-Ford Algorithm for the single-sink (or single-source) shortest path problem. Let us develop the algorithm using the following example:



How can Dynamic Programming be used to find the shortest path from all nodes to t? First of all, as usual for Dynamic Programming, let's just compute the lengths of the shortest paths first, and afterwards we can easily reconstruct the paths themselves. The idea for the algorithm is as follows:

(i) For each node **v**, find the length of the shortest path to t that uses at most one (**1**) edge, or write down ∞ if there is no such path.

This is easy: if **v=** t we get **0**; if **(v,t)∈E** then we get **len(v,t)**; else just put down ∞.

(ii) Now, suppose for all **v** we have solved for length of the shortest path to **t** that uses **(i−1)** or fewer edges. How can we use this to solve for the shortest path that uses **i** or fewer edges? The shortest path from **v** to **t** that uses **i** or fewer edges will first go to some neighbour **x** of **v**, and then take the shortest path from **x** to **t** that uses **(i−1)** or fewer edges, which we have already solved for. So, we just need to take the **min** over all neighbours **x** of **v**. How far we need to go depends on at most **i=(n−1)** edges

3.5 ALL-PAIRS SHORTEST PATH PROBLEM

The shortest path between two nodes might not be a direct edge between them, but instead involve a detour through other nodes. The all-pairs shortest path problem requires that we determine shortest path distances between every pair of nodes in the network.

3.5.1 FLOYD–WARSHAL'S ALGORITHM

The Floyd-Warshal's algorithm shaves off the O(logn) and runs in time $O(n^3)$. The idea is that instead of increasing the number of edges in the path, we will increase the set of vertices we allow as intermediate nodes in the path.

We describe the Floyd-Warshal algorithm for finding the shortest path between all nodes in a graph. The shortest path between two nodes of a graph is a sequence of connected nodes so that the sum of the edges that inter-connect them is minimal.

3.5.2 MATLAB PROGRAM FOR THE FLOYD-WARSHAL'S ALGORITHM

```
[Data,y,x]=xlsread('D:\Masters\floydexample.xlsx','Sheet1','b2:k11');
 [n,m]=size(Data);
MaxD=2*max(max(Data));
for i=1:n
for j=1:n
if(x{i,j}=='inf') Data(i,j)=MaxD;end
end
end
for i=1:n
   for j=1:n
      Temp=Data(i,j);
```

```
        for k=1:m
                if(Temp>Data(i,k)+Data(k,j))
                   Temp=Data(i,k)+Data(k,j);
                end
        end
        Data(j,i)=Temp;Data(i,j)=Temp;
    end
end
 Data
```

An illustrative example and output of the Floyd-Warshall's method is shown in Appendix A

3.5.3 MINIMUM CONNECTOR

A spanning tree of a graph is a tree that touches all the vertices (so, it only makes sense in a connected graph). A minimum spanning tree (MST) is a spanning tree whose sum of edge lengths is as short as possible (there may be more than one). We will sometimes call the sum of edge lengths in a tree, the size of the tree. For instance, imagine you are setting up a communication network among a set of sites and you want to use the least amount of wire possible. Notice that our definition is only for undirected graphs. Kruskal's algorithm and Prim's algorithm are two standard approaches to solving this problem (Comerford C., Kovar D., and Keehan M., 2004)

3.5.4 KRUSKAL'S ALGORITHM

The Kruskal's Algorithm starts with a forest which consists of n trees. Each and every one tree consists only by one node and nothing else. In every step of the algorithm, two different trees of this forest are connected to a bigger tree. Therefore, we keep having less and bigger

trees in our forest until we end up in a tree which is the minimum genetic tree (MGT) .In every step we choose the side with the least cost, which means that we are still under greedy policy. If the chosen side connects nodes which belong in the same tree the side is rejected, and not examined again because it could produce a circle which will destroy our tree. Either this side or the next one in order of least cost will connect nodes of different trees, and this we insert connecting two small trees into a bigger one (Comerford C., Kovar D., and Keehan M., 2004)

3.5.5 PRIM'S ALGORITHM

Prim's algorithm is an algorithm in graph theory that finds a minimum spanning tree for a connected weighted graph. This means it finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized. If the graph is not connected, then it will only find a minimum spanning tree for one of the connected components. Prim's algorithm works from starting point and builds up the spanning tree step by step, connecting edges into the existing solution. It can be applied directly to the distance matrix, as well as to the network itself.

The algorithm can be stated as follows;

Step 1 Choose a starting vertex.

Step 2 Join this vertex to the nearest vertex directly connected to it.

Step 3 join the next nearest vertex, not already in the solution to any vertex in the solution, provided it does not form a cycle.

Step 4 repeat until all vertices have been included.

Now we shall apply the algorithm to the distance matrix below with the solution taken straight from the graph alongside.

An illustrative example and solution of the Prim's algorithm is shown in Appendix B.

3.6 SUMMARY

In this chapter, we have looked at the Methodology of the study including; facility location methods of solution, and all-pairs shortest path problems forms and solutions. In the next chapter we will look at the analysis of data, and discussion of results.

CHAPTER 4

DATA COLLECTION, ANALYSIS, AND DISCUSSION OF RESULTS

4.0 INTRODUCTION

In this chapter, we shall present the secondary data from Zoomlion Ghana Limited. Analysis will be done on the data to determine the location of the semi-obnoxious facility (waste dump-site) using the 'factor-rating method' and then the shortest path for conveying or transporting the waste to the dump-site using the 'all-pairs shortest path method', specifically the Floyd-Warshall's Algorithm or Method.

4.1 DATA PRESENTATION AND ANALYSIS FOR DUMP-SITE LOCATION

Facility location problem is concerned with the location of one or more facilities in some space, so as to optimise some specified criteria.

The technical staff of Zoomlion Ghana limited came out with the following factors for sitting a waste dump-site, weight ratings, and scores for three proposed places for the sitting of a waste dump-site. The results are presented in Table 4.1.

TABLE 4.1 WASTE DUMP-SITE FACILITY LOCATION TABLE

No	Factors Considered for a Dump Site Location	Weight Rating	Gbalahi	Changnaa Yili	Kpalsi
1	Community Approval	5	90	70	50
2	Dump Site Construction Cost	3	55	85	30
3	Assembly's Approval	4	100	50	60
4	Travel Distance	2	70	40	80
5	Accessibility of Dump Site	1	90	85	70
6	Maintenance Cost	3	95	60	60

7	Reclaim of Degraded Land	5	100	70	100

4.2 MATLAB PROGRAM FOR THE 'FACTOR-RATING METHOD'.

We present the matlab programming codes for the 'factor-rating method' for Semi-obnoxious facility location (waste dump-sitr) by Zoomlion Ghana Limited.

%g represents gbalahi, c represents changnaayili, k represents kpalsi, which are all proposed communities where the waste dump site is to be sited, and w represents weight ratings

```
w=[5 3 4 2 1 3 5]
g=[90 55 100 70 90 95 100];c=[70 85 50 40 60 70 85];k=[50 30 60 80 70 60 100];
format short
sum_weighting=sum(w)
ratio=w./sum_weighting
gbalahi=ratio.*g
changnaayili=ratio.*c
kpalsi=ratio.*k
sum_gbalahi=sum(gbalahi)
sum_changnaayili=sum(changnaayili)
sum_kpalsi=sum(kpalsi)
site_sums=[sum_gbalahi,sum_changnaayili,sum_kpalsi]
bestsite=max(site_sums)
```

4.3 MATLAB OUTPUT FOR WASTE DUMP-SITE FACILITY LOCATION

```
w =

     5     3     4     2     1     3     5

sum_weighting =
```

23

ratio =

0.2174 0.1304 0.1739 0.0870 0.0435 0.1304 0.2174

gbalahi =

19.5652 7.1739 17.3913 6.0870 3.9130 12.3913 21.7391

changnaayili =

15.2174 11.0870 8.6957 3.4783 2.6087 9.1304 18.4783

kpalsi =

10.8696 3.9130 10.4348 6.9565 3.0435 7.8261 21.7391

sum_gbalahi =

88.2609

sum_changnaayili =

68.6957

sum_kpalsi =

64.7826

site_sums =

88.2609 68.6957 64.7826

bestsite =

88.2609

4.4 DISCUSSION OF RESULTS FOR THE WASTE DUMP-SITE LOCATION

Notice that, the site with the highest value implies the best site for the location of the semi-obnoxious facility (waste dump-site) by Zoomlion Ghana Limited, and the one with the least value implies less suitability for such a facility location as shown in Table 4.2 from matlab output.

Therefore, **Gbalahi,** which has the highest value of **88.2609** is the best place to locate the semi-obnoxious facility (waste dump-site), the least however been **kapalsi** of **64.7826,** indicating less suitability for the waste dump-site location

TABLE 4.2 WASTE DUMP-SITE FACILITY LOCATION TABLE FOR ZOOMLION GHANA LIMITED

No	Factors Considered for a Dump Site Location	Weight Rating	Gbalahi	Changnaayili	Kpalsi	Rating Ratio	Gbalahi	Changnaayili	Kpalsi
1	Community Approval	5	90	70	50	0.2174	19.5652	15.2174	10.8696
2	Dump Site Construction Cost	3	55	85	30	0.1304	7.1739	11.0870	3.9130
3	Assembly's Approval	4	100	50	60	0.1739	17.3913	8.6957	10.4348
4	Travel Distance	2	70	40	80	0.0870	6.0870	3.4783	6.9565
5	Accessibility of Dump Site	1	90	60	70	0.0435	3.9130	2.6087	3.0435
6	Maintenance Cost	3	95	70	60	0.1304	12.3913	9.1304	7.8260
7	Reclaim of Degraded Land	5	100	85	100	0.2174	21.7391	18.4783	21.7391
		23	**600**	**460**	**450**		**88.2609**	**68.6957**	**64.7826**

4.5 DATA PRESENTATION FOR THE SHORTEST PATH DISTANCES

Secondary data of kilometric distances is taken from Zoomlion Ghana Limited, and modified for the purposes of programming. The symbol ' ∞' which means that there is no direct connection between vertices is replaced with '**inf**', and the symbol '-' which means that there is no movement is replaced with '**0**' respectively. The data is shown in Appendix D.

4.6 MATLAB PROGRAM FOR THE SHORTEST PATH DISTANCES

```
[Data,y,x]=xlsread('D:\MPHILSTUFF\THESIS\distances.xlsx','Sheet1','b2:ax50');
        %Read data from excel sheet
 [n,m]=size(Data);       %Determines size of data
MaxD=2*max(max(Data));    %Finds maximum distance and doubles it to replace non-
connectivity distances with it
for i=1:n
for j=1:n
if(x{i,j}=='NaN') Data(i,j)=MaxD;end          %Replaces non-connectivity distances with a
finite number MaxD
end
end
for i=1:n
   for j=1:n
      Temp=Data(i,j);
      for k=1:m
            if(Temp>Data(i,k)+Data(k,j))    %Compares direct distances with alternative
paths distances
               Temp=Data(i,k)+Data(k,j);    %Replaces direct path with shorter alternative
path
            end
      end
      Data(j,i)=Temp;Data(i,j)=Temp;          % Final replacement for the shortest path
   end
end
```

% Data % displays the data

xlswrite('D:\MPHILSTUFF\THESIS\distances.xlsx',Data,'Sheet2'); % Writes back the data/solution to excel spreadsheet

4.7 MATLAB OUTPUT FOR THE SHORTEST PATH DISTANCES

Apart from Tamale the regional capital, all the districts and municipal assemblies have very few containers placed at vantage collection points for waste collection by Zoomlion Ghana Limited. The lack of development in the urban roads sector coupled with the relatively less quantum of waste generated limits the number of containers in these places as well as the possibility of having more paths and shorter paths.

Zoomlion Ghana Limited places containers at vantage points (usually areas or public places), collects the waste and then convey or transport it to the dump site using trucks. The number of containers in an area or location depends on the level of activities and the quantum of waste generated.

We present the matlab output for the shortest path in Appendix E.

4.8 DISCUSSION OF RESULTS FOR THE SHORTEST PATH DISTANCES

Several observations can be made with regards to this output data in Appendix E. The output shows that conveying or transporting the waste from one source point to another destination point is higher in most cases for a direct path than taking a transit or detour. For instance conveying the waste from C upto G representing collection points Kalpohin, Nyanshegu, Tishigu, Gumani, and Gumbihini respectively to the dump site B(Gbalahi dump site) is shorter taking a detour or transit than just a direct path. For example, conveying the waste from M (Penticost area) to B (Gbalahi dump site) is 10.3 kilometres directly, and taking a detour gives 10.1 indicating that the detour gives a shorter path than the direct path.

Also, before the application of the all-pairs shortest path method, the total direct distance of one-cycle of conveying the waste to the dump-site is 568km, and after the application of the methodology it is reduced to 556km indicating a reduction of 12.18km of travel distance. Nonetheless, despite the fact that in some cases the distances are the same for a direct path, it is shorter in most cases taking a detour or transit.

4.9 SUMMARY

In this chapter, we have presented and analysed data for both the factor rating method for Semi-obnoxious facility location, and the Floyd-Warshall's method for the shortest path of conveying the waste. We have realised that Gbalahi is the best site for the waste dump-site, and that transporting the waste to the Gbalahi dump-site directly may constitute a longer distance than taking a detour or transit in most cases. The next chapter is detailed for the conclusions and recommendations of the study.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Reading through this thesis work, we have realised that most waste management companies in Ghana do not have any scientific method in solving the high demand for effective waste management by moving the waste from collection points to the dump site. As such, most waste management companies are not able to identify the best site for locating the dump site, and then conveying the waste using shorter paths to optimise cost, time, and risk factors involved.

This therefore, affects the socio-economic activities in the areas in which they operate.

A model has therefore been developed or proposed to help Zoomlion Ghana Limited to effectively and efficiently manage waste in the Northern Region of Ghana.

The research shows that Gbalahi is the best site for the waste dump-site, and that transporting the waste to the Gbalahi dump site directly in most cases constitutes a longer distance than taking a detour or transit.

Hence, we conclude that the scientific method being used to develop the proposed model can have a gigantic increase in the profit margin if Zoomlion Ghana Limited adopts this model.

5.2 RECOMMENDATIONS

From the conclusion we realized that using scientific methods on transportation or conveying the waste would increase the profits margin of Zoomlion Ghana Limited. Hence, we recommend that Zoomlion Ghana Limited should adapt this model in its waste dump site location and conveying of the waste to the dump site.

Furthermore, it is recommended that Zoomlion Ghana Limited be advised to establish a research department to use scientific methods to find an appropriate mathematical model to meet the high demand on transportation of the waste to be more efficient and effective.

Also, the urban road network in the Metropolitan, Municipal, and District Assemblies should be improved or constructed to provide alternative paths or routes.

Lastly, it is recommended that apart from Zoomlion Ghana Limited using this scientific model, transportation companies and other stake holders should employ scientific methods and mathematical methods in most of the road constructions as well as rehabilitation of roads.

REFERENCES

(1).Amponsah S. K., (2009). Optimization Techniques 1. Institute of Distance Learning. KNUST, Kumasi, pp. 176-182.

(2) Amponsah S. K., (2009). Operations Research, Institute of Distance Learning. KNUST, Kumasi, pp. 9-16.

(3) Ghosh D., (2003). Neighborhood search heuristics for the uncapacitated facility location problem. European Journal of Operational Research, vol. 150, no. 1, pp. 150–162.

(4) Beresnev V. L., Gimady E. H., and Dementev V. T., (1978). Extremal Problems of Standardization, Nauka, Novosibirsk, Russia, , pp. 10–17.

(5) Gimady E. H., (1970). The Choice of Optimal Scales in One Problem Class of Location or Standartization. Manage Systems, Nauka, Novosibirsk, Russia, 6th edition, , pp. 130–162.

(6) Corneuéjols G., Fisher M. L., and Nemhauser G. L., (1977). Location of bank accounts to optimize float: an analytic study of exact and approximate algorithms. Management Science, vol. 23, no. 8, pp. 789–810.

(7) Khumawala B. M., (1972). An efficient branch and bound algorithm for the warehouse location problem. Management Science, vol. 18, no. 12, pp. 718–733.

(8) Krarup J., and Pruzan P. M., (1983). The Simple plant location problem: survey and synthesis. European Journal of Operation Research, vol. 12, no. 1, pp. 36–81.

(9) Mirchandani P. B., and Francis R. L., (1990). Discrete Location Theory. Wiley-Interscience, New York, pp. 120–132.

(10) Klose A.,(1998). A branch and bound algorithm for an UFLP with a side constraint. International Transactions in Operational Research, vol. 5, no. 2, pp. 155–168.

(11) Van Roy T. J.,(1986). A cross decomposition algorithm for capacitated facility location. Operations Research, vol. 34, no. 1, pp. 145–163.

(12) Barcelo J., Hallefjord A., Fernandez E., and Jornsten K., (1990). Lagrangean relaxation and constraint generation procedures for capacitated plant location problems with single sourcing. Operation Research Spektrum, vol. 12, no. 2, pp. 79–88.

(13) Erlenkotter D., (1978). A dual-based procedure for uncapacitated facility location. Operations Research, vol. 26, no. 6, pp. 992–1009.

(14) Koerkel M., (1989). On the exact solution of large-scale simple plant location problems. European Journal of Operational Research, vol. 39, no. 2, pp. 157–173.

(15) Cornuéjols G., Nemhauser G. L., and Wolsey L. A., (1990) The uncapacitated facility location problem, in Discrete Location Theory, pp. 119–171.

(16) Alves M. L., and Almeida M. T., (1992) Simulated Annealing algorithm for the simple plant location problem: a computational study, pp. 180–192.

(17) Aydin M. E., and Fogarty T. C., (2004) A distributed evolutionary simulated annealing algorithm for combinatorial optimization problems, Journal of Heuristics, vol. 10, no. 3, pp. 269–292.

(18) Al-Sultan K. S., and Al-Fawzan M. A., (1999) A tabu search approach to the uncapacitated facility location problem, Annals of Operations Research, vol. 86, pp. 91–103.

(19) Michel L., and Van Hentenryck P., (2004). A simple tabu search for warehouse location. European Journal of Operational Research, vol. 157, no. 3, pp. 576–591.

(20) Sun M., (2006). Solving the uncapacitated facility location problem using tabu search. Computers and Operations Research, vol. 33, no. 9, pp. 2563–2589.

(21) Kratica J., Tosic D., Filipović V., and Ljubic I., (2001). Solving the simple plant location problem by genetic algorithm. RAIRO Operations Research, vol. 35, no. 1, pp. 127–142.

(22) Jaramillo J. H., Bhadury J., and Batta R., (2002). On the use of genetic algorithms to solve location problems. Computers and Operations Research, vol. 29, no. 6, pp. 761–779.

(23) Gen M., Tsujimura Y., and Ishizaki S., (1996). Optimal design of a star-LAN using neural networks. Computers and Industrial Engineering, vol. 31, no. 3-4, pp. 855–859.

(24) Vaithyanathan S., Burke L. I., and Magent M. A., (1996). Massively parallel analog tabu search using neural networks applied to simple plant location problems. European Journal of Operational Research, vol. 93, no. 2, pp. 317–330.

(25) Eberhart R. C., and Kennedy J., (1995) New optimizer using particle swarm theory, in Proceedings of the 6th International Symposium on Micro Machine and Human Science (MHS '95), pp. 39–43.

(26) Van den Bergh F., and Engelbecht A. P., (2000). Cooperative learning in neural networks using particle swarm optimizers. South African Computer Journal, vol. 26, pp. 84–90.

(27) Salman A., Ahmad I., and Al-Madani S., (2002). Particle swarm optimization for task assignment problem. Microprocessors and Microsystems, vol. 26, no. 8, pp. 363–371.

(28) Allahverdi A., and Al-Anzi F. S., (2006). A PSO and a Tabu search heuristics for the assembly scheduling problem of the two-stage distributed database application. Computers and Operations Research, vol. 33, no. 4, pp. 1056–1080.

(29) Tasgetiren M. F., Liang Y. C., Sevkli M., and Gencyilmaz G., (2007). A particle swarm optimization algorithm for makespan and total flowtime minimization in the permutation flowshop sequencing problem. European Journal of Operational Research, vol. 177, no. 3, pp. 1930–1947.

(30) Eberhart R. C., and Shi Y., (1998). Comparison between genetic algorithms and particle swarm optimization, in Evolutionary Programming. VII, vol. 1447 of Lecture Notes in Computer Science, pp. 611–616.

(31) Naka S., Genji T., Yura T., and Fukuyama Y., (2003). A hybrid particle swarm optimization for distribution state estimation. IEEE Transactions on Power Systems, vol. 18, no. 1, pp. 60–68.

(32) Yoshida Y., Kawata K., Fukuyama Y., and Nakanishi Y., (1999). A particle swarm optimization for reactive power and voltage control considering voltage stability, in Proceedings of the International Conference on Intelligent System Application to Power System (ISAP '99), pp. 117–121.

(33) Sevkli M., and Guner A. R., (2006) A continuous particle swarm optimization algorithm for uncapacitated facility location problem, in Ant Colony Optimization and Swarm Intelligence, vol. 4150 of Lecture Notes in Computer Science, pp. 316–323, Berlin.

(34) Tamir A., (1982) Polynomially Bounded Algorithms for Locating p-Centers on a Tree, Math. Programming, pp. 304-315.

(35).Christofides N., and Viola P., (1971) The Optimum Location of Multi-Centers on a Graph, Operation Reserach Quart., 22, pp. 145-154.

(36) Garfinkel R. S., (1978) Locating an Obnoxious Facility on a Network, Transportation Science, 12 pp. 107-118.

(37) Chavatal V., (1979). A Greedy Heuristic for the Set-Covering Problem. Mathematics Operation Research, 4 pp. 233-235.

(38)Dearing P. M., Francis R. L., and Lowe T. J., (1976). Convex Location Problems on Tree Networks. Operation Research, pp. 628-642.

(39) Francis R. L., Lowe T. J., and Ratliff H. D., (1978). Distance Constraints for Tree Network Multi-facility Location Problems. Operation. Research, 26, pp. 570-596.

(40) Goldman A. J., (1975). Concepts of Optimal Location for Partially Noxious Facilities. Bull. Operation Research Society, pp. 150–162.

(41) Hakimi S. L., (1965). Optimum Distribution of Switching Centers in a Communication Network and Some Related Graph Theoretic Problems. Operation Research, 13, pp. 462-475.

(42) Halpern J., (1980). Finding Minimal Center-Median Convex Combination (Cent-Dian) of a Graph. Management Science, 24, pp. 535-544.

(43).Hillsman E. L. and Rushton G., (1975) The p-Median Problem with Maximum Distance Constraints: A Comment, Geographical Anal., 7, pp. 85-89.

(44) Ho A. C., (1982) Worst Case Analysis of a Class of Set Covering Heuristics, Mathematics Programming, 23, pp. 170-180.

(45) Hsu W. L. and Nemhauser G. L., (1979) Easy and Hard Bottleneck Location Problems, Discrete Applied. Mathematics, 1 pp. 209-215.

(46) Karivo, and Hakimi S. L., (1979a) An Algorithmic Approach to Network Location Problems. Applied Mathematics, 37, pp. 513-538.

(47) Karivo, and Hakimi S. L., (1979b) An Algorithmic Approach to Network Location Problems. Applied Mathematics, 37, pp. 539-560.

(48) Lowe T. J., (1978) Efficient Solutions in Multi-objective Tree Network Location Problems, Transportation Science, 12, pp. 298-316.

(49) Moon I. D., (1977). Application of Graph Theory to a Location Problem. Presented at the Joint National Meeting of ORSA/TIMS, Atlanta, pp. 23-56.

(50) Revelle C., and Swain R., (1970). Central Facilities Location, Geographical Analysis 2, pp. 30-42.

(51) Marks D., and Liebman J. C., (1970). An Analysis of Private and Public Sector Location Models. Management Science 16, pp. 692-707.

(52) Shier D. R., (1977). A Min-Max Theorem for p-Center Problems on a Tree. Transportation Science, 11, pp.243-252.

(53) Tansel B. C., Francis R. L., and Lowe, (1983). Location on Networks: A Survey. Management Science, 29, pp.482-511.

(54) Chen M. L., (1968). Duality and Distance Constraints for the Nonlinear p-Center Problem and Covering Problem on a Tree Network. Operation Research, 30, pp. 725-744.

(55) Teitz M. B.and Bart P., (1968) Heuristic Methods for Estimating the Generalized Vertex Median of a Weighted Graph, Operation Research, 16, pp. 955-961.

(56) Toregas C., Swain R., Revelle C., and Bergman L., (1971) The Location of Emergency Service Facilities, Operation Research, 19, pp. 1363-1373.

(57) White J. A.,and Case K. E., (1974) On Covering Problems and the Central Facilities Location Problem, Geographical Analysis, 6, pp. 281-293.

(58) Eric, and Nedo, (2000) Proceedings of International Conference on Industrial Hazardous Waste Management, Bangkok, Thailand, pp. 23-40.

(59) LaGrega M., Buckingham P., and Evans J., (2001) Hazardous Waste Management. McGraw-Hill Book Co., pp. 45-70.

(60) Aardal K., Chudak F., and Shmoys D. B., (1999). A 3-approximation algorithm for the k-level uncapacitaed facility location problem. pp. 161-167.

(61) Andrews M., and Zhang L., (1998). The access network design problem, pp. 40–59.

(62) Arya A., Garg N., Khandekar R., Munagala K., and Pandit V., (2001). Local search heuristic for k-median and facility location problems. Proceedings of ACM STOC, pp. 21–29.

(63) Charikar M., Guha S., Tardos E., and Shmoys D., (1999). A constant factor approximation algorithm for the k-median problem. In Proceedings of 31st ACM STOC, pp. 1–10.

(64) Guha S., Meyerson A., and Munagala K., (2001). A constant factor approximation for the single sink edge installation problems. Proceedings of ACM STOC, pp. 383–388.

(65) Jain K., and Vazirani V., (2000). An approximation algorithm for the fault tolerant metric facility location problem. Proceedings of APPROX, LNCS 1913, pp.177–183.

(66) Jain K., and Vazirani V., (2001) Approximation algorithms for metric facility location and k-median problems using the primal-dual schema and lagrangian relaxation. Journal of ACM, 48(2), pp. 274–296

(67) Kaufman L., vanden Eede M., and Hansen P., (1977) A plant and warehouse location problem. Operations Research Quarterly, 28, pp. 547–557.

(68) Khuller S., Pless R., and Sussmann Y., (2000).Fault tolerant p-center problems. Theoretical Computer Science, 242, pp. 237–245.

(69) Li B., Golin M, Italiano G., Deng X., and Sohraby K., (1999).On the optimal placement of web proxies in the internet. Proceedings of INFOCOM, pp. 1280–1290.

(70) Plesnik J., (1987) A heuristic for the p-center problem in graphs. Discrete and Applied Mathematics, 17 pp. 263– 268.

(71) Bozer Y. A., Schorn E. C., and Sharp G. P., (1990). Geometric approaches to solve the Chebychev traveling salesman problem. IIE Transactions, v. 22, pp. 238-254.

(72) Bozer Y. A., and White J. A., (1984). Travel-time models for automated storage/retrieval systems. Institute of Industrial Engineers Transactions, v. 16, pp. 329-338.

(73) Hwang H., and Lim J. M., (1993). Deriving an optimal dwell point of the

storage/retrieval machine in an automated storage/retrieval system, International Journal of Production Research, v. 31, pp. 2591-2602.

(74) Gass S. L., and Witzgall C., (2004). An approximate minimax circle closest to a set of points. Computers and Operations Research, v. 31, pp. 637-643.

(75) Laporte G., Lopes L., and Soumis F., (1998). Optimal sequencing rules for some large-scale flexible manufacturing problems under the Manhattan and Chebychev metrics. International Journal of Flexible Manufacturing Systems, v. 10, pp. 27-42.

(76) Gaboune B., Laporte G., and Soumis, F., (1993). Expected distances between two uniformly distributed random points in rectangles and rectangular parallelepipeds. Journal of the Operational Research Society, v. 44, pp. 513-519.

(77) Francis R. L., McGinnis L. F. and White J. A., (1992). Facility Layout and Location: An Analytical Approach. Prentice Hall, New Jersey, pp. 184 – 238.

(78) Peters B., Smith J., and Hale T., (1996). Closed form models for determining the optimal dwell point location in automated storage and retrieval systems. International Journal of Production Research, v. 34, pp. 1757-1772.

(79) Wesolowsky G. O., (1993). The Weber problem. History and perspectives. Location Science, v. 1, pp. 5-23.

(80) Asami Y., and Walters I. (1989). Imperfect Information, Uncertainty and Optimal sampling in the Location Theory. Journal of Regional Science. 5, pp. 507-521.

(81) Baumol W., and Wolfe P., (1958). A Warehouse Location Problem. Operations Research. 6(2), pp. 252-263.

(82)Brandeau M., and Chiu S., (1989). An Overview of Representative Problems in Location Research. Management Science. 35, pp. 645-674.

(83) Brown P., and Gibson D., (1972). A Quantified Model for Site Selection-Application to a Multi-plant Location Problem. AIIE Transactions. 4(1), pp. 1-10.

(84) Erlenkotter D., (1975). Capacity Planning for Large Multi-location System: Approximate and Incomplete Dynamic Programming Approaches. Management Science. 22(3), pp. 274-285.

(85) Geoffrion A., (1978). A Guide to Computer Assisted Methods for Distribution System Planning. Sloan Management Review. 24(5), pp. 535-544.

(86) Kuehn A., and Hamburger M. (1963). A Heuristic Program for Locating Warehouses. Management Science. 9(4), pp. 643-666.

(87) Lee S., Green G., and Kim C., (1981). A Multiple Criteria Model for the Location Problem. Computers and Operations Research. 8(1), pp. 1-8.

(88) Moon I., and Goldman A., (1989). Tree Network Location Problems with Minimum Separations. IIE Transactions. 21, pp. 230-240.

(89) Rosenthal J., White J., and Young D., (1978). Stochastic Dynamic Location Analysis. ManagementScience. 24(6), pp. 645-653.

(90) Saaty T., (1996). Multi-criteria Decision Making: The Analytic Hierarchy Process, pp. 13-15.

(91) Church R. L. and Meadows M. E., (1977). Results of a New Approach to Solving the p-Median Problem with Maximum Distance Constraints, Geographical Anal., 9, pp. 364-378.

(92) Rojeski P., and Revelle C., (1970). Central Facilities Location under an Investment Constraint. Geographical Analysis, 2, pp. 343-360.

(93) Chandra and Rasekaran R., and Daughety A., (1981). Location on Tree Networks: p-Center and n-Dispersion Problems. Mathematics and Operation Research, pp. 50-57.

APPENDICES

APPENDIX A

AN ILLUSTRATIVE EXAMPLE AND OUTPUT OF THE FLOYD-WARSHALL'S METHOD.

LOCATIONS	A	B	C	D	E	F	G	H	I	J
A	-	9.1	10.3	10.2	11.9	12.1	15.2	11.9	10.4	8.8
B	9.1	-	1.6	1.9	3.4	2.8	∞	∞	2	0.6
C	10.3	1.7	-	1.8	1.9	3.7	6.8	2.6	1.1	1.1
D	10.2	2.2	1.8	-	3.6	2.2	7.8	3.6	1.1	1.4
E	11.9	3	1.9	3.4	-	4	∞	∞	2.8	3.6
F	12.1	4.5	3.7	2.2	3.9	-	∞	∞	2.3	3.7
G	15.2	∞	∞	∞	5	∞	-	4.2	6.7	∞
H	11.9	∞	∞	∞	2.9	∞	∞	-	2.9	∞
I	10.4	2	1.1	1.2	2.8	2.3	7	2.8	-	∞
J	8.8	0.8	1.8	1.4	3.6	∞	∞	4.2	∞	-

MATLAB OUTPUT FOR THE ABOVE EXAMPLE

Data =

Columns 1 through 7

0	9.1000	9.9000	10.2000	11.8000	11.9000	15.2000
9.1000	0	1.6000	1.9000	3.4000	2.8000	8.4000
9.9000	1.6000	0	1.8000	1.9000	3.4000	6.8000
10.2000	1.9000	1.8000	0	3.6000	2.2000	7.8000
11.8000	3.4000	1.9000	3.6000	0	4.0000	8.7000
11.9000	2.8000	3.4000	2.2000	4.0000	0	9.0000
15.2000	8.4000	6.8000	7.8000	8.7000	9.0000	0
11.9000	4.2000	2.6000	3.6000	4.5000	5.1000	4.2000
10.4000	2.0000	1.1000	1.1000	2.8000	2.3000	6.7000

8.8000	0.6000	1.1000	1.4000	3.0000	3.4000	7.9000

Columns 8 through 10

11.9000	10.4000	8.8000
4.2000	2.0000	0.6000
2.6000	1.1000	1.1000
3.6000	1.1000	1.4000
4.5000	2.8000	3.0000
5.1000	2.3000	3.4000
4.2000	6.7000	7.9000
0	2.9000	3.7000
2.9000	0	2.2000
3.7000	2.2000	0

APPENDIX B

AN ILLUSTRATIVE EXAMPLE AND SOLUTION OF THE PRIM'S METHOD

	E	F	C	D	A	B
E	∞	19	13	12	∞	∞
F	19	∞	∞	20	∞	∞
C	13	∞	∞	15	∞	14
D	12	20	15	∞	10	12
A	∞	∞	∞	10	∞	8
B	∞	∞	14	12	8	∞

Choose a starting vertex say E. Delete the row E. Look for the smallest entry in column E.

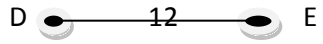
1

	E	F	C	D	A	B
~~E~~	~~∞~~	~~19~~	~~13~~	~~12~~	~~∞~~	~~∞~~
F	19	∞	∞	20	∞	∞
C	13	∞	∞	15	∞	14
D	12	20	15	∞	10	12
A	∞	∞	∞	10	∞	8
B	∞	∞	14	12	8	∞

• E

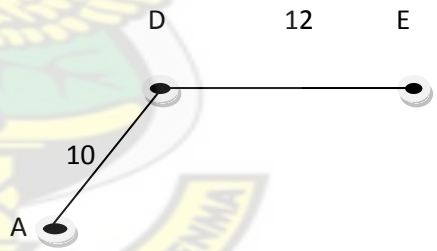
ED is the smallest edge joining E to the other vertices. Put edge ED into the solution. Delete row D. Look for the smallest entry in columns E and D

	1			2		
	E	F	C	D	A	B
F	19	∞	∞	20	∞	∞
C	13	∞	∞	15	∞	14
~~D~~	~~12~~	~~20~~	~~15~~	~~∞~~	~~10~~	~~12~~
A	∞	∞	∞	10	∞	8
B	∞	∞	14	12	8	∞



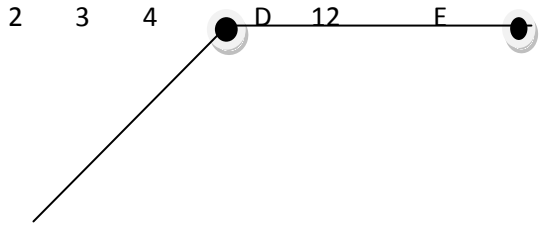
AD is the smallest edge joining E and D to the other vertices. Put edge DA into the solution Delete row A. Look for the smallest entry in columns E,D and A

	1			2	3	
	E	F	C	D	A	B
F	19	∞	∞	20	∞	∞
C	13	∞	∞	15	∞	14
~~A~~	~~∞~~	~~∞~~	~~∞~~	~~10~~	~~∞~~	~~8~~
B	∞	∞	14	12	8	∞

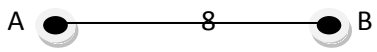


AB is the smallest edge joining E,D and A to the other vertices. Put edge AB into the solution. Delete row B. Look for the smallest entry in the columns E, D, A, B.

	1					
	E	F	C	D	A	B
F	19	∞	∞	20	∞	∞

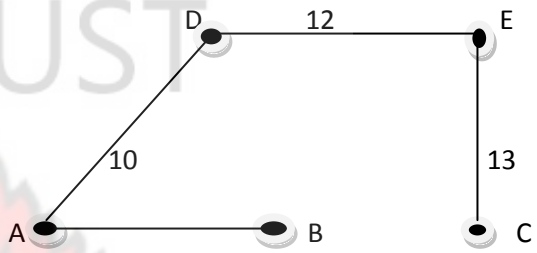


C	13	∞	∞	15	∞	14
~~B~~	~~∞~~	~~∞~~	~~14~~	~~12~~	~~8~~	~~∞~~



EC is the smallest edge joining E, D, A and B to the other vertices. Put edge EC into the solution. Delete row C. Look for the smallest entry in the columns E, D, A, B and C

	1		5	2	3	4
	E	F	C	D	A	B
F	19	∞	∞	20	∞	∞
~~C~~	~~13~~	~~∞~~	~~∞~~	~~15~~	~~∞~~	~~14~~

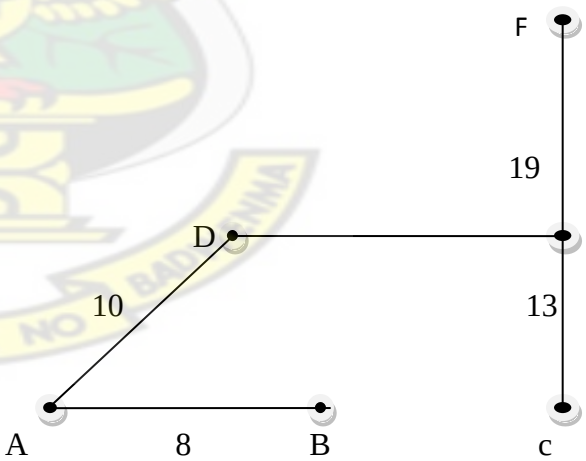


EF is smallest edge joining E, D, A, B and C to the other vertices. Put EF into the solution.

	1	6	5	2	3	4
	E	F	C	D	A	B
~~F~~	~~19~~	~~∞~~	~~∞~~	~~20~~	~~∞~~	~~∞~~

Now connect all vertices into the spanning tree

Length = 19+13+12+10+8=62km



APPENDIX C

QUESTIONNAIRE FOR WASTE DUMP-SITE FACILITY LOCATION

ACADEMIC QUESTIONNAIRE

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KNUST)

DEPARTMENT OF MATHEMATICS

This questionnaire is designed to address the research topic, 'Location of Semi-obnoxious Facility and the Transportation of Solid Wsate in the Northern Region of Ghana. A Case Study of Zoomlion Ghana Limited.

The researcher and the University guarantees the confidentiality of any information provided, since this research is purely for academic purposes.

(A) ID and Department of Respondent: ……..

(B) Apart from landfilling, list the other ways by which Zoomlion Ghana Limited manages wastes

Item	Waste management forms by Zoomlion Ghana. Limited
1	
2	
3	

(D) List the Waste Dump Sites of Zoomlion Ghana Limited

Item	Waste Dump Site List of Zoomlion Ghana limited
1	
2	
3	

(E) What were the reasons/factors for using this place(s) as dump sites? For example is it because of accessibility, cost, community acceptance etc.

Item	Factor/reason for a dump site choice	Priority Ranking of factors/reasons
1		
2		
3		
4		
5		
6		
7		
8		
9		

(F) Has Zoomlion Ghana Limited transformed or constructed these dump sites before using it.

Yes ☐ No ☐

(G) Given the factors/reasons in D and the various dump sites in E above, complete the table below. Using a scale of 1-10, rate the various dump sites for each factor/reason. In case of difficulty please refer to i.

Factor Rating Table for Dump Sites

Item	Factor/reason for a dump site	Dump site A Name ……	Dump site B Name ……	Dump site C Name ……	Dump site D Name ……	Dump site E Name ……
1						
2						
3						
4						
5						
6						
7						
8						

(H) ExampleA waste management company has proposals for the dump sites A,B, and C, and considers three factors including ; accessibility, cost, and community acceptance as the reasons/factors for using a particular site. Using a scale of 1-10 by the staff of the waste management company, the results are as follows.

Item	Factor/reason for a dump site	Weight ratio	Dump site A Name …….	Dump site B Name …….	Dump site C Name …….
1	Accessibility	1	5	7	9
2	Cost of maintenance	3	10	6	4
3	Community acceptance	2	8	3	7

APPENDIX D

KILOMETRIC DISTANCES OF CONVEYING WASTE FROM COLLECTION POINTS TO THE GBALAHI WASTE DUMP-SITE

LOCATIONS	Gbalahi	Kalpo.	Nyan shegu	Tishigu	Gumani	Gumbi Hini	Gurugu	Hill Top	Saka saka	Inter Royals	Jisona yili	Kalp JSS
Gbalahi	—	9.1	10.3	10.2	11.9	12.1	15.2	11.9	10.4	8.8	13.8	8.3
Kalpo.	9.1	—	1.6	1.9	3.4	2.8	∞	∞	2	0.6	∞	0.4
Nyanshegu	10.3	1.7	—	1.8	1.9	3.7	6.8	2.6	1.1	1.1	∞	2.1
Tishigu	10.2	2.2	1.8	—	3.6	2.2	7.8	3.6	1.1	1.4	6	2.2
Gumani	11.9	3	1.9	3.4	—	4	∞	∞	2.8	3.6	3.6	2.8
Gumbihini	12.1	4.5	3.7	2.2	3.9	—	∞	∞	2.3	3.7	∞	4.7
Gurugu	15.2	∞	∞	∞	5	∞	—	4.2	6.7	∞	2.9	∞
HillTop	11.9	∞	∞	∞	2.9	∞	∞	—	2.9	∞	6.7	3.7
Sakasaka	10.4	2	1.1	1.2	2.8	2.3	7	2.8	—	∞	5.2	2.4
Inter Royals	8.8	0.8	1.8	1.4	3.6	∞	∞	4.2	∞	—	∞	1.2
Jisonayili	13.8	∞	∞	∞	3.6	6.4	2.9	5.3	5.2	7.2	—	6.6
Kalpo JSS	8.3	0.4	2.1	2.2	2.8	5.1	∞	4	2.6	1.2	6.4	—
Pentecost	10.3	2	2	∞	3.2	∞	∞	3.3	0.75	1.6	5.6	2.4
Sagnarigu	15	∞	∞	6.8	6.1	4.4	7.6	3.4	∞	7.9	10.1	6.8
Stadium	13.8	5.8	4.6	4	4.9	∞	6.4	2.2	4.8	4.6	8.9	5.6
Timber Mkt	10.9	∞	∞	∞	4	∞	6.3	2.1	1.7	∞	8.8	3.7
T-Poly(Getf)	14.6	∞	∞	4.8	5.1	∞	3.8	2.1	5	6.3	6.3	5.8
T-Poly(Ho1)	14.6	∞	∞	4.8	5.1	∞	3.8	2.1	5	6.3	6.3	5.8
T-Poly(Ho2)	14.6	∞	∞	4.8	5.1	∞	3.8	2.1	5	6.3	6.3	5.8
VRA subs.	12	∞	∞	2.2	3.2	0.75	4.7	0.55	3.2	3.7	7.2	4
Ward K.	9.3	2	2	0.6	∞	∞	∞	3.7	1.5	0.65	6.4	2.4
Aboaboo Mkt	11.3	3.7	3.4	2.1	4.5	∞	7.2	3	2.3	2.9	9.7	4.1
Buglan Fong	11.4	3.6	3.5	2	4.6	∞	∞	∞	∞	2.6	7	5

Changli	10.9	3.6	4.1	2	5.2	3.6	∞	∞	∞	2.5	7.6	4
SabonJida	11.4	3.9	3.5	2	4.6	∞	∞	∞	2.4	3.1	9.7	5.1
Customs	10.2	∞	3.8	1.3	4.9	3.2	∞	3.7	2.7	1.9	∞	3.3
DVLA	13.8	∞	∞	4.4	∞	∞	∞	4.8	∞	5.4	11.5	7.4
Zongo	11	3.7	4.2	2.1	5.3	3.3	∞	∞	∞	2.6	7.7	4.1
Gbanjuli	11.2	4.7	4.3	2.9	5.4	∞	∞	∞	∞	2.5	7.9	5.9
Kasajani	12.6	∞	∞	∞	5.3	∞	∞	∞	∞	4.1	9.3	5.3
Lama. Palace	13.2	∞	∞	∞	7.1	∞	8.6	4.4	∞	5	11.1	6.9
Bayanwaya	11.4	∞	∞	∞	5.1	∞	∞	∞	∞	3.1	7.5	5.5
Old Cemetry	11.2	3.9	4.3	2.8	5.4	3.5	∞	∞	∞	2.9	7.9	4.3
Police Headq.	9.9	2.7	2.6	1	4.7	3.1	∞	∞	2.5	1.6	7.2	3
Taxico	10.6	3.3	∞	2.3	4.9	3.3	∞	∞	∞	2.2	7.3	3.7
Victory	11.2	∞	∞	∞	4.1	2.2	6.8	∞	∞	2.5	9.3	3.7
Zogbeli JSS	12.6	∞	4.4	∞	5.6	∞	8.3	4.1	∞	3.9	10.7	5.1
Zogbeli Park	12.6	4.7	4.4	∞	5.6	∞	8.3	∞	∞	3.9	10.7	5.1
Dohinaa Yili	11.4	5.6	5.3	3.8	6.4	∞	∞	∞	∞	2.9	8.8	6.8
Ghanasco	11.3	6.3	5.9	4.7	7	5.4	∞	∞	∞	3.8	∞	5.1
Kukuo Mkt	11	5.5	5.2	3.9	6.3	4.6	∞	∞	∞	2.8	8.7	4.8
Kukuo Transf	10.6	3.1	5.9	3.4	7	∞	∞	∞	∞	2.3	9.5	4
Lamankaraa	13.2	∞	∞	∞	6.4	∞	∞	∞	4.1	4.8	8.8	6
Nalung Fong	12.7	4.9	4.7	3.3	5.8	∞	∞	∞	∞	3.9	8.3	5.3
NHIS-Laman	12.5	∞	∞	∞	5.7	∞	∞	∞	∞	4.1	8.1	5.3
Nyohini Soc.	13.9	∞	∞	4.7	5.9	∞	7.3	∞	4.8	5.5	8.3	6.9
Sawaaba A	13.7	∞	∞	∞	5.6	∞	7.1	2.9	∞	5.3	8.1	6.2
Teach. Hosp	11.5	5.8	5.5	∞	6.6	4.9	∞	∞	∞	3.1	9	6.2
Workshop	12.9	∞	∞	∞	6.1	∞	∞	∞	∞	∞	∞	∞

CONTINUATION OF TABLE

Pente Cost	Sag narigu	Stadium	Timber Mkt	T-Poly (Getf)	T-Poly Hos1	T-Poly Hos2	VRA Subs	Ward K.	Aboabo Mkt	Buglan Fong	Changli	Sabon Jida COP
10.3	15	13.8	10.9	14.6	14.6	14.6	12	9.3	11.3	11.4	10.9	11.4
2	∞	6.2	∞	∞	∞	∞	∞	2	4.1	3.6	3.5	3.8
2	∞	4.6	∞	∞	∞	∞	3	1.9	3.6	3.4	4.1	∞
0.4	6.8	4	1.7	6	6	6	2.2	0.7	2.4	2.2	1.9	2.2
3.2	∞	4.9	∞	∞	∞	∞	3.2	3.5	∞	∞	5.2	4.5
1.8	∞	2.6	∞	∞	∞	∞	0.75	3.1	∞	∞	∞	∞
∞	7.5	6.4	6.3	4.1	4.1	4.1	4.7	∞	7.2	∞	∞	∞
2.3	3.3	2.2	2.1	2.2	2.2	2.2	0.55	3.6	3	∞	∞	3.1
0.75	∞	4.8	1.7	5.2	5.2	5.2	2.2	1.5	2.5	∞	∞	2.3
1.6	7.2	4.9	2.5	6.6	6.6	6.6	3.7	0.65	3.2	2.6	2.5	3
5.6	8.5	7.3	6.4	6.6	6.6	6.6	5.7	6.4	7.2	6.9	7.6	7
2.4	7.1	6	3.7	6.4	6.4	6.4	4.3	2.4	4.4	3.9	3.9	4.2
—	6.4	3.6	1.3	5.7	5.7	5.7	1.7	0.8	2.1	1.8	2.5	1.9
6.4	—	1.8	5.2	1.3	1.3	1.3	3.7	7.2	3.9	4.9	5.6	4.3
3.6	1.8	—	3.4	2.9	2.9	2.9	1.9	4	2.1	3	3.8	2.5
1.3	4.1	2.2	—	4.5	4.5	4.5	1.6	1.9	0.65	1.6	2.3	1.5
4.4	1.3	2.9	4.2	—	∞	∞	2.7	5.7	5.2	5.3	6.1	5.3
4.4	1.3	2.9	4.2	∞	—	∞	2.7	5.7	5.2	5.3	6.1	5.3
4.4	1.3	2.9	4.2	∞	∞	—	2.7	5.7	5.2	5.3	6.1	5.3
1.7	3.7	1.9	1.6	2.9	2.9	2.9	—	3	2.5	2.7	3.5	2.6
0.8	7.2	4.4	2.1	6.1	6.1	6.1	3.2	—	2.7	2.3	2.3	2.5
1.9	4	2.2	0.7	5.4	5.4	5.4	2.5	2.2	—	1.3	2.1	1.1
1.9	4.8	3	1.6	5.6	5.6	5.6	2.7	2.2	1.3	—	0.75	0.75
2.5	5.7	3.8	2.5	6.5	6.5	6.5	3.5	2.1	2.2	0.8	—	1.6

1.9	4.6	2.7	1.4	5.4	5.4	5.4	2.5	2.4	1.1	0.8	1.6	—
2.3	∞	∞	∞	∞	∞	∞	3.2	∞	∞	1.1	1.1	1.5
4.3	4.4	2.6	4.1	5.5	5.5	5.5	4.3	4.8	3.8	2.7	3.5	2.5
2.6	5.4	3.5	2.2	6.1	6.1	6.1	3.2	2.2	1.9	0.55	0.5	1.2
2.8	6	4.1	2.6	6.7	6.7	6.7	3.7	3.3	2.5	1.3	0.65	2
3	2.3	0.45	1.9	3.4	3.4	3.4	2.2	3.4	1.6	2.5	3.3	1.9
3.8	4.1	2.2	2.7	5.1	5.1	5.1	4	4.3	2.4	2.3	3	2.2
2.4	5.3	3.5	2.1	6.1	6.1	6.1	3.1	2.7	1.8	0.5	0.8	1
2.8	5.6	3.8	2.5	6.4	6.4	6.4	3.5	2.5	2.1	0.85	0.7	1.6
1.5	5.4	3.6	1.9	6	6	6	3	1.2	1.9	1	0.95	1.3
2.2	5.4	3.5	2.2	6.2	6.2	6.2	3.2	1.8	1.9	0.95	0.5	1.4
1.5	4.2	2.4	1.1	5	5	5	2.1	1.9	0.7	0.95	1.7	0.4
2.9	3.4	1.5	1.7	4.4	4.4	4.4	3.5	3.3	1.4	2.4	3.2	1.4
2.9	3.4	1.5	1.7	4.4	4.4	4.4	3.5	3.3	1.4	2.4	3.2	1.4
3.7	6.9	5.1	3.5	7.6	7.6	7.6	4.7	4.2	3.4	2.6	2.3	2.9
∞	∞	∞	∞	∞	∞	∞	∞	3.4	∞	∞	3	3.8
3.6	6.7	4.9	3.4	7.2	7.2	7.2	4.6	2.6	3.2	3	2.2	3
4.4	7.5	5.7	4.1	8	8	8	5.3	2.8	4	3.7	3	3.8
3.7	3.8	2	2.2	4.8	4.8	4.8	4.1	4.4	2.2	2.2	3	1.8
3.2	5.6	3.8	2.9	6.7	6.7	6.7	4	3.6	2.6	1.3	1.6	1.7
3	4.4	2.6	2.2	5.5	5.5	5.5	3.7	3.7	2.2	1.5	2.4	1.3
4.4	2.8	1.2	2.9	3.8	3.8	3.8	3	5	2.8	3.6	4.5	3.4
4.2	2.6	1.3	2.7	3.6	3.6	3.6	3	4.9	2.7	3.5	4.3	2.8
3.9	7	5.2	3.7	7.5	7.5	7.5	4.9	2.9	3.5	3.3	2.5	3.3
∞	∞	4.5	∞	∞	∞	∞	∞	∞	∞	1.5	1.8	2.3

CONTINUATION OF TABLE

Customs	DVLA	Zongo	Gban juli	Kasa Jani	Lamas Palace	Bayan waya	Old Cemetry	Police Headq	Taxico	Victory	Zogbeli JSS	Zogbeli Park
10.2	13.8	11	11.2	12.6	13.2	11.4	11.2	9.9	10.6	11.2	12.6	12.6
2.9	∞	3.6	4.7	∞	∞	∞	3.8	2.6	3.2	∞	∞	∞
2.9	∞	∞	4.3	∞	∞	3.9	4.4	2.6	3.8	∞	∞	∞
1.3	4.4	2	3.1	∞	∞	∞	2.2	1	1.6	∞	∞	∞
4.9	∞	∞	5.4	5.9	6.4	5	5.5	4.1	4.9	4.3	∞	∞
3.2	5.1	∞	3.8	∞	∞	∞	3.5	3.1	3.2	∞	∞	∞
∞	∞	∞	∞	8.4	∞	∞	∞	∞	∞	6.8	8.3	8.3
3.7	∞	∞	∞	2.7	∞	∞	4	∞	∞	2.6	∞	∞
2.7	∞	∞	∞	∞	∞	2.7	3.2	2.1	∞	∞	∞	∞
1.9	5.4	2.6	2.5	4.4	4.8	3.1	2.9	1.6	2.2	2.8	4.2	4.2
∞	11.5	7.7	7.9	8.4	8.8	7.4	∞	∞	∞	∞	∞	∞
3.3	7.4	4	5.1	5.6	6	4.4	4.2	3	3.6	4	∞	∞
1.7	4.3	2.6	2.8	3.3	3.7	2.3	2.8	1.4	2.2	1.7	3.1	3.1
∞	4.4	5.4	5.9	2.3	4.1	5.3	∞	∞	∞	∞	∞	∞
∞	2.6	3.6	4.1	0.5	2.2	3.4	∞	∞	∞	∞	∞	∞
∞	4.1	2.4	2.6	1.8	2.6	2	∞	∞	∞	∞	1.6	1.6
∞	5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞
∞	5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞
∞	5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞
3.2	4.3	3.2	3.7	3.7	4.6	3.1	∞	∞	∞	2.1	∞	∞
1.7	4.8	2.4	3.5	3.9	4.4	2.8	2.6	1.3	2	2.4	3.8	3.8
∞	3.8	1.9	2.4	1.7	2.6	1.7	∞	1.7	1.8	0.7	1.6	1.6
∞	2.7	0.55	1.3	2.5	2.2	0.5	0.85	1.1	∞	0.95	2.4	2.4
1.1	3.5	0.5	0.65	3.4	3.1	0.8	0.7	1	0.5	1.8	3.2	3.2

1.6	2.5	1.4	2.2	2.3	2	∞	1.6	1.5	1.6	0.4	1.4	1.4
—	3.6	1.2	1.1	∞	∞	1.6	1.4	0.4	∞	1.7	∞	∞
3.6	—	3.3	5.3	2.2	1.1	2.5	∞	3.8	∞	∞	2.4	2.4
1.2	3.2	—	0.95	3	2.7	0.3	0.27	1.1	1	1.5	2.9	2.9
1.1	4	0.95	—	3.7	3.5	1.6	1	1.3	0.6	2.1	3.5	3.5
∞	3.2	3	3.6	—	1.6	2.9	∞	∞	∞	1.9	1.1	1.1
∞	1.1	2.8	3.5	1.9	—	2.1	∞	∞	∞	2.8	1.3	1.3
∞	2.9	0.3	1.2	3	2.4	—	0.6	∞	∞	1.4	2.8	2.8
1.4	3.5	0.27	1	3.3	3.1	0.6	—	1.3	1.2	1.8	3.2	3.2
0.3	3.5	1	1.2	3.1	3	1.5	1.3	—	0.65	1.5	3	3
0.8	3.5	1	0.6	3.1	3	1.4	1.2	0.75	—	1.5	2.9	2.9
1.5	3.1	1.5	2	1.9	2.7	1.3	1.8	1.3	1.5	—	1.8	1.8
∞	2.4	2.9	3.4	1.1	1.3	2.8	∞	2.7	2.9	1.8	—	
∞	2.4	2.9	3.4	1.1	1.3	2.8	∞	2.7	2.9	1.8		—
1.7	2.4	2.7	1.7	4.6	7.7	3.1	2.7	2.2	1.7	3	4.5	4.5
2.4	∞	3.3	2.4	∞	∞	∞	3.4	2.8	2.4	3.6	5	5
1.6	7	2.6	1.6	4.4	4.9	3.5	2.6	2	1.6	2.8	4.3	4.3
2.1	7.6	3.3	2.4	5.2	5.6	4.2	3.4	2.8	2.3	3.6	5	5
∞	2.4	2.6	3.4	1.6	0.45	2.4	∞	3	2.9	2.2	1	1
∞	2.7	1.1	2	3.8	2.2	0.85	∞	∞	2.3	2.3	2.7	2.7
∞	1.3	2	2.8	2.3	1.1	1.7	∞	∞	∞	2	1.7	1.7
∞	2.2	4.2	4.8	1.1	2.7	4.1	∞	∞	∞	3	2.2	2.2
∞	2.4	4	4.6	1	2	3.9	∞	∞	∞	2.9	2	2
1.9	5.8	2.9	1.9	4.7	5.2	3.8	2.9	2.3	1.9	3.1	4.6	4.6
∞	3.5	1.3	2.1	∞	3.9	1.3	1.1	2.6	2.5	2.5	∞	∞

CONTINUATION OF TABLE

Dohinaa Yili	Ghanasco	Kukuo Mkt	Kukuo Transf	Laman karaa	Nalung Fong	NHIS Laman	Nyohini Soc	Sawaaba Area	Teaching Hospital	Workshop Road Side
11.4	11.3	11	10.6	13.2	12.7	12.5	13.9	13.7	11.5	12.9
5.6	6.3	5.5	3.1	∞	4.9	∞	∞	∞	5.8	∞
5.3	5.9	5.2	5.9	∞	4.7	∞	∞	∞	5.5	∞
4	4.7	3.9	3.4	∞	3.3	∞	∞	∞	4.2	∞
6.4	7	6.3	7	6.4	5.8	5.7	∞	∞	6.6	6.1
4.7	∞	4.6	∞	∞	∞	∞	∞	∞	4.9	4.2
∞	∞	∞	∞	∞	∞	∞	7.3	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	3.1	2.9	5.4	∞
∞	4.8	∞	∞	∞	∞	∞	4.8	4.6	4.3	∞
2.9	∞	2.8	2.3	∞	3.9	∞	∞	∞	3.1	∞
∞	9.5	∞	∞	∞	8.3	∞	∞	∞	∞	∞
6	∞	4.8	4	∞	5.3	∞	∞	∞	6.2	∞
3.7	∞	3.6	4.4	3.7	3.2	3	4.4	4.2	3.9	3.4
∞	∞	∞	∞	3.8	∞	4.4	2.8	∞	∞	∞
∞	∞	4.9	5.7	∞	∞	∞	1.2	1.3	∞	∞
3.5	∞	3.4	4.1	2.2	∞	2.2	2.9	2.7	∞	∞
∞	∞	∞	∞	∞	∞	∞	3.8	3.6	∞	∞
∞	∞	∞	∞	∞	∞	∞	3.8	3.6	∞	∞
∞	∞	∞	∞	∞	∞	∞	3.8	3.6	∞	∞
∞	∞	∞	∞	∞	∞	∞	3	3	∞	∞
2.7	∞	2.6	2.8	4.4	3.6	3.7	5	4.9	2.9	3.7
∞	4	∞	∞	2.2	∞	2.2	2.8	2.7	∞	∞
3.1	3.8	3	3.7	2.2	1.3	1.5	3.6	3.5	3.3	1.5
2.3	3	2.2	3	3	1.6	2.4	∞	4.3	2.5	1.8
3.1	∞	3	3.8	1.8	1.7	1.3	3.4	2.8	3.3	2.3

1.7	2.4	1.6	2.1	3.1	∞	2.5	∞	∞	1.9	∞
∞	7.1	∞	∞	2.4	2.7	1.3	∞	∞	∞	3.5
2.7	3.3	2.6	3.3	2.6	1.1	2	4.2	4	2.9	1.3
1.7	2.4	1.6	2.4	3.4	2	2.8	4.8	4.6	1.9	2.1
∞	5.2	∞	∞	1.6	∞	2.3	1.1	1	∞	∞
∞	5.7	∞	∞	0.45	2.2	1.1	2.7	2	∞	3.9
3.6	4.2	3.5	4.2	2.4	0.85	1.7	4.1	3.9	3.8	1.3
2.7	3.4	3.6	3.4	3	0.95	2.4	4.4	4.3	2.9	1.1
2.2	2.8	2	2.8	3	2.3	2.3	4.2	4.1	2.3	2.6
1.7	2.4	1.6	2.3	∞	2.3	∞	4.2	4	1.9	2.5
2.9	3.6	2.8	3.6	2.2	2.3	2	3	2.9	3.1	2.5
∞	5	4.3	5	1	2.7	1.7	2.2	2	∞	3.9
∞	5	4.3	5	1	2.7	1.7	2.2	2	∞	3.9
∞	1.3	0.55	1.3	4.6	6.4	4	5.7	5.6	0.85	4.6
1.3	—	1.7	1.6	5.8	5.1	5	∞	∞	1	∞
0.55	1.1	—	0.85	5	4.3	4.2	∞	∞	0.65	∞
1.3	∞	0.85	—	5.7	5.1	4.9	∞	∞	1.3	∞
4.6	∞	4.5	5.3	—	2.2	0.65	2.5	1.7	∞	2.9
6.4	∞	3.8	4.6	2.1	—	1.5	4.4	3.6	3	1
∞	∞	∞	∞	0.65	1.6	—	3.2	2.4	∞	2.2
∞	∞	∞	∞	2.4	4.9	3.1	—	0.8	∞	∞
∞	∞	∞	∞	1.7	4.6	2.4	0.8	—	∞	∞
0.85	1.4	0.65	1.3	5.3	3	4.5	∞	∞	—	2.2
∞	∞	∞	∞	2.9	∞	2.2	∞	∞	2.2	—

CONTINUATION OF TABLE

DVLA	Zongo	Gban juli	Kasa Jani	Lamas Palace	Bayan waya	Old Cem.	Police Headq.	Taxico	Victory	Zogbeli JSS	Zogb. Park	Dohi Yili	Ghana Sco
13.8	11	11.2	12.6	13.2	11.4	11.2	9.9	10.6	11.2	12.6	12.6	11.4	11.3
∞	3.6	4.7	∞	∞	∞	3.8	2.6	3.2	∞	∞	∞	5.6	6.3
∞	∞	4.3	∞	∞	3.9	4.4	2.6	3.8	∞	∞	∞	5.3	5.9
4.4	2	3.1	∞	∞	∞	2.2	1	1.6	∞	∞	∞	4	4.7
∞	∞	5.4	5.9	6.4	5	5.5	4.1	4.9	4.3	∞	∞	6.4	7
5.1	∞	3.8	∞	∞	∞	3.5	3.1	3.2	∞	∞	∞	4.7	∞
∞	∞	∞	8.4	∞	∞	∞	∞	∞	6.8	8.3	8.3	∞	∞
∞	∞	∞	2.7	∞	∞	4	∞	∞	2.6	∞	∞	∞	∞
∞	∞	∞	∞	∞	2.7	3.2	2.1	∞	∞	∞	∞	∞	4.8
5.4	2.6	2.5	4.4	4.8	3.1	2.9	1.6	2.2	2.8	4.2	4.2	2.9	∞
11.5	7.7	7.9	8.4	8.8	7.4	∞	∞	∞	∞	∞	∞	∞	9.5
7.4	4	5.1	5.6	6	4.4	4.2	3	3.6	4	∞	∞	6	∞
4.3	2.6	2.8	3.3	3.7	2.3	2.8	1.4	2.2	1.7	3.1	3.1	3.7	∞
4.4	5.4	5.9	2.3	4.1	5.3	∞	∞	∞	∞	∞	∞	∞	∞
2.6	3.6	4.1	0.5	2.2	3.4	∞	∞	∞	∞	∞	∞	∞	∞
4.1	2.4	2.6	1.8	2.6	2	∞	∞	∞	∞	1.6	1.6	3.5	∞
5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞	∞	∞
5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞	∞	∞
5.5	5.9	6.4	3.4	5.1	5.8	∞	∞	∞	4.8	∞	∞	∞	∞
4.3	3.2	3.7	3.7	4.6	3.1	∞	∞	∞	2.1	∞	∞	∞	∞
4.8	2.4	3.5	3.9	4.4	2.8	2.6	1.3	2	2.4	3.8	3.8	2.7	∞
3.8	1.9	2.4	1.7	2.6	1.7	∞	1.7	1.8	0.7	1.6	1.6	∞	4
2.7	0.55	1.3	2.5	2.2	0.5	0.85	1.1	∞	0.95	2.4	2.4	3.1	3.8
3.5	0.5	0.65	3.4	3.1	0.8	0.7	1	0.5	1.8	3.2	3.2	2.3	3
2.5	1.4	2.2	2.3	2	∞	1.6	1.5	1.6	0.4	1.4	1.4	3.1	∞

3.6	1.2	1.1	∞	∞	1.6	1.4	0.4	∞	1.7	∞	∞	1.7	2.4
—	3.3	5.3	2.2	1.1	2.5	∞	3.8	∞	∞	2.4	2.4	∞	7.1
3.2	—	0.95	3	2.7	0.3	0.27	1.1	1	1.5	2.9	2.9	2.7	3.3
4	0.95	—	3.7	3.5	1.6	1	1.3	0.6	2.1	3.5	3.5	1.7	2.4
3.2	3	3.6	—	1.6	2.9	∞	∞	∞	1.9	1.1	1.1	∞	5.2
1.1	2.8	3.5	1.9	—	2.1	∞	∞	∞	2.8	1.3	1.3	∞	5.7
2.9	0.3	1.2	3	2.4	—	0.6	∞	∞	1.4	2.8	2.8	3.6	4.2
3.5	0.27	1	3.3	3.1	0.6	—	1.3	1.2	1.8	3.2	3.2	2.7	3.4
3.5	1	1.2	3.1	3	1.5	1.3	—	0.65	1.5	3	3	2.2	2.8
3.5	1	0.6	3.1	3	1.4	1.2	0.75	—	1.5	2.9	2.9	1.7	2.4
3.1	1.5	2	1.9	2.7	1.3	1.8	1.3	1.5	—	1.8	1.8	2.9	3.6
2.4	2.9	3.4	1.1	1.3	2.8	∞	2.7	2.9	1.8	—		∞	5
2.4	2.9	3.4	1.1	1.3	2.8	∞	2.7	2.9	1.8		—	∞	5
2.4	2.7	1.7	4.6	7.7	3.1	2.7	2.2	1.7	3	4.5	4.5	∞	1.3
∞	3.3	2.4	∞	∞	∞	3.4	2.8	2.4	3.6	5	5	1.3	—
7	2.6	1.6	4.4	4.9	3.5	2.6	2	1.6	2.8	4.3	4.3	0.55	1.1
7.6	3.3	2.4	5.2	5.6	4.2	3.4	2.8	2.3	3.6	5	5	1.3	∞
2.4	2.6	3.4	1.6	0.45	2.4	∞	3	2.9	2.2	1	1	4.6	∞
2.7	1.1	2	3.8	2.2	0.85	∞	∞	2.3	2.3	2.7	2.7	6.4	∞
1.3	2	2.8	2.3	1.1	1.7	∞	∞	∞	2	1.7	1.7	∞	∞
2.2	4.2	4.8	1.1	2.7	4.1	∞	∞	∞	3	2.2	2.2	∞	∞
2.4	4	4.6	1	2	3.9	∞	∞	∞	2.9	2	2	∞	∞
5.8	2.9	1.9	4.7	5.2	3.8	2.9	2.3	1.9	3.1	4.6	4.6	0.85	1.4
3.5	1.3	2.1	∞	3.9	1.3	1.1	2.6	2.5	2.5	∞	∞	∞	∞

APPENDIX E

MATLAB OUTPUT SOLUTION FOR THE SHORTEST PATH

LOCATIONS	Gbalahi	Kalpo hini	Nyan Shegu	Tishigu	Gumani	Gumbi hini	Gurugu	Hill Top	Saka saka	Inter Royals	Jisona yili	Kalpo hini
Gbalahi	0	8.7	9.9	9.9	11.1	11.5	15.2	11.9	10.4	8.8	13.8	8.3
Kalpohin	8.7	0	1.6	1.9	3.2	2.8	8.25	4.1	2	0.6	6.8	0.4
Nyanshegu	9.9	1.6	0	1.8	1.9	3.4	6.8	2.6	1.1	1.1	5.5	2
Tishigu	9.9	1.9	1.8	0	3.6	2.2	6.8	2.65	1.1	1.35	6	2.2
Gumani	11.1	3.2	1.9	3.6	0	3.95	6.5	3.75	2.8	3	3.6	2.8
Gumbihini	11.5	2.8	3.4	2.2	3.95	0	5.45	1.3	2.3	3.25	6.45	3.2
Gurugu	15.2	8.25	6.8	6.8	6.5	5.45	0	4.2	6.7	7.85	2.9	7.9
HillTop	11.9	4.1	2.6	2.65	3.75	1.3	4.2	0	2.75	3.7	6.25	3.7
Sakasaka	10.4	2	1.1	1.1	2.8	2.3	6.7	2.75	0	2.15	5.2	2.4
Inter Royals	8.8	0.6	1.1	1.35	3	3.25	7.85	3.7	2.15	0	6.6	1
Jisonayili	13.8	6.8	5.5	6	3.6	6.45	2.9	6.25	5.2	6.6	0	6.4
Kalpohini JSS	8.3	0.4	2	2.2	2.8	3.2	7.9	3.7	2.4	1	6.4	0
Pentecost	10.1	2	1.85	0.4	3.2	1.8	6.4	2.25	0.75	1.45	5.6	2.4
Sagnarigu	14.85	7.2	5.9	5.7	6.7	4.4	5.4	3.3	5.7	6.5	7.9	7
Stadium	13.05	5.25	4.6	3.9	4.9	2.6	6.4	2.2	3.9	4.65	7.3	5.65
Timber Mkt	10.9	3.1	2.8	1.7	4.5	2.35	6.3	2.1	1.7	2.5	6.4	3.5
T-Poly(Getf.)	14.1	6.25	4.8	4.8	5.9	3.45	4.1	2.2	4.9	5.85	6.6	5.9
T-Poly(Hos1)	14.1	6.25	4.8	4.8	5.9	3.45	4.1	2.2	4.9	5.85	6.6	5.9
T-Poly(Hos2)	14.1	6.25	4.8	4.8	5.9	3.45	4.1	2.2	4.9	5.85	6.6	5.9
VRA subs.	11.8	3.55	3	2.1	3.2	0.75	4.7	0.55	2.2	3.15	5.7	3.95
Ward K.	9.3	1.25	1.75	0.7	3.5	2.6	7.2	3.05	1.5	0.65	6.4	1.65
Aboaboo Mkt	11.3	3.75	3.45	2.35	5	3	6.95	2.75	2.35	3.15	7.05	4.15
Buglan Fong	10.9	3.2	3.4	2	5	3.45	7.4	3.25	2.55	2.6	6.9	3.6

Changli	10.85	3.1	3.55	1.9	5.05	3.7	8.15	4	3	2.5	7.6	3.5
Sabonjida	11.2	3.5	3.4	2.2	4.5	3.25	7.2	3	2.3	2.9	7	3.9
Customs	10.2	2.5	2.9	1.3	4.4	3.2	7.9	3.7	2.4	1.9	7.3	2.9
DVLA	13.4	5.7	5.9	4.4	7	5.05	9	4.8	4.8	5.1	9.5	6.1
Zongo	10.9	3.2	3.6	2	5.1	3.77	7.9	3.75	3	2.6	7.45	3.6
Gbanjuli	11.1	3.1	3.6	2.2	5.3	3.8	8.4	4.25	3.3	2.5	7.9	3.5
Kasajani	12.6	4.9	4.6	3.5	5.4	3.1	6.9	2.7	3.5	4.3	7.8	5.3
Lamash. P	12.9	5.2	5.4	4	6.4	4.7	8.5	4.3	4.3	4.6	8.8	5.6
Bayanwaya	11.2	3.5	3.8	2.3	5	3.85	7.8	3.65	2.7	2.9	7.4	3.9
Old Cemetry	11.17	3.47	3.87	2.2	5.37	3.5	8.17	4	3.2	2.87	7.72	3.87
Police Headq.	9.9	2.2	2.6	1	4.1	3.1	7.8	3.65	2.1	1.6	7	2.6
Taxico	10.55	2.8	3.25	1.6	4.75	3.2	8.3	4.1	2.7	2.2	7.6	3.2
Victory	11.2	3.4	3.55	2.1	4.3	2.85	6.8	2.6	2.45	2.8	7.3	3.8
Zogbeli JSS	12.5	4.7	4.4	3.3	5.9	3.95	7.9	3.7	3.3	4.1	8	5.1
Zogbeli Park	12.5	4.7	4.4	3.3	5.9	3.95	7.9	3.7	3.3	4.1	8	5.1
Dohinaa Yili	11.4	3.5	4	3	5.9	4.7	9.6	5.4	4.1	2.9	9	3.9
Ghanasco	11.3	4.5	5	3.7	6.8	5.6	10.3	6.1	4.8	3.9	9.5	4.9
Kukuo Mkt	11	3.4	3.9	2.9	5.8	4.6	9.5	5.3	4	2.8	8.9	3.8
Kukuo Transf	10.6	2.9	3.4	3.4	5.3	5.3	10	5.8	4.3	2.3	8.9	3.3
Lamankaraa	12.85	5.15	5	3.9	6.3	4.55	8.5	4.3	3.9	4.55	8.6	5.55
Nalung Fong	12	4.3	4.65	3.1	5.8	4.45	8.65	4.5	3.55	3.7	8.2	4.7
NHIS-Lamas	12.2	4.5	4.7	3.3	5.7	4.55	8.5	4.3	3.6	3.9	8.3	4.9
Nyohini Soc.	13.7	6	5.7	4.6	6.1	3.75	7.3	3.1	4.6	5.4	8.5	6.4
Sawaaba Area	13.6	5.8	5.5	4.4	6.2	3.75	7.1	2.9	4.4	5.2	8.6	6.2
Teach. Hosp.	11.5	3.7	4.2	3.2	6.1	4.9	9.6	5.4	4.3	3.1	9.2	4.1
Workshop R.	12.2	4.5	4.9	3.3	6.1	4.2	8.9	4.75	4	3.9	8.4	4.9

CONTINUATION OF TABLE

Pente Cost	Sag narigu	Stadium	Timber Mkt	T-Poly GetF	T-Poly Hos1	T-Poly Hos2	VRA Subs	Ward K.	Aboabo Mkt	Buglan Fong	Changli	Sabon jida
10.1	14.85	13.05	10.9	14.1	14.1	14.1	11.8	9.3	11.3	10.9	10.85	11.2
2	7.2	5.25	3.1	6.25	6.25	6.25	3.55	1.25	3.75	3.2	3.1	3.5
1.85	5.9	4.6	2.8	4.8	4.8	4.8	3	1.75	3.45	3.4	3.55	3.4
0.4	5.7	3.9	1.7	4.8	4.8	4.8	2.1	0.7	2.35	2	1.9	2.2
3.2	6.7	4.9	4.5	5.9	5.9	5.9	3.2	3.5	5	5	5.05	4.5
1.8	4.4	2.6	2.35	3.45	3.45	3.45	0.75	2.6	3	3.45	3.7	3.25
6.4	5.4	6.4	6.3	4.1	4.1	4.1	4.7	7.2	6.95	7.4	8.15	7.2
2.25	3.3	2.2	2.1	2.2	2.2	2.2	0.55	3.05	2.75	3.25	4	3
0.75	5.7	3.9	1.7	4.9	4.9	4.9	2.2	1.5	2.35	2.55	3	2.3
1.45	6.5	4.65	2.5	5.85	5.85	5.85	3.15	0.65	3.15	2.6	2.5	2.9
5.6	7.9	7.3	6.4	6.6	6.6	6.6	5.7	6.4	7.05	6.9	7.6	7
2.4	7	5.65	3.5	5.9	5.9	5.9	3.95	1.65	4.15	3.6	3.5	3.9
0	5.3	3.5	1.3	4.4	4.4	4.4	1.7	0.8	1.95	1.8	2.3	1.9
5.3	0	1.8	4.1	1.3	1.3	1.3	3.7	5.7	3.9	4.8	5.55	4.2
3.5	1.8	0	2.3	2.9	2.9	2.9	1.9	3.9	2.1	3	3.75	2.4
1.3	4.1	2.3	0	4.3	4.3	4.3	1.6	1.9	0.65	1.6	2.3	1.5
4.4	1.3	2.9	4.3	0	2.6	2.6	2.7	5.2	4.95	5.3	6.05	5.2
4.4	1.3	2.9	4.3	2.6	0	2.6	2.7	5.2	4.95	5.3	6.05	5.2
4.4	1.3	2.9	4.3	2.6	2.6	0	2.7	5.2	4.95	5.3	6.05	5.2
1.7	3.7	1.9	1.6	2.7	2.7	2.7	0	2.5	2.25	2.7	3.45	2.5
0.8	5.7	3.9	1.9	5.2	5.2	5.2	2.5	0	2.55	2.3	2.25	2.5
1.95	3.9	2.1	0.65	4.95	4.95	4.95	2.25	2.55	0	1.3	2.05	1.1
1.8	4.8	3	1.6	5.3	5.3	5.3	2.7	2.3	1.3	0	0.75	0.75
2.3	5.55	3.75	2.3	6.05	6.05	6.05	3.45	2.25	2.05	0.75	0	1.5
1.9	4.2	2.4	1.5	5.2	5.2	5.2	2.5	2.5	1.1	0.75	1.5	0

1.7	5.8	4	2.65	5.9	5.9	5.9	3.2	1.6	2	1.4	1.1	1.6
4.3	4.4	2.6	3.5	5.5	5.5	5.5	4.3	4.8	3.5	2.7	3.3	2.5
2.35	5.3	3.5	2.15	5.85	5.85	5.85	3.2	2.3	1.85	0.55	0.5	1.3
2.6	5.9	4.1	2.6	6.4	6.4	6.4	3.7	2.5	2.4	1.3	0.65	2.05
3.1	2.3	0.5	1.8	3.4	3.4	3.4	2.4	3.7	1.7	2.5	3.25	2.3
3.7	3.9	2.1	2.6	5	5	5	4	4.3	2.6	2.2	2.9	2
2.3	5.2	3.4	2	5.8	5.8	5.8	3.1	2.6	1.7	0.5	0.8	1.25
2.6	5.57	3.77	2.42	6.12	6.12	6.12	3.47	2.57	2.12	0.82	0.7	1.57
1.4	5.5	3.7	2.35	5.8	5.8	5.8	3.1	1.3	1.7	1.1	1	1.5
2	5.7	3.9	2.45	6.3	6.3	6.3	3.6	1.95	1.8	1.25	0.5	1.6
1.7	4.2	2.4	1.35	4.8	4.8	4.8	2.1	2.4	0.7	0.95	1.7	0.4
2.9	3.4	1.6	1.6	4.5	4.5	4.5	3.2	3.5	1.6	2.15	2.9	1.4
2.9	3.4	1.6	1.6	4.5	4.5	4.5	3.2	3.5	1.6	2.15	2.9	1.4
3.4	7.1	5.3	3.5	7.6	7.6	7.6	4.9	2.7	3.5	2.95	2.2	3.1
4.1	7.5	5.7	4.5	8.3	8.3	8.3	5.6	3.7	4	3.65	2.9	4
3.3	6.7	4.9	3.4	7.5	7.5	7.5	4.8	2.6	3.4	2.85	2.1	3
3.6	7.5	5.7	4.1	8	8	8	5.3	2.8	4.1	3.5	2.8	3.7
3.5	3.8	2.1	2.2	5	5	5	3.8	4.1	2.2	2.15	2.9	1.8
3.1	5.9	4.1	2.85	6.6	6.6	6.6	3.95	3.4	2.55	1.3	1.6	1.7
3	4.4	2.75	2.2	5.65	5.65	5.65	3.8	3.6	2.2	1.5	2.25	1.3
4.2	2.8	1.2	2.9	3.8	3.8	3.8	3	4.8	2.8	3.6	4.35	3.4
4	3.1	1.3	2.7	3.6	3.6	3.6	3	4.6	2.7	3.5	4.25	2.8
3.6	7.3	5.5	4.05	7.6	7.6	7.6	5.1	2.9	3.7	3.15	2.4	3.3
3.3	6.3	4.5	3.1	6.8	6.8	6.8	4.2	3.6	2.8	1.5	1.8	2.25

CONTINUATION OF TABLE

Customs	DVLA	Zongo	Gban juli	Kasa Jani	Lamas Palace	Bayan waya	Old Cemetry	Police Headq	Taxico	Victory	Zogbeli JSS	Zogbeli Park
10.2	13.4	10.9	11.1	12.6	12.9	11.2	11.17	9.9	10.55	11.2	12.5	12.5
2.5	5.7	3.2	3.1	4.9	5.2	3.5	3.47	2.2	2.8	3.4	4.7	4.7
2.9	5.9	3.6	3.6	4.6	5.4	3.8	3.87	2.6	3.25	3.55	4.4	4.4
1.3	4.4	2	2.2	3.5	4	2.3	2.2	1	1.6	2.1	3.3	3.3
4.4	7	5.1	5.3	5.4	6.4	5	5.37	4.1	4.75	4.3	5.9	5.9
3.2	5.05	3.77	3.8	3.1	4.7	3.85	3.5	3.1	3.2	2.85	3.95	3.95
7.9	9	7.9	8.4	6.9	8.5	7.8	8.17	7.8	8.3	6.8	7.9	7.9
3.7	4.8	3.75	4.25	2.7	4.3	3.65	4	3.65	4.1	2.6	3.7	3.7
2.4	4.8	3	3.3	3.5	4.3	2.7	3.2	2.1	2.7	2.45	3.3	3.3
1.9	5.1	2.6	2.5	4.3	4.6	2.9	2.87	1.6	2.2	2.8	4.1	4.1
7.3	9.5	7.45	7.9	7.8	8.8	7.4	7.72	7	7.6	7.3	8	8
2.9	6.1	3.6	3.5	5.3	5.6	3.9	3.87	2.6	3.2	3.8	5.1	5.1
1.7	4.3	2.35	2.6	3.1	3.7	2.3	2.6	1.4	2	1.7	2.9	2.9
5.8	4.4	5.3	5.9	2.3	3.9	5.2	5.57	5.5	5.7	4.2	3.4	3.4
4	2.6	3.5	4.1	0.5	2.1	3.4	3.77	3.7	3.9	2.4	1.6	1.6
2.65	3.5	2.15	2.6	1.8	2.6	2	2.42	2.35	2.45	1.35	1.6	1.6
5.9	5.5	5.85	6.4	3.4	5	5.8	6.12	5.8	6.3	4.8	4.5	4.5
5.9	5.5	5.85	6.4	3.4	5	5.8	6.12	5.8	6.3	4.8	4.5	4.5
5.9	5.5	5.85	6.4	3.4	5	5.8	6.12	5.8	6.3	4.8	4.5	4.5
3.2	4.3	3.2	3.7	2.4	4	3.1	3.47	3.1	3.6	2.1	3.2	3.2
1.6	4.8	2.3	2.5	3.7	4.3	2.6	2.57	1.3	1.95	2.4	3.5	3.5
2	3.5	1.85	2.4	1.7	2.6	1.7	2.12	1.7	1.8	0.7	1.6	1.6
1.4	2.7	0.55	1.3	2.5	2.2	0.5	0.82	1.1	1.25	0.95	2.15	2.15
1.1	3.3	0.5	0.65	3.25	2.9	0.8	0.7	1	0.5	1.7	2.9	2.9
1.6	2.5	1.3	2.05	2.3	2	1.25	1.57	1.5	1.6	0.4	1.4	1.4

0	3.6	1.2	1.1	3.5	3.4	1.5	1.4	0.4	1.05	1.7	3	3
3.6	0	2.8	3.7	2.2	1.1	2.5	3.07	3.6	3.8	2.9	2.4	2.4
1.2	2.8	0	0.95	3	2.4	0.3	0.27	1.1	1	1.5	2.7	2.7
1.1	3.7	0.95	0	3.7	3.35	1.25	1	1.25	0.6	2.1	3.45	3.45
3.5	2.2	3	3.7	0	1.6	2.9	3.27	3.2	3.4	1.9	1.1	1.1
3.4	1.1	2.4	3.35	1.6	0	2.1	2.67	3.3	3.35	2.4	1.3	1.3
1.5	2.5	0.3	1.25	2.9	2.1	0	0.57	1.4	1.3	1.4	2.65	2.65
1.4	3.07	0.27	1	3.27	2.67	0.57	0	1.3	1.2	1.77	2.97	2.97
0.4	3.6	1.1	1.25	3.2	3.3	1.4	1.3	0	0.65	1.5	2.9	2.9
1.05	3.8	1	0.6	3.4	3.35	1.3	1.2	0.65	0	1.5	2.9	2.9
1.7	2.9	1.5	2.1	1.9	2.4	1.4	1.77	1.5	1.5	0	1.8	1.8
3	2.4	2.7	3.45	1.1	1.3	2.65	2.97	2.9	2.9	1.8	0	
3	2.4	2.7	3.45	1.1	1.3	2.65	2.97	2.9	2.9	1.8		0
1.7	5.3	2.65	1.7	4.8	5.05	2.95	2.7	2.1	1.7	2.9	4.5	4.5
2.4	6	3.3	2.4	5.2	5.7	3.6	3.4	2.8	2.4	3.6	5	5
1.6	5.2	2.55	1.6	4.7	4.95	2.85	2.6	2	1.6	2.8	4.3	4.3
2.1	5.7	3.3	2.4	5.5	5.5	3.6	3.4	2.5	2.3	3.6	5	5
3.1	1.55	2.6	3.4	1.6	0.45	2.35	2.87	2.95	3.4	2.2	1	1
2.3	2.7	1.1	1.95	3.75	2.2	0.85	0.95	2.2	2.1	2.1	2.7	2.7
2.5	1.3	2	2.8	2.25	1.1	1.7	2.27	2.3	2.75	1.7	1.65	1.65
4.6	3.3	4.1	4.8	1.1	2.7	4	4.37	4.2	4.2	3	2.2	2.2
4.4	3.1	4	4.6	1	2	3.9	4.27	4.1	4	2.9	2	2
1.9	5.5	2.85	1.9	5	5.2	3.15	2.9	2.3	1.9	3.1	4.7	4.7
2.5	3.5	1.3	2.1	4	3.2	1.3	1.1	2.4	2.3	2.45	3.65	3.65

CONTINUATION OF TABLE

Dohi Naa	Ghanasco	Kukuo Mkt	Kukuo Transf	Laman karaa	Nalung Fong	NHIS-Lamans	Nyohini Soc	Sawaaba Area	Teaching Hospital	Workshop Road Side
11.4	11.3	11	10.6	12.85	12	12.2	13.7	13.6	11.5	12.2
3.5	4.5	3.4	2.9	5.15	4.3	4.5	6	5.8	3.7	4.5
4	5	3.9	3.4	5	4.65	4.7	5.7	5.5	4.2	4.9
3	3.7	2.9	3.4	3.9	3.1	3.3	4.6	4.4	3.2	3.3
5.9	6.8	5.8	5.3	6.3	5.8	5.7	6.1	6.2	6.1	6.1
4.7	5.6	4.6	5.3	4.55	4.45	4.55	3.75	3.75	4.9	4.2
9.6	10.3	9.5	10	8.5	8.65	8.5	7.3	7.1	9.6	8.9
5.4	6.1	5.3	5.8	4.3	4.5	4.3	3.1	2.9	5.4	4.75
4.1	4.8	4	4.3	3.9	3.55	3.6	4.6	4.4	4.3	4
2.9	3.9	2.8	2.3	4.55	3.7	3.9	5.4	5.2	3.1	3.9
9	9.5	8.9	8.9	8.6	8.2	8.3	8.5	8.6	9.2	8.4
3.9	4.9	3.8	3.3	5.55	4.7	4.9	6.4	6.2	4.1	4.9
3.4	4.1	3.3	3.6	3.5	3.1	3	4.2	4	3.6	3.3
7.1	7.5	6.7	7.5	3.8	5.9	4.4	2.8	3.1	7.3	6.3
5.3	5.7	4.9	5.7	2.1	4.1	2.75	1.2	1.3	5.5	4.5
3.5	4.5	3.4	4.1	2.2	2.85	2.2	2.9	2.7	4.05	3.1
7.6	8.3	7.5	8	5	6.6	5.65	3.8	3.6	7.6	6.8
7.6	8.3	7.5	8	5	6.6	5.65	3.8	3.6	7.6	6.8
7.6	8.3	7.5	8	5	6.6	5.65	3.8	3.6	7.6	6.8
4.9	5.6	4.8	5.3	3.8	3.95	3.8	3	3	5.1	4.2
2.7	3.7	2.6	2.8	4.1	3.4	3.6	4.8	4.6	2.9	3.6
3.5	4	3.4	4.1	2.2	2.55	2.2	2.8	2.7	3.7	2.8
2.95	3.65	2.85	3.5	2.15	1.3	1.5	3.6	3.5	3.15	1.5
2.2	2.9	2.1	2.8	2.9	1.6	2.25	4.35	4.25	2.4	1.8
3.1	4	3	3.7	1.8	1.7	1.3	3.4	2.8	3.3	2.25

1.7	2.4	1.6	2.1	3.1	2.3	2.5	4.6	4.4	1.9	2.5
5.3	6	5.2	5.7	1.55	2.7	1.3	3.3	3.1	5.5	3.5
2.65	3.3	2.55	3.3	2.6	1.1	2	4.1	4	2.85	1.3
1.7	2.4	1.6	2.4	3.4	1.95	2.8	4.8	4.6	1.9	2.1
4.8	5.2	4.7	5.5	1.6	3.75	2.25	1.1	1	5	4
5.05	5.7	4.95	5.5	0.45	2.2	1.1	2.7	2	5.2	3.2
2.95	3.6	2.85	3.6	2.35	0.85	1.7	4	3.9	3.15	1.3
2.7	3.4	2.6	3.4	2.87	0.95	2.27	4.37	4.27	2.9	1.1
2.1	2.8	2	2.5	2.95	2.2	2.3	4.2	4.1	2.3	2.4
1.7	2.4	1.6	2.3	3.4	2.1	2.75	4.2	4	1.9	2.3
2.9	3.6	2.8	3.6	2.2	2.1	1.7	3	2.9	3.1	2.45
4.5	5	4.3	5	1	2.7	1.65	2.2	2	4.7	3.65
4.5	5	4.3	5	1	2.7	1.65	2.2	2	4.7	3.65
1.1	1.3	0.55	1.3	4.6	3.65	4	5.7	5.6	0.85	3.05
1.3	0	1.65	1.6	5.5	4	4.9	6.3	6.2	1	3.2
0.55	1.65	0	0.85	4.7	3.55	4.1	5.8	5.6	0.65	2.85
1.3	1.6	0.85	0	5.2	4.3	4.6	6.5	6.3	1.3	3.5
4.6	5.5	4.7	5.2	0	2.15	0.65	2.5	1.7	5	2.85
3.65	4	3.55	4.3	2.15	0	1.5	4.4	3.6	3	1
4	4.9	4.1	4.6	0.65	1.5	0	3.15	2.35	4.4	2.2
5.7	6.3	5.8	6.5	2.5	4.4	3.15	0	0.8	6.1	5.1
5.6	6.2	5.6	6.3	1.7	3.6	2.35	0.8	0	5.9	4.55
0.85	1	0.65	1.3	5	3	4.4	6.1	5.9	0	2.2
3.05	3.2	2.85	3.5	2.85	1	2.2	5.1	4.55	2.2	0

APPENDIX F

PHOTOGRAPH OF GBALAHI WASTE DUMP-SITE AND COLLECTION CONTAINERS

GBALAHI WASTE DUMP-SITE

WASTE COLLECTION CONTAINERS