COST-EFFICIENCY ANALYSIS OF SOLID WASTE TRUCKS USING DATA ENVELOPEMENT ANALYSIS PROGRAMME - A STUDY OF ZOOMLION GHANA LIMITED

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MASTER OF SCIENCE THESIS

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CERTIFICATION

I hereby certify that this submission is my own work towards the Msc., 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 of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This thesis is dedicated to God Almighty, to my family and to all whose prayers and sacrifice have brought me this far.

ABSTRACT

This study focuses on the cost-efficiency analysis of solid waste trucks and seeks to identify the factors that account for the various variations in the cost components.

The main objective of this project is to carry out a cost-efficiency analysis of the solid waste trucks using the Data Envelopment Analysis Programme.

Data Envelopment Analysis is essentially an optimization algorithm, which develops efficiency scores for all Decision Making Units on a scale of zero to 100% or 0-1 with units that have 100% or 1 efficiency score being called fully efficient.

In this study, a cost efficiency measurement of solid waste trucks was carried out using data on a sample of 28 trucks (10 skip trucks, 5 roll-on/roll-off trucks and 13 compaction trucks. A constant return to scale model was used in the analysis and efficiency scores were developed for all solid waste trucks.

The study revealed that 3 out of the 28 trucks were found to have received a cost-efficiency score of 1 (100%). It also revealed that the dominant source of the cost inefficiency is as a result of high allocative inefficiencies. This implies that the managers of the trucks were relatively good at using the minimum level of inputs at a given level of output but they were not that good at selecting the optimal mix of inputs given the prices.

An analysis was also carried out to account for the variations in the cost components of the trucks. From the study, it was revealed that factors that contribute to these variations include the age of the truck, the distance (in km) travelled by each truck, the frequency of breakdown, the traffic condition pertaining to the routed that the trucks ply among others.

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	Allocative Efficiency
AMA	Accra Metropolitan Assembly
CE	Cost Efficiency
CRS	Constant Return to Scale
DEA	Data Envelopment Analysis
DEAP	Data Envelopment Analysis Programme
D.O.C	Direct Operating Cost
DMU	Decision Making Unit
DRS	Decreasing returns to scale
IRS	Increasing returns to scale
MSWM	Municipal solid waste management
NADMO	National Disaster Management Organisation
NYEP	National Youth Employment Programme
SWM	Solid waste management
TE	Technical Efficiency
VRS	Variable Return to Scale

1. INTRODUCTION

This chapter provides the background information to the study. It also presents the problem statement, aims and objectives of the study, justification, operational definitions and the structure of the report. It spells out the importance of the cost-efficiency analysis of solid waste collection trucks and its relation to the quality of service it provides in the management of solid waste.

1.1 BACKGROUND

We were generating solid waste when we were living in caves, though it appears that then we were relatively successful at recycling, using skins for clothing and bones to make tools. In recent years we have created for ourselves major environmental problems because of our preference for living in concentrated urban areas, buying more than we need and advertising extensively by means of paper and packaging. Many city administrations have not been able to cope with the rapid escalation of the solid waste problem, and consequently have left densely settled areas with no service, polluted precious air by the open burning of wastes, and damaged land and water resources by careless dumping of the residues of our proud civilisation.

Faced with these failures, municipal administrations have looked for experts and new ways of raising funds to pay the ever-increasing costs of solid waste management. First, they recruited and trained their own experts, but the results were not always successful, and failures were blamed on insufficient funds, bureaucratic restrictions, and inadequate decision-making procedures. Often small-scale entrepreneurs and groups of residents took action to fill in the gaps, organising or providing services on a local scale that at least moved their wastes out of their immediate neighbourhoods, and often earning much-needed income from the reuse of materials separated from the mixed waste. The most recent approach has been to invite private enterprise to take over the task, to increase coverage, improve efficiency and reduce the pollution of natural resources. Have we at last arrived at the ultimate solution? Do we need to look elsewhere for sustainable solid waste management, or have we finally found the right approach? What further change may be necessary? (Coad, 2005).

Municipal solid waste management (MSWM) is a major responsibility of local governments typically consuming between 20% and 50% of municipal budgets in developing countries. It is a complex task which depends as much upon organization and cooperation between households, communities, private enterprises and municipal authorities as it does upon the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal. Furthermore, waste management is an essential task which has important consequences for public health and well-being, the quality and sustainability of the urban environment and the efficiency and productivity of the urban economy. In most cities of developing countries, waste management is inadequate: a significant portion of the population does not have access to a waste collection service and only a fraction of the generated waste is actually collected. Systems for transfer, recycling and/or disposal of solid waste are unsatisfactory from the environmental, economic and financial points of view.(Schubeler et al., 1996).

General issues in the collection and transportation of solid waste include:

- High collection costs and low service levels. As mentioned earlier, a major proportion of a municipal authority's budget is spent on collection, whereas service typically covers only 30%-70% of the urban population and is often infrequent (less than once a week in the rural areas).

- Poor labour management and supervision.
- Inadequate cooperation from citizens with the municipal authority's collection schedules and methods.
- Inappropriate type and size of collection vehicles.
- Non-rational routes for collection service.
- Failure to optimize vehicle productivity by selecting the appropriate crew size and shift duration.
- Inadequate container capacity at the communal collection points.
- Long vehicle down-times from poor equipment maintenance/repair.
- Long haulage times to disposal sites coupled with lack of transfer stations.
- Harsh driving conditions at disposal sites causing vehicle and tyre damage.

(As cited in Service delivery training module 1 of 4, Solid waste collection and transportation).

In recent years solid waste services have undergone operational reorganization in many countries. This organizational change has gone hand in hand with increasing calls for better functioning and results, not only in terms of tailoring services to improve the quality of everyday life in urban centers but also as a consequence of greater concern over sustainability and environmental protection. However, despite the extent of changes to these services very few empirical analyses have been conducted as regards their economic aspects.

The overall economic effectiveness of waste collection and disposal service depends, on the one hand, upon the life-cycle costs of facilities, equipment and services and, on the other hand, on the long-term economic impact of waste management systems.

Nearly every day, almost 100 refuse collection trucks lumber through the streets of every urban center in the country collecting household and commercial waste. The contribution they make to the quality of life in cities, hauling away their wastes day after day, is enormous. Without them, cities would be overrun with garbage. ***(As cited in Greening garbage trucks: Trends in alternative fuel use by James S. Cannon).*** Despite many good practices from around the world, inappropriate technologies, particularly for solid waste collection and disposal, still exist in many developing countries. Donor-provided equipment is often inappropriate to the nature of the waste, while collection vehicles are frequently ill-suited to extremes in climate or road conditions, resulting in a large proportion of vehicles being out of use. Poor handling and lack of maintenance of equipment is a major cause of breakdowns. Waste management experts know that vehicles that are too large and overloaded can cause excessive damage to road surfaces and be unsuited to congested areas, and that the complex mechanisms of sophisticated compactor trucks can demand frequent repair. Experts would agree that, in terms of public acceptance and sustainability, the reliability and costs of a collection system are more important than the appearance of the collection vehicles, but unfortunately many decision-makers do not accept this logic.

A major problem still unresolved in many cities in the region is the frequency and efficiency of waste collection. Frequency varies all the way from daily to once a week (not including the many areas of cities which are not serviced at all).

Frequency, in many cases, is not determined by technical considerations such as putrefaction rates of the wastes, weather, vehicle availability, and routing necessities, but rather by how affluent an area is. Both collection of market wastes and street sweeping in commercial areas are most often the responsibility of the solid waste authority. In residential areas each residence is typically responsible for cleaning their part of the curb. In the case of street sweeping, small-scale enterprises have had a very important role in the region. These small-scale enterprises tend to be the first (as compared to collection and disposal enterprises) to become self-sustaining.

1.2 PROBLEM STATEMENT

In recent years, increase in the cost of solid waste collection services can be mainly attributed to the following factors:

- Increase in fuel prices
- Increase in labour charges
- Increase in operation cost
- Increase in waste generation, among many factors

As a result of these factors, most of the waste companies in order to make profits and still remain in business, tend to increase their user charges in order to make up for likely losses that will arise and the consumers are usually at the suffering end.

User charges are occasionally increased however little attention is given to the measures by which direct cost can be reduced and output increased. There is the need to put in place measures that will help to optimize cost-efficiency and this can only be done when one is able to identify the various factors that are likely to prevent the trucks from operating at a cost-efficient level.

The main driving force or success story of every waste collection company is directly linked to the availability and functionality of its equipment (such as waste collection trucks, etc.) and the commitment of its labour force. Companies succeed or fail for a variety of reasons. Many among these reasons are lack of logistics and poor performance of solid waste trucks. Most often than not, the trucks for waste collection encounter frequent breakdowns and this to a large extent affects the productivity and quality of service that would be rendered to customers.

Vehicle productivity of a given company is directly influenced by the number of trips that each vehicle makes in a day and the quantity of waste collected in tonnes per trip. The number of daily trips is affected by the availability of vehicles on the road since a vehicle may not be able to make the maximum number of trips for the day due to a breakdown in the course of a day's operation, the traffic conditions and the nature of the road. The combined effects of the number of trips that each collection vehicle makes per day, the quantity of waste collected in tonnes per trip and the daily quantity of waste collected (tonnes) by individual vehicles determine the level of a company's overall vehicles productivity.(Oduro-Kwarteng andDijk, 2008).

1.3 JUSTIFICATION

Population dynamics have significant influence on the amount of waste generated and its proper handling in the municipality. The population of Accra is rapidly increasing because of the rural-urban migration among other factors. Associated with the increasing population are rising levels of affluence, shorter product cycles, and the large number of packaging, consumption and the demand for portable products that have brought increases in the waste stream. The rapid increase in volumes of unattended to solid wastes with the associated risk to human health is a source of concern. There is also a steady increase in the cost and logistical difficulties of municipal solid waste management. The success story of every waste management company aside all factors is largely dependent on the available resources needed to implement aims and goals. Among these resources are the solid waste trucks. In as much as the study area is focused in Accra, results from this research canserve as a guidelinefor other waste management companies in their operational duties.

The study seeks to carry out a cost-efficiency analysis using the DEAP. This would inform the company on the trucks that are operating at a cost-efficient level and those that are not. It would also help the company to identify the various explanatory factors and take measures to curb the situation.

These identified loopholes would help the company to put into place strategic management decisions that would help improve their operational activities and service provision nation-wide. It can also serve as a guide for the company and other waste management operators.

1.4 RESEARCH QUESTIONS

This study seeks to assess the cost efficiency of solid waste trucks and provide answers to questions like:

- What has been the performance of the solid waste trucks?
- Are the solid waste trucks operating at a 100% cost-efficient level
- What are the variations in the cost-efficiency of the trucks?

1.5 AIMS AND OBJECTIVES

The main aim of this study is to carry out a cost-efficiency analysis of solid waste trucks using the Data Envelopment Analysis Program (DEAP)

Specifically, the research aims at achieving the following objectives:

- To assess the variations in the cost-efficiency of solid waste trucks.
- To assess factors affecting the cost-efficiency of the trucks using Data Envelopment Analysis Program (DEAP),
- To identify measures for reducing direct cost.

1.6 SCOPE OF THE STUDY

The geographical scope of this research is the Accra Metropolitan Area in the Greater Accra Region of Ghana with emphasis on the specific operational sub-metros of Zoomlion Ghana Limited.

Contextually, the research seeks to assess the performance (through a cost-efficiency analysis) of the solid waste trucks in the operations of the company and suggest measures by which they can improve upon in the area.

1.7 BACKGROUND OF COMPANY

Zoomlion Ghana Limited is the leading waste management company in Ghana. The company is committed to the provision of services which prevent environmental pollution and safeguard public health, such as solid waste pre-collection, street sweeping, drain cleaning, liquid waste collection and haulage to disposal sites. Their mission is to offer environmental sanitation services by the introduction and utilization of simple but modern technologies and methods of waste management at affordable and competitive rates.

The company began its operations in the year 2006. It currently handles 70 per cent of the solid waste generated in the towns and cities of Ghana. The company currently operates in all Metropolitan/Municipal/District assemblies in Ghana. The range of services include among others.

- Solid waste collection,
- Landfill management,
- Landscaping and Beautification services,
- Janitorial and Indoor cleaning Services
- Vector Control Services
- Fabrication and sale of Refuse containers.

The company has also ventured into other sectors, such as agriculture, heavy duty equipment hiring, sale and rental of construction and waste management equipment as well as oil waste management services.

Zoomlion has core staff strength of about 3000, and a field staff of about 65,100 under a government initiative dubbed "The National Youth Employment Programme" (NYEP).

Under this initiative, there are several modules of which waste and sanitation is one. This initiative creates employment for the youth as well as provides support in areas of the economy where the nation lacks the requisite Human Resource and Technical capacity.

1.8 LIMITATIONS OF THE RESEARCH

The only limitation to this study was the absence of actual distances travelled by the trucks from their areas of operation to the landfill site. This could be attributed to the fact that most of the trucks do not have odometers. As a result, the distances used in this study is an approximated distance.

1.9 STRUCTURE OF THE REPORT

This research is organised into five chapters. Chapter 1 introduces the research and gives a background to the research. It also gives an insight into the context of the study and the research objectives. Chapter 2 presents a review on the definitions and concepts of solid waste management. It also reviews related works to this research. Chapter 3 presents the research methodology for the study. Chapter 4 presents the main findings of the research and discussion of these findings. Chapter 5 presents the conclusion and the implications of the findings. It presents the theoretical and practical conclusions from the study

LITERATURE REVIEW

2. INTRODUCTION

2.1 CONCEPTS OF WASTE

2.1.1 Definition of Waste

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

2.1.2 Classification of Waste

Solid waste can be classified into different types depending on their source, their physical state, their composition and the level of risk associated with their disposal or treatment.

Waste can be classified according to the source from which they emanate from. Sources of waste can either be residential, commercial, industrial, agricultural, biomedical/hospital etc. An example of source classification of solid waste is represented in Table2-1.

Table 2-1 Sources and Types of Municipal Solid Waste

SOURCE	TYPICAL FACILITIES OR LOCATIONS WHERE WASTE ARE GENERATED.	TYPES OF SOLID WASTE
Residential	Single-family and multi-family dwellings, low, medium and high-rise apartments, etc.	Food wastes, rubbish, ashes, special waste
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, etc.	Food wastes, rubbish, special wastes, hazardous wastes, demolition and construction waste
Institutional	Schools, government centers, medical facilities, prisons, etc.	Food wastes, rubbish, special wastes, hazardous wastes, demolition and construction waste
Open areas	Streets, parks, alleys, playgrounds, beaches, recreational areas, etc.	Special waste, rubbish
Agriculture	Crops, orchards, vineyards, dairies, feedlots, farms	Spoilt food wastes, agricultural wastes, hazardous wastes (e.g. pesticides).

Treatment plant sites	Water, wastewater, and industrial treatment processes etc.	Treatment-plant wastes, principally composed of residual sludges.

Source: **World Bank/IBRD, 1999. What A Waste: Solid Waste Management in Asia, Tchobanoglous et al (1985).**

Waste can also be classified according to their material composition such as food wastes, rubbish, ashes and residues, demolition and construction wastes, special waste, treatment plant wastes etc. Table 2-2 gives a brief outline of waste classified according to their material composition.

Table 2-2- Classification of Municipal Solid Waste according to Material Composition.

Component	**Description**
Food wastes	They include animal, fruit or vegetable residues.
Rubbish	They consist of combustible and non-combustible solid waste excluding food waste and other putrescible waste. They include paper, cardboard, plastics, textiles, rubber, leather, glass, crockery, tin cans, aluminium cans, garden trimmings, furniture, etc.
Ashes and residues	This refers to the materials remaining from the burning of wood, coal, coke and other combustible waste. They are normally composed of fine, powdery materials, cinders, clinkers and partially burned materials, etc.
Demolition and construction wastes	Demolition wastes include wastes from razed buildings and other structures. Construction wastes include wastes from the

	construction, remodelling and repairing of residential, commercial and industrial buildings. Wastes in these category include stones, concrete, bricks, electrical, plumbing and heating parts, etc.
Special wastes	This refers to wastes such as street sweepings, roadside litter, dead animals, catch-basin debris, abandoned vehicles etc.
Treatment-plant wastes	This includes the solid and semisolid wastes from water, wastewater and industrial waste treatment facilities.

Source: Tchobanoglous et al., (1985)

Based on their physical state, waste can also be classified either as solid, liquid, gaseous or radioactive waste. Table 2-3 gives an example of such classification.

Table 2-3- Classification of Waste based on their Physical State

Waste type	Examples
Solid waste	Food wastes, rubbish, special waste
Liquid waste	Sewage sludge, waste water
Gaseous waste	Factory smoke, vehicle exhaust smoke, fumes from burning waste dumps
Radioactive waste	Radiation, uranium, plutonium, excess energy

2.1.3 The Concept of Waste Management

Tchobanoglous et al., (1993: 7), defines solid waste management as:

"…..that discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations and that is also responsive to public attitudes".

Municipal solid waste is defined to include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings.

Management is a cyclical process of setting objectives, establishing long term plans, programming, budgeting, implementation, operation and maintenance, monitoring and evaluation, cost control, revision of objectives and plans, and so forth. Management of urban infrastructure services is a basic responsibility of the municipal government.

According to Schubeller et al.,(1996), municipal solid waste management (MSWM) refers to the collection, transfer, treatment, recycling, resource recovery and disposal of solid waste in urban areas. The goals of MSWM include:

- To protect environmental health,
- To promote the quality of the urban environment,
- To support the efficiency and productivity of the economy
- To generate employment and income.

The Ecolife dictionary defines the concept of waste management to involve the collection, removal, processing, and disposal of materials considered waste. Waste materials can be solid, gaseous, liquid, or even hazardous and are generally generated through human activity. (www.ecolife.com.> dictionary)

Wikipedia defines waste management as the collection, transport, processing or disposal, managing and monitoring of waste materials. The term usually relates to materials produced by human activity, and the process is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is a distinct practice from resource recovery which focuses on delaying the rate of consumption of natural resources. All wastes materials, whether they are solid, liquid, gaseous or radioactive fall within the remit of waste management. (www.wikipedia.org).

It can be deduced from these definitions that waste management is the practice of protecting the environment from the polluting effects of waste materials in order to protect public health and the natural environment, (Baabereyir, 2009). Thus, the priority of a waste management system must always be the provision of a cleansing service which helps to maintain the health and safety of citizens and their environment (Cooper, 1999).

2.2 SOLID WASTE COLLECTION.

Local authorities are responsible for ensuring that a service is provided to the communities they serve. Collection of waste can be done by the local authority, a conventional contractor, or an emerging entrepreneur.

In selecting the appropriate waste management approach for a particular community, several factors ought to be considered and these factors include:

Table 2-4-Factors to consider for appropriate Waste Management Approach.

FACTORS	POINTS TO NOTE
Affordability	• Capital and operational costs; • Level of income within the community • Grants or subsidies available.

Accessibility	• Road infrastructure and conditions
Level of education	• Literacy and awareness of the community to understand the principles of waste management.
On-site storage facilities	• Availability and suitability; • Composition and volume of the waste.
Potential benefits	• Clean and healthy environment; and • Job creation and upliftment.
Available facilities and infrastructure	• Appropriate vehicles; and • Available expertise
Distance to disposal site	• Transfer facility requirements
Pollution potential	• Blocked sewers and storm water canals; and • Illegal dumping and littering.

2.3 COLLECTION SYSTEMS

Table 2-5- Various Collection Systems

System	Description	Advantages	Disadvantages
SHARED: Residents can bring out waste at any time			
Dumping at designated	Residents and other generators are	Low capital costs	Loading the waste into trucks is slow and

location	required to dump their waste at a specified location or in a masonry enclosure.		unhygienic. Waste is scattered around the collection point. Adjacent residents and shopkeepers protest about the smell and appearance.
Shared container	Residents and other generators put their waste inside a container which is emptied or removed.	Low operating costs	If containers are not maintained they quickly corrode or are damaged. Adjacent residents complain about the smell and appearance.
INDIVIDUAL: The generators need a suitable container and must store the waste on their property until it is collected.			
Block collection	Collector sounds horn or rings bell and waits at specified locations for residents to bring waste to the collection vehicle.	Economical. Less waste on streets. No permanent container or storage to cause complaints.	If all family members are out when collector comes, waste must be left outside for collection. It may be scattered by wind, animals and waste pickers.
Kerbside collection	Waste is left outside property in a container and picked up by passing vehicle, or swept up and collected	Convenient. No permanent public storage.	Waste that is left out may be scattered by wind, animals, children or waste pickers. If collection service is

	by sweeper.		delayed, waste may not be collected or some time, causing considerable nuisance.
Door to door collection	Waste collector knocks on each door or rings doorbell and waits for waste to be brought out by resident.	Convenient for resident. Little waste on street.	Residents must be available to hand waste over. Not suitable for apartment buildings because of the amount of walking required.
Yard collection	Collection labourer enters property to remove waste.	Very convenient for residents. No waste in street.	The most expensive system, because of the walking involved. Cultural beliefs, security considerations or architectural styles may prevent labourers from entering properties.

SOURCE :web.mit.edu/urbanupgrading/.../issues.../waste-collection.html

2.3.1 Collection Vehicles

There are several options available for transporting collected waste for disposal, ranging from the basic hand cart to the technically sophisticated and motorised front- and rear-loading compaction vehicles. All options have a place in providing an effective collection service in the varied and mixed development areas currently faced by engineers and administrators.

The type of vehicle selected will also depend on the waste composition, as high-density waste (high ash content) will not require compaction. The relationship between payload and distance to the landfill or transfer station must also be considered.

Types of waste collection vehicles include:

2.3.1.1 Hand Carts

Hand carts, although not commonly used in Ghana, can be designed for specific applications. These may include small informal communities with no planned or designed road infrastructure, and even planned developments during the early stages where occupancy does not warrant sophisticated equipment, particularly in what can be considered the lower income groups. Although limited in carrying capacity, hand carts can be effectively employed where job creation and limited capital expenditure are the main considerations. The use of hand carts has the advantage of not only providing more employment opportunities within the community due to the relatively small areas of responsibility of the operator, but also of combining street cleaning with normal refuse collection. The main disadvantage is that they would need to be supplemented with a communal bin system and the appropriate vehicle for final disposal.

2.3.1.2 Animal-drawn carts

Animal-drawn carts are also not commonly used yet they have similar applications to the hand cart. The only significant difference is that the area of responsibility can be increased due to a relatively larger carrying capacity. A disadvantage is that animal-drawn carts can only be used if a community-based waste collection system is implemented and the "contractor" has his own choice of transport. Should the disposal facility be within a practically attainable distance, the need for support facilities could also be eliminated, provided access via freeways is not required.

2.3.1.3 Tractor and trailer

The tractor and trailer, although not the first, was probably the most common means of mechanical transport for waste collection prior to the introduction of compaction units, and can still be effectively utilised in most developed and undeveloped areas. The variations and combinations available are numerous and must be carefully assessed prior to implementation. The tractor-trailer combination can be operated where road conditions are not suitable for trucks, but is limited to a maximum 10 kilometre distance to the disposal facility, provided access via freeways is not required.

2.3.1.4 Rear-end Loaders (Compaction trucks)

Rear-end loaders are available in sizes varying from 10 m^3 to 21 m^3, and have a relatively advanced compaction system allowing a compaction ratio of up to 4:1. This high compaction ratio and carrying capacity, with the versatility of being capable of handling containers up to 6 m^3 , has made the rear end loader the most popular and commonly used collection vehicle in developed areas. This is particularly so where volumes are high and distances to disposal facilities are in excess of 10 km. The main disadvantages of using the rear-end loader are relatively high maintenance costs, and that they can only be effectively used where good road infrastructures are in place.

2.3.1.5 Load Luggers (Skip trucks)

The skip truck is a special application vehicle and limited to container applications. The most common application is the handling of bulk containers from industries and large businesses, communal collection systems and the removal of builders rubble from construction sites.

2.3.1.6 Roll-on roll-off

Roll-on roll-off vehicles are specially designed vehicles with very specific applications. They are mainly used for the transportation of large capacity open or closed compacted containers ranging from 18 m³ to 30 m³.

2.4 COST-EFFECIENCY ANALYSIS

Efficiencyrefers to the success with which an organization uses its resources to produce outputs i.e. the degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical, allocative, cost and dynamic efficiency.

Efficiency can also be defined as the extent to which the program has converted or is expected to convert its resources/inputs (such as funds, expertise, time, etc.) economically into results in order to achieve the maximum possible outputs, outcomes, and impacts with the minimum possible inputs. An assessment of efficiency relates the results of a program to its costs. Ideally, this would attempt to put a monetary value on the benefits arising from the activities of the program, compare these with the costs of the program, and calculate the internal rate of return that equalizes the present value of the benefits and costs. ***(Based on DAC glossary and IEG evaluation criteria).***

An efficiency indicator defines the relationship between a system's input resources and output products or services. It also shows how efficiently a company utilizes the contracted budget for the collection and transportation of waste. Efficiency indicators include:

- Cost per truck
- Cost per ton of solid waste
- Cost per ton km of haul distance.

An effectiveness indicator on the other hand measures the system's ability to meet its objectives. It demonstrates how effective the service is in terms of the population being served, and/or the area being covered by the company's service. Effectiveness indicators include:

- The population to be served
- The area being covered.

A traditional way to combine variables in a utility function is to use a cost/effectiveness ratio, called an "efficiency" measure. It measures utility by the "cost per unit produced". On the surface, that would appear to make comparison between two contexts possible by comparing the two cost/effectiveness ratios.

It also must be recognized that effectiveness will usually entail consideration of a number of products and services and costs a number of sources of costs. Cost/effectiveness measurement requires combining the sources of cost into a single measure of cost and the products and services into a single measure of effectiveness.

Efficiency measures the company's ability to transform its inputs (resources and demands) into production of outputs (services). The objective in doing so is to optimize the balance between the level of outputs and the level of inputs. The success of the company, like that of other organizations, depends on its ability to behave botheffectively and efficiently.

The issue at hand, then is how to combine the several measures of input and output into a single measure of efficiency and this can be done through the 'data envelopment analysis'

2.5 DATA ENVELOPMENT ANALYSIS

There is an increasing concern among organizations to study level of efficiency with which they work relative to their competitors. Traditional performance measurement system provides a very unbalanced picture of performance that can lead managers to miss important opportunities for improvement. The most common methods of comparison or performance evaluation were regression analysis and stochastic frontier analysis. These measures are often inadequate due to the multiple inputs and outputs related to different resources, activities and environmental factors.

Data Envelopment Analysis (DEA) provides a means of calculating apparent efficiency levels within a group of organizations. In DEA study, efficiency of an organization is calculated relative to the group's observed best practice.

Data envelopment analysis is a Linear Programming Problem that provides a means of calculating apparent efficiency levels within a group of organizations. (Bhagavath,1997).

2.6 HISTORY OF DEA

In an article which represents the inception of DEA, (Farrell, 1957) was motivated by the need for developing better methods and models for evaluating productivity.

He argued that while attempts to solve the problem usually produced careful measurements, they were also very restrictive because they failed to combine the measurements of multiple inputs into any satisfactory overall measure of efficiency. Responding to these inadequacies of separate indices of labour productivity, capital productivity, etc., Farrell proposed an activity analysis approach that could more adequately deal with the problem. His measures were intended to be applicable to any productive organization; in his words, '… from a workshop to a whole economy'. In the process, he extended the concept of "productivity" to the more general concept of "efficiency"

Data Envelopment Analysis (DEA) is a data oriented approach for evaluating the performance of a set of peer entities called Decision Making Units (DMUs) which convert multiple inputs into multiple outputs. The definition of a DMU is generic and flexible. Recent years have seen a great variety of applications of DEA for use in evaluating the performances of many different kinds of entities engaged in many different activities in many different contexts in many different countries.

These DEA applications have used DMUs of various forms to evaluate the performance of entities, such as hospitals, US Air Force wings, universities, cities, courts, business firms, and others, including the performance of countries, regions, etc. Because it requires very few assumptions, DEA has also opened up possibilities for use in cases which have been resistant to other approaches because of the complex (often unknown) nature of the relations between the multiple inputs and multiple outputs involved in DMUs.

Since DEA in its present form was first introduced in 1978, researchers in a number of fields have quickly recognized that it is an excellent and easily used methodology for modelling operational processes for performance evaluations. This has been accompanied by other developments. For instance, (Zhu 2002) provides a number of DEA spreadsheet models that can be used in performance evaluation and benchmarking. DEA's empirical orientation and the absence of a need for the numerous *a priori* assumptions that accompany other approaches (such as standard forms of statistical regression analysis) have resulted in its use in a number of studies involving efficient frontier estimation in the governmental and non-profit sector, in the regulated sector, and in the private sector.

In their originating study, (Charnes, Cooper, and Rhodes,1978) described DEA as a 'mathematical programming model applied to observational data [that] provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces – that are cornerstones of modern economics'.

Formally, DEA is a methodology directed to frontiers rather than central tendencies. Instead of trying to fit a regression plane through the centerof the data as in statistical regression, for example, one 'floats' a piecewise linear surface to rest on top of the observations. Because of this perspective, DEA proves particularly adept at uncovering relationships that remain hidden from other methodologies. For instance, consider what one wants to mean by "efficiency", or more generally, what one wants to mean by saying that one DMU is more efficient than another DMU. This is accomplished in a straightforward manner by DEA without requiring explicitly formulated assumptions and variations with various types of models such as in linear and nonlinear regression models. (Cooper et al., 2004)

2.7 DATA ENVELOPEMENT ANALYSIS AND DIFFERENT EFFICIENCY CONCEPTS

Typically using linear programming, DEA calculates the efficiency of an organisation within a group relative to observed best practice within that group. The organisations can be whole agencies (for example, Departments of Health), separate entities within the agency (for example, hospitals) or disaggregated business units within the separate entities (for example, wards).

To discuss DEA in more detail it is necessary to look at the different concepts of efficiency.

2.7.1 Technical Efficiency

Technical efficiency is just one component of overall economic efficiency. However, in order to be economically efficient, a firm must first be technically efficient. Profit maximisation requires a firm to produce the maximum output given the level of inputs employed (i.e. be technically efficient), use the right mix of inputs in light of the relative price of each input (i.e. be input allocative efficient) and produce the right mix of outputs given the set of prices (i.e. be output allocative efficient) (Kumbhaker and Lovell, 2000). These concepts can be illustrated graphically using a simple example of a two input (x_1, x_2)-two output (y_1, y_2) production process (Figure 2-1). Efficiency can be considered in terms of the optimal combination of inputs to achieve a given level of output (an input-orientation), or the optimal output that could be produced given a set of inputs (an output-orientation).

In Figure 2-1, the firm is producing a given level of output (y_1^*, y_2^*) using an input combination defined by point A. The same level of output could have been produced by radially contracting the use of both inputs back to point B, which lies on the isoquant associated with the minimum level of inputs required to produce (y_1^*, y_2^*)

(i.e. Iso(y_1^*, y_2^*)). The input-oriented level of technical efficiency ($TE_I(y,x)$) is defined by 0B/0A. However, the least-cost combination of inputs that produces (y_1^*, y_2^*) is given by point C (i.e. the point where the marginal rate of technical substitution is equal to the input price ratio w_2/w_1). To achieve the same level of cost (i.e. expenditure on inputs), the inputs would need to be further contracted to point D. The cost efficiency (CE(y,x,w)) is therefore defined by 0D/0A. The input allocative efficiency (AE_I(y,w,w)) is subsequently given by CE(y,x,w)/TE_I(y,x), or 0D/0B in Figure 2-1.(Kumbhaker and Lovell, 2000).

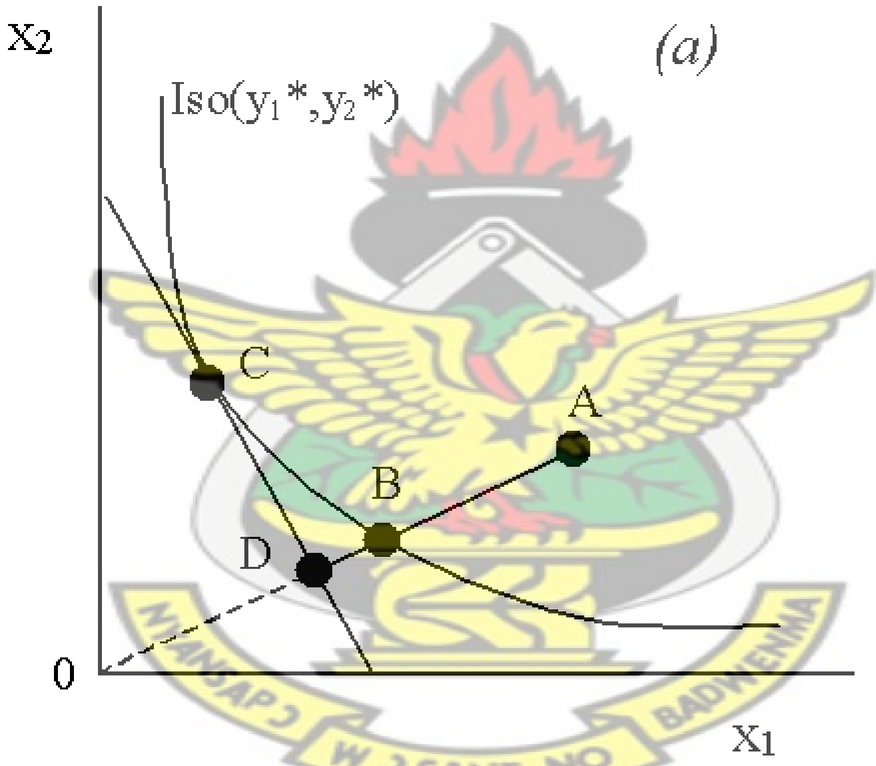

Figure 2-1- Technical Efficiency graph

It also refers to the conversion of physical inputs (such as the services of employees and machines) into outputs relative to best practice. In other words, given current technology, there is no wastage of inputs whatsoever in producing the given quantity of output. An organization operating at best practice is said to be 100% technically efficient. If operating below best practice levels, then the organization's technical efficiency is expressed as a percentage of best practice. Managerial practices and the scale or size of operations affect technical efficiency, which is based on engineering relationships but not on prices and costs.(Bhagavath, 1997)

2.7.2 Allocative Efficiency

Thisrefers to whether inputs, for a given level of output and set of input prices, are chosen to minimize the cost of production, assuming that the organization being examined is already fully technically efficient. Allocative efficiency is also expressed as a percentage score, with a score of 100% indicating that the organization is using its inputs in the proportions that would minimize costs. An organization that is operating at best practice in engineering terms could still be allocatively inefficient because it is not using inputs in the proportions which minimize its costs, given relative input prices. (Bhagavath, 1997)

2.7.3 Cost Efficiency

Thisrefers to the combination of technical and allocative efficiency. An organization will only be cost efficient if it is both technically and allocatively efficient. Cost efficiency is calculated as the product of the technical and allocative efficiency scores (expressed as a percentage), so an organization can only achieve a 100% score in cost efficiency if it has achieved 100% in both technical and allocative efficiency. (Bhagavath, 1997)

In order to capture the variations of efficiency over time, (Charnes et al.,1985) proposed a technique called ‘window analysis’ in DEA. Window analysis assesses the performance of a DMU over time by treating it as a different entity in each time period. This method allows for tracking the performance of a unit or a process. For example, if there are ***n*** units with data on their input and output measures in ***k*** periods, then a total of ***nk*** units need to be assessed simultaneously to capture the efficiency variations over time. In the traditional window analysis described above, when a new period is introduced into the window the earliest period is dropped out. A variation to this method was proposed by Talluri et al.,(1997) to effectively monitor the performance of a unit over time and assist in process improvement and benchmarking. Essentially, this technique, referred to as the 'modified window analysis,' drops the poorest performing period instead of the earliest period. This allows for a new period to be challenged against the best of the previous periods and, thereby, assisting in process improvement and benchmarking. (Talluri, 2000)

2.8 DEA MODEL

DEA is a linear programming based technique for measuring the relative performance of organizational units where the presence of multiple inputs and outputs makes comparisons difficult. The DEA mathematical model is as follows:

The *u*'s and *v*'s are variables of the problem and are constrained to be greater than or equal to some small positive quantity _ in order to avoid any input or output being ignored in computing the efficiency.

$$U_{r,} V_{I} \geq \epsilon$$

The solution to the above model gives a value *h*, the efficiency of the unit being evaluated. If *h* = 1 then this unit is efficient relative to the others. But if it is less than l then some other units are more efficient than this unit, which determines the most favourable set of weights. This flexibility can be a weakness because the judicious choice of weights by a unit possibly unrelated to the value of any input or output may allow a unit to appear efficient.

To solve the model, we need to convert it into linear programming formulation

$$\textit{Max } h = \sum_r u_r y_{ry0}$$

subject to dual variable

$$\sum_i v_i x_{ij0} = 100(\%) \qquad Z_0$$

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0, j = 1, \wedge, n \qquad \lambda_j$$

$$-v_i \leq -\epsilon \;\; i = 1, 2, \wedge, m \qquad s_i^+$$

$$-u_r \leq -\epsilon \;\; r = 1, 2, \wedge, t \qquad s_r^-$$

This is referred to as formulation CCR (Charnes, Cooper, andRhodes, 1978) model. The dual model can be constructed by assigning a dual variable to each constraint in the primal model. This is shown below.

$$Min 100 Z_0 - \epsilon \sum_i s_i^+ - \epsilon \sum_r s_r^-$$

Subject to

$$\sum_j \lambda_j x_{ij0} = x_{ij0} Z_0 - s_i^+, i = 1, \wedge, m$$

$$\sum_j \lambda_j y_{rj} = y_{rj0} + s_r^-, r = i, \wedge, t$$

$$\lambda_j, s_i^+, s_r^- \geq 0$$

The dual variables λ's are the shadow prices related to the constraints limiting the efficiency of each unit to be no greater than 1. Binding constraint implies that the corresponding unit has an efficiency of 1 and there will be a positive shadow price or dual variable. Hence positive shadow prices in the primal, or positive values for the λ's in the dual, correspond to and identify the peer group for any inefficient unit.

The above models assume constant return to scale. If we add a variable to the model, we can construct a DEA model with variable return to scale. Variable returns meanthat we might get different levels of output due to reduced performance or economics of scale. This version of the model is popularly known as BCC (Banker, Charnes, and Cooper 1984). *(*Bhagavath,1997).

2.8.1 Input-Orientated Measures

Modern efficiency measurement began with Farell (1957). He drew upon the work of (Debreu, 1951) and (Koopmans,1951) to define a simple measure of firm efficiency which could account for multiple inputs. He proposed that the efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measures are then combined to provide a measure of the economic/cost efficiency.

An input-orientated measure addresses the question 'By how much can input quantities be proportionally reduced without changing the output quantities produced?'Farell (1957) illustrated his idea using a simple example involving firms which use two inputs (x_1 and x_2) to produce a single unit of output (y), under the assumption of constant returns to scale. Knowledge of the unit isoquant of the fully efficient firm, represented by $SS^{1..}$ in the figure below permits the measurement of technical efficiency. If a given firm uses quantities of inputs, defined by the point P, to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP, which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/0P, which represents the percentage by which all inputs could be reduced. The technical efficiency (TE) of a firm is most commonly measured by the ratio:

$$TE_I = 0Q/0P,$$

and this is equals to one minus $QP/0P$. It will take a value between zero and one, and hence provides an indicator of the degree of technical inefficiency of the firm. A value of one indicates that firm is fully technically efficient.

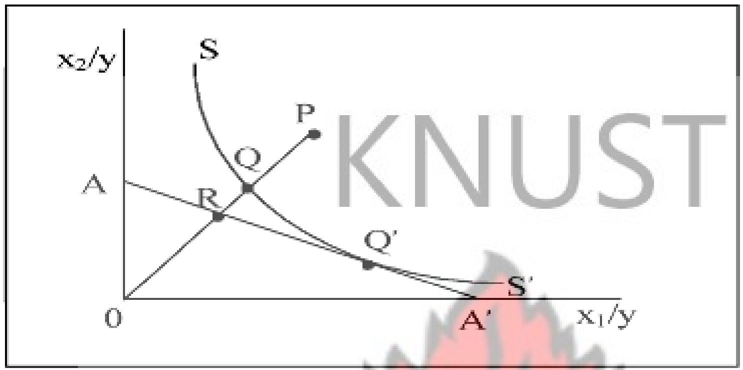

Figure 2-2- Technical and Allocative Efficiencies using an Input-Orientation

If the input price ratio, represented by the line AA[1] in Figure 2-2, is also known, allocative efficiency may also be calculated. The allocative efficiency (AE) of the firm operating at P is defined to be the ratio $AE_I = 0R/0Q$, since the distance RQ represents the reduction in production costs that would occur if production were to occur at the allocatively and technically efficient point Q', instead of at the technically efficient, but allocatively inefficient, point Q.

The total economic efficiency (EE) is defined to be the ratio $CE_I = 0R/0P$, where the distance RP can also be interpreted in terms of a cost reduction. The product of the technical and allocative efficiency provides the overall cost efficiency.(Bhagavath 1997)

$$TE_I \times AE_I = (0Q|0P) \times (0R|0Q) = (0R|0P) = CE_I$$

2.8.2 Output-Orientated Measures

An output-orientated measure addresses the question "By how much can output quantities be proportionally expanded without altering the input quantities used?" This is an output-orientated measure as opposed to the input –oriented measure discussed above. The difference between this two can be illustrated as follows:

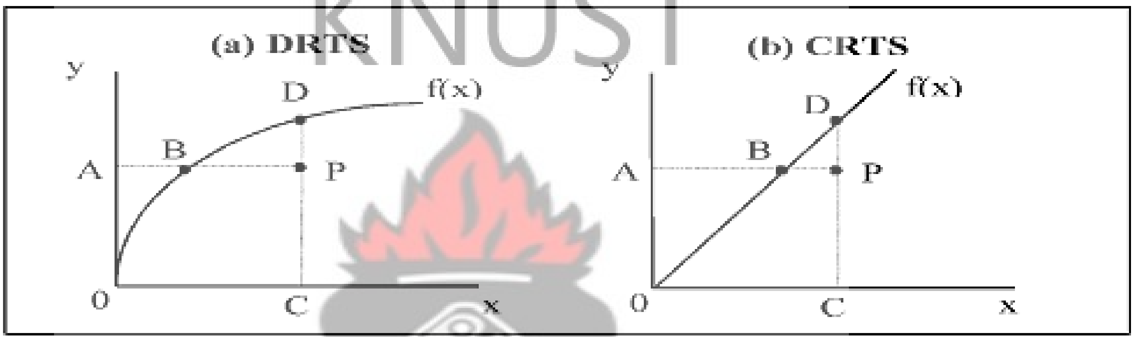

Figure 2-3-Input and Output Orientated Technical Efficiency Measures and Returns to scale

From Figure 2-3(a) where we have decreasing returns to scale technology represented by *f* (*x*), and an inefficient firm operating at the point P. The Farrell input-orientated measure of TE would be equal to the ratio AB/AP, while the output-orientated measure of TE would be CP/CD. The output- and input orientated measures will only provide equivalent measures of technical efficiency when constant returns to scale exist, but will be unequal when increasing or decreasing returns to scale are present (Fare and Lovell 1978). The constant returns to scale case is depicted in Figure 2- 3(b) where it can be observed that AB/AP=CP/CD, for any inefficient point P we care to choose.

One can consider output-orientated measures further by considering the case where production involves two outputs (*yi* and *y*) and a single input (*xi*). Again, if we assume constant returns to scale, we can represent the technology by a unit production possibility curve in two dimensions. This example is depicted in Figure 2-4 where the line ZZ' is the unit production possibility curve and the point A corresponds to an inefficient firm.

Note that the inefficient point, A, lies *below* the curve in this case because ZZ' represents the upper bound of production possibilities. (Bhagavath (1997)

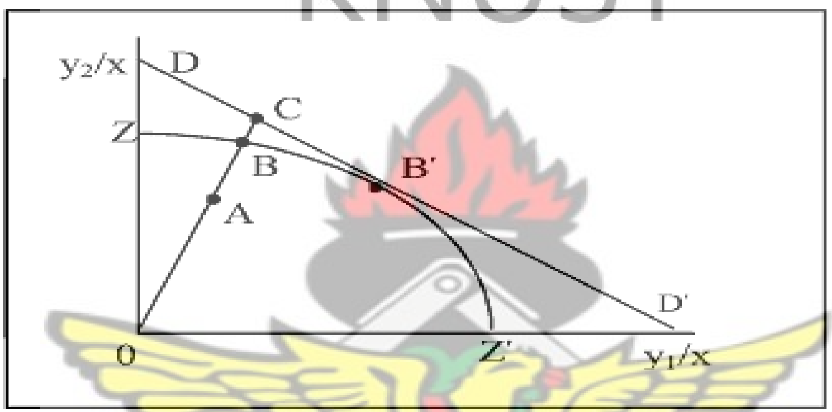

Figure 2-4- Technical and Allocative Efficiencies from an Output Orientation

2.9 DEA APPLICATIONS

Since DEA was first introduced by Charnes, Cooper, and Rhodes (1978), this methodology has been widely applied to the efficiency measurement of many organizations. Sherman and Gold (1985) used DEA model for evaluating bank branch operating efficiency. Shang and Sueyoshi (1995) applied the model to the selection of flexible manufacturing systems. Sueyoshi (1994) developed a model for evaluating the efficiencies of 24 public telecommunication companies in 23 countries.

Bhagavath (1997) used the DEA methodology to measure the technical efficiency of state road transport undertakings in India. In his study, three input variables and one output variable were considered for efficiency measurement. Input variables included fleet size, average kilometers travelled per bus per day and cost per bus per day. The output variable considered for the study was revenue per bus per day. The study involved the application of DEA to assess the efficiency of 44 State transport undertakings (STUs) during the year 2000-01.

Joel *et al.* (2010) employed DEA in order to measure the relative technical efficiency of urban water utilities in regional New South Wales (NSW) and Victoria. They show that the almost Universal policy of water restrictions is likely to reduce relative efficiency and the typically larger utilities located in Victoria are characterized by a higher degree of managerial efficiency.

2.10 HOW DEA WORKS?

By providing the observed efficiencies of individual agencies, DEA may help identify possible benchmarks towards which performance can be targeted. The weighted combinations of peers and the peers themselves may provide benchmarks for relatively less efficient organisations. The actual levels of input use or output production of efficient organisations (or a combination of efficient organisations) can serve as specific targets for less efficient organisations, while the processes of benchmark organisations can be promulgated for the information of managers of organisations aiming to improve performance.

The ability of DEA to identify possible peers or role models as well as simple efficiency scores gives it an edge over other measures such as total factor productivity indices.

Fried and Lovell (1994) listed the following as questions that DEA can help to answer for managers:

- How do I select appropriate role models to serve as possible benchmarks for a program of performance improvement?

- Which production facilities are the most efficient in my organisation?

- If all my operations were to perform according to best practice, how many more service outputs could I produce and how much could I reduce my resource inputs by, and in what areas?

- What are the characteristics of efficient operating facilities and how can they guide me in choosing locations for expansion?

- What is the optimum scale for my operations and how much would I save if all my facilities were the optimum size?

- How do I account for differences in external circumstances in evaluating the performance of individual operating facilities?

The simple model of DEA already outlined can satisfy the first four of these questions. To answer the last two, some extensions to the model are needed.

2.11 ADVANTAGES AND LIMITATIONS OF DEA.

The main advantages of DEA are that:

- It can readily incorporate multiple inputs and outputs and, to calculate technical efficiency, only requires information on output and input quantities (not prices).

This makes it particularly suitable for analysing the efficiency of government service providers, especially those providing human services where it is difficult or impossible to assign prices to many of the outputs;

- Possible sources of inefficiency can be determined as well as efficiency levels. It provides a means of 'decomposing' economic inefficiency into technical and allocative inefficiency. Furthermore, it also allows technical inefficiency to be decomposed into scale effects, the effects of unwanted input which the agency cannot dispose of, and a residual component.

- By identifying the 'peers' for organisations which are not observed to be efficient, it provides a set of potential role models that an organisation can look to, in the first instance, for ways of improving its operations. This makes DEA a potentially useful tool for benchmarking and changeimplementation programs. This role is strengthened by DEA's ability to incorporate differences in operating environments beyond management control and, thus, to make more like-with-like comparisons.

However, like any empirical technique, DEA is based on a number of simplifying assumptions that need to be acknowledged when interpreting the results of DEA studies. DEA's main limitations include the following.

- Being a deterministic rather than statistical technique, DEA produces results that are particularly sensitive to measurement error. If one organisation's inputs are understated or its outputs overstated, then that organisation can become an outlier that significantly distorts the shape of the frontier and reduces the efficiency scores of nearby organisations. In regression–based studies, the presence of error terms in the estimation tends to discount the impact of outliers, but in DEA they are given equal weight to that of all other organisations. It is important to screen for potential outliers when assembling the data. One useful check is to scrutinise those organisations whose output-to-input ratios lie more than about two-and-a-half standard deviations from the sample mean.

- DEA only measures efficiency relative to best practice within the particular sample. Thus, it is not meaningful to compare the scores between two different studies because differences in best practice between the samples are unknown. Similarly, a DEA study that only includes observations from within the state or nation cannot tell us how those observations compare with national or international best practice.

- DEA scores are sensitive to input and output specification and the size of the sample. Increasing the sample size will tend to reduce the average efficiency score, because including more organisations provides greater scope for DEA to find similar comparison partners. Conversely, including too few organisations relative to the number of outputs and inputs can artificially inflate the efficiency scores. Increasing the number of outputs and inputs included without increasing the number of organisations will tend to increase efficiency scores on average. This is because the number of dimensions in which a particular organisation can be relatively unique (and, thus, in which it will not have similar comparison partners) is increased. DEA gives the benefit of the doubt to organisations that do not have similar comparison organisations, so they are considered efficient by default. There are different rules as to what the minimum number of organisations in the sample should be; one rule is that the number of organisations in the sample should be at least three times greater than the sum of the number of outputs and inputs included in the specification. (Nunamaker 1983).

Despite these limitations, data envelopment analysis is a useful tool for examining the efficiency of service providers. Just as these limitations must be recognised, so must the potential benefits of using DEA (in conjunction with other measures) be explored to increase our understanding of public and private sector performance and potential ways of improving it.

RESEARCH METHODOLOGY

3. INTRODUCTION

This chapter aims to build on the previous chapters and also provide the methodology for the research.

3.1 RESEARCH STRATEGY

3.1.1 Research Strategy

Research strategy for this study involves the use of both quantitative and qualitative data. Sources of data used for this study includes key informant interviews, observations and secondary data.

3.2 THE STUDY AREAS

Historically the Accra Metropolitan Assembly (AMA) began as a Town Council and was first established by the Town Council Ordinance of 1894, after the introduction of Native Authorities by the colonial government in 1878. The native authorities were local government units made up of non-elected paramount chiefs, sub-chiefs and elders. The traditional rulers served as central figures in local government and were only given powers to pass bye-laws. The Accra Metropolitan Assembly is one of the ten (10) District Assemblies that make the Greater Accra Region and one of the One Hundred and seventy (170) Districts within the country Accra is the Metropolitan, Regional and National Capital and this role places Accra in a very unique position in Ghana. Geographically, the Accra Metropolis covers an area of 173 sq. km. The Southern boundary of AMA is the Gulf of Guinea stretching from Gbegbeyese to La. It shares boundary with the Ledzokuku-Krowor Assembly on the East. On the Northern and Western frontiers there are Ga East, Ga West, and the Ga

South District. Structurally, the AMA is made up of the General Assembly at the apex, followed by Eleven (11) Sub-Metropolitan District Councils which are subordinate bodies of the Assembly performing functions assigned to them by the instrument that sets up the Assembly or delegated to them by the Assembly. These includes the Ablekuma South sub-metropolitan area, Ablekuma North sub-metropolitan area, Ablekuma Central sub-metropolitan area, Osu Klottey sub-metropolitan area, Ayawaso Central sub-metropolitan area l, Ayawaso West sub-metropolitan area, Ayawaso East sub-metropolitan area, Ashiedu Keteke sub-metropolitan area, La sub-metropolitan area, Okai koi North sub-metropolitan area and the Okai koi South sub-metropolitan area.

With regard to waste management in the metropolitan area, the sub-metropolitan areas have been outsourced to the various waste management companies within the region. Waste management services includes the collection, transportation, disposing of both solid and liquid waste,cleaning of drains and open spaces and cutting of grass in open spaces.

Out of the eleven sub-metropolitan areas under AMA, Zoomlion Ghana Limited operates in three sub-metropolitan areas namely the Ayawaso West sub-metropolitan area, the Ayawaso Central sub-metropolitan area and the Ablekuma Central Metropolitan area. It carries out both communal and door-to door collection of waste in these sub-metros.

Figure 3-1- Map of Accra Metropolitan Area

3.2.1 Ayawaso West sub-metropolitan area.

The Ayawaso west sub-metropolitan area consists of five electoral areas. They include Abelemkpe, Dzorwulu, Roman Ridge/Airport Residential Area, Okponglo and Legon. It is bounded in the north by Kpeshie South Sub-Metro, in the west by Ga District, in the south by Okai koi South-Metro and in the east by Central Ayawaso Sub-Metro. The setup of the Sub-Metro is made up of the Administration Department, Treasury Department, Audit Unit, NADMO, Birth & Deaths Registry, Metropolitan Guards Unit, Waste Management, Metro Health, Building inspectorate, and Roads Unit.

Figure 3-2-Map of Ayawaso sub-metropolitan area

3.2.2 Ayawaso Central sub-metropolitan area

It consists of five (5) electoral areas' Kokomlemle, Aryee Diki, Nima East, Kotobabi and Alajo. It is bounded by the Okaikoi South Sub-Metro in the north, West Ayawaso Sub-Metro in the east, Osu Klottey Sub-Metro in the west. The setup of the Sub-Metro is made up of the Administration Department, Treasury Department, Audit Unit, NADMO, Birth & Deaths Registry, Metropolitan Guards Unit, Waste Management, Metro Health, Building inspectorate and Roads Unit.

3.2.3 Ablekuma Central sub-metropolitan area

It consists of five (5) electoral areas Abossey Okai, Mataheko, Gbortsui, Laterbiokoshie and Nnenmeete. It shares boundaries with Ablekuma North Sub Metro to the north, Ablekuma South Sub Metro to the south, and to the east by Okaikoi South Sub Metropolitan District Council. Its total land area is 11.5 square kilometer. The setup of this Sub-Metropolitan District Council is made of the

Administration, Treasury Department, Waste Management Department, Metropolitan Works Department, Metropolitan Public Health Department, Metropolitan Security Unit, Internal Audit Unit, NADMO, Roads Unit and the Rating Unit.

Figure 3-3- Map of Ablekuma Central metropolitan area

3.3 UNIT OF ANALYSIS

The unit of analysis used in this study are the waste collection trucks used by the company in its operations. These trucks consist of the skip trucks, roll-on/roll-off trucks and compaction trucks. The skip and roll-on/roll-off trucks are mainly used in the communal collection of waste whereas the compaction trucks are mainly employed in the door-to door collection of waste. For cost-efficiency analysis, data on ten (10) skip trucks, five(5) roll-on/ roll-off trucks and thirteen(13) compaction trucks were used for the study.

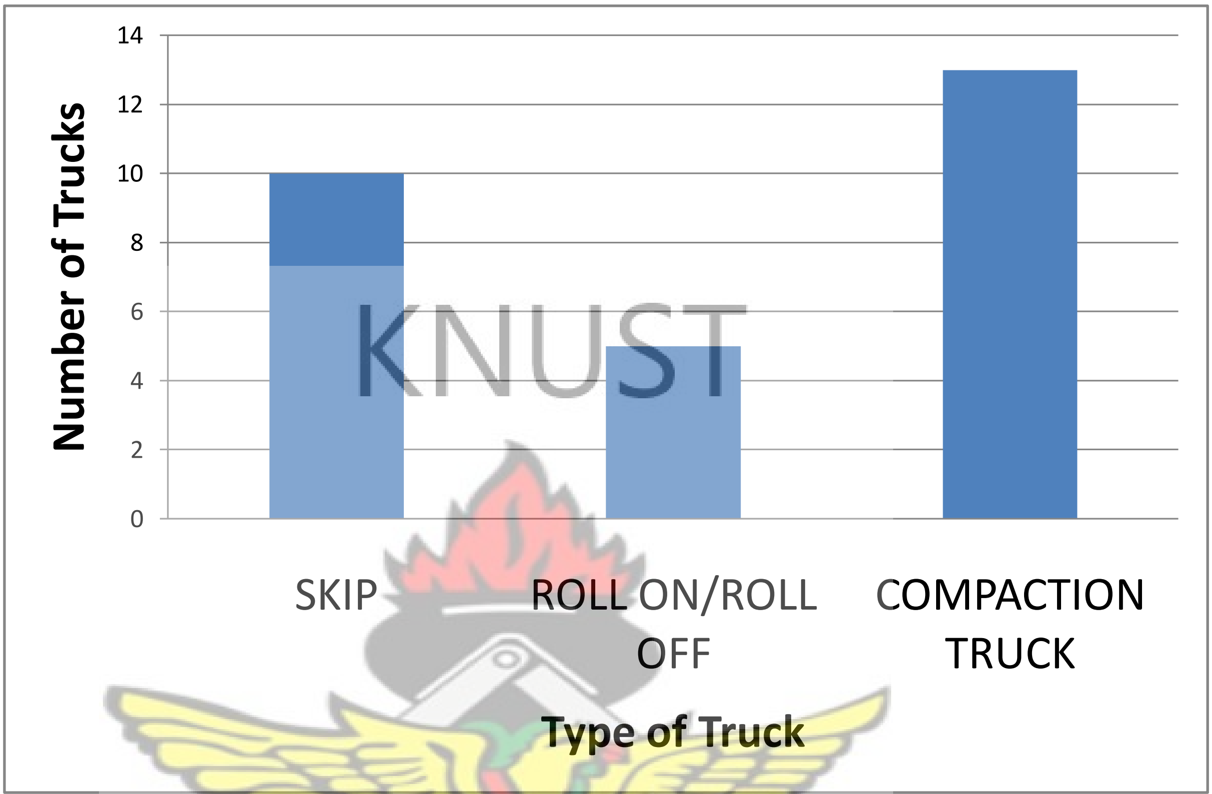

Figure 3-4- Unit of Analysis

3.4 DATA COLLECTION INSTRUMENTS

3.4.1 Data Needs

The data relevant for determining the cost efficiency of the waste trucks in this study included the following: number of trips made by each truck per month, the fuel cost per total number of trips, the estimated total tonnage of waste collected per truck, the tipping fee (money paid at the landfill site for disposal of waste). Other data collected includes the make of the vehicles, the labour cost (both driver and janitors), the cost of repairs and maintenance per truck and the direct operating cost per truck.

3.4.2 Primary Data

Primary data for this study was gathered through questionnaires, interview and observations made during visits to the regional office of the company. A survey questionnaire measuring all the constructs of this study was sent to the company and there was a positive feedback from the company. Data on the number and types of vehicles, quantities of waste collected, and number of trips made by each truck were collected. The direct operating cost and direct efficiency cost of each truck was computed using these records.

3.4.3 Key Informants Interview

Interview with key informants such as the co-ordinating supervisors, the technical supervisor etc. was conducted to find out more about the operation areas of the trucks, the direct operating cost per truck per month, the performance of the trucks and the cost involved in the collection and disposal of waste from the various sub-metros.

3.5 VARIABLES

Variables used in this study were classified as input and output variables.

3.5.1 Input Variables

They are also known as independent variables and can be defined as the variables that have effects on the performance of solid waste trucks. Input variables used in this study include the fuel cost per truck, the cost of repairs and maintenance and the labour cost. The direct operating cost per truck was derived by summing up all the input costs.

3.5.1.1 Fuel Cost (FC)

For every vehicle to be able to move from one point to another point, many factors come into play. One of the most important factors is the availability of fuel (except in the cases of hybrid vehicles). The fuel cost refers to the cost involved in providing a truck with fuel in order for it to be able to carry out its daily operations.It is a product of the total litres of fuel consumed per truck and the cost per litre of fuel.

3.5.1.2 Repairs and Maintenance cost (R&M)

This refers to the cost involved in repairing and maintaining the truck in a good shape so that it would be able to carry out its operations.

3.5.1.3 Labour cost (LC)

This refers to the cost of wages paid to the drivers and janitors during an accounting period on daily, weekly, monthly, or job basis, plus payroll and related taxes and benefits (if any).

3.5.1.4 Direct operating cost (D.O.C)

This can also be referred to as the direct cost involved in carrying out operations. The total direct operating cost is a sum total of all the input variables. The input variables are made up of the fuel cost, the repairs and maintenance cost and the labour cost (this includes the salaries of the driver and the janitors of that truck).

Mathematically, this can be represented by:

$$\boldsymbol{DOC} = \boldsymbol{Fc} + \boldsymbol{R}\&M + Lc \quad \ldots\ldots\ldots\ldots \quad \textbf{Equation 1}$$

Where:

DOC = *Direct operating cost*

Fc = *Fuel cost per truck*

Lc=*Labour cost*

3.5.2 Output Variables

They are also known as dependent variables and like the name clearly states, it is dependent on the input variable. For the purpose of this study, the output variables used are the number of trips made per truck and the estimated total tonnage of waste collected per truck.

3.5.2.1 Number of trips (Nt)

A trip refers to the total distance a vehicle travels from its collection point to its final disposal site. The number of trips a vehicle makes per day or per month is the sum total of the number of tips it goes to make at the landfill site. Factors that would affect the number of trips a vehicle would make in a day includes the condition of the vehicle, the distance from the collection point to the final disposal site, the condition of the road, the traffic condition, the litres of fuel given etc.

3.5.2.2 Estimated total tonnage (Ett)

The estimated total tonnage of a truck is the product of the tons of waste it has been designed to carry and the number of trips the truck is able to make within a specified time frame. This can be represented mathematically as:

$$Ett = Nt \times Wt \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad \text{Equation 2}$$

Where:

Ett = Estimated total tonnage

Nt= Number of trips

Wt= tons of waste.

3.5.3 Total direct efficiency cost

This is a product of the total direct operating cost and the estimated total tonnage of waste per truck. Mathematically, it can be represented as:

$\boldsymbol{D.E.C = D.O.C \div Ett}$ ……………………. **Equation 3**

But $\boldsymbol{DOC = Fc + R}\&M + Lc$ **and** $\boldsymbol{Ett = Nt \times Wt}$

$\therefore \boldsymbol{D.E.C} = (\boldsymbol{Fc + R}\&M + Lc) \div (\boldsymbol{Nt \times Wt})$ ……………………. **Equation 4**

Where:

D.E.C = *Direct Efficiency cost*

D.O.C = *Direct operating cost.*

Ett = *Estimated total tonnage*

Nt =*Number of trips per truck*

Fc=*Fuel cost*

R&M= *Repairs and maintenance cost*

Lc=*Labour cost*

3.6 DATA ANALYSIS

The analysis was conducted by using a computer program DEAP (Coelli, T., 1996), and Microsoft Excel. Data analysis consists of categorizing data, cross-tabulating and carrying out a DEA to assess the variations in cost-efficiency among the trucks. Comparative analyses of the trucks were conducted to assess the variations in cost-efficiency and explore the key factors that contribute to the variations. Comparative analysis was made between the various types of trucks used in the solid waste service delivery within the same category and across different categories to assess the extent of variations in cost-efficiency and establish factors that explain the differences in their cost-efficiency.

3.6.1 DEAP Computer Program.

This is a program written in FORTRAN (Lahey F77LEM/32) for IBM compatible PCs. It is a DOS program but can be easily run form WINDOWS using FILE MANAGER. The program involves a simple batch file system where the user creates a data file and a small file containing instructions. The user starts the program by typing 'DEAP' at the DOS prompt and is then prompted for the name of the instruction file. The program then executes these instructions and produces an output file which can be read using a text editor, such as a NOTEPAD or EDIT, or using a word processor, such as WORD or WORD PERFECT.

3.6.1.1 Data file

The program requires that data be listed in a text file and expects the data to appear in a particular order. The data must be listed by observation (i.e., one row for each firm). There must be a column for each output and each input, with all the outputs listed first and then all inputs listed.

If the cost efficiency option is chosen, then the price information for the inputs will have to be provided. The price columns should be listed to the right of the input data columns and appear in the same order.

If the Malmquist option is chosen, a panel data will be required. The panel must be balanced i.e., all firms must be observed in all time periods.

3.6.1.2 Instruction file

This is a text file which is usually constructed using a text editor or a word processor. The easiest way to create an instruction file is to make a copy of the

DBLANK.INS file which is supplied with the program. This can then be edited and the relevant information typed in.

3.6.1.3 Output file

An output file is a text file which is produced by DEAP when an instruction file is executed. The output file can be read using a text editor, such as NOTEPAD or EDIT, or using a word processor, such as WORD or WORD PERFECT. It can also be imported into a spread sheet program, such as EXCEL or LOTUS. This allows for further manipulation into tables and graphs for subsequent inclusion into report documents.

3.7 CONCEPTUAL FRAMEWORK FOR ANALYSIS

Frameworks are usually described as the abstract, logical structure of the meaning that guides the development of a study. All frameworks are based on the identification of key concepts and the relationship among those concepts. A frameworks can be derived from related concepts (conceptual) or existing theories (theoretical). (Nalzaro, 2012).

Concepts are sometimes seen as foundations of communication which are abstracted from perceptions and are used to convey and transmit information (Nachmias and Nachmias, 1996; Lundeqvist, 1999).

A conceptual framework is used in research to outline possible courses of action or to present a preferred approach to an idea or thought. It consists of concepts that are placed within a logical and sequential design. (Nalzaro, 2012).

Outlined below is a schematic diagram showing the framework for analysis used in this research.

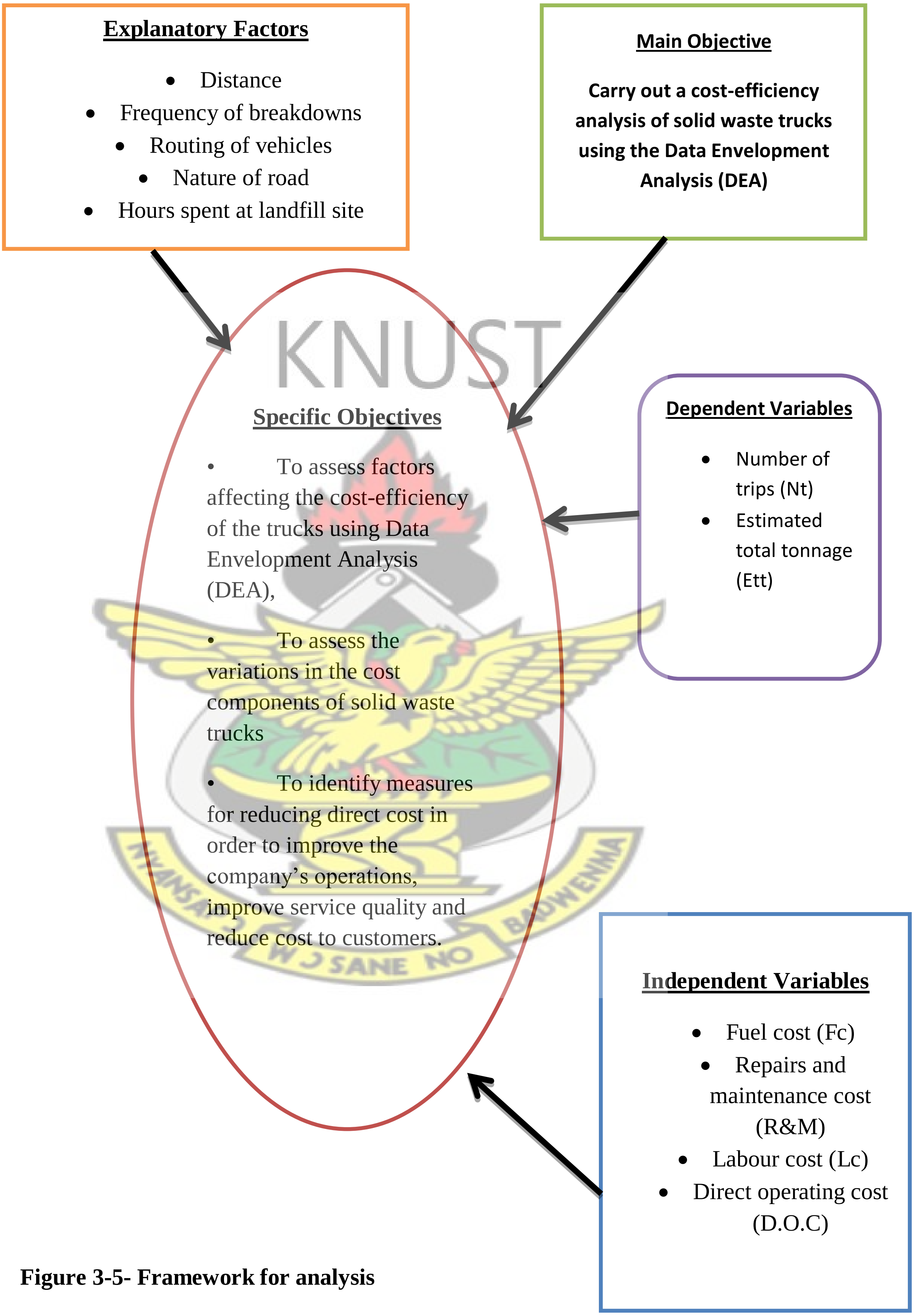

Figure 3-5- Framework for analysis

4 RESULTS AND DISCUSSIONS

4.1 CHARACTERISTICS OF THE TRUCKS

The main types of trucks used by the company in its operations are the skip trucks, the roll-on/roll-off trucks and the compactor trucks. The skip trucks and the roll-on/roll-off trucks are mainly used for communal collection of solid waste whereas the compactor trucks are mainly used for door-to-door collection of waste.

The company uses mostly 12m³ skip trucks, 23m³ roll-on/roll-off trucks and 18m³ compaction trucks.

4.1.1 Make of the Truck.

The trucks used are mainly Dongfeng and Ashok Leyland trucks. Dongfeng trucks are produced by Dongfeng Motor Corporation in China whereas the Ashok Leyland trucks are manufactured by a company in India. Table 4-1 gives a presentation the details of the solid waste trucks

Table 4-1- Details of Truck

TYPE OF VEHICLE	VEHICLE REG NO.	MAKE	CAPACITY (m³)	TONNAGE OF TRUCK (m³)
SKIP	GT 423 Z	Donfeng	12	6
SKIP	GN 8489-11	Donfeng	12	6
SKIP	GN 273-11	Donfeng	12	6
SKIP	GE 6477 X	Donfeng	12	6
SKIP	GT 412 Z	Donfeng	12	6
SKIP	GS 3889-09	Donfeng	12	6
SKIP	GS 3750-09	Donfeng	12	6

SKIP	GS 3680-09	Donfeng	12	6
SKIP	GT 1665-11	Donfeng	12	6
SKIP	GS 3681-09	Donfeng	12	6
ROLL-ON	GW 1208 Z	Donfeng	23	11.5
ROLL-ON	GW 3446 Z	Donfeng	23	11.5
ROLL-ON	GW 5313 Z	Donfeng	23	11.5
ROLL-ON	GW 594 Z	Donfeng	23	11.5
ROLL-ON	GS 567-09	Donfeng	23	11.5
COMP	GT 2007-12	Ashok Leyland	18	9
COMP	GT 2265-12	Ashok Leyland	18	9
COMP	GT 9214-10	Ashok Leyland	18	9
COMP	GT 9215-10	Ashok Leyland	18	9
COMP	GT 9213-10	Ashok Leyland	18	9
COMP	GS 3128-09	Ashok Leyland	18	9
COMP	GS 3129-09	Ashok Leyland	18	9
COMP	GS 2038 Z	Ashok Leyland	18	9
COMP	GT 2138-10	Ashok Leyland	18	9
COMP	GE 9970-09	Ashok Leyland	18	9
COMP	GT 9303-11	Ashok Leyland	18	9
COMP	GS 568-09	Ashok Leyland	18	9
COMP	GS 3674-09	Ashok Leyland	18	9

4.2 ANALYZING TECHNICAL-EFFICIENCY USING DEAP

Technical efficiency is defined as the conversion of physical inputs (such as the services of employees and machines) into outputs relative to best practice. In other words, given current technology, there is no wastage of inputs whatsoever in producing the given quantity of output. An organization operating at best practice is said to be 100% technically efficient. If operating below best practice levels, then the organization's technical efficiency is expressed as a percentage of best practice. (Bhagavath, 1997).

An input orientated variable return to scale was used to determine the efficiency measures in this study. In the DEAP, any shortfall of a truck from the 100% or 1 technical efficiency mark means that there is inefficiency or use of excess resources equivalent to the shortfall in efficiency. Table 4-2, presents the summary of technical efficiency results for the 28 solid waste trucks. The technical efficiency results show that out of the 28 trucks, 9 trucks were found to have a technical efficiency of 1. The results also showed that out of the 28 trucks, none was found to have an efficiency rating of less than 50% or 0.5. Thus, 28 of the solid waste trucks were above an average of 50% or 0.5.From this figure, 3 skip trucks, 2 roll-on/roll-off trucks and 4 compaction trucks were found to be fully efficient i.e., attained an efficiency score of 1 and as a result lie exactly on the technical efficient score of 1. Also from the graph, it can be realized that all of the trucks were above a 0.5 efficient level.

Table 4-2-Technical Efficiency Summary for Solid Waste Trucks

TECHNICAL EFFICIENCY SUMMARY FOR TRUCKS				
		SKIP TRUCKS		
Truck	**crste**	**vrste**	**scale**	**return to scale**
1	0.71	0.912	0.799	irs
2	0.937	1	0.937	drs
3	0.785	0.789	0.995	irs
4	1	1	1	
5	0.752	0.784	0.959	irs
6	0.693	1	0.693	irs
7	0.834	0.872	0.957	irs
8	0.677	0.788	0.859	irs
9	0.59	0.772	0.765	irs
10	0.877	0.886	0.99	drs
mean	**0.786**	**0.88**	**0.893**	
		ROLL-ON/ROLL-OFF TRUCKS		
Truck	**crste**	**vrste**	**scale**	**return to scale**
1	0.844	0.991	0.852	irs
2	1	1	1	
3	0.762	0.889	0.857	irs
4	0.733	1	0.733	irs
5	0.799	0.816	0.979	irs
mean	**0.828**	**0.939**	**0.884**	

COMPACTION TRUCKS				
Truck	**crste**	**vrste**	**scale**	**return to scale**
1	0.632	0.743	0.852	irs
2	0.659	0.92	0.716	irs
3	0.987	1	0.987	drs
4	0.85	0.873	0.974	drs
5	0.924	1	0.924	drs
6	0.777	0.851	0.913	irs
7	0.875	0.922	0.949	irs
8	0.628	0.879	0.715	irs
9	0.773	0.85	0.91	irs
10	0.485	1	0.485	irs
11	0.577	0.853	0.677	irs
12	0.921	0.921	1	
13	1	1	1	
mean	**0.776**	**0.909**	**0.854**	

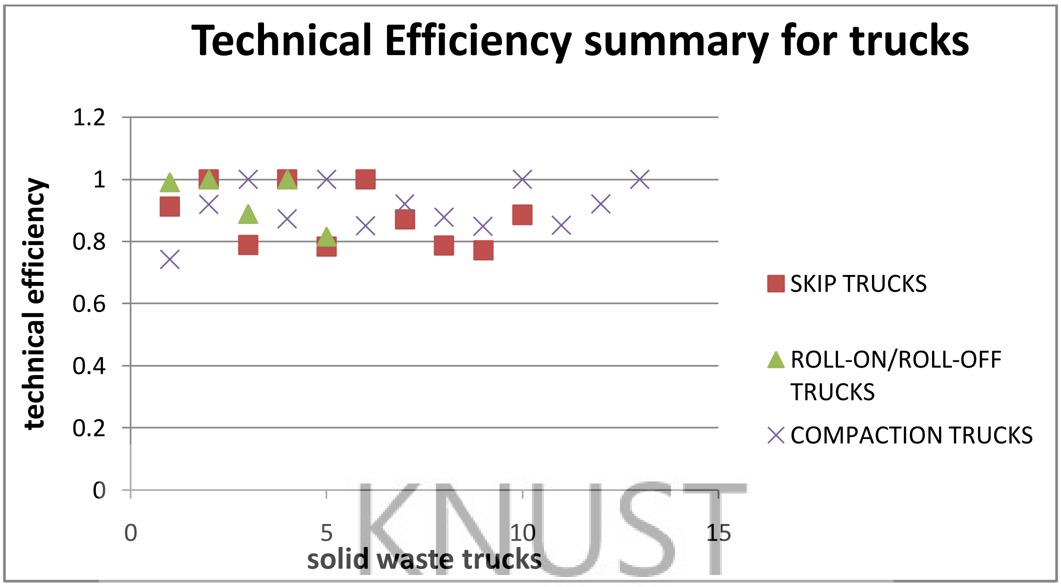

Figure 4-1- Technical Efficiency Summary for Trucks

4.2.1 Skip trucks

Using the DEAP, a value of 1 or 100% is assigned to a decision making unit (DMU), which is technically efficient. Any value less than this imply that the DMU is not technically efficient. From Table 4-3, Truck 2 (GN 8489-11), truck 4 (GE 6477X) and truck 6(GS 3889-09) have a technical efficiency value of 1 and so can be concluded to be technically efficient. The other seven trucks recorded values less than 1.

From Table 4-3, under the assumption of the variable return to scale (VRS), the average technical efficiency score for the skip trucks is 0.88 which implies that on the average, the skip trucks could have used 0.12 fewer resources for the same amount of output.

Under the constant return to scale (CRS) assumption, the average technical efficiency score is 0.786 and this is less than the average efficiency under VRS. The average score under scale efficiency is 0.893. This implies that on an average, the scale of operation has shifted from the most productive scale by 0.107.

From Table 4-3, only 1 truck (GE 6477X) is found to have a unity scale efficiency score, which means it operates at the most productive scale size and only 3 trucks are found to have a unity technical efficiency score and these are trucks GN 8489-11, GE 6477 X and GS 3889-09.

Table 4-3- Technical Efficiency Results for Skip Trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR SKIP TRUCKS				
Truck	**crste**	**vrste**	**scale**	
1	0.71	0.912	0.799	irs
2	0.937	1	0.937	drs
3	0.785	0.789	0.995	irs
4	1	1	1	
5	0.752	0.784	0.959	irs
6	0.693	1	0.693	irs
7	0.834	0.872	0.957	irs
8	0.677	0.788	0.859	irs
9	0.59	0.772	0.765	irs
10	0.877	0.886	0.99	drs
mean	**0.786**	**0.88**	**0.893**	
Note: crste = technical efficiency from CRS DEA				

vrste= technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste

4.2.2 Roll-on/Roll-off Trucks

From Table 4-4, the average technical efficiency recorded under the assumption of the variable return to scale (VRS) for roll-on/roll-off trucks are 0.939. This implies that on an average, the roll-on/roll-off trucks could have used 0.061 less fuel to produce the same amount of output. The average technical efficiency recorded under the CRS assumption was 0.828 and this is less than that which was recorded for VRS. For scale efficiency, the mean score is found to be 0.884. This means that on an average, the actual scale of output has diverged from the most productive scale by 0.116. Also from the table, it is observed that out of the five trucks, only two are found to be technically efficient. These are trucks are GW 3446 Z and GW 594 Z.

Table 4-4-Technical Efficiency Results for Roll-on/Roll-off trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR SKIP TRUCKS				
Truck	**crste**	**vrste**	**scale**	**return to scale**
1	0.844	0.991	0.852	irs
2	1	1	1	
3	0.762	0.889	0.857	irs
4	0.733	1	0.733	irs
5	0.799	0.816	0.979	irs

Mean	0.828	0.939	0.884	
Note: crste = technical efficiency from CRS DEA				
vrste= technical efficiency from VRS DEA				
scale = scale efficiency = crste/vrste				

4.2.3 Compaction Trucks

From Table 4-5, the average technical efficiency recorded under the assumption of the variable return to scale (VRS) for compaction trucks are 0.909. This implies that on an average, the compaction trucks could have used 0.091 less fuel to produce the same amount of output. The average technical efficiency recorded under the CRS assumption was 0.776 and this is less than that which was recorded for VRS. For scale efficiency, the mean score is found to be 0.854. This means that on an average, the actual scale of output has diverged from the most productive scale by 0.146. Also from the table, it is observed that out of the thirteen trucks, only four are found to be technically efficient. These are trucks are GT 9214-10, GT 9213-10, GE9970-09 and GS 3674-09.

Table 4-5- Technical Efficiency Results for Compaction trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR COMPACTION TRUCKS				
Truck	**crste**	**vrste**	**scale**	
1	0.632	0.743	0.852	irs
2	0.659	0.92	0.716	irs

3	0.987	1	0.987	drs
4	0.85	0.873	0.974	drs
5	0.924	1	0.924	drs
6	0.777	0.851	0.913	irs
7	0.875	0.922	0.949	irs
8	0.628	0.879	0.715	irs
9	0.773	0.85	0.91	irs
10	0.485	1	0.485	irs
11	0.577	0.853	0.677	irs
12	0.921	0.921	1	
13	1	1	1	
mean	**0.776**	**0.909**	**0.854**	
Note: crste = technical efficiency from CRS DEA				
vrste= technical efficiency from VRS DEA				
scale = scale efficiency = crste/vrste				

4.3 ANALYZING COST-EFFICIENCY USING DEAP

Cost efficiency refers to the combination of technical and allocative efficiency. A truck will only be cost efficient if it is both technically and allocatively efficient. Cost efficiency is calculated as the product of the technical and allocative efficiency scores (expressed as a percentage), so truck can only achieve a 100% score in cost efficiency if it has achieved 100% in both technical and allocative efficiency (Bhagavath,1997).

The cost-efficiency score for the trucks were determined using the DEAP Version 2.1 under a Constant Returns to Scale input-orientated DEA model. The output variable used for this analysis was the estimated total tonnage whereas the input variables used were the fuel cost and repairs and maintenance cost of each truck. In calculating the cost-efficiency of the trucks, there is the need to include a price data. The price data used for the analysis are the tipping fees and the labour cost which is constant for all the trucks. In this analysis, both the allocative efficiency and the cost efficiency for each truck are calculated.

From the results, only 3 trucks are operating at a 100% cost-efficiency level. The breakdown is as follows: 1 skip truck, 1 roll-on/roll-off truck and 1 compaction truck.

Amean of the cost efficiency scores for each truck type (i.e. skip, roll-on/roll-off or compaction) was calculated to find out which one was more cost efficient and which truck type was less cost efficient. From the analysis, roll-on/roll-off trucks on an average recorded higher cost efficiency because compared to the other trucks (skip and compaction trucks).

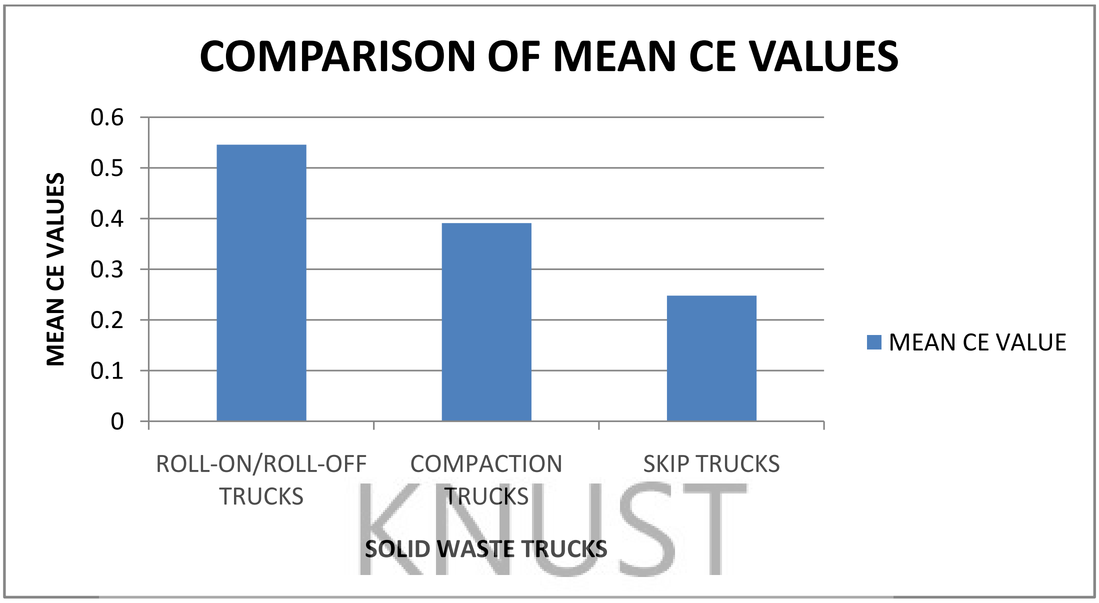

Figure 4-2 Comparison of mean CE values

4.3.1 Skip Trucks

Table 4-6 presents the cost-efficiency summary for skip trucks. From the table, the average cost efficiency score for the trucks is 0.248 (24.8%), the average allocative efficiency score is 0.222 (22.2%) and the average technical efficiency score is 0.933 (93.3%).

From the results, the company could improve the cost-efficiency of the trucks by 75.2% on average. The allocative inefficiency for the trucks seems higher than the technical inefficiency; this suggests that the dominant source of cost inefficiency of the trucks is allocative rather than technical. Comparing their averages, the trucks could improve their technical efficiency by 6.7% and allocative efficiency by 77.8%.

Table 4-6- Cost-Efficiency Summary for Skip Trucks

COST EFFICIENCY DEA FOR SKIP TRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	TE	AE	CE
1	0.804	0.293	0.235
2	1	0.39	0.39
3	0.828	0.13	0.108
4	0.708	0.15	0.106
5	0.795	0.086	0.068
6	0.742	0.097	0.072
7	0.861	0.281	0.242
8	0.827	0.066	0.054
9	1	1	1
10	0.933	0.222	0.207
MEAN	**0.85**	**0.271**	**0.248**
Note: TE = Technical Efficiency			
AE = Allocative Efficiency			
CE = Cost Efficiency			

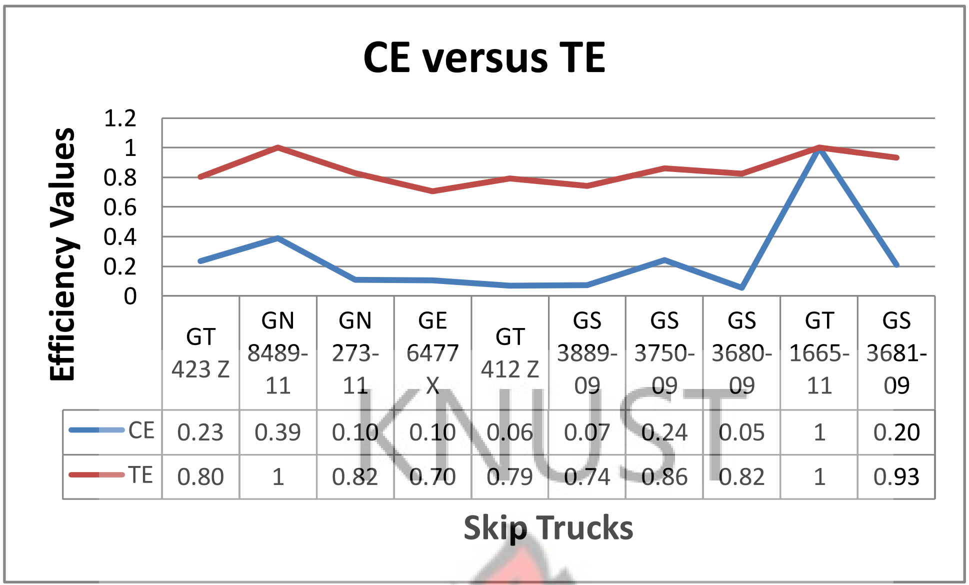

Figure 4-3 - - Cost-Efficiency values against Technical-Efficiency values

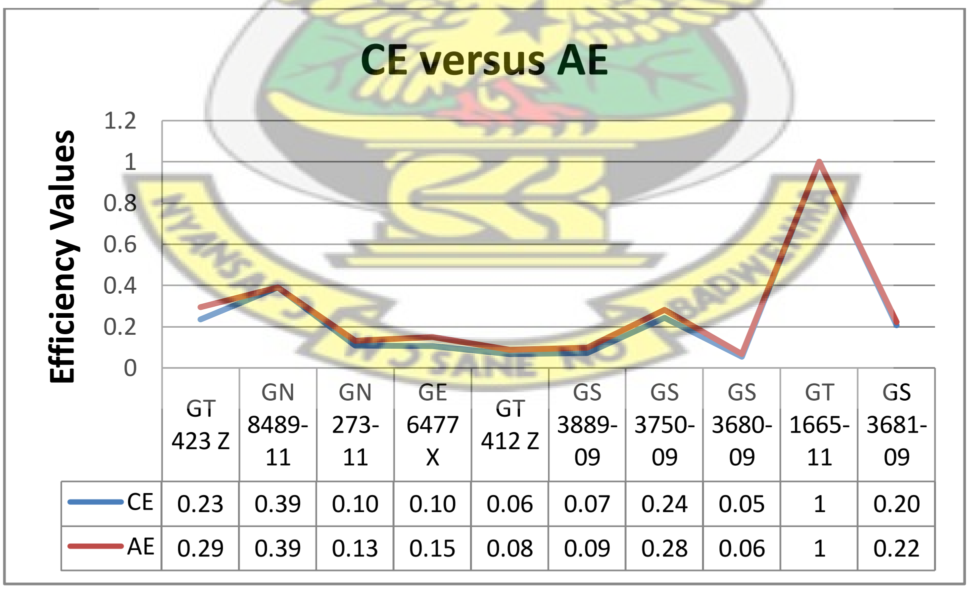

Figure 4-4 - Cost Efficiency values versus Allocative Efficiency values

4.3.2 Roll-on/Roll-off Trucks

From Table 4-7, the average technical efficiency score recorded is 0.821 (82.1%), the average allocative efficiency score recorded is 0.618 (61.8%) and the average cost efficiency score recorded is 0.545 (54.5%).

From Figure 4-5 and Figure 4-6, in comparing the technical efficiency scores and the allocative efficiency scores for roll-on/roll-off trucks, it can be deduced that the scores for the technical efficiency is almost higher than that for the allocative efficiency. Allocative inefficiency is always higher than the technical inefficiency except in the cases of trucks 1 and 2. The dominant source of cost inefficiency can be as a result of the allocative inefficiencies of the trucks. On an average, the truck could improve its technical efficiency by 17.9% and allocative efficiency by 38.2%.

Table 4-7- Cost Efficiency Summary for Roll-on/Roll-off Trucks

COST EFFICIENCY DEA FOR ROLL-ON/ROLL-OFF TRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	TE	AE	CE
1	0.928	0.99	0.919
2	1	1	1
3	0.758	0.513	0.389
4	0.672	0.281	0.189
5	0.749	0.309	0.231
MEAN	**0.821**	**0.618**	**0.545**
Note: TE = Technical Efficiency			
AE = Allocative EfficiencyCE = Cost Efficiency			

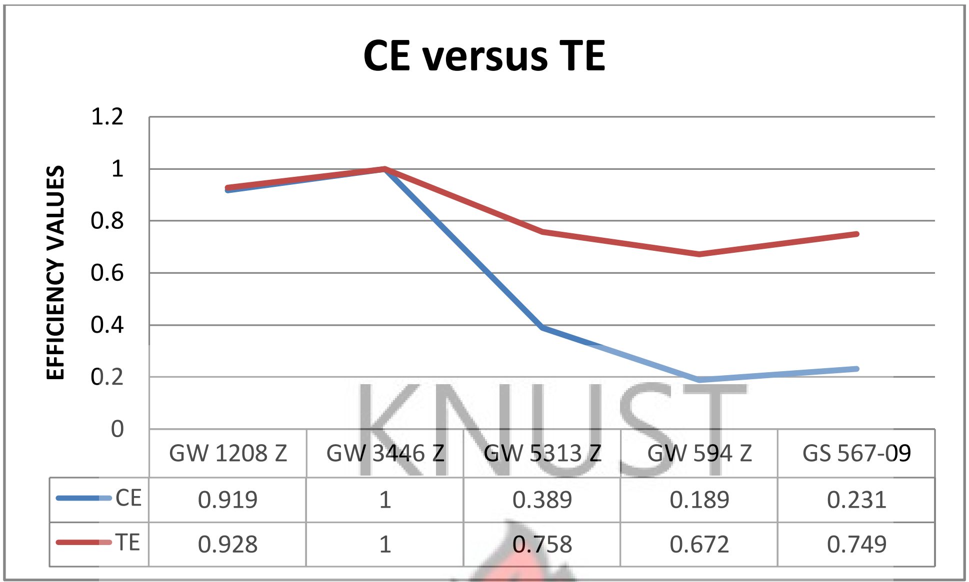

Figure 4-5 - Cost-Efficiency values against Technical-Efficiency values

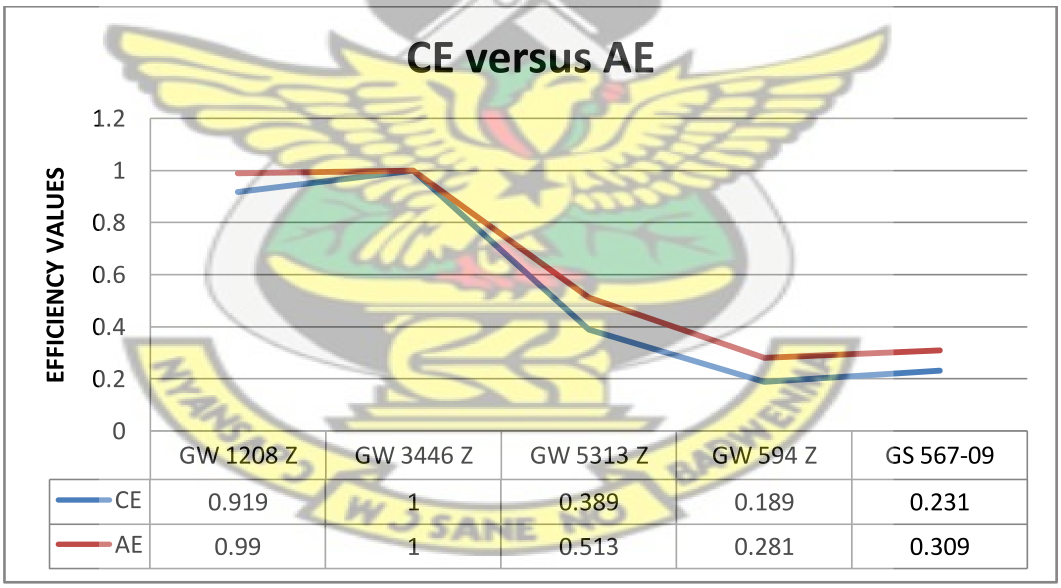

Figure 4-6 - Cost-Efficiency values against Allocative-Efficiency values

4.3.3 Compaction Trucks

Table 4-8 presents the cost-efficiency summary for compaction trucks. From the table, the average cost efficiency score for the trucks is 0.391 (39.1%), the average allocative efficiency score is 0.435 (43.5%) and the average technical efficiency score is 0.883 (88.3%).

From the results, the company could improve the cost-efficiency of the trucks by 60.9% on average. Comparing Figure 4-7 and Figure 4-8, it can be deduced that the allocative inefficiency for the trucks seems higher than the technical inefficiency; this suggests that the dominant source of cost inefficiency of the trucks is allocative rather than technical. Comparing their averages, the trucks could improve their technical efficiency by 11.7% and allocative efficiency by 56.5%.

Table 4-8- Cost Efficiency Summary for Compaction Trucks

COST EFFICIENCY DEA FOR COMPACTIONTRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	TE	AE	CE
1	0.833	0.585	0.487
2	0.925	0.652	0.603
3	1	0.332	0.332
4	0.856	0.291	0.249
5	0.898	0.181	0.163
6	0.753	0.18	0.135
7	1	0.532	0.532

8	0.913	0.685	0.625
9	0.811	0.381	0.309
10	0.548	0.377	0.207
11	1	1	1
12	0.94	0.266	0.25
13	1	0.194	0.194
MEAN	**0.883**	**0.435**	**0.391**
Note: TE = Technical Efficiency			
AE = Allocative Efficiency			
CE = Cost Efficiency			

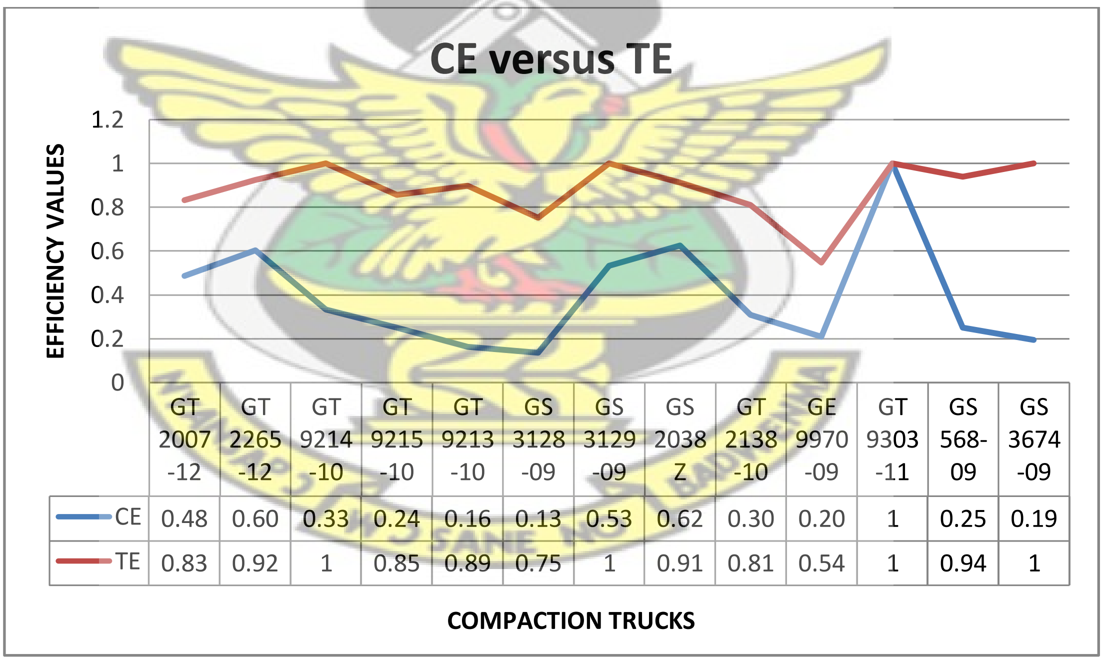

Figure 4-7 - Cost-Efficiency values against Technical-Efficiency values

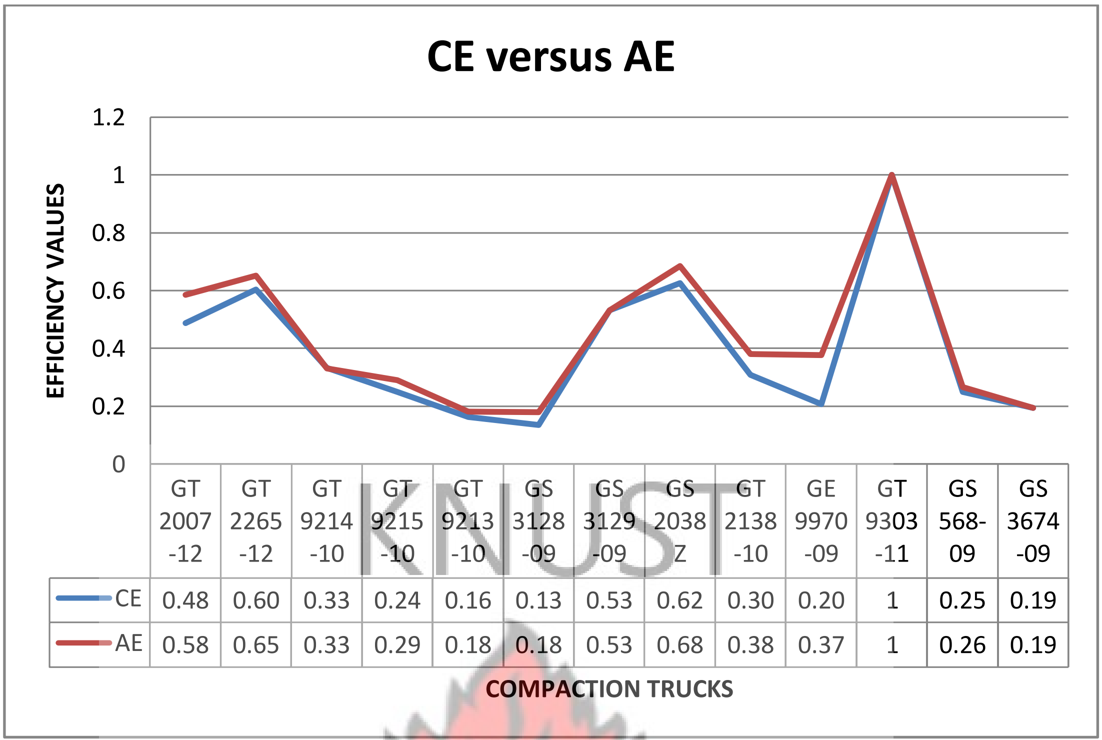

Figure 4-8 - Cost-Efficiency values against Allocative-Efficiency values

4.4 FACTORS AFFECTING COST-EFFICIENCY VALUES OF SOLID WASTE TRUCKS

Efficiency can be defined as the extent to which a program or organization converts or is expected to convert its resources or inputs economically into results in order to achieve the maximum possible outputs with minimum possible inputs. An attempt of cost efficiency relates the results of a program to its cost.

Cost-variations analysis among trucks was carried out to identify the various cost differences and identify the factors that contribute to these variations. This was carried out to measure the extent to which the age of the trucks and the distances they cover in their operation have an effect on the cost efficiency scores. A critical study of the trucks reveals that some of cost efficiency scores recorded was higher than others.

4.4.1 Distance

This refers to the distance travelled by each truck from its area of operation to its final disposal site. Currently, all trucks use for this study has their final disposal site to be Kpone in the Tema Municipality. The exact distances travelled by the trucks are not available as a result of malfunctioning of their odometers. However, an approximated distance was considered for the purposes of this study and this to an extent is a true representation of the actual distance.

Figure 4-2, shows a map indicating the distance (route) travelled by trucks operating in the Ablekuma Central municipal assembly through the Tema Motorway. The approximated distance from Ablekuma to Kpone is about 45.9 km (which is about 49 minutes' drive on a light traffic day). Due to the traffic nature of the road during the rush hours of the day (i.e. mornings and evenings), drivers tend to spend more than the approximated time on the road. From the study, it was revealed that most of the drivers spend close to an hour or two hours, on a heavy traffic day. The longer a vehicle spends in traffic, the more litres of fuel it consumes. This in the long run affects the number of estimated trips each truck will make and also increases the fuel consumption per truck.

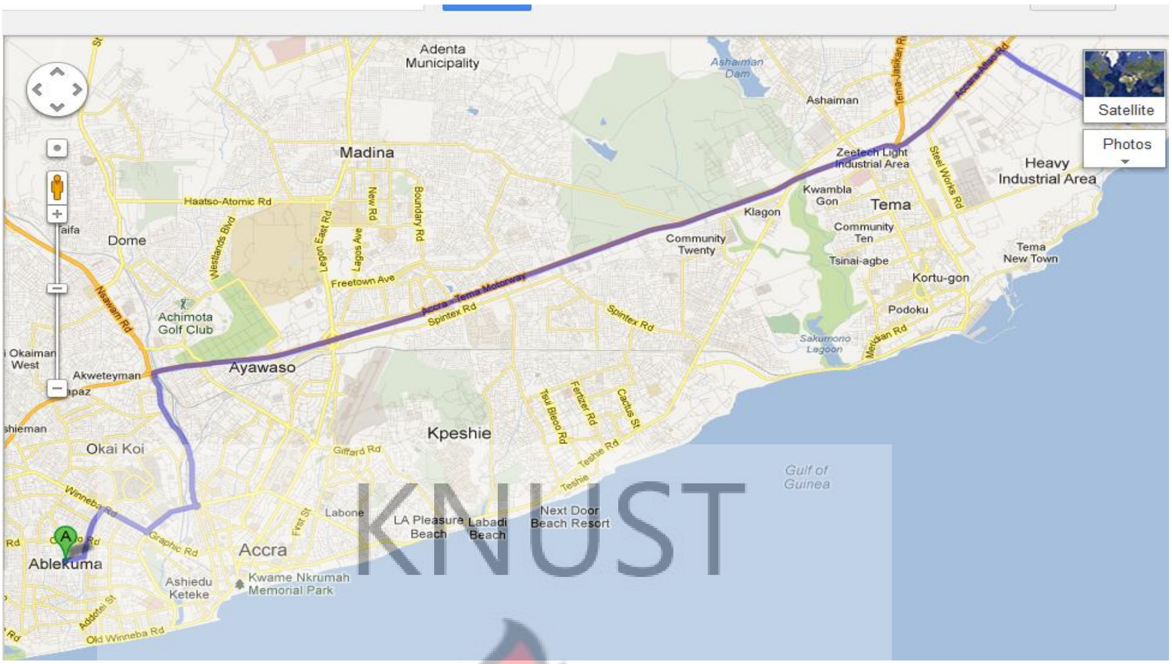

Figure 4-9- Map showing Distance between Ablekuma and Kpone, Tema

Trucks travelling from the Ayawaso sub-metropolitan assembly travel an approximated distance of 31.6 km (which is about 32 minutes' drive on a light traffic day) to Kpone, through the Tema Motorway. Findings from the study revealed that truck drivers spend close to about an hour on the road. This automatically increases the rate of fuel consumption and also to an extent affect the number of trips they make.

Figure 4-10- Map showing Distance between Ayawaso and Kpone, Tema

Lastly, there are also some trucks (compaction trucks) that operate in the Makola market. These trucks travel an average approximated distance of 38.5 km (which is about 42 minutes' drive on a light traffic day). From the study, it was again revealed that these trucks spend an average of 1-2hours on the way due to the heavy traffic situation on the route.

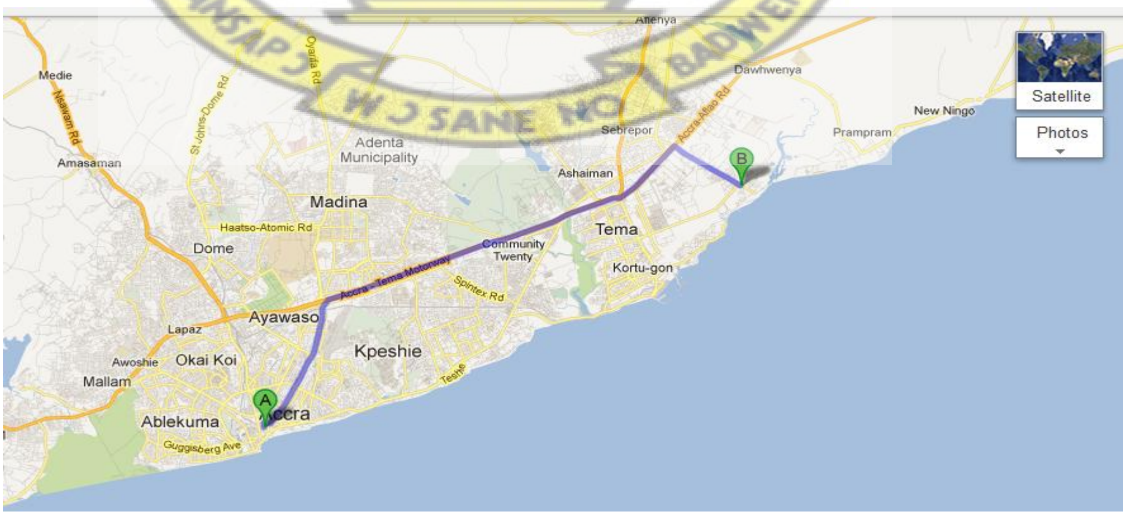

Figure 4-11- Map showing Distance between Makola and Kpone, Tema

The traffic conditions prevailing on a particular road determines how much fuel a truck will consume during its operations. The longer the traffic situation, the much more fuel consumed due to the travelling rate of the cars (slower travelling rate). The situation is different when the traffic condition is shorter (vehicles will move at a much faster rate). The Tema Motorway road, depending on the time of the day, can be a heavy-traffic route or a light traffic-route. Heavy traffic hours occur in the mornings between the hours of 7am to 10am (19:00-22:00 hours) and in the evenings between the hours of 6pm-9pm (18:00-21:00hours) in areas around the toll booth and the Tema roundabout.

4.4.2 Age of Trucks.

The age of a truck will tend to have a significant effect on its performance. A comparative analysis was carried out between the cost-efficiency scores of the trucks to see how new trucks perform against old trucks. From the study, findings revealed generally, the newer trucks (i.e. trucks that have been in operation for a year) have higher cost efficiency scores compared to the older ones (i.e. trucks that have been in operation for four years and above)

4.4.2.1 Skip Trucks

Comparing the cost efficiency scores of trucks (since they are all new trucks) GN 8489-11, GN 273-11 and GT 1665-11, truck GT 1655-11 gained a score of 1 as compared to the other two trucks. Truck GT 1665-11 travels an approximate distance of 34km whereas trucks GN8489-11 and GN 273-11 travel an approximate distance of 32.6km and 33.6km respectively. One would expect that truck GN 8489-11, will record a higher efficiency value since it travels a much shorter distance compared to the other two trucks, but this is however not the issue. This can be attributed to other factors such as the traffic conditions on the route that it uses or the nature of the road.

Considering the other trucks that have been in operation for four years, comparing trucks GT 423 Z, GT 412 Z and GS 3680-09, since they operate in the same sub-metropolitan area (Ayawaso Central) and travel the same distance, from Table 4-10, GT 412 Z, recorded the highest cost efficiency score of 0.235 than the other two trucks. Figure 4-5, gives a graphical illustration and shows the trend of the variations.

Table 4-9- Inventory of Skip Trucks

VEHICLE REG NO.	***AREA OF OPERATION***	***AVERAGE DISTANCE TRAVELED***	***FINAL DUMPING SITE***	***AGE OF THE TRUCK***	***CE***
GN 8489-11	AYAWASO EAST	32.6	TEMA (KPONG)	1	0.39
GN 273-11	AYAWASO CENTRAL	33.6	TEMA (KPONG)	1	0.108
GT 1665-11	AMA	34		1	1
GT 423 Z	AYAWASO CENTRAL	33.6	TEMA (KPONG)	4	0.235
GE 6477 X	OSU KLOTTEY	36.5	TEMA (KPONG)	4	0.106
GT 412 Z	AYAWASO CENTRAL	33.6	TEMA (KPONG)	4	0.068
GS 3889-09	ABLEKUMA SOUTH	51.5	TEMA (KPONG)	4	0.072

GS 3750-09	ABLEKUMA CENTRAL	49.5	TEMA (KPONG)	4	0.242
GS 3680-09	AYAWASO CENTRAL	33.6	TEMA (KPONG)	4	0.054
GS 3681-09	AYAWASO EAST	32.6	TEMA (KPONG)	4	0.207

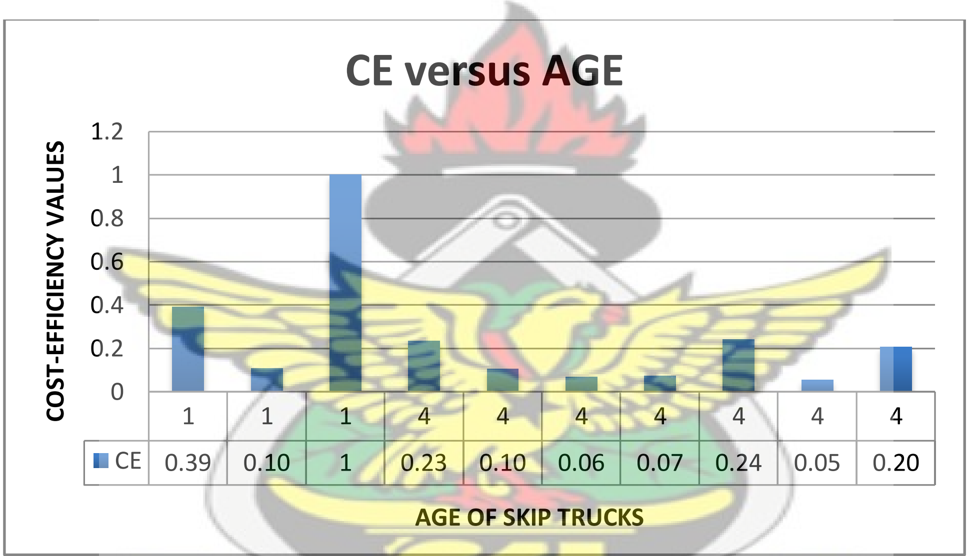

Figure 4-12 - Cost Efficiency scores against Age of skip Trucks.

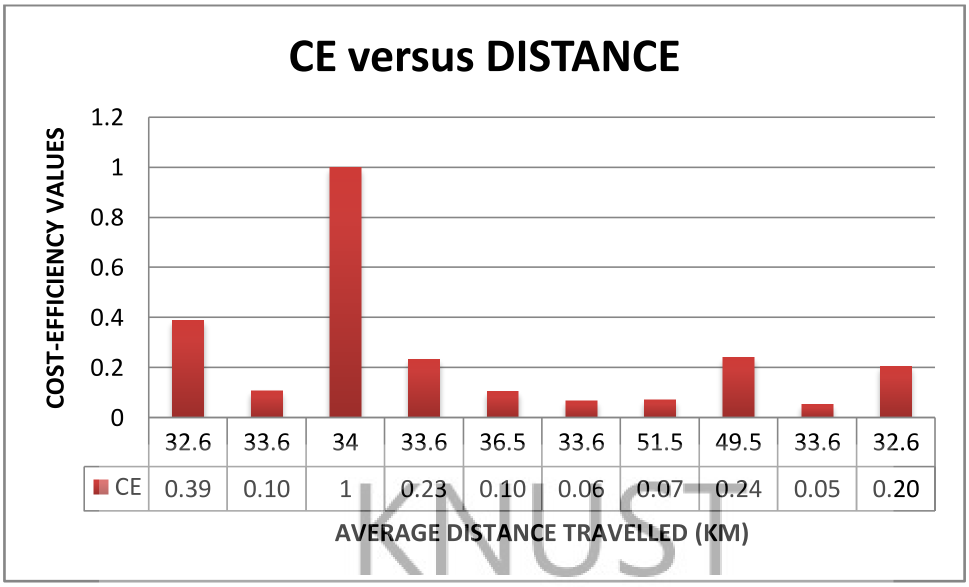

Figure 4-13 -Cost Efficiency scores against Average Distance Travelled (km)

4.4.2.2 Roll-on/Roll-off Trucks

Comparing the cost efficiency scores of all the trucks (since they have all been in operation for the same number of years), it can be deduced that the shorter the travel distance, the higher the cost efficiency score. GW 3446 Z operates in the Ayawaso west sub-metropolitan area, which is about 31.6 km whereas GS 567-09 operates in the Makola Market Center, which is about 38.5 km. GS 567-09 travels a longer distance, hence would consume more fuel but not make more trips as compared to GW 3446 Z which travels a shorter distance and is therefore able to make a lot more trips. Figure 4-6 gives a graphical representation and shows the trend.

Table 4-10- Inventory of Roll-on/Roll-off Trucks

VEHICLE REG NO.	AREA OF OPERATION	AVERAGE DISTANCE TRAVELED	FINAL DUMPING SITE	AGE OF THE TRUCK	CE
GW 1208 Z	AYAWASO WEST	31.6	TEMA (KPONG)	4	0.919
GW 3446 Z	AYAWASO WEST	31.6	TEMA (KPONG)	4	1
GW 5313 Z	AYAWASO CENTRAL	32.6	TEMA (KPONG)	4	0.389
GW 594 Z	ABLEKUMA SOUTH	51.5	TEMA (KPONG)	4	0.189
GS 567-09	MAKOLA	38.5	TEMA (KPONG)	4	0.231

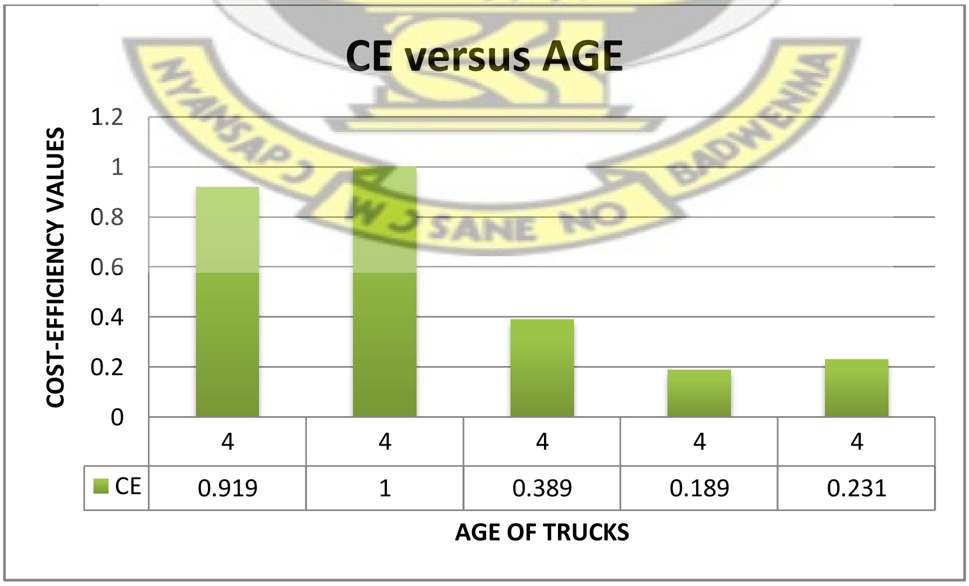

Figure 4-14- Fuel cost against estimated tonnage of waste per truck

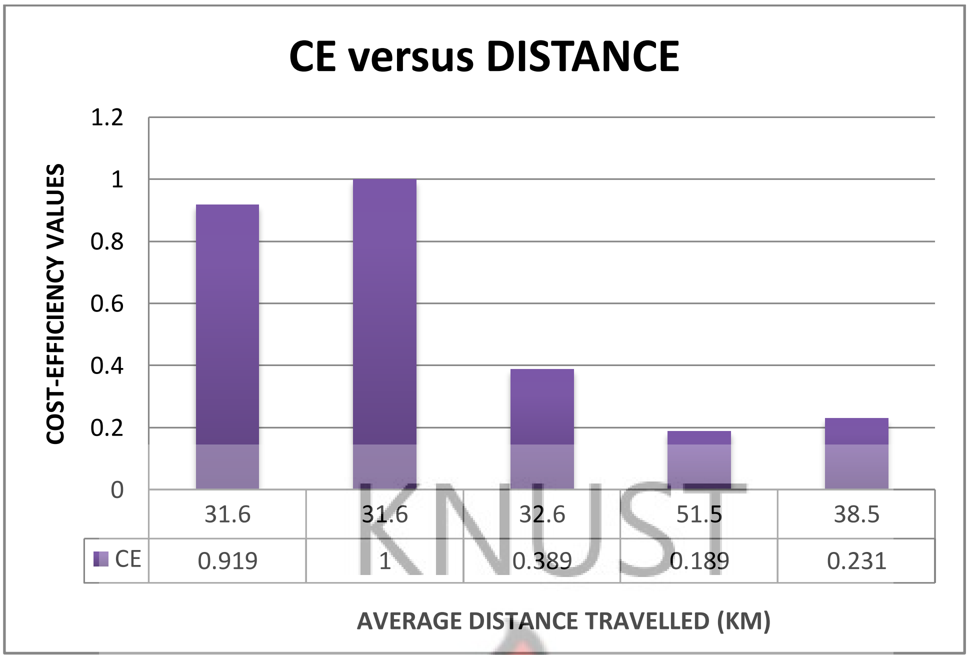

Figure 4-15 - Cost Efficiency Score versus Average Distance Travelled (in km)

4.4.2.3 Compaction Trucks

Comparing the cost efficiency scores of all the trucks, using the distance they travel (they all travel the same distance), generally, it can be concluded that the newer trucks (trucks that have been in operation for a year or less) recorded a relatively higher cost efficiency score compared to the older trucks.

Table 4-11- Inventory of Compaction Trucks

VEHICLE REG NO.	AREA OF OPERATION	AVERAGE DISTANCE TRAVELED (KM)	FINAL DUMPING SITE	AGE OF THE TRUCK	CE
GT 2007-12	MAKOLA	38.5	TEMA (KPONG)	1	0.487
GT 2265-12	MAKOLA	38.5	TEMA (KPONG)	1	0.603
GT 9303-11	MAKOLA	38.5	TEMA (KPONG)	1	1
GT 9214-10	MAKOLA	38.5	TEMA (KPONG)	2	0.332
GT 9215-10	MAKOLA	38.5	TEMA (KPONG)	2	0.249
GT 9213-10	MAKOLA	38.5	TEMA (KPONG)	2	0.163
GT 2138-10	MAKOLA	38.5	TEMA (KPONG)	3	0.309
GS 3128-09	MAKOLA	38.5	TEMA (KPONG)	4	0.135
GS 3129-09	MAKOLA	38.5	TEMA (KPONG)	4	0.532
GS 2038 Z	MAKOLA	38.5	TEMA (KPONG)	4	0.625
GE 9970-09	MAKOLA	38.5	TEMA (KPONG)	4	0.207
GS 568-09	MAKOLA	38.5	TEMA (KPONG)	4	0.25
GS 3674-09	MAKOLA	38.5	TEMA (KPONG)	4	0.194

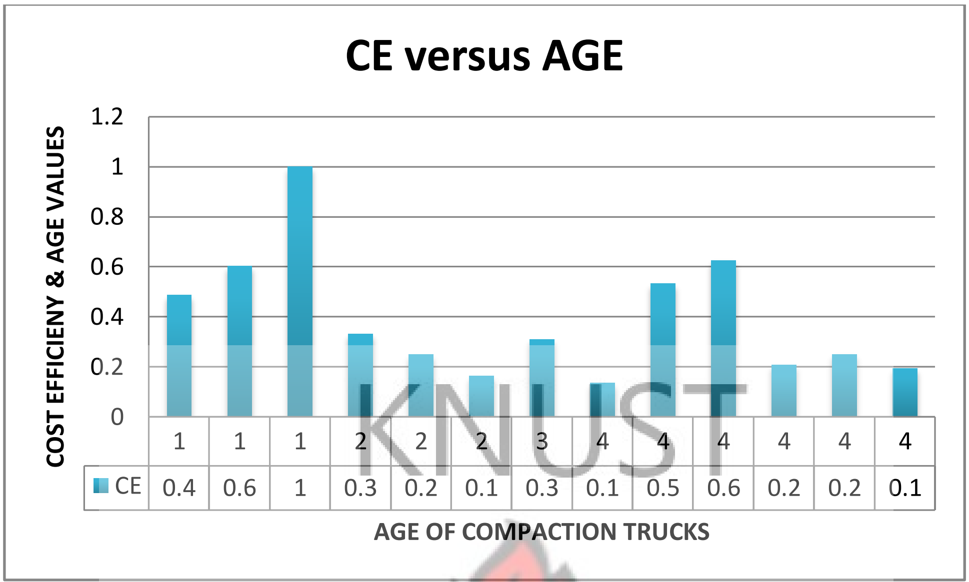

Figure 4-16 - Cost-Efficiency Scores versus Age of Compaction trucks

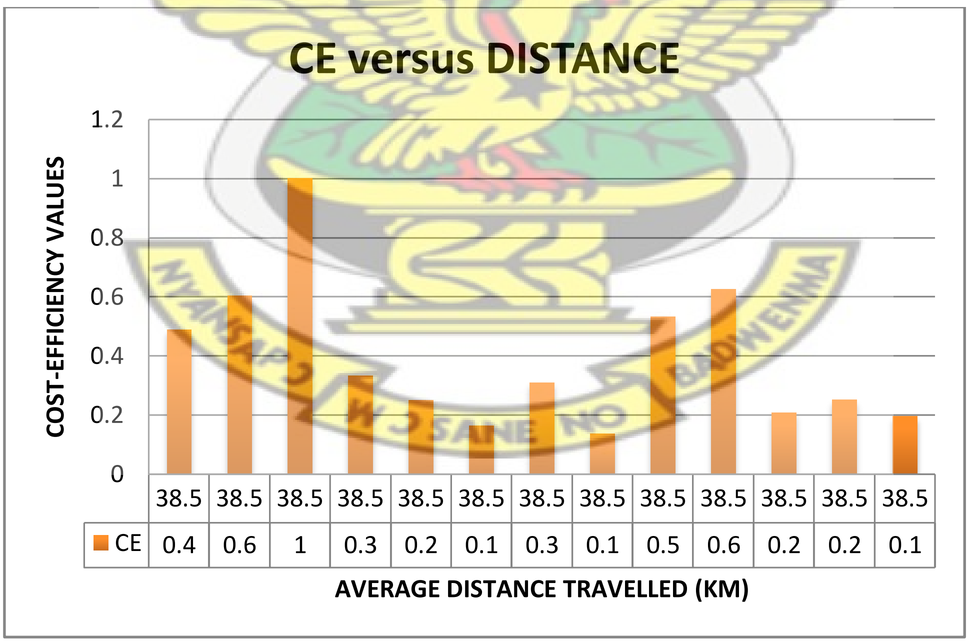

Figure 4-17 - Cost-Efficiency Scores versus Average Distance Travelled (km)

4.4.3 Variations in the direct operating cost

The direct operating cost is the sum totals of all input variables such as the fuel cost, the repairs and maintenance cost as well as the labour cost for each truck. There is no variation in the labour cost of the drivers and so this cost component has minimal effect on the variations in the direct operating cost of the trucks. The cost components that account for the variations are the fuel cost and the repairs and maintenance cost. Since the fuel cost for all trucks are not the same and also all trucks do not experience the same kind of damage, their cost will vary.

4.4.3.1 Skip Trucks

Table 4-12- Operating Cost for Skip Trucks

TYPE OF VEHICLE	VEHICLE REG NO.	TOTAL FUEL COST	R&M COST	D.O.C
SKIP	GT 423 Z	15250.273	3558.73	25629.003
SKIP	GN 8489-11	45121.924	7617.58	59559.504
SKIP	GN 273-11	29540.835	16371.91	52732.745
SKIP	GE 6477 X	23872.015	11399.54	42091.555
SKIP	GT 412 Z	26408.421	22509.5	55737.921
SKIP	GS 3889-09	11221.895	8428.5	25333.495
SKIP	GS 3750-09	24015.174	5860.1	36695.274
SKIP	GS 3680-09	20400.32	22865.25	50085.57
SKIP	GT 1665-11	15960.149	410	23190.149
SKIP	GS 3681-09	28712.072	9068.54	44600.612

Labour cost for all skip truck drivers is a constant. This has no effect on the variations of the direct operating cost since it is the same across board. Variations in the direct operating cost exist because of the difference in the fuel cost and repairs and maintenance cost.

From Table 4-13 above, truck GN 8489-11, recorded the highest direct operating cost (GHC 59559.504) whereas truckGT 1665-11 Z recorded the lowest direct operating cost (GHC 2319.149). The variations can be attributed to their fuel cost and repairs and maintenance cost.

Truck GN 8489-11 recorded a repairs and maintenance cost lower than GS 3680-09, however a look at their direct operating cost indicates that GN 8489-11 to be the highest. This can be attributed to the fact that the fuel cost for GN 8489-11 was higher than GS 3680-09.

4.4.3.2 Roll-on/Roll-off Trucks

The labour cost for all roll-on/roll-off drivers is the same and therefore does not really influence the variations in the direct operating cost of the trucks. The variations in the direct operating cost of the trucks are as a result of the differences in their fuel cost and their repairs and maintenance cost.

From Table 4-14, truck GS567-09 records a high direct operating cost (GHC 88491.26). This is as a result of its high fuel cost and repairs and maintenance cost. Comparing the direct operating costs of trucks GW 1208 Z and GW 594 Z, GW 1208 Z records GHC 41543.343whereas GW 594 Z records GHC 60089.854. Even though GW 1208 Z records a higher fuel cost than GW 594 Z, with reference to the repairs and maintenance, the reverse happens. It can therefore be concluded that a high fuel cost alone does not guarantee a high direct operating cost for the truck. The repairs and maintenance cost also accounts for the increase or decrease in the direct operating cost of a truck.

Table 4-13- Operating Cost for Roll-on/ Roll-off Trucks

TYPE OF VEHICLE	VEHICLE REG NO.	FUEL COST	R&M COST	D.O.C
ROLL-ON	GW 1208 Z	25982.84	8738.78	41543.343
ROLL-ON	GW 3446 Z	26949.443	10732.43	44505.319
ROLL-ON	GW 5313 Z	26292.98	21020.78	54133.76
ROLL-ON	GW 594 Z	21465.134	31804.72	60089.854
ROLL-ON	GS 567-09	34839.06	46832.2	88491.26

4.4.3.3 Compaction Trucks

The labour cost for compaction truck drivers is a constant. This has no effect on the variations of the direct operating cost since it is the same across board. The main components that account for the variations as previously stated are the fuel cost and the repairs and maintenance cost of each truck.

From Table 4-15 below, truck GT 9213-10 records the highest direct operating cost (GHC 47064.248) and this can be attributed to its high repairs and maintenance cost. Truck GT 9215-10, recorded a high fuel cost but a lower repairs and maintenance cost, and as result, this affected its direct operating cost.

Truck GT 2007-12 recorded GHC 21294.557 as its fuel cost and truck GS 3674-09 recorded GHC 18322.382 as its fuel cost. Comparing their direct operating costs, GS 3674-09 recorded a higher direct operating cost than GT 2007-12. This can be attributed to their repairs and maintenance cost.

Table 4-14- Operating Cost for Compaction Trucks

TYPE OF VEHICLE	VEHICLE REG NO.	FUEL COST	R&M COST	D.O.C
COMP	GT 2007-12	21294.557	3419.71	32414.267
COMP	GT 2265-12	16178.97	2098.93	25277.9
COMP	GT 9214-10	20236.635	7543.22	35479.855
COMP	GT 9215-10	23665.405	10227.98	41593.385
COMP	GT 9213-10	22660.138	16704.11	47064.248
COMP	GS 3128-09	20296.94	15080.74	43077.68
COMP	GS 3129-09	19273.478	3770.8	30747.724
COMP	GS 2038 Z	16866.447	1989.59	26556.037
COMP	GT 2138-10	20569.174	6310.41	34579.584
COMP	GE 9970-09	12922.5	4020.23	24642.73
COMP	GT 9303-11	17045.639	1000.61	25746.249
COMP	GS 568-09	19376.149	9285.63	36361.779
COMP	GS 3674-09	18322.382	12604.22	38626.602

4.5 MEASURES TO REDUCE DIRECT COST

From the study the following factors were identified as measures that when put in place, will help to reduce direct cost.

- Construction of transfer stations
- Carry out periodic maintenance on trucks
- Working hours should be well scheduled. Traffic conditions on the road should be incorporated in the scheduling of working hours

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the study, the following conclusions were made:

The DEAP revealed that out of the 28 trucks that were analysed, only nine (9) are being fully technical efficient. This is to say that only 9 trucks received a value of 1(100%) indicating that these trucks are being fully efficient. The programme also revealed that all the 28 trucks that were analysed are operating at atechnical efficiency level above 0.5 (50%).

The cost efficiency analysis also revealed that out of the 28 trucks, only 3 trucks recorded 100% cost-efficiency score. Also out of the 28 trucks, only 7 are operating at a cost-efficiency score above 0.5 (50%) The dominant source of the cost inefficiency can be attributed to the allocative inefficiencies of the trucks. Most of the trucks are operating at an optimal technical efficiency level; however, the same cannot be said for their allocative efficiencies.

Another conclusion that was drawn from the study was that the variations in the cost efficiency scores of the trucks is dependent on either the age of the truck, the approximated distance they travel, the number of trips they are able to make, the frequency of breakdown and the traffic conditions that exists on the route they travel.

5.2 RECOMMENDATIONS

Recommendations from this study include the following:

- All odometers of the trucks should be repaired. This will enable the company to know the actual distance covered by each truck driver per day and this will also help to monitor the fuel consumption of each truck.
- The crew size should be arranged to optimize vehicle productivity. A Larger crew size could load vehicle faster and optimize vehicle productivity. The method of loading should be facilitated and janitors should be well trained and equipped.
- Working hours should be well scheduled. Traffic conditions on the road should be incorporated in the scheduling of working hours
- Repairs and maintenance of trucks should be frequent. If possible, all trucks should have a servicing day; this would help to ensure that the truck is in good condition and would also help to curb extreme damages or breakdowns that are likely to happen during operation.
- Periodic re-routing of vehicles should also be adopted.
- There should be back-up trucks, drivers and janitors in case of extreme damages or accidents.
- Drivers and janitors should be motivated regularly. This will go a long way to boost up their morale and love for the work.

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APPENDICES

Appendix 1:Details of Trucks

TYPE OF VEHICLE	VEHICLE REG NO.	MAKE	CAPACITY (m^3)	TONNAGE OF TRUCK (m^3)
SKIP	GT 423 Z	Donfeng	12	6
SKIP	GN 8489-11	Donfeng	12	6
SKIP	GN 273-11	Donfeng	12	6
SKIP	GE 6477 X	Donfeng	12	6
SKIP	GT 412 Z	Donfeng	12	6
SKIP	GS 3889-09	Donfeng	12	6
SKIP	GS 3750-09	Donfeng	12	6
SKIP	GS 3680-09	Donfeng	12	6
SKIP	GT 1665-11	Donfeng	12	6
SKIP	GS 3681-09	Donfeng	12	6
ROLL-ON	GW 1208 Z	Donfeng	23	11.5
ROLL-ON	GW 3446 Z	Donfeng	23	11.5
ROLL-ON	GW 5313 Z	Donfeng	23	11.5
ROLL-ON	GW 594 Z	Donfeng	23	11.5
ROLL-ON	GS 567-09	Donfeng	23	11.5
COMPACTION	GT 2007-12	Ashok Leyland	18	9
COMPACTION	GT 2265-12	Ashok Leyland	18	9
COMPACTION	GT 9214-10	Ashok Leyland	18	9
COMPACTION	GT 9215-10	Ashok Leyland	18	9
COMPACTION	GT 9213-10	Ashok Leyland	18	9
COMPACTION	GS 3128-09	Ashok Leyland	18	9

COMPACTION	GS 3129-09	Ashok Leyland	18	9
COMPACTION	GS 2038 Z	Ashok Leyland	18	9
COMPACTION	GT 2138-10	Ashok Leyland	18	9
COMPACTION	GE 9970-09	Ashok Leyland	18	9
COMPACTION	GT 9303-11	Ashok Leyland	18	9
COMPACTION	GS 568-09	Ashok Leyland	18	9
COMPACTION	GS 3674-09	Ashok Leyland	18	9

Appendix 2: Technical Efficiency Results

a) Skip Trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR SKIP TRUCKS				
	TECHNICAL EFFICIENCY SCORES.			
Truck	**crste**	**vrste**	**scale**	**Return to scale**
1	0.71	0.912	0.799	irs
2	0.937	1	0.937	drs
3	0.785	0.789	0.995	irs
4	1	1	1	
5	0.752	0.784	0.959	irs
6	0.693	1	0.693	irs
7	0.834	0.872	0.957	irs

8	0.677	0.788	0.859	irs
9	0.59	0.772	0.765	irs
10	0.877	0.886	0.99	drs
mean	**0.786**	**0.88**	**0.893**	

Note: crste = technical efficiency from CRS (constant return to scale) DEA

vrste= technical efficiency from VRS (variable return to scale) DEA

scale = scale efficiency = crste/vrste

Irs- increasing return to scale, drs – decreasing return to scale

TRUCK BY TRUCK RESULTS

TRUCK 1	**OUTPUT**	**INPUT**
ORGINAL VALUE	2580	13492.81
RADIAL MOVEMENT	0	-1185.694
SLACK MOVEMENT	0	0
PROJECTED VALUE	2580	12307.116

TRUCK 2	**OUTPUT**	**INPUT**
ORGINAL VALUE	10632	42123.9
RADIAL MOVEMENT	0	0
SLACK MOVEMENT	0	0
PROJECTED VALUE	10632	42123.9

TRUCK 3	**OUTPUT**	**INPUT**
ORGINAL VALUE	5760	27249.25
RADIAL MOVEMENT	0	-5740.737

TRUCK 4	**OUTPUT**	**INPUT**
ORGINAL VALUE	5904	21925.18
RADIAL MOVEMENT	0	0

SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	5760	21508.513		**PROJECTED VALUE**	5904	21925.18
TRUCK 5	**OUTPUT**	**INPUT**		**TRUCK 6**	**OUTPUT**	**INPUT**
ORGINAL VALUE	4950	24444.2		**ORGINAL VALUE**	1962	10518.92
RADIAL MOVEMENT	0	-5279.43		**RADIAL MOVEMENT**	0	0
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	4950	19164.761		**PROJECTED VALUE**	1962	10518.92
TRUCK 7	**OUTPUT**	**INPUT**		**TRUCK 8**	**OUTPUT**	**INPUT**
ORGINAL VALUE	4908	21844.19		**ORGINAL VALUE**	3384	18573.94
RADIAL MOVEMENT	0	-2800.957		**RADIAL MOVEMENT**	0	-3940.433
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	4908	19043.233		**PROJECTED VALUE**	3384	14633.507
TRUCK 9	**OUTPUT**	**INPUT**		**TRUCK 10**	**OUTPUT**	**INPUT**

ORGINAL VALUE	2472	15546.63		**ORGINAL VALUE**	6312	26713.39
RADIAL MOVEMENT	0	-3552.014		**RADIAL MOVEMENT**	0	-3045.173
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	2472	11994.616		**PROJECTED VALUE**	6312	23668.217

b) Roll-on/Roll-off trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR ROLL-ON/ROLL-OFF TRUCKS				
Truck	**crste**	**vrste**	**scale**	**return to scale**
1	0.844	0.991	0.852	irs
2	1	1	1	
3	0.762	0.889	0.857	irs
4	0.733	1	0.733	irs
5	0.799	0.816	0.979	irs
Mean	**0.828**	**0.939**	**0.884**	
Note: crste = technical efficiency from CRS (constant return to scale) DEA				
vrste= technical efficiency from VRS (variable return to				

scale) DEA						
scale = scale efficiency = crste/vrste						
Irs- increasing return to scale, drs – decreasing return to scale						
TRUCK BY TRUCK RESULTS						
TRUCK 1	**OUTPUT**	**INPUT**		**TRUCK 2**	**OUTPUT**	**INPUT**
ORGINAL VALUE	6405.5	23089.923		**ORGINAL VALUE**	8855	26952.889
RADIAL MOVEMENT	0	-198.704		**RADIAL MOVEMENT**	0	0
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	6405.5	22891.219		**PROJECTED VALUE**	8855	26952.889
TRUCK 3	**OUTPUT**	**INPUT**		**TRUCK 4**	**OUTPUT**	**INPUT**
ORGINAL VALUE	6486	25913.92		**ORGINAL VALUE**	4922	20431.334
RADIAL MOVEMENT	0	-2889.219		**RADIAL MOVEMENT**	0	0
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	6486	23024.701		**PROJECTED VALUE**	4922	2043.334

TRUCK 5	**OUTPUT**	**INPUT**
ORGINAL VALUE	8452.5	32202.87
RADIAL MOVEMENT	0	-5971.392
SLACK MOVEMENT	0	0
PROJECTED VALUE	8452.5	26285.478

c) Compaction trucks

INPUT ORIENTATED DEA				
SCALE ASSUMPTION : VRS				
EFFICIENCY SUMMARY FOR COMPACTION TRUCKS				
Truck	**crste**	**vrste**	**scale**	
1	0.632	0.743	0.852	irs
2	0.659	0.92	0.716	irs
3	0.987	1	0.987	drs
4	0.85	0.873	0.974	drs
5	0.924	1	0.924	drs
6	0.777	0.851	0.913	irs

7	0.875	0.922	0.949	irs
8	0.628	0.879	0.715	irs
9	0.773	0.85	0.91	irs
10	0.485	1	0.485	irs
11	0.577	0.853	0.677	irs
12	0.921	0.921	1	-
13	1	1	1	-
mean	**0.776**	**0.909**	**0.854**	

Note: crste = technical efficiency from CRS DEA

vrste= technical efficiency from VRS DEA

scale = scale efficiency = crste/vrste

Irs- increasing return to scale, drs – decreasing return to scale

TRUCK BY TRUCK RESULTS

TRUCK 1	**OUTPUT**	**INPUT**		**TRUCK 2**	**OUTPUT**	**INPUT**
ORGINAL VALUE	3654	20495.085		**ORGINAL VALUE**	2853	15351.93
RADIAL MOVEMENT	0	-5272.276		**RADIAL MOVEMENT**	0	-1221.137
SLACK MOVEMENT	0	0		**SLACK MOVEMENT**	0	0
PROJECTED VALUE	3654	15222.809		**PROJECTED VALUE**	2853	14130.793
TRUCK 3	**OUTPUT**	**INPUT**		**TRUCK 4**	**OUTPUT**	**INPUT**
ORGINAL VALUE	5121	18410.225		**ORGINAL**	5175	21597.805

			VALUE		
RADIAL MOVEMENT	0	0	RADIAL MOVEMENT	0	-2744.631
SLACK MOVEMENT	0	0	SLACK MOVEMENT	0	0
PROJECTED VALUE	5121	18410.255	PROJECTED VALUE	5175	18853.174
TRUCK 5	OUTPUT	INPUT	TRUCK 6	OUTPUT	INPUT
ORGINAL VALUE	5409	20772.488	ORGINAL VALUE	4059	18539.48
RADIAL MOVEMENT	0	0	RADIAL MOVEMENT	0	-2764.527
SLACK MOVEMENT	0	0	SLACK MOVEMENT	0	0
PROJECTED VALUE	5409	20772.488	PROJECTED VALUE	4059	15774.953
TRUCK 7	OUTPUT	INPUT	TRUCK 8	OUTPUT	INPUT
ORGINAL VALUE	4311	17485.004	ORGINAL VALUE	2844	16054.914
RADIAL MOVEMENT	0	-1366.496	RADIAL MOVEMENT	0	-1936.391
SLACK MOVEMENT	0	0	SLACK MOVEMENT	0	0
PROJECTED VALUE	4311	16118.508	PROJECTED	2844	14118.523

TRUCK 9	OUTPUT	INPUT
ORGINAL VALUE	4041	18536.034
RADIAL MOVEMENT	0	-2785.621
SLACK MOVEMENT	0	0
PROJECTED VALUE	4041	15750.413

TRUCK 11	OUTPUT	INPUT
ORGINAL VALUE	2643	16237.552
RADIAL MOVEMENT	0	-2393.056
SLACK MOVEMENT	0	0
PROJECTED VALUE	2643	13844.496

TRUCK 13	OUTPUT	INPUT
ORGINAL VALUE	4689	16633.842
RADIAL MOVEMENT	0	0
SLACK MOVEMENT	0	0

VALUE

TRUCK 10	OUTPUT	INPUT
ORGINAL VALUE	1719	12584.792
RADIAL MOVEMENT	0	0
SLACK MOVEMENT	0	0
PROJECTED VALUE	1719	12584.792

TRUCK 12	OUTPUT	INPUT
ORGINAL VALUE	4689	18062.209
RADIAL MOVEMENT	0	-1428.367
SLACK MOVEMENT	0	0
PROJECTED VALUE	4689	16633.842

PROJECTED VALUE	4689	16633.842	

Appendix 3: Cost Efficiency Results

a) Skip Trucks

COST EFFICIENCY DEA FOR SKIP TRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	**TE**	**AE**	**CE**
GT 423 Z	0.804	0.293	0.235
GN 8489-11	1	0.39	0.39
GN 273-11	0.828	0.13	0.108
GE 6477 X	0.708	0.15	0.106
GT 412 Z	0.795	0.086	0.068
GS 3889-09	0.742	0.097	0.072
GS 3750-09	0.861	0.281	0.242
GS 3680-09	0.827	0.066	0.054
GT 1665-11	1	1	1
GS 3681-09	0.933	0.222	0.207
MEAN	**0.85**	**0.271**	**0.248**
Note: TE = Technical Efficiency			
AE = Allocative Efficiency			
CE = Cost Efficiency			

b) Roll-on/Roll-off Trucks

COST EFFICIENCY DEA FOR ROLL-ON/ROLL-OFF TRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	**TE**	**AE**	**CE**
GW 1208 Z	0.928	0.99	0.919
GW 3446 Z	1	1	1
GW 5313 Z	0.758	0.513	0.389
GW 594 Z	0.672	0.281	0.189
GS 567-09	0.749	0.309	0.231
MEAN	**0.821**	**0.618**	**0.545**
Note: TE = Technical Efficiency			
AE = Allocative Efficiency			
CE = Cost Efficiency			

c) Compaction Trucks

COST EFFICIENCY DEA FOR COMPACTIONTRUCKS			
SCALE ASSUMPTION:CRS			
EFFICIENCY SUMMARY			
TRUCK	**TE**	**AE**	**CE**
GT 2007-12	0.833	0.585	0.487
GT 2265-12	0.925	0.652	0.603
GT 9214-10	1	0.332	0.332
GT 9215-10	0.856	0.291	0.249
GT 9213-10	0.898	0.181	0.163
GS 3128-09	0.753	0.18	0.135
GS 3129-09	1	0.532	0.532
GS 2038 Z	0.913	0.685	0.625
GT 2138-10	0.811	0.381	0.309
GE 9970-09	0.548	0.377	0.207
GT 9303-11	1	1	1
GS 568-09	0.94	0.266	0.25
GS 3674-09	1	0.194	0.194
MEAN	**0.883**	**0.435**	**0.391**
Note: TE = Technical Efficiency			
AE = Allocative Efficiency			
CE = Cost Efficiency			

Appendix 4: Inventory of Trucks

TYPE OF VEHICLE	VEHICLE REG NO.	AREA OF OPERATION	AVERAGE DISTANCE TRAVELED (km)	FINAL DUMPING SITE	AGE OF THE TRUCK	CE
SKIP	GT 423 Z	AYAWASO CENTRAL	32.6	TEMA (KPONG)	4YRS	0.235
SKIP	GN 8489-11	AYAWASO EAST	33.6	TEMA (KPONG)	1YR	0.39
SKIP	GN 273-11	AYAWASO CENTRAL	32.6	TEMA (KPONG)	1YR	0.108
SKIP	GE 6477 X	OSU KLOTTEY	36.5	TEMA (KPONG)	4YRS	0.106
SKIP	GT 412 Z	AYAWASO CENTRAL	32.6	TEMA (KPONG)	4YRS	0.068
SKIP	GS 3889-09	ABLEKUMA SOUTH	51.5	TEMA (KPONG)	4YRS	0.072
SKIP	GS 3750-09	ABLEKUMA CENTRAL	49.5	TEMA (KPONG)	4YRS	0.242
SKIP	GS 3680-09	AYAWASO CENTRAL	32.6	TEMA (KPONG)	4YRS	0.054
SKIP	GT 1665-	AMA				1

	11					
SKIP	GS 3681-09	AYAWASO EAST	33.6	TEMA (KPONG)	4YRS	0.207
TYPE OF VEHICLE	**VEHICLE REG NO.**	**AREA OF OPERATION**	**AVERAGE DISTANCE TRAVELLED (km)**	**FINAL DUMPING SITE**	**AGE OF THE TRUCK**	**CE**
ROLL-ON	GW 1208 Z	BREAKDOWN		TEMA (KPONG)	4YRS	0.919
ROLL-ON	GW 3446 Z	AYAWASO WEST	31.6	TEMA (KPONG)	4YRS	1
ROLL-ON	GW 5313 Z	AYAWASO CENTRAL	32.6	TEMA (KPONG)	4YRS	0.389
ROLL-ON	GW 594 Z	ABLEKUMA SOUTH	51.5	TEMA (KPONG)	4YRS	0.189
ROLL-ON	GS 567-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.231
TYPE OF VEHICLE	**VEHICLE REG NO.**	**AREA OF OPERATION**	**AVERAGE DISTANCE TRAVELLED (km)**	**FINAL DUMPING SITE**	**AGE OF THE TRUCK**	**CE**
COMP	GT 2007-12	MAKOLA	38.5	TEMA (KPONG)	1YR	0.487

COMP	GT 2265-12	MAKOLA	38.5	TEMA (KPONG)	1YR	0.603
COMP	GT 9214-10	MAKOLA	38.5	TEMA (KPONG)	2YRS	0.332
COMP	GT 9215-10	MAKOLA	38.5	TEMA (KPONG)	2YRS	0.249
COMP	GT 9213-10	MAKOLA	38.5	TEMA (KPONG)	2YRS	0.163
COMP	GS 3128-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.135
COMP	GS 3129-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.532
COMP	GS 2038 Z	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.625
COMP	GT 2138-10	MAKOLA	38.5	TEMA (KPONG)	3YRS	0.309
COMP	GE 9970-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.207
COMP	GT 9303-11	MAKOLA	38.5	TEMA (KPONG)	1YR	1
COMP	GS 568-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.25
COMP	GS 3674-09	MAKOLA	38.5	TEMA (KPONG)	4YRS	0.194