KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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MODELING THE TRNSPORTATION OF SOLID WASTE FROM THE TRANSFER STATIONS TO THE DISPOSAL SITES IN TAMALE METROPOLIS

BY

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DECLARATION

I, SALIFU ABDALLAH hereby declare that this thesis is my own work for the M.Sc. and that to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree by the university or any other university, except where due acknowledgment has been made in the context.

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ABSTRACT

Solid waste management framework preoccupies itself with the collection, treatment and disposal of wastes within the boundaries of districts, municipalities and metropolis. Increasing environmental concerns and the emphasis on materials and energy are overwhelmingly changing the modus operandi of solid waste management as a whole and its transportation in particular. This study targeted Tamale metropolis so that a comprehensive and workable as well as efficient approach to solid waste transportation could be obtained through modeling for effective system of solid waste management. For management purposes, the Metropolis has been divided into two with one section managed by the Waste Management Department (WMD) and the other by ZoomLion (ZL). It was estimated that 240-260 tons of waste was generated a day in the management area of the WMD out of which about 70% was hauled daily. This left a backlog of 30% uncollected every day. Within the management area of ZL, about 110-115 tons of waste was generated a day and about 46% was hauled daily. This left a backlog of about 54%. This deficit has led to littering, heaping of waste and overflowing of skips. This avoidable situation could lead to contagious diseases such as typhoid, malaria, cholera and many more. Data for this thesis were obtained from primary and secondary sources. These were used to construct models for minimizing the cost of waste transportation to the available disposal sites. Vogel's Approximation Method (VAM) and Modified Distribution (MODI) method were used to determine the initial feasible solution and optimal solution respectively. The model determined the optimal routes for waste transportation in each of the operational areas. Using the model, WMD would clear 175 tons of solid waste daily using GH¢171.45 instead of GH¢ 383.94; and ZL Ghana Ltd, Tamale would clear 51tons

using GH¢197.80 instead of GH¢977.03 if no condition has changed. Working outside the models may increase the expenditure.

DEDICATION

This piece of work is dedicated to my little children Khadijah Suhuyini Abdallah, Mohammed Mbo Abdallah and Iman. The work is also dedicated to my dear wife Faiza Martey for her unrelenting support and prayer towards a successful completion of this work. It is also dedicated to my late father and to my aged mother whose word of encouragement has pushed me this far.

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LIST OF ABBREVIATIONS/ACRONYMS

AMA.............. Accra Metropolitan Assembly

DACF..............District Assembly Common Fund

DESSAPs........District level Environmental Sanitation Strategies and Action Plans

EHSDs............Environmental Health and Sanitation Departments

EPA.................Environmental Protection Agency

ESICOME.......Expanded Sanitary Inspection and Compliance Enforcement

ESP..................Environmental Sanitation Policy

GH¢.................Ghana Cedi

GIM.................Ghana Innovation Market Place

GSS..................Ghana Statistical Service

IFS……………Initial Feasible Solution

IGF...................Internally Generated Fund

ISWM...............Integrated Solid Waste Management

KMA.................Kumasi Metropolitan Assembly

Ltd.....................Limited

MLGRD............Ministry of Local Government and Rural Development

MMDAs............Metropolitan, Municipal and District Assemblies

MODI………….Modified Distribution

MSW.................Municipal Solid Waste

NESP.................National Environmental Sanitation Policy

NESPoCC..........National Environmental Sanitation Policy Co-ordination Council

RHSs………… Right Hand Sides

SWM.................Solid Waste Management

TAMA................Tamale Metropolitan Area

UNEP.................United Nations Environmental Programme

USEPA...............United States Environmental Protection Agency

VAM……………Vogel's Approximation Method

WMD..................Waste Management Department

ZL……………..ZoomLion

CHAPTER ONE

INTRODUCTION

1.1 . Background to the study

Managing solid waste is a huge task that has to do with the control of generation, separation, storage, collection, transportation and final disposal of waste without injuring the environment and its services. The growing problem of solid waste management is of serious concern across the length and breadth of the globe. The problem is being exacerbated by:

- continuous pursuit of economic development for greater material prosperity and rising living standards
- the unwillingness of the society to reuse and recycle the solid wastes it generates every now and then.

In Ghana the type of wastes generated varies from region to region. The living standard, lifestyle and the natural resource endowment of a particular region reflects the characteristics and volume of solid waste generated by the region. Solid waste transportation which is the issue of concern is largely the responsibility of Metropolitan, Municipal and District Assemblies (MMDA). However, government policy since 1999 enables private sector participation in the solid waste management industry. The focus has, however, been on the transportation of waste. According to the Government of Ghana (1999), Municipal Assemblies in Ghana require all premises to have primary storage facilities (dustbins) and these dustbins should be approved by the Assembly with regard to the size, material and capacity. The recent sanitation and pollution level of Ghana raised eye brow of the citizens. To ensure successful private sector participation, the bottlenecks regarding financial resource and effective management, specifically transportation need to be streamlined. It has been revealed that when governments of African Countries were required by the World Health Organization (WHO) to prioritize their environmental health concerns, solid waste management was identified as the second most important problem after water quality accessibility (Puopiel, 2010).

Transportation is a critical link in the waste management system. District, Municipal and Metropolitan Assemblies in Ghana face common challenges in solid waste management, particularly relating to the transportation system. When the transport element in solid waste management is properly planned and managed, it will contribute immensely to efficient and effective waste management. There is, therefore, the need to properly plan the routes of vehicles involved in transporting solid waste to disposal sites with the view to minimizing transport costs in waste management. Tamale Metropolis, with its ever increasing sprawling settlement pattern and increasing budget constraints, presents a very good case for studying how to apply optimization techniques to improve solid waste management. This will help improve the environment and public health in the metropolis.

1.2. Problem Statement

For a substantial period of time now, solid waste generation has increased tremendously and its management has taken a centre stage of local Government concerns. The disposal of solid waste has given Tamale Metropolis a herculean task. The main issue relates to the transportation. According to WMD of the Metropolis the solid waste transportation problem faced by the metropolis is due to:

- the inability of the solid waste transportation management to clear all the waste generated a day and this leads to diseases such as malaria, cholera, typhoid, dysentery etc.;
- high cost of solid waste transportation;
- irregular collection of solid waste generated;
- lack of well defined routes for hauling vehicles
- lack of adequate resources to effectively transport the solid waste.

The main challenge, therefore, is how to minimize the cost of solid waste transportation in the Tamale metropolis in order to increase the quantity of solid waste hauled to the disposal sites within budget constraints.

The Tamale metropolis has been zoned into two for waste management purposes. The Waste management department (WMD) of the Tamale Metropolitan Assembly is in charge of one zone while a private company, Zoom Lion (ZL) is responsible for the other zone.

It was estimated by WMD and ZL, Tamale that 240-260 tons of waste is generated a day in the management area of WMD in the Tamale metropolis and out of this, about 70% was hauled daily. This leaves a backlog of 30% uncollected a day. Within the management area of ZL, about 110-115 tons of waste is generated a day and about 46% is hauled daily. This leaves a backlog of about 54%. This deficit leads to littering, heaping of waste and overflowing of skips. This avoidable situation could lead to contagious diseases such as typhoid, malaria, cholera and many more.

In order to properly address the transportation challenge, there is the need to build a mathematical model as a decision tool for the waste management officials. In that direction, a number of questions need to be answered, such as:

- What is the quantity of solid waste generated a day?
- What is the quantity that can be cleared daily?
- What is the daily cost on solid waste transportation?
- How much does it cost to transport a ton of solid waste to each disposal site from each transfer station?
- How many transfer stations are in the metropolis?
- What is the total capacity of each transfer station?
- What is the distance from each transfer station to each disposal site?
- How many landfill sites are there in the metropolis? Are there other disposal sites?

1.3 Aims and Objectives of the study

The study is aimed at finding a suitable model to cut down the cost of transporting solid waste from transfer stations to disposal sites in Tamale metropolis.

The research seeks to achieve the following objectives:

1. To formulate mathematical models of transporting solid waste to final disposal sit;
2. To determine the optimal routes for the solid waste transportation vehicles;
3. To solve the model problems using data from WMD and ZL

1.4. Project justification

There is a growing concern globally about increasing waste generation and the challenges of waste management. This is owing to the concern over the consequences of improper waste management on the environment. The increasing waste generation is the result of the ever increasing human population and the increasing consumption of goods and services resulting from increasing wealth. Developing countries like Ghana face several development challenges but key among them is the solid waste management. With increasing urbanization local authorities are now overwhelmed with having to deal with large volumes of solid waste generated each day. Solid waste management in urban areas in Ghana has become even more challenging as a result of increasing sprawl. This has increased the cost of transporting solid waste from transfer stations to the final disposal sites.

Increasing sprawl in Tamale has increased the cost of transporting waste from the transfer stations to the final disposal site. The transportation cost can be reduced considerably with proper route assignment. This study seeks to provide a transportation model for transporting solid waste from transfer stations to the final disposal sites at the minimum cost. This can ensure that with the same budget more solid waste can be transported to the final disposal sites resulting in reduction of uncollected wastes. It will therefore result in a more effective and efficient solid waste management in Tamale for improved environmental quality and public health benefits. The study may serve as a reference point for Districts, Municipalities and Metropolitan Assemblies in the country regarding efficient solid waste transportation. The research will contribute immensely to the existing body of knowledge on solid waste transportation.

1.5 Project organization

This thesis has been organized into six (6) chapters. Chapter one is on introduction to the whole study. It focuses on background to the study, statement of the problem, aims and objectives of the study, delimitation, project justification, project organization and the limitation of the study. Chapter two (2) concentrates on related literature review on solid waste management and modeling. Chapter three (3) is based on the methodology used in collecting the data from the field and the model construction. Chapter five (4) analyzes and discusses the findings of the models and the field data and the last chapter, chapter six (5) summarizes the study, conclusion and recommendation.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

Problems of solid waste have gained recognition ever since human beings stopped hunting and gathering and started forming settled communities. The following quotation from an old Jewish scriptural text has reflected the sorry state of human behavior towards nature "we waste what we have, our food, our fuel, our wealth and our gifts. Then we watch in surprise the destruction of our world. What we do not explore or gouge out of the earth, we pollute. What we do not pollute, we kill. We do not see, or wish to see, the damage we do. Later we regret" (Fei Baffoe, 2010). This chapter digs into history, definitions, ideas, concepts and theories of solid waste and its management, especially on transportation of solid waste and concepts of modeling.

2.2 Waste

The term waste is defined in the German Waste Act of August 27, 1993 as portable objects that have been abandoned by the owners (as cited in Fei-Baffoe, 2010). From the same source, the term waste can also be used in reference to the protection of public health and in particular of the environment. Something can become waste when it is no longer useful to the owner or it is used and failed to fulfill its purpose (Puopiel, 2010). It is obvious from the various definitions that something becomes waste on condition that it fails to yield its initial potentials for which reason it has been acquired. Though somebody can manage some usefulness out of it in another environment, the German definition failed to recognize the subjectivity engaged in that context.

2.2.1 Solid Waste

Solid waste, which is the nucleus of the study, is defined as wastes arising from human and animal activities that are solid and are discarded as useless or unwanted (Fei-Baffoe, 2010). The Ghana Innovation Market Place (2009) defines solid waste as neither waste water discharges nor atmospheric emission arising from domestic, commercial, industrial and institutional activities in an urban area. According to Zerbock (2003), solid waste includes hazardous, non-hazardous, industrial, commercial and domestic waste such as:

- household organic trash
- street sweeping
- institutional garbage and
- Constructional waste.

According to Rhyner et al.(1995), Solid waste can also be defined as unwanted or discarded material with insufficient liquid content to be free flowing. The term refuse is synonymous with solid waste (Rhyner et al., 1995). From Zerbock (2003) and Rhyner et al (1995) one may also safely say that solid waste is any material which is neither liquid nor gas and has outgrown its original usefulness and can be hazardous or non-hazardous. It could also be seen as anything solid that is thrown away by its owner because it has lost its economic value.

2.2.2 Types of solid waste

Tchobanoglous et al (1993) have defined the types of solid waste as seen below.

Food wastes: The animal, fruit, or vegetable residues (also called garbage) resulting from the handling, preparation, cooking, and eating of foods.

Rubbish: This refers to combustible and non-combustible solid waste excluding food waste or other putrecible material.

Demolition and construction waste: waste from razed buildings and other structures are classified as demolition wastes. Wastes from the construction, remodeling, and repairing of residential, commercial and industrial buildings and similar structures are classified as construction wastes.

Special wastes: Waste such as street sweepings, roadside litter, catch-basin debris, dead animals and abandoned vehicles are classified as special wastes.

Treatment- Plants waste: The solid and semisolid waste from water, waste water, and industrial waste treatment facilities are included in this classification.

The Centre for Environment and Development in 2003 classified types of solid waste based on origin, characteristics and on the risk potential. The centre also outlined sources of solid waste as residential, waste from shops, commercial establishments, hotels/restaurants, eating stalls, slaughter houses and many more. Some solid wastes are separated at source of generation, others at the transfer stations for various reasons and those that cannot be recycled, reused may be transported to the site of final disposition.

The type of solid waste for transportation can influence the cost of transportation since they have varied degrees of weight at equal quantities.

2.2.3 **Sources of solid wastes**

Knowledge of the sources and types of solid wastes, along with data on the composition and rate of generation is basic to the engineering management of solid waste (Tchobanoglous et al., 1985).

According to Tchobanoglous et al. (1985), general sources and types of solid waste are:

- *Residential source*: Food waste, rubbish, ashes, special waste;
- *Commercial*: Food waste, rubbish ashes, demolishing and construction waste, occasionally hazardous wastes;
- *Open area*: Special waste, rubbish;
- *Treatment plant sites*: Treatment-plant waste principally composed of residual sludge.

The commercial source is the source that is most likely to generate more solid waste which usually exerts a great deal of pressure on the solid waste management team in general and the transportation team in particular, especially where market is situated.

2.2.4 Solid Waste Transportation

Solid waste transportation is a process of carrying sold waste from the collection site to the processing centre or disposal site. According to Tchobanoglous et al. (1985) There are a number of processing techniques that can aid in boosting the level of efficiency of solid waste transportation system and to recover materials and prepare the waste for subsequent processing as seen in the Table 1.

Table 1: Processing techniques used to recover materials and to prepare waste for further processing

Processing technique	**Function**	**Representative equipment and/or facilities and application**
Mechanical size and shape reduction	Alternative of the size and shape of solid waste component	Equipment used to reduce the size of solid waste includes hammer mills, shredders, roll crushers, grinders, clippers, jaw crushes, rasp mills, and hydropulpers.
Mechanical component separation	Separation of recoverable material usually at a processing facility	Trammels and vibrating screens are use for processes and unprocessed waste; disk screen for processed wastes, zigzag, vibrating air, rotary air and air knife rectifiers for processed waste. Jig, pneumatic sink/float, inertial, inclined or shaking table floatation and optical sorting are used to separate the light and heavy materials in solid wastes.
Magnetic and electro-	Separation of ferrous and non-ferrous	Magnetic separation is used for ferrous materials, eddy current separation for

mechanical separation	materials from processed solid waste	aluminum, electrostatic separation for glass in waste free of ferrous and aluminum scrap, magnetic fluid separation for non-ferrous materials
Dry and dewatering	Removal of moisture from solid wastes	Convection, conduction and radiation dryers have been used for solid wastes and sludge. Centrifugation and filtration are used to dewater treatment plant sludge

Source: (Tchobanoglous et al., 1985)

2.2.5 **Transfer and Transport**

According to Tchobanoglous et al. (1985), the functional element of transfer and transport refers to the means, facilities and appurtenances used to effect the transfer of waste from relatively short collection vehicles to larger vehicles and to transport them over extended distances to either processing centers or disposal sites. Transfer and transport operations become a necessity when haul distances to available disposal site or processing centers increase to the point that direct hauling is no longer economically feasible. According to that same source, motor vehicles, railroads and ocean-going vessels are the principal means now used to transport solid wastes.

Out of the three means mentioned above, motor vehicle transport is the means that is used in the Tamale metropolis and it is expected to meet the following requirements: the vehicle must transport solid waste at minimum cost; the waste must be covered during the haul operation; vehicle must be designed for highway traffic; vehicle capacity must be such that allowable weight limits are not exceeded; methods used for unloading must be simple and dependable Tchobanoglous et al. (1985).

The maximum volume that can be hauled in highway transport vehicle depends on the regulations in place within the metropolis where the operations occur. The literature on the motor transport is putting emphasis on the various mechanisms that will help protect the health of the people, prevent traffic offenses, and promote efficiency and frequency of waste collection and to reduce the cost of solid waste transportation. Though laudable idea, it needs strong backing by law and dedicated service on the part of management.

2.2.6 Land filling

This involves the regulatory disposal of solid waste on or in the top layer of the earth's crust. This aids in accommodating solid waste that cannot be avoided or recycled. It is the least ranked element of the waste management hierarchy and it is therefore the least desirable way of dealing with society's waste. The placement of solid waste in landfills is the oldest and definitely the most prevalent form of ultimate waste disposal (Zerbock, 2003). Landfill is one of the elements of waste management (generation, separation, storage, transfer, transportation, recycling etc) that nobody wants but everybody needs (Kreith, 1994). According to Kreith, there are simply no combinations of waste management techniques that do not require land filling to make them work. Considering the basic management options of solid waste, landfills are the only management technique that is both necessary and sufficient. What technically makes landfills different from dumps is that landfills have some level of engineering designs that requires some elements of responsibilities for suitable management.

According to Kreith (1994) some wastes are simply not recyclable, those recyclable eventually reach a point where their intrinsic value is completely dissipated and they can no longer be recovered, and recycling itself produces residuals. He further highlighted that the technology and operation of modern landfill can assure the protection of human health and the environment. Factors that must be considered in evaluating potential landfill sites are: Available land area, Soil conditions and topography, Surface water hydrology, Geologic and hydrogeology conditions, Climatologic condition, Local environment conditions and Ultimate use of site. (Tchobanaglous, 1985).

Despite the exposure of the weaknesses of landfill it is of immense asset for a greater percentage of countries worldwide with regard to solid waste management. Production of gases and leachate occurrence have contributed to the low ranking of landfill as an element of solid waste management, and since there are technical expertise that can ensure a better use of engineering skills to ensure the safety to a large extent of its usage, there is still hope for the elimination of some of the disadvantages involved in its usage. Having complete and effective structures can promote frequency and efficiency of solid waste collection and transportation and this can ensure the effective use of available financial resources.

2.2.7. Integrated Solid Waste Management (ISWM)

Generally, Integrated Waste Management is a framework for designing and putting into action new waste management systems and for analyzing and optimizing existing systems. In integrated waste management, both technical and non-technical systems must be analyzed together since they both have influence on each other. Integrated waste management as a preferable option of waste management considers all options that have been discussed earlier. There is the need for shared responsibilities so that manufacturers, distributors, retailers, consumers and other organized bodies to be responsible for the correct management of waste they create. This approach to waste management should target environmental effectiveness, economic efficiency and social acceptability. It has also created room for varying degree of management in different geographical locations. What has made this approach interesting is its continual assessment to accommodate changes in quantity and quality of the waste stream. The details of IWM concept vary around the world. In California IWM approach includes public education and outreach programs, along with efforts to create markets for recyclables. In South Africa, IWM aims to integrate and optimize waste management in order to maximize efficiency and minimize environmental impacts and financial costs of waste and improve the quality of its citizens (Fei-Baffoe, 2010).

Planners can ensure effective implementation of IWM by factoring the following into their planning process: Considering all aspects of the formal parts of the waste system within one framework; Produces a workable plan based on the objectives of the entire system; Putting all waste-related functions under the same division of agency, which is an important means of chalking success in integration; Creating integrated financial structure for instance, using disposal fees to finance materials recovery or public education; Assessing all metropolitan solid waste management system cost, identifying opportunities for revenue generation. IWM though laudable is financially stressful and methodologically engaging, with patience and application of the appropriate measures it will yield a desirable results. If waste generators are given the impetus to manage the solid waste they generate, it may ease the financial burden in managing the solid waste.

2.3 Solid waste management in Ghana

Solid waste disposal in Ghana has become a major challenge to MMDAs. As a result of urbanization and increasing densities of population and waste generation, Metropolitan Assemblies find it difficult to deal with the large quantities of solid waste generated daily. This is due to the fact that, people resort to indiscriminate dumping as the only means to managing their domestic solid waste thus resulting in littering and heaping of waste (Puopiel, 2010). This has serious environmental and health consequences and can lead to diseases like malaria, cholera and other sanitation related diseases.

2.3.1 Waste Management Regulation and Policy

According to the Ministry of Local Government and Rural Development (MLGRD) (2004), general waste management in Ghana is the responsibility of the MLGRD, which supervises the decentralized Metropolitan, Municipal and District Assemblies (MMDAs). However, the ministry indicates that, regulatory authority is vested in the Environmental Protection Agency (EPA) under the auspices of the Ministry of Environment, Science, Technology and Innovation (MESTI). 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 (EHSD). The policy framework guiding the management of hazardous, solid and radioactive waste includes the Local Government Act (1994), Act 462; the Environmental Protection Agency Act (1994), Act 490; the Pesticides Control and Management Act (1996), Act 528; the Environmental Assessment Regulations 1999, (LI 1652); the Environmental Sanitation Policy of Ghana (1999); the Guidelines for the Development and Management of Landfills in Ghana, and the Guidelines for Bio-medical

Waste (2000). All these Acts and Regulations emanate from the National Environmental Action Plan (MLGRD, 2004).

Furthermore, the Ministry has published the National Environmental Sanitation Policy (NESP) since May 1999 and revised 2010. Accordingly, the policy looks at the basic principles of environmental sanitation, problems and constraints. The role and responsibilities assigned to communities, ministries, departments and agencies and the private sector impinge on environmental management and protection, legislation and law enforcement and the criteria for specifying services and program, funding, equipment and supplies. Out of the National Sanitation Policy, the MLGRD has also developed a technical guideline document titled 'The Expanded Sanitary Inspection and Compliance Enforcement (ESICOME) Program guidelines. The program guidelines which are implemented by the MMDA's, routinely looked at four broad areas namely; effective environmental health inspections (Sanitary Inspections), dissemination of sanitary information (Hygiene Education), pests/vector control and law enforcement. All MMDAs have developed waste management and environmental health plans to help solve the numerous sanitation problems. Generally, the National Environmental Sanitation Policy Co-ordination Council (NESPoCC) is responsible for coordinating the policy and ensuring effective communication and cooperation between the many different agencies involved in environmental management in their respective Districts (MLGRD**,** 2004).

The Ministry further indicates that in an effort to address the problem of waste management, Government has over the years put in place adequate national policies, regulatory and institutional frameworks. Due to this the Environmental Sanitation Policy

(ESP) was formulated in 1999. This policy was revised in 2010 and strategic action plans developed for implementation according to the report. Various relevant legislations for the control of waste have also been enacted. These include the following:

Local Government Act, 1990 (Act 462); Environmental Assessment Regulations, 1999 (LI 1652); Criminal Code, 1960 (Act 29); Water Resources Commission Act, 1996 (Act 522); Pesticides Control and Management Act, 1996 (Act 528); National Building Regulations, 1996 (LI 1630) (MLGRD, 2004).

The Ministry also in collaboration with the Ministry of Environment, Science, Technology and Innovation (MESTI), EPA and the Ministry of Health had prepared the following guidelines and standards for waste management: National Environmental Quality Guidelines (1998); Ghana Landfill Guidelines (2002); Manual for the preparation of district waste management plans in Ghana (2002); Guidelines for the management of healthcare and veterinary waste in Ghana (2002); Handbook for the preparation of District level Environmental Sanitation Strategies and Action Plans (DESSAPs).

It is observed from the above that, despite the numerous sanitations regulations and policies that have been put in place by the MLGRD to deal with the solid waste menace in the country, there has not been adequate improvement in the area of solid waste management. Rather it has moved from bad to worst and therefore has failed to achieve its goal of clearing filth in the country. Additionally, drawing from the views given by the Sanitation Country Profile Ghana and the National Report for Waste Management in Ghana, it can be said with certainty that MMDAs are the primary authorities to manage solid waste at the local level (Fei-Baffoe, 2010). It is an indication that there is no any monitored workable policy on the road network for efficient transportation of the solid waste at a reduced cost so as to improve upon the waste transportation system, especially in Tamale Metropolis that is why a lot of monies is spent on solid waste transportation and yet no good results is achieved.

2.3.1 Problems of managing solid waste in Ghana

According to UNEP (2009), a chunk of solid wastes remain uncollected and less than 50 percent of the population is served. UNEP has suggested that if most of the waste could be diverted for material and resource recovery, then a substantial reduction in final volumes of waste could be achieved and the recovered material and resources could be utilized to generate revenue to fund waste management. This forms the premise for the Integrated Solid Waste Management (ISWM) system which is based on 3Rs (reduce, reuse and recycle) principle**.** ISWM system has been pilot tested in a few locations (Wuxi, PR China; Pune, India; Maseru, Lesotho) and has been well received by local authorities. It has been shown that with appropriate segregation and recycling system significant quantity of waste can be diverted from landfills and converted into resource (UNEP, 2009). Similarly, the United States Environmental Protection Agency (1999) has said that if a state or local government wants to plan for and implement ISWM, they have to consider hierarchy of methods which are reduce, recycle, and incinerate/landfill.

According to Ogawa (2005), a typical solid waste management system in a developing country displays an array of problems, including low collection coverage and irregular collection services, crude open dumping and burning without air and water pollution control.

He categorized these challenges into technical, financial, institutional and social constraints. He further discussed these constraints in relation to the sustainability of solid waste in developing countries.

a. Technical Constraints

According to Ogawa (2005), in most developing countries, there are inadequate human resources at both the national and local levels with technical expertise necessary for solid waste management planning and operation. Many officers in charge of solid waste management, particularly at the local level, have little or no technical background or training in engineering or management. Modeling the various sectors to cut down cost is lacking.

b. Financial Constraints

Ogawa (2005) intimated that, solid waste management is given a very low priority in developing countries, except perhaps in capital and large cities. As a result, very limited funds are provided to the solid waste management sector by the governments, and the levels of services required for protection of public health and the environment are not attained. The problem is acute at the local government level where the local taxation system is inadequately developed and, therefore, the financial basis for public services, including solid waste management, is weak. This weak financial basis of local governments can be supplemented by the collection of user service charges. However, users' ability to pay for the services is very limited in poorer developing countries, and their willingness to pay for the services which are irregular and ineffective.

c Institutional Constraints

Ogawa (2005) further indicates that, several agencies at the national level are usually involved at least partially in solid waste management. He however, indicated that there are often no clear roles or functions of the various national agencies defined in relation to solid waste management and also no single agency or committee designated to coordinate their projects and activities.

“The lack of coordination among the relevant agencies often results in different agencies becoming the national counterpart to different external support agencies for different solid waste management collaborative projects without being aware of what other national agencies are doing. This leads to duplication of efforts, wasting of resources, and unsustainably of overall solid waste management program. The lack of effective legislation for solid waste management, which is a norm in most developing countries, is partially responsible for the roles/functions of the relevant national agencies not being clearly defined and the lack of coordination among them”(Ogawa, 2005).

According to Ogawa (2005), Legislation (Public Health Act, Local Government Act, Environmental Protection Act) related to solid waste management in developing countries is usually fragmented.

Zurbrugg (2009) further added that, solid waste collection schemes of cities in the developing world generally serve only a limited part of the urban population. The people remaining without waste collection services are usually the low-income population living in peri-urban areas. One of the main reasons is the lack of financial resources to cope with the increasing amount of generated waste produced by the rapid growing cities.

Often inadequate fees charged and insufficient funds from a central municipal budget cannot finance adequate levels of service. Zurbrug indicated that, apart from financial constraints that affect the availability or sustainability of a waste collection service; operational inefficiencies of solid waste services such as deficient management capacity of the institutions and inappropriate technologies affect effective waste management. Zurbrugg (2009) therefore underscores the key challenges of waste management which include financial and institutional constraints. Any venture has serious challenges but how they are managed is the point of concern.

2.4 Modeling and Decision Analysis

1. Concept of modeling

According to Hornby (2010), a model is defined as a simple description of a system, used to explaining how something works or calculating what might happen. Bierman et al, (1991) described a model as a simplified representation of an empirical situation. From the view of various authors, one may say that a model is a calculated idea that has a wide range of abilities to create an enabling environment in any system that has proper structures or framework to serve a desirable purpose of intention. Bridging the gap between realism and feasibility is the most crucial and delicate step in the modeling process. There is the need to simplify a model mathematically without sacrificing efficient features of the real-world situation.

2. Environmental Modeling Basics

Environmental modeling is an applied science which deals with the relationships between human physical systems and biological processes (Robert, 2000). Most engineering fields are able to rely on both matured body of knowledge and limited scale test that accurately predicts the system under different conditions. The scale of environmental model problems will cover large geo-political areas which involves government agencies who are inherently policy-based and bureaucratic.

3. Domain Knowledge in Modeling

Modeling is about engineering a system where a scientific discipline is applied to specific objectives for specified systems in order to achieve the objectives. The objective set may range from concrete to abstract (e.g. optimize the use of collecting vehicles), which is heavily influenced by how much is known about the problem (Robert, 2000). It is a known fact that information concerning the system is not always available. An objective which would have read 'is an additional garbage truck needed to optimize garbage pickup in the Tamale Metropolis' could instead become "How to optimize the solid waste pickup routes in Tamale Metropolis."Changing the scale of the objective is a strategy used to gain the background knowledge required to set the concrete goals to be achieved. A common approach to achieving the goal is to generate a model of the system under study.

4. Systems modeling under uncertainty

Ideally, the typical engineering problem solving process would resemble the context of the Figure 1.

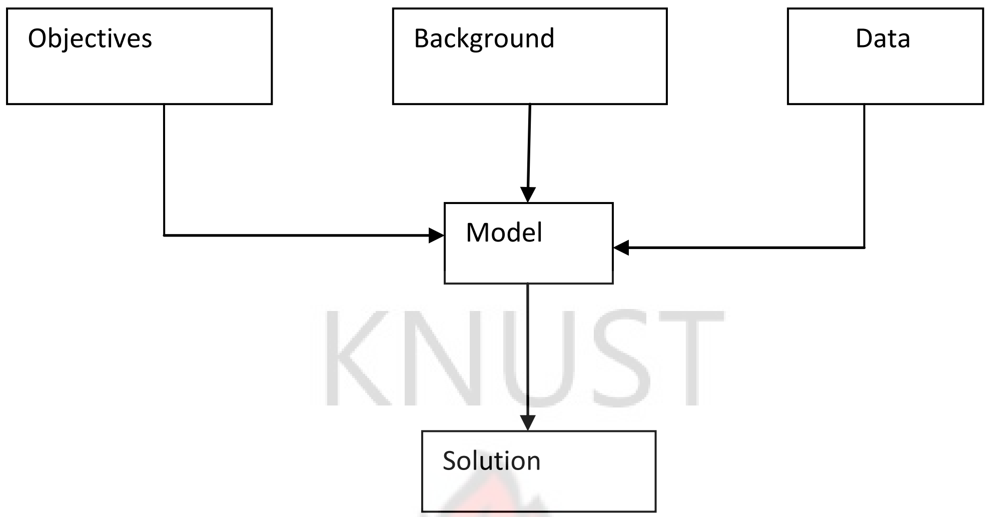

Figure: 1. A typical Solution Process for Engineering Problems

A model is established from the elements for the system with acceptable simplifying assumptions and solved for the specified objective(s). In contrast, a realistic Environmental Engineering problem, the scope of the objective could be very wide and domain knowledge may be available. System data may have been already gathered, but it may not be the specific and required to pursue future objectives.

2.5 Linear Programming Model

A model, which is used for optimum allocation of scarce or limited resources to competing products or activities under such assumptions as certainty, linearity, fixed technology, and constant profit per unit, is linear programming (Murthy, 2003). Linear Programming is one of the most versatile, powerful and useful techniques for making managerial decisions. Linear programming technique may be used for solving broad range of problems arising in business, government, industry, hospitals, libraries, etc. Whenever we want to allocate the available limited resources for various competing activities for achieving our desired objective, the technique that helps us is **LINEAR PROGRAMMING**. As a decision making tool, it has demonstrated its value in various fields such as production, finance, marketing, research and development and personnel management, determination of optimal product mix (a combination of products, which gives maximum profit), transportation schedules(Murthy, 2003).

1. Properties of Linear Programming Model

Any linear programming model (problem) must have the following properties:

- The relationship between variables and constraints must be linear.
- The model must have an objective function.
- The model must have structural constraints.
- The model must have non-negativity constraint.

Consider a product mix problem and the applicability of the above properties in the following:

Example: A company manufactures two products X and Y, which require the following resources. The resources are the capacities machine M_1, M_2, and M_3. The available capacities are 50, 25, and 15 hours respectively in the planning period. Product X requires 1 hour of machine M_2 and 1 hour of machine M_3. Product Y requires 2 hours of machine M_1, 2 hours of machine M_2 and 1 hour of machine M_3. The profit contribution of products X and Y are 12 Ghana cedis and 10 Ghana cedis respectively. The contents of the statement of the problem can be summarized as follows:

Table2. Summary of the Sample Problem on Linear Programming.

Machine	Products		Availability in hours
	X	Y	
M_1	0	2	50
M_2	1	2	25
M_3	1	1	15
Profit in Ghana cedi per unit	12	10	

In the above problem, Products X and Y are competing candidates or variables.

Machine capacities are available resources. Profit contribution of products X and Y are given.

Now let us formulate the model.

Let the company manufacture x units of X and y units of Y. As the profit contributions of X and Y is 12 Ghana cedi and 10 Ghana cedi respectively. The objective of the problem is to maximize the profit Z, hence objective function is:

Maximize $Z = 12x + 10y$**: OBJECTIVE FUNCTION.**

This should be done so that the utilization of machine hours by products x and y should not exceed the available capacity. This can be shown as follows:

For Machine M1: $0x + 2y \leq 50$

For Machine M2: $1x + 2y \leq 25$**:** **LINEAR STRUCTURAL CONSTRAINTS.**

For machine M3: $1x + 1y \leq 15$

But the company can stop production of x and y or can manufacture any amount of x and y. It cannot manufacture negative quantities of x and y. Hence,

Both x and y are ≥0: NON -NEGATIVITY CONSTRAINT

As the problem has got objective function, structural constraints, and non-negativity constraints and there exist a linear relationship between the variables and the constraints in the form of inequalities, the problem satisfies the properties of the Linear Programming Problem (Murthy, 2003). The presence of the characteristics of linear programming model in a problem is an indication that the problem is solvable. From what is discussed, there is no way a factory will have a negative production but the factory may have zero production that is the factory may not produce anything but in the case of solid waste generation there is no way there will be no solid waste generation hence a variable may be **>0** and not **≥0.**

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1 Introduction

Based on the lessons from the literature, relevant data were collected to construct the waste transportation model for the Tamale Metropolis. The data were sourced through primary and secondary sources using appropriate techniques.

3.2 Primary data

This is the data that were collected in the course of preliminary field investigation and face-to face interview with the relevant solid waste management authority. The data collected were used in this chapter, chapter four and discussed in chapter five. The primary data collection process was based on the target population, data collection method, type of data required and number of respondents

(1)Target population: Staff of WMD (Landfill Manager) and Zoom Lion Ghana Ltd. (Landfill Supervisor); Planning and Budget Officers-Metropolitan Assembly; Technical officers of both WMD and ZL of TAMA.

(2)Data collection method: Face-to-face interview**;**

(3)Type of data required: Types of waste generated ;Quantity generated daily; Mode and frequency of waste collection; number of transfer stations in the metropolis; Provision of skips and dustbins; distance in km from transfer stations to the final disposal sites; available final disposal sites; Availability of resources for solid waste transportation; Challenges of solid waste transportation; etcetera; IGF generated in a month; Amount spent on waste collection in a month, Amount of DACF spent on waste management; Problems of managing waste.

3.2.1 Overview of the Study Area

Tamale Metropolis is situated in the Northern part of Ghana. It is the regional capital of the Northern Region.Geographically, the Metropolis lies between latitude $9^{o}16$ and $9^{o}34$North and Longitudes $0^{o}36$ and $0^{o}57$West and it is informally described as the gate way to the North. During the 1984 population census the Metropolis had a population of 167,778 inhabitants. This figure rose up to **293,881** in 2000 (GSS, 2000). In 2000 PHC, 146,979 were males and 146,902 were females out of the total figure of 293,881 in the Metropolis. This figure shows an increase of 75% over the 1984 population of 167,778 with an intercensal growth rate of 3.5%.

The results of the 2010 Population and Housing Census have indicated that the population size of the Tamale Metropolitan Area was 371,351(GSS, 2012). This represents 15 per cent of the population of the entire region. There were 185,995 males and 185,356 females. The average household size was found to be 6.2. With an urban population of 67.1%, the Metropolis is the only district in the Region which is predominantly urban. This implies that the Metropolis could be a growth pole for the three northern regions attracting both population and economic development in the area.

The Metropolis has to take concerted efforts to transform the area so that it would not have to grow like others such as Accra and Kumasi where some areas in these Metropolises have grown into slums and attracting social vices. The age structure of the population of a high fertility country such as Ghana is basically shaped by the effect of mortality. As it is the case with the Metropolis the structure of the population indicates a broad base that gradually tapers off with increasing age due to death. The youthfulness of the population promises the most important human resource potential which will determine the strength and resilience in pursuing the social, economic and political development goals. The population growth rate of the metropolis is higher than the national population since 2000 and this is seen in the table 3.

Table 3: the populations of TAMA and NATIONAL in 1984, 2000, 2010 and their growth rates

City	**1984**	**2000**	**2010**	**Growth Rate**	
				(1984-2000)	(2000-2010)
TAMA	167,778	293,881	371,351	3.5	2.6
Nation	**12,296,081**	**18,912,079**	**24,223,431**	**2.7**	**2.4**

Source: PHC 2000 and 2010

The Metropolis is characterized by increasing population growth and changing life styles of the people. This has led to the production of large volumes of wastes of all kinds. The study focuses solely on solid waste transportation in the metropolis. The study also concentrated on the transportation cost between transfer stations and the disposal sites. Figure 2 is the map of Northern Region indicating TAMA as the area of study.

Figure 2: Source: Puopil (2010).

Figure 3, which is the map of TAMA, shows the transfer stations and the disposal sites captured in the model.

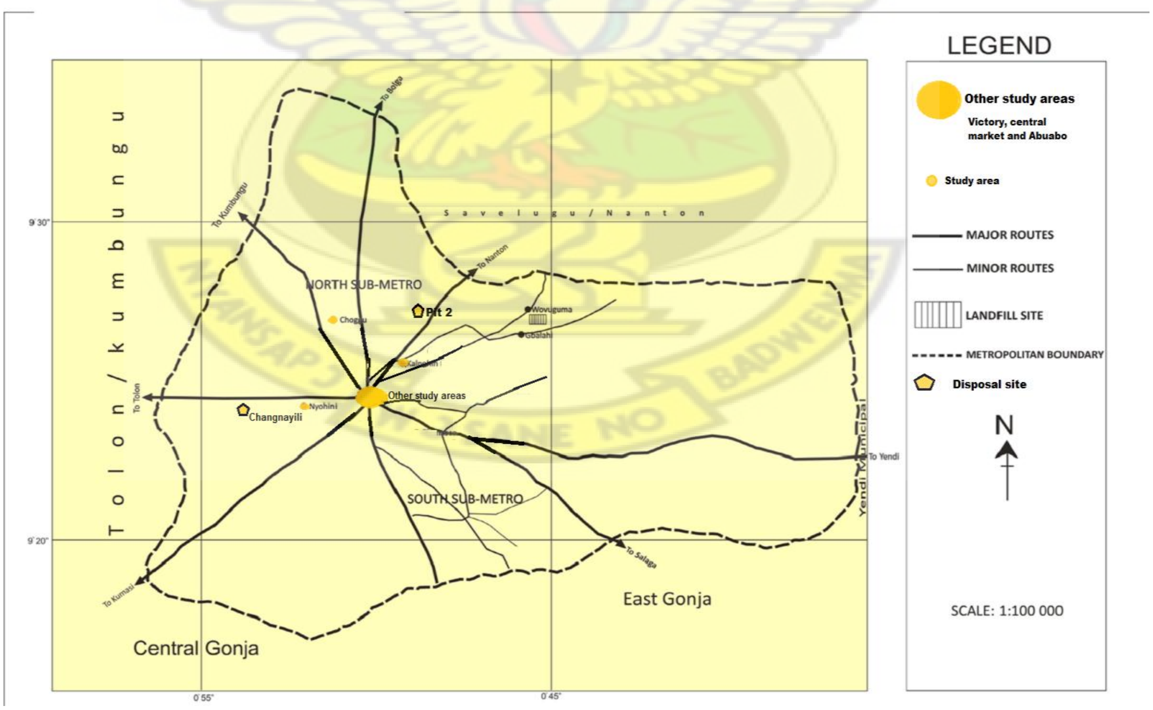

Figure 3: Map showing TAMA and other study area

3.2.2 Mathematical Models formulation

These models were formulated as follows:

(1) Construction of the general mathematical model of transportation from transfer stations to a number of disposal sites;

(2) Construction of WMD and ZL Models using the General mathematical Transportation Model

(3) Description of the **VAM (**Vogel's Approximation Method) in determining the optimal routes of the transportation for the various solid waste management institutions (ZL and WMD) in the metropolis;

(4) Description of how to test the optimality of the Basic Feasible Solutions obtained for ZL and WMD using MODI (Modified Distribution) method;

(5) How to use Microsoft excels to confirm the optimal costs of transportation for ZL and WMD

(a) Construction of General Mathematical Formulation of Transportation Problems:

- Suppose there are 'm' transfer stations (T_1, T_2, T_3, _, _, T_m), where the solid waste is piled up and 'n' disposal sites where it is to be disposed of.
- Let the quantity of waste available in transfer stations be a_1, a_2, a_3, _, _,_ a_m and
- The quantity of waste received at the disposal sites (m_1, m_2, m_3, _, _, m_n) be b_1, b_2, b_3, _, _, _ b_n.
- The unit cost in Ghana cedis of transporting solid waste from transfer stations i to the disposal sites j is C_{ij} (C_{11}, C_{12}, _, _ C_{mn}),

- Let X_{ij} (X_{11}, X_{12}, X_{13}, _, _, X_{mn}) be the quantity of solid waste carried from transfer stations i to the disposal sites j.
- Let d_{ij} (d_{11}, d_{12}, d_{13},-,-,d_{mn}) be the distances from the transfer stations to the disposal sites
- Finding an optimum transportation schedule which minimizes the total cost of transportation from the transfer stations/ final collecting sites to the disposal sites.
- The assumption is displayed in the Table 4:

Table 4: General Mathematical Model for Solid Waste Transportation.

Transfer station	Disposal sites m_1 m_2 m_3 - - - m_n	Total waste available at each transfer station in tons/day
T_1 T_2 T_3 - - T_m	$C_{11}X_{11}$ $C_{12}X_{12}$ $C_{13}X_{13}$ - - - $C_{1n}X_{1n}$ $C_{21}X_{21}$ $C_{22}X_{22}$ $C_{23}X_{23}$ - - - $C_{2n}X_{2n}$ $C_{31}X_{31}$ $C_{32}X_{32}$ $C_{33}X_{33}$ - - - $C_{3n}X_{3n}$ - - $C_{m1}X_{m1}$ $C_{m2}X_{m2}$ $C_{m3}X_{m3}$ - - - $C_{mn}X_{mn}$	a_1 a_2 a_3 - - a_m
Total waste received at each disposal site in tons/day	b_1 b_2 b_3 - - - b_n	$\sum_{i=1}^{m} ai = \sum_{j=1}^{n} bj$

The total minimum transportation cost is

$$\mathbf{Z = \sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} * C_{ij} \; (Z = X_{11}C_{11} + X_{12}C_{12} + \_\ \_\ \_ + XmnCmn.)}$$

Z is **the objective function** subject to the following conditions;

$$T_1: X_{11} + X_{12} + X_{13} + \text{- - -} + X_{1n} \leq a_1$$

$$T_2: X_{21} + X_{22} + X_{23} + \text{- - -} + X_{2n} \leq a_2$$

$$T_3: X_{31} + X_{32} + X_{33} + \text{- - -} + X_{3n} \leq a_3$$

-

-

$$T_m: X_{m1} + X_{m2} + X_{m3} + \text{- - -} + X_{mn} \leq a_m$$

and

$$m_1: X_{11} + X_{21} + X_{31} + \text{- - -} + X_{m1} = b_1$$

$$m_2: X_{12} + X_{22} + X_{32} + \text{- - -} + X_{m2} = b_2$$

$$m_3: X_{13} + X_{23} + X_{33} + \text{- - -} + X_{m3} = b_3$$

-

-

$$m_n: X_{1n} + X_{2n} + X_{3n} + \text{- - -} + X_{mn} = b_n$$

Structural constraints

Where $X_{ij} \geq 0$; where i=1, 2, 3….m and j=1, 2, 3….n (**non-negativity constraints**).

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Using the general model, the model for WMD and ZL can be constructed below. These models can be distinguished from each other using ‘w’ and ‘l’ as a subscript for objective functions of WMD and ZL respectively and ‘wn’ and ‘ln’ as subscript for objective functions for their night models respectively.

(b) WMD Model (Day)

Table5.Daily Transportation Cost per Unit of Solid Waste from each Transfer Station to the Disposal Sites:

From\To	Landfill	P_1	P_2	Total/tons
T_1	GH₵1.26	GH₵0.72	GH₵0.72	50
T_2	GH₵1.17	GH₵0.81	GH₵0.63	50
T_3	GH₵1.08	GH₵0.99	GH₵0.54	40
T_4	GH₵1.17	GH₵0.90	GH₵0.45	35
Total/tons	120	30	25	175

Minimize $Z_w = 1.26X_{11} + 0.72X_{12} + 0.72X_{13} + 1.17X_{21} + 0.81X_{22}$

$+0.63X_{23} + 1.08X_{31} + 0.99X_{32} + 0.54X_{33} + 1.17X_{41} + 0.90X_{42} + 0.45X_{43}$

Subject to:

T_1: $X_{11} + X_{12} + X_{13} \leq 50$

T_2: $X_{21} + X_{22} + X_{23} \leq 50$

T_3: $X_{31} + X_{32} + X_{33} \leq 40$

T_4: $X_{41} + X_{42} + X_{43} \leq 35$ — Structural constraints

and

L: $X_{11} + X_{21} + X_{31} + X_{41} = 120$

P1: $X_{12} + X_{22} + X_{32} + X_{42} = 30$

P2: $X_{13} + X_{23} + X_{33} + X_{43} = 25$

Where $X_{ij} \geq 0$; where i=1, 2, 3, 4 and j=1, 2, 3 (**non-negativity constraints**).

(c) ZL Model (Day)

Table 6. Daily Transportation Cost per unit of Solid Waste from each Transfer Station to the Disposal Sites**:**

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	GH¢5.16	GH¢3.44	GH¢3.87	15
Central market (C)	GH¢4.73	GH¢3.87	GH¢3.44	15
Hill top (H)	GH¢5.59	GH¢4.30	GH¢4.30	11
Kalpohini (K)	GH¢3.87	GH¢6.02	GH¢2.15	10
Total/tons	20	16	15	51

Minimize: $Z_l=5.16X_{11}+3.44X_{12}+3.87X_{13}+4.73X_{21}+3.87X_{22}+3.44X_{23}+5.59X_{31}+4.30X_{32}+4.30X_{33}+3.87X_{41}+6.02X_{42}+2.15X_{43}$

Subject to:

A: $X_{11}+X_{12}+X_{13} \leq 15$

C: $X_{21}+X_{22}+X_{23} \leq 15$

H: $X_{31}+X_{32}+X_{33} \leq 11$

K: $X_{41}+X_{42}+X_{43} \leq 10$

and

L: $X_{11}+X_{21}+X_{31}+X_{41}=20$

P_1: $X_{12}+X_{22}+X_{32}+X_{42}=16$

P_2: $X_{13}+X_{23}+X_{33}+X_{43}=15$

Structural constraints

Where $X_{ij} \geq 0$; where i=1, 2, 3, 4 and j=1, 2, 3(**non-negativity constraints**).

(d) **WMD Night Collection Model**

Table 7.Night transportation cost per ton, from each transfer station to the disposal sites:

From\To	Landfill	P_1	P_2	Total/tons
T_1	GH₵0.84	GH₵0.48	GH₵0.48	50
T_2	GH₵0.78	GH₵0.54	GH₵0.42	50
T_3	GH₵0.72	GH₵0.66	GH₵0.36	40
T_4	GH₵0.78	GH₵0.60	GH₵0.30	35
Total/tons	120	30	25	175

Minimize $Z_{wn} = 0.84X_{11} + 0.48X_{12} + 0.48X_{13} + 0.78X_{21} + 0.54X_{22}$

$+0.42X_{23} + 0.72X_{31} + 0.66X_{32} + 0.36X_{33} + 0.78X_{41} + 0.60X_{42} + 0.30X_{43}$

Subject to:

T_1: $X_{11} + X_{12} + X_{13} \leq 50$

T_2: $X_{21} + X_{22} + X_{23} \leq 50$

T_3: $X_{31} + X_{32} + X_{33} \leq 40$

T_4: $X_{41} + X_{42} + X_{43} \leq 35$

and

L: $X_{11} + X_{21} + X_{31} + X_{41} = 120$

P1: $X_{12} + X_{22} + X_{32} + X_{42} = 30$

P2: $X_{13} + X_{23} + X_{33} + X_{43} = 25$

Structural constraints

Where $X_{ij} \geq 0$; where i=1, 2, 3, 4 and j=1, 2, 3 (**non-negativity constraints**).

(e) ZL Night Collection Model

Table8.Unit Cost of solid waste from the various final collection sites to the disposal sites.

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	GH¢3.48	GH¢2.32	GH¢2.61	15
Central market (C)	GH¢3.19	GH¢2.61	GH¢2.32	15
Hill top (H)	GH¢3.77	GH¢2.90	GH¢2.90	11
Kalpohini (K)	GH¢2.61	GH¢4.06	GH¢1.45	10
Total/tons	20	16	15	51

Minimize $Z_{ln}=3.48X_{11}+2.32X_{12}+2.61X_{13}+3.19X_{21}+2.61X_{22}+2.32X_{23}+3.77X_{31}+2.90X_{32}+2.90X_{33}+2.61X_{41}+4.06X_{42}+1.45X_{43}$.

Subject to:

A: $X_{11}+X_{12}+X_{13} \leq 15$

C: $X_{21}+X_{22}+X_{23} \leq 15$

H: $X_{31}+X_{32}+X_{33} \leq 11$ — Structural constraints

K: $X_{41}+X_{42}+X_{43} \leq 10$

and

L: $X_{11}+X_{21}+X_{31}+X_{41}=20$

P_1: $X_{12}+X_{22}+X_{32}+X_{42}=16$

P_2: $X_{13}+X_{23}+X_{33}+X_{43}=15$

Where $X_{ij} \geq 0$; where i=1, 2, 3, 4 and j=1, 2, 3(**non-negativity constraints**).

(3) Types of Transportation Problems

- Minimisation Balanced Transportation Problems
- Minimisation Unbalanced Transportation Problems
- Maximisation Balanced Transportation Problems
- Maximisation unbalanced Transportation Problems
- All the above models with degeneracy.

The thesis considered the minimisation balanced transportation problem using one (VAM) of the methods below for feasibility:

(4)Initial Feasible Solution Determination Methods of solving Transportation Problems:

- North- West Corner Rule method
- Row-minima Method
- Column minima method
- Matrix Minima Method or least cost method
- Vogel's Approximation method (VAM)

(5) Methods for Checking Optimality:

- Stepping-Stone Method
- Modified Distribution Method, UV or MODI method

MODI was chosen to test the optimality of the solutions of the models in this research.

(6) Brief Explanation of Initial basic feasible solution of a transportation problem:

A feasible solution of a p-origin, q-destination problem is said to be basic if the number of positive allocations are equal to (p+q-1). Initial basic feasible solution of a transportation problem using VAM is explained as follows:

(a) Vogel's approximation method (unit cost penalty method)-VAM

VAM is an improved version of the least-cost method that generally, but not always, produces better starting solutions. VAM is based upon the concept of minimizing opportunity (or penalty) costs. The opportunity cost for a given supply row or demand column is defined as the difference between the lowest cost and the next lowest cost alternative. It is preferred to the methods mention above because it generally yields, an optimum, or close to optimum, starting solutions. Consequently, if we use the initial solution obtained by VAM and proceed to solve for the optimum solution, the amount of time required to arrive at the optimum solution is greatly reduced. The steps involved in determining an initial solution using VAM are as follows:

Step1. Write the given transportation problem in tabular form (if not given).

Step2. Compute the difference between the minimum cost and the next minimum cost corresponding to each row and each column which is known as penalty cost.

Step3. Choose the maximum difference or highest penalty cost. Suppose it corresponds to the i^{th} row. Choose the cell with minimum cost in the i^{th} row. Again if the maximum corresponds to a column, choose the cell with the minimum cost in this column.

Step4. Suppose it is the $(i, j)^{th}$ cell. Allocate minimum (a_i, b_j) to this cell. If the minimum $(a_i , b_j) = a_i$, then the availability of the i^{th} origin is exhausted and demand at the j^{th} destination remains as b_j-a_i and the i^{th} row is deleted from the table. Again if min $(a_i, b_j) = b_j$, then demand at the j^{th} destination is fulfilled and the availability at the i^{th} origin remains to be a_i-b_j and the j^{th} column is deleted from the table.

Step5. Repeat steps 2, 3, and 4 with the remaining table until all origins are exhausted and all demands are fulfilled.

(b)Reasons for Choosing Vogel's Approximation Method

This initial feasible solution approach was chosen for this piece of research due to the following few reasons: generally, it produces a better optimum or close to optimum starting solution; the amount of time required to arrive at the optimum solution is relatively shorter.

(b) Brief Explanation of MODI

Symbolic representation of how MODI should be used to determine optimality is shown below:

$\pm y = y_1 - x_2$; where $+y$ is cost increase;$-y$ is cost decrease; y_1 is AC; x_2 is SC

$X_2 = \sum$ of nominal D and R cost of the unoccupied cells. Where D is dispatch and R is reception.

(c) **Reason for chosen MODI in optimality**

The reason for which **MODI** is used in this research to test the optimality instead of stepping stone method is that in stepping stone the loop for every empty cell would have to be written and this makes it tedious and time consuming but for MODI, a simple formula as seen above can easily be used without consuming a lot of time.

3.3 Secondary data

These data were obtained from books, articles and internet sources to review the related literature, used in chapter three and discussed in chapter four. Another source of the secondary data was the District Medium Term Development Plan (DMTDP) of the Metropolitan Assembly. In the process of obtaining the data, focus was on objective of waste management by the Assembly; strategies; collaborators and indicative cost; vehicles used in managing the solid waste; the network of the routes to the landfill sight etcetera.

3.4 Using Microsoft excels to confirm the optimal costs of transportation for ZL and WMD.

In using excel solver to solve problems certain procedure must be followed. This is outlined as follows;

(a) type all the decision variables in the problem in different cells in a row;

(b) in a succeeding row ,type their respective objective function coefficients;

(c) Leaving a few more row, type the names of the resources in the problem in order in a column;

(d) For each resource, type the coefficients of each of the decision variables in the row corresponding to the resource;

(e) Leaving a column after the system that would have been created by steps (c) and (d),type the respective right- hand side (RHS) of each constraint on the row corresponding to the name of the resource associated with that particular constraint;

(f) Leaving a few rows, type the decision variables in the problem in different cells and type zeros(the initial values of the decision variables) in their corresponding cells in the succeeding row;

(g) Leaving a few more row, type what the problem seeks to achieve (optimal cost);

(h) In the cells to the right of what was typed in (g) above, type the objective function using sum products; where the first array would be the cells containing the objective function coefficients and the second array containing the zeros as in step (f). the answer will be zero for initial value of the objective function;

(i) In the column that was left in step(e) ,type the equation of each constraint using sum product; where the first array would be the cells containing the coefficients of the decision variable of that particular constraint and the second array would be the cells containing the zeros(f) the values in that particular column will also be zero;

(j) Click on the Data menu;

(k) From the items under Data, double-click on solver, a dialogue box would pop up;

(l) For set target to on the dialogue box, select the cell that would accommodate the objective function value;

(m) Select min for minimization;

(n) For by changing cells, select the cells that contain the zeros of the decision variable in step (f);

(o) For subjects to the constraints, click on white space directly beneath it and click on add. Another dialogue box would pop up;

(p) For cell reference on the dialogue box that pops up, select the cells containing the zeros in the column to the left of the column containing the RHS;

(q) Select the appropriate equality;

(r) Select the cells containing the RHS of the constraints for constraint in the add constraint pop-up menu;

(s) Click on OK. This would bring us back to the solver parameters dialogue box;

(t) Click on options on the solver parameters dialogue box;

(u) Choose assume linear model(since linear programming is on focus now) and assume non-negative;

(v) Click on OK;

(w) Click on solve.

In going through the steps above the same optimal cost was obtained as the case of the manual solving. That is GH¢171.45 in WMD and GH¢197.80 as in ZL model. The detail reports are seen in the Appendix B for both institutions.

3.5 Summary

The chapter contains means by which information was sourced (both primary and secondary sources); the type of transportation models (minimisation Balanced Transportation Problems, minimisation Unbalanced Transportation Problems, maximisation Balanced Transportation Problems, maximisation unbalanced Transportation Problems); methods of finding IFS (North- West Corner Rule method, Row-minima Method, Column minima method, Matrix Minima Method or least cost method and Vogel's Approximation method) and steps involved in the use of Microsoft excel to solve the model problems.

CHAPTER FOUR

RESULTS AND DISCUSSION

5.1 Introduction

This is the chapter that looked at the prospects and some data collected from WMD and ZL and also throws more light on some issues coming up from the constructed model. Some comparisons are made to bring about some useful recommendations.

5.2 Solid Waste transportation Plan of TAMA

According to the Medium-Term Development Plan (2010-2013) of the Tamale Metropolitan Area, the main objective of WMD is to ensure that 80% refuse generated in the Metropolis is collected and properly disposed off, by December, 2013 to ensure efficient waste management. House to house collection of refuse is expected to improve from 32% to 60% by the end of the 2013.

Strategies were outlined to ease the solid waste transportation problem in the Metropolis. These include: improve stock of sanitary equipment, promote private participation in solid waste collection and disposal, promote education on hygiene, and promote community participation in waste management. A series of activities were proposed. These include: assess equipment needs of the WMD, procure equipment, sensitize public on private participation in waste management; build capacity of staff of WMD and acquire more sanitary facilities (100 dustbins). There is a problem with funding because waste management in any part of the globe is capital intensive. The Metropolis spent an amount of GH₵ 1,000,000.00 annually on waste management but this amount is woefully inadequate. The Metropolis would need to spend approximately GH₵ 2,500,000.00 in this area to ensure that the objective of the department is achieved.

All the mechanisms put in place may lead to reduction of cost of solid waste management in general and the transportation in particular since waste would be well gathered and transported collectively instead of pieces.

5.3 Primary Data Discussion

The solid waste management units work with both heavy and light machines in the areas of waste disposals. The Equipment Strength of WMD and ZL in Tamale Metropolis as seen in the table 9 is discussed as follows:

Table 9: Equipment Based of Waste Management Institution in the Metropolis

Equipment	WMD (number available)	Number required	ZoomLion (number available)	Number required	Total available	Total required	Average Age of some equipment/yrs
Dustbins	550	1000	1047	3000	1,597	4000	1-6
Skips	118	200	73	103	191	303	1-6
Oboafotricycle	-	-	100	200	100	200	6
Motorist	-	-	8	50	8	50	
Graders	1	2	1	2	2	4	1-6
SkipLoaders	3	4	7	-	10	4	6
Compaction trucks	1	2	2	1	3	3	
Roll on/Roll off trucks	3	4	3	3	6	7	6
Motorking	-	-	3	7	3	10	

Source: WMD and ZL, March, 2011

Analyses of the equipment base from table 9 are grouped into their respective uses namely storage, collection and transportation. In terms of waste storage three hundred and three (303) skips were required by ZoomLion Ghana Ltd. and WMD to be supplied in both the middle and low class residential areas. However, one hundred and ninety one (191) which is about 63% of the total required were available and distributed for solid waste storage in the Metropolis. Consequently, if this extra skips were not supplied this could result in people dumping waste at unapproved sites. Also, about four-thousand (4000) dustbins were needed for solid waste storage in the residential areas for effective service in the Metropolis particularly those living in the high class residential areas. This is because dustbins are the main equipment for storing solid waste in order to prevent dumping of waste at unapproved sites so that they can be gathered well at the transfer stations for efficient transportation.

In terms of waste collection and transportation in the Metropolis Oboafo tricycle, motor-cycles, skips loaders, roll on/roll off and compaction trucks were mainly used. The Oboafo tricycle and motor cycles were used for primary collection and transferring of waste collected into skips for final collection and disposal at the landfill. However, these were not enough to ensure regular collection and transportation of waste to the landfill. For instance about two-hundred (200) Oboafo tricycles were needed by the waste management institutions for the door-to-door collection. Also, the compaction trucks which were used for the door-to-door collection were only three (3) for the entire Metropolis which according to the Waste Management Units are woefully inadequate and therefore additional three (3) were required. In effect, if the few existing core waste equipment for collection and transportation like skip loaders, compaction trucks and roll on/roll off trucks are broken down for just a day or two it will result in heaping of waste in the metropolis and this could pull down the enviable reputation earned by the Metropolis over the years. This can lead to outbreak of communicable diseases such as cholera, typhoid and chicken pox.

On staffing situation of the two institutions on solid waste management, the Metropolis has high caliber of personnel at the top management position. Table 10 shows the technical staff of WMD and ZoomLion Ghana Ltd. Tamale.

Table 10: Technical Staff of Waste Management Institutions in TAMA

Institution	Personnel	Number	Qualification
WMD	Directors	2	MSc.CivilEngineering
	Engineer	1	BSc.CivilEngineering
	Technical Supervisors	8	Dip. Environmental Health
	supervisors	3	Certificate
ZoomLion Ghana Ltd	Regional operation supervisors	1	B.A. Social Science
	Assist. Regional Operations Supervisor	1	M.A. Environmental Management
	Technical Supervisor	1	Advance Certificate in Engineering

Source: WMD and ZL.March, 2011.

From table 10, the WMD had more technical staff than the ZoomLion Ghana Ltd. Once the ZoomLion was into solid waste management, technical staffs like engineers are required especially at the landfill site to ensure effective waste disposal. Even if the operation supervisors were engineers that would have still been inadequate. Additionally, the technical supervisors were woefully inadequate as compared to the WMD which had eight (8). This is because one (1) person cannot supervise solid waste collection in the whole Metropolis with over thirty (30) communities. The landfill analyzed below is simply an indication that the staff available is inadequate:

5.4 Final Disposal of Waste

The final disposal site of solid waste in the Metropolis was landfill site at Gbalahi, about 13 kilometres away from the city centre. This is the only site of final disposal. It would definitely result in pressure and this needed re-enforcing pits as provided in the model. A visit to the landfill site showed that, it was in a bad shape. Ideally, sanitary landfill should have the following functional elements: Weighing Bridge, Internal access, Treatment plant, Leachate collection system, Gas recovery and the location should be far away from human settlement and existing water bodies. This was not the case with the landfill in Tamale. Though there was presence of the facilities mentioned above they were not functional. For example, the weighbridge was present but out of use. Additionally, the landfill has no internal access and the site was closer to a community called Wovuguma. This community was about one kilometer (1km) away from the site. One major cell was almost filled to capacity and the other one was empty. Some of the Waste dumped in the cells was not leveled and compacted as required of a sanitary landfill. This left a mountain of waste at the site (see Appendix c). Worst of it all, burning of waste occurred at the site. Therefore, the landfill can simply be described as an ordinary dumping pit.

Monthly expenditure on the various components of solid waste transportation by ZL Ghana, Tamale is seen in the Table 11. It is seen from Table 11 that much is spent on fuel than the other components.

Table 11: Monthly Expenditure on the Various Components of Solid Waste Transportation by ZL Ghana, Tamale

Vehicle	Quantity	Amount on fuel in GH₵	Amount on maintenance in GH₵	Amount on labour in GH₵	Incentives in GH₵
Skip trucks	3	6720	2100	2520	1800
Small roll- on truck	1	1920	700	840	600
Big roll-on truck	1	320	800	840	600
Compaction truck	2	1976	2200	1680	1200
Pay loader	1	1000	375	670	450
Total	7	11936	6175	6550	4650

Source: ZL Ghana Ltd, Tamale

Expenditure on the various components of solid waste transportation by WMD, Tamale is seen in Table 12. It is seen from the table that much is spent on fuel than the other components just as in ZL. This is because 3880 Ghana cedis is spent monthly on fuel if the weekly expenditure is converted to monthly expenditure.

Table 12: Expenditure on the Various Components of Solid Waste Transportation by WMD, Tamale

Vehicle	Quantity	Amount on fuel consumed each week in GH₵	Amount on maintenance for two months in GH₵	Amount on labour in a month in GH₵
Skip trucks	2	288	560	947
roll- on truck	2	288	860	947
Dozea at landfill site	1	144	750	353.50
Pay loader	1	250	750	353.50
Total	6	970	2920	2601

Source: WMD, Tamale, March, 2012

5.5 Revenue

Waste management has huge financial implications. The Assembly depends heavily on District Assembly Common Fund (DACF) to finance waste management. The Assembly has been recording a high growth rate of an average of 91.17 per cent achievement of the yearly budget. However, the actual performance over the period has increased from 36 per cent to 350 per cent (Poupil, 2010).

Formally, the Assembly uses its own revenue collectors, but in the period she employed development partners who assisted in revenue collection especially in the area of property rate. Table 13: shows locally generated revenue, targeted and actuals from 1999-2002 in Ghana cedis (GH¢).

Table 13: Locally Generated Revenue from 1999-2002

Year	Budgeted (GH¢)	Actual (GH¢)	Performance (%)
1999	26,4404.02	23,002.584794	87.12
2000	102,809.6	31,390.475500	30.53
2001	65,648.7	45,780.089311	69.73
2002	71,300.8	126,427.031503	177.31
Grand total	266,163.12	226,600.181108	91.17

Source: Tamale Metropolitan Assembly, 2011.

If the Internally Generated Fund (IGF) of the Assembly could be increased, it would constitute a potential sustainable source of funding for waste management. This is because the Assembly is the major financier of solid waste management in the area.

The daily generation and clearance of solid waste in the metropolis is seenintable14

Table 14: Daily Generation and Clearance of Solid Waste in the Metropolis

Waste Management Unit	Average solid waste generated daily within the management area	Average quantity of waste cleared daily	Percentage of solid waste cleared daily
WMD	250tons	175tons	70%
ZL	110tons	51tons	46%
Total	360tons	226tons	63%

Source: WMD and ZL Ghana, Tamale, March, 2012

From Table 14 the researcher has noticed that out of 360 tons of waste generated daily, both WMD and ZL were able to clear only 226 tons leaving a backlog of 134 tons. The total amount of money used to clear the 226 tons was about GH₵1360.97. ZL as a private solid waste collection department spent a total amount of aboutGH₵977.03 a day to clear about 51 tons of solid waste and WMD used a total amount of about GH₵383.94 to clear 175 tons of solid waste.

The revelation above is simply an indication that there is a leakage in the transportation system of ZL in other words there may be some lapses leading to the fuel waste which has obvious influence on the transportation management. It could also be that the 175 tons of solid waste claimed to have been cleared daily by WMD creates room for questions otherwise they would be better in managing the solid waste in the Metropolis than ZL Ghana, Tamale.

5.6 Discussion of Models

(1) Some assumptions made in the models:

- Cost per unit ton for WMD and ZoomLion Day models were calculated using Salary of labour, CRF(Capital Recovery Factor), speed of vehicle, incentives, etc.
- Three final disposal sites were available with two being described as reinforcing disposal sites of which one is currently in use besides the landfill site.
- The transportation system was narrowed down to the transportation from the final collection stations to the final disposal sites.
- All variables were converted to daily use; for example amount of fuel which was given in weekly consumption was converted to daily consumption.
- It was also assumed that the solid waste transportation team works every day that is seven days a week.
- Unit costs for night models were obtained using an average time (1hr) of travel in the night.
- It is also assumed that unit cost is an estimate not a perfect value (Unit Cost Planning Council; 2004).

(2) Constructed Transportation Model of WMD and ZL

(a) Solution of Day Solid Waste Collection Model (WMD)

In Tamale Metropolis so many people throw their waste into skips and unapproved dumping sites and some were later found in the transfer stations and finally to the approved disposal site(s). The available and functional transfer stations within the ambit of WMD were Sabongida transfer station (T_1), Victory transfer station (T_2), Tishigu transfer station 1(T_3), Tishigu transfer station2 (T_4).The disposal sites are engineered landfill sites (L), pit 1 (P_1) and pit 2 (P_2). P_1 and P_2 are forcing constraints that form part of the model in order to divert waste flow from landfill when the need arises. Currently p_1 which is at Changnayili is in use due to the community request. See the appendix A for working details of the various models constructed below.

Table 15 displays the average distances in Km from transfer stations to the final disposal sites and the total waste dispatched and received by the transfer stations to the disposal sites respectively.

Table 15: The Average Distances in Km from Transfer Stations to the Final Disposal Sites:

From\To	Landfill	P_1	P_2	Total/tons
T_1	14km	8km	8km	50
T_2	13km	9km	7km	50
T_3	12km	11km	6km	40
T_4	13km	10km	5km	35
Total/tons	120	30	25	175

The optimum distribution of the solid waste available at the transfer stations to the disposal sites in WMD model is shown in Table 16.

Table 16: Solid waste allocation scheduled in the WMD Day model

From/To	Landfill Site		Pit_1		Pit_2		Total/tons
T_I	20	1.26	30	0.72		0.72	50
T_2	50	1.17		0.81		0.63	50
T_3	40	1.08		0.99		0.54	40
T_4	10	1.17		0.90	25	0.45	35
Total/tons	120		30		25		175

Minimum cost (Z) =20*1.26+30*0.72+50*1.17+40*1.08+10*1.17 +25*0.45= GH₵171.45

(b) Solution of Day Solid Waste Collection Model (ZL)

ZoomLion is a well established private waste management unit that manages more than 50% of the areas within the boundaries of the Metropolis. The quantity of waste produced in their area of management was less than the waste produced in the area being managed by WMD. This was due to the fact that most of the areas under Zoomlion are rural and the rate at which they generate waste was relatively low. Table 17: displays the distance in km from the collection sites (A, C, H, and K) to the disposal sites (L, P_1, and P_2); the quantity of waste in tons hauled from each clearing site as well as the total waste in tons received at the final disposal site.

Table 17: distances in km and totals of solid waste in tons hauled from the final collection sites to the disposal site.

From/To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	12km	8km	9km	15
Central market (C)	11km	9km	8km	15
Hill top (H)	13km	10km	10km	11
Kalpohini (K)	9km	14km	5km	10
Total/tons	20	16	15	51

The optimum distribution of the solid waste available at the transfer stations to the disposal sites in ZL model is shown in Table 16.

Table 18: Solid Waste Allocation in the ZL Day Collection Model

From/To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		5.16	15	3.44		3.87	15
Central market (C)	10	4.73		3.87	5	3.44	15
Hill top (H)	10	5.59	1	4.30		4.30	11
Kalpohini (K)		3.87		6.02	10	2.15	10
Total	20		16		15		51

Minimum cost (Z) =15*3.44+ 10*4.73+5*3.44+10*5.59+1*4.30+10*2.15=GH¢197.80

(c) Solution of Night Solid Waste Collection Model (WMD)

The solution of night collection as seen in table 19 has indicated beyond reasonable doubt that it will be a better option.

Table 19: Solid waste allocation scheduled in the WMD night model

From/To	Landfill Site		Pit_1		Pit_2		Total/tons
T_I	20	0.84	30	0.48		0.48	50
T_2	50	0.78		0.54		0.42	50
T_3	40	0.72		0.66		0.36	40
T_4	10	0.78		0.60	25	0.30	35
Total/tons	120		30		25		175

Z =20*0.84+30*0.48+50*0.78+40*0.72+10*0.78 +25*0.30= GH₵114.30

(d) Solution of Night Solid Waste Collection Model (ZL)

The load schedule for the night collection for ZL as seen in table 20 is not entirely different from what is said about WMD since it will also be a better option than the day collection.

Table 20: Solid waste allocation within the ZL Night model

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		3.48	15	2.32		2.61	15
Central market (C)	10	3.19		2.61	5	2.32	15
Hill top (H)	10	3.77	1	2.90		2.90	11
Kalpohini (K)		2.61		4.06	10	1.45	10
Total	20		16		15		51

Z=15*2.32+10*3.19+5*2.32+10*3.77+1*2.90+10*1.45=GH₵133.40

(3)Vogel's Approximation Method (VAM)

This initial feasible solution approach is chosen for this piece of research due to the following reasons: generally, it produces better solutions; it yields an optimum or close to optimum starting solution; the amount of time required to arrive at the optimum solution is greatly reduced in order to reduce large number of steps required to obtain the optimal solution, it is advisable to proceed with the initial feasible solution which is close to the optimal solution. Vogel's method often gives the better initial feasible solution to start with. It reduces the time in reaching the optimal solution.

Concept of Minimizing the Opportunity Cost: In this method, we use concept of opportunity cost. *Opportunity cost is the penalty for not taking correct decision*. To find the row opportunity cost in the given matrix, deduct the smallest element in the row from the next highest element. Similarly to calculate the column opportunity cost, deduct smallest element in the column from the next smallest element. Write row opportunity costs of each row just by the side of available constraint and similarly write the column opportunity cost of each column just below the requirement constraints. These are known as penalty column and penalty row. The rationale in deducting the smallest element from the next smallest element is explained using table 20.

From table 20, row two the smallest element is 2.32 and the next highest element is 2.61. If we transport one unit (a ton of solid waste) through the cell having cost GH₵2.32 the cost of transportation per unit will be GH₵2.32, Instead we transport through the cell having cost of GH₵2.61 then the cost of transportation will be GH₵2.61 per unit. That is for not taking correct decision, we are spending GH₵0.29 more (GH₵2.61-2.32=0.29). This is the penalty for not taking correct decision and hence the opportunity cost. If the smallest element is 2.90 and the row having one more 2.90 as in row three, then we have to take next smallest element as 2.90 and not any other element. Then the opportunity cost will be zero, this applies to any column with the same characteristics. In general, if the row has two elements of the same magnitude as the smallest element then the opportunity cost of that row or column is zero. If any empty cell has zero as its opportunity cost, then we can write alternate optimal solution. The following operation validated or confirmed the choice of **Vogel's Approximation Method** for this piece of work or thesis. This is done by finding the Initial Feasible Solution (**IFS)** of the sample model of the **ZL FOR DAY COLLECTION** using the various methods available (North-West corner, Row-Minima, Column- Minima, Matrix-Minima or Least cost or inspection Method) and compares their IFS with the **VAM**

(4) North-West corner method

The major disadvantage of this method is that it is not sensitive to costs and consequently yields poor initial solutions even though it is easy to apply. The steps involved in determining an initial solution using north–west corner rule will yield the results in table 21:

Table 21: Results of North-West corner method

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)	15	5.16		3.44		3.87	15
Central market (C)	5	4.73	10	3.87		3.44	15
Hill top (H)		5.59	6	4.30	5	4.30	11
Kalpohini (K)		3.87		6.02	10	2.15	10
Total	20		16		15		51

IFS=15*5.16+5*4.73+10*3.87+6*4.30+5*4.30+10*2.15=GH₵208.55

(5) Row Minima Method

In this method, allocations are made on the basis of lower cost along the rows. The steps involved in determining an initial solution using Row-Minima Method will provide the following results:

Table 22: Results of Row Minima Method:

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		5.16	15	3.44		3.87	15
Central market (C)		4.73	1	3.87	14	3.44	15
Hill top (H)	10	5.59		4.30	1	4.30	11
Kalpohini (K)	10	3.87		6.02		2.15	10
Total	20		16		15		51

IFS=15*3.44+1*3.87+14*3.44+10*5.59+1*4.30+10*3.87= GH₵202.53

(6) Column-Minima Method

In this method, allocations are made on the basis of lower cost along the column. The steps involved in determining an initial solution using Column-Minima Method will give rise to the following results:

Table 23: Results of Column-Minima Method:

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		5.16	15	3.44		3.87	15
Central market (C)	10	4.73	1	3.87	4	3.44	15
Hill top (H)		5.59		4.30	11	4.30	11
Kalpohini (K)	10	3.87		6.02		2.15	10
Total	20		16		15		51

IFS=15*3.44+10*4.73+1*3.87+4*3.44+11*4.30+10*3.87=GHC202.53

(7) Least Cost Method

In this method, allocations are made on the basis of economic desirability. The steps involved in determining an initial solution using least-cost method will yield the following results:

Table2 4: Results of Least Cost Method:

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		5.16	15	3.44		3.87	15
Central market (C)	9	4.73	1	3.87	5	3.44	15
Hill top (H)	11	5.59		4.30		4.30	11
Kalpohini (K)		3.87		6.02	10	2.15	10
Total	20		16		15		51

IFS=15*3.44+9*4.73+1*3.87+5*3.44+11*5.59+10*2.15=GH₵198.23

Considering the IFS of tables 21, 22, 23 and 24 of the same balanced minimization transportation problem (ZL DAY MODEL) of costs GH₵208.55; GH₵202.53; GH₵202.53 and GH₵198.23 respectively; it was prudent to fall on VAM which has the IFS of GH₵197.80, this value is the optimal solution of the solved model. It can be seen that the VAM offers the best routes for the solid waste Transportation.

5.7 Optimality Test:

If the basic feasible solution for a transportation problem is obtained, the next duty is to test whether the solution obtained is an optimal one or not. This is done using **MODI.**

The reason for which **MODI** is used in this research to test the optimality has already been spelt out in chapter Three.

In stepping stone method, to get the opportunity cost of empty cells; for every cell we have to write a loop and evaluate the cell, which is a laborious process. In MODI, we can get the opportunity costs of empty cells without writing the loop. After getting the opportunity cost of all the cells, the cell with highest positive opportunity cost had selected and included in the modified solution. From all indications, the VAM method is the best for finding the basic feasible solution and Modified Distribution Method is better than Stepping Stone Method in finding the optimal solution.

5.8 Comparing the WMD and ZL Models

(1)Day Collection of Solid Waste:

Considering the day collection of the solid waste by both WMD and ZL it would be safe to say that the former can manage the solid waste better than the later, even though transportation of solid waste is one component of the solid waste management. Their transportation abilities have reflected in the amount of solid waste they were able to clear daily, which is 175 tons of solid waste was cleared using only GH₵383.94. In the case of ZL an amount of GH₵977.03 was spent on the transportation of 51tons of solid waste in a day.

(2) Night collection of solid waste:

Currently WMD and ZL as the only institutions that transport solid waste from the final collection sites to final disposal sites do so in the day time only, but the thesis has come out with night models to take care of the future with the anticipation that the human population of the Metropolis may increase, there may be a change in the life styles of the dwellers of the Metropolis and increase in the production of solid waste, the people may buy more vehicles which can increase the traffic jam menace. These menaces of traffic jam include tear and wear of vehicles, increase in fuel consumption and increase in the time for transportation. There is a free flow of traffic in the night than in a day time and the night models may aid reduce the transportation cost of solid waste. As at now about one hour thirty minutes (1hr.30min.) is used to transport the solid waste due to the traffic jam and about fifty (50) speed rumps on the way to the final disposal sites, less of the time may be used to the reinforcing P1 and P2.The researcher found out that one hour (1hr) could be used in the night time instead of 1:30 min. when he used his motor bike to ascertain the reality in the day and night times and therefore the night models were of necessity.

5.9 Comparing the Day Models to the Night Ones:

Comparing the day and night model of WMD, it was realized that the amount of money (GH₵171.45) that determined the best routes in transporting 175 tons of solid waste in a day would be reduced to GH₵114.30 if the night model was adopted to clear the same quantum of waste. The extra money could be used to haul more solid waste and this could increase the percentage (%) of solid waste that is transported on daily bases. The story was not different in the case of ZL. The total amount of money (GH₵197.80) that determined the best routes in transporting 51tons of solid waste daily would be reduced to GH₵133.40 upon adoption of the night model to clear the same quantity of solid waste. It is obvious from the analysis that if the current prevailing conditions have changed and the night models are used there would be improvement in the frequency and efficiency of the solid waste transportation as a component of solid waste management.

5.10 Interpreting Results from the Answer and Sensitivity Reports of Microsoft Excel Solver Solutions

From the answer report of ZL Model as example(see Appendix B), it can be seen that the optimal value (final value) for the cost is GH₵197.8 while the values of C_{11},C_{12},C_{13},C_{21},C_{22},C_{23},C_{31},C_{32},C_{33},C_{41},C_{42} andC_{43} for which the above-mentioned cost was realized were 0,3.44,0,6.45,0,0,6.02,0,0,0,0 and 2.15 Ghana cedis respectively. For the constraints, notice that constraint 1, 2, 3 and 4 had slacks of Zero. Slack variables basically represent idle or unused resources which can be referred to as the unused RHSs (Right Hand Sides) of the constraints. A binding constraint may be defined as one with a slack of zero. In other words binding constraints are constraints whose RHSs are all used up after the allocations to the various decision variables have been made. The status for all the constraint were binding because; the original values of their RHS were the same values after the allocations to the decision variables had been made; all available resources were used up in the day.

From the sensitivity report the allowable increase/decrease columns tell us that, provided the coefficient of c_{12} in the objective function lies between 15+(1E+30) and 15-(1E+30) the values of the variables in the optimal Linear Programming (LP) solution will remain unchanged. Note that the actual optimal solution value will change as the objective function coefficient of it is changing.

The column containing the reduced cost shows by how much the objective function value would change if say, a decision variable that had no allocation being made to it was forced to have some allocation.

The shadow price tells us exactly how much the objective function will change if we change the RHS of the corresponding constraint within the limits given in the allowable increase/decrease columns.

5.11 Summary

Night collection of solid waste in the Metropolis will be a better option since it is capable of reducing fuel consumption, minimizing tear and wear and can influence the frequency of collection positively. The excel solver produced answer report, sensitivity report and limits reports.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

Transportation of solid waste is a key component of solid waste management. The transportation of solid waste was binding on the two institutions (WMD and ZL Ghana Ltd). This thesis sought to cut down the cost of transporting solid waste from the final collection site to the final disposal site and this was achieved by establishing models for effective and efficient transportation.WMD used GH₵ 383.94 and in the model they would use GH₵171.45 which is 45% of GH₵ 383.94 resulting in 55% cost decrease. What this meant is that in a day, they might be able to save a cost of GH₵ 212.49. Some of the data collected through primary means from WMD and ZL were used to set up the models.

6.2 Summary of Key Findings

(1) The Transfer Stations (Final Collection Sites)

These were places where activities associated with the transfer of wastes from the smaller collection vehicles to the larger transport equipment and the subsequent transport of the wastes usually over a long distance to the disposal site took place. Scavenging and reuse though informal were some of the techniques used to reduce quantity of solid waste. The other is disposal which dealt with those activities associated with ultimate disposal of solid wastes including those waste collected and transported directly to a landfill site. The gathering of solid waste at the transfer station was to ensure effective solid waste collection and ultimate reduction of its transportation cost. Therefore the provision of adequate dustbins and skips for the areas could prevent indiscriminate dumping of waste thus promoting the effective and efficient use of the transfer stations.

(2) Basic Feasible Solutions and Optimal Cost

Vogel's Approximation Method (VAM) was chosen over other methods mentioned earlier to find the basic feasible solution because of its ability to get one closer to the optimal solution than the others. The Modified Distribution Method (MODI) was also chosen over the Stepping Stone Method because of its ability to evaluate the opportunity cost of the empty/unloaded cells collectively instead of finding the loop of every empty cell for evaluation of its opportunity cost. The basic feasible solutions from best alternative routes of the various set up models which were tested for optimality using the **MODI** are GH¢171.45 and GH¢114.30 for day and night collection respectively for WMD and GH¢197.80 and GH¢133.40 for day and night collection respectively for ZL. The efficiency of the use of **VAM** and **MODI** in solving transportation problems has actually been proven with those figures. **Any attempt to alter the loaded cells and for that matter changing the suggested routes might increase the transportation cost.**

(3) Final Disposal

The landfill did not meet the requirement of a sanitary landfill and therefore could be described as an ordinary open dump. Despite the fact that the landfill had a weighbridge, gas recovery system, leachate collection system, they were not functioning. The landfill too had no internal access and also cited near a settlement. Additionally, solid waste was not usually separated into their various components before final disposal unless informally (eg.scavenging); this activity could reduce the volume of solid waste to reduce the cost of transportation. In the end some valuable resources in the landfill which could have been otherwise re-used got buried. The burning of waste also occurred in the landfill which was totally unacceptable and this could reduce the frequency of solid waste transportation as time would be spent in controlling the fire before new arrivals of waste could be entertained.

6.3 Conclusion

The WMD as at the time of data collection was spending about three hundred and eighty three Ghana cedis ninety four pesewa (GH¢ 383.94) a day and ZoomLion was spending nine hundred and seventy seven Ghana cedis three pesewa (GH¢977.03) a day. By the research, the WMD would be spending about one hundred and seventy one Ghana cedis, forty five pesewa (GH¢171.45) a day and ZL would be spending about one hundred and ninety seven Ghana cedis, eighty pesewa (GH¢197.80) a day. Thus by implementing the findings of this research the WMD and ZL will reduce the cost on waste collection in the metropolis by 55% and 80% respectively. The average percentage cost reduction for both institutions in the metropolis is 73%.The night models which will reduce the cost of transportation of solid waste by 70 % (for WMD) and 86 % (for ZL) is recommended for future use.

6.4 Recommendations

The findings of this research have called for certain measures that are to be recommended to the waste management institutions in order to improve upon the efficiency within the framework of the transportation system. These measures, no doubt, would aid in cutting down the cost of transportation when adhered to. These recommendations are:

(1)The Hauling Trucks

The skip and Roll-on Roll-off trucks with capacity 4.1tonnes are recommended in executing the prescribed work of the models so that they will always load the vehicles to their maximum capacities for the attainment of high loading efficiency in contrast to those trucks with higher capacities which are likely to move without being full, which could increase the cost of transportation.

(2) The quantity of solid waste generated and cleared a day

It was estimated that 240-260 tons of waste was generated a day in the management area of WMD in the Tamale metropolis and out of this, about 70% were hauled daily. This left a backlog of 30% uncollected a day. Within the management area of ZL, about 110-115 tons of waste was generated a day and about 46% were hauled daily. This left a backlog of about 54%. This deficit led to littering, heaping of waste and overflowing of skips. Adequate dustbins and skips should be provided by ZoomLion Ghana Ltd. in collaboration with the WMD and Metropolitan Assembly for residents in the Metropolis for waste storage. This should be provided particularly for the low and middle class residential areas to avoid dumping of waste in open spaces, gutters, boilers and roadside.

With this, residents will spend less time to dispose of their domestic waste at the skip site. These measures will ensure that solid waste generated a day can be controlled and managed to the skips and to the places of final collection and disposal. This can minimize the causes and spread of diseases such as malaria, cholera, typhoid and other sanitation related diseases.

(3) Cost of Transportation of Solid Waste

The high cost of solid waste transportation has called for certain financial and managerial interventions. The waste management institutions should be adequately resourced by the Metropolitan Assembly to ensure efficient and effective waste management in general and solid waste transportation in particular. The Metropolitan Assembly should liaise with other corporate bodies like the United Nations Development Program (UNDP) as well as the sister city in the United States (US) to pull financial resources to support the institutions in charge of managing solid waste especially the ZoomLion Ghana Ltd. With the support, adequate dustbin, skips and core waste management equipment such as compaction trucks, roll on/roll off trucks, skip loaders would be purchased to ensure effective waste collection, transportation and disposal. Currently there is an NGO called Deco in the Metropolis that is using some of the waste to generate manure for farmers at subsidized prices. This should be encouraged and supported by the assembly and other NGOs so that it can help cut down the tonnage of waste that are to be transported and this could cut down cost of transportation. By-laws should be instituted in the Metropolis for the people, particularly those in low class residential areas to pay instantly for careless dumping of solid waste. Also 'pay as you throw principle' should be introduced. All these should be done through education by letting residents know the importance of environmental cleanliness and how they can contribute to it. This will go a long way to support the financial base of the waste management institutions so that the transportation sector will get some managerial improvement.

(4) Regular Collection of Solid Waste Generated

There should be regular solid waste collection by ZoomLion Ghana Ltd and WMD, especially in highly populated areas like Sabongida, Moshi Zongo, kalpohini, Choggu etcetera and public places like Aboabo market, Central market, and victory cinema to avoid heaping of waste and over flowing of skips with solid waste. There should be regular monitoring of waste collection by the Metropolitan Assembly. This will keep the place constantly clean and prevent any possible outbreak of communicable diseases. The transfer stations should have the operational capacities such that the collection vehicles do not have to wait too long to load, so that fuel consumption will be minimal. The station should be at places within easy access. It should also be at places where its construction and operations will be most economical. All this suggested characteristics would improve upon the frequency of collection as well as proper loading for the final disposal hence effective use of the limited financial resources when considered.

5) Provision of adequate resources

Resources such as transfer stations, landfill site, vehicles, equipment and able transportation management team are needed to ensure effective and efficient transportation of solid waste to the disposal site.

The landfill site as one of the resources should be properly managed to avoid heaping and burning of waste. The following should be revived for the landfill to work effectively: the weighbridge, gas recovery system and leachate collection system. With the weighbridge the quantity of waste that goes into the landfill can be easily determined. With proper leachate system put in place the possibility of waste polluting groundwater in the area will be prevented. Also, waste dumped in the landfill should be spread, compacted and covered with soil within the shortest possible time. This will prevent heaping of waste in the landfill. Additionally, the landfill management should ensure that waste that is carried to the landfill does not contain fire. Any container that contains fire should be isolated and fire quenched before dumping is done. This will go a long way to prevent the burning of waste in the landfill. The Environmental Protection Agency (EPA) which is the regulatory authority on sanitation should ensure routine monitoring of management of the landfill site. The landfill site in the near future should also be relocated because of its negative environmental impact on the lives of people in a nearby community (Wovuguma). The relocation will prevent the community from being constantly engulfed by smoke from the landfill. This will also prevent the possible percolation of the hazardous waste from polluting water sources of the community. The site should have a useful life greater than 1 year. When all these are instituted, the landfill will be effectively used and its life span will be prolonged. Moneys could be reserved to carry more waste to the disposal site if the landfill site is managed well instead of constructing new ones that would cost a lot of money due to misuse of the facility.

It is also important to provide adequate storage facilities, auxiliary machines at the transfer stations to ease collection process, and to invest in the transportation system to promote efficiency of solid waste transportation.

(6) Models adoption

The various models put up in the thesis are also recommended for the waste management institutions if they want to cut down cost of solid waste transportation. The night models for instance will be a better option. These when adopted could save a huge sum of money which could be used to clear more waste and keep the environment clean and safe. The optimal routes that are suggested in the models should be adhered to. This can help reduce the cost of transportation.

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APPENDICES

APPENDIX A

Working Details of the Models

A1: Unit Transportation Cost Computation

The unit transportation cost (**c_{ij}**) per ton of refuse being hulled from point *i* to a destination *j* is given by the formula below:

$$c_{ij} = \frac{(a + bs + C_{nc} + I_{in})\, d_{ij}}{T_{w*}V_a}[ton^{-1}]$$

Where

a= cost of using bulldozer to load collection trucks per day

b=Capital Recovery factor (CRF) of collection truck

s=capacity of collection truck

c_{nc} =Average salary of driver and labourer on truck per day

I_{in}=Incentives given to driver and labourer on truck

d_{ij} =Average distance between collection and disposal points

v_a= Average speed of collection truck

T_w=quantity of waste cleared /day

CRF is a decimal whose value is equal to one minus the percentage depreciation [1-% depreciation in the value of collection truck] Nelson (2002, 57). This is seen in table A1:

Table A1: Percentage depreciation and CRF.

Truck	Purchased price	Useful life in years	depreciation of useful life	%depreciation in the value of useful life	CRF
skip truck	66500	6	9975	15	0.85
Roll-on Roll-off truck	66500	6	9975	15	0.85

A2: WMD Model (Day)

$$\mathbf{c_{ij}} = \frac{(a + bs + C_{nc} + I_{in})\, d_{ij}}{T_{w*}V_a} \,[\text{ton}^{-1}]$$

a=GH¢74.99;s=4.1tons;b=CRF=0.85;c_{nc}=GH¢15.78;I_{in}=GH¢20;T_w=175tons;v_a=7.22km/h

d_{ij}/km= 14,8,8,13,9,7,12,11,6,13,10,5.Example,if a truck is to carry a load from T_1 to L, d_{ij} will be14km hence $\mathbf{c_{ij}}$=(74.99+0.85*4.1+15.78+20)14/(175*7.22)= GH¢1.26

Table A2: Calculating the opportunity cost (OP) for each row(R) and column(C):

From/To	Landfill Site	Pit_1	Pit_2	Total/tons	COC
T_I	1.26	0.72	0.72	50	0
T_2	1.17	0.81	0.63	50	0.18
T_3	1.08	0.99	0.54	40	0.45
T_4	1.17	0.90	0.45	35	0.45
Total/tons	120	30	25	175	
ROC	0.09	0.09	0.09		

Table A3: Solid waste allocation schedule:

From/To	Landfill Site	Pit_1	Pit_2	Total/tons
T_I	20 1.26	30 0.72	0.72	50
T_2	50 1.17	0.81	0.63	50
T_3	40 1.08	0.99	0.54	40
T_4	10 1.17	0.90	25 0.45	35
Total/tons	120	30	25	175

IFS (Z_w) =20*1.26+30*0.72+50*1.17+40*1.08+10*1.17 +25*0.45= GH₵171.45

Optimum test:

Calculation of nominal D and R cost per ton of loaded cells;

D (T_1) + R (L) =**1.26**; D (T_1) + R (P_1) =**0.72**; D (T_2) + R (L) =**1.17**; D (T_3) +R (L) =**1.08**; D (T_4) + R (L) =**1.17**; D (T_4) + R (P_2) =**0.45**

If D(T_1)=**0** then R(L)=**1.26**;D(T_2)=**-0.09**;D(T_3)=**-0.18**;

D (T_4) = 0.09; R (P_1) =0.72; R (P_2) =0.54

Calculation of shadow cost of the empty cells:

D (T1) +R (P2) =0+0.54 =**0.54**; D (T_2) +R (P_1) =-0.09+0.72=**0.63**; D (T_2) +R (P_2) =**0.45**

D (T_3) + R (P_1) =**0.54**; D (T_3) + R (P_2) =**0.36**; D (T_4) + R (P_1) =**0.63**

Empty cell	AC-SC=+Cost increase -Cost decrease
T_1:P_2	0.72-0.54= +0.18
T_2:P_1	0.81-0.63= +0.18
T_2:P_2	0.63-0.45= +0.18
T_3:P_1	0.99-0.54= +0.45
T_3:P_2	0.54-0.36= +0.18
T_4:P_1	0.90-0.63=+0.27

With the results obtained it means that no cost reduction is possible hence the solution is optimum.

A3 ZoomLion Model (Day)

ZoomLion is a well established private waste management unit that manages most of the suburbs in the Metropolis. The quantity of waste produce in their area of operation is less than the waste produce in the area being managed by WMD. Table A4 displays the distance in km from the collection sites (A, C, H, and K) to the disposal sites (L, P_1, P_2); the quantity of waste in tons hauled from each clearing site as well as the total waste in tons received at the final disposal sites.

(1)Finding Basic Feasible Solution

Table A4: distances in km and totals of solid waste in tons

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	12km	8km	9km	15
Central market (C)	11km	9km	8km	15
Hill top (H)	13km	10km	10km	11
Kalpohini (K)	9km	14km	5km	10
Total/tons	20	16	15	51

Cost of per ton of solid waste in the following table from the various final collection site to the disposal sites:

Table A5: Cost of per ton of solid waste

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo (A)	GH¢5.16	GH¢3.44	GH¢3.87	15
Central market (C)	GH¢4.73	GH¢3.87	GH¢3.44	15
Hill top (H)	GH¢5.59	GH¢4.30	GH¢4.30	11
Kalpohini (K)	GH¢3.87	GH¢6.02	GH¢2.15	10
Total/tons	20	16	15	51

Table A6: Calculation of opportunity cost of column and row:

From\To	Landfill site(L)	Pit1	Pit2	Total	COC
Aboabo(A)	5.16	3.44	3.87	15	0.43
Central market (C)	4.73	3.87	3.44	15	0.43
Hill top (H)	5.59	4.30	4.30	11	0
Kalpohini (K)	3.87	6.02	2.15	10	1.75
Total	20	16	15	51	
ROW	0.86	0.43	1.29		

Table A7: solid waste allocation schedule:

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		5.16	15	3.44		3.87	15
Central market (C)	10	4.73		3.87	5	3.44	15
Hill top (H)	10	5.59	1	4.30		4.30	11
Kalpohini (K)		3.87		6.02	10	2.15	10
Total	20		16		15		51

The initial feasible solution is:

Minimum cost (Z_I) =15*5.16+ 10*4.73+5*3.44+10*5.59+1*4.30+10*2.15=GH¢197.80

(2) OPTIMALITY TEST

Calculation of nominal D and R cost of loaded cells;

D (A) + R (P1) =3.44; D (C) + R (L) =4.73; D (C) + R (P2) =3.44; D (H) +R (L) =5.59;

D (H) + R (P1) = 4.30; D (K) + R (P2) =2.15

Set D (A) at zero to find other values:

Therefore(PI)=**3.44**; D(C)=**0**;R(P2)=**3.44**; R(L)=**4.73**; D(H)=**0.86**; D(K)=**-1.29**

Using the calculated values to calculate the shadow cost (SC) of the non- loaded cells:

The non-loaded cell are: A: L, A: P2, C: P1, H: P2, K: L, K: P1

D (A) + R (L) =0+4.73=**4.73**

D (A) +R (P2) =0+3.44=**3.44**

D (C) + R (P1) =0+3.44=**3.44**

D (H) + R (P2) =0.86+3.44=**4.3**

D (K) + R (L) =-1.29+4.73=**3.44**

D (K) + R (P1) =-1.29+3.44=**2.15**

Empty cell/A C – SC = + cost increase (↑)

-cost reduction (↓)

A:L/AC-SC=5.16-4.73**=+0.43**

A: P2 /AC-SC=3.87-3.44**=+0.43**

C: P1/AC-SC=3.87-3.44**=+0.43**

H: P2/AC-SC=4.30-4.30**=0**

K: L/AC-SC=3.87-3.44**=+0.43**

K: P1/AC-SC=6.02-2.15**=+3.87**

All the computed values are positives indicating that any change will increase the cost hence minimum solution is obtained.**H:P2** is an indication of an alternative allocation with the same optimal solution.

A4: WMD Model (Night Collection)

Using the same procedure as the day model with the average speed of 10.33km/h (in the night there is free flow of traffic hence relative increase in speed), the calculation for the night model was obtained as follows:

$$c_{ij} = \frac{(a + bs + C_{nc} + I_{in})\, d_{ij}}{T_{w*}V_a} [ton^{-1}]$$

a=GH¢33.33; **s**=4.1tons; **b**=CRF=0.85;

c_{nc}=GH¢15.78;I_{in}=GH¢20;T_w=175tons;v_a=10.33km/h

d_{ij}/km= 14,8,8,13,9,7,12,11,6,13,10,5.Example,if a truck is to carry a load from T_1 to **L**, d_{ij} will be14km hence c_{ij} =(74.99+0.85*4.1+15.78+20)14/(175*10.33)= **GH¢0.84**

TableA8: Route schedule for WMD Night model:

From/To	Landfill Site		Pit_1		Pit_2		Total/tons
T_I	20	0.84	30	0.48		0.48	50
T_2	50	0.78		0.54		0.42	50
T_3	40	0.72		0.66		0.36	40
T_4	10	0.78		0.60	25	0.30	35
Total/tons	120		30		25		175

IFS (Z_{wn}) =20*0.84+30*0.48+50*0.78+40*0.72+10*0.78 +25*0.30= **GH₵114.30**

A.5: ZoomLion Night Model:

Table A9: Distance in km from transfer stations to the disposal sites

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	12km	8km	9km	15
Central market (C)	11km	9km	8km	15
Hill top (H)	13km	10km	10km	11
Kalpohini (K)	9km	14km	5km	10
Total/tons	20	16	15	51

Table A10a: cost of transferring 1ton to each disposal site

From\To	Landfill site	Pit1	Pit2	Total/tons
Aboabo(A)	GH¢3.48	GH¢2.32	GH¢2.61	15
Central market (C)	GH¢3.19	GH¢2.61	GH¢2.32	15
Hill top (H)	GH¢3.77	GH¢2.90	GH¢2.90	11
Kalpohini (K)	GH¢2.61	GH¢4.06	GH¢1.45	10
Total/tons	20	16	15	51

Table A 10b: unit cost of each route used

From\To	Landfill site(L)	Pit1	Pit2	Total
Aboabo(A)	3.48	2.32	2.61	15
Central market (C)	3.19	2.61	2.32	15
Hill top (H)	3.77	2.90	2.90	11
Kalpohini (K)	2.61	4.06	1.45	10
Total	20	16	15	51

TableA11: loads indicating optimal routes:

From\To	Landfill site(L)		Pit1		Pit2		Total
Aboabo(A)		3.48	15	2.32		2.61	15
Central market (C)	10	3.19		2.61	5	2.32	15
Hill top (H)	10	3.77	1	2.90		2.90	11
Kalpohini (K)		2.61		4.06	10	1.45	10
Total	20		16		15		51

Z_{ln}=15*2.32+10*3.19+5*2.32+10*3.77+1*2.90+10*1.45=**GH₵133.40**

APPENDIX B

MICROSOFT EXCEL SOLVER RESULSTS

Answer, sensitivity and limits Report ZL. Model (Day)

Microsoft Excel 12.0 Answer

Report

Worksheet: [Book1]Sheet1

Report Created: 12/26/2012 6:32:49 PM

Target

Cell(Min)

Cell	Name	Original Value	Final Value
$B$20	Cost	0	197.8

Adjustable

Cells

Cell	Name	Original Value	Final Value
$C$16	$Variablec_{11}$	0	0
$D$16	$Variablec_{12}$	0	3.44
$E$16	$Variablec_{13}$	0	0
$F$16	$Variablec_{21}$	0	6.45
$G$16	$variablec_{22}$	0	0
$H$16	$Variablec_{23}$	0	0
$I$16	$Variablec_{31}$	0	6.02
$J$16	$Variablec_{32}$	0	0
$K$16	$Variablec_{33}$	0	0
$L$16	$Variablec_{41}$	0	0

$M$16	Variablec_{42}	0	0
$N$16	Variablec_{43}	0	2.15

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$O$8	A	51.6	$O$8=$Q$8	Binding	0
$O$9	C	64.5	$O$9=$Q$9	Binding	0
$O$10	H	60.2	$O$10=$Q$10	Binding	0
$O$11	K	21.5	$O$11=$Q$11	Binding	0

Microsoft Excel 12.0 Sensitivity Report

Worksheet: [Book1]Sheet1

Report Created: 12/26/2012 6:32:50 PM

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$C$16	Variablec_{11}	0	0	0	1E+30	0
$D$16	Variablec_{12}	3.44	0	15	1E+30	1E+30
$E$16	Variablec_{13}	0	0	0	1E+30	0
$F$16	Variablec_{21}	6.45	0	10	0	1E+30
$G$16	Variablec_{22}	0	0	0	1E+30	0
$H$16	variablec_{23}	0	0	5	1E+30	0
$I$16	variablec_{31}	6.02	0	10	0	1E+30
$J$16	Variablec_{32}	0	0	1	1E+30	0
$K$16	Variablec_{33}	0	0	0	1E+30	0
$L$16	Variablec_{41}	0	0	0	1E+30	0

$M$16	Variablec_{42}	0	0	0	1E+30	0
$N$16	Variablec_{43}	2.15	0	10	1E+30	1E+30

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$O$8	A	51.6	1	51.6	1E+30	51.6
$O$9	C	64.5	1	64.5	1E+30	64.5
$O$10	H	60.2	1	60.2	1E+30	60.2
$O$11	K	21.5	1	21.5	1E+30	21.5

Microsoft Excel 12.0 Limits Report

Worksheet: [Book1]Limits Report 1

Report Created: 12/26/2012 6:32:50 PM

Cell	Target Name	Value
$B$20	Cost c_{11}	197.8

Cell	Adjustable Name	Value	Lower Limit	Target Result	Upper Limit	Target Result
$C$16	Variablec_{11}	0	0	197.8	#N/A	#N/A
$D$16	Variablec_{12}	3.44	3.44	197.8	3.44	197.8
$E$16	Variablec_{23}	0	0	197.8	#N/A	#N/A
$F$16	Variablec_{21}	6.45	6.45	197.8	6.45	197.8
$G$16	Variablec_{22}	0	0	197.8	#N/A	#N/A
$H$16	Variablec_{23}	0	0	197.8	0	197.8
$I$16	Variablec_{31}	6.02	6.02	197.8	6.02	197.8

\$J\$16	Variablec_{32}	0	0	197.8	0	197.8
\$K\$16	Variablec_{33}	0	0	197.8	#N/A	#N/A
\$L\$16	Variablec_{41}	0	0	197.8	#N/A	#N/A
\$M\$16	Variablec_{42}	0	0	197.8	#N/A	#N/A
\$N\$16	Variablec_{43}	2.15	2.15	197.8	2.15	197.8

Answer, Sensitivity and Limits Report for WMD Model (Day)

Microsoft Excel 12.0 Answer Report

Worksheet: [Book1]Sheet1

Report Created: 12/30/2012

3:41:43PM

Target Cell (Min)

Cell	Name	Original Value	Final Value
\$B\$20	cost c_{11}	0	171.5

Adjustable Cells

Cell	Name	Original Value	Final Value
\$C\$16	Variable c_{11}	0	0
\$D\$16	variable c_{12}	0	1.633333333
\$E\$16	Variable c_{13}	0	0
\$F\$16	Variable c_{21}	0	0.98
\$G\$16	Variable c_{22}	0	0
\$H\$16	variable c_{23}	0	0
\$I\$16	Variable c_{31}	0	0.98
\$J\$16	Variable c_{32}	0	0
\$K\$16	variable c_{33}	0	0

$L$16	Variable c_{41}	0	0
$M$16	Variable c_{42}	0	0
$N$16	Variable c_{43}	0	1.372

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$O$6	T1	49	$O$6=$Q$6	Binding	0
$O$7	T2	49	$O$7=$Q$7	Binding	0
$O$8	T3	39.2	$O$8=$Q$8	Binding	0
$O$9	T4	34.3	$O$9=$Q$9	Binding	0

Microsoft Excel 12.0 Sensitivity Report

Worksheet: [Book1]Sheet1

Report Created: 12/30/2012 3:41:44 PM

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$C$16	variable c_{11}	0	0	20	1E+30	0
$D$16	variable c_{12}	1.633333333	0	30	0	1E+30
$E$16	variable c_{13}	0	0	0	1E+30	0
$F$16	variable c_{21}	0.98	0	50	1E+30	1E+30
$G$16	variable c_{22}	0	0	0	1E+30	0
$H$16	variable c_{23}	0	0	0	1E+30	0
$I$16	variable c_{31}	0.98	0	40	1E+30	1E+30
$J$16	variable c_{32}	0	0	0	1E+30	0
$K$16	variable c_{33}	0	0	0	1E+30	0
$L$16	variable c_{41}	0	0	10	1E+30	0
$M$16	variable c_{42}	0	0	0	1E+30	0

$N$16	variable c_{43}	1.372	0	25	0	1E+30

Constraint

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$O$6	T1	49	1	49	1E+30	49
$O$7	T2	49	1	49	1E+30	49
$O$8	T3	39.2	1	39.2	1E+30	39.2
$O$9	T4	34.3	1	34.3	1E+30	34.3

Microsoft Excel 12.0 Limits Report

Worksheet: [Book1]Limits Report 1

Report Created: 12/30/2012 3:41:44 PM

Cell	Target Name	Value
$B$20	cost c_{11}	171.5

Cell	Adjustable Name	Value	Lower Limit	Target Result	Upper Limit	Target Result
$C$16	variable c_{11}	0	0	171.5	0	171.5
$D$16	variable c_{12}	1.633333333	1.633333333	171.5	1.633333333	171.5
$E$16	variable c_{13}	0	0	171.5	#N/A	#N/A
$F$16	variable c_{21}	0.98	0.98	171.5	0.98	171.5
$G$16	variable c_{22}	0	0	171.5	#N/A	#N/A
$H$16	variable c_{23}	0	0	171.5	#N/A	#N/A
$I$16	variable c_{31}	0.98	0.98	171.5	0.98	171.5
$J$16	variable c_{32}	0	0	171.5	#N/A	#N/A

$K$16	variable c_{33}	0	0	171.5	#N/A	#N/A
$L$16	variable c_{41}	0	0	171.5	0	171.5
$M$16	variable c_{42}	0	0	171.5	#N/A	#N/A
$N$16	variable c_{43}	1.372	1.372	171.5	1.372	171.5

APPENDIX C

Landfill Site

FigureC1: Weighbridge

FigureC2: Containers left to the mercy of weather by WMD at the landfill site

FigureC3: The machine for burying solid waste at the site (front view)

FigureC4: Side view

FigureC5: The dumping site

FigureC6: Another view of the Dumping site

FigureC7:The loaded vehicle on its way to the landfill