KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF DISTANT LEARNING

OPTIMIZING TRANSPORTATION COST OF SOLID WASTE

A CASE STUDY IN THE NEW JUABEN MUNICIPALITY

BY

STEPHEN MELFAH

MARCH 2012

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(B.SC. MATHEMATICS, PGDE)

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DECLARATION

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

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Head of Department	Signature	Date

DEDICATION

To my dear wife, Matilda, and children

Jeremiah and Daniel

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I would like to express my profound gratitude to God Jehovah for endowing me with strength and for surrounding me with wonderful people who in diverse ways offered assistance.

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ABSTRACT

Ridding our cities, towns and communities of filth has been one of the major concerns of various governments in Ghana. Metropolitan, Municipal and District Assemblies have the responsibility of ensuring that the populace is not engulfed with filth to the detriment of their health.

Owing to the skyrocketing prices of petroleum products and high maintenance cost of vehicles used in the collection and transportation of solid waste by Zoomlion in the New Juaben Municipality. This thesis sought to determine the number of trips each type of vehicle (skip, compactor and roll-on) used in the transportation should go per day to minimize operational cost.

The problem was formulated as an Integer Linear Programming problem and was solved using the software AMPL and the CPLEX solver.

The results show that if only one roll-on vehicle makes 14 trips per day, the expected quantum of solid waste needed to be hauled to the landfill site at Akwadum, 5km away, per day, can be achieved at a minimum cost of GH70.

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ABBREVIATIONS

AMPL	A Mathematical Programming Language
GIS	Graphic Information System
ISWN	Integrated Solid Waste Management
LIP	Linear Integer Programming
LP	Linear Programming
MSW	Municipal Solid Waste
SW	Solid Waste
SWM	Solid Waste Management

CHAPTER 1

INTRODUCTION

Chapter one will discuss the background of the study, the statement of the problem, the objectives, the methodology adopted, and the justification of the study.

1.1 Background of the Study

The New Juaben Municipality covers a land area of 110 square kilometers. It shares boundaries on the north-east with East Akim District, on the south-east with Akuapim-North District, Yilo Krobo on the east and Suhum Kraboa Coaltar on the west. In essence, the area of the land stretches from Suhyen to Okroase to Aboabo and to Akwadum. The compactness of the land size compared to the large volume of waste generated puts a tremendous responsibility on the planners of the municipality to keep refuse at the landfill site in a more hygienic condition and to manage waste efficiently.

The 2000 Population and Housing Census puts the estimated population of the municipality at 156 750 for the year 2010 (Statistical Service Department – Eastern Regional Office). Koforidua, the regional and municipal capital of the New Juaben Municipality harbors over 65% of the entire population in the district. The remaining 52 settlements have smaller population sizes which do not normally measure up to the population thresholds required for the provision of essential socio-economic services.

Household size in the municipality is 10.9 and this is the highest in the region. The New Juaben municipality has 67.1% of its inhabitants living in room(s) in compound houses which is higher than the regional average of 43.1%. The district has 11.3% of households living in separate houses. The high population density in the municipality underscores the need to manage waste properly in order to avert any health hazard.

The New Juaben Municipal Assembly has managed the waste generated in the municipality single-handedly for some decades .It was recently that the Government of Ghana embraced the idea of private companies to partake in the management of waste.

The New Juaben Municipal Assembly is one of the four municipals established under the Local Government Act 462 of 1988.The municipality was granted its present status by the Legislative Instrument (LI) 1426 of 1988.

New Juaben Municipal Assembly has contracted Zoomlion Ghana Limited to take charge of solid waste generated while the Assembly concentrates on liquid waste management. Zoomlion is a private waste management company. It started its operations in the country in 1995. Disposal of municipal solid waste in sanitary landfills is still the main waste management method employed by the New Juaben Municipal Assembly as in most municipalities in Ghana and the developing nations.

The amount of solid waste generated in the municipality is collected from various locations and transported to the only landfill site at Akwadum. The landfill site was constructed by the Assembly and commissioned in 1993 with an expected life span of 35 years. It comprises of a tipping bay and paved vehicle turning bays. The station is manned by six (6) trained staff and equipped with a bulldozer for spreading and compacting the waste dumped at the site (Technical Report, 2010).

Waste management is a major challenge to all cities and towns all over the world especially in developing countries. Waste collection and treatment in urban areas are a real concern to local governments. Following increasing ecological consciousness, not only individuals but also industrial companies have started to lend their support (Alves et al., 2010).Many districts in Ghana do not have adequate and good road infrastructure for the collection and transportation of waste generated. This has resulted in cities lagging woefully behind in terms of cleanliness. This puts the population of cities and towns in a precarious situation. Outbreaks of cholera and other preventable communicable diseases in unplanned suburbs in some cities and towns clearly underscore the connection between the proper management of waste and the health of the populace.

1.2 Statement of the Problem

Extensive commercial activities are carried out at various locations in the municipality. Mondays and Thursdays are special market days in the municipality. On these days, farmers from the outlying villages bring their farm produce to the city to sell. Also, traders from far and near bring their wares for merchandising. Apart from the main market, heavy commercial activities go on at the lorry stations, mini-bus (trotro) stations, Agatha Market near the defunct railway station, Serwaa Market opposite Tutuwa House, open spaces and on pavements. Jackson Park which has been serving as a ceremonial ground is turned into beads market on Thursdays.

Traders and tourists from various places converge at the park to buy or sell beads designed attractively in many forms.

This extensive commercialization tends to generate a lot of refuse the constituents of which include rotten and leftover food items, polythene bags, wrapper of packaged goods, rubber bottles, empty drinking cans and sachets of mineral drinking water. Ferrel and Hizlan (2001) assert that convenience packing of consumer products is one significant source of increase volume. Waste produced at these places is collected by Zoomlion at centralized locations and then transported finally to the landfill site.

About 90% of solid waste generated in the municipality is disposed off at the landfill site located at kilometer 5 on the Akwadum road. The remaining 10% is disposed off by open incineration at unauthorized dumping sites. It is approximated that 159 tons of refuse is generated daily in the municipality (Technical Report, 2010). The regional office of Zoomlion Company at Koforidua has three types of vehicles for the collection and transportation of solid waste. These are skip, compactor, and roll-on-roll-off.

One roll-on vehicle, two skip loaders and two compactors are used in conveying the waste from 45 container sites to the landfill site on daily basis. At times, owing to the frequent breakdown of the equipment, lifting some of the containers has not been regular and has resulted in accumulated and overflow of refuse at some sites.

Some of the refuse generated find their way into gutters and drains in the municipality. Zoomlion is working assiduously to maintain the city clean and tidy. In addition to the 45 containers placed at various strategic locations, Zoomlion has supplied some households with litter bins which they collect at a fee. Moreover, the company engages in curbside collection of refuse which is working out well.

The increase in fuel cost, high cost of labour and vehicle maintenance, inadequate number of operational vehicles and poor road network militate against smooth operations of Zoomlion Ghana Ltd and the Assembly. The tight budget allocation for waste management has been subjected to much stress by these problems that it is becoming increasing difficult for the institutions to face the task squarely. These institutions have predominantly depended on its experience acquired during the years on the job and the application of some scientific theories to tackle problems they encounter.

The operations of Zoomlion Ghana Ltd are in its metamorphic stages in the municipality. Even though they have relied on experts who apply some relevant scientific theories to manage waste, the application of operations research using optimization techniques is minimal or nearly non-existent.

Large chunk of municipals budget is used for the collection and the transportation of municipal solid waste .So if there is a way of minimizing the collection and transportation cost, it will go a long way to heip Assembly and Zoomlion.

1.3Objectives

One of the problems confronting the New Juaben Municipal Assembly and its contracted partners Zoomlion, is to transport solid waste generated in the municipality at a minimum cost in the midst of skyrocketing fuel and maintenance costs. The objective of the thesis is to find the optimal solution to the linear programming problem which will minimize the transportation cost by determining the number of trips each vehicle should make per day.

1.2 Methodology

The problem in this study was modeled as an Integer Linear Programming problem. In this work the Branch and Bound algorithm was used to solve the Integer Linear Programming problem. The data which is a secondary data was obtained from the office of the New Juaben Municipal Assembly and the regional office of Zoomlion Ghana Ltd. for the year 2010.

The model was solved using the software AMPL and the solver CPLEX by typing the inequalities into a file at the ampl: prompt. AMPL is a comprehensive and powerful algebraic modeling language for linear and non-linear optimization problems, in discrete or continuous variables (Fourer et al, 2003). Information was sourced from the internet, Koforidua Polytechnic Library and New Juaben Municipal Library at Koforidua.

1.3 Justification

Uncollected rubbish spilled onto the streets and into alleys due to breakdown of vehicles emitted obnoxious scent in the sweltering heat and invites flies, vultures and rodents to some nearby homes. This culminates in the increase in the incidence of cholera and malaria.

According to Jilani et al (2002), improper management of solid waste results in atmospheric and water pollution, odor nuisance and aesthetic nuisance. If this trend is not curtailed, the Ministry of Health will have to spend stupendous amount of money to treat cholera and malaria patients and this will adversely affect the economy of Ghana.

The thesis will be relevant to the New Juaben Municipal Assembly and Zoomlion Ghana Ltd. since it will furnish them with reliable decision tool. Moreover, it will benefit other researchers to identify other areas where research can be conducted.

1.6 Organization of Thesis

Chapter 1 looked at the quantum of solid waste generated in the New Juaben Municipality which has a relatively small land size but with high population density especially in Koforidua, the municipal and regional capital. It also considered the challenges the New Juaben Municipal Assembly and Zoomlion Ghana Ltd. are encountering in the collection and transportation of solid waste to the land fill site at Akwadum.

In chapter 2, researches of authors whose work have a direct bearing on how to manage solid waste and how utilizing operations research methods will optimize the transportation cost were considered. The results of their findings were critically analyzed in order have appropriate guide for this research work. In chapter 3, the methodology adopted for the thesis was considered. The problem of transporting solid waste generated in the municipality at a minimum cost was formulated as an integer programming problem. AMPL computer language tool with the CPLEX solver were used. In chapter 4, the optimal solution which was found using the computer software was analyzed and interpreted. Comparative analysis was made using the optimized results and the existing values. In chapter 5, a summary of the entire thesis work was considered and the some suggestions and recommendations were given.

1.7 Summary

It is the desire of the New Juaben Municipal Assembly and Zoomlion Ghana Ltd. to use their limited resources to manage effectively and judiciously the solid waste generated in the municipality. This is to ensure good and vibrant health for the inhabitants thereby increasing the productivity of the country. Optimization technique is a powerful tool that can be harnessed in this regard.

CHAPTER 2

LITERATURE REVIEW

Disposal of municipal solid waste is a problem commonly confronting all industrialized countries around the world and that transportation is an important component that needs to be carefully investigated (Mohd et al., 2004). According to Rathi (2007), municipal assemblies of the developing countries are not able to handle the increasing quantity of waste, which leads to uncollected waste on roads and other public places. By inference, the problem of disposing off solid waste by considering an effective way of minimizing the transportation cost in the developing countries cannot be gainsaid.

The growing concern for the greenhouse effect and the sustainability of the planet earth has engendered in various governments, well-meaning citizens and institutions, the need to manage waste efficiently. Improved advertizing techniques which have resulted in the production of attractive packaged goods and high levels of consumption of goods generate a lot of waste.

There are numerous definitions of what constitutes waste. According to the European Environmental Protection Act (1990)   "waste is any substance which constitutes scrap material any substance or article, which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled."

According to Tchobanoglous et al. (1993), the Solid Waste Management process can be commonly classified into generation, collection, storage, processing, transportation and disposal.

Waste may be categorized with respect to the source that generated it. Waste types distinguished under this classification are (i) municipal solid waste which is generated by households as well as organic waste, glass, paper and other recyclable materials, (ii) residual waste that is generated by waste treatment facilities like composting units and incineration plants, (iii) industrial waste which is generated by industrial sectors, (iv) construction waste which is generated by construction and demolition sectors, (v) contaminated soil and (vi) other wastes which is a diverse set of smaller types of categories.

In his book 'Waste Market', Dijkgfaaf (2008) wrote that Municipal Solid Waste flow accounts for about 40% of all waste that requires treatment and that this waste category presents perhaps the greatest waste management problems in the Netherlands. He also highlighted how the issue concerning waste is at the heart of many nations. He said that in 2006, he was one of the participants at a conference on Local Government Reform in Barcelona and noticed that researchers from Spain, Scandinavian countries, the UK and the USA were also studying issues concerning waste.

He asserted that in 1972, a Dutch household paid 44 euro per year on the average for the collection and treatment of waste, and in 1990, the real costs were two times higher and then in 2003 a household paid more than five times as much. Due to this sharp rise in costs, several policy measures were introduced all with the view of minimizing waste collection costs.

According to Allen et al. (2007), recent outbreaks of cholera and other preventable communicable diseases in unplanned suburbs in some cities and towns clearly demonstrate the connection between the proper management of solid waste and the health of the populace. The rapid growth of population and urbanization decreases the non-renewable resources and disposal of effluent and toxic waste indiscriminately, are the major environmental issues posing threats to the existence of humans.

According to Nishanth et al. (2010), solid waste management is a global environmental problem in today's world. The increase in commercial, residential and infrastructure development due to population growth has negative impact on the environment. Urban solid waste management is considered as one of the most serious environmental problems confronting municipal authorities in the developing countries. One of these impacts is due to location of dumping site in unsuitable areas.

Solid waste models that have been developed in the last two decades are varied in goals and methodologies. Solid waste generation prediction, facility site selection, facility capacity expansion, facility operation, vehicle routing, system scheduling waste flow and overall system operation have been some of these goals (Badran and El-Hagger, 2006).

Ghose et al. (2000) say that some of the techniques that have been used include linear programming, integer programming, mixed- integer programming, non-linear programming, dynamic programming, goal programming, grey programming, fuzzy programming, quadratic programming, stochastic programming, two-stage programming, interval-parameter programming, geographic information system.

The enormity of waste management problems facing many municipalities has resulted in the emergence of a global consensus to develop local level solutions and community participation for better Municipal Solid Waste Management. A number of studies have been carried out to compare different methods of waste disposal and processing for different places. Some researchers have riveted their attention on vehicle routing systems.

Solid waste collection routing is one of the main components of solid waste management. Agha (2006) argued that despite the fact that the collection process constitutes 74% of SWM cost, it has been given little attention. Cost reduction strategies in Solid Waste routing may include optimizing the collection routing, thus minimizing the travelled distance and travelling time. A second strategy involves minimizing the number of truck trips to landfill sites. A third strategy involves maximizing the number of fully loaded trips to the disposal sites. Using the maximum extent of the available equipment is another strategy.

Agha (2006) used mixed-integer programming model to optimize the routing system for Deir El-Balah in the Gaza Strip. The model minimized the total distance travelled by the collection vehicles. The results revealed that the application of the model improved the collection system by reducing the total by 23.4% which translated into a savings of US $1140 per month. He further argued that in spite of the fact that the collection process constitutes 74% of SWM cost, it has been given little attention.

Nuortio et al. (2006) described the optimization of vehicle routes and schedules for collecting municipal solid waste in Eastern Finland. They used a recently developed guided variable neighborhood thresholding metaheuristic method which has been adapted to solve real-life waste collection problems to generate solutions. This approached was used to study the collection of waste in two regions in Eastern Finland. The results showed that a significant change can be obtained by using this approach compared with the existing practice.

Other researchers have proposed an integrated method to solve waste management problems. Rathi (2007), who carried out his research work in Mumbai, India, argued that there is no unique method that is capable of solving the problem of waste management. He was therefore a proponent of the idea that an integrated method with the aim to minimize environmental and social costs associated with waste management is the best. He formulated a linear programming model to integrate different options and stakeholders involved in Municipal Solid Management in Mumbai. Also, he asserted that municipal assemblies of the developing countries are not able to handle the increasing quantity of waste, which leads to uncollected waste on roads and other public places.

Prawiradinata (2004) developed an analytical model to solve for optimal waste management policies in the state of Ohio, USA. In the research, an analytical model of a single landfill and integrated solid waste management were formulated as optimization models. The simple analytical model was designed using control theory to answer questions about the optimal lifespan and replacement of a landfill and about the opportunities to substitute alternative disposal methods for landfill. The ISWM model which was formulated as a mixed-integer program helped waste management authorities to plan for the long-term future of facilities and the possible implementation of recycling and composting options.

Ferrell and Hizlan (1997) asserted that constructing an integrated and coherent municipal solid waste management plan is increasingly important because both the volume of municipal solid waste and the costs associated with traditional solutions are rising at much faster rate than in the past.

Solid waste generation prediction has been the preoccupation of some researchers. A study conducted in Kuala Lumpar, Malaysia by Saeed et al. (2009) presented a forecasting study of municipal solid waste generation rate and the potential of recyclable components. The generation rates and the composition of solid wastes of various classes like street cleaning, industrial and constructional, institutional, residential and commercial were analyzed. The study showed that increased solid waste generation of Kuala Lumpar is alarming.

The attention of other researchers was captured by the escalating cost of transportation of municipal solid waste. They therefore undertook some studies that would optimize the transportation cost of solid waste generated in our communities.

Wang et al.(1995) employed mixed –integer programming to determine an optimal transportation system model for two competing transportation models for the movement of recovered paper from selected sources in the state of Iowa, USA to anticipated markets within the state and the optimum number of intermediate processing stations to minimize transportation cost. They concluded that truck transportation is the most practical mode because of its flexibility in routing and unit hauling capacity.

Jalilzadeh and Parvaresh (2004) investigated the total time spent for collection and transportation of solid waste by various types of vehicles (van, mini truck, truck FAUN and compactor) used in the city of Urmia, Iran. The result of the study illustrated that van is the most economic vehicle for solid waste collection system in Urmia city. Moreover, these authors say that more than 60% of solid waste management cost is usually allocated for the purpose of collection and transportation of generated solid waste in the city of Urmia, Iran.

An insightful study on the optimization of transportation cost of municipal solid waste was conducted by Kulcar (1996) who used operations research method with system engineering to minimize the waste transportation cost in a major urban area, Brussels. Due to the complexity of the real situation, he developed a model to consider a set of points for the collection routes. Several means of transportation were used – transportation by vehicle, rail and canal were evaluated. Collector vehicles resided overnight in depots and daily evacuated out to an incinerator.

Rhoma et al. (2009) used one of the populated cities in Germany – Duisburg in Nord-Rhine Westphalia. Municipal Solid Waste mathematical model was presented as capable of estimating the collection and the transportation cost as well as the environmental impact. The model presented a reasonably effective way to predict the fuel consumption and distance travelled for waste collection in different areas with different collection intervals within alternative network option. They contend that collection of solid waste has become more complex because of high fuel and labor cost from the total amount of money spent for collection and that 50% to 70% of the transport and disposal of solid waste was spent on collection phase. These challenge researchers to search for more efficient solid waste management methods.

Nganda (2007) proposed Integer Linear Programming and Mixed Integer Linear Programming models to tackle the problem of solid waste management at Kampala city, Uganda. The study confirmed the models to be valid and robust. The performance of the models was studied using a Hypothetical case study and other smaller models like AMPL/CPLEX. The Mixed Integer Linear Programming model was found to be more precise in measuring waste flow amounts among various modes in the model and total daily costs incurred in the management of waste. However, in the Ugandan situation where the technology to measure the amount of weight per truck is non-existent, the Integer Linear Programming model was found to be appropriate. The coefficients of the decision variables were replaced with the total cost per trip from waste collection points.

Martagan et al. (2006) conducted a study to look at the problem of transporting metal waste from 17 factories to 5 intermediate containers and finally to a disposal centre in an organized region of automobile parts suppliers in Turkey. They applied the classic mixed-integer programming model for the two-stage supply chain to minimize the transportation cost. After building the model and reaching the optimal solution for minimizing the total cost, Java program was coded in order to visualize the solution. The visualization of the optimal provided several interesting insights that would not be easily discovered otherwise.

The study conducted by Badran and El-Haggar (2005) in Port Said in Egypt had interesting results. They used operational research methodologies which had not been applied in any

Egyptian governorate to study the optimization of solid waste management system. Mixed integer programming was used to model the proposed system and the solution was performed using MPL software V4.2. The results revealed that the best model would include 27 collection stations of 15-ton daily capacity and 2 collection stations of 10-ton daily capacity. The results also showed that transfer of waste between the collection stations and landfill site should not occur. The profit generated by the proposed model was equivalent to US $8418.23.

Detofeno (2010) characterized the waste collection problem in the city of Joinville, Brazil as arcs coverage and employed the Teitz and Bart heuristics methods to obtain p-medians, adopted Gillelt and Johnson algorithms and applied Chinese Postman Algorithm to minimize the distances in the collection of waste. The application of these mathematical algorithms and computer implementation for the optimization of routes in a problem of arcs covering minimized the total distance covered daily by approximately 8.6%.

Also, Carvalho (2001) in Detofeno (2010) asserts that cleaning services absorb between 7% and15% of the resources of a municipal budget, of which 50% are used extensively to collect and transport waste and hence its optimization can lead to a significant saving of public fund.

In a study conducted in Illorin in the Kwara State of Nigeria, Ajibade(2008), used Integer Linear Programming to minimize the collection cost of solid waste. He made use of TORA Optimization model to solve an integer linear programming problem and GIS method for the location of collection containers and the optimum distribution and utilization of the vehicles in the various zones. The research suggested the introduction of smaller containers to be strategically and spatially positioned for manual collection and the relocation of some of the vehicles.

Xiangyou (1997) developed an inexact nonlinear programming and applied to municipal solid waste management planning under uncertainty. The model was applied to the planning of waste management activities in the Hamilton-Wentworth Region of Canada. The results provided decision support for the region's waste management activities and useful information for examining the feasibility and applicability of the developed methodology.

Additionally, Lu et al. (2009) were concerned about the impact of greenhouse gas emission on climate change and therefore developed an inexact dynamic optimization model which is grounded upon conventional mixed-integer linear programming approaches for the cost minimization of solid waste disposal and the mitigation of greenhouse gas emission. The results indicated that desired waste-flow patterns with a minimized system cost and greenhouse emission amount could be obtained. The proposed model could be regarded as a useful tool for realizing comprehensive municipal solid waste with regard to mitigating climate change impacts.

Apaydin and Gonullu (2007) carried out a study in Trazbon city located in the northeast side of Turkey using the shortest path model to optimize solid waste collection processes by aiming at minimum distance. To use route optimization process, data relating to spending, truck type, capacity, solid waste production, number of inhabitants and Global Positioning System receiver data for each route were collected and all the data were analyzed with each other. The results of the study had 4-59% success for distance and 14-56% for time and this eventually contributed a benefit of 24% in total cost.

Filipiak et al. (2009) conducted a study in the township of Millburn, New Jersey, USA to look at the curbside collection of municipal solid waste using operations research tools. The research work identified some network models, especially the Chinese Postman Problem algorithm as one of the approaches that could be used to calculate the truck routes and the optimum sequence of each of the vehicles needed to collect the generated waste.

Tavares et al. (2009) used Geographic Information Systems 3D route modeling software for waste collection and transportation to investigate the optimization of fuel consumption. The model was first applied to route waste collection vehicles in Praia, the capital of Cape Verde and secondly to route the transport of waste from different municipalities of Santiago Island to incineration plant. The results yielded a minimization of fuel consumption by 8% for Praia and 12% fuel reduction for Santiago Island.

Loumas et al. (2007) used Genetic Algorithm for the identification of optimal routes in the collection of municipal solid waste. They argue that approximately 60-80% of total money spent on managing solid waste is used for the collection stage and that a small percentage improvement in the collection operation can result in a significant saving in the overall cost. The municipal solid waste management system they proposed was based on geo-reference spatial database which was supported by a geographic information system that took into consideration static and dynamic data. These include the positions of waste bins, road network and related traffic, population density of the area under study, waste collection schedules, truck capacities and their characteristic

Nasserzadeh et al. (1991) employed mathematical modeling – Lagragian model, mathematical model of the finite difference type to design a number of modifications and changes in operational conditions which have a major influence on the overall performance of the large municipal solid waste incinerator plant in Sheffield, England. Calculations made from the results from the modeling work indicated significant savings about 18% in the running and maintenance costs.

Ogwueleka (2009) proposed a heuristic method to generate a feasible solution to an extended Capacitated Arc Routing Problem on undirected network, inspired by the refuse collection problem in Onitsha, Nigeria. The heuristic procedure consists of route first, cluster second method. The adoption of the proposed heuristic in Onitsha resulted in reduction of the number of existing vehicles, a 22.88% saving in refuse collection and 16.31% reduction in vehicle distance traveled per day.

Alidi and Al-Faraj (1990) developed a dynamic mixed-integer linear programming model for managing and planning the municipal solid waste systems of Dammam Metropolitan area, Saudi Arabia. The model was tested by applying it to a hypothetical municipal solid waste system. The model developed is general in structure and can be used to address other problems such as the problem of hazardous waste management, petroleum products distribution and food processing industries.

A research conducted in a small part of Attica's prefecture a suburb of Athens by Karadimas et al. (2006) used an innovative model for the estimation of urban solid waste productivity using an intelligent system based on fuzzy logic. The study considered several parameters of waste production such as population density, maximum building density, commercial traffic, area and type of shops, road network and its relative information linked with allocation of waste bins. The results showed the effectiveness of the system in the estimation process of the optimal number of waste bins in each region. The proposed system can be used as a tool by planners and decision makers in the process to estimate precisely the solid waste generation.

Chang and Wang (1996) applied multi-objective mixed integer programming techniques for reasoning the potential conflict between environmental and economic goals and for evaluating sustainable strategies for waste management in a metropolitan region in the city of Kaohsiung in Taiwan. The results provided a set of total solutions for long term waste stream allocation, siting, resource recovery and tipping fees evaluation.

Minciardi et al. (2008) modeled the problem of sustainable municipal solid waste with a non-linear, multi-objective formulation. They exemplified the application of their procedure by considering the interaction with two different decision makers that are assumed to be in charge of planning the MSW system in the city of Genova in Italy.

The foregone arguments and assertions made by the cited authors give credence to the fact that operations research methods could be employed to study the problem of optimizing the transportation cost of solid waste in the New Juaben Municipality. The results of this study could furnish decision makers and planners in the New Juaben Municipal Assembly and Zoomlion Ghana Ltd. reliable information to make prudent and sound decisions.

CHAPTER 3
METHODOLOGY

Chapter 3 will consider how a linear programming problem is formulated, sensitivity analysis, duality, simplex method and its algorithm, integer programming, and the algorithm steps for the branch and bound method.

3.1 Formulation of Linear Programming Model

According to Taha (2007), the most prominent operational research technique is linear programming. It is designed for models in which the objective function and the constraint functions are all linear. Other techniques include integer programming, dynamic programming, network programming, and goal programming.

Even though a key assumption of linear programming is that all its functions are linear, which essentially holds for numerous practical problems, it frequently does not hold. At times, the functions of the model are nonlinear. The solution methods of nonlinear programming can generally be classified as either direct or indirect algorithms. Examples of the direct methods are gradient algorithms. In the indirect methods, the original problem is replaced by an auxiliary one from which the optimum is determined. Examples of these solutions include quadratic programming, separable programming, and stochastic programming.

Linear Programming (LP) is a standard tool that has been used in recent years to save much money for many companies or businesses in the industrialized countries. LP involves the planning of activities to obtain an optimal result. The model has three basic components: .

Decision variables that we seek to determine, objective that need to optimize, and constraints that the solution must satisfy.

Most solutions of operation research techniques are usually obtained not by using a specific formula but are found by the use of algorithm. The principal phases of implementing operations research in practice include: (i) problem definition (ii) model construction (iii) solution of model, (iv) validation of model, and (v) implementation of the solution (Taha, 2007).

Problem definition is done by giving verbal summary of the problem. Here, the objective of the study is determined, the limitations under which the model operates are stated and the decision alternatives are made. The proper definition of the decision variables is an essential first step in the development of the model. Model construction entails an attempt to translate the problem defined into mathematical relationship.

A model is linear program if the objective and constraints functions are linear. This implies that the proportionality and additive properties are satisfied. The proportionality property requires that the contribution of each decision variable in both the objective function and constraints to be directly proportional to the value of the variable. Additivity requires that the objective function be the direct sum of the individual contributions of the different variables. Similarly, the left side of each constraint must be the sum of the individual usages of each variable from the corresponding resource.

The most common type of application of Linear Programming involves allocating resources to activities. Usually, the amount available for each resource is limited, but a careful allocation of resources to activities must be made. Let *m* denote the number of different kinds of resources that can be used and *n* denote the number of activities being considered, then, the mathematical model for the general problem of allocating resources to activities can be formulated as follows:

Maximize $z = c_1x_1 + c_2x_2 + \ldots\ldots + c_nx_n$

Subject to the restrictions: $a_{11}x_1 + a_{12}x_2 + \ldots\ldots + a_{1n}x_n \leq b_1$

$$a_{12}x_2 + a_{22}x_2 + \ldots\ldots + a_{2n}x_n \leq b_2$$

$$\ldots\ldots\ldots\ldots$$

$$a_{1m}x_m + a_{m2}x_2 + \ldots\ldots + a_{mn}x_n \leq b_m$$

$$x_1 \geq 0,\ x_2 \geq 0, \ldots\ldots,\ x_n \geq 0$$

The function being maximized $z = c_1x_1 + c_2x_2 + \ldots\ldots + c_nx_n$ is called the objective function. The restrictions are normally referred to as constraints. The *m* constraints with function of all variables $a_{i1}x_1 + a_{i2}x_2 + \ldots\ldots + a_{in}x_n$ on the left hand side are called functional constraints, $x_j \geq 0$, j= 1, 2, 3, ……….,n restrictions are called the non-negativity constraints (Hillier and Lieberman, 2001).

TABLE 3.1 (Resource usage per unit of activity)

Resource	Activity	Amount of resource available
1	a_{11} a_{12}……………………a_{1n}	b_1
2	a_{21} a_{22}……………………a_{2n}	b_2
.	.	.
.	.	.
.	.	.
M	a_{m1} a_{m2}……………………a_{mn}	b_m
Contribution to Z per unit of activity	c_1 c_2……………………c_n	

This model does not generally fit for all LP problems. Other legitimate forms include the following

1. Minimizing rather than maximizing of the objective function.
2. Some functional constraints with a greater-than-or –equal-to inequalities.
3. Some functional constraints are in equation form.
4. Deleting the inequality constraints for some decision variables, x_j unrestricted for some values of j.

3.2 Sensitivity Analysis

Model solution involves the use of well-defined optimization algorithms. An important aspect of the model solution phase is sensitivity analysis. It is designed to study the effect of changes in the parameters of the Linear Programming model on the optimum solution. Such analysis is regarded as an integral part of the solution of any Linear Programming problem. It gives a model a dynamic characteristic that allows a researcher to study the behavior of the optimal solution as a result of making changes in the model's parameters. The ultimate objective of the analysis is to obtain information about possible new optimum solutions corresponding to changes in the parameters with minimal additional computations.

Sensitivity analysis is useful when the values of the problem parameters are not known accurately. The ranges within which the values of the parameters can change before the optimal solution is no longer optimal give an indication of how critically the decisions implied by the optimal solution depend on the accuracy of the specified parameters. Sensitivity analysis considers the effect on the optimal solution by changing the objective function coefficients and also by changing the right hand side coefficients of the constraints. At times certain parameter values may represent managerial decisions. In this case, the choice of the parameter values may be the main issue to be studied and this can be done through sensitivity analysis.

3.3 Duality

Every Linear Programming problem called the primal has associated with it another LP problem called the dual. One of the key uses of duality theory lies in the interpretation and implementation of sensitivity analysis. Because most of the parameter values used in the original model are just estimates of future conditions, the effect on the optimal solution if other conditions prevail instead needs to be investigated.

One important application of duality theory is that the dual problem can be solved directly by the simplex method in order to identify an optimal solution of the primal problem.

If the primal problem of a Linear Programming problem is:

Maximize $z = 3x_1 + x_2 + 4x_3$

Subject to:

$3x_1 + 3x_2 + x_3 \leq 18$

$2x_1 + 2x_2 + 4x_3 = 12$

$x_1 \geq 0$, $x_3 \geq 0$, x_2 unrestricted,

Then, by vector transposition, the dual problem becomes:

Minimize $u = 18w_1 + 12w_2$

Subject to:

$3w_1 + 2w_2 \geq 3$

$3w_1 + 2w_2 = 1$

$w_1 + 4w_2 \geq 4$

$w_1 \geq 0$, w_2 unrestricted.

The RHS of the primal is the vector of the coefficients of the objective function of the dual problem and the vector of coefficients of the objective function of the primal problem is the RHS of the dual problem. Also, the matrix of coefficients of the constraints in the dual problem is the transpose of the matrix of the coefficients of the constraints in the primal problem. Finally, all the inequalities ≤ in the primal problem are changed to ≥ in the dual problem.

It has been observed about the dual problem that the number of functional constraints affects the computational effects of the simplex method far more than the number of variables does. If m>n, so that the dual problem has fewer functional constraints (n) than the primal problem (m), then applying the simplex method directly to the dual problem instead of the primal problem may achieve a substantial reduction in computational effort.

3.4 Simplex Method and its Algorithm

When a LP model is formulated with more than two decision variables the graphical method which is useful and illustrative cannot be employed, instead, the simplex method is used. One method of solving LP problems is to use the simplex method developed by George Dantzig in 1947. A simplex is an n-dimensional convex figure that has exactly (n+1) extreme points. The simplex method refers to the idea of moving from one extreme point to another on the convex set that is formed by the constraint set and non-negativity conditions of the LP problem. Solution algorithm refers to an iterative procedure having fixed computational rules that lead to a solution to the problem in a finite number of steps. The simplex method is algebraic in nature and is based upon the Gauss-Jordan elimination procedure. The simplex algorithm is an iterative procedure that provides a structured method for moving from one basic feasible solution to another, always maintaining or improving the objective function until an optimal solution is obtained.

The first step in setting up the simplex method is to convert the functional inequality constraints to equivalent equality constraints. To convert a less than or equal to (≤) inequality to an equation, a non- negative slack variable is added to the left-hand side of the constraint and an artificial variable is used for an equality constraint. The conversion from (≥) inequality to (=) is achieved by using a surplus variable and an artificial variable (Amponsah, 2007).

The major steps in the simplex algorithm are as follows:

Step 1: Given the problem formulation with m equalities in n unknowns, select a set of m

Step 2: Analyze the objective function to see if there is a non-basic variable that is equal to zero in the initial basic feasible solution, but would improve the value of the objective function if made positive. If no such variable can be found, the current basic feasible solution is optimal. The simplex algorithm stops. If however such a variable can be found, the simplex algorithm continues to step 3.

Step 3: Select a leaving variable using the feasibility condition.

Step 4: Determine the new basic solution by using the appropriate Gauss-Jordan computations. Go to step 2.

3.5 Integer Programming

There are several ways of solving pure integer programming problems. The best known ones are Cutting Planes method and Branch and bound method. The enumeration of all possible integer solutions to a linear programming problem would not be a practicable approach to solving the problem because of the tremendously high number of solutions (Amponsah, 2007).

For example, a problem with 30 (0 – 1) variables has 2^{30} i.e. over one billion possible variable solutions. The number of solutions grows exponentially with the number of variables. The Branch and Bound is a method of implicit enumeration. This means that only a small fraction of the solutions are explicitly examined.

Integer Programming problems are essentially Linear Programming problems with additional requirements regarding the integrality of some or all the variables. If these integrality requirements are relaxed, the relaxed Linear Programming problem could serve as a bound on the best possible value for the optimal objective function value of the Integer Programming problem. If it is minimization, this would be a lower bound.

The first Branch and Bound algorithm was developed in 1960 by A. Land and G. Doig says Taha (2007) for the general mixed and pure Linear Programming. He further added that in 1965, E. Balas developed the additive algorithm for solving Linear Programming with pure binary (zero or one) variable. The additive algorithm's computations were so simple that it was hailed as a possible breakthrough in the solution of general Integer Linear Programming.

The Branch and Bound method employs a strategy in which the feasible region is divided into smaller sub-groups (or nodes), each being examined for integer feasibility. The information regarding the bounds on the objective function value is constantly updated and used to guide us in a selective examination of nodes. The Branch and Bound method can be described as an iterative algorithm that involves two operations: (i).Branching (ii) Bounding.

Branching involves the subdivision of a linear programming feasible region into two sub regions. Every time we branch we create two nodes (feasible sub regions) corresponding to the introducing of two mutually exclusive constraints. Some constraints impose bounds on variables. The bounds have integer values and are of the form $x_k \leq [x_k^*]$ and $x_k \geq [x_k^*] + 1$where $[x_k^*]$ is the largest integer that is less than the non-integer value x_k^*

For example if x_k^* is equal to 3.7, then the two constraints which are imposed by branching are $x_k \leq 3$ and $x_k \geq 4$. The imposition of such integer valued bounds on variables x_k results in the elimination of non integer points.

Bounding involves solving the linear programming problem defined at a given node. Further partitioning of a given feasible sub-region (node) can only give worse values for the value of the objective function. This is because with every subsequent partition we solve linear programming problem with smaller feasible regions. So the optimal value of the objective function at a given node is a lower bound for the optimal value of the objective function of subsequent nodes that are created by branching from it.

At any step we choose to branch at the node with lowest lower bound if the solution at that node does not satisfy the integrality requirements. The process is terminated when a solution of a node reached does not satisfy the integrality requirements and has the lowest value for the lower bound than any of the existing nodes.

3.6 Algorithm Steps for Branch and Bound

The Integer Linear Programming problem to be solved is:

Minimize $c^T x$ ……………………… 1

Subject to

$Ax = b$…………………………….. 2

$x \geq 0$ ……………………………… 3

x_j integer for some j € I

Step 1: Relax the integrality requirements (4). The resulting Linear Programming problem is referred to as Node 1. The optimal value of the objective function is the initial Lower bound for the objective function value. If the relaxed LP is found infeasible, the integer programming problem is infeasible, so stop.

Step 2: Compare the lower bound values for any currently defined nodes. If the solution at the node with the lowest Lower bound value satisfies the integrality requirements, stop, that solution is the optimal. If the lowest Lower bound is undefined (∞), stop, the problem is infeasible.

Step 3: Branch at the node with the lowest Lower bound value, by imposing two mutually exclusive constraints on the value of the variable x_k whose present value (x_k*) violates the integrality requirements.

CHAPTER 4

ANALYSIS OF RESULTS

4.1 Data Collection

The data for the thesis was obtained from the Regional Office of Zoomlion at Koforidua. Other relevant information was sought for at the New Juaben Municipal Assembly. These include the cost of fueling each type of vehicle for a month, cost of repairs and maintenance for each type of vehicle during a month, monthly salaries of janitors who accompany the vehicles, and the capacities of each type of vehicle. The data is a secondary source from the Regional Office of Zoomlion Company, Ghana Ltd.

The Zoomlion Office in the New Juaben Municipality has three types of vehicles – skip, compactor and roll-on-roll-off, for the transportation of solid waste. The vehicles work for 6 days in a week, Monday to Saturday. There are 45 collection containers positioned at vantage points in the municipality. The vehicles are stationed at the office and move to the designated locations and convey the solid waste to the landfill site at Akwadum, 5 kilometers away. Distances from the collection containers to the landfill site are assumed to be equal and that the vehicles are reasonably filled to capacity before transporting the waste to the landfill site.

The average monthly operational costs for the vehicles are shown in Table 4.1 below. This includes fuel cost, repairs and maintenance costs, and the salaries of the janitors accompanying each vehicle. The amounts have been quoted in Ghana cedis (GH¢).

TABLE 4.1(Monthly operational costs, quoted in Ghana cedis GH¢.)

VEHICLE	FUEL	MAINTENANCE AND REPAIRS	SALARY	TOTAL
Skip	1200	70	300	1570
Compactor	2000	1700	300	4000
Roll-on	450	75	300	825

Source: Zoomlion Ghana Ltd. (Regional Office, Koforidua, 2010)

The monthly budget for each item: fuel, maintenance and repairs, and salaries for the janitors are displayed in Table 4.2.

TABLE 4.2(Monthly budget, quoted in Ghana cedis GH¢)

ITEM	BUDGETED AMOUNT
Fuel	5900
Maintenance & Repairs	2110
Salary	1200

Source: Zoomlion Ghana Ltd. (Regional Office, Koforidua, 2010)

Also, Table 4.3 shows the number of janitors accompanying each vehicle and the number of trips made by each vehicle daily.

TABLE 4.3(Number of Janitors accompanying a vehicle & the number of trips per day)

VEHICLE	NUMBER OF JANITORS	NUMBER OF TRIPS
Skip	1	10
Compactor	2	2
Roll-on	1	7

Source: Zoomlion Ghana Ltd. (Regional Office, Koforidua, 2010)

Table 4.4 shows the capacities of the various vehicles and the quantum of solid waste expected to be evacuated.

TABLE 4.4 (Capacities of vehicles)

VEHICLE	CAPACITY IN CUBIC METERS
Skip	12
Compactor	12
Roll-on	25
Total volume to be evacuated by vehicles per day	350

Source: Zoomlion Ghana Ltd. (Regional Office, Koforidua, 2010)

On daily basis, the company would like to transport at least 350 cubic meters of solid waste to the landfill site at Akwadum in order to utilize its funds judiciously. The waste generated in the municipality is transported six days in a week i.e. from Monday to Saturday.

4.2 Data Analysis

Making use of the fact that the vehicles work for six days in a week, Monday to Saturday, and making the assumption that there are 25 working days in a month, the cost per day was computed for each type of vehicle and the results displayed in Table 4.5.

TABLE 4.5 (Cost and budgeted amount per day, quoted in Ghana cedis GH¢)

VEHICLE	FUEL	MAINTENANCE	SALARY	TOTAL	BUDGETED AMOUNT PER DAY
Skip	48	2.80	12	62.80	236
Compactor	80	68	24	172.00	85
Roll-on	18	3	12	33	48

Then, taking cognizance of the fact that a skip makes10 trips per day, compactor 2 trips, and roll-on 7 trips per day, the cost per trip was calculated and the results displayed in Table 4.6

TABLE 4.6 (Daily average costs per trip for types of vehicles)

VEHICLE	FUEL	MAINTENANCE AND REPAIRS	SALARY	TOTAL
Skip	4.80	0.28	1.20	6.30
Compactor	40.00	34.00	12.00	86.00
Roll-on	2.60	0.43	1.70	5.00

Source: Zoomlion Ghana Ltd. (Regional Office, Koforidua, 2010)

4.3 Model Formulation

The objective function is the total cost incurred in the transportation of the solid waste from the 45 containers to the landfill site at Akwadum. This comprises of the fuel cost, repair and maintenance cost and the cost of labor. The decision variables are v_1, v_2 and v_3; the number of trips that the skip, compactor and roll-on respectively make in a day.

Considering Table 4.6, the total amount spent per trip on a skip is GH¢6.30, GH¢86.00 on compactor and GH¢ 5.00 on a roll-on. It was desired to find the number of trips that will minimize the transportation cost. Therefore the objective function is: minimize $C=6.30v1+86v2+5v3$. ……….. 1

..

The budgetary constraints are considered for the fixed working capital. From Table4.5, the total cost of fuel per day for all the vehicles should not be more the budgetary allocation for vehicles, GH¢ 236.00(Ghana cedis). If the number of trips made per day by skip, compactor and roll-on are v1, v2,and v3 respectively, then the cost for fuel used per day, then from Table 4.6, the inequality will be $4.8v1+40v2+2.6v3\leq236$………….. 2

Also, the budgetary provision of capital per day for maintenance and repairs should not be more than GH¢ 85.00 (Ghana cedis) as depicted in Table 4.5. Using Table4.6, the total amount spent on maintenance should satisfy the inequality $0.28v1+43v2+0.43v3\leq85$………….. 3

Moreover, the budgetary allocation for the janitors on the vehicles should not be greater than GH¢48.00 Ghana cedis). Picking values from both Tables 4.5 and 4.6, the total expenditure for the janitors will satisfy the inequality $1.2v1+12v2+1.7v3 \leq 48$………….. 4

In addition, the capacity constraint requires that the volume of solid waste hauled to the landfill site should be at least 350 cubic meters. From Table 4.4, the total volume of waste will satisfy the inequality $12v1+12v2+25v3 \geq 350$………… 5

The problem of determining the number of trips that each type of vehicle operated by Zoomlion in the New Juaben Municipality should make in a day in order to minimize the transportation cost of hauling the solid waste from 45 collection containers to the landfill site was formulated as an Integer Programming problem, since number of trips will assume only integral values.

Here, the transportation costs are measured in terms of costs per trip made from the collection points to the landfill site at Akwadum and the decision variables are multiplied by the total cost per trip. An Integer Programming problem is a mathematical optimization or feasibility program in which some or all of its variables are restricted to be integers (Wosley, 1998). Bringing all the five equations together, the model is represented by:

Minimize $C = 6.3v_1 + 86v_2 + 5v_3$ ………………………equation 1

Subject to $4.8v_1 + 40v_2 + 2.6v_3 \leq 236$…………………..equation 2

$0.28v_1 + 34v_2 + 0.43v_3 \leq 85$………………...equation 3

$1.2v_1 + 12v_2 + 1.70\, v_3 \leq 48$…………………equation 4

$12v_1 + 12v_2 + 25v_3 \geq 350$ ………………….equation 5

The number of trips for the different types of vehicles form the decision variables; v_1=skip, v_2=compactor, v_3=roll-on. The constraints are the cost of fuel, cost of repairs and maintenance, salaries of janitors, and the volume of solid waste required to be hauled.

4.4 Computational Procedure

The solution to the optimization problem which was formulated as linear integer programming model was obtained using the AMPL software and the solver CPLEX. The solver CPLEX employs the branch and bound method.

According to Fourer et al. (2003), AMPL allows us to use common notation and familiar concepts to formulate optimization models and examines solutions while the computer manages communication with appropriate solver.

Also, Gay (1997) asserts that the AMPL modeling system allows constrained optimization problems to be expressed in an algebraic notation close to conventional mathematics. AMPL's solve command causes AMPL to instantiate the current problem, send it to a solver and attempt to read a solution computed by the solver.

CPLEX is designed to solve linear programs, integer programs, mixed integer programs and quadratic programs. CPLEX employs either simplex or a barrier method to solve linear programming problems.

4.5 Specifications of Computer Used

The solution to the model was obtained by using Pentium M Acer laptop computer with processor 1.50GHz, VGA of 64.0MB, memory of 240 MB RAM and hard disk space of 20GB. From Appendix 1, there was one (1) dual simplex iteration(0 in phase 1). The program was run three times to ensure consistent and accurate results.

4.6 Results

The results, displayed in Appendix 1, showed that an optimal solution was found: C=70, v_1=0, v_2=0.and v_3=14. This means that if only one roll-on vehicle makes 14 trips per day, it will be able to haul the expected volume of solid waste to the landfill site at a cost of GH¢70. For a day, it is expected that at least 350m^3 of solid waste to be lifted to the landfill site.

4.7 Discussion

Currently, Zoomlion operates 2 skips, 2 compactors and 1 roll-on, vehicles. A skip makes 10 trips, compactor 2 trips and a roll-on 7 trips for the haulage of solid waste from the city to the landfill site at Akwadum on daily basis. If these values are used in the computations, the total operational cost for a day is $C= 2\times6.3\times10 + 2\times86\times2 + 5\times7=$ GH¢511

The corresponding volume of waste that will be hauled, $V=2\times12\times10+ 2\times12\times2 + 25\times7= 463m^3$.

Even if 2 roll-on vehicles are used and the current number of trips per day, 7, is maintained, the operational cost will be GH¢70; which is far less than what been computed above.

Various combinations of the number of skips, compactors, and roll-on were made and used in conjunction with the current number of trips made per day by each type of vehicle $v_1=10$, $v_2=2$ and $v_3=7$; to compute for the total cost and the total volume of waste transported. This was done to make a comparative analysis with the optimized values. The results are shown in the table below.

TABLE 4.7(Operational costs and total volume for varying numbers of vehicles)

Number of skips	Number of compactors	Number of roll-on vehicles	Operational cost per day in GH¢	Volume of waste transported in m^3
2	2	1	511	463
2	1	2	368	614
1	2	2	467	518
1	1	2	305	494
1	2	1	442	343
2	1	1	333	439
1	1	1	270	315

From table 4.7, the minimum operational cost of GH¢270 is attained when a skip, a compactor and a roll-on vehicle are put into operation but this violates the capacity constraint because $315m^3$ is less than the required minimum of $350m^3$. The next minimum value is GH¢305 and this is attained when a skip, a compactor and 2 roll-on vehicles are used which though satisfies the capacity constraint but not economically viable because this is about 4½ times more than the optimized value of GH¢70.

The optimized values for the number of trips made each day by the different types of vehicles v_1=0, v_2=0, v_3=14; were used to compute the optimized total cost and the optimized volume of solid waste transported for varying numbers of vehicles and the results tabulated in Table 4.8.

$C=6.3\times0+86\times0+5\times14=70$ and

$V=12\times0+12\times0+25\times14=350$.

The table was constructed to ascertain and verify the reliability of the results obtained and the veracity of the deductions made.

TABLE 4.8(Optimized total costs and volume for different numbers of roll-on vehicles)

Number of skips	Number of compactors	Number of roll-on vehicles	Optimized total cost in GH¢	Volume of waste transported in m^3
0	0	1	70	350
0	0	2	140	700
0	0	3	210	1050
0	0	4	280	1400
0	0	5	350	1750

From Table 4.8, it is evident that if as many as 5 roll-on vehicles of capacity 25m^3 make 14 trips each per day, the cost of transportation will be GH¢350, which is much lower when compared with the current value of GH¢511. Therefore, the table shows the expediency of using roll-on vehicles in the transportation of solid waste. The compactors and the skips when used in transporting solid waste make the operational cost rise astronomically.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Waste management is one of the indispensable core functions of a Municipal Assembly since this ensures good hygiene for the inhabitants by mitigating the incidence of preventable diseases like malaria, cholera, typhoid which are rife in communities with squalid conditions.

Transportation of solid waste in the New Juaben Municipality from 45 collection points to the landfill site at Akwadum, about 5km away, which poses a herculean task to city management institutions due to the fact that fuel prices are on the ascendency and the cost of repairing and maintaining vehicles keep on soaring, was successfully modeled as an integer programming problem using Tables 4.1, 4.2, 4.3, 4.4and 4.5.

This research work sought to utilize optimization techniques to find the optimal solution to the integer programming model in order to minimize operational cost. With the aid of the software AMPL and its compatible solver CPLEX, an optimal solution was obtained for the model.

It could be inferred from the results obtained that if only one roll-on-roll-off vehicle makes 14 trips per day, the quantum of solid waste that is required to be transported to the landfill site a day can be achieved at a minimum cost of GHc70.

5.2 Recommendation

Taking cognizance of the current financial constraints and the quantum of solid waste generated and therefore should be evacuated from the communities to the landfill site at Akwadum in the New Juaben municipality, it will be prudent on the part of management if additional roll-on-roll-off vehicles are procured for cost effective waste management in the municipality.

By inference from the results obtained, it will be economically advantageous if other municipal assemblies and metropolitan authorities use predominantly roll-on vehicles to evacuate waste generated in their municipalities.

A visit to the landfill site at Akwadum reveals that solid waste is being transported and dumped at the site, waste is not being managed properly. The obnoxious scent that emanates from the site, coupled with the rodents and flies that have infested the area, pose a serious environmental threat to the nearby residents and to the entire community. Others may be encouraged to research into how waste generated at this site can be converted into wealth.

Owing to time and financial constraints, and the difficulty in accessing data and information, the research work was restricted to the New Juaben Municipality. The research can be replicated in other municipalities.

REFERENCES

1. Agha S.R., (2006). Optimizing Routing of Municipal Solid Waste Collection in Deir El-Balah, Gaza Strip, The Islamic University Journal Vol. 14 No. 2, p.75-89.
2. Ajibade, L.T., (2008). Waste Ergonomics Optimization in Illorin, Nigeria, Ethiopian Journal of Environmental Studies and Management vol. 1 No. 2, pp83-90.
3. Alidi,Abdulaziz S., and Al-Faraj, Taqi N., (1990). A Municipal Solid Wastes Planning. Model for Metropolitan Area; Geo Journal vol. 22, Kluwer Academic Publishers, p 439 – 443.
4. Allen A.R, Dillon A.M, O'Brien M, (1997). Approaches to Landfill Site Selection in Ireland. Engineering Geology and Environmental Balkema, Rotterdam, pp. 1569-1574
5. Alves C., Macedo R., Carvalho J.; (2010). Optimizing Transportation Processes in Urban Waste Collection System, Business Sustainability vol.1, pages 299-305.
6. Amponsah S. K., (2007). Optimization Techniques 1, Faculty of Distance Learning, KNUST, Kumasi, pp62-118.
7. Apaydin O.and Gonullu M. T., (2007). Route Optimization for Solid Waste Collection: Trabzon (Turkey) Case Study Global NEST Journal, Vol. 9 No. 1 pp 6 – 11.
8. Badran, M.F. and El-Haggar, S.M., (2006). Optimization of Municipal Solid Waste Management in Port Said - Egypt. Waste Management 26, 534-545
9. Chang Ni- Bin and Wang S. F., (1996). Solid Waste Management System Analysis by Multi-objective Mixed Integer Programming Model, Journal of Environmental Management, Volume 48, Issue 1, pp.17-43.
10. Daskalopoulos, E., Badr, O., Probert, S.D., (1998). An Integrated Approach to Solid Waste Management. Resources, Conservation and Recycling vol. 24, pp33-50.
11. Detofeno, T., C., (2010). Optimizing Routes for the Collection of Urban Solid Waste: A Case Study for the city of Joinville, State of Santa Catania, Iberoamerican Journal of Industrial Engineering, vol.2, pp124-136.
12. Dijkgraaf E., (2008). R. H. J. M. Gradus (eds), The Waste Market, Springer Science and Business Media B. V. page 1- 5.

13. Ferrel, Hizlan, (1997). South Carolina Counties Use a Mixed-Integer Programming-Based Decision Support Tool for Municipal Solid Waste Management, Interfaces 27, pp 23-34.
14. Filipiak K. A., Layek Abdel-Malek, Hsin-Neng Hseih, Jay N. Meegoda, (2009). Optimization of Municipal Solid Waste Collection System: Case Study, Journal of Hazardous, Toxic and Radiation Waste, Vol. 13, Issue 3, Technical Papers.
15. Fourer,R., Gay, D., and Kernighan, B., (2003). AMPL, A Modeling Language for Mathematical Programming, 2nd ed. Brooks/Cole-Thomson, Pacific Grove, CA.
16. Gay, D. M., (1997). Hooking Your Solver to AMPL, Technical Report 94-4-06, Computing Sciences Research Center, Bell Laboratories, Murray Hill, NJ 07974.
17. Ghose, M.K., Dikshit, A.K.and Sharma, S.K., (2006). A GIS based transportation model for solid waste disposal - A case study on Asansol Municipality. Waste Management 26, 1287-1293.
18. Hiller F.S. and Lieberman G.J., (2001). Introduction to Operations Research, 7th Edition, The McGraw-Hill Companies Inc., New York, p 25-36, 576 – 616.
19. Jalilzadeh A., Parvaresh A., (2004). Evaluation of Chronological Aspects of Collection and Transportation of Municipal Solid Waste System in Urmia, Iran, J. Environmental Health Sci. Eng. vol 2, No. 4, pp267-276.
20. Jiliani T., (2002). State of Solid Waste Management in Khulna City. Unpublished Undergraduate Thesis, Environmental Science Discipline, Khulna University, Khulna, pp. 25-85.
21. Karadimas Nikolaos V., Loumous Vassili and Orsoni Allesandra, (2006). Municipal Solid Waste Generation Modeling Based On Fuzzy Logic, Prqcedings of 20th European Conference on Modeling and Simulation, pp 1-6.
22. Kulcar, T., (1996). Optimizing Solid Waste Collection in Brussels, European Journal of Operational Research, Vol. 90, p. 71.
23. Loumos V.G., Karadimas N. V., and Papatzelou K., (2007). Genetic Algorithms for Municipal Solid Waste Collection and Routing Optimization; Artificial Intelligence and Innovations 2007, from Theory to Applications, dl.ifip.org/index.php/ifip/article/view/10921.

24. Lu H. W., Huang G. H., He L. and Zeng G. N. (2009). An Inexact Dynamic Optimization Model for Municipal Solid Waste Management in Association with Greenhouse Gas Emission Control, Journal of Environmental Management, Vol. 90, Issue 1, Jan 2009, pages 396-409.
25. Martagan et al., (2006). Optimizing Waste Collection in an Organized Industrial Region: A Case Study, 4th International Logistics and Supply Chain Management Congress, pp1-9.
26. Minciardi R., Paolucci M., Robba M. and Sacile R., (2008). Multi-objective Optimization of Solid Waste Flows: Environmentally Sustainable Strategies for Municipalities, Waste Management, Volume 28, Issue 11, pages 2202 - 2212.
27. Mohd S. G., et al., (2004). Mathematical Model for Optimal Development and Transportation of Recycled Waste Materials, Environmental Informatics Archives, Volume 2 (2004), 233 – 241.
28. Nasserzadeh V., Switenbank J., Scott D., and Jones B., (1991). Design Optimization of a Large Municipal Solid Waste Incinerator, Waste Management, Vol. 11 pp 249-261.
29. Nganda M., K., (2007). Mathematical Models in Municipal Solid Waste Management, Chalmers University of Technology and Goteborg University, Goteborg, Sweden, pp1-3,9-36, 56.
30. Nishanth T., Prakash M. N., Vijith H., (2010). Suitable Site Determination for Urban Solid Waste Disposal Using GIS and Remote Sensing Techniques in Kottayam Municipality, India, International Journal of Geomatics and Geosciences vol. 1, No. 2.
31. Noche, B.; Rhoma, F. A., Chinakupt, T.; Jawale, M., (2010). Optimization Model for Solid Waste Management System Network Decision, Case Study. Computer and Automation Engineering (ICCAE), The 2nd International Conference, pages 230-236.
32. Nuortio T., J. Kytojoki, H. Niska, O. Braysy, (2006). Improved Route Planning and Scheduling of Waste Collection and Transport, Expert Systems with Application, Vol. 30, Issue 2,pages 223 – 232.

33. Ogwueleka T. C., (2009). Route Optimization for Solid Waste Collection, Onitsha (Nigeria) Case Study, Journal of Applied Services and Environmental Management Vol. 13 No. 2 pp 37-40.
34. Prawiradinata, R. S., (2004). Integrated Solid Waste Management Model: The Case of Central Ohio District The Ohio State University, pdf Document.
35. Rathi, S., (2007). Optimizing model for integrated Municipal Solid Waste Management in Mumbai, India, Environmental and Development Economics 12, Cambridge University Press, pp105-121.
36. Rhoma, F., (2009). Environmental and Economical Optimization for Municipal Solid Waste Collection Problems, A Modeling and Algorithmic Approach Case Study, www.wseas.us/e-library/conference/2010/MAMECTIS-37 pdf
37. Saeed O., M., (2009). Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpar, Malaysia, Elsevier Waste Management 29, 2209-2213.
38. Taha,H.,A., (2007). An Introduction to Operations Research, Eighth edition, Pearson Education, Inc., Upper Saddle River, New Jersey, pp 11-73, 81-146.
39. Tavares G., Zsigraiova Z., Semiao V., Carvalho M. G., (2009). Optimization of Municipal Solid Waste Collection Routes for Minimum Fuel Consumption Using 3D GIS Modeling, Waste Management, Vol. 29, 1176-1185.
40. Tchobanoglous, G., Vigil, Samuel, and Theisen, H**., (**1993). Integrated Solid Waste Management: Engineering Principles and Management Issues, McGraw-Hill, NY. Inc.
41. Technical Committee, (2010). Environmental Sanitation Strategies and Action Plans (DESSAP), New Juaben Municipal Assembly, Koforidua.
42. Wang Chin-Huang, J. C. Even, S. K. Adams, (1995). A Mixed-Integer Model for Optimal Processing and Transport of Secondary Materials. Elsevier Resources, Conservation and Recycling 15, pp 65-78.
43. Wolsey, L. A., (1998). Integer Programming, John Wosley & Inc., New York..
44. Xiangyou Wu, (1997). Inexact Nonlinear Programming and its Application to Solid Waste Management and Planning, pdf. Document.

APPENDIX 1

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ampl: var v1>=0;

ampl: var v2>=0;

ampl: var v3>=0;

ampl: minimize c:6.3*v1+86*v2+5*v3;

ampl: subject to c1:4.8*v1+40*v2+2.6*v3<=236;

ampl: c2:0.28*v1+34*v2+0.43*v3<=85;

ampl: c3:1.2*v1+12*v2+1.7*v3<=48;

ampl: c4:12*v1+12*v2+25*v3>=350;

ampl: option solver cplex;

ampl: solve;

CPLEX 11.2.1: optimal solution; objective 70

1 dual simplex iterations (0 in phase I)

ampl: display c,v1,v2,v3;

c = 70

v1 = 0

v2 = 0

v3 = 14


ampl:
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