CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The focus in this study is on municipal solid waste (MSW). MSW consists of wastes resulting from municipal activities and services such as street waste, dead animals, market waste and abandoned vehicles. Moreso, the term is commonly applied in a wider sense to incorporate domestic wastes, institutional wastes and commercial wastes. MSW vary in composition and characteristics both within the same country and throughout the globe. The variations depend on a number of factors such as social customs, standard of living, geographical location, climate etc. The major constituents of MSW are paper and putrescible organic matter; generally metals, glasses, ceramics, plastics, textiles, dirt and wood may always be present. The relative proportions of these latter materials depend on local factors. Although there may be significant seasonal variations within a year, the average proportion of wastes constituents reaching a disposal site(s) for a particular urban area changes in long term.

Income determines life-style – consumption patterns and cultural behaviour - of a people, and waste composition varies with socio-economic status within a particular community. Data for different degrees of national wealth (annual per-capita income) and composition of Nigeria's urban waste characterisics are presented in the **Tables A** and **B** in the Appendices.

Several conclusions may be drawn from the comparative data in **Tables A and B** as follows:

a) The proportion of paper waste varies with national income;
b) Countries of low income produce greater proportion of putrescible organic matter (food waste) than those of high income;
c) Variation in waste composition is more dependent on national income than geographical location, although the latter is also significant;
d) Waste density is a function of national income, being two to three times higher in the low-income countries than in countries of high income;
e) Moisture content is also higher in low-income countries; and
f) The composition of waste in a given urban center varies significantly with socio-economic status (household income).

In order to plan, design and operate a sustainable solid waste management system, it is essential to have a thorough knowledge of the quantities generated, the composition of wastes and its characteristics. This implies, therefore, that municipal solid waste management (MSWM) is not a simple affair; it does not imply just putting waste into a waste bin or vehicle and unloading it at a public dump site. It includes in its scope, all administrative, financial, legal, planning, and engineering functions involved in solution to all problems of solid wastes. The solutions may involve complex interdisciplinary relationships among such fields as political science, city and regional planning, geography, economics, public health sociology, demography, communications, conservation, as well as engineering and material science (Takele, 2004).

The activities involved with the management of solid wastes from the point of generation to final disposal have been grouped into six functional elements:

1) Waste generation 2) On-site handling, storage, and processing
3) Collection 4) Transfer and transport
5) Processing and recovery, and 6) Disposal.

Interrelationships among these six functional elements are depicted in Figure 1.

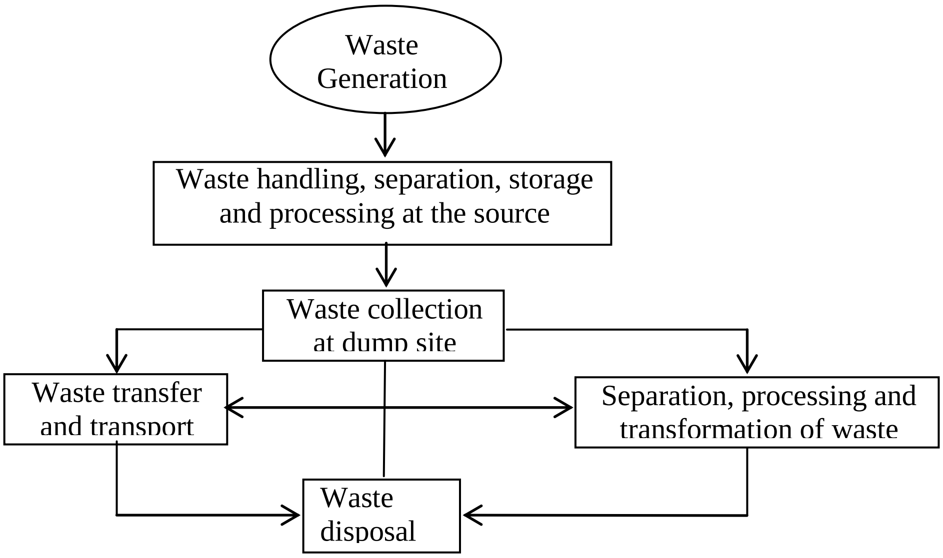


Figure 1: Interrelationship of functional elements comprising a MSWM System

By considering each functional element separately, it is possible to identify the fundamental aspects and relationships involved in each element and to develop, where possible, quantifiable relationships for the purpose of making engineering comparison analyses, and evaluations.

Refuse collection and handling are part of waste management process and according to Adeshina(2000), refuse collection is the process of transferring solid wastes from the storage receptacle to the place of disposal. Essentially, this involves emptying the storage containers into a vehicle in which the wastes are transported. Refuse transportation is a very costly service, and every city should assess both vehicles and methods so as to find the system which is most appropriate to its local conditions in terms of quality of service and cost of operation. The suitability of collection equipment for local situations is important, if the service rendered is to be sanitary, effective, and economic. From the foregoing, therefore, waste management entails all planning, policies and actions taken in the collection, transportation, processing, recycling or disposal of waste materials of all sorts, be it solid, liquid and/or gas.

Meanwhile, Ogwueleka(2009) carried out extensive studies on characterisation of solid waste from nine urban cities in Nigeria in 2007. The average characteristics of the MSW generated in those areas are presented in **Table C** of the Appendices. It can be seen from the comparative data in this table that great majority of the total solid waste generated in Nigeria is organic. The high level of reuse of recyclable waste reflects the extent of poverty in the developing countries. Hoornweg *et al.*(1999) reported that waste stream in developing countries is over 50% organic material; whereas in Bandung, Indonesia and Colombia, Sri Lanka residential waste composed of 78% and 81% compostable material, and market wastes 89% and 90% compostable, respectively(Cointreau, 1982).

Twenty five million tonnes of municipal solid waste are generated annually in Nigeria (Ogwueleka, 2009). **Table C** of the Apendices also shows the waste generation rates and breakdown density for urban and rural areas in Nigeria. The generation rates ranged from 0.66 kg/cap/day in urban areas to 0.44 kg/cap/day in rural areas as opposed to 0.7-1.8 kg/cap/day in developed countries; being typical of low income towns and is highly influenced by the population income. Waste densities and moisture are much higher in developing countries which require different technology and management systems (Cointreau *et al.*, 1984; Ogwueleka, 2009). The density of solid waste in Nigeria ranged from 250 kg/m^3 to 370 kg/m^3, higher than solid waste densities found in developed countries (Ogwueleka, 2009). Density refers to the number of capacity of waste storage and collection facilities required; high density reduces the effectiveness of compaction vehicles for waste transfer.

Article on the chemical characteristics of Nigeria's MSW is scarce. Such a report, if given, will indicate the organic content of the samples on a dry weight basis. Besides, knowledge of the chemical characteristics of the said wastes is essential in selecting and designing waste processing and disposal facilities.

Waste management in Anambra State, with particular reference to Awka, Onitsha, Nnewi, Ekwulobia and some other local government areas (LGAs) is becoming an increasing and a complex problem daily(Otti, 2011). As reported by UN.Habitat (2012), this problem is aggravated by unplanned market sites and the lack of a well-located sanitary landfill for waste disposal. Solid waste management (SWM) services are poor and inadequate. There is no proper method used for handling sewage and, generally, the solid and liquid waste are disposed of irresponsibly.

Anambra State has not had any well defined method used in collecting and keeping data on solid waste (or any other form of waste) in the state; most of the existing data are not organized and cannot be relied upon due to the unscientific and crude methods by which they were obtained. These claims are supported by both field research and literature. Olorunfemi and Odiata(1998) reported that lack of data on solid wastes in Nigeria, which is at all levels (from wards, through the local government areas/districts/urban centres, the state to the federal) has remained the most conspicuous and probably, the most important problem militating against the successful and effective management of solid wastes by their respective waste management authorities. Even where such data exist, they are generally unreliable, scattered and unorganized(World Bank, 2003).

In Awka municipality, the various types of wastes that come from each of the broad categories of sources are contained in **Table 1**. The table is concise and self explanatory.

Table 1: Categorized sources of wastes

S/N	Source	Type of Waste/Waste Generated
1.	**Residential** (Household: single-and multi-family) **homes**	Rubbish (Combustibles: Newspapers, books and sheets/pieces of paper, cartons, ball wood, clothing, disposable tableware, wood furniture, plastics, etc); Garbage (food scraps, from preparation, cooking, and/or serving of food, food packaging, etc); cans and bottles, ashes, and occasionally large waste from house; Hazardous waste (toxic, highly flammables, pathogenic, radioactive materials, explosives, etc); Yard wastes (leaves, garden debris, trimming, pruning, etc)
2.	**Institutions** (schools, libraries, hospitals, prisons, churches)	Cafeteria and restroom trash can wastes, office papers, classroom wastes, yard trimmings
3.	**Commercial establishments**(office buildings, retail and wholesale establishments, hotels and restaurants, eateries, markets)	Rubbish, Garbage, Corrugated boxes, yard trimmings, Hazardous waste, construction and demolition wastes
4.	**Industries/Technical Workshops** (plants, mills, factories, fabrication, packaging and administrative; wastes processing ones not included)	Corrugated boxes, office papers, plastic film, wood pallets, iron filings and pieces of metals, lunchroom wastes, construction and demolition wastes
5.	**Municipal** (residential, instiyutions, industries, etc)	Street sweeping, sewage treatment plant waste, wastes from schools and other institutions, Dead animal and man, Abandoned vehicles

[Source: Field survey]

Klundert and Anschiitz(2000) considered the word ‘sustainable’ as used in SWM as a state of being appropriate to local conditions from a technical, environmental, social, economic, financial, institutional, and political perspective. It also means being capable of maintaining itself over time without running out of resources needed for its upkeep. Dictionary.reference.com defined sustainability as, 1. “the ability to be sustained, supported, upheld, or confirmed.”, and 2. under Environmental Science, the word is seen as, “…the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance.”

In terms of management and development, the United Nation (UN) defined sustainable development (SD) in its 1987 report “Our Common Future” as development that meets the present needs of the society without compromising the ability of future generations to satisfy their own needs. Keoleian and Menerey(1994), in concurring with the UN’s definition, went further to define sustainable development as a dynamic state that harmonizes economic activities with ecological processes. Continued economic develop-ment, as has been widely recognized, should be accompanied with more appropriate use of natural resources. The Royal Academy of Engineering explained sustainable development as the process of moving human activities to a pattern that can be sustained in perpetuity. It is an approach to environment and development issues that seeks to reconcile human needs with the capacity of the planet to cope with the consequences of human activities(Onwualu, 2014).

Our industrial society is not yet on a path towards sustainability(Boulder Sitarz Daniel, 1993; Meadows et al, 1992; UNWCE, 1987; Keoleian and Menerey, 1994). Resource recovery is a key component in a business' ability to maintaining ISO14001 accreditation. Companies are encouraged to improve their environmental efficiencies each year. One way to do this is by changing a company from a system of managing wastes to a resource recovery system (such as recycling: glass, food waste, paper and cardboard, plastic bottles etc.)

The two words ‘sustainable’ and ‘integrated’ are closely inter-related. For example, using different collection and treatment options, at different habitat scales, can form the basis of a system that is adapted to local (physical, social, economic, etc.) conditions(Klundert and Anschiitz, 2000).

1.1.1 Overview of Some Important Concepts Applied in the Study

1.1.1.1 Queuing theory and its applications

Sharma(2009-10) explained queuing theory as being concerned with the statistical description of the behavior of queues with finding, e.g., the probability distribution of the number of items/objects in the queue from which the mean and variance of queue length and the distribution of waiting time for a customer, or the distribution of a server's busy periods can be found.

In their own view, Ohaneme *et al*(2011) and Medhi(2003) explained queuing theory as the mathematical study of waiting lines. The theory permits the derivation and calculation of several performance measures, which include the average waiting time in the queue or the system, the expected number waiting or receiving service, the probability of encountering the system empty, having an available server or having to wait a certain time to be served and most importantly the system utilization. As a result of its applications in industries, technology, telecommunications networks, information technology and management sciences, it has been an interesting research area for many researchers active in this field.

Hillier and Lieberman(2001) stresses that the basic structure of a queuing model, which includes queues that must obey a queuing rule and service mechanics, can be separated into input and output queuing system. The inter-arrival time may be deterministic or stochastic in nature. Arrival can occur from unlimited population (infinite) or limited (finite or restricted population)(Adedayo *et al*, 2006; Hillier and Lieberman, 2001). An infinite queue is one in which for all practical purposes, an unlimited number of customers can be held there while a finite queue refers to the limited size customer pool that will use a service system and, at times, form a line(www.ateneonline.it/../6184-7_tn06.pdf).

Hillier and Lieberman(2001) also put forth the performance parameters in a queuing system as system utilization, mean number in the system, mean number in queue, the average waiting time for an arrival not immediately served, mean time in system, mean time in queue, and probability of zero customers in the system, probability of waiting.

To apply a queuing model to any situation, one should first describe the input process and the output process(Singh, 2007). An input process is known as the arrival pattern. Customers are known as arrivals which are usually generated one at a time by an input source randomly from finite or infinite population. These customers enter the queuing system and join a queue to be served. The required service is then performed for the customer by the service mechanism, after which the customer leaves the queuing system(Hillier and Lieberman, 2001).

In everyday life, it is seen that a number of people arrive at certain utility points for one reason or the other; either to render a service or to receive a service. Examples include patients waiting in line to see a doctor, people in line at an airport waiting to pay for a flight ticket or board an air plane, et cetera. Other examples include letters arriving at a typist's desk, and a number of machines that broke down in a machine shop waiting for repairs. In queuing systems analysis, when a person or thing renders a service to another, he/she/it is referred to as the *server* and the receiver of the service is termed the *customer*.

Servers or customers may be positioned in a single line or parallel lines; and in giving or receiving service, situations vary. There are situations where customers go to servers to receive service like customers cashing money over the counter in a bank and motorists buying fuel at a fuel station, and *there are also situations where servers go to the customers to give their service like a maintenance engineer or technician that goes to repair a broken down machine at a machine shop, and a waste disposal truck that goes to evacuate waste from a roadside waste dumpsite*.

1.1.1.2 Historical overview of queuing theory

The history of queuing theory dates back to the year 1906 when the Danish mathematician, A. K. Erlang, published his first result on his investigation of the challenges faced by the Danish Telephone Company. The work was titled “The theory of Probabilities and Telephone Conversation”. Erlang used probability technique to determine the number of telephone lines needed at the Danish Telephone Company(Erlang, 1909). The applications of the theory and technique to telephone service and other areas soon began after and increased significantly.

In 1927, Molina published his paper titled, “Application of the Theory of Probability to Telephone Trunking Problems”. A year later, Thornton Fry published his own paper on “Probability and its Engineering Uses”, which discussed much of Erlang’s earlier work.

In the early 1930’s, Felix Pollaczeck did some further pioneering work on Poisson input, arbitrary output, and single and multiple channel problems. Kendall(1951) was the pioneer who viewed and developed queuing theory from the perspective of stochastic processes. Other names working in the same field during that period included Kolmogorov and Khintchine in Russia, Crommelin in France and Palm in Sweden. Kleinrock(1976) also did some extensive work on the theory of queuing systems and their computer applications. The work in queuing theory picked up momentum rather slowly in its early days, but in 1960's started to accelerate and there have been a great deal of work in the area and its applications since then(Alireza, 2010).

Recent literature on queuing indicate that queuing theory is now applied to hospitals, airline companies, banks, petroleum service stations, manufacturing firms etc., where the waiting time of their customers in queue has to be minimized. The reasons for this is that, in the more highly developed countries where standards of living are high, time becomes more valuable as a commodity and consequently, customers are less willing to wait for service. Therefore, operations managers need to find suitable means in delivering faster services to their customers to reduce their waiting time for service (Davis et al, 2003).

In recent times, queuing theory and the diverse areas of its applications has grown tremendously. Takagi(1991) considered queuing phenomena with regard to its applications and performance evaluation in computer and communication systems. Obamiro(2003) applied queuing model in determining the optimum number of service facility in Nigerian Hospitals. He however achieved this by determining some queuing parameters which enabled him to improve the performance of the system.

Mgbemena(2010) developed a model of the queuing system of some banks in Nigeria using regression analysis. In her work, she used the single line multi-server queuing model and determined the queuing parameters of the model. This fit enabled her to create a queuing management software in MATLAB that shows at a glance, the queuing system's behavior of the unit that needs attention at any time. The essence was to improve the customer service system in Nigerian banks.

Ohaneme *et al*(2011) proposed the single line multi-server queuing system which they simulated using c-programming. The model was intended to be adopted and used by the Nigerian National Petroleum Corporation (NNPC) Mega petroleum station in Awka, Anambra State for prevention of congestion and delay of customers prevalent at the station.

Mbachu *et al*(2014) developed a decision support system by using Microsoft Excel to evaluate the queuing performance at NNPC mega stations in Nigeria, using NNPC mega stations in Enugu and Owerri as case studies. They used the developed model to simulate the average arrival rates of customers to these stations and obtained the best system utilization at various arrival rates, which they claimed could assist in determining the best number of servers that can serve well at both minimum and maximum demand periods in single-line Multi-server queue systems.

1.1.1.3 Basics of queuing theory and queuing systems characteristics

The basic structure of a queuing model is shown in Figure I of the Appendices. Such includes queues that must obey a queuing rule and service mechanics, and can be separated into input and output queuing system(Hillier and Lieberman, 2005).

A queuing system can be completely described by the following characteristics:

a. ***The input (or arrival pattern):*** This describes the way in which the customers arrive and join the system. The arrival pattern of queuing system is best described in terms of probabilities and consequently, the probability distribution for inter-arrival times (the time between two successive arrivals) or the distribution of number customers arriving in unit time must be defined. Arrival pattern describes the behavior of customers' arrivals. It is specified by the inter-arrival time between any two consecutive arrivals(Medhi, 2003). The inter-arrival time may be deterministic or stochastic in nature. Arrival can occur from unlimited population (infinite) or limited (finite or restricted population)(Adedayo *et al*, 2006).

Arrival Characteristics in a Queue are displayed in Figure IV - in the Appendices. Waiting line formulas generally require an arrival rate, or the number of units per period (such as an average of one every six minutes). A constant arrival distribution is periodic, with exactly the same time between successive arrivals. In productive systems, the only arrivals that truly approach a constant interval period are those subject to machine control. Much more common are variable (random) arrival distributions. In observing arrivals at a service facility, we can look at them from two viewpoints: First, we can analyze the time between successive arrivals to see if the times follow some statistical distribution. Usually we assume that the time between arrivals is exponentially distributed. Second, we can set some time length(T) and try to determine how many arrivals might enter the system within T. We typically assume that the number of arrivals per time unit is Poisson distributed. (www.ateneonline.it/../6184-7_tn06.pdf)

Poisson probability distribution of arrivals and the exponential probability distribution for inter-arrival time or service time are given by equns (*i*) and (*ii*) respectively, in the Appendices section.

b. ***The service mechanism (or service pattern):*** This is specified when the number of customers to be served at a given time is known, what the statistical distribution of service time is, and when service is available.

c. ***The 'queue discipline':*** This is the rule determining the formation of the queue, the manner of the customers while waiting, and manner in which they are chosen for service. The types include: 'First in, first out' (FIFO) or 'First come, first served' (FCFS), 'Last in, first out' (LIFO) or 'First in, last out' (FILO).

d. ***Customer's behavior:*** Customers generally behave in four ways when standing in a queue:

i. *Balking:* A customer may decide not to join the queue because the line is too long, or if he/she considers the queue to be too long.

ii. *Reneging:* A customer may leave the queue when he/she loses his/her patience of waiting.

iii. *Priorities:* In certain applications some customers are served before others regardless of their order of arrival. This customer has priority over others.

iv. *Jockeying:* Customers may jockey from one queue to another as may be observed in a supermarket

e. ***Size of the population:*** The collection of customers may be very large or of moderate size. A waiting line or queue occurs when customers wait before being served because the service facility is temporarily engaged. A queue is characterized by the maximum permissible number of customers that it can contain. Queues are called infinite or finite(Hillier and Lieberman, 2001). An infinite queue is one in which for all practical purposes, an unlimited number of customers can be held there, while a finite queue refers to the limited size customer pool that will use a service system and, at times, form a line, (www.ateneonline .it/../6184-7_tn06.pdf).

f. ***Maximum length of a queue or capacity of the system:*** At times only a given number of customers may be served or allowed to stay in the system although the total number of the customers in the population may or may not be finite.

g. ***Departure:*** Once a customer(s) is served or a server(s) rendered the required service, he/she departs and may not likely re-enter the system to queue again. It is usually assumed that departing customers do not return into the system immediately.

Adedayo, *et al*(2006) is of the opinion that once a customer is served, two exit fates are possible as shown in Figure II of the Appendices.

In observing arrivals at a service facility, we can look at them from two viewpoints: First, we can analyze the time between (a) The customer may return to the source population and immediately become a competing candidate for service again. (b) There may be a low probability of re-service.

1.1.1.4 Input and output processes in queuing systems

To apply a queuing model to any situation, one should first describe the input process and the output process, Singh (2007). An input process is known as the arrival pattern. Customers are known as arrivals which are generated one time by an input source randomly from finite or infinite population. These customers enter the queuing system and join a queue to be served. The required service is then performed for the customer by the service mechanism, after which the customer leaves the queuing system, Hillier and Lieberman (2005). The provision of services using certain rule and discharge of customers is referred to as output process. Another fact worth mentioning here is that the key word in queuing models is "average". It takes the average of the random numbers of customers arriving, the service time arrival intervals, et cetera(Singh, 2007).

1.1.1.5 Types of queuing systems

Servers may be in parallel or in series. There are four major types of queuing system. Lapin(1981) broadly categorized queuing system into the following.

1. ***Single-server, Single-phase system:*** This is a situation in which single queue of customers are to be served by a single service facility (server) one after the other. An example is bottles or cans of minerals or beer to be cocked in a production process. Diagrammatically, it is depicted in Figure III of the Appentices.

2. ***Single-server, Multiple-phases System:*** In this situation, there's still a single queue but customers receive more than one kind of service before departing the queuing system as shown in Figure V in the Appendices column. For example, in the university, students first arrive at the registration desk, get the registration done and then wait in a queue for their forms to be signed, after signing; they join another queue for submission. Students have to join queue at each phase of the system.

3. ***Multiple-servers, Single-phase System:*** This is a queuing system characterized by a situation whereby there is more than one service facility (servers) providing identical service but drawn on a single waiting line. An example is a petroleum service station. As illustrated by Figure VI of the Appendices.

4 ***Multiple servers, Multiple-phases System:*** According to Singh(2007), this type of system has numerous queues and a complex network of multiple phases of services involved as can be seen in Figure VII of the Appendices. This type of service is typically seen in a hospital setting, multi-specialty outpatient clinics, patient first form the queue for registration, and then he/she is triage for assessment, then for diagnostics, review, treatment, intervention or prescription and finally exits from the system or triage to different provider.

1.1.1.6 Types of models for different queuing systems

Various types of queuing models exist, among which are:

1. Model A (M/M/1): Single-Server queuing model with Poisson arrivals and exponential service times

This is also referred to as the "birth and death model" and is the most common case of queuing problems involving the single-channel, or single server, waiting line. In this situation, arrivals form a single line to be serviced by a single station (see Figure VIII in the Appendices). We assume that the following conditions exist in this type of system:

a. Arrivals are served on a first-in, first-out (FIFO) basis, and every arrival waits to be served, regardless of the length of the line or queue.

b. Arrivals are independent of preceding arrivals, but the average number of arrivals (arrival rate) does not change over time.

c. Arrivals are described by a Poisson probability distribution and come from an infinite (or very, very large) population.

d. Service times vary from one customer to the next and are independent of one another, but their average rate is known.

e. Service times occur according to the negative exponential probability distribution.

f. Amount of space available for waiting customers is infinite.

When these conditions are met, the series of equations shown as (*iii*) to (*ix*) in the Appendices can be developed(Prabhu, 1987). For the waiting time, w, of a unit which has to wait such that $w \leq W < w\ dw$, the probability of waiting if defined by eqn (*x*) of the Appendices.

2. *Model B (M/M/s): Multiple-Server queuing model*

A multiple-channel queuing system is one in which two or more servers or channels are available to handle arriving customers and all the servers are assumed to perform at the same rate. In this model, it is assumed that customers waiting for service form one single line and then proceed to the first available server. It is also assumed that arrivals follow a Poisson distribution and service times are exponentially distributed. Service is first come, first served and there is an infinite queue capacity. It is also assumed that the servers of the waiting line are identical and all have equal capacity. The Multi-server single-phase waiting lines are found in many banks today and most especially in the petroleum service stations. (Refer to Figure 6 of the Appendices for a typical multichannel configuration). The queuing equations for Model B (which also has the technical name M/M/*s*) are shown as eqns (*xi*) to (*xviii*) of the Appendices. These equations are obviously more complex than those used in the single-server model; yet they are used in exactly the same fashion and provide the same type of information as the simpler model.

3. *Model C (M/D/1): Constant-service-time model*

Some service systems have constant, instead of exponentially distributed, service times. When customers or equipment are processed according to a fixed cycle e.g. as in the case of an automatic car wash or an amusement park ride, constant service times are appropriate. Because constant rates are certain, the values for *Lq*, *Wq*, *Ls*, and *Ws* are always less than they would be in Model A, which has variable service rates. As a matter of fact, both the average queue length and the average waiting time in the queue are halved with Model C. Constant-service-model formulas are given as eqns (*xix*) to (*xxii*) of the Appendices..

4. *Model D: Limited-population model*

When there is a limited population of potential customers for a service facility, we must consider a different queuing model. This model would be used, for example, if we were considering equipment repairs in a factory that has 5 machines, if we were in charge of maintenance for a fleet of 10 commuter airplanes, or if we ran a hospital ward that has 20 beds. The limited-population model allows any number of repair people (servers) to be considered. This model differs from the three earlier queuing models because there is now a *dependent* relationship between the length of the queue and the arrival rate. An illustration is an extreme situation where a factory had five machines and all were broken and awaiting repair; the arrival rate would drop to zero. In general, then, as the *waiting line* becomes longer in the limited population model, the *arrival rate* of customers or machines drops. Below, are the queuing formulas for the limited-population model. Note that they employ a different notation than Models *A, B,* and C. *F* is the waiting-time efficiency factor = 1- D, and *D* represents the probability that a machine needing repair will have to wait in line, H is the average number of customers being served, J is the average number of customers not in line or in service, *L* is the average number of customers waiting for service, *N* is the number of potential customers, *T* is the average service time, U is the average time between customer service requirements per customer, W is the average time customer waits in line and *X* is the service factor. *D* and *F* are needed to compute most of the other finite model formulas. See eqns (*xxiii*) to (*xxviii*) of the Appendices.

1.1.1.7 Performance measures of a queuing system

Hillier and Lieberman(2005) put forth the following performance parameters in a queuing system:

- **a.** System Utilization (ρ): System Utilization is the most important measure of a queuing system. It is the ratio of system capacity used to available capacity. It measures the average time the system is busy. System utilization of zero means that there is nobody in the system. On the other hand, a system utilization of one or more signifies that there is infinite number of people on the waiting line. This means that the available servers cannot cope with the arriving demand. Thus something has to be done on the service facility(Egolum, 2001).
- **b.** Mean Number in the system (Ls): Mean number in the system is the average number of system users (entities) in the system; it includes those in the queue and those being served by the server(s).
- **c.** Mean Number in Queue (L_q): Mean number in the queue is the average or expected number of system users in the queue (waiting line), waiting for their turn to be served.

d. The average waiting time for an arrival not immediately served (W_a)

e. Mean Time in System (W_s): Mean time in the system is the expected value or average waiting time an entity will spend in the queuing system. It includes the average time waiting for service to begin and the average service time.

f. Mean Time in Queue (W_q): Mean time in the queue is the expected value or average time an entity will spend in the queue, waiting for service to begin.

g. probability of zero customers in the system (P_O)

h. Probability of waiting (P_w): This is the probability that an arrival will have to wait for its service to begin.

1.1.1.8 Birth-and-Death Processes

In the context of queuing theory(Hillier and Lieberman, 2005); the term *birth* refers to the arrival of a new customer into the queuing system, and *death* refers to the *departure* of a served customer. Only one birth or death may occur at a time: therefore, transitions always occur to the "next higher" or "next lower" state. The rates at which births and deaths occur are prescribed precisely by the parameters of the exponential distributions that describe the arrival and service patterns. All the possible transitions can be illustrated in the rate diagram in Figure VIII of the Appendices. The *state* of the system at time *t* ($t \geq 0$), denoted by N(*t*), is the number of customers in the queuing system at time *t*. The birth-and-death process describes *probabilistically* how N(*t*) changes as *t* increases. More precisely, the assumptions of the birth-and-death process are the followings:

Assumption 1. Given N(*t*) = *n*, the current probability distribution of the *remaining* time until next *birth* (arrival) is *exponential* with parameter λ_n ($n = 0, 1, 2, \ldots$).

Assumption 2. Given $N(t) = n$, the current probability distribution of the *remaining* time until the next *death* (service completion) is *exponential* with parameter (n = 1, 2,..).

Assumption 3. The random variable of assumption 1 (the remaining time until the next birth) and random variable of assumption 2 (the remaining time until the next death) are mutually dependent. Furthermore, an arrival causes a transition from state *n* into sate *n*+1, and the completion of a service changes the system's state from *n* to *n*-1. No other transitions are considered possible. This birth-and-death process illustration as shown in the appended Figure 8 leads directly to the formulae that measure the performance of this queuing system.

1.1.1.9 Queuing Network Model

Most real life queuing systems have more than one service facility(Koizumi, 2002). The output of one facility may proceed to another facility for further processing, or return to facility already visited for rework or additional work of a different type. Applications abound in diverse areas, such as hospital-care centers, assembly lines flow shops, and job shops in manufacturing, traffic flow in a network of highways, client server computer systems, telecommunication system, and airport terminals. Therefore, a queuing model which composes of a set of linked queues called stations (i.e. multiple stations) is called a queuing network model. Queuing network is a version of queuing model that deals with analysis of customers that require more than one service from different service facilities one after the other, and they have to queue up for service before each of the servers. See example of a queuing network in the Appendices shown as Figure IX. A variety of queuing network frameworks have been developed to represent various system mechanisms .The system in a network model is characterized by:

a. An open or a closed system, and

b. Linkage of station (tandem, arbitrarily linked with or without feedback flow)(Koizumi, 2002). As in a single server station model, each station in network system owns characteristics including, (i) inter-arrival times, (ii) service times, (iii) the number of servers (iv) the maximum capacity of station, and, (v) queue discipline. In a queuing network model, waiting spaces between stations (i.e. part of each station's "capacity") are expressed as "buffer".

1.1.1.10 Limitations of queuing theory

Queuing models have several limitations. Some of the limitations are the basic assumptions for the application of queuing models and according to Singh(2007) they include the following: (a) Takes average of all variables rather than the real numbers. (b) Assumes steady state situation in most cases of queuing system.

1.1.2 Simulation

Simulation, as we know, is a representative model for real situations. Some more suitable definitions of the word are given in Chapter 17 of Sharma(2009-10) and are given as presented below:

1. *Simulation is a representation of reality through the use of a model or other device which will react in the same manner as reality under a given set of conditions.*
2. *Simulation is the use of system model that has designed the characteristics of reality in order to produce the essence of actual operation.*
3. *According to Donald G. Malcolm, a simulated model may be defined as one which depicts the working of a large scale system of men, machines, materials and information operating over a period of time in a simulated environment of the actual real world conditions.*
4. *According to T. H. Naylor et al(1966), simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical relationships necessary to describe the behaviour and structure of a complex real-world system over extended periods of time.*
5. *Churchman has defined simulation as follows: "X simulates Y" is true and only if: (a) X and Y are formal systems; (b) Y is taken to be the real system; (c) X is taken to be an approximation of the real system; and (d) the rules of validity in X are non-error-free, otherwise X will become the real system.*

1.1.2.1 Types of simulation

There are mainly two types of simulation namely, Analogue (or Environmental) simulation and Computer (or System) simulation.

1. ***Analogue (or Environmental) simulation:*** This entails simulating the reality in physical form, like a children's cycling park with various signals and crossings in an exhibition is a simulated (represented) model of city-traffic in real system.
2. ***Computer (or System) simulation:*** This is the type of simulation used for complex and intricate problems of managerial decision making, where the analogue simulation may not be applicable and the actual experimentation with the system may be uneconomical also. Under these situations, the complex system is formulated into a mathematical model for which a computer program is developed, and then the problem is solved by using high speed electronic computer.

1.1.2.2 Classification of simulation models and why simulation is used

As published by Sharma (2009-10), simulation models can be classified into the following four categories:

1. *Deterministic Models:* In these models, the input and output variables are not allowed to be random variables and the models are described by exact functional relationship.
2. *Stochastic Models:* In these models, at least one of the variables or functional relationship is given by probability functions.
3. *Static Models:* These models do not take variable time into consideration.
4. *Dynamic Models:* These models deal with time varying interaction.

Common reasons why simulation technique is used as a tool in solving real-life problems include:

1. If the mathematical analysis is either too complex or too expensive, simulation technique lends itself as the next option for use.
2. Simulation techniques allow experimentation with a model of the real-life system rather than the actual operating system.
3. Sometimes there is no sufficient time to allow the actual system operate extensively. This is exemplified by a desire to study long term trends in world population. Here, it is not possible to wait for the desired number of years to see the results. Simulation allows for incorporation of time into an analysis.
4. A non-technical manager can comprehend simulation more easily than a complex mathematical model.
5. Use of simulation enables a manager to provide insight into certain managerial problems where analytical solutions of a model is not possible or where the actual environment is difficult to observe. This explains the reason why simulation is used in space flights or the charting satellite.

1.1.2.3 Limitations of simulation technique

The limitation of the simulation technique can be briefly outlined as follows:

1. It is not possible to obtain optimum results by simulation since the model mostly deals with uncertainties; as such the results are only reliable approximations involving statistical errors.

2. In many situations, it is not possible to quantify all the variables which affect the behavior of the system.
3. In problems involving very large number of variables, it may not be possible to make a computer program on account of the number of the variables and inter-relationships among them. In some cases, number of the variables may exceed the capacity of the of the available computer.
4. Simulation can be comparatively costlier and time consuming in certain situations.
5. Other important limitations stem from too much tendency to depend on the simulation models; even in simple problems which can otherwise be solved by more appropriate techniques of mathematical programming.

1.1.2.4 Phases of simulation model

A simulation model mainly consists of two basic phases:

Phase 1: *Data Collection* - Data generation involves the sample observation of variables and can be carried out with the help of any of the following methods:

i. Using the random number tables;
ii. resorting to mechanical devices (for example, roulettes wheel);
iii. Using electronic computers.

Phase 2: *Book-keeping* - This phase of simulation deals with updating the system when new events occur, monitoring and recording the system states as and when they change; and keeping track of quantities of our interest (such as idle time and waiting time) to compute the measures of effectiveness.

1.1.3 Markov chain - an overview

In 1907, A. A. Markov began the study of an important new type of chance process. In this process, the outcome of a given experiment can affect the outcome of the next experiment. This type of process is called a Markov chain. Markov chain is a way of modeling a system. The system can be companies, animals, people et cetera. The main properties of a Markov chain is that it has states and transitions. A Markov chain is given by the probabilities of transiting between two states.

Our study of probability teaches us that independent trials processes are the basis of classical probability theory and much of statistics. Two of the principal theorems for these processes are the Law of Large Numbers and the Central Limit Theorem. It has been proved that when a sequence of chance experiments forms an independent trials process, the possible outcomes for each experiment are the same and occur with the same probability. Further, knowledge of the outcomes of the previous experiments does not influence our predictions for the outcomes of the next experiment. The distribution for the outcomes of a single experiment is sufficient to construct a tree and a tree measure for a sequence of *n* experiments, and we can answer any probability question about these experiments by using this tree measure.

Modern probability theory studies chance processes for which the knowledge of previous outcomes influences predictions for future experiments. In principle, when we observe a sequence of chance experiments, all of the past outcomes could influence our predictions for the next experiment. For example, this should be the case in predicting a student's grades on a sequence of exams in a course. But to allow this much generality would make it very difficult to prove general results. Markov chain has been used extensively for modeling systems in physical sciences, biological sciences, sports, gambling et cetera.

1.1.3.1 Use of probability and transition matrices in Markov model

From the foregoing, therefore, Markov chain can be explained as a discrete-time stochastic process on *n* states defined in terms of a transition probability matrix (*M*) with rows *i* and columns *j*. Mathematically, a Markov model is expressed thus

$$\boldsymbol{M} = (P_{ij}) \qquad (1)$$

These conditional probabilities p_{ij} are called transition probabilities. If the number of states is finite (for instance n_0), they can be arranged in a transition probability matrix *M* so that the first subscript (*i*) stands for row and the second (*j*) for column. *M* is a square matrix (n_0 x n_0) with non negative elements and unit row sums. If we associate a time scale to the sequence of trials as Figure 2 depicts,

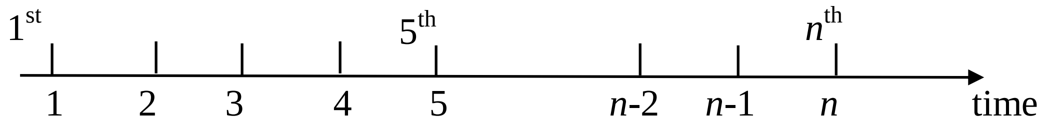


Figure 2: Time scale for sequence of trials

where:

n corresponds to the future

n-1 corresponds to the present

1 to (*n*-2) corresponds to the past,

then, the Markov property can be stated as follows:

$$P\{\text{Future/Present and Past}\} = P\{\text{Future/Present}\} \qquad (2)$$

We stress that the evolution of a Markov chain is **memoryless**: the transition probability P_{ij} depends only on the state i and not on the time t or the sequence of transitions taken before this time.

1.1.3.2 Features of transition matrix

A transition matrix has several features, among which are:

1. It is square, since all possible states must be used both as rows and as columns.
2. All entries are between 0 and 1, inclusive; this is because all entries represent probabilities.
3. The sum of the entries in any row (or column, consistency must be maintained) must be 1, since the numbers in row give the probability of changing from the state at the left to one of the states indicated across the top. Eqn (3) refers.

$$\begin{array}{cc} \text{States} & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \end{array} & \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix} \end{array} = \boldsymbol{M} \qquad (3)$$

In transition matrix, the states are indicated at the side and at the top. An example is as shown in eqn (3). A transition matrix, such as matrix ***M*** above, also shows two key features of a Markov chain. A sequence of trials of an experiment is a Markov chain if

1. the outcome of each experiment is one of a set of discrete states;
2. the outcome of an experiment depends only on the present state, and not on any past states.

1.1.4 Meaning and categories of inventory management:

Inventory (stock of goods) has been variously defined. Sharma(2009-10) defined inventory as the stock of goods, commodities or other economic resources that are stored or reserved in order to ensure smooth and efficient running of business affairs. Also, inventory refers to any stored resource used to satisfy a current or future need (raw materials, work-in-process, finished goods, etc.) It represents as much as 50% of invested capital at some companies. Excessive inventory levels are costly and insufficient inventory levels lead to stockouts(Pearson, 2007)

As contained in Sharma and Sharma(2006), inventory may be classified into two main categories namely,

1. **Direct inventory:** Refers to items which play one direct role or the other in a manufacturing process and become an integral part of the finished goods. Direct

   inventory may be kept in any of the following forms:

(a) *Raw material inventory*: These are raw materials kept in stock for use in production of goods. This inventory is provided for the following reasons:

i. For economical bulk purchasing

ii. To enble production rate changes

iii. To provide production buffer against delays in transportation

iv. For seasonal fluctuations

(b) *Work-in-process inventory:* This is a collection of semi-finished goods or goods still being processed which are stored during the production process. Reasons for keeping this form of inventory include:

i. To enable economical lot production.

ii. To cater for the variety of products

iii. For replacement of wastages

iv. To maintain uniform production even if amount of sales may vary

(c) *Finished-goods inventory:* Are finished goods awaiting shipment from the factory. They are provided:

i. Maintaining off-shelf delivery

ii. To allow stabilization of the production level

iii. For sales promotion

(d) Spare parts inventory

2. Indirect inventory: This include those items which are necessarily required for manufacturing but do not become any component of the finished goods. Example include: petrol, oil, grease, office material, maintenance material, et cetera.

1.1.4.1 Terms used in inventory control

The following are some of the terms used in inventory control

a) **Demand:** This is the number of items required per period. The demand is the most critical, yet an uncontrollable component, without demand there would be no need for maintaining inventory.

b) **Lead time**: This refers to the time between placing an order and its receipt in stock. It may be assumed deterministic or probabilistic depending upon the reputation of supplier or his past behaviour. Lead time can be classified as administrative lead time, transporting lead time and inspection lead time. Consideration of lead time is one of the important factors in inventory management.

c) **Quantity discount/Economy of scale:** This is an allowance granted by the vendor to the purchaser of the materials for encouraging large size orders. Sometimes there are an agreement between the vendor and the purchaser that quantity discount will be allowed by the vendor on purchase of certain specified quantity of an item. There are two main types of quantity discounts: (1) all-units and (2) incremental (Nahmias, 2005).

Numerical examples include:

i. *Incremental unit discount*: Units 1-100 cost ₦50 each; Units 101-199 cost ₦48 each; units 200 and up cost ₦36 each. So when 150 units are ordered, the total cost is ₦50 x 100 + ₦48 x 50.

ii. *All units discount*: An order of 1-1000 units costs ₦50 each; an order of 1001-5000 units costs ₦65 each; an order of more than 5000 units costs ₦60 each. So when 1500 units are ordered, the total cost is ₦65 x 1500.

In the presence of a strategic customer who responds optimally to discount schedule, the design of optimal quantity discount scheme by the supplier is complex and has to be done carefully. This is particularly so when the demand at the customer is itself un-certain. An interesting effect called the “reverse bullwhip” takes place where an increase in consumer demand uncertainty actually reduces order quantity uncertainty at the supplier (Altintas et al, 2008).

d) **Safety stock**: This is also known as minimum stock level of material/item below which the actual stock should not be allowed to fall. The fixation of this level acts as safety measure and hence, it is known as 'Safety Stock' or 'Buffer Stock'. In case the actual stock falls below this level, there is a danger of interruption in production and management has to give top priority to the acquisition of its fresh supplies. The main objective of fixing the minimum level of materials is to ensure that required quantity of various input materials are available in stores at all times. The main factors which are taken into account in fixing the level include:

i. The average rate of consumption of materials during production
ii. The time required to obtain fresh supplies under top priority conditions
iii. Reorder level/point
iv. The production requirement of materials
v. The minimum quantity of materials which could be produced advantageously

1.1.4.2 Types of inventory models

There are basically five types of inventory models (Sharma, 2009-10) which include:

1. **Fluctuation inventories:** These are reserve stocks or safety stocks carried because sales and production times cannot be predicted accurately. In real-life problems, there are fluctuations in demand and lead-times that affect the production of items.

2. **Anticipation inventories:** These are built up in advance for the season of large sales, promotion programme or plant shut-down period. In fact, anticipation inventories store the men and machine hours for future requirements.

3. **Cycle (lot-size) inventories:** In practical situations, it seldom happens that the rate of consumption is the same as the rate of production or purchasing. So the items are

procured in large quantities than they are required, which results in cycle (or lot-size) inventories.

4. **Transportation inventories:** These exist because the materials are required to move from one place to another. When the transportation time is long, the items under transport cannot be served to customers. These inventories exist solely because of transportation time.

5. **Decoupling inventories:** Are needed for meeting out the demands during the decoupling period of manufacturing or purchasing.

1.1.4.3 Economic order quantity analysis and the underlying assumptions - An overview

The Economic Order Quantity (EOQ) or economic lot size (ELS), is the number of units that a company should add to inventory in order to minimize the total costs of inventory—such as holding costs, order costs, and shortage costs. It refers to the lot size of goods or materials for which the total cost per period is minimum. In other words, EOQ is the order quantity that minimizes total inventory holding costs and ordering costs. EOQ is used as part of a continuous review inventory system in which the level of inventory is monitored at all times and a fixed quantity is ordered each time the inventory level reaches a specific reorder point(Wikipedia, 2014)

The EOQ provides a model for calculating the appropriate reorder point and the optimal reorder quantity to ensure the instantaneous replenishment of inventory with no shortages. It can be a valuable tool for small business owners who need to make decisions about how much inventory to keep on hand, how many items to order each time, and how often to reorder to incur the lowest possible costs. The EOQ model assumes that demand is constant, and that inventory is depleted at a fixed rate until it reaches zero. At that point, a specific number of items arrive to return the inventory to its beginning level. Since the model assumes instantaneous replenishment, there are no inventory shortages or associated costs. Therefore, the cost of inventory under the EOQ model involves a tradeoff between inventory holding costs (the cost of storage, as well as the cost of tying up capital in inventory rather than investing it or using it for other purposes) and order costs (any fees associated with placing orders, such as delivery charges). Ordering a large amount at one time will increase a small business's holding costs, while making more frequent orders of fewer items will reduce holding costs but increase order costs. The EOQ model finds the quantity that minimizes the sum of these costs.

Therefore, we can apply EOQ when we want to determine the optimal number of units to order so as to minimize the total cost associated with the purchase, delivery and storage of a product. The required parameters to the solution are the total demand for the year, the purchase cost for each item, the fixed cost to place the order and the storage cost for each item per year. Note that the number of times an order is placed will also affect the total cost, though this number can be determined from the other parameters.

Economic order quantity (EOQ) is one of the oldest classical production scheduling models. The framework used to determine this order quantity is also known as **Wilson EOQ Model** or **Wilson's Lot size model** or **Wilson Formula**. The model was developed by Ford W. Harris in 1913(Harris, 1990), but R. H. Wilson, a consultant who applied it extensively, is given credit for his in-depth analysis(Hax and Candea, 1984).

The underlying assumptions

a) The ordering cost is constant.
b) The rate of demand is known or relatively uniform
c) The lead time is fixed.
d) The purchase price of the item is constant i.e. no discount is available
e) The replenishment is made instantaneously, the whole batch is delivered at once.
f) Only one product is involved.

1.2 Statement of Problem

Solid wastes generation (discard) rate in Awka metropolitan area of Anambra State has continued to surpass the rate at which the wastes are evacuated (disposed) to the final dump site at Agu-Awka. This process gap leads to accumulation of these wastes at various locations in the area, causing some social, economic and health problems, also making the environment look dirty, among other problems. This is a serious source of worry, not only to the state government and its agency, ASWAMA, but also, to the residents as well. Waste generation in the state is inevitable and cannot be stopped but, at least, the generated quantity should be kept at a minimal inventory level that will help alleviate the said worries of the Anambra State government and the residents of Awka City. How can this effective minimal inventory level be achieved, considering the costs involved?

Meanwhile, the unscientific methods of waste data collection and management make good and reliable engineering analyses that will bring about effective and efficient waste management decisions in the state difficult to achieve for ASWAMA. Something must be done to address these problems, ASWAMA needs some help. Besides, mathematical models for analyzing data collected on waste management and for predicting variations in waste productions are needed to ensure that waste in Anambra State (or any such location) are managed scientifically and in a sustainable manner too.

1.3 Aim and Objectives

The research aims at developing models for sustainable municipal solid waste management (SMSWM). In doing so, the study pursued the following objectives:

1. To study the method(s) of managing solid waste in Anambra State, using Awka, the capital city, as a case study.
2. To develop mathematical, forecasting and iconic models for use in solid waste inventory management (SWIM).
3. To determine the per capita disposal rate of Awka municipality.
4. To show the application of Markov chain, Pareto rule and Fishikawa diagram in MSWM.

1.4 Significance of the Study

From the foregoing, this work is significant in the sense that it will:

1. Enable identification of the capabilities (strength, weaknesses, opportunities and threats) of ASWAMA in managing waste in Anambra State.
2. Present some new mathematical and forecasting models for use in solid waste management.
3. Provide bases for short-term and long-term performance evaluation of a waste management system or any other system exhibiting similar features of accumulation.
4. Enable generation of information on the different sub-streams of waste to design, implement and monitor an effective and efficient system for collection, transportation, recycling, treatment, recovery and disposal of various streams of solid waste and applicable data for continuous improvements in MSWM.
5. It will also contribute to knowledge enhancement in the academic world.

1.5 Scope and Limitations of the Study

The field study lasted for thirty six months, starting from January 1, 2012 to December 31, 2014, during which the rates of influx and discharge of solid waste materials at sixty six roadside waste dumpsites in twelve ASWAMA zones of Awka capital city of Anambra State and the final open dump site at Agu-Awka, at the outskirt of the city, were monitored. The number of dump sites monitored were taken as the sample population. Waste considered in the work were mainly the solid type, or where such other types of waste mixed up with the general wastes sent to final dump site or landfill.

In its model development, the study considered only the costs of managing solid wastes from the points of their collection at roadside dumpsites to the final disposal site.

Out of scope of the study are: individual load counts from waste generators or their broader sources (homes, offices, hotels, etc); waste salvaged at the sites of generation and disposal; waste disposed of at dumps in hospitals, banks, schools, churches, illegal dump sites/places - empty lots, alleys, ditches etc; waste processing and recovery, dead animal bodies and scraped vehicles abandoned along the streets; and waste sorting and characterization at points of generation/disposal.

Constraints in the study include lack of fund, lack of the required number of research personnel, and lack of means of measuring the exact volumes (preferably, weights) of quantities of solid wastes dumped/transferred to the final dump site.

CHAPTER 2

LITERATURE REVIEW

2.1 Study Location

The present Anambra is one of the states in south-eastern Nigeria that were created from the old Anambra State on 27th August, 1991. It is located at 6°20′N 7°00′E (Wikipedia, 2012), Figure 3 refers, and consists of twenty one local government areas which are contained within a total land area of 4,844 km^2. See Figure 4. The state is bounded by Kogi State to the north, Enugu State to the east, Imo and Rivers States to the south, and Delta and Edo States to the west. Anambra State derives it's name from Anambra River that traverses the state. The state is nicknamed "*Light of the Nation*", meaning "*Ife Mbà"* in Igbo language. Going by the 2006 population census in Nigeria, Anambra State has a population of 4,177,828 people (NPC, Awka, 2014) with a density of 840/km^2, ranking tenth (10th) among the thirty six (36) states of the Nigerian federation. Total GDP of the state in 2007 was $11.83 billion, with a per capita of $1,615 (Adichie C., 2008). The capital city of Anambra State is Awka.

Figure 3: Location of Anambra State in the map of Nigeria [Source: Wikipedia, 2013]

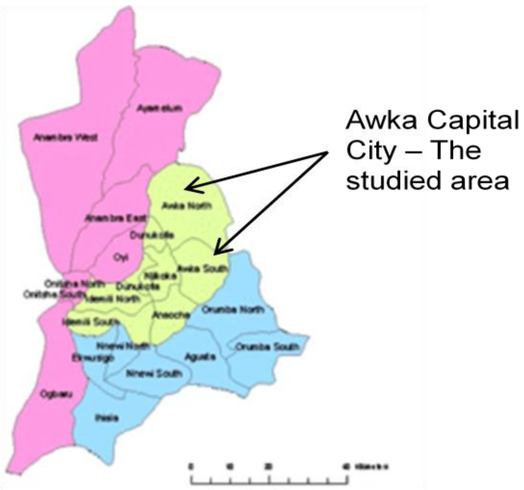


Figure 4: Map of Anambra State depicting the various local government areas in the state [Source: Wikipedia, 2014]

2.1.1 Waste management in Anambra State

When it became obvious in 1984 to protect the environment of the state, especially from the problems caused by solid wastes generation and poor handling, the then military government in power established a full-fledged Agency called Anambra State Environmental Sanitation Agency (ANSESA) to deal with the said problems in the state. After the establishment of ANSESA, it functioned for about 14 years before being dissolved.

In 1998, a new waste management board known as Anambra State Environmental Protection Agency (ANSEPA) was constituted in place of ANSESA. ANSEPA functioned for a number of years without making much positive impact on the state's environment; instead, it received varied degrees of criticisms from people within and outside the state for poor performances. Some of the critics of ANSEPA described it as a total failure, a huge disappointment and a wasted effort and resources of the state.

In 2011, ANSEPA was dissolved and a new board known as Anambra State Waste Management Agency (ASWAMA) was formed in its place. Consequently, ASWAMA has been in directly control of waste management in Anambra State, as empowered by the Laws of Anambra State (2011). The law was enacted by the Anambra State House of Assembly. The agency works under the State Ministry of Environment and is sponsored by the Anambra State Government and is charged with the following major responsibilities:

a) Removal, collection and disposal of domestic commercial and industrial generated waste.
b) Cleaning and maintenance of Public drainage facilities
c) Cleaning streets of Awka, Onitsha and Nnewi urban areas
d) Removal and disposal of scrapped vehicles abandoned at legal points within the State.
e) Sweeping of major streets/roads in the State

Presently ASWAMA operates fully in Awka Metropolis, particularly in Awka South Local Government Area (LGA) where the seat of Government of the state is situated. This explains the reason why Awka area was chosen as the case study. The agency renders intervention services to other LGAs managed by their respective local government authorities and private waste management formations - contractors, traders associations, NGOs and/or CBOs. Table 2 conveys this information very clearly. Table 2 shows the various LGAs of the state where generated wastes are mostly managed by their respective local authorities; except LGAs in Awka, Nnewi and Onitsha, where the state government participates by collaborating with private waste managers.

However, in Onitsha and Nnewi Local Government Areas, ASWAMA works in collaboration with a private waste management contracting firm which wished to be identified with the name Laga International Ltd. The collaboration works under a programme called the Anambra State Integrated Development Strategy (anids). See Plates 1 and 2 in the Appendices.

Table 2: Local Government Areas of Anambra State where ASWAMA operates

S/N	Name Of Local Government Area	Serviced By			No. Of Zones In The Area
		ASWAMA		Private Contractor/ Organizations	
		State	LG		
1	Aguata		✓	✓	10
2	Anambra East		✓	✓	
3	Anambra West		✓	✓	
4	Anaocha		✓	✓	
5	Awka North	✓	✓	✓	12
6	Awka South	✓	✓	✓	
7	Ayamelum		✓	✓	
8	Dunukofia		✓	✓	
9	Ekwusigo		✓	✓	
10	Idemili North		✓	✓	
11	idemili South		✓	✓	
12	Ihiala		✓	✓	
13	Njikoka		✓	✓	
14	Nnewi North	✓	✓	✓	7
15	Nnewi South	✓	✓	✓	
16	Ogbaru		✓	✓	
17	Onitsha North	✓	✓	✓	9
18	Onitsha South		✓	✓	
19	Orumba North		✓	✓	
20	Orumba South		✓	✓	
21	Oyi		✓	✓	

Plates 2(a-d) in the Appendices, are photographs of a number of locations in Anambra State where solid waste were dumped into and around stationary public used bins. A closer look at the pictures quickly reveals how dirty and unkempt these garbage make our environment look.

Therefore, the need to protect our natural environment and keep it clean on individual, organizational and governmental levels for the benefit of all cannot be over-emphasized. Out there in our environment are collections of waste of all sorts waiting for proper disposal by any caring servant(s) or agency. In Anambra State, especially the urban and semi-urban centres, one notices that the rate of influx of waste materials into different dump (legal and illegal) locations far outweighs their rate of disposal, leading to accumulation of these discarded materials at the dumpsites, with their consequent social, economic, environmental and health problems.

2.2 Pareto principle - An overview

The Pareto principle (also known as the 80–20 rule, the law of the vital few and traival many, the principle of factor sparsity), Ankunda(2011), states that, for many events, roughly 80% of the effects come from 20% of the causes(Bunkley, 2008). Management consultant Joseph M. Juran suggested the principle and named it after Italian economist Vilfredo Pareto, who, while at the University of Lausanne in 1896, published his first paper "Cours d'économie politique." The original observation was in connection with population and wealth. Pareto noticed that 80% of Italy's land was owned by 20% of the population(Pareto and Page,1971). He then carried out surveys on a variety of other countries and found to his surprise that a similar distribution applied. Essentially, Pareto showed that approximately 80% of the land in Italy was owned by 20% of the population; Pareto developed the principle by observing that 20% of the peapods in his garden contained 80% of the peas(Wikipedia, 2015)

The principle is a common rule of thumb in business; e.g., "80% of your sales come from 20% of your clients." Mathematically, the 80–20 rule is roughly followed by a power law distribution (also known as a Pareto distribution) for a particular set of parameters, and many natural phenomena have been shown empirically to exhibit such a distribution(Newman, 2011)

Wikipedia(2015) reports that the Pareto principle has been variously applied in different fields of life. In economics, a chart that gave the inequality a very visible and comprehensible form, the so-called 'champagne glass' effect(Gorostiaga, 1995) was contained in the 1992 United Nations Development Program Report, which showed the distribution of global income to be very uneven, with the richest 20% of the world's population controlling 82.7% of the world's income(UNDP, 1992).

In science, the more unified a theory is, the more predictions it makes, and the greater the chance is of some of them being cheaply testable. Modifications of existing theories make much fewer new unique predictions, increasing the risk that the few predictions remaining are very expensive to test(Charles Sanders Peirce, 1877–1878).

According to Wikipedia, distribution in business, is claimed to appear in several different aspects relevant to entrepreneurs and business managers. For example:

80% of a company's profits come from 20% of its customers

80% of a company's complaints come from 20% of its customers

80% of a company's profits come from 20% of the time its staff spend

80% of a company's sales come from 20% of its products
80% of a company's sales are made by 20% of its sales staff.

Therefore, many businesses have an easy access to dramatic improvements in profitability by focusing on the most effective areas and eliminating, ignoring, automating, delegating or retraining the rest, as appropriate(Wikipedia, 2015)

In computer science and engineering control theory, such as for electromechanical energy converters, the Pareto principle can be applied to optimize efforts(Gen and Cheng, 2002). For example, Microsoft noted that by fixing the top 20% of the most-reported bugs, 80% of the related errors and crashes in a given system would be eliminated (Rooney, 2002). In load testing, it is common practice to estimate that 80% of the traffic occurs during 20% of the time(Wikipedia, 2015)

In software engineering, Lowell Arthur expressed a corollary principle: "20 percent of the code has 80 percent of the errors. Find them, fix them!"(Pressman, 2010). In occupational health and safety, the Pareto principle is used to underline the importance of hazard prioritization. Assuming 20% of the hazards will account for 80% of the injuries and by categorizing hazards, safety professionals can target those 20% of the hazards that cause 80% of the injuries or accidents. Alternatively, if hazards are addressed in random order, then a safety professional is more likely to fix one of the 80% of hazards which account for some fraction of the remaining 20% of injuries(Woodcock, 2010).

Aside from ensuring efficient accident prevention practices, the United States Coast Guard states that the Pareto principle also ensures hazards are addressed in an economical order as the technique ensures the resources used are best used to prevent the most accidents.

2.2.1 Other applications of the Pareto rule

In the systems science discipline, Epstein and Axtell(1996) created an agent-based simulation model called SugarScape, from a decentralized modeling approach, based on individual behavior rules defined for each agent in the economy. Wealth distribution and Pareto's 80/20 principle became emergent in their results, which suggests the principle is a natural phenomenon(Epstein and Axtell, 1996), The Pareto principle has many applications in quality control(Wikipedia, 2015). It is the basis for the Pareto chart, one of the key tools used in total quality control and six sigma. The Pareto principle serves as a baseline for ABC-analysis (Dickie, 1951) and XYZ-analysis, widely used in logistics and procurement for the purpose of optimizing stock of goods, as well as costs of keeping and replenishing that stock(Rushton, Oxley & Croucher, 2000).

Myrl Weinberg reported that in the United States, 20% of patients have been found to use 80% of health care resources.

Several criminology studies have found 80% of crimes are committed by 20% of criminals(Wikipedia, 2015). This statistic is used to support both stop-and-frisk policies and broken windows policing, as catching those criminals committing minor crimes will likely net many criminals wanted for (or who would normally commit) larger ones.

In the financial services industry, this concept is known as profit risk, where 20% or fewer of a company's customers are generating positive income, while 80% or more are costing the company money.

2.3 SWOT analysis - An overview

According to Wikipedia, the free encyclopedia, a SWOT analysis (or SWOT matrix) is a structured planning method used to evaluate the **s**trengths, **w**eaknesses, **o**pportunities, and **t**hreats involved in a project or in a business venture. A SWOT analysis can be carried out for a product, place, industry or person. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favorable and unfavorable to achieve that objective. The technique is credited to Albert Humphrey, who led a convention at the Stanford Research Institute (now SRI International) in the 1960s and 1970s using data from Fortune 500 companies(Humphrey, 2005; TAM UK). The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit.

Setting the objective should be done, Wikipedia continue, after the SWOT analysis has been performed. This would allow achievable goals or objectives to be set for the organization.

S*trengths*: characteristics of the business or project that give it an advantage over others.

W*eaknesses*: characteristics that place the business or project at a disadvantage relative to others

O*pportunities*: elements that the project could exploit to its advantage

T*hreats:* elements in the environment that could cause trouble for the business or project

Identification of SWOTs is important because they can inform later steps in planning to achieve the objective. First, the decision makers should consider whether the objective is attainable, given the SWOTs. If the objective is *not* attainable a different objective must be selected and the process repeated. Users of SWOT analysis need to ask and answer questions that generate meaningful information for each category (strengths, weaknesses, opportunities, and threats) to make the analysis useful and find their competitive advantage.

One way of utilizing SWOT is matching and converting. Matching is used to find competitive advantage by matching the strengths to opportunities. Converting is to apply conversion strategies to convert weaknesses or threats into strengths or opportunities. An example of conversion strategy is to find new markets. If the threats or weaknesses cannot be converted, a company should try to minimize or avoid them(Mehta, 2000)

2.3.1 Internal and external factors in SWOT analysis

SWOT analysis aims to identify the key internal and external factors seen as important to achieving an objective. The factors come from within a company's unique value_chain. SWOT analysis groups key pieces of information into two main categories:

internal factors – the *strengths* and *weaknesses* internal to the organization

external factors – the *opportunities* and *threats* presented by the environment external to the organization

Analysis may view the internal factors as strengths or as weaknesses depending upon their effect on the organization's objectives. What may represent strengths with respect to one objective may be weaknesses (distractions, competition) for another objective. The factors may include all of the 4Ps; as well as personnel, finance, manufacturing capabilities, and so on.

The external factors may include macroeconomic matters, technological change, legislation, and sociocultural changes, as well as changes in the marketplace or in competitive position. The results are often presented in the form of a matrix.

SWOT analysis is just one method of categorization and has its own weaknesses. For example, it may tend to persuade its users to compile lists rather than to think about actual important factors in achieving objectives. It also presents the resulting lists uncritically and without clear prioritization so that, for example, weak opportunities may appear to balance strong threats.

It is prudent not to eliminate any candidate SWOT entry too quickly. The importance of individual SWOTs will be revealed by the value of the strategies they generate. A SWOT item that produces valuable strategies is important. A SWOT item that generates no strategies is not important.

2.3.2 Uses of SWOT analysis and its criticisms

The usefulness of SWOT analysis is not limited to profit-seeking organizations. SWOT analysis may be used in any decision-making situation when a desired end-state (objective) has been defined. Examples include: non-profit organizations, governmental units, and individuals. SWOT analysis may also be used in pre-crisis planning and preventive crisis management. SWOT analysis may also be used in creating a recommendation during a viability study/survey.

Some findings from Menon *et al*(1999) and Hill and Westbrook(1997) have shown that SWOT may harm performance. Other complementary analyses have been proposed, such as the Growth-share matrix.

2.4 Causal loop diagram [An excerpt from Wikipedia, the free encyclopedia]

A causal loop diagram (CLD) is a diagram that aids in visualizing how different variables in a system are interrelated. The diagram consists of a set of nodes and edges. Nodes represent the variables and edges are the links that represent a connection or a relation between the two variables. A link marked positive indicates a positive relation and a link marked negative indicates a negative relation. A positive causal link means the two nodes change in the same direction, i.e. if the node in which the link starts decreases, the other node also decreases. Similarly, if the node in which the link starts increases, the other node increases as well. A negative causal link means the two nodes change in opposite directions, i.e. if the node in which the link starts increases, the other node decreases and vice versa.

Closed cycles in the diagram are very important features of the CLDs. A closed cycle is either defined as a reinforcing or balancing loop. A reinforcing loop is a cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable reinforcing the initial deviation i.e. if a variable increases in a reinforcing loop the effect through the cycle will return an increase to the same variable and vice versa. A balancing loop is the cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable a deviation opposite to the initial one i.e. if a variable increases in a balancing loop the effect through the cycle will return a decrease to the same variable and vice versa. If a variable varies in a reinforcing loop the effect of the change reinforces the initial variation. The effect of the variation will then create another reinforcing effect. Without breaking the loop the system will be caught in a vicious cycle of circular chain reactions. For this reason, closed loops are critical features in the CLDs.

2.4.1 Historical overview of causal loop diagrams

The use of nodes and arrows to construct directed graph models of cause and effect dates back to the invention of path analysis by Sewall Wright in 1918, long before System Dynamics. Due to the limitations of genetic data, however, these early causal graphs contained no loops — they were directed acyclic graphs. The first formal use of Causal Loop Diagrams was explained by Dr. Dennis Meadows at a conference for educators (Systems Thinking & Dynamic Modeling Conference for K-12 Education in New Hampshire sponsored by Creative Learning Exchange. clexchange.org).

Meadows explained that when he and others were working on the World3 model (circa 1970–72), they realized they would not be able to use the computer output to explain how the feedback loops worked in their model when presenting their results to others. They decided to show feedback loops (without the stocks, flows and every variable), using arrows connecting the names of major model components in the feedback loops. Richard Turnock suspected that this may have been the first formal use of Causal Loop Diagrams.

2.4.2 Positive and negative causal links

Positive causal link means that the two nodes change in the same direction, i.e. if the node in which the link starts decreases, the other node also decreases. Similarly, if the node in which the link starts increases, the other node increases.

Negative causal link means that the two nodes change in opposite directions, i.e. if the node in which the link starts increases, then the other node decreases, and vice versa.

2.4.3 Reinforcing and balancing loops

To determine if a causal loop is reinforcing or balancing, one can start with an assumption, e.g. "Node 1 increases" and follow the loop around. The loop is: **reinforcing** if, after going around the loop, one ends up with the same result as the initial assumption. It is **balancing,** if the result contradicts the initial assumption. Or, to put it in other words:
Reinforcing loops have an even number of negative links (zero also is even).
Balancing loops have an odd number of negative links.

Identifying reinforcing and balancing loops is an important step for identifying *Reference Behaviour Patterns,* i.e. possible dynamic behaviours of the system.
Reinforcing loops are associated with exponential increases/decreases. Balancing loops are associated with reaching a plateau. If the system has delays (often denoted by drawing a short line across the causal link), the system might fluctuate.

2.5 Brief discussions on some basic costs concepts

2.5.1 Cost-benefit analysis - origin and meaning

According to Prest and Turvey(1965), the origins of cost-benefit analysis can be traced back to Jules Dupuit's classic article "On the Measurement of the Utility of Public Works" (1844), much of the subsequent scholarly development occurred in the United States and arose from the challenges of water-resource development. In 1950, the U.S. Federal Interagency River Basin Committee's Subcommittee on Benefits and Costs published a report entitled, Proposed Practices for Economic Analysis of River Basin Projects [also known as the Green Book], which became noteworthy for bringing in the language of welfare economics. In 1958, Otto Eckstein published Water-Resource Development: The Economics of Project Evolution and Roland McKean published his Efficiency in Government Through Systems Analysis: With Emphasis on Water Resources Development. The latter book is also considered a classic in the field of operations research. In subsequent years, several other important works appeared: Jack Hirshleifer, James DeHaven, and Jerome W. Milliman published a volume entitled Water Supply : Economics, Technology, and Policy(1960); and a group of Harvard scholars including Robert Dorfman, Stephen Marglin, and others published Design of Water-Resource Systems: New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning (1962)(NCEE)

2.5.1.1 Cost-benefit analysis methodology for solid waste management

It is claimed that CBA is a methodology that has the ability to handle a wide range of problems. CBA can be applied to any decision that involves a relocation of resources within the society(Hanley, 1999). The main distinctive characteristics of CBA that determine its necessity and sufficiency for application to MSW management are:

a) Uniformity of showings for costs and results;

b) The possibility of comparing alternative variants with the purpose of ensuring an acceptable result;

c) Flexibility during the decision-making process in terms of societal values and priorities. At present, priorities in the waste management sphere are(European Commission, 1999):

   i. Prevention of waste;

ii. Recycling and reuse; and

iii. Optimal final disposal

d) The possibility of substantiating the commonly acceptable level of environmental pollution during the process of improving quality; and

e) The adaptability of the form in which the results of the analysis are presented to decision makers.

The ability of different waste management models to accommodate CBA has been analyzed by Moutavtchi, 2012 and is shown in **Table D** of the Appendices.

Analysis of the available waste management models using CBA has shown that, at present, calculation of the financial damage to the environment as a loss of means during implementation of a SWM scheme (showing the current damage), or as a possible positive financial result at a change of the scheme (showing the prevented damage) is not offered by these prevailing models in an explicit form(Moutavtchi, 2012).

2.5.2 Full cost accounting (FCA) methodology for SWM

The FCA methodology provides a base for developing different concepts and tools for environmental–economic substantiation of waste management activity, taking into account the range of this activity and the requirements of the national, regional and local normative–legal base, existing stereotypes, etc. For most countries, the cost structure presented in **Table E** of the Appendices is regarded as understandable and convenient for the practical implementation of SWM schemes.

The following list of basic functions of FCA emphasize that it is:

a) An information support tool for decision making in integrated waste management;

b) A tool for rational planning of SWM activity; i.e. budgeting of a project;

c) A tool for balanced analysis of elements of the whole SWM scheme including collection, recycling, composting, etc.;

d) A tool for efficiency evaluation of a SWM scheme and its attending services;

e) A tool for calculation of competitive rates for services, charges for pollution and prices of solid waste facilities(US EPA, 1997).

The basic cost accounting concept proposed in the FCA methodology(US EPA, 1997) is presented in **Table F** of the Appendices.

Thus, the FCA methodology provides a basis for developing different concepts and tools for ecological–economic substantiation of waste management activities taking into account the range of activity, the requirements of national, regional and local normative–legal bases and existing stereotypes(European Commission, 1996, Makarieva, 1999, Pakhomova *et al*, 2001). Consequently, the FCA methodology is considered suitable as the basis for the cost structure theory set-up in the present work and as an ECO–EE tool.

2.5.2.1 Difference between full cost accounting and other accounting methods

AWAST(2004) stated five basic principles it considers that distinguish FCA from other accounting methods to include:

1. **Accounting of costs rather than expenditures:** An expenditure is an amount of money fixed for the acquisition of a good or service. A cost is the sum of all the expenditures carried out around an equipment over its life span. This cost will then be annualized via the countable techniques of amortization and depreciation, each year contributing to its deterioration.

2. **Accounting of hidden costs:** It is significant to take into account the value of the good used. An equipment acquired, thanks to a help or subsidy has a value, even if the community has not carried out expenditure for the acquisition of this material.

3. **Accounting of monitoring costs and indirect costs:** Some costs can be shared with other services (in particular general administration). In order to "stick" as close as possible to the real cost of the service, it seems relevant to break down these indirect costs in proportion of what can be allotted to the management service. A solution suggested consisted, concerning employees, in calculating a ratio with the number of municipal employees assigned to the municipal waste service compared to the total number of municipal employees (it is possible to improve the precision of this ratio by breaking it up by die).

4. **Accounting of past and future expenditures:** Frequently, they are not appearing on annualized budgets. That requires a research task of investments carried out in the past, which lead today to carry out certain expenditures (cf. re-curring expenditures). Taking into account only these expenditures does not reflect the real cost of the service. The reasoning is worth when regarding future expenditure Privileging the installation of a landfill without, for example, taking into account the costs of closing and reprocessing can lead to management errors.

5. **Accounting according to two approaches** (Figure XIV in the Appendices, refers): The system of domestic waste management in its entirety distinguish the concepts of cost per path (a) and cost per activity (b).

(a) In the centre of a path, there is a treatment process. One will speak thus about the thermal path, the organic path, and the recycling path. A path is made up of activities as a whole (collection, transport, treatment, valorization, and storage) brought back to a particular treatment (vertical approach).

NB: It is possible to speak about path either by referring to a treatment process or by referring to the waste nature (household refuse path ...). Adopting a FCA approach crossed by nature of waste poses once again the data availability problem. Which break down adopt when waste of different nature follows an identical path of treatment?

(b) One can distinguish the activity of collection, transport, the transfer activity, the treatment activity, the activity of valorization etc. The result obtained is a cost every nature of waste intermingled (horizontal approach). The cost of an activity is divided between the various paths. To each activity, it should be possible to make correspond a percentage of "responsibility" for this activity in the cost of the path (example: the collection activity represents X% of the thermal path cost).

The benefits to expect with the adoption of such an approach include:

i. The identification of costs centers and the knowledge of action levers for a better management of the service by the competent authorities.
ii. A communication towards citizens on the cost of proposed service, especially when a specific pricing is adopted
iii. A rationalization of the service with the research of a balance between vided service and cost.
iv. The elimination of inefficiencies and the highlighting of opportunities or profit.
v. A stronger position in the negotiation of contracts, allowed by the cognitive aspect of the method.
vi. The financial comparison between the recourse to a private service provider and a state owned company for the furniture of the service.
vii. The adoption of the various treatment paths, combination for an optimized management of the global service.

viii. The comparison between different waste elimination strategies. How, by associating the whole installations and paths, obtain the best "mix" of service?

ix. The determination of the budget and setting of the necessary amount of taxes to recover in order to finance the service. The FCA approach can prove to be a very powerful tool within the installation and the development of a specific pricing, function of the citizen's behaviour, respecting the principle of a balanced budget. It allows the siting of the suitable general tax level (the total amount of receipts to recover from users).

x. The highlighting of eventual prohibitive costs per ton. The comparison, from the financial point of view of different recycling programmes.

It should be noted that the finality of the FCA approach is not to reduce to the maximum the cost of supply of the service. It remains a tool of knowledge to guide local authorities in their choices while evaluating the financial consequences resulting from a decision on the system in its globality. [Excerpted from AWAST (2004)]

2.5.3 Capital costs estimates

AWAST(2004) reported that Turton(1991) and Timmerhaus(1998) considered building two models of cost, applicable for every process of treatment; a capital cost model, the other being related to operating cost. The researcher is not interested in economic analysis of the ASWAMA project for comparison of profitability between alternatives and as such will not retain discussion on cash flows.

For each cost, the thought process may be expressed in the following three steps:

1. Identification of the various costs that affect chemical process.
2. Presentation of the postulated relationship that links up different costs to the amount of money needed for opening dumpsites and the daily opera tions of the process.
3. A summary of the parameters used in calculating costs and whose values were either found in the literature or estimated by the researcher.

2.5.3.1 Classification of capital costs

Figures XV and XVI of the Appendices show classifications made by Turton and Timmerhaus respectively. As Turton and Timmerhaus specify, a checklist of cost items is necessary because capital costs are often underestimated, problems stems from the failure to include all of the operating units needed in the process. But identification of capital costs had been the main problem when comparing Turton(1991) and Timmerhaus(1998).(AWAST, 2004).

The main differences between Turton and Timmerhaus classifications(AWAST, 2004) are:

i. Equipment cost: one includes freight, taxes and insurance in the equipment cost account, the other creates a new cost account.
ii. Labour to install equipment and materials is a cost account for Turton whereas it is included in equipment installation cost for Timmerhaus.
iii. Electrical equipment is included in materials for installation for Turton and a new account for Timmerhaus.
iv. Construction overhead does not appear in the classification of Timmerhaus.

The distinction made by Timmerhaus in comparison with Turton shows that it is significant to well specify the costs we will use for calculation and what we include in these costs. Capital investment is the total amount of money needed to supply the necessary plant and manufacturing facilities plus the amount of money required as working capital for facilities operation. Wilson(1981) gave a breakdown of capital investiment items which are shown in **Table G** of the Appendices.

2.5.4 Operating cost estimates

According to AWAST, the estimation of operating costs at an early stage of planning tend to receive less attention than capital cost estimation. If sufficient experience of similar operations in the past is available, then there is little problem. However, this is unlikely to be the case for a waste processing plant.

2.5.4.1 Classification of operating costs (Figure XVII of the Appendices, refers)

Many elements influence operating cost. Both Turton and Timmerhaus have retained approximately the same classification for operating costs(AWAST, 2004). Difference exists in the areas of Financing and Gross-Earning expense which are not included in operating cost for Turton.

The raw materials cost is taken to be zero for most solid waste treatment processes but exceptions do occur; and indirect cost factors, rates, insurance, overheads and administration, and sales expenses, are ignored or estimated with low values in most studies(AWAST, 2004). EMSEA(2013-14) gives a breakdown of operating cost items as shown in **Table H** of the Appendices.

Operating cost is commonly calculated on one of three bases namely: daily basis, unit-of-product basis, or annual basis. The annual basis is probably the best choice for estimation of total cost because,

1) The effect of seasonal variations is smoothened out
2) Plant on stream time or equipment-operating factor is considered
3) It permits more rapid calculation of operating costs at less than full capacity
4) It provides a convenient way of considering infrequently occurring but large expenses such as annual turnaround cost.

Wilson(1981) did not make distinction between fixed and variable costs but between direct and indirect costs that have the cost information provided in Figure XVII of the Appendices. These costs information consists of the following three categories:

1. **Direct Manufacturing Costs**: these costs represent operating expenses that vary with production rate. When product demand drops, production rate is reduced below the design capacity. At this lower rate we would expect a reduction in factors making up the direct manufacturing costs. These reductions may be directly proportional to the production rate (e.g. raw materials) or might be reduced slightly (e.g. maintenance costs or operating labour)
2. **Fixed Manufacturing Costs**: These costs are independent of changes in production rate.
3. **General Expenses**: These costs represent an overhead burden that is necessary to carry out business functions. General expenses seldom vary with production level.

2.6 General Discussion on Theories/Principles of Solid Waste Management

2.6.1 Definitions and classification of wastes

Waste can be in any of the following forms: solid, liquid, gaseous or radioactive, each of which is briefly discussed below:

i. **Liquid wastes:** These are substances generated from industrial sites and/or household domestic activities, and are liquid or semi-liquid in nature. Most of these wastes are hazardous and include all discarded liquid substances that are injurious, posing danger to health or causing damage to our natural environment. Examples include oil spill and leachate pollution substances.

ii. **Gaseous wastes:** These include biogases from abattoirs and composting materials. Also among these are such other released gaseous substances as sulphides, carbon (IV) oxide (CO_2), Carbon (II) oxides (CO) et cetera, some of which are injurious, posing danger to health or causing damage to our natural environment.

iii. **Radioactive Wastes:** These are all wastes of radioactive substances

iv. **Solid wastes:** These consist of garbage and rubbish which are usually generated during extraction and processing activities in our homes, offices, markets, industries, agricultural farms, construction sites, mines et cetera, some of which are seen littering our streets and public places or are collected in waste containers kept at various positions in town. In general, this form of waste does not include human excreta, but includes specifically all tangible wastes emanating from activities going on in the above mentioned points. Examples of solid wastes include sheets of papers, clothing, iron filings and pieces of metals (scraps), bottles and cans, food scraps, food packaging, disposable tableware, wood pallets and such other tangible discardable materials that may be considered as good for refuse. In waste management practice, these discarded materials at public dump sites are referred to as MSW or urban solid wastes (USW).

Major types of wastes include agricultural waste, chemical waste, construction waste, demolition waste, electronic waste (by country), food waste, green waste, hazardous waste, heat waste, industrial waste, litter, marine debris, medical waste, mining waste, municipal solid waste, post-consumer waste, radioactive waste, sewage, toxic waste, wastewater, etc.

2.6.2 Definition of solid waste management

Management is a dynamic process and it cannot be limited to a place, time or area(Ezigbo, 2012). Its process involves setting objectives and developing plans to achieve them, implementing the plan through leadership and controlling, and appraising performance against previously set standards(Koontz and Donnel, 1980). Tchobanoglous *et al*(1993) defined waste management as the discipline associated with the control of generation, storage, collection, transfer, transport, processing, and disposal of waste in a manner that is in accordance with the best principle of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes.

Rodgers(2011) defined SWM as a systematic control of generation, storage, collection, transportation, separation, processing, recovery and disposal of solid waste. In the smallest of places, SWM is accepted as a major aspect of the indigenous community organization and traditional home management; hence every house/compound has a designed area for solid waste collection/disposal and or incineration(Sanda, 2008). Among the most crucial environmental challenges facing developing countries is the municipal/urban solid waste. Cointream(1982) defined municipal solid waste (MSW) as non-air and sewage emissions created within and disposed of by a municipality, including household garbage, commercial refuse, construction and demolition debris, dead animals, and abandoned vehicles. And the Department of Environmental Quality Promotion(2002) pointed out that the majority of substances that make up MSW include paper, vegetable matter, plastics, metals, textiles, glass and rubber.

2.6.2.1 Solid waste management techniques

The stages involved in waste management are depicted in Figure 5.

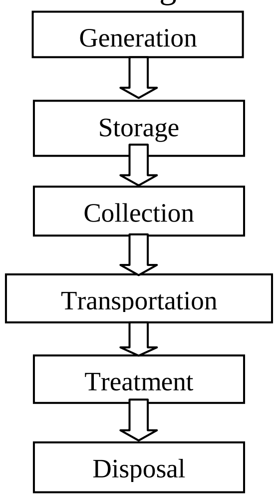


Figure 5: A flow chart showing the stages of a waste management system

Generally, management of domestic, industrial and commercial waste consists of collection and disposal of the generated waste.

1. **Waste Generation:** This is building up of discarded materials after the usefulness has been taken from the original products. At present, waste gene-ration is an activity that is yet to be well controlled by man.

2. **Waste Collection:** This entails both gathering/picking up and hauling of the discarded materials to a location where the collection vehicle is emptied. The unloading of the collection vehicle is also considered part of the collection operation (Tchobanoglous et al, 1993)

***i.* The hauled-container system:** In this system, the waste containers are hauled from the collection point to the final point of disposal, processing facility or trans- fer station. In this system, the collection vehicle empties just one container per trip. In other words, the number of trips equals the number of container locations(Sincero and Sincero, 1996).

***ii*. The stationary-container system:** This system involves emptying the waste container directly into a collection vehicle at the point of collection. There are two types in this system: a) large containers which must be emptied by mechanical means, and b) small containers which can be emptied manually(Sincero and Sincero, 1996). In this second system, the collection vehicle empties more than one container in one trip. **Plates 2 and 3** in the Appendices show loaded waste containers waiting for a disposal vehicle(s).

3. ***Waste Transportation*:** This is one of the key components of waste management system. It involves moving the quantities of waste generated at one spot to another point of transfer or final disposal. Here various types of vehicles ranging from handcarts to modern mechanized vehicles are used. See **Plate 4** of the Appendices.

4. **Waste Treatment:** This includes all techniques used in preparing and making a collection of waste materials safe for disposal. Rao(2008) presented the important steps in effective hazardous waste management to include the following:

   i. Waste minimization
   ii. Detoxification and neutralization of liquid waste streams by physical, chemical and/or biological means.
   iii. Destruction of combustible hazardous waste in high temperature incinerators.
   iv. Stabilization/solidification of sludge and ash from steps (ii) and (iii).
   v. Disposal of treated residues in specially designed landfill

5. **Waste Disposal:** This includes all techniques and practices involved in getting rid of generated waste. Several methods of disposing waste include open dumping, sanitary landfill (controlled tipping), incineration and composting.

2.6.2.2 Risks/costs associated with improper solid waste management

The poor state of SWM in urban areas (of developing countries) is now not only an environmental problem but also a major social handicap(Daskalopoulos et el, 1998). See Plate 5 in the Appendices. The indiscriminate and improper dumping of MSW is increasing and is compounded by a cycle of poverty, population explosion, decreasing standards of living, poor governance, and the low level of environmental awareness.

Rao(2008) opines that the relationship between solid waste and human disease is difficult to prove. However, improper solid waste handling is a health hazard and causes damage to the environment. It also brings about adverse effects on our environment and may also lead to poor health and well-being of our future generations. Improper management of wastes includes activities like inappropriate siting, design, operation, or maintenance of dumps and landfills. Some of the dangers in poor handling of solid wastes as pointed out in Teleke(2004) include:

i. Uncollected wastes often end up in drains, causing blockages which result in flooding and unsanitary conditions.

ii. Flies breed in some constituents of solid wastes, and flies are very effective vectors that spread disease.

iii. Mosquitoes breed in blocked drains and in rainwater that is retained in discarded cans, tires and other objects. Mosquitoes spread disease, including malaria and dengue.

iv. Rats find shelter and food in waste dumps. Rats consume and spoil food, spread disease, damage electrical cables and other materials and inflict un-pleasant bites.

v. The open burning of waste causes air pollution; the products of combustion include dioxins which are particularly hazardous.

vi. Aerosols and dusts can spread fungi and pathogens from uncollected and de-composing wastes.

vii. Uncollected waste degrades the urban environment, discouraging efforts to keep streets and open spaces in a clean and attractive condition. SWM is a clear indicator of the effectiveness of a municipal administration - if the provision of this service is inadequate large numbers of citizens (voters) are aware of it. Plastic bags are a particular aesthetic nuisance and they cause the death of grazing animals which eat them.

viii. Waste collection workers face particular occupational hazards, including strains from lifting, injuries from sharp objects and traffic accidents.

ix. Dumps of waste and abandoned vehicles block streets and other access ways.

x. Dangerous items (such as broken glass, razor blades, hypodermic needles and other healthcare wastes, aerosol cans and potentially explosive containers and chemicals from industries) may pose risks of injury or poisoning, particularly to children and people who sort through the waste.

xi. Heavy refuse collection trucks can cause significant damage to the surfaces of roads that were not designed for such weights.

xii. Waste items that are recycled without being cleaned effectively or sterilized can transmit infection to later users. Examples are bottles and medical supplies.

xiii. Polluted water (leachate) flowing from waste dumps and disposal sites can cause serious pollution of water supplies. Chemical wastes (especially persistent organics) may be fatal or have serious effects if ingested, inhaled or touched and can cause widespread pollution of water supplies.

xiv. Large quantities of waste that have not been placed according to good engineering practice can slip and collapse, burying and killing people.

xv. Waste that is treated or disposed of in unsatisfactory ways can cause a severe aesthetic nuisance in terms of smell and appearance.

xvi. Liquids and fumes, escaping from deposits of chemical wastes (perhaps formed as a result of chemical reactions between components in the wastes), can have fatal or other serious effects.

xvii. Landfill gas (which is produced by the decomposition of wastes) can be explosive if it is allowed to accumulate in confined spaces (such as the cellars of buildings).

xviii. Methane (one of the main components of landfill gas) is much more effective than carbon dioxide as a greenhouse gas, leading to climate change.

2.6.3 Factors affecting the type, quantity and complexity of waste generated in a given area

Waste generation starts from the point when a material is seen as no longer being of value to the user and it is discarded, thrown away or kept for disposal.

Many factors affect the type, quantity and complexity of wastes generated in a given area. Most of these factors are itemized as follows:

i. The state of the national economy

ii. The lifestyle of the people

iii. The demographic profile of the population

iv. The size and type of dwelling

v. Age

vi. Religion

vii. The extent to which the 3Rs are carried out

viii. Presence of pets and domestic animals

ix. Seasonal variations

x. Presence of laws and ordinances governing waste management

xi. Company buy-back guarantees for used containers and packaging

xii. Residents concern about the environment

xiii. Willingness to separate the waste

2.6.4 Expression of unit generation and solid waste generation rates

In addition to knowing the source and composition of solid waste, it is equally important to have uniform units of expression. For example, universally accepted units for:

a. Household waste (kg/capita/day)

b. Commercial waste (kg/*x*/day where *x* can be m^2 of floor area of commercial establishment, unit volume or dollar in sales, the number of employees, etc.)

c. Institutional waste (kg/*x*/day where *x* can be the number of students, m^2 of the area of park or public place, number of visitors, etc.)

d. Market waste (kg/*x*/day where *x* can be the number of market lots, m^2 of floor area, dollar in sales, etc.)

e. Industrial waste (kg/*x*/day where *x* can be unit volume or dollar of production output, m^2 of floor area, the number of employees, etc.)

f. street sweeping waste (kg/km/day)

g. drain cleaning waste (kg/km/day)

h. total waste (kg/capita/day)

Solid waste generation rates estimate the amount of waste created by residences or businesses over a certain amount of time (day, year, etc.). Waste generation includes all discarded materials, whether or not they are later recycled or disposed in a landfill. Waste generation rates for residential and commercial activities can be used to estimate the impact of new developments on the local waste stream. They may be useful in providing a general level of information for planning purposes.

2.6.5 Variation in solid waste generation rates

The quantities of solid waste generated vary daily, weekly, monthly and seasonally. Information on the variations to be expected in the peak Residential waste generation rate usually peak during Christmas holiday season and during spring house cleaning days. In many communities, unlimited collection service is provided on designated clean-up days. In general, as the size of the waste source increases (e.g. from individual residences to a community) the variation in the peak day, week and month decreases.

2.6.6 Factors affecting waste generation rates

Several factors affect the rates at which wastes are generated in a given geographical location, some of which are:

1. Effect of source reduction and recycling activities on waste generation

The effects of source reduction and the extent of recycling activities on waste generation are considered in the following discussion:

a. **Source reduction:** Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, and/or a longer useful life. Waste reduction may also occur at the household, commercial or industrial facility through selective buying patterns and the reuse of products and materials. Because source reduction is not a major element waste reduction at the present time, it is difficult to estimate the actual impact that source reduction programs have had (or will have) on the total quantity of waste generated. Nevertheless, source reduction will likely become an important factor in reducing the quantity of waste generated in the future. For example, if the postage rate for bulk mail were increased significantly, the quantity of bulk mail would be reduced sharply. Some of the other ways in which source reduction can be achieved follow:

i. Decrease unnecessary or excessive packaging

ii. Develop and use products with greater durability and reparability (e.g., more durable appliances and tires)

iii. Substitute reusable products for disposable, single-use products (e.g., reusable plates and cutlery, refillable beverage containers, cloth diapers and towels)

iv. Use fewer resources (e.g., two-sided copying)

v. Increase the recycled materials content of products

vi. Develop rate structures that encourage generators to produce less waste.

b. Extent of recycling: The existence of recycling programs within a community definitely affects the quantities of wastes collected for further processing or disposal.

2. Effect of public attitudes and legislation on waste generation

Along with source reduction and recycling programs, public attitudes and legislation also significantly affect the quantities generated.

Public Attitudes: Ultimately, significant reduction in the quantities of solid wastes generated occur when and if people are willing to change – of their own volition- their habits and lifestyles to conserve natural resources and to reduce the economic burdens associated with the management of solid wastes. A program of continuing education is essential in bringing about a change in public attitudes.

Legislation: Perhaps the most important factor affecting the generation of certain type of wastes is the existence of local, state, and federal regulations concerning the use of specific materials. Legislation dealing with packaging and beverage container materials is an example. Encouraging the purchase and use of recycled materials by allowing a price differential (typically 5 to 10 percent) for recycled materials is another method.

3. Effect of geographic and physical factors on waste generation

Geographic and physical factors that affect the quantities of waste generated and collected include location, season of the year, the use of kitchen waste food grinders, waste collection frequency, and the characteristics of the service area. Because broad generalizations are of little or no value, the impact of these factors must be evaluated separately in each situation.

a. **Geographic location**: Different climates influence both the amount of certain type of solid wastes generated and the time period over which the wastes are generated. For example, substantial variations in the amount of yard and garden wastes generated in various parts of the country are related to climates. That is, in the warmer southern areas, where the growing season is considerably longer than in the northern areas, yard wasters are collected not only in considerably greater amounts but also over a longer time. Because of the variations in the quantities of certain types of solid wastes generated under different climates, special studies should be conducted when such information will have a significant impact on the system. Often, the nece-ssary information can be obtained from a load-count analysis.

b. **Season of the year:** The quantities of certain types of solid wastes are also affected by the season of the year. For example, the quantities of food waste related to the growing season for vegetables and fruits, seasonal sampling also will be required to assess changes in the percentage distribution of the waste materials comprising municipal solid waste , especially in areas of the country with extensive vegetation.

c. **Use of kitchen food waste grinders**. While the use of kitchen food waste grinders definitely reduces the quantity of kitchen wastes collected, whether they affect quantities of wastes generated is not clear, because the use of home grinders varies widely throughout the country, the effects of their use must be evaluated separately in each situation if such information is warranted. Unit waste allowances made in the field of waste water treatment for estimating the additional suspended solids capita contributed from homes with food grinders varies from 0.1 to 0.04 kg/capita. Typically, the clues used in the waste water field only reflect the increase in solids removed at wastewater treatment facilities and do not reflect the material that has solublized in the process of being transported. More realistic values for estimating the effect of food waste grinders are 0.04 to 0.05 kg/capita.

Alternatively, for homes with food waste grinders one can assume that 25 to 33 percent of the total amount of food waste generated is ground up(Takele, 2004)

d. **Frequency of collection**: In general, where unlimited collection service is provided, more wastes are collected. This observation should not be used to infer that more wastes are generated. For example, if a homeowner is limited to one or two containers per week, he or she may, because of limited container capacity, store newspapers or other materials; with unlimited service, the homeowner would tend to throw them away. In this situation the quantity of wastes generated may actually be the same, but the quantity collected is considerably different. Thus, the fundamental question of the effect of collection frequency on waste generation remains unanswered.

e. **Characteristics of service area:** Peculiarities of the service area can influence the quantity of solid wastes generated. For example, the quantities of yard wastes generated on a per capita basis are considerably greater in many of the wealthier neighborhoods than in other parts of town. Other factors that will affect the amount of yard waste include the size of the lot, the degree of landscaping, and the frequency of yard maintenance.

2.6.7 Methods used in estimating waste quantities

Different methods are applied in estimating the quantities of waste generated in a given place. The estimation may be based on data gathered by conducting a waste characterization study, using previous waste generation data or some combination of the two approaches. The most commonly used of the methods include: load-count analysis, weight-volume analysis and materials-balance analysis.

a. **Load-count analysis method:** This is a method in which the number of individual loads and the corresponding waste characterization (type of waste) and estimated volume are noted over a specified time period. Weight data are also recorded where scales are available. The unit generation rates are determined by using the field and, if need be, published data also.

b. Weight-volume analysis method: This method gives a more reliable information than the load-count analysis method. This method entails using platform weighing machine/gadgets to determine weight of the waste collection vehicle at the entrance to the transfer station or the final dump site/landfill. This method is used where the specific weight of the various forms of waste are to be determined.

c. Materials mass-balance method: This approach is so far the most reliable method for determining the generation and movement of waste at each source such as domestic homes, commercial or manufacturing outfit. The steps usually taken in this approach are:

1. Draw a system boundary around the unit to be studied.
2. Identify all the activities that occur within or cross the boundary and affect waste generation.
3. Identify the rate of waste generation associated with each of the activities going on within the boundary, and
4. Finally, using appropriate mathematical relationships, determine the quantity of waste generated, collected and stored or disposed.

2.6.8 Waste Management Hierarchy

The waste hierarchy (illustrated in Figure XIX in the Appendices section) is a classification of waste management options in order of their environmental impact, such as: reduction, reuse, recycling and recovery. In the European Union Waste Framework Directive 2008 the waste hierarchy has five steps: prevention; preparing for re-use; recycling; other recovery, e.g. energy recovery; and disposal(Directive 2008/98/EC on waste, Waste Framework Directive).

The waste hierarchy has taken many forms over the past decade, but the basic concept has remained the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

Some waste management experts have recently incorporated an additional R: "Re-think", with the implied meaning that the present system may have fundamental flaws, and that a thoroughly effective system of waste management may need an entirely new way of looking at waste. *Source reduction* involves efforts to reduce hazardous waste and other materials by modifying industrial production. Source reduction methods involve changes in manufacturing technology, raw material inputs, and product formulation. At times, the term "pollution prevention" may refer to source reduction.

Another method of source reduction is to increase incentives for recycling. Many communities in the United States are implementing variable-rate pricing for waste disposal (also known as Pay As You Throw - PAYT) which has been effective in reducing the size of the municipal waste stream(Mark Ruzzin, "Pay-As-You-Throw"). Source reduction is typically measured by efficiencies and cutbacks in waste. *Toxics use reduction* is a more controversial approach to source reduction that targets and measures reductions in the upstream use of toxic materials. Toxics use reduction emphasizes the more preventive aspects of source reduction but, due to its emphasis on toxic chemical inputs, has been opposed more vigorously by chemical manufacturers. *Toxics use reduction* programs have been set up by legislation in some states, e.g., Massachusetts, New Jersey, and Oregon.

2.6.8.1 How the waste hierarchy works

The Rs are categories at the top of our disposal options. They include a variety of initiatives for disposing of discards. Generally, options lowest on the list are least desirable.

a. **Reduce -** to buy less and use less. Incorporates common sense ideas like turning off the lights, rain barrels, and taking shorter showers, but also plays a part incomposting/grasscycling (transportation energy is reduced), low-flow toilets, and programmable thermostats. Includes the terms: Re-think, Pre-cycle, Carpool, Efficient, and Environmental Footprint(Wikipedia.org).
b. **Reuse -** elements of the discarded item are used again. Initiatives include waste exchange, hand-me-downs, garage sales, quilting, travel mugs, and composting (nutrients). Includes the terms laundry, repair, regift, and upcycle(Wikipedia. org).
c. **Recycle -** discards are separated into materials that may be incorporated into new products. This is different from Reuse in that energy is used to change the physical properties of the material. Initiatives include Composting, Beverage Container Deposits and buying products with a high content of post-consumer material.

   Within recycling there is distinction between two types:

i. **Upcycle: -** converting low-value materials into high-value products (more desirable)

ii. **Downcycle: -** converting valuable products into low-value raw materials (less desirable)

The promotion of waste minimization has existed for decades, as evidenced by the paper department store bag which urged shoppers to reuse their bags as part of the World War II war effort. The 3R's of reduce, reuse and recycle have been considered to be a base of environmental awareness and a way of promoting ecological balance through conscious behavior and choices. It is generally accepted that these patterns of behavior and consumer choices will lead to savings in materials and energy which will benefit the environment.

The three Rs are not the only disposal options:

i. **Generate -** capturing useful material for waste to energy programs includes Methane Collection, Gasification, and Digestion, and the term Recover.

ii. **Incinerate -** high temperature destruction of material. Differs from Gasification in that oxygen is used; differs from burning in that high temperatures consume material efficiently and emissions are controlled.

iii. **Devastate -** to discard into the natural environment, or to "trash" the planet. Includes litter, landfill, burn barrels, unnecessary vehicle idling, and dumping discards onto land or into water.

2.6.8.2 Zero waste initiative

Wikipedia, the free encyclopedia explains zero waste as a philosophy that encourages the redesign of resource life cycles so that all products are reused. No trash is sent to landfills and incinerators. The process recommended is one similar to the way that resources are reused in nature.

Zero Waste is a goal that is ethical, economical, efficient and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for others to use. Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them. Implementing Zero Waste will eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health(wikipedia.org).

In industry this process involves creating commodities out of traditional waste products, essentially making old outputs new inputs for similar or different industrial sectors. An example might be the cycle of a glass milk bottle. The primary input (or resource) is silica-sand, which is formed into glass and then into a bottle. The bottle is filled with milk and distributed to the consumer. At this point, normal waste methods would see the bottle disposed in a landfill or similar. But with a zero-waste method, the bottle can be saddled at the time of sale with a deposit, which is returned to the bearer upon redemption. The bottle is then washed, refilled, and resold. The only material waste is the wash water, and energy loss has been minimized(wikipedia.org).

Zero waste can represent an economical alternative to waste systems, where new resources are continually required to replenish wasted raw materials. It can also represent an environmental alternative to waste since waste represents a significant amount of pollution in the world(wikipedia.org).

2.7 Review of Journal Articles/Empirical Works on Solid Waste Management

Reports on solid waste and its management abound, but surprisingly those on sustainable solid waste management are still very few. Shekdar(2009) argued that solid waste management has been an integral part of every human society; and solid waste problem started partly from national increase in population and more importantly from immigration (Egunjobi, 1986). Existing literatures record that the recent rapid growth in the volume of wastes generated in African cities is believed to be due to urbanization trends and rapid industrialization in the continent. According to Ludwig *et al*(2003), the changes in consumption patterns with alterations in the waste characteristics have also resulted in a quantum jump in solid waste generation.

As thousands of solid wastes are generated daily in Africa, most of them are dumped along with general wastes, discarded hazardous and infectious materials, into open dumps, wetlands and waterways, contaminating surface and ground water and posing major health hazards to the inhabitants of the continent(EGSSAA, 2009). This, especially, is a dangerous condition that complicates wastes management problem. More also, the accelerated growth of urban population with unplanned urbanization, increasing economic activities and lack of training in modern solid waste management practices in the continent also complicates the efforts to improve solid waste services. Besides, where these wastes are left to accumulate, it leads to degradation of the environment, stresses natural resources and leads to health problems(CPCB, 2000; NEERI, 1994; UN, 2000).

Worried about the volumes of solid waste generated daily in Nigeria, which are not properly managed, Ihueze(2014) discussed how to convert these waste to wealth in national transformation. Key notes in the discussion include factors affecting national transformation, education and technology for waste control, power and manufacturing industries in Nigeria, infrastructure and wealth generation, national wastes and sustainability, engineering waste management and wealth, and industrial engineering and wealth creation.

Ohakwe *et al*(2011) investigated into the general attitude and concerns of resident of three cities in Southeastern Nigeria towards the present waste management practices, the siting of a SWM facility and residents' attitude toward such facility. The result of their search revealed that there was a need to review the present waste management policy on construction of any SWM facility in the country; that a comprehensive study of the concerns and attitudes of the people should be employed as to avoid the community being a problem to the facility. The paper made a case for adoption of the three 'R' strategies as a national policy in waste management.

Grzesik & Jakubiak(2014) discussed on choosing municipal waste management scenario with the life cycle assessment (LCA) methodology. The paper stressed that planning integrated municipal waste management systems is extremely challenging; that such systems should be technologically correct, economically effective, socially accepted and environmentally friendly. Results of their model show that: landfilling and incineration of residual waste have negative impact on the environment; incineration has much lower negative impact than for landfilling; the lowest environmental impact is indicated for the mechanical biological treatment (MBT) scenario; and the highest share in the negative effect for MBT scenario has landfilling of the stabilized organic fraction (poor quality compost). The paper finally presented LCA methodology as an effective management tool for identifying and assessing the environmental impacts and could be employed to choosing the waste management option, with the lowest negative effects on human health and the environment.

Chukwuemeka *et al*(2012) in their own study evaluated the chains of problems militating against SWM in Nigeria with particular stress on Enugu State. The scientific investigation revealed among other things that resources normally voted by Government annually to manage solid waste was always very meager, and that there was no environmental education at all as was observed during the field investigation. Furthermore, some of the waste management staff were poorly trained and no plan in the future to give them further training or to improve already acquired skills. Based on the findings, some of the major recommendations proposed in the paper include: that solid waste management should be provided with a separate head in the budget for the purpose of adequate revenue allocation, implementation and monitoring; the participation of the local communities in SWM should be encouraged; environmental education should be intensified by both the state and local governments; also primary, secondary and tertiary schools curricula should inculcate detailed topics on SWM.

In a similar work done by Adewole(2009), the latter reviewed the waste management practices and the issue of sustainable development in Nigeria, using Lagos State as a case study. The paper reported that mainly, private sector participation, highway managers, local government and Lagos State Waste Management Authority are responsible for the collection and disposal of all types of waste generated in Lagos State; that in terms of solid waste, only six (including existing and new) dumpsites (erroneously referred to as landfills) exist in Lagos State, while all the closed dumpsites are still being used illegally among several other illegal dumpsites that adorn the landscape. It also stressed that most of the industries if not all in Isolo Industrial Environment of Lagos State, for example has no pollution abatement programme for their effluent, during the course of study. It was also discovered that Lagos Lagoon alone is estimated to absorb 10,000 m^3 of industrial effluent daily. The paper further stressed that waste disposal habit of the people, corruption, work attitude, inadequate plants and equipment among others are militating against effective waste management to attain sustainable development in Nigeria as a whole. Data generated by the study also shows that the method adopted by these agencies was found to be ineffective and fall short of international standards in waste management practices and sustainable development.

Still dealing on the attitudes of people in waste management, Kayode and Omole (2011) researched on the factors affecting solid wastes generation and disposal in Ibadan Metropolis, Nigeria. The study adopted a survey design approach, obtaining their data by means of questionnaires which were randomly distributed to 215 respondents and from existing literature. The collected data were analyzed using frequency and correlation matrix. Results showed that the composition of waste generated in Ibadan Metropolis were a reflection of variation of socio-economic factors of the people. Their report also showed that socio-economic factors such as income, age, education, occupation and building types had greater influence on the choice of method of disposal in Ibadan Metropolis. Consequently, the authors claimed that effective SWM could be achieved through the adoption of urban renewal strategy of the chaotic areas, with provision of sizeable fund by the government and by properly educating the people, among other things.

In another report, Otti(2011) considered a deterministic model needed for short and long term waste management and management information system in Anambra State Sanitation and Environmental Protection Agency (ANSEPA). The study aimed at determining which type of integrated solid waste management option or programme would be used to implement minimized cost and maximized benefit (benefit cost ratio) over a long period of planning period. The model was also intended to be used by decision makers in finding the solution to environmental, economic, sanitary, technical and social goals, through the use of equipment, routine maintenance, personnel and sundry.

Meanwhile, Thomas *et al*(1979) showed how to extend the use of mathematical programming method in solving optimization problems even in solid waste management. And in a paper he presented in a symposium on Environmental and Social harmony at the Enugu State University, Agukoronye(1994) encouraged environmental education and public participation in environmental management. Dharam and Vivian(1995) and Minn *et al*(2010) strongly supported Agukoronye's idea of involving people environmental actions at the grassroots, though with particular reference to Myanmar.

Malarin and Vaugham(1997) discussed an approach to economic analysis of solid waste disposal alternatives. In their work, a mixed integer optimization approach to the selection of sanitary landfill site sizes and location in a regional context was explained and illustrated using stylized cost and location information adapted from a real case study. The rationale for the exercise was that individual waste disposal site investments should not be seen in isolation from the spatial relationships with other sites in a regional system as ignoring these relationship could raise system operating and capital costs. In assuming that the reader is familiar with economic activity analysis and non-market valuation techniques, the text opined that because it was difficult to sort through and prioritize disposal alternatives by inspection or repeated simulation of the total costs of all possible combination of sites and scales when the region is "large", it recommended a least-cost optimization technique which does the sorting automatically once the problem had been properly specified. Shekdar(2009) dealt on integrated approach in sustainable solid waste management with the paper having its focus on Asian countries.

In another report, Jeff(2014) discussed on transforming MSW into a net carbon reducer. The article reported that while MSW contribute relatively little to climate change namely 3 - 5% of anthropogenic greenhouse gases (GHG) emissions, the waste management sector offers immediate, cost-effective and fast-acting opportunities to achieve sustainable cuts in global GHG emissions; that the private sector is actively participating in this trend by utilizing funding and other opportunities under notably the clean development mechanism of Kyoto Protocol.

Rafia *et al*(2008) examined the factors that might influence waste generation and people's willingness to recycle in Dhakka City, Bangladesh. The authors used ordinary least square regression and logistic regression analysis to determine the dominant factors in these regard, which they presented to include age, education and knowledge about recycling.

Ozor(2010) made a study on the design of a SWM system for Nnamdi Azikiwe, Awka. Report revealed that random sampling technique was employed in the data collection and that the quantity of solid waste (SW) generated in the university within the study period were determined and characterized. A mathematical model for predicting SW generation within the university was developed using multiple regression technique. A system for efficient management of generated SW was modeled. The university generated an average of 13,206.5 kg of SW per week at a rate of 0.1099 kg/person/day, with the highest volume of the waste generated at the construction sites which accounted for 61.82% of the total SW stream. Further still, the study reported that the domestically generated waste was the most important factor in predicting SW generation within the university. The study model was tested at 0.05 level of significance and was found to be highly significant with a coefficient of determination R^2 = 0.9999. The collection system designed for ease of management of the SW in the university revealed also that it would take 8.93 hr/wk to evacuate the entire SW that were to be generated using a front-loader collection vehicle and a stationary collection system.

The Decision Maker's Guide to Solid Waste Management Vol. II (sic. Second Edition, 1995) was developed particularly for solid waste management practitioners in the U.S. such as local government officials, facility owners and operators, consultants, and regulatory agency specialists, the guide contains technical and economic information to help practitioners meet the daily challenges of planning, managing, and operating municipal solid waste (MSW) programs and facilities. The guide's primary goals are to encourage reduction of waste at the source and to foster implementation of integrated solid waste management systems that are cost-effective and can protect human health and the environment. It covers key technical, legal, economic, political, and social issues that must be addressed to develop effective waste management programs. Detailed guidance is provided on collection and transfer, source reduction, recycling, composting, combustion, and land disposal of solid waste.

The Environmental Resources Management(ERM, 2000) discussed the subject of strategic planning for municipal solid waste management. This is a Guide that provides comprehensive information, supporting methodologies and tools to assist development of Strategic MSWM Plans at the local and regional level. It contains a new set of tools for strategic solid waste planning field-tested in Peru, the Philippines and Vietnam.

IETC/UNEP(1996) directed its report towards municipal solid waste management (MSWM) decision-makers of developing countries and countries in transition, NGOs and community-based organizations involved in waste management. The source book is designed to serve as a general reference guide to researchers, scientists, science and technology institutions and private industries on global state-of-the-art environmentally sound technologies for MSWM. The publication provides a list of information sources, overviews of practices around the world in environmentally sound management of MSW (waste reduction, collection and transfer, composting, incineration, landfills, special wastes, waste characterization, management and planning, training, public education and financing).

Lifset(1997, 1998) in its own report, provides a summary of an Internet discussion on SWM in developing-country cities which brought together planners, organizers, consultants and academics from government, development agencies, private companies, NGOs and universities in 30 countries.

Rushbrook and Pugh’s(1999) target in their own report was on senior waste management staff in local authorities. It provides waste management with practical guidance on how to make gradual improvements. The emphasis is on upgrading disposal of wastes at modest cost, while still providing acceptable levels of environmental protection in widely different climatic, cultural and political regimes. Guidance is also provided on siting, developing, and operating full sanitary landfills, along with comprehensive policies and programs to reduce waste generation and increase recycling.

In 1994, Cointreau-Levine presented a discussion on the need for reduction of government activity through the participation of the private sector in service delivery. The paper poses the questions of whether and how to involve the formal private sector in the provision of municipal solid waste services. The paper also presents decision-making criteria and recommends steps for a phased involvement of the private sector, where justified.

Lardinois(1996) describes the nature, type, origins, economics and institutional relationships of micro and small enterprises and cooperatives providing solid waste collection services in Bolivia, Brazil, Colombia, Costa Rica, El Salvador, Guatemala and Peru, based on research carried out between January and May 1996. And Johannessen et al (1999a) on their own part made a survey of landfills in Asia, Africa and Latin America. The authors reported the following three cross-regional findings: (1) the extensive use of daily soil cover on newly deposited or compacted waste; (2) little management of landfill gas, and; (3) problematic and often inadequate leachate management measures. The report review long-term environmental impacts and offers recommendations for improving World Bank projects that have solid waste components.

The first SWM models during the 1970s were optimization models and dealt with specific aspects of the problem, for example, vehicle routing. The models developed during the 1980s extended the system boundaries of the earlier models and covered MSW management at the system level. The models looked at the relationships between the different factors in the waste management system, rather than at each separately. These models aimed at minimizing the costs of mixed waste management and, to a certain extent, included recycling. Examples of such approaches are the attempt by Roberge and Baetz(1994) to formulate the problem as a general mixed integer linear programming (MILP) problem, and by Gottinger(1991) to attempt to economise operations of SWM systems also by the use of MILP. During the 1990s, for example, also recycling was included in the majority of the models developed for the planning of MSW management. Later models included the whole life cycle of products. Up till then, very few literature was available on detailed costing information on integrated waste management systems(Morrissey and Browne, 2004).

In 1975, Conway L. Lackman developed a joint production model of solid waste recovery and extended it to include some rules of efficient resource allocation with regard to waste products. Part II of the paper contained a brief discussion of the taxonomy of SWM; Part III developed a model of joint production and Part IV extended the joint production model adding externalities (social costs) resulting in recycling production model. Aspects of the model examined include assumptions of the model, joint production of finished goods, intermediate goods and solid waste, and decision rules (marginal conditions for optimization).

Arnold van de Klundert and Justine Anschiitz(2000) investigated into the sustainability of alliances between stakeholders in waste management (WM), using the concept of integrated solid waste management (ISWM). The paper identified ISWM as differing from conventional approaches towards WM by seeking stakeholder participation by including waste prevention and resource recovery explicitly, by encouraging the analysis of interactions with other urban systems and by promoting an integration of different habitat scales (city, neighbourhood, household). The report also revealed that ISWM could be used as a policy tool and as an assessment/analysis tool, but placed more emphasis on the latter tool. The paper focused on the perspective of stakeholders in WM and the contribution to sustainability of the alliances between stakeholders. The paper concluded that the assessment process was not easy, but could provide valuable information about alliances and a basis for comparison. Finally, the paper stressed the needs for future research to further research to further develop the concept of ISWM as a tool for assessing the sustainability of WM.

More recent approaches by, for example, Kijak and Moy(2004) has the ambition to achieve a more sustainable waste management by balancing social and economic impacts at different geographical levels, the social cost representing the opportunity cost to society of a given policy initiative(Vigso, 2004). Thereby, life-cycle assessment (LCA) is applied to evaluate the integrated management of MSW. In later years, LCA has been used to optimize SWM systems and identify environmentally sustainable solutions (e.g. Kirkeby *et al*, 2006). However, still only limited information is available for getting good cost estimates, the literature is rather poor on relevant information and only scattered data are available (Tsilemou and Panagiotakopoulos, 2006).

In Moutavtchi *et al*(2008), the authors proposed a cost structure for evaluating the ecological–economic efficiency (ECO–EE) of a MSW management scheme. The methodology proposed was based on the recommendations of the full cost accounting (FCA) methodology for MSW management/SWM and takes into account existing Baltic Sea countries' stereotypes and national standards, employing the previously introduced waste managements' efficient decision (WAMED) model and the company statistical business tool for environmental recovery (COSTBUSTER) indicator. The most important findings of the Paper can be itemized as follows:

1. Cost–benefit analysis (CBA) was shown to be useful in decision-making in municipal solid waste (MSW) management and SWM as an efficient tool of information support for implementation of holistic and financially integrated schemes, taking into account the prevailing societal priorities and values. 2. It concluded that the presented provisions for evaluation of the ECO–EE of a MSW management scheme reflect an integrated approach to solving the problem of simultaneously decreasing the negative impacts of MSW/SWM on the environment and human health while increasing the financial benefits.

Moutavtchi *et al*(2010) reviewed the environmental evaluation of MSW management as based on cost–benefit analysis (CBA). A waste management's efficient decision

(WAMED) model based on CBA was developed to evaluate the environmental economic efficiency of SWM schemes. The most important findings of the Paper include: 1. It is found that the WAMED model considers the entire scheme and is identified as a single-purpose, complex, short term model for municipal and regional decision making. 2. It provides a unified and adaptive information support tool for MSW/SWM management actors. 3. The model also reflects an integrated approach to solving the problem of MSW/SWM by simultaneously decreasing the negative impacts on the environment and human health while increasing the financial benefits through the implementation of MSW management projects.

Stenis *et al*(2011) proposed a cost structure for evaluating and improving the ecological-economic efficiency (ECO-EE) of solid waste baling management schemes ending with incineration for heat and power production. The methodology proposed employs the previously introduced waste managements' efficient decision model (WAMED) and the company statistical business tool for environmental recovery indicator (COSTBUSTER). The previously introduced equality principle and the efficient use of resources for optimal production economy (EUROPE) model are applied to the emissions in case of accidental burning of bales, treatment of leachate, and the abatement with odours at a scheme. A case study presents the practical application of the proposed methodology. The most important findings of this Paper are: 1. It concluded that the presented methodology for evaluation and improvement of the ECO-EE of solid waste baling management schemes, simultaneously decreases the negative impact on the environment and human health while increasing the financial benefits through the implementation of MSW management projects. 2. The presented methodology provides an investment decision making support tool for the implementation of solid waste baling management projects. 3. The presented methodology enables carrying out comparative analysis of actual and prevented financial damages at realization of schemes to increase also the efficiency of the use of natural resources.

In their own paper, Nammari *et al*(2003) described how over a period of seven months the temperature and the emissions from six cylindrical and two rectangular stored bales containing waste for later use as fuel were measured. The most important findings of this Paper are: 1. It was found that only the rectangular bales showed significant production of CO_2. 2. The increase of CO_2 concentrations was less at a rate of 0.0259 % vol. per day during a 8-week period, after which the CO_2 emission decreased at a rate of 0.0224% vol. per day during a 25-week period. 3. All the bales exhibited aerobic decomposition in the sampling point 4. In measuring the leachate concentrations, it was evident that the bales were actually in the equivalent acid-generating phase of a young landfill. 5. The temperature inside the bales did not increase higher than the ambient air temperature.

Nammari(2004) described how environmental and safety aspects of seasonal storage of baled municipal solid waste to be used as fuel for energy production (waste fuel) were investigated and experiments were carried out on burning of bales. The flammability, combustion processes and emissions were studied by simulating, in small-scale, potential effects of a possible fire in full-scale bale storage area. Despite the high water content and the high density of the bales, after setting fire, the bales burned well, even though no risk for self-ignition exists.

Hogland(2002) described how experiments were carried out on the burning of baled solid waste to obtain information on the flammability of baled waste and also on the pollutants formed during combustion, which would be spread into the environment during a possible fire in a bale storage area. Given the high water content and high density of bales, the possibility of them catching fire seemed remote. Unexpectedly however, they burnt well. The amount of smoke released was not extreme and, according to subjective olfactory perceptions, the smoke did not appear to be aggressive or pungent. Also, the behavior of leachate and storm water around solid waste bales was studied.

Meanwhile, Moutavtchi(2001) described one of the most serious problems in the Kaliningrad region which is solid waste management (mainly, household waste and industrial waste): its disposition, neutralization, landfilling and utilization. The most important findings of Moutavtchi 's paper include: 1. Existing traditional plants for incineration of medical polymeric waste gives 53% of common emissions of such hazardous pollutants as dioxins. As regard the future Kaliningrad landfill, it will be playing important role and be one of the main links in the whole chain of landfilling and utilization of waste. 2. The most important element of the landfill is its location and quality of isolation system. 3. The area of the landfill is planed with annual plots, and construction will be started from land surface with taking into account its slope. For isolation a basis film is laid and simultaneously installed the section of a pipeline for leachate. Every 25 meters a control pit is constructed.

Moutavtchi *et al*(2003) proposed a model for the evaluation of ecological-economic effectiveness (ECO–EE) of municipal solid waste (MSW) management schemes. The model was based on the economic analysis — cost-benefit analysis, and uses the "through" approach to estimate costs for application of a scheme. The most important findings of the paper are: 1. The necessity of the comparative analysis of actual and prevented damage to the environment and human health at application of a scheme is substantiated. 2. Basic provisions on selection of an optimal MSW management scheme are proposed for discussion.

Again, Moutavtchi *et al*(2004) proposed a cost structure for evaluating the ecological-economic effectiveness (ECO-EE) of a municipal solid waste (MSW) management scheme. The proposal was based on the recommendations of the full cost accounting (FCA) methodology for MSW management and taking into account existing international stereotypes (in the Baltic Sea countries) and national Swedish norms. The most important findings of the paper are: 1. The necessity for the use of the cost-benefit analysis (CBA) in decision-making in MSW management was substantiated. 2. A pilot variant of practical application of the proposed theoretical provisions of CBA to landfilling (Kalmar, Sweden) was presented.

During the last decade, systems analysis had become a more frequently used tool in municipal waste management. Klang *et al*(2006) investigated how one such analysis, carried out in a Swedish county, was perceived by local municipal officers and politicians as support in the decision-making process. A questionnaire was sent to municipal officers and politicians in local government committees and municipal councils. The respondents considered the most important aspects in evaluating scenarios to be: possibilities for municipal co-operation to minimize cost and negative environmental influence; sound working conditions for refuse disposal personnel; low emissions of greenhouse gases; keeping household economy in mind; and using technologies that were known and reliable. Aspects of relatively low importance were the number of locally generated job opportunities, and minimizing work efforts for the households. The study also showed differences between male and female respondents and between politicians and municipal officers, on how scenarios were valued and on which aspects of the systems analysis were of greatest importance for this valuation. The authors claimed that respondents, on average, were satisfied with the systems analysis, and its usefulness as a decision-support tool. Finally, the paper recommended that more work should be carried out to explain and present the results of the systems analysis to further improve its usefulness.

Moutavtchi(2012) made an analysis on the ability of different waste management models to accommodate CBA. The author also opined that analysis of the available waste management models using CBA has shown that, at present, calculation of the financial damage to the environment as a loss of means during implementation of a SWM scheme (showing the current damage), or as a possible positive financial result at a change of the scheme (showing the prevented damage) is not offered by these prevailing models in an explicit form.

Viatcheslav *et al*(2010) investigated management of solid waste by application of a waste managements' efficient decision (WAMED) model. The study aimed at developing a general model for the evaluation of ecological-economic efficiency that will serve as an information support tool for decision making at the corporate, municipal, and regional levels. The article encompassed cost-benefit analysis in solid waste management by applying a sustainability promoting approach that is explicitly related to monetary measures. The WAMED model which was based on cost-benefit analysis was proposed and developed to evaluate the ecological-economic efficiency of solid waste management schemes. The employment of common business administration methodology tools was also featured. A classification of competing waste management models was introduced to facilitate evaluation of the relevance of the previously introduced WAMED model. Suggestions were made for how to combine the previously introduced EUROPE model, based on the equality principle, with the WAMED model to create economic incentives to reduce solid waste management-related emissions. A fictive case study presents the practical application of the proposed cost-benefit analysis-based theory to the landfilling concept. It is concluded that the presented methodology reflects an integrated approach to decreasing negative impacts on the environment and on the health of the population, while increasing economic benefits through the implementation of solid waste management projects

Gottinger(1986) developed a model described as a network flow problem and a special purpose algorithm for regional SWM. The model was applied to waste management and facility siting decisions in the Munich Metropolitan area, West Germany. Meanwhile, Hogland *et al*(2001) discussed how the storage of baled waste fuel will increase in the near future, stressing that studies on the stability of baled waste during storage are necessary, to promote better handling from both energy recovery and safety viewpoints. Further still, Omuta(1987) discussed the issue of urban solid waste generation and management, specifically on the implications of Environmental Sanitation Policy in Nigeria; while a mathematical model for strategic evaluation of municipal solid waste management system was formulated by Kaila(1987).

Onwualu(2014) in collaborating with Gagnon *et al*(2008), reviewed the general principles of sustainable development based on the three most common dimensions namely: Environment, Society and Economy. The paper went on to name the requirements in each of these dimensions as follows: 1). *Under Environmental Dimension*, the requirements are:

preservation of biodiversity and respect for all life forms regardless of how useful they are to human kind; stay within ecosystems' carrying capacity in terms of waste assimilation and resource generation; offset the use of non renewable resources by investments in renewable substitutes; enforce precautionary principle in face of potentially severe social or environmental harm; and publicize information on the state of the environment to induce responsible behaviour. 2). *Under the Economy Dimension*, the holding conditions include: eliminate the concept of waste; stimulate innovation on a continuous basis; maintain positive, genuine, long term investment considering all types of capital; organize work and commerce so that every human being can meet their needs; and internalize all costs within the value of goods and services. 3). *The Society Dimension* include: guarantee access to ecosystem services essential to health and wellbeing; foster social cohesion by eliminating exclusion and respecting the rights of every individual; offer individuals and communities the opportunity to increase their capabilities; allocate in a fair manner benefits and costs related to economic activity and public policies; and seek stakeholder involvement, while respecting the accountability and subsidiarity principles.

Meanwhile, in a research carried out by Hector and William(1997) on an approach to the economic analysis of solid waste disposal alternatives for Inter-American Development Bank, they explained and illustrated a mixed integer optimization approach to the selection of sanitary landfill site sizes and locations in a regional context, using stylized cost and location information adapted from a real case study. The rationale for the exercise was that individual solid waste disposal site investments should not be viewed in isolation from the spatial setting and their cost relationships with other sites in a regional system, because ignoring these relationships is likely to raise system operating and capital costs. But, because it is difficult to sort through and prioritize disposal alternatives by inspection or repeated simulation of the total costs of all possible combinations of sites and scales when the region is "large", a least-cost optimization method was recommended which does the sorting automatically once the problem has been properly specified. After reviewing the basics of the heuristic approach to solid waste disposal site selection, the optimization model was laid out and solved in the case study context, initially in terms of financial costs. In a subsequent section, a way of incorporating the relative environmental damages of alternative locations into the model was suggested, and the example was re-solved with environmental costs included to show how they can influence the identification of the best set of sites. Suggestions about model refinements appeared in a concluding section. In fact, the paper was meant for a good practice in waste management.

Stypka of the Department of Environmental Engineering, Cracow University of Technology, Poland in his article titled, "Integrated Solid Waste Management Model As A Tool Of Sustainable Development", applied the first version of the Integrated Municipal Waste (IMW-1) model developed by White P.R., Franke M., and Hindle P., to analyze the present and the planned waste management systems in the two towns: Krakow, Poland and Stockholm, Sweden. To help in the decision process the integration of the model results was proposed. The aggregation was based on the modified Polish emission fees. As a result of this integration the environmental impacts on water and on air were presented in monetary units and were comparable with the economic cost. Such integration allowed the presentation of the simple comparison of the Krakow and Stockholm systems made in the report.

Due to increased environmental concerns and the emphasis on material and energy recovery are gradually changing the orientation of MSW management and planning, Najm *et al*(2002) developed an optimization model for regional integrated solid waste management I. Model formulation which should be applied to serve as a solid waste decision support system for MSW management taking into account both socio-economic and environmental considerations. The model accounts for solid waste generation rates, composition, collection, treatment, disposal as well as potential environmental impacts of various MSW management techniques. The model follows a linear programming formulation with the framework of dynamic optimization. The model can serve as a tool to evaluate various MSW management alternatives and obtain the optimal combination of technologies for the handling, treatment and disposal of MSW in an economic and environmentally sustainable way. The sensitivity of various waste management policies was also addressed. The work was presented in a series of two papers: (I) model formulation, and (II) model application and sensitivity analysis.

Sanjeevi and Shahabudeen(2015) made a review on the Development of performance indicators for municipal solid waste management (PIMS). The paper aimed at reviewing papers on municipal solid waste management (SWM) systems, especially on performance indicators (PIs). It suggested practical methods to manage municipal solid waste and these indicators by the administrators. The authors reported that round the Worldwide, about 4 billion metric tons of solid waste (SW) was generated annually; that the management of SW across cities was increasingly getting more complex and the funds available for providing service to citizens were shrinking. Analysis of the non-technical research papers showed that focus areas on SW can be grouped into 18 types, one being PIs. Going by history, the paper opined, PIs for municipal SWM (PIMS) commenced with the publication of guidelines by various government agencies, which started in 1969. This was followed by a few benchmarking studies which various international institutions commenced in 1998. Many published comparative studies also disseminated good practices across the cities. From the 1990s onwards, research work started defining PIMS. These initiatives by various researchers took multiple dimensions, which were reviewed in the paper. In almost all studies, the PIMS is measured in terms of investment decisions, public acceptance levels, social participation and environmental needs. The multiple indicators are complex, however, and managers of cities need simple tools to use. To make it simple, five-factor PIs were arrived at, considering simplicity and covering all the factors. A research agenda was outlined for future directions in the areas of cost reduction, citizens' services, citizen involvement and environmental impact.

Mika and Mika(2007) made a feasibility study on energy recovery from municipal solid waste in an integrated municipal energy supply and waste management system. The study presented a decision-support model for determining the feasibility of a planned energy-from-waste (EfW) investment for an integrated waste management and energy supply system. The study aimed at presenting an easy-to-understand, inexpensive and fast-to-use tool to decision-makers for modeling and evaluating different kinds of processes. Special emphasis was put on forming the model and interpretation of the results of the example case. The simple integrated system management (SISMan) model was presented through a practical example of the use of the model. In the example the viability of the described system was studied by comparing five different cases including different waste-derived fuels (WDF), non-segregated municipal solid waste (MSW) being one of the fuel options. The nominal power output of the EfW plant varied in each case according to the WDF classification. The numeric values for two main variables for each WDF type were determined, the WDF price at the gate of the EfW plant and the waste management fee (WMF) according to the `polluter pays' -principle. Comparison between the five cases was carried out according to two determinants, the WMF related to each case and the recovery rate related to each case. The numeric values for the constants and variables used in the calculations were chosen as realistically as possible using available data related to the issue. In the example of this paper, the mass-incineration solution (`pure' MSW as a fuel) was found to be the most viable solution for the described system according to the calculations. However, the final decision of the decision-makers might differ from this in the real world due to extra `fuzzy' information that cannot be reliably included in the calculations. The paper shows that certain key values of modeled systems can be calculated using an easy-to-use tool at the very early stages of a larger design process involving municipal and business partners. The use of this kind of tools could significantly decrease the overall design costs of large systems in the long run by cutting out irrational system options at the very beginning of the planning.

There had been a large increase in the transportation of waste material in Germany, which was attributed to the implementation of the European Directive 75/442/EEC on waste. Similar situations are expected to emerge in other European countries. Consequently, a model named LINK^{opt}, for minimization of joint total costs for industrial waste producers and waste management companies, was developed by Ingela *et al*(2004). The model is a mixed-integer, linear programming model for mid- and long-term planning of waste management options on an inter-company level. The model is used to determine a waste management system with minimal decision-relevant costs considering transportation, handling, storage and treatment of waste materials. The model can serve as a tool for evaluating various waste management strategies and for obtaining the optimal combination of investment options. In addition to costs, ecological aspects are considered by determining the total mileage associated with the waste management system. The model was applied to a German case study evaluating different investment options for a co-operation between Daimler-Chrysler AG at Rastatt, its suppliers, and the waste management company SITA P+R GmbH. The results show that the installation of waste management facilities at the premises of the waste producer would lead to significant reductions in costs and transportation.

In their third and final part of the three-part technical report written by Muhammad *et al*(2015) to describe the mass, energy and material balances of the solid recovered fuel production process produced from various types of waste streams through mechanical treatment, this article focused on the production of solid recovered fuel from municipal solid waste. The stream of municipal solid waste used here as an input waste material to produce solid recovered fuel was energy waste collected from households of municipality. The article presented the mass, energy and material balances of the solid recovered fuel production process. These balances were based on the proximate as well as the ultimate analysis and the composition determination of various streams of material produced in a solid recovered fuel production plant. All the process streams are sampled and treated according to CEN standard methods for solid recovered fuel. The results of the mass balance of the solid recovered fuel production process showed that 72% of the input waste material was recovered in the form of solid recovered fuel; 2.6% as ferrous metal, 0.4% as non-ferrous metal, 11% was sorted as rejects material, 12% as fine fraction and 2% as heavy fraction. The energy balance of the solid recovered fuel production process showed that 86% of the total input energy content of input waste material was recovered in the form of solid recovered fuel. The remaining percentage (14%) of the input energy was split into the streams of reject material, fine fraction and heavy fraction. The material balances of this process showed that mass fraction of paper and cardboard, plastic (soft) and wood recovered in the solid recovered fuel stream was 88%, 85% and 90%, respectively, of their input mass. A high mass fraction of rubber material, plastic (PVC-plastic) and inert (stone/rock and glass particles) was found in the reject material stream.

Further still, Muhammad *et al*(2016) reported that in production of solid recovered fuel (SRF), certain waste components have excessive influence on the quality of product. The proportion of rubber, plastic (hard) and certain textiles was found to be critical as to the elemental quality of SRF. The mass flow of rubber, plastic (hard) and textiles (to certain extent, especially synthetic textile) components from input waste stream into the output streams of SRF production was found to play the decisive role in defining the elemental quality of SRF. The paper presented the mass flow of polluting and potentially toxic elements (PTEs) in SRF production. The SRF was produced from municipal solid waste (MSW) through mechanical treatment (MT). The results showed that of the total input chlorine content to process, 55% was found in the SRF and 30% in reject material. Of the total input arsenic content, 30% was found in the SRF and 45% in fine fraction. In case of cadmium, lead and mercury, of their total input content to the process, 62%, 38% and 30%, respectively, was found in the SRF. Among the components of MSW, rubber material was identified as potential source of chlorine, containing 8.0 wt.% of chlorine. Plastic (hard) and textile components contained 1.6 and 1.1. wt.% of chlorine, respectively. Plastic (hard) contained higher lead and cadmium content compared with other waste components, i.e. 500 mg kg^{-1} and 9.0 mg kg^{-1}, respectively.

In November 2010, Athanasios et al published their paper on "Electricity and combined heat and power from municipal solid waste; theoretically optimal investment decision time and emissions trading implications". The paper opined that waste management had become a great social concern for modern societies. Landfill emissions was identified among the major contributors of global warming and climate changes with significant impact in national economies. The energy industry constituted an additional greenhouse gas emitter, while at the same time it was characterized by significant costs and uncertain fuel prices. As a result, different policies and measures were triggered worldwide to address the management of municipal solid wastes on the one hand and the impacts from energy production on the other. Emerging methods of energy recovery from waste may address both concerns simultaneously. In the work, a comparative study of co-generation investments based on municipal solid waste was presented, focusing on the evolution of their economical performance over time. A real-options algorithm has been adopted investigating different options of energy recovery from waste: incineration, gasification and landfill biogas exploitation. The financial contributors were identified and the impact of greenhouse gas trading was analyzed in terms of financial yields, considering landfilling as the baseline scenario. The results indicated an advantage of combined heat and power over solely electricity production. Gasification, is known to had failed in some European installations. Incineration on the other hand, proved to be more attractive than the competing alternatives, mainly due to its higher power production efficiency, lower investment costs and lower emission rates. Although these characteristics may not drastically change over time, either immediate or irreversible investment decisions might be reconsidered under the current selling prices of heat, power and CO_2 allowances.

Applying multi-criteria decision-making to improve the waste reduction policy in Taiwan, Jun-Pin *et al*(2010) noted that over the past two decades, the waste reduction problem had been a major issue in environmental protection. Both recycling and waste reduction policies had become increasingly important. As the complexity of decision-making had increased, it became evident that more factors must be considered in the development and implementation of policies aimed at resource recycling and waste reduction. There were many studies focused on waste management excluding waste reduction. The study paid more attention to waste reduction. Social, economic, and management aspects of waste treatment policies were considered in the study. Further, a life-cycle assessment model was applied as an evaluation system for the environmental aspect. Results of both quantitative and qualitative analyses on the social, economic, and management aspects were integrated via the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method into the comprehensive decision-making support system of multi-criteria decision-making (MCDM). A case study evaluating the waste reduction policy in Taoyuan County was presented to demonstrate the feasibility of the developed model. In the case study, reinforcement of MSW sorting was shown to be the best practice. The authors also claimed in the report that the model in the study could be applied to other cities faced with the waste reduction problems.

In a mini review made on municipal solid waste management using Geographical Information System aided methods, Debishree and Sukha(2014) identified Municipal Solid Waste Management (MSWM) as one of the major environmental challenges in developing countries. Many efforts to reduce and recover the wastes had been made, but still land disposal of solid wastes was the most popular one. Finding an environmentally sound landfill site was a challenging task. The paper addressed various aspects of MSWM (suitable landfill site selection, route optimization and public acceptance) using the Geographical Information System (GIS) coupled with other tools. The salient features of each of the integrated tools with GIS were discussed in the paper. The paper also addressed how GIS can help in optimizing routes for collection of solid wastes from transfer stations to disposal sites to reduce the overall cost of solid waste management. A detailed approach on performing a public acceptance study of a proposed landfill site was presented in the report. The study would help municipal authorities to identify the most effective method of MSWM.

Astrid and Paul(2014) made a literature review on the assessment methods for solid waste management. Assessment methods are common tools to support decisions regarding waste management. The objective of the review article was to provide guidance for the selection of appropriate evaluation methods. For this purpose, frequently used assessment methods were reviewed, categorized, and summarized. In total, 151 studies have been considered in view of their goals, methodologies, systems investigated, and results regarding economic, environmental, and social issues. A goal shared by all studies was the support of stakeholders. Most studies were based on life cycle assessments, multi-criteria-decision-making, cost-benefit analysis, risk assessments, and benchmarking. Approximately 40% of the reviewed articles are life cycle assessment-based; and more than 50% apply scenario analysis to identify the best waste management options. Most studies focus on municipal solid waste and considered specific environmental loadings. Economic aspects were considered by approximately 50% of the studies, and only a small number evaluated social aspects. The choice of system elements and boundaries varied significantly among the studies; thus, assessment results were sometimes contradictory. Based on the results of the review, the authors recommend the following considerations for assessing waste management systems: (i) a mass balance approach based on a rigid input–output analysis of the entire system, (ii) a goal-oriented evaluation of the results of the mass balance, which takes into account the intended waste management objectives; and (iii) a transparent and reproducible presentation of the methodology, data, and results.

A major challenge for modern waste management lies in a smart integration of waste-to-energy installations in local energy systems in such a way that the energy efficiency of the waste-to-energy plant is optimized and that the energy contained in the waste is, therefore, optimally utilized. The extent of integration of thermal waste treatment processes into regular energy supply systems plays a major role with regard to climate control. In tackling this challenge in their research, Ragoßnig *et al*(2009) dealt with the specific waste management scenarios aimed at maximizing the energy recovery from waste (*i.e*. actual scenario and waste-to-energy process with 75% energy efficiency [22.5% electricity, 52.5% heat]) yield greenhouse gas emission savings due to the fact that more greenhouse gas emissions are avoided in the energy sector than caused by the various waste treatment processes. Comparing dedicated waste-to-energy-systems based on the combined heat and power (CHP) process with concepts based on sole electricity production, the energy efficiency proved to be crucial with regard to climate control. This underlined the importance of choosing appropriate sites for waste-to-energy-plants. The research looked at the effect with regard to the climate impact of various waste management scenarios that could be applied alternatively by a private waste management company in Austria. The research was, therefore, based on a specific set of data for the waste streams looked at (waste characteristics, logistics needed, *etc*.). Furthermore, the investigated scenarios were defined based on the actual available alternatives with regard to the usage of treatment plants for the given company. The standard scenarios for identifying climate impact implications due to energy recovery from waste were based on the respective marginal energy data for the power and heat generation facilities/industrial processes in Austria.

According to Federica *et al*(2012), diverting waste from landfill is one of the basic priorities on improving the use of resources and reducing the environmental impacts of waste management. In order to achieve this goal it is necessary to limit the amount of materials sent to final disposal and promote energy recovery. In Italy the use of recycling is registering a growing trend but the recourse to landfill is still too high with respect to European Commission targets. The aim of the paper was to analyze the financial and economic benefits that energy recovery could produce by diverting waste from landfills in an Italian region, as landfilling cannot be a solution in the long term because of its finite capacity and for various other ecological reasons. A sensitivity analysis on the critical variables of this plan and a risk analysis are also provided.

Athanasiou(2015) conducted a preliminary techno-economic feasibility study for a single municipal solid waste mass burning to an electricity plant for the total municipal solid waste potential of the Region of Eastern Macedonia – Thrace, in Greece. For a certain applied and highly efficient technology and an installed capacity of 400,000 t of municipal solid waste per year, the available electrical power to grid would be approximately 260 GWh per year (overall plant efficiency 20.5% of the lower heating value). The investment for such a plant was estimated at €200m. Taking into account that 37.9% of the municipal solid waste lower heating value can be attributed to their renewable fractions, and Greek Law 3851/2010, which transposes Directive 2009/28/EC for Renewable Energy Sources, the price of the generated electricity was calculated at €53.19/MWh_e. Under these conditions, the economic feasibility of such an investment depends crucially on the imposed gate fees. Thus, in the gate fee range of 50–110 € t^{-1}, the internal rate of return increases from 5% to above 15%, whereas the corresponding pay-out time periods decrease from 11 to about 4 years.

Nowadays, the industry produces an enormous amount of solid waste that has very negative environmental effects. Owing to waste variety and its scattered sites of production, selecting the most proper solid waste treatment is difficult. Simultaneously, social con-cern about environmental sustainability rises every day and, as a consequence, improvement on waste treatment systems is being demanded. However, when a waste treatment system is being designed, not only environmental but also technical and economic issues should be considered. These developments led José *et al*(2014) to put forward a methodology for providing industrial factories with an easy way to identify, evaluate and select the most suitable solid waste treatment.

Waste-to-energy (WtE) facilities have been established worldwide as a sustainable method for the disposal of residual waste. In their own study, Henning and Ansgar(2011) compared the following WtE systems: (1) municipal solid waste incinerators (MSWIs) with energy recovery; (2) co-incineration of waste in old lignite or coal-fired power plants; (3) substitute [refuse-derived fuel (RDF)] incinerators with energy recovery; and (4) co-incineration of defined waste fractions in cement kilns. In general the municipal solid waste incinerators in Europe are designed for a broad range of municipal and commercial waste without a pre-treatment of the waste. All other WtE processes including the cement kilns require a pre-treatment and are more limited in terms of RDF composition; namely particle size, chlorine content, calorific value. As to Germany, the emission limit values for all facilities are similar. A sensitivity analysis of the economics of boilers using RDF and municipal solid waste leads to the conclusion that the feasibility of RDF incinerators might partially recover if the prices for primary energy increase again. On the other hand, pre-treatment of waste leads to higher costs for RDF. Incineration and recycling capacities are large enough in middle Europe to avoid landfilling of organic waste. The steep decline of gate fees observed in some national spot markets is a clear indicator of an already existing overcapacity. Considering the enormous amount of greenhouse gas emissions saved by WtE facilities in comparison with landfilling, free capacities of WtE installations should be used to incinerate waste from EU member states where waste disposal is still predominantly based on landfilling.

Menikpura *et al*(2012) reported that at present, there are many environmental, economic and social problems associated with poor municipal solid waste (MSW) management in Thailand. The development of sustainable solid waste management systems is a crucial aspect and should be based on an integrated approach. Therefore, an integrated system was designed for Nonthaburi Municipality incorporating recycling, anaerobic digestion, incineration and landfill technologies. In order to assess sustainability, a clear methodology was developed via life cycle thinking and a set of endpoint composite indicators has been proposed considering the most critical ultimate damages/effects of MSW management on the environment, the economy and society. Results from the study showed that the appropriate integration of technologies offers important prospects with regards to socio-economic and environmental aspects, contributing, therefore, to improved sustain-ability for the overall MSW management system. The methodology and the proposed indicators would be useful in strategic planning, including decision- and policy-making with respect to the development of appropriate sustainable MSW management systems.

According to Parnuwat and Orathai(2014), sustainable waste management was introduced more than ten years ago, but it has not yet been applied to the Thai petrochemical industry. Therefore, under the philosophy of sustainable waste management, the research aimed to apply the reduce, reuse, and recycle (3R) concept at the petrochemical factory level to achieve a more sustainable industrial solid waste management system. Three olefin plants in Thailand were surveyed for the case study. The sources and types of waste and existing waste management options were identified. The results indicate that there are four sources of waste generation: (1) production, (2) maintenance, (3) waste treatment, and (4) waste packaging, which correspond to 45.18%, 36.71%, 9.73%, and 8.37% of the waste generated, respectively. From the survey, 59 different types of industrial wastes were generated from the different factory activities. The proposed 3R options could reduce the amount of landfill waste to 79.01% of the amount produced during the survey period; this reduction would occur over a period of 2 years and would result in reduced disposal costs and reduced consumption of natural resources. This study could be used as an example of an improved waste management system in the petrochemical industry.

2.8 Summary of Literature Review

In summary, all the reviewed articles aimed at proffering methods for managing solid waste materials generated within a given geographical area in a way that minimizes their adverse effects on public health and the environment. In the efforts to achieve this aim, huge sums of money and time are consumed.

Chukwuemeka *et al*(2012) evaluated the chains of problems militating against SWM in Nigeria with particular stress on Enugu State, while Ozor(2010) in designing a SWM system for Nnamdi Azikiwe University, Awka, used a random sampling technique in his data collection, after which the quantity of solid waste (SW) generated in the university within the study period were determined and characterized. Thomas *et al*(1979) showed how to extend the use of mathematical programming method in solving optimization problems even in solid waste management. Malarin and Vaugham(1997) discussed on application of a mixed integer optimization approach to economic analysis of solid waste disposal alternatives; specifically on the selection of sanitary landfill site sizes and location in a regional context.

The Environmental Resources Management(ERM, 2000) made a case of strategic planning for municipal solid waste management and Ihueze(2014) presented some processes he considered that would lead to proper waste management for national transformation and sustainable development in Nigeria. In their own work, Rafia *et al*(2008) examined the factors that might influence waste generation and people's willingness to recycle in Dhakka City, Bangladesh. Arbuthnot(1974) had earlier dealt on environmental knowledge and recycling behavior as a function of attitude and personality characteristics. Berger(1997) focused on the demographics of recycling and structure of environmental behavior. A structural model of reuse and recycling for use in Mexico was proposed by Corral-Verdugo (1996).

More recent approaches by some authors like Kijak and Moy(2004) have the ambition to achieve a more sustainable waste management practices. Lackman(1975) developed a joint production model of solid waste recovery and extended it to include some rules of efficient resource allocation with regard to waste products. Arnold van de Klundert and Justine Anschiitz(2000) investigated into the sustainability of alliances between stakeholders in waste management (WM), using the concept of ISWM. Onwualu(2014) in corroborating with Gagnon *et al*(2008), reviewed the general principles of sustainable development based on the three most common dimensions namely: Environment, Society and Economy. More so, while Stypka(undated) modeled ISWM as a tool of sustainable development, Najm *et al* (2002) developed an optimization model for regional integrated solid waste management. Parnuwat and Orathai(2014), under the philosophy of sustainable waste management, applied the 3R (reduce, reuse, and recycle) concept at the petrochemical factory level to achieve a more sustainable industrial SWM system. Adewole(2009) made a review on the WM practices and the issue of sustainable development in Nigeria, using Lagos State a case in study. Further still, Kayode and Omole(2011) on their own part investigated the factors affecting solid waste generation and disposal in Ibadan Metropolis, Nigeria. Also, Otti(2011) dealt on a deterministic model needed for short and long term waste management and management information system in Anambra State Sanitation and Environmental Protection Agency (ANSEPA).

ISSMW is a philosophy that is yet to be adopted by many communities of the globe. This may explain the reason for the scarce journal publications in this area. A close observation of the foregoing review shows vividly that though much work have been done in the area of waste management, there are still more work to be done in the area of models development for municipal solid waste management. Besides as an emerging practice in waste management, the need to provide and equip ISSWM with enough management tools like mathematical and forecasting models cannot be overstressed. Moreover, among all the existing works reviewed, none of the authors discussed or showed the applications of Queuing theory, Markov chain and/or the Pareto 80:20 rule in solid waste management; neither did any of them used the Fishbone (Fishikawa) model to explain out the factors militating against provision of effective and efficient SWM services in a given area nor showed how the popular inventory management theory could be applied in SWM. Researchers who made their attempts had always ended up developing some other new models or applied some existing models in solving certain aspects of SWM. Consequently, this study is embarked upon to fill these knowledge gaps by way of introducing and discussing a theory termed "Solid waste inventory management (SWIM)"; also by developing new mathematical, forecasting and iconic models for use in MSWM .

CHAPTER 3

MATERIALS AND METHODS

This chapter explains the structure of Anambra State waste management system elements and systematically discusses the various research techniques used in the study; dealing specifically on the sources of data and the methodologies used in achieving the objectives of the research. The chapter also contains the reasons for collecting both qualitative and quantitative data for this work.

3.1 Study of Anambra State Solid Waste Management System

For one to make a meaningful contribution or discussion about a system, he/she must have had some substantial knowledge about the system and its operations. Hence, the researcher commenced this study by making several pre-visits to different waste managers' offices and dump sites in Awka, Onitsha, Nnewi and Ekwulobia Urban Centres to enable him appreciate the structure and nature of waste management practices in these areas.

The structure of waste management system in Anambra State is depicted in Figures 6. The figure shows the basic waste handling processes in Awka waste management.

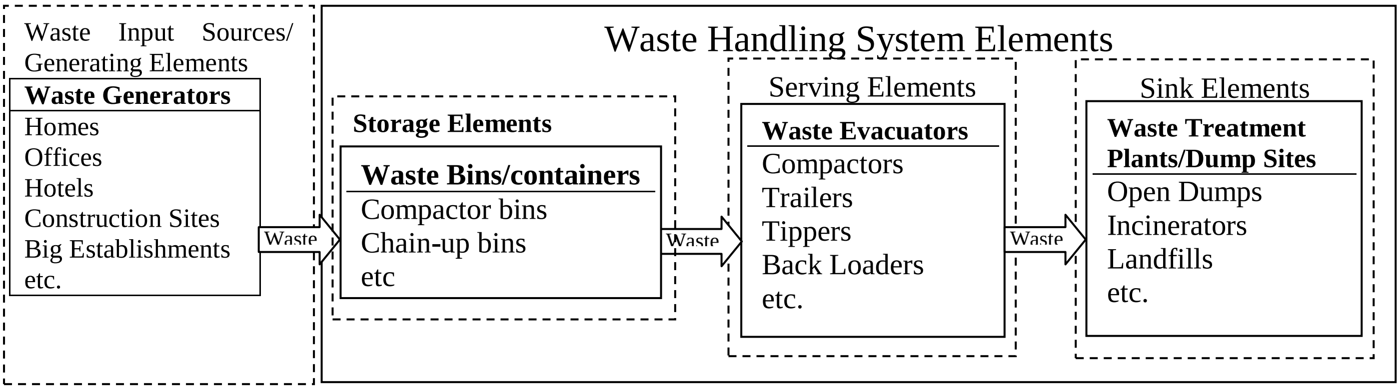


Figure 6: Basic waste handling processes in a waste management system

Solid wastes generated in different homes and other sources are discarded at the various roadside waste dumpsites (as storage containers) in the area. The dumped waste are later collected by waste evacuating vehicles (as serving/disposing elements) and sent to the final dump site (as sink element) located at Ring Road at Agu-Awka. Waste evacuation takes place on daily bases. However, not all the sites were visited daily.

3.1.1 Data Collection Methodology

Both primary and secondary data were collected and used in the study.

3.1.2 Delineation of Awka City for effective solid waste management

For purposes of proper waste management, ASWAMA divided Awka Urban City into twelve (12) Zones and kept over two hundred (200) public used bins in over one hundred and twenty (120) roadside waste dumpsites at different strategic locations in the area. However, a total of sixty six (66) roadside dump sites and a hundred and ninety six (196) waste bins kept at strategic positions across the twelve Zones were monitored during the field study (**Table J** in the Appendices section refers). The bins were basically of two types (see **Table 3**) - big ones (chain-up bins) and small ones (compactor bins).

Table 3: Calculated volumes of the bin types

Bin Type	No. Monitored	Calculated Unit Vol. (m^3)	Assumed Unit Vol. (m^3)	Approx. No. Of Compactor Bin Unit Vols. in Bin
Compactor	53	0.8	1.07	1.0
Chain-up	38	3.2	4.3	4.0

Table 3 shows the mean capacities of the waste bins/containers kept at various locations in Awka City as contained in **Table J** in the Appendices. The shown volumes were calculated as the mean values for bins kept at the various dumpsites.

3.1.3 Collection of secondary data

Some of the secondary data sources used in the study include: textbooks, journal articles, newsletters, official reports, and the internet. Official reports referred to here include reports from private and government recognized institutions like the Anambra State Waste Management Agency (ASWAMA), the local government area authorities, the ministry of information and the National Population Commission (NPC) in the state, government recognized private contractors, non-governmental organizations, (NGOs), community-based organizations (CBOs), the internet, et cetera.

3.1.4 Collection of primary data - a survey

Three groups of research agents were trained and sent for the field study. They were,

1. The researcher, who went to and collected information from ASWAMA, environmental science experts, NPC Head Office in Awka, and also supervised other

agents.

2. Agents (Roadside Dumpsite Agents) sent to take records on the rates of filling and evacuation of public waste bins/containers kept along the streets/lanes of Awka. These agents established phone and physical contacts and worked in collaboration with a number of persons living very close to the spots were the waste containers were kept.
3. Agents sent to obtain data on activities of disposal trucks at the final dump site at Agu-Awka. These agents, four in number, were named Agu-Awka (Final) Dump Site Agents.

All the agents had writing and protective materials as part of their tools kit. They were permitted to take photographs and/or video recordings where necessary. The chief researcher, while collecting data personally also went round from time to time to monitor the activities of these agents. The agents submitted their reports at the Chief Researcher's request, otherwise they did so at the end of every week.

3.1.5 Sample population of workers

From enquiries made as at the start of the study, the total number of staff of ASWAMA was estimated as two hundred and three (203) workers. Consequently, a total of two hundred copies of the research questionnaire were prepared and arbitrarily distributed among these workers, both the permanent and casual workers as follows:

1. Top management level (TML) staff comprising the Manager Director (MD), the Secretary, members of the board of trustees and other officers directly placed under the MD in the company’s organizational structure (see Figure 42), totaling nineteen (19) persons in all.
2. Lower level management (LLM) staff consisting of all the thirty eight (38) supervisory officers.
3. Other staff of the company (OSC) which consists of other workers other than those in management cadre – both permanent and casual staff.

3.1.6 Validity and reliability of the data instruments used

a) The researcher and his agents administered and retrieved copies of the questionnaire personally from the worker respondents. The agents were intimated and well briefed on the sincere requirements of both the instruments and the responding workers. The workers who filled the forms did so freely.

b) Sources of the information obtained from literature and the internet were verified and properly referenced.

c) The developed models were simulated in Microsoft Excel Spreadsheet, using a thirty six month field data collected in the study of the Awka MSWM.

d) The sample population of respondents and the number of waste dumpsites used in the study were verified using the Yaro Yamen's formula so as to ensure that they were scientifically acceptable, and

e) Sensitivity analysis was done on the variables, parameters and assumptions used in the study to determine their effects on the results modeled.

These steps made the data instrument used reliable.

3.1.7 Unit of measure and items numbering methodology

Due to lack of the required equipment (platform scales and such other tools/equipment for measuring the quantities of waste) for more accurate measure (i.e. weight-volume or materials mass balance approach), the load-count analysis method were used in the study, with unit of measure in number of waste bin loads per run(Ihueze and Chukwumuanya, 2015).

For clarity, all the items - tables, plates/figures and mathematical models/equations shown inside the body of the report were serially numbered in Arabic numerals (1, 2, 3, ...); while those in the Appendices are numbered serially in English alphabets (A, B, C, …, for tables), or in Roman figures (I, II, III, …, for figures, and *i*, *ii*, *iii, …*, for equations).

3.1.8 Data analyses methodology

Both quantitative and qualitative data from primary and secondary sources were discussed in the study.

3.1.8.1 Methods used in qualitative data analysis

a) Inventory management techniques was applied in developing the Theory of Solid

b) Waste Inventory Management/Control (SWIM/SWIC)

c) Causal loop methodology was used in describing Awka municipal solid waste management system.

d) SWOT analysis was used in investigating the capabilities of ASWAMA

e) Fishbone (Fishikawa) diagram was employed in explaining the major causes of ASWAMA's poor performance in providing quality SWM services to the state.

f) Pareto principle was applied in determining the most dominating factors militating against provision of effective and efficient waste management in Anambra State.

3.1.8.2 Methods used in quantitative data analysis

a) Data obtained were first organized and then used to compute the combined average waste generation and evacuation rates for the studied dumpsites in Awka municipality; where no actual data existed, assumptions or guided values were used. Microsoft Excel spreadsheet was used to achieve this fit.

b) Optimization techniques of Thomas *et al*(2001) and Baumol(1972) in combination with FCA approach, was applied in developing waste evacuation cost estimation and waste production forecasting models for SSWM.

c) Queuing theory was used in modeling of waste production and evacuation processes for necessary evaluation of the systems performance.

d) Multiple regression analysis was used to investigate how the identified predictor variables (number of dumpsites grouped into zones) combine to affect the response variable (total quantity of waste generated in a given period). Statistical tools of Minitab, MatLab and Excel spreadsheet were useful here.

e) Application of Markov chain was also a useful tool in SWM.

3.2 Development of Theory of Solid Waste Inventory Management (SWIM) or Solid Waste Inventory Control (SWIC)

A new way of looking at waste and its management is needed. Otherwise, the process of achieving an environmentally sound industry may be unacceptably slow. The paradigm shift that is argued for here involves equating industrial waste with normal products in terms of the allocation of revenues and costs, an approach that is termed the equality principle (Stenis, 2002). Consequently, a theory of solid waste inventory management (SWIM) is proposed and discussed herein this report following the conventional inventory management ideology. The theory is centered on developing models for determining quantities of waste generated and the quantities that should be evacuated to maintain a minimal inventory of waste in a given location. It also provides methods of estimating costs of waste evacuation and for evaluating a waste manager's performance for sustainable solid waste management, using full cost accounting and economic order quantity approach.

3.2.1 Meaning of solid waste inventory and its management

Before delving into detailed discussion of the theory of SWIM, there is the need to explain the following concepts:

i. Solid Waste Inventory refers to any heap or quantity of waste (including reusable and recyclable materials, general waste, etc.) that is under the control of a waste manager.

    a. Excessive waste inventory levels constitute a risk to the environment; small waste generations (inventory levels) may lead to some waste workers lossing their jobs and some other waste dealers/pickers/scavengers lossing some revenue. However, minimal waste generation/inventory/stock level is a great need of the society.

ii. Solid waste inventory management, SWIM (or Solid waste inventory control, SWIC) implies the use of scientific methods in determining the quantities of waste produced in an area and the much that should be evacuated from the accumulated stock at a minimal cost as to meet the clean requirements of the environment and the 3-R (reuse, reduce and re-cycle) principles of waste management.

iii. SWIC implies using standard techniques to manage waste in such a way that the desired degree of service is provided at competitive prices or at minimum ultimate cost.

iv. Proper solid waste inventory control should be a close loop system as depicted in Figure 7 and should also lend its support to sustainable integrated solid waste management and development.

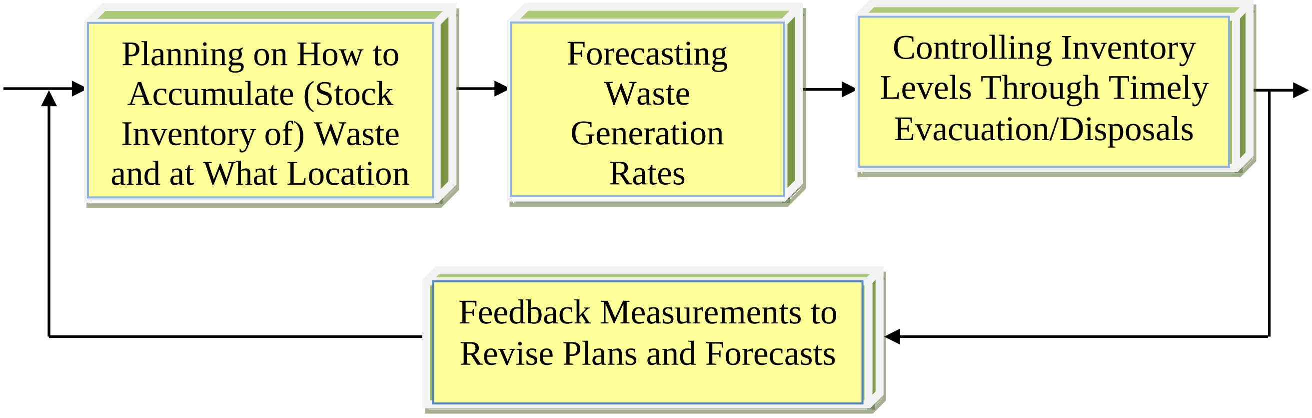


Figure 7: Waste inventory control system with a feedback mechanism
[Source: Field study]

3.2.2 SWIM decisions and terms used

Objective: Minimize total cost of waste evacuation

Decisions: How much waste to evacuate/dispose?

When to evacuate/dispose waste?

Solid waste inventory management (SWIM) or solid waste inventory control (SWIC) is a new theory being introduced in this study and, as has been stated earlier, is developed from the basic principles of inventory management; especially by the use of the economic order quantity approach. Economic order quantity (EOQ) is one of the oldest classical production scheduling models. The framework used to determine this order quantity is also known as **Wilson EOQ Model** or **Wilson Formula**. The model was developed by Ford W. Harris in 1913(Harris, 1990), but R. H. Wilson, a consultant who applied it extensively, is given credit for his in-depth analysis(Hax and Candea, 1984).

Several extensions can be made to the EOQ model developed by Mr. Pankaj Mane, including backordering costs and multiple items. Additionally, the economic order interval can be determined from the EOQ and the economic production quantity model (which determines the optimal production quantity). A version of the model, the Baumol-Tobin model, has also been used to determine the money demand function, where a person's holdings of money balances can be seen in a way parallel to a firm's holdings of inventory (Caplin and Leahy, 2010).

The following terms are used in SWIM:

a) **Generation rate:** This is the quantity of waste produced per period in a named geographical area. Waste generation is the most critical, yet an uncontrollable component of waste management; without waste generation there would be no need for maintaining inventory or establishing a waste management unit in the first place.

b) **Evacuation/Disposal rate:** This is the quantity of waste removed from a pile of waste existing in a given area per period. Waste disposal is dependent on waste generation and management decision. In places where waste production rate exceeds its disposal rate, waste accumulates at such spots.

c) **Waste lead time**: This refers to the time between when waste starts accumulating and when it is evacuated/disposed. It may be assumed deterministic or probabilistic. Waste lead time has two components which are **waste generation lead time** (WGLT) and **waste evacuation lead time** (WELT). Waste generation lead time is the time taken to fill an empty container of known size or volume with waste. Waste evacuation lead time on the other hand is the inter-disposal time of a disposal vehicle in its visits to a given dumpsite. That is, it is the length of time taken from the last time a waste container of known capacity is emptied of its contents to the next time it is full and re-emptied. Waste evacuation lead time can be classified further as **waste inspection lead time** which is the time in-between two consecutive inspection visits to a dumpsite to determine the state of waste in stock at the site, **waste administrative lead time** which is the period in-between the last point a waste manager takes decision on a quantity of waste due for evacuation and the next point when a similar decision is made, and **waste transportation lead time** which is the period from the time the management made a decision on waste to be evacuated or transferred (from one point to another) to the time it takes a waste disposal truck to execute/implement the decision. Consideration of lead time is a very important factor in waste inventory management.

d) **Quantity discount/economy of scale**: Is defined as an allowance granted by a vendor to a purchaser of certain materials for encouraging large size orders. In a waste management system, commercial waste transporters act as the vendors while the waste manager assumes the position of the purchaser of transportation service. Sometimes there is an agreement between the waste manager and the waste transporter that quantity discount will be allowed by the latter on evacuation of certain specified quantity of waste. Two main types of quantity discounts are: 1). all-units, and 2). incremental(Nahmias, 2005).

According to Altintas *et al*(2008), in a case where a strategic customer responds optimally to discount schedule, the design of optimal quantity discount scheme by the supplier is complex and has to be done carefully. This is particularly so in waste management where the waste generation/production quantity is itself uncertain.

e) **Allowable waste excess stock (AWES)**: If waste generation is unusually high during evacuation lead time, overflow of the waste container will occur and litter the ground if there is no additional container to accommodate the excess stock. AWES is the maximum quantity of waste added to a predefined quantity when the set waste evacuation lead time is not met. It is an extra inventory that may be allowed to accumulate when a disposal truck(s) fails to evacuate a set quantity of waste produced at a known spot within a predefine period of time. It is assumed here that waste is dumped in a confined place or location where space should be minimized, with allowance made for the AWES. AWES quantity should be seen as an emergency measure where rate of waste production is high or where waste disposal system delays. Hence, it can still be referred to as a 'Buffer Stock'. If the dumped waste increases above this quantity, the accumulating waste overflows the defined boundaries and litters the surroundings. Occurrence of such a situation signify poor waste management in the system. There is also a danger of the accumulated waste causing some other space and health problems to the environment.

   AWES should be kept in an extra vessel(s)/containers and not on the floor of a dumpsite. Therefore, the main reason why accommodation should be made for allowable waste excess stock is to avoid waste overflowing its defined boundaries to litter the surroundings and make the area look unkempt. It also makes planning and waste evacuation scheduling easier and more effective.

   The following factors should be taken into account when designing or deciding the accommodation for excess stock level:

   i. The average rate of waste generation/production in an area
   ii. The average time taken to fill a given size of waste container or space.
   iii. Normal capacity of waste container

iv. Waste evacuation requirements

v. The optimum quantity of waste which could be evacuated advantage-ously

Formula for use in calculating the maximum allowable waste safety stock quantity is:

$$MAWES = MAWSS = NCWC + (NGR \times NET) \quad (4)$$

where,

MAWES = maximum allowable waste excess stock

MAWSS = maximum allowable waste safety stock

NCWC = Normal capacity of waste container

NGR = Normal generation rate

NET = Normal evacuation (disposal) time or evacuation lead time

3.2.3 Economic order quantity variables and the total cost function

The function of the EOQ model is to determine the optimal order size that minimizes total inventory cost. There are several variations of the EOQ model, depending on the assumptions made about the inventory system. Figure **X** of the Appendices shows the trade-off between ordering cost and holding cost. Total cost admits a global optimum.

Purchase cost is not a relevant cost for determining the optimal order quantity.

i. **Minimizing EOQ model costs**

Only ordering and carrying costs need to be minimized (all other costs are assumed constant). As Q (order quantity) increases:

a) Carrying cost increases

b) Ordering cost decreases (since the number of orders per year decreases)

ii. **EOQ total cost**

Components of Total Cost

a) Cost of items

b) Cost of ordering

c) Cost of carrying or holding inventory

d) Cost of stockouts

e) Cost of safety stock (extra inventory held to help avoid stockouts)

f) Total ordering cost, see eqn (29-a) of the appendices.

g) Total carrying cost, see eqn (29-b) of the appendices.

h) Total purchase cost, see eqn (29-c) of the appendices.

Note:

(Q/2) is the average inventory level, and purchase cost does not depend on Q

iii. **Finding *Q****

Recall that at the optimal order quantity (Q^*): Carrying cost = Ordering cost, expressed as eqn (*xxx*) of the appendices, and rearranged to obtain eqn (*xxxi*) of the appendices.

iv. **Two methods for carrying cost**

Carry cost (C_h) can be expressed either as:

a. a fixed cost, such as C_h = ₦5000 per unit per year (5-a)

Or

b. a percentage of the item's purchase cost (p)

$$C_h = I \times p \qquad (5\text{-b})$$

I = a percentage of the purchase cost

v. **Average inventory value**

After Q^* is found one can calculate the average value of inventory on hand from eqn (33) of the appendices.

vi. **Calculating ordering and carrying costs for a given *Q***

Sometimes C_o and C_h are difficult to estimate. One can use the EOQ formula to calculate the value of C_o or C_h that would make a given Q optimal. These are given in eqns (*xxxiv*-a) and (*xxxiv*-b) of the appendices.

3.2.4 Quantity discount/economy of scale in EOQ Models

There are basically four steps used to analyze quantity discount models

a. Calculate Q^* for each discount price
b. If Q^* is too small to qualify for that price, adjust Q^* upward
c. Calculate total cost for each Q^*
d. Select the Q^* with the lowest total cost

i. **Reorder point:** Determining when to order (Figure **XI** of the Appendices refers)

After *Q** is determined, the second decision is when to order. Orders must usually be placed *before* inventory reaches 0 due to order lead time. Lead time is the time from placing the order until it is received

The reorder point (ROP) depends on the lead time (L) and is expressed as eqn (35) of the Appendices.

ii. **Economic production quantity:** Determining how much to produce

The EOQ model assumes inventory arrives instantaneously. In many cases inventory arrives gradually. The **economic production quantity** (EPQ) model assumes inventory is being produced at a rate of *p* units per day. (See Figure **XII** of the Appendices). There is a **setup cost** each time production begins.

iii. **Determining Lot Size or EPQ:** Average inventory level

We will need the average inventory level for finding carrying cost. The required relations are given as eqns (*xxxvi*) to (*xl*) in the Appendices section.

As in the EOQ model:

i. The production cost does not depend on *Q*

ii. The function is nonlinear

Finding *Q**

Also in the EOQ model, at the optimal quantity, *Q**: Setup cost = Carrying cost, which enables eqns (*xli*) and (*xlii*) in the Appendices to be obtained.

iv. **Length of the production cycle**

The production cycle will last until *Q** units have been produced, and producing at a rate of p units per day means that it will last (*Q**/p) days

vi. **Use of safety stock**

Safety stock (SS) is extra inventory held to help prevent stockouts. Frequently demand is subject to random variability (uncertainty). If demand is unusually high during lead time, a stockout will occur if there is no safety stock. Figure 19 refers.

Other extensions to the EOQ

Several extensions can be made to the EOQ model developed by Mr. Pankaj Mane, including backordering costs and multiple items. Additionally, the economic order interval can be determined from the EOQ and the economic production quantity model (which determines the optimal production quantity). A version of the model, the Baumol-Tobin model, has also been used to determine the money demand function, where a person's holdings of money balances can be seen in a way parallel to a firm's holdings of inventory (Caplin and Leahy, 2010).

3.2.5 Overview of economic waste evacuation quantity and the underlying assumptions

Economic waste evacuation quantity (EWEQ) or Economic waste disposal lot size (EWDLS), is the quantity of waste that a waste manager should evacuate in order to minimize the total costs of waste disposal - such as holding costs, setup costs, transportation costs, and environmental (damage or havoc) costs. It refers to the lot size of waste for which the total cost per disposal run is minimum. In other words, EWEQ is the disposal quantity that minimizes total waste inventory holding costs, setup costs and evacuation costs.

Figure 8 displays waste inventory levels over time based on EWEQ principles.

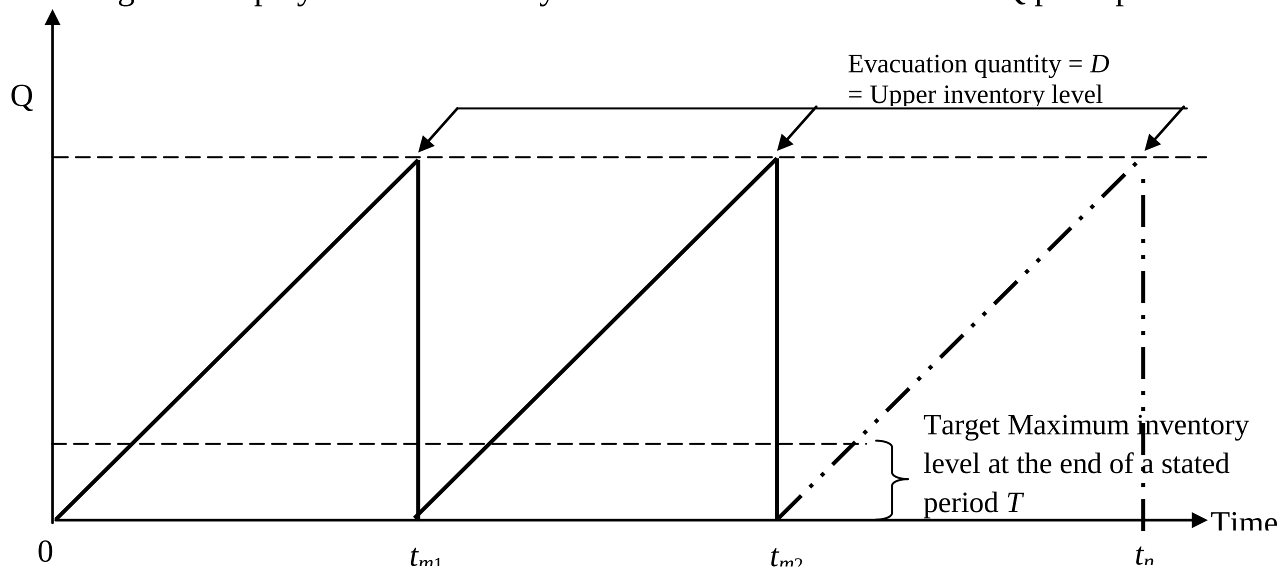


Figure 8: Waste inventory level over time based on EWEQ assumptions

As shown in Figure 8, EWEQ provides a model for calculating the appropriate re-disposal points: t_{m1}, t_{m2}, …, t_n, and the optimal evacuation quantity, *D*, to ensure that minimal waste inventory is kept in a given location. It should be used as part of a continuous review inventory system in which the level of waste in stock is monitored at all times and a fixed quantity evacuated each time the inventory level reaches a specified evacuation or disposal point. It can be a valuable tool for waste managers and small waste disposal truck owners who need to make decisions about how much inventory should be allowed to accumulate in a given dumpsite, what quantity should be evacuated at each run of a disposal vehicle, and how often to repeat evacuation runs as to incur the lowest possible costs.

Therefore, we can apply EWEQ when we want to determine the optimal quantity of waste to evacuate so as to minimize the total cost associated with the generation, storage and transportation of some quantity of waste. The required parameters of the model are:

i. the total generation for the year,

ii. the evacuation cost per disposal truck run,

iii. the optimum waste evacuation quantity,

iv. the fixed cost of storage per given unevacuated quantity of waste per year.

We note that the number of disposal runs will also affect the total cost of evacuation, though this number can be determined from the other parameters. The underlying assumptions of EWEQ can be summarized as follows:

a. Fund for waste disposal is always readily available.
b. The state (quantity) of waste at the dumpsite(s) is always monitored.
c. Rate of waste generation is known or relatively uniform
d. Waste evacuation lead time is fixed.
e. Unit cost per run of waste disposal vehicle is constant i.e. no discount is available
f. Waste evacuation is made instantaneously, the whole batch is disposed/transported at once.
g. Only a given waste type (or the general waste or where other forms of waste mix with the general waste as a collection or mixed lump) is considered.
h. The total cost of waste produced (generated) in an area is equal to the total cost of managing the waste under the full cost accounting (FCA) system.
i. The total cost of waste evacuation in the objective function is proportional to the number of evacuation runs required to keep a minimal inventory level in a given
    a. period
j. The cost per evacuation run is a linear function of the optimum evacuation quantity
k. Over the course of a given period, evacuation runs of integer quantity may be involved.

3.3 Development of Mathematical and Forecasting Models for SWIM

3.3.1 EWEQ variables and models

The function of the EWEQ model as earlier noted aims at determining the optimal waste disposal quantity that minimizes total cost of waste evacuation. There may be several variations of the EWEQ model as there are in EOQ model, depending on the assumptions made about the waste inventory system and how the variables are interpreted.

Figure 9 shows the variation of costs of waste evacuation and the evacuated quantity.

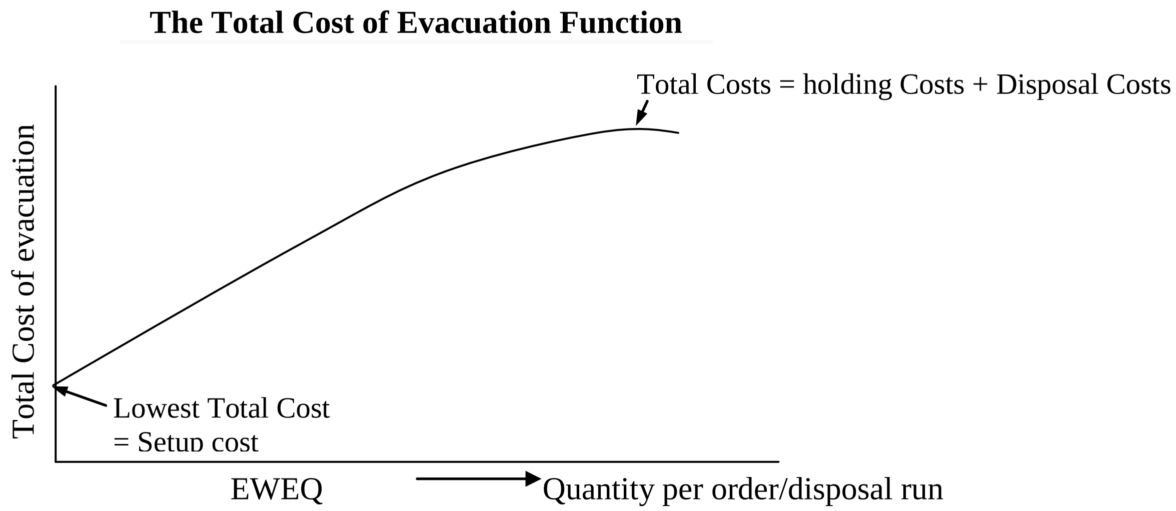


Figure 9: Variation in costs of evacuation with waste disposal lot size

Vital notes in this theory include:

i. **Minimizing EWEQ model costs**

Only cost of evacuation, setup cost and carrying (holding) costs need to be minimized (all other costs are assumed constant). As quantity of waste generated increases total cost of its evacuation (waste inventory costs + waste disposal costs) increases (since the number of runs per year increases)

ii. **EWEQ total cost**

Components of EWEQ total cost are

a) Cost of waste evacuation

b) Cost of carrying or holding waste inventory

c) Setup costs (C_s)

Other cost items include those provided by US EPA under the FCA methodology for sustainable integrated solid waste management.

***iii.* Two methods for carrying cost in SWIM**

As it is obtainable in traditional inventory management practices, cost of waste inventory can be expressed either:

a. As a fixed cost, such as

   i. C_h = ₦2000 per unit quantity per year, or

b. As a percentage (I) of the cost of evacuated quantity of waste

$$C_h = I \times C_E \tag{6}$$

***iv.* Average waste inventory value**

After D is found, we can calculate the average value of inventory of waste on hand, using

$$\text{Average inventory value} = C_n \times (D/2) \tag{7}$$

v.* Calculating cost of evacuation and carrying costs for a given *Q

It may be a little difficult to estimate C_h in a given dumpsite. However, we can use the EOQ formula (eqn *xxxiv*-b in the Appendices) to calculate the value of C_h that would make a given Q optimal.

3.3.2 Determining disposal lot size or EWEQ: average waste inventory level

The average waste inventory level (quantity in stock) is needed for finding the waste carrying (holding) cost. The average waste inventory level is ½ the maximum generated quantity. The EWEQ model assumes the following relations:

$$\text{Maximum allowable waste inventory level} = [\lambda t_{GL} + \lambda(t_n - t_m)] \tag{8a}$$

$$= [D + q_{ES}] = Q_{MA} \tag{8b}$$

$$\text{Average waste inventory} = \tfrac{1}{2}Q_{MA} \tag{9}$$

$$\text{Setup cost } (C_s) = (D/Q_{MA}) \times C_n \tag{10}$$

$$\text{Carrying cost} = I \times (Q_{MA}/D) \times C_n \tag{11}$$

$$\text{Total cost of evacuation} = C_n \times Q_{MA}/D \tag{12}$$

3.3.3 Determining how much to evacuate (dispose)

In applying the EWEQ model, it is assumed that waste evacuation is instantaneous, and that inventory is replenished at a fixed rate until it reaches the maximum capacity of the containing vessel or the allowable excess stock level. This assumption is illustrated in Figure 10.

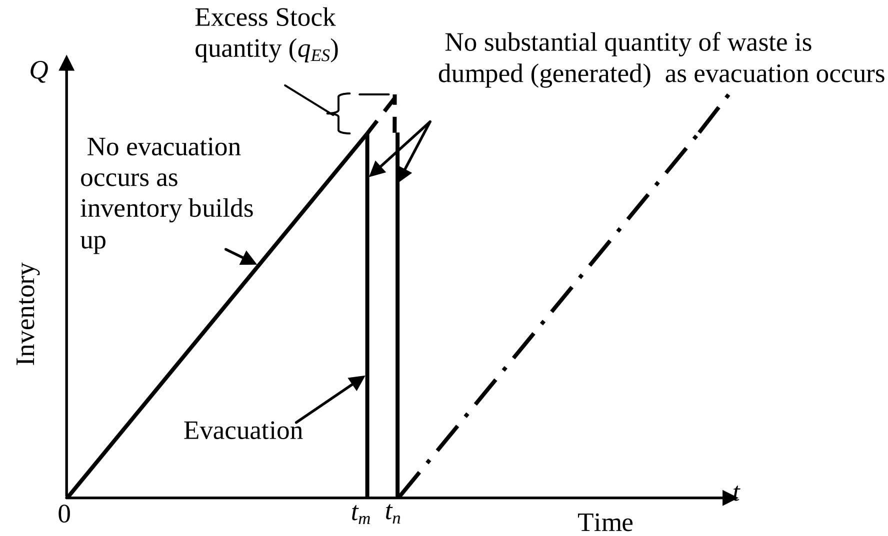


Figure 10: Waste inventory control with evacuation based on EWEQ assumptions

This implies that a specific quantity of waste arrive after evacuation to return the inventory to its full level within the set waste generation lead time. In reality waste may be seen as arriving exponentially at the dumpsites and in some cases it is evacuated in smaller batches at the waste crew members discretion or as the capacity of the disposal truck's bucket (or container) may allow. In considering waste evacuation to be instantaneous, the EWEQ model also assumes that waste are always in stock and that there is always some associated costs with the waste in stock. Consequently, the cost of inventory under the EWEQ model involves a tradeoff between inventory holding costs (the cost of storage, as well as the cost of tying up capital in inventory rather than investing it or using it for other purposes) and other costs represented under the full cost accounting (FCA) strategy. Evacuating a large amount of waste at one time will reduce holding costs paid by the state or a waste manager, while making less evacuations will increase holding costs and costs of damages to environment. The EWEQ model aims at finding the quantity that minimizes the sum of these costs.

3.3.4 Re-evacuation point (REP): Determining when to evacuate

Frequently, waste generation is subject to random variability (uncertainty). In EWEQ model waste is assumed as being evacuated at a rate of D units per given time and that there is always a setup cost each time evacuation begins. The setup cost refers to the fixed cost component of cost of evacuation - equipment must be made available, ready and maintained, salaries of waste workers in crew and taxes must be paid, and so on.

Meanwhile, waste generation cycle will last until Q units have been generated and generating waste at a rate of D units per day means that it will last (Q/D) days

After D is determined, the second decision is when to evacuate the waste

Evacuation should usually be done when inventory reaches container capacity or before it exceeds the maximum allowable excess stock quantity.

Waste generation lead time (WGLT) should be determined and fixed. This will help in determining when to fix the time for evacuation (evacuation lead time).

That is to say, re-evacuation depends on the WGLT.

$$REP = (t_{GL})_m = \sum_{i=1}^{m} t_{ij}, \qquad m \leq n \tag{13a}$$

Or for some strong reason(s), where $m < n$,

$$REP = (t_{GL} + t_{qES}) = (\sum_{i=1}^{m} t_{ij})_{GL} + (\sum_{i=1}^{n} t_{ij} - \sum_{i=1}^{m} t_{ij})_{GL} = (t_m + t_{(n-m)})_j \tag{13b}$$

Re-evacuation points of waste in EWEQ is illustrated in Figure 11.

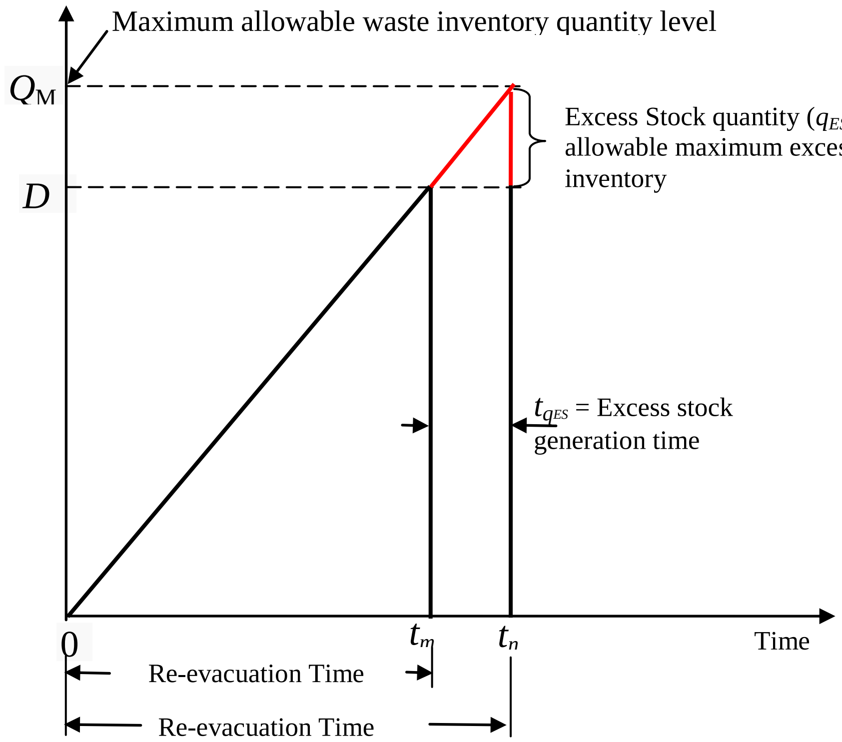


Figure 11: Waste re-evacuation point based on EWEQ assumptions

3.3.5 Estimation of costs of evacuation from the optimum waste evacuation quantity

The overhead costs of managing solid waste in an effective, efficient and sustainable manner in an area has been known to be very high and the means of generating enough fund to sponsor the project is scarce(Ihueze and Chukwumuanya, 2015). This sub-section focuses on developing a cost estimation and waste production forecasting models for sustainable solid waste management using economic order quantity methodology and full cost accounting approach. In doing this, the following assumptions are made:

a) No monitoring of the waste bin (roadside dumps) locations; instead send evacuation (disposal) trucks to all the locations daily to remove any quantity of waste found at the dump sites; or
b) Effectively monitor all the waste bin sites and as soon as a certain quantity of waste has been generated at any point in time, send for a disposal truck(s) to remove this quantity of waste; or
c) No monitoring of the waste bin sites; instead the number of available disposal trucks are sent on regular basis, other than daily basis, may be twice or more times per week or per month, or as the case may be, to the various dump sites to remove the quantity of waste found at the sites; or
d) No monitoring of the waste bin locations. Available disposal trucks are sent on daily basis to randomly selected bin sites to remove any quantity of waste found there.
e) The total cost of waste produced (generated) in an area is equal to the total cost of managing the waste under the full cost accounting (FCA) system.
f) The total cost of evacuation in the objective function is proportional to the number of evacuation runs required to keep a minimal inventory level in a given period
g) The cost per evacuation run (C_r) is a linear function of the optimum evacuation quantity (D)
h) Over the course of a given period, evacuation runs of integer quantity may be involved

Meanwhile, the study considered the recommendations of the full cost accounting (FCA) methodology made by US EPA(1997) for MSW management which stresses that it is necessary to consider capital investments and all other costs that occur when implementing a SWM scheme project. It also considered, the “through” approach - which means going "through" (i.e. to consider) all costs involved in a scheme rather than limiting the calculation to certain cost types when forming the cost structure. This approach enables management to obtain a clearer picture of the market situation based on their constant knowledge accumulation. Efforts have been made in this research to adopt this same method of cost evaluation within the reach of the available data and current waste management practices in Anambra State.

It was a little difficult estimating C_h for a given dumpsite. However, the EOQ formula (eqn 34-b) was eventually used and is hereby recommended for use in calculating the value of C_h that would make a given Q optimal.

Subsections 3.3.1 to 3.3.4 discussed some methods used in SWIM for estimating quantities of waste generated within a given area. For a given dumpsite, the following relations could be established:

$$q_j = Q_{p,j} - Q_j \tag{14}$$

Rewriting eqn (14) in terms of Q_j, to show the number of evacuator runs and the mean disposable quantity:

$$q_j = Q_{p,j} - r_j D_j \tag{15a}$$

where the quantity evacuated varies, the average of D quantity of waste evacuated from the given dumpsite in a period t is given by the equation:

$$\bar{D}_i = r_i^{-1} Q_i \tag{15b}$$

So,

$$q_j = Q_{p,j} - r_j \bar{D}_j \tag{16}$$

$$Q_{p,i} = q_i + r_i \bar{D}_i \tag{17a}$$

For all the dumpsites in the area under consideration,

$$\Sigma Q_{p,ij} = \Sigma q_{ij} + \Sigma(r\bar{D})_{ij} \tag{17b}$$

Or

$$Q = Q_{rem} + Q_{eva} \tag{17c}$$

By following the method of Thomas *et al*(2001) and Baumol(1972) in determining the optimal production schedule, we assume the Qs in eqn (17c) have known values. If the problem were posed so that a minimal level of waste in stock (inventory) is specified, it would not change the structure of the problem. Let also

$$C_h = k_1 D \tag{18}$$

Going by the immediate above seventh assumption,

$$(C_r)_T = k_2 + k_3 D \tag{19a}$$

where

$$C_r = k_3 D \tag{19b}$$

And the total cost of evacuation only obtained from this linear function is:

$$C_E = r\,(k_2 + k_3 D) \tag{20}$$

Eqn. (15a) may not be a realistic assumption because the incremental cost of evacuation could decrease somewhat for large runs. As such, instead of the linear cost function, a non-linear function (see Figure 8) of the following form may be chosen:

$$(C_r)_T = k_2 + k_4 D^{½} \quad (21)$$

and

$$C_E = r\,(k_2 + k_4 D^{½}) \quad (22)$$

The total cost C_T resulting from the quantity of waste generated over the given period is the sum of the carrying cost and the total cost of evacuation made within the period. For the linear cost function, eqn (19a), we state that:

$$(C_T)_L = k_1 D + r\,(k_2 + k_3 D) \quad (23)$$

And for the nonlinear cost function, eqn. (22), we obtain:

$$(C_T)_{NL} = k_1 D + r\,(k_2 + k_4 D^{½}) \quad (24)$$

The objective functions in (23) and (24) are functions of two variables namely, D and r. However, D and r are related as follows:

$$r = QD^{-1} \quad (25)$$

Eqn (25) clearly shows that only one independent variable exists for this problem, which we select as D; while the dependent variable is r. If we eliminate r from the objective function in (23) and (24), we obtain the objective cost function of waste evacuation for the linear function:

$$C_T = k_1 D + k_2 QD^{-1} + k_3 Q \quad (26)$$

And for the non-linear function:

$$C_T = k_1 D + k_2\,QD^{-1} + k_4 QD^{-½} \quad (27)$$

where the values of parameters in k are determined by the waste management concerned, either from past evacuation records or by act of law.

Meanwhile, one of the assumptions made in arriving at eqn (26) is that over the course of a given period, evacuation runs of integer quantity may be involved. Before we use the method of differential calculus to determine the quantity of waste that minimizes the objective function, a crucial question arises at this point. Can D be treated as a continuous variable? In the present case, with D being the only variable and a large one too, it can be treated as a continuous variable and after obtaining the optimal D, the value of practical D is obtained by rounding up or down(Thomas et al, 2001). There are several optimization methods one can use in determining the values of D which minimizes the objective function.

3.3.5.1 Optimization by Gradient method

If we differentiate eqn (26), the term k_3Q vanishes, showing that k_3 plays no part in determining the optimal value of D. However, k_3 contributes to the total cost. We can solve for the optimal values of D either by analytical method or by numerical method. To obtain the optimal solution for D, we differentiate the cost function in eqn (26) with respect to D and equate the derivative to zero. Thus

$$dC_T/dD = k_1 - k_2\, QD^{-2} = 0 \qquad (28)$$

Rearranging eqn (28) in terms of D, we obtain the optimal D as:

$$D^{opt} = \{(k_1)^{-1}k_2Q\}^{½} \qquad (29)$$

We can obtain eqn (29) without knowing specific numerical values for the parameters. If for any reason the value of k_1, k_2 or Q changes, then the corresponding value of D^{opt} is easily found.

We can check if D^{opt} from eqn (29) minimizes the objective function by taking the second derivative of C_T and showing it to be positive. That is

$$d^2C_T/dD^2 = 2k_2\, QD^{-3} > 0? \qquad (30)$$

Also, working with the non-linear function, the cost vary as given by eqn (22), thus allowing for some economy of scale, which then leads to eqn (24). We differentiate eqn (24) and equate the derivative to zero to obtain,

$$dC_T/dD = k_1 - k_2\, QD^{-2} - {}^{1}/_{2}k_4\, QD^{-3/2} = 0 \qquad (31)$$

Eqn (31) is a complicated polynomial that cannot be solved explicitly for D^{opt}, so we resort to a numerical solution. To minimize eqn (20), we have two options, either to:

1). minimize eqn (24) directly or

2) find the square root of eqn (31).

It would be easier to minimize C_T directly by a numerical method rather than take the derivative of C_T , equate it to zero, and solve the resulting nonlinear equation. The second derivative of eqn (24) is

$$d^2C_T/dD^2 = k_2\, QD^{-3} + {}^{3}/_{4}k_4\, QD^{-5/2} \qquad (32)$$

To check if D^{opt} from eqn (31) minimizes the objective function, we substitute the values of k_2, k_4, Q and D into eqn (32) and solving the expression to see if $d^2C_T/dD^2 > 0$.

3.3.5.2 Optimization by Newton-Raphson iteration

Newton-Raphson iteration method can also be used in solving for D, but eqn (26) and eqn (28) should be used in the form of eqn (33a), and eqns (27) and (29) should be used in the form of (33b).

$$D_{m+1} = D_m - \frac{k_1D + k_2QD^{-1} + k_3D}{k_1 - k_2QD^{-2}} \qquad (33a)$$

$$D_{m+1} = D_m - \frac{k_1D + k_2QD^{-1} + k_4D^{-}}{k_1 - k_2QD^{-2} - {}^{1}/_{2}k_4D^{-3/2}} \qquad (33b)$$

Where the values of k_1, k_2, k_3, k_4, and Q are already known. Initial guess value of D is assumed and iteration continued until a constant value of D that optimizes the objective function is obtained. Use of Excel spreadsheet is helpful here.

3.3.5.3 Sensitivity of the EWEQ formula

The purpose of sensitivity analysis is to identify the criticality of the variables, parameters and assumptions used in an analysis to the results modeled. While the primary purpose of sensitivity analysis is to determine whether a change in any key parameter results in a negative net present value (NPV), it is also important to assess the impact of different parameters on the magnitude of the NPV that is achieved. This provides policy makers with an indication of the level of certainty associated with the modeled results in addition to identifying the critical parameters and assumptions in terms of the impact on the net benefit of the policy or program. (Lassen et al, 2010)

Like in EOQ formula, EWEQ assumes that all inputs are known with certainty but in reality these values are often estimates. The relations that enable sensitivity analysis to be performed on the parameters used in the study were adopted from Thomas *et al* (2001) as eqns (34) to (50).

By substituting D^{opt} from eqn (29) into the total cost function in eqn (27) and simplifying the expression,

$$(C_T)^{opt} = 2(k_1k_2Q)^{½} + k_3Q \qquad (34)$$

And taking the partial derivatives of C_T with respect to k_1, k_2, k_3, and Q, we obtain:

$$(\mathcal{S}^c)_{k1} = \partial(C_T)^{opt}/\partial k_1 = \{(k_1)^{-1}k_2Q\}^{½} \qquad (35)$$

$$(\mathcal{S}^c)_{k2} = \partial(C_T)^{opt}/\partial k_2 = \{k_1(k_2)^{-1}Q\}^{½} \qquad (36)$$

$$(\mathcal{S}^c)_{k3} = \partial(C_T)^{opt}/\partial k_3 = Q \qquad (37)$$

$$(\mathcal{S}^c)_{Q} = \partial(C_T)^{opt}/\partial Q = \{k_1k_2Q^{-1}\}^{½} + k_3 \qquad (38)$$

Eqns (35) to (50) are the absolute sensitivity coefficients. Let the expressions for the sensitivity of D^{opt} be also developed. We recall that eqn (29) gives

$$D^{opt} = \{(k_1)^{-1}k_2Q\}^{½}$$

By taking the partial derivatives of D^{opt} with respect to k_1, k_2, k_3, and Q, then:

$$(S^{D})_{k1} = \partial D^{opt}/\partial k_1 = -0.5(k_1)^{-1}\{(k_1)^{-1}k_2Q\}^{½} \quad (39)$$
$$(S^{D})_{k2} = \partial D^{opt}/\partial k_2 = 0.5(k_2)^{-1}\{(k_1)^{-1}k_2Q\}^{½} \quad (40)$$
$$(S^{D})_{k3} = \partial D^{opt}/\partial k_3 = 0 \quad (41)$$
$$(S^{D})_{Q} = \partial D^{opt}/\partial Q = 0.5Q^{-1}\{(k_1)^{-1}k_2Q\}^{½} \quad (42)$$

And for the relative sensitivity analysis, the following equations hold:

$$S^{C}_{k_1} = \frac{\partial C^{opt}/C^{opt}}{\partial k_1/k_1} = \frac{\partial \ln C^{opt}}{\partial \ln k_1} = \{(k_1)^{-1}k_2Q\}^{½} \,.\, (k_1/C^{opt}) \quad (43)$$
$$S^{C}_{k_2} = \frac{\partial C^{opt}/C^{opt}}{\partial k_2/k_2} = \frac{\partial \ln C^{opt}}{\partial \ln k_2} = \{(k_1)^{-1}k_2Q\}^{½} \,.\, (k_2/C^{opt}) \quad (44)$$
$$S^{C}_{k_3} = \frac{\partial C^{opt}/C^{opt}}{\partial k_3/k_3} = \frac{\partial \ln C^{opt}}{\partial \ln k_3} = \{(k_1)^{-1}k_2Q\}^{½} \,.\, (k_3/C^{opt}) \quad (45)$$
$$S^{C}_{Q} = \frac{\partial C^{opt}/C^{opt}}{\partial Q/Q} = \frac{\partial \ln C^{opt}}{\partial \ln Q} = \{(k_1)^{-1}k_2Q\}^{½} \,.\, (Q/C^{opt}) \quad (46)$$
$$S^{D}_{k_1} = \frac{\partial D^{opt}/D^{opt}}{\partial k_1/k_1} = \frac{\partial \ln D^{opt}}{\partial \ln k_1} = \{(-0.5(k_1)^{-1}\{(k_1)^{-1}k_2Q\}^{½} \,.\, (k_1/D^{opt}) \quad (47)$$
$$S^{D}_{k_2} = \frac{\partial D^{opt}/D^{opt}}{\partial k_2/k_2} = \frac{\partial \ln D^{opt}}{\partial \ln k_2} = \{0.5(k_2)^{-1}\{(k_1)^{-1}k_2Q\}^{½}. (k_2/D^{opt}) \quad (48)$$
$$S^{D}_{k_3} = \frac{\partial D^{opt}/D^{opt}}{\partial k_3/k_3} = \frac{\partial \ln D^{opt}}{\partial \ln k_3} = 0 \quad (49)$$
$$S^{D}_{Q} = \frac{\partial D^{opt}/D^{opt}}{\partial Q/Q} = \frac{\partial \ln D^{opt}}{\partial \ln Q} = 0.5Q^{-1}\{(k_1)^{-1}k_2Q\}^{½} \,.\, (Q/D^{opt}) \quad (50)$$

3.3.6 Queue modeling of waste generation and evacuation process

Accumulation is a natural phenomenon and another form of queue. Waste, like any other thing in life whose number or volume continues to increase at some rate in a given system accumulates when there exists inability to dispose such waste at the same rate at which it is generated or produced. Accumulation of waste in our environment makes the environment untidy and leads to many societal problems, which includes environmental, economic and public health problems.

Meanwhile, SWM structure in Anambra State can be approximated to what is obtainable in a queuing system as Figure 12 illustrates. Here, wastes of all types from homes, offices, markets, etc. arrive at the various public used waste bin locations and while waiting (as customers) to be served (evacuated/transferred/transported) to the final dump station by disposal trucks accumulate there as municipal solid waste. The waste are dumped both during the day and in the night hours through a discrete influx of these materials to the site. The waste disposal trucks are deployed to the various waste dump stations for service as illustrated in Figure 12.

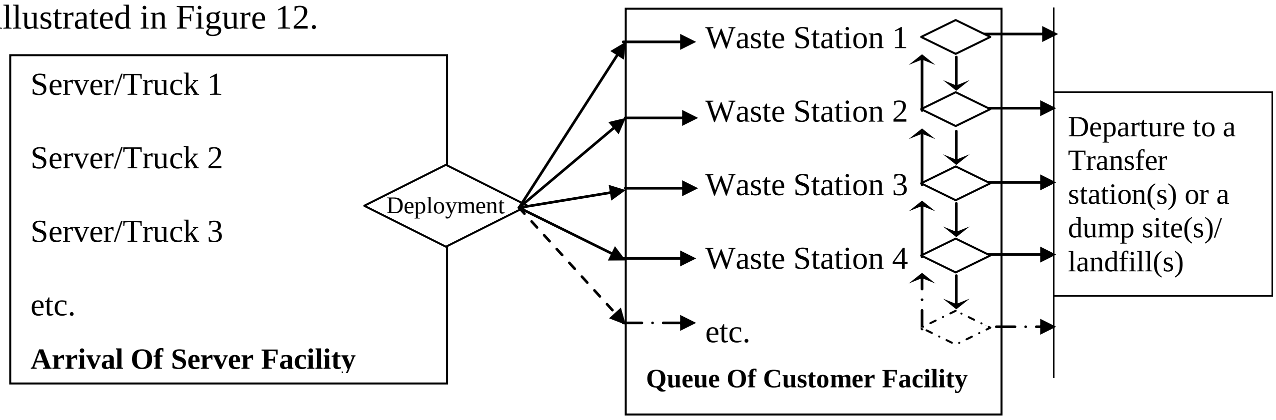
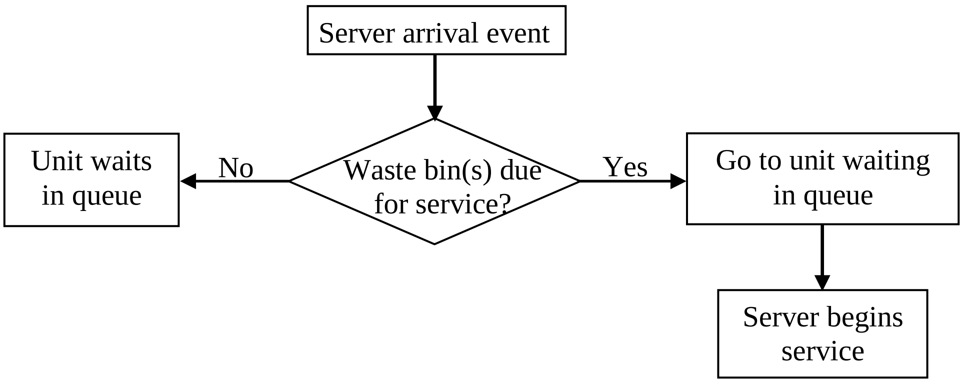
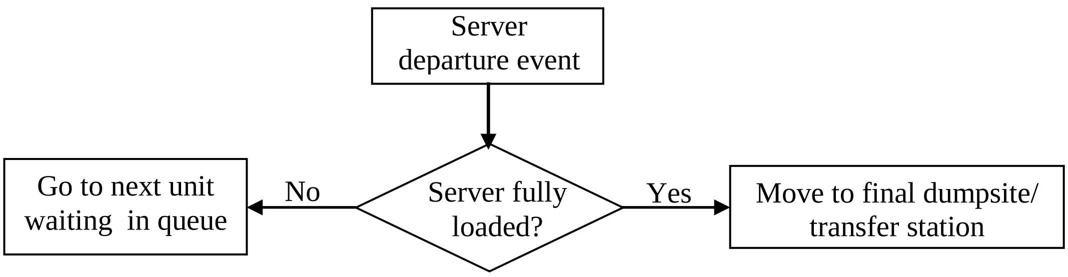


Figure 12: Flow diagram of a typical Multiple Servers-Multiple Waste Depot System

The waste accumulation structure is dynamic in discipline. Both service in random order (SIRO) and priority service are applicable here. In both cases, the waste bins at the various dump stations waiting to be evacuated (as customers) are considered as being in a single queue and randomly served. The servers (evacuator trucks) go to any of the bin stations that is free and waiting for service. The server arrival and departure events are depicted in Figures 13a and 13b.



(a): Disposal vehicle arrives dumpsite for service



(b): Disposal vehicle leaves dumpsite *j* for final dumpsite/transfer station

Figure 13: Arrival and departure events of a service facility

The following assumptions are made, and where necessary they will also apply to other models developed in this research :

a. The number of waste containers (bins) in use is known but in terms of the quantities of waste to be generated it is unknown, infinite and unrestricted. That is to say, there are many batched quantities of solid waste (measured in terms of bin sizes) to be evacuated (served) in a given period (hourly, daily, weekly, etc)
b. Waste existing at various public used roadside dumpsites are in queue
c. The service/unloading time of bins is controllable
d. The waste bins are arbitrarily but strategically distributed (placed) at various locations within the research area.
e. Quantity of solid waste found at roadside dumpsites at any given time is the total waste generated by the people living/operating within the area.
f. Waste generation and disposals are stochastic, dynamic and man-machine-material interaction processes of the system
g. The system is non-fully automated
h. The number and capacities of the disposal vehicles are known.
i. Arrival rate of waste at the dump sites is stochastic, but the evacuation is executed according to management plans.
j. State (quantity) of waste before and after evacuation at a given dumpsite in a given period(s) is always recorded.
k. Waste not brought to a public dumpsite is negligible/not considered at all.
l. Size and number of waste bins (containers) and bin locations (dumpsites) may vary, but such data is recorded and treated from the point of such a variation
m. For purposes of the present study, unless where otherwise stated, loading of an evacuator at a waste bin/dump site is measured by the fraction of full loaded chain-up bins carried by the truck per its trip from the site.
n. Any indisposed quantity of waste at a given waste bin site, after a truck's visit to the site on a day is considered a new joiner to the line of bins waiting for service during the truck's next visit to the site.
o. Any day none of the disposal trucks (servers) works in a given dumpsite is assumed as server's idle time (i.e. $N_{(\mu=0)}$) for that dump site.

p. For a recording that starts at evening check of day $i = 1$, $q_{d,ij} = 0$ and $q_{N,ij} \geq 0$; if recording starts at morning check: $q_{N,ij} = 0$ and $q_{d,ij} > 0$.

To make the development of the models in the study better understood, a simulation table consisting of k inputs x_{ij} for k number of dumpsites ($j = 1, 2,...,k$; $i = 1,2,...,n$, and a number of the desired responses y_{ij}, was constructed in a Microsoft Excel spreadsheet as shown in **Table 4**.

Table 4: Simulation table for queue model development, demonstration and validation

	Dumpsite 1													…	Dumpsite k						All Dumpsite				
Time	Inputs x_{i1}			Responses, y_1										…	Inputs x_{i1}			Responses, y_1			Σy_i (Responses)				
i (days)	L_q	q_d	q_N	$q_{(d+N)}$	λ_q	μ_q	L_R	L_s	W_a	W_q	W_s	η	$P_t(t)$	…	L_q	q_d	q_N	$q_{(d+N)}$	…	$P_t(t)$	$q_{(d+N)}$	λ_q	μ_q	…	$P_t(t)$
1														…											
2														…											
. .														…											
n														…											
$\Sigma =$																									
Mean																									

In estimating the quantities of waste generated and evacuated in a given dumpsite j, it is assumed that check starts in the morning of day $i = 1$, with $L_{w,(i-1)j} \geq 0$, $q_{N,(i-1)j} \geq 0$, $\mu_{q,ij} = 0$, $q_{d,ij} = 0$, $q_{N,ij} = 0$ and $\mu_{q,(i-1)j} = (r\,D)_{(i-1)j}$. Thus, in accordance with eqn. (17)

$$q_{M,ij} = (Q - rD)_{(i-1)j} + q_{N,(i-1)j} = q_{M,oj} \qquad (51a)$$

Or rewriting eqn. (47a) in terms of queue parameters

$$L_{q,oj} = q_{M,ij} = L_{w,(i-1)j} + q_{N,(i-1)j} \qquad (51b)$$

At the evening check of the same 1st day we also assume that $q_{M,ij} \geq 0$, $L_{w,ij} \geq q_{M,0j}$, $q_{N,ij} = 0$ and $\mu_{q,ij} \geq 0$. By this we obtain that

$$q_{d,ij} = \left(L_{w,ij} + \mu_{q,ij}\right) - q_{M,oj} \qquad (51c)$$

At the morning check of the next day, i+1, with $\mu_{q,ij} \geq 0$, $L_{w,ij} \geq q_{d,ij} \geq 0$, $q_{N,ij} \geq 0$,

$$L_{q,(i+1)j} = \left(L_{w,ij} + q_{N,ij}\right) \qquad (52a)$$

At the evening check of day i+1 still, with no evacuation made and $q_{N,ij} \geq 0$. Thus

$$q_{d,(i+1)j} = (L_w + \mu_q)_{(i+1)j} - q_{M,(i+1)j} \qquad (52b)$$

From the foregoing, therefore, we conclude that for a given day i, the total quantity of waste (number of bin loads) deposited at dump site j,

$$q_{(d+N)j} = (q_d + q_N)_{ij} \qquad (52c)$$

A waste container is considered full or overflowing if and only if:

$$V_b = \sum_{i=1}^{m} q_{(d+N)ij} \geq 1 \quad (\text{where } 1 \leq m \leq n) \qquad (53a)$$

And number of fully and/or over loaded bins

$$N_{Bf} = \frac{\sum_{i=1}^{n} q_{(d+N)}}{V_b} \geq 1 \qquad (53b)$$

Let for a given dumpsite *j*,

$$D = N_{Bf} \text{ x } V_b \qquad (53c)$$

Time from $t = 1$ to $t = m$ taken for ($\sum_{i=1}^{m} q_{(d+N)ij} = D$) = $\boldsymbol{t}_{GL}$ (say) (53d)

Number of WGLTs in a period t = 1 to t = *n* is obtained from the relation:

$$N_{tGL} = \frac{\sum_{i=1}^{n} q_{(d+N)}}{D} \geq 1 \qquad (53e)$$

For *k* number of dumpsites, daily quantity of waste arriving (deposited) in a period *i* to *n* days is obtained thus, $\lambda_q = (L_q + q_d)_{ij}$ (54a)

While the combined mean quantity of waste arriving (deposited) in a period *i* to *n* days is obtained thus, $\lambda = \frac{1}{nk} \sum_{i=1}^{n} \sum_{j=1}^{k} \lambda_{q,ij}$ (54b)

Combined mean number of waste bins served over a given period

$$\mu = \frac{1}{nk} \sum_{i=1}^{n} \sum_{j=1}^{k} \mu_{q,ij} \qquad (55)$$

With $\mu_{q.ij} \geq 0$, number of loaded bins in the queue on the n^{th} day

$$L_{q,n} = L_{q,o} + (\sum_{i=1}^{n-1} q_{(\text{d+N})} - \sum_{i=1}^{n-1} \mu_q)_{ij} \qquad (56a)$$

Number of loaded bins in the system on the n^{th} day

$$L_{s,n} = L_{q,o} + (\sum_{i=1}^{n-1} q_{(\text{d+N})} - \sum_{i=1}^{n-1} \mu + q_d)_{ij} \qquad (56b)$$

For *k* number of dumpsites, the average number of waste bins in the system

$$L_s = \frac{1}{nk} \sum_{j=1}^{k} (L_{q,o} + \sum_{i=1}^{n-1} q_{(\text{d+N})} - \sum_{i=1}^{n-1} \mu + q_d)_{ij} \qquad (56c)$$

And the number of loaded bins waiting for service in the system on the n^{th} day

$$L_{w,n} = L_{q,o} + (\sum_{i=1}^{n-1} q_{(\text{d+N})} - \sum_{i=1}^{n} \mu_q + q_d)_{ij} \qquad (57)$$

From the general queuing theory, we obtain

$$W_q = L_q \lambda^{-1} \qquad (58a)$$

$$W_s = L_s \lambda^{-1} \qquad (58b)$$

$$W_a = \frac{1}{n} \sum_{i=1}^{n} N_{(\mu=0)} \qquad (58c)$$

A waste management system's daily evacuation efficiency (portion of waste evacuated) is defined by the relation,

$$\eta_{ij} = \frac{\mu_{q,ij}}{\lambda_{q,i,j}} \text{ x } 100\% \qquad (59a)$$

While the overall system's efficiency is defined by the relation

$$\eta = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}\mu_{q,ij}}{(\sum L_{q,oj} + \sum_{i=1}^{n}\sum_{j=1}^{k} q_{(d+N))_{ij}}} \qquad (59b)$$

And the waste disposal system utilization

$$\rho = \frac{\lambda}{s\mu} \qquad (60)$$

Each idle time of server in the system is defined by the conditions that:

$$\left.\begin{aligned} \mu &= 0 \\ q_{(d+N)} &\geq 0 \\ t_{os} &= t_{\mu=0} \\ \text{and} \quad N_{\mu=0} &= 1 \text{ (say)} \end{aligned}\right\} \quad N_{Bf} \geq 1 \qquad (61)$$

Thus, total number of idle times of disposal truck(s) serving *k* number of dumpsites in a given period,

$$N_{s,o} = \sum_{i=1}^{n}\sum_{j=1}^{k} N_{(\mu=0),ij} \qquad (62)$$

Therefore, probability that a server is idle

$$(P_o)_s = (N_s)_o \text{ x } n^{-1} \qquad (63)$$

Probability that waste container(s) in the system is full and/or overflowing,

$$P_{Bf} = \sum_{i=1}^{n}\sum_{j=1}^{k}\left(\frac{N_{Bf}}{n}\right)_{ij} \quad \{\text{where } N_{Bf} : N_{Bf} = (N_{Bf} + N_{Bof})\} \qquad (64)$$

It is assumed that disposal trucks (servers) visit dumpsites either in the morning or evening hours of a day and that during the visits, the waste bins should be totally emptied such that

$$\left.\begin{aligned} N_{\mu>0} &\geq N_b \\ q_{(d+N)} &= 0 \\ \text{and} \quad N_{\lambda=0} &= 1 \text{ (say)} \end{aligned}\right\} \qquad (65)$$

By this assumption, the probability of no waste in dumpsite *j* at morning check of a given period,

$$P_{o,d,j} = \left(\frac{\sum N_{\lambda=0}}{n}\right)_{d,ij} \leq 0.5 \qquad (66a)$$

Probability of no waste in dumpsite *j* at evening check of a given period,

$$P_{o,N,j} = \left(\frac{\sum N_{\lambda=0}}{n}\right)_{N,ij} \leq 0.5 \qquad (66b)$$

Therefore, probability of no waste in dumpsite *j* is

$$P_{o,,j} = \left(\frac{N_{\lambda=0}}{2n}\right)_{d,ij} + \left(\frac{N_{\lambda=0}}{2n}\right)_{N,ij} \leq 1 \qquad (66c)$$

For the entire system, the probability of no waste in *k* number of dumpsites is

$$P_{o,k} = \frac{1}{k}\sum_{j=1}^{k}\left\{\left(\frac{\sum N_{\lambda=0}}{2n}\right)_d + \left(\frac{\sum N_{\lambda=0}}{2n}\right)_N\right\}_{ij} \le 1 \qquad (66d)$$

Probability that new stock of waste arrives at dumpsite *j* in a given period,

$$P_{\lambda} = \frac{\sum_{i=1}^{n} q_{(d+N)}}{\left(L_{q,oj} + \sum_{i=1}^{n} q_{(d+N)}\right)} \qquad (67)$$

The transient probability can be based specifically on either the daily arriving stock $q_{(d+N)}$ or on daily total stock λ_q. That is to say,

$$P(t)_{q_{(d+N)}} = \frac{q_{(d+N)}}{\sum_{i=1}^{n} q_{(d+N)}} \qquad (68a)$$

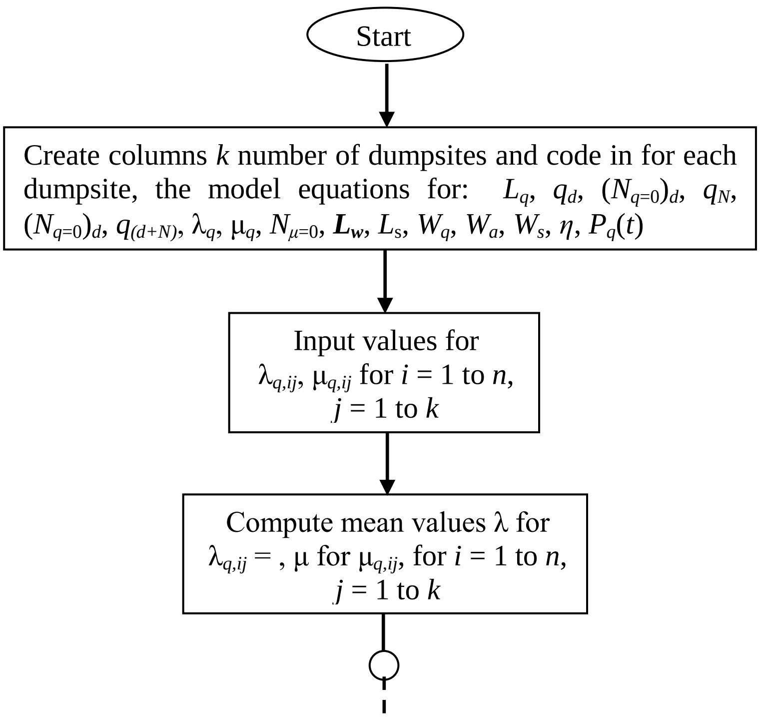
Or

$$P(t)_{\lambda_q} = \frac{\lambda_q}{\sum_{i=1}^{n} \lambda_q} \qquad (68b)$$

It can be seen clearly from the above equations that the performance measures are functions of two basic queuing parameters - waste arrival rate (the average rate of waste container fill) and the container service rate (the average rate of waste evacuation). Values computed for these parameters give how well the management service mechanism handles volumes of waste generated in the given system.

3.3.6.1 Flow chart for systematic application of the waste queuing models

Flow chart for application of the waste queuing models developed in this study in Excel spreadsheet is depicted in Figure 14. Values for two basic queuing parameters - λ and μ - for i = 1 to n and j = 1 to k are required as input data which Excel uses to generate values for other parameters based on coded models of interest.



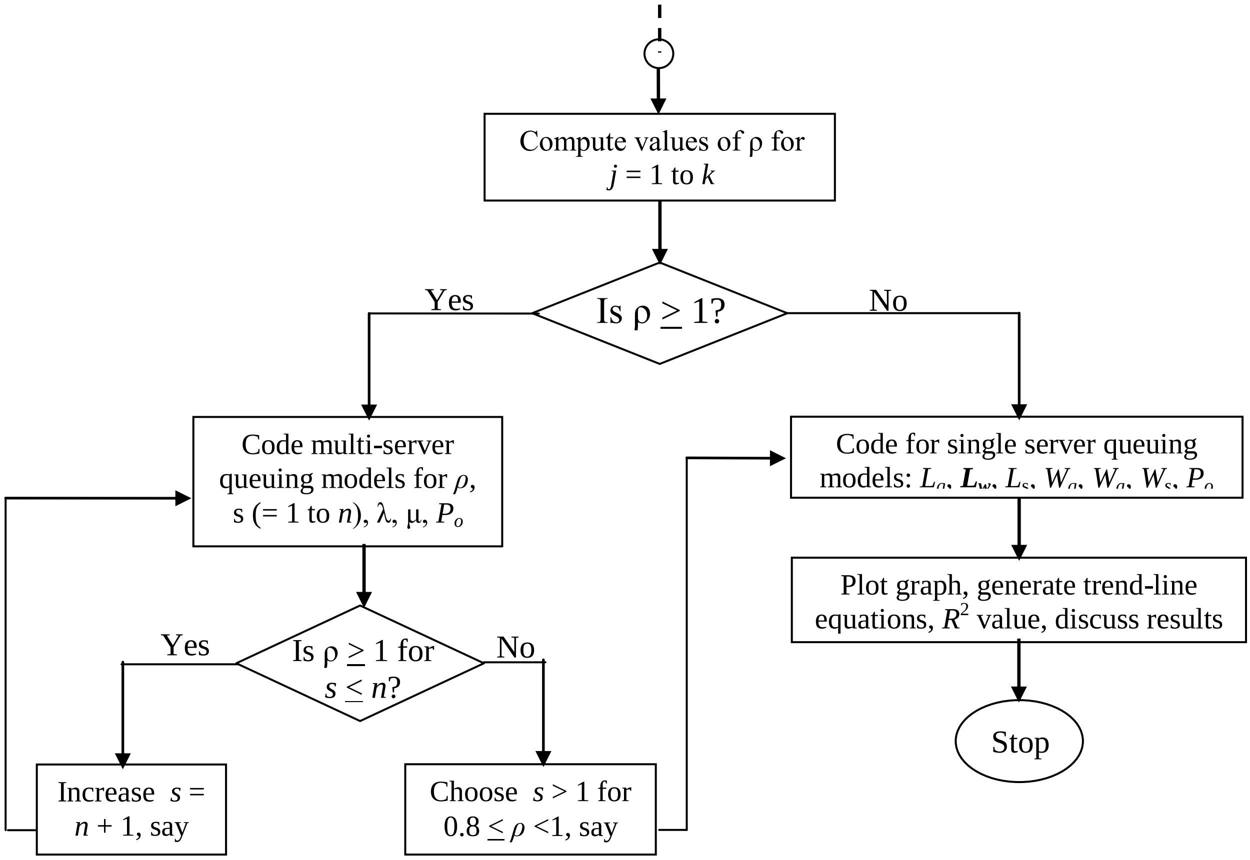


Figure 14: Flow chart for application of the study waste queuing models

3.3.7 Modeling of Awka Urban City Waste disposal rate

Data in **Table 11** reveal that the quantities of solid wastes generated in the various zones of Awka Urban city were not the same and are independent of the total land surface area of their generating zones; rather they depend on the population (P) and goods consumption rate (C_R) of the residents and visitors carrying on activities in the area during the base period. It was also observed that not all the solid waste generated in the zones were dumped at the public roadside bins; some were dumped into drainages, some into private pits, some were either buried or burnt, and others were deposited at places which were out of the reach of ASWAMA workers. The actual quantities of waste (q_{act}) that are of concern in the study are the ones found at the legal dumpsites in Awka area which ASWAMA has access to. If q_{Lost} represents monthly sum of all the waste not recovered by ASWAMA in each of the zones of Awka, then:

$$q_{act} = (q_T - q_{Lost}) \qquad (69)$$

And for all the zones,

$$Q_{act} = \sum_{j=1}^{k} (q_T - q_{Los}) \qquad (70)$$

So, as must have been noticed from the foregoing, actual quantity of waste managed by ASWAMA monthly or annually can be calculated from the relation

$$Q_{act} = \sum_{i=1}^{n}(q_E + q_R) \quad (71)$$

If the number of residential houses (N_{RH}) and the average population of people (P_{ave}) living in those houses in a given geographical location are known, we can determine the unit or per capita disposal rate of waste in the area using the following relation,

$$\text{PCDR} = \frac{Q_{\text{act}}}{N_{\text{RH}} \text{ x } P_{\text{ave}} \text{ x } {}^{d}/_{T}} \quad (72a)$$

Neglecting N_{RH}, where the actual population of the residents of the area is known, we use the relation,

$$\text{PCDR} = \frac{Q_{\text{act}}}{P_{\text{ave}} \text{ x } {}^{d}/_{T}} \quad (72b)$$

3.3.8 Modeling of SWIM for Markov chain application

Suppose there are three waste containers kept at different points (see Figure 15) in a given location and waste are randomly dumped into these containers.

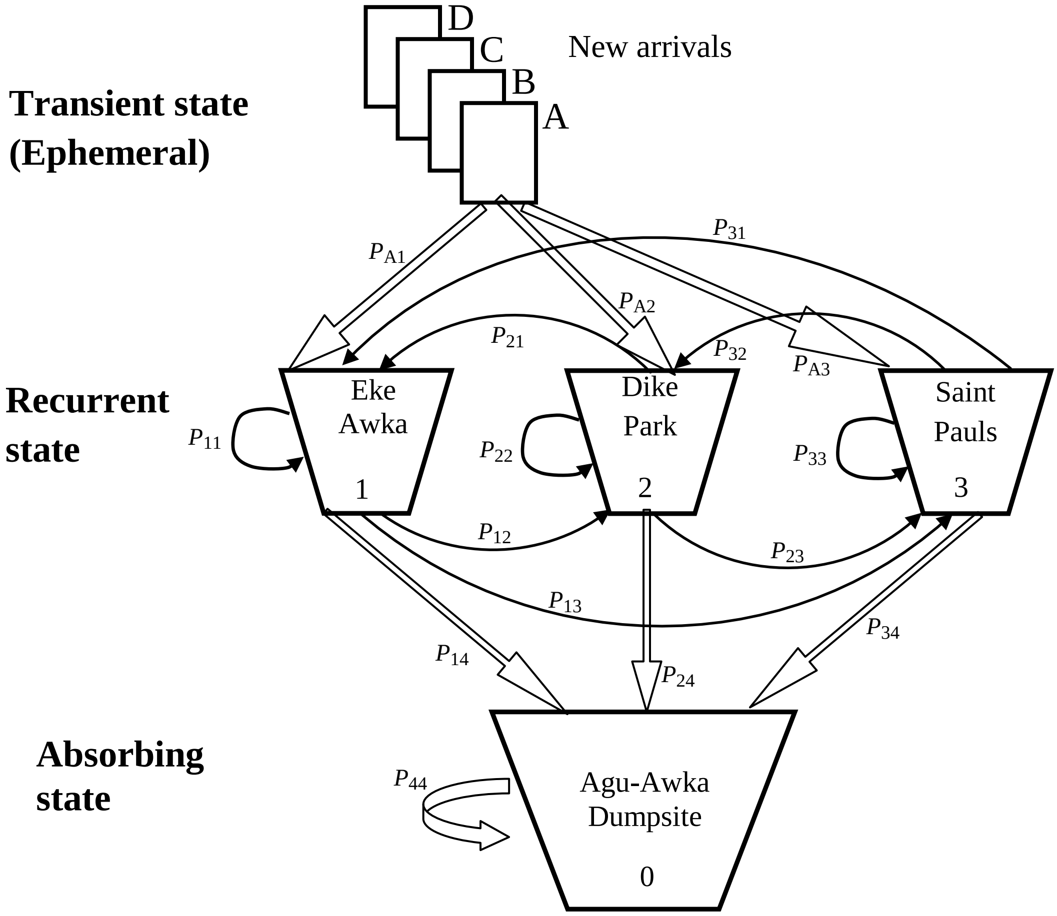
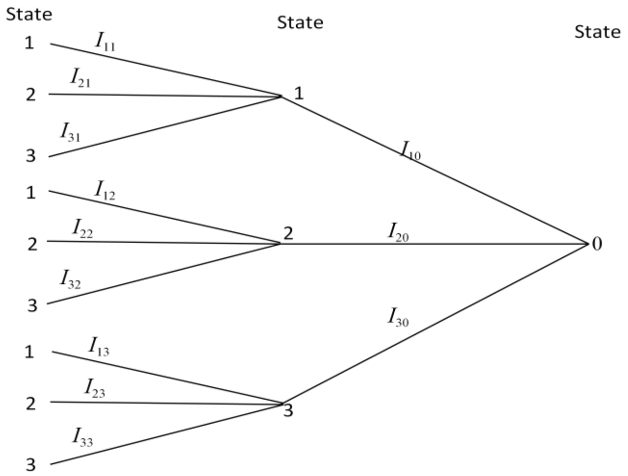


Figure 15: Markov chain for a waste disposal system

Arrival of these waste (A, B, C, D, …) changes the states of the containers in terms of waste volume of accumulation. This means that each of these containers can assume any (recurrent) state (1, 2, 3) from being empty to being filled or overflowing with waste. The accumulated waste in these containers are finally sent the final dump site (absorbing state).

3.3.8.1 Distribution of solid waste disposal states for Markov analysis

Figure 15 is a diagrammatic representation of the stated states of a waste disposal system with the probability vectors defined. To see how these proportions would change after each day generation, we use the tree diagram of Figure 16.



Probability

$$\left.\begin{array}{lr} P_{11} = I_{11} \times I_{10} & \text{(a)} \\ P_{21} = I_{21} \times I_{10} & \text{(b)} \\ P_{31} = I_{31} \times I_{10} & \text{(c)} \\ P_{12} = I_{12} \times I_{20} & \text{(d)} \\ P_{22} = I_{22} \times I_{20} & \text{(e)} \\ P_{32} = I_{32} \times I_{20} & \text{(f)} \\ P_{13} = I_{13} \times I_{30} & \text{(g)} \\ P_{23} = I_{22} \times I_{30} & \text{(h)} \\ P_{33} = I_{33} \times I_{30} & \text{(i)} \end{array}\right\} \quad (73)$$

Figure 16: A tree diagram of the state distribution

For example, to find the final proportions of waste at points 1, 2 and 3 (states 1 - 3) as at the end of the experiment (after the three day generation), we add the probabilities:

$$P_{11} + P_{12} + P_{13} = I_{10} \quad (74a)$$

$$P_{21} + P_{22} + P_{23} = I_{20} \quad (74b)$$

$$P_{31} + P_{32} + P_{33} = I_{30} \quad (74c)$$

It is assumed here that the final distribution of states I_{10}, I_{20} and I_{30} (expressed in percentages), came after one generation which emanated from the initial waste dump proportions I_{10} in state 1, I_{20} in state 2, and I_{30}, in state 3. The distribution can also be written as probability vectors as in eqn (73), with the percents changed to decimals rounded to the nearest hundredth.

3.3.8.2 Formulation of transition matrix in SWIM for Markov chain application in Awka Municipal Solid Waste Management

Table 5 is a transition table formulated for quantities of solid waste produced in each of the twelve ASWAMA zones (**Table J** in the Appendices refers) of Awka Municipality in each month of a year. Each of these waste productions is represented by *P* (probability vectors), expressed in percentage of the total monthly generations from all the zones in each month rounded up to the nearest reasonable number. The table consists of twelve orthogonal arrays (twelve rows and twelve columns) of numerical values, with P_{ij} as the data elements (state distribution of solid waste production) for the twelve Zones in a (twelve month) year.

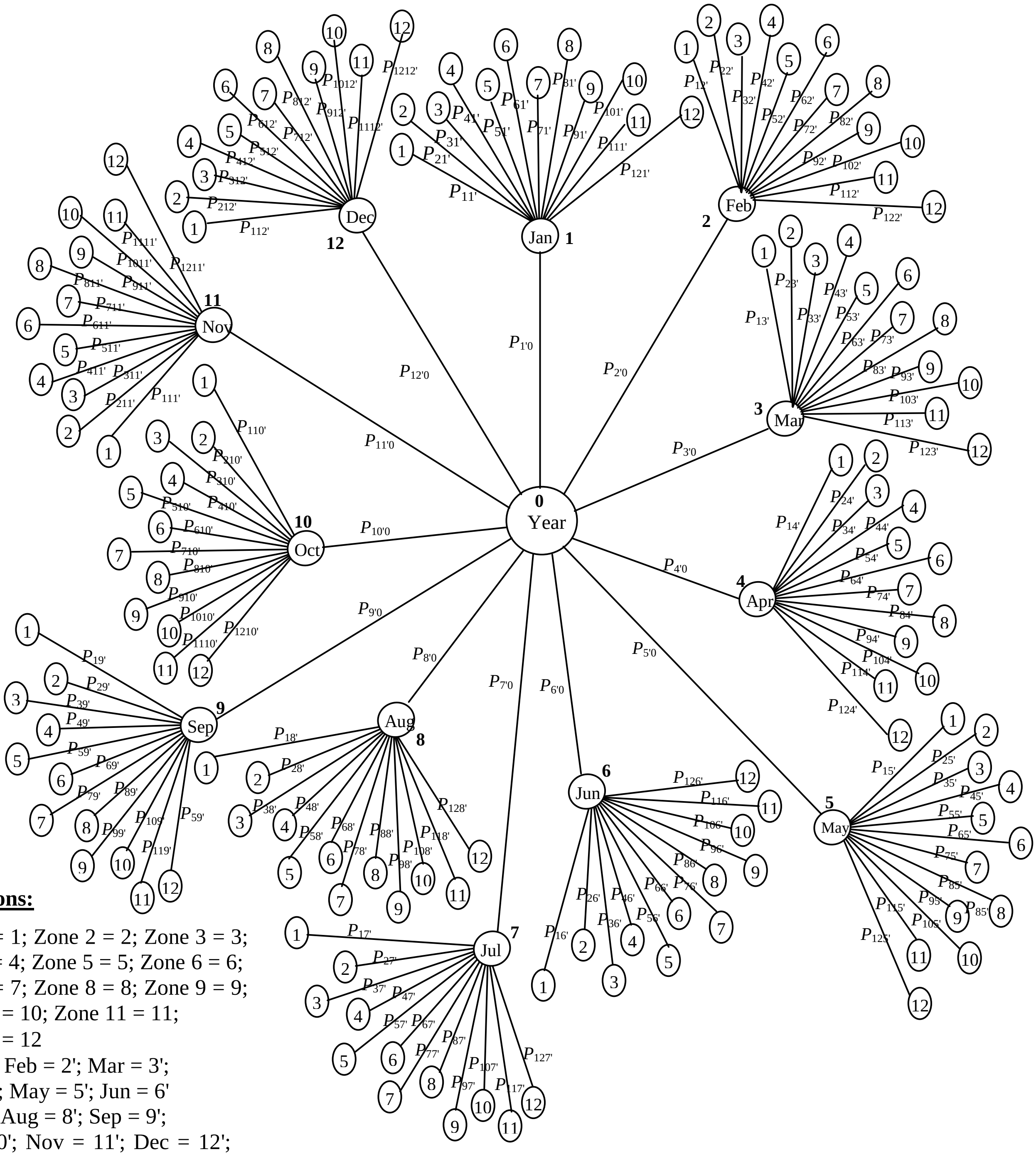
Table 5: Transition table for quantities of solid waste produced in Awka area

Zone Codes ↓ →	States ↓ →	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		1	2	3	4	5	6	7	8	9	10	11	12
		1	2	3	4	5	6	7	8	9	10	11	12
1	1	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{110}	P_{111}	P_{112}
2	2	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}	P_{29}	P_{210}	P_{211}	P_{212}
3	3	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	P_{36}	P_{37}	P_{38}	P_{39}	P_{310}	P_{311}	P_{312}
4	4	P_{41}	P_{42}	P_{43}	P_{44}	P_{45}	P_{46}	P_{47}	P_{48}	P_{49}	P_{410}	P_{411}	P_{412}
5	5	P_{51}	P_{52}	P_{53}	P_{54}	P_{55}	P_{56}	P_{57}	P_{58}	P_{59}	P_{510}	P_{511}	P_{512}
6	6	P_{61}	P_{62}	P_{63}	P_{64}	P_{65}	P_{66}	P_{67}	P_{68}	P_{69}	P_{610}	P_{611}	P_{612}
7	7	P_{71}	P_{72}	P_{73}	P_{74}	P_{75}	P_{76}	P_{77}	P_{78}	P_{79}	P_{710}	P_{711}	P_{712}
8	8	P_{81}	P_{82}	P_{83}	P_{84}	P_{85}	P_{86}	P_{87}	P_{88}	P_{89}	P_{810}	P_{811}	P_{812}
9	9	P_{91}	P_{92}	P_{93}	P_{94}	P_{95}	P_{96}	P_{97}	P_{98}	P_{99}	P_{910}	P_{911}	P_{912}
10	10	P_{101}	P_{102}	P_{103}	P_{104}	P_{105}	P_{106}	P_{107}	P_{108}	P_{109}	P_{1010}	P_{1011}	P_{1012}
11	11	P_{111}	P_{112}	P_{113}	P_{114}	P_{115}	P_{116}	P_{117}	P_{118}	P_{119}	P_{1110}	P_{1111}	P_{1112}
12	12	P_{121}	P_{122}	P_{123}	P_{124}	P_{125}	P_{126}	P_{127}	P_{128}	P_{129}	P_{1210}	P_{1211}	P_{1212}

The data in **Table 5** is rewritten as a transition matrix *M*. In the transition matrix, *M,* a given monthly waste production is assumed to come from any of the twelve discrete states

$$\begin{array}{c} \text{States} \\ 1\\2\\3\\4\\5\\6\\7\\8\\9\\10\\11\\12 \end{array} \begin{array}{c} \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \end{matrix} \\ \begin{pmatrix} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} & P_{17} & P_{18} & P_{19} & P_{110} & P_{111} & P_{112} \\ P_{21} & P_{22} & P_{23} & P_{24} & P_{25} & P_{26} & P_{27} & P_{28} & P_{29} & P_{210} & P_{211} & P_{212} \\ P_{31} & P_{32} & P_{33} & P_{34} & P_{35} & P_{36} & P_{37} & P_{38} & P_{39} & P_{310} & P_{311} & P_{312} \\ P_{41} & P_{42} & P_{43} & P_{44} & P_{45} & P_{46} & P_{47} & P_{48} & P_{49} & P_{410} & P_{411} & P_{412} \\ P_{51} & P_{52} & P_{53} & P_{54} & P_{55} & P_{56} & P_{57} & P_{58} & P_{59} & P_{510} & P_{511} & P_{512} \\ P_{61} & P_{62} & P_{63} & P_{64} & P_{65} & P_{66} & P_{67} & P_{68} & P_{69} & P_{610} & P_{611} & P_{612} \\ P_{71} & P_{72} & P_{73} & P_{74} & P_{75} & P_{76} & P_{77} & P_{78} & P_{79} & P_{710} & P_{711} & P_{712} \\ P_{81} & P_{82} & P_{83} & P_{84} & P_{85} & P_{86} & P_{87} & P_{88} & P_{89} & P_{810} & P_{811} & P_{812} \\ P_{91} & P_{92} & P_{93} & P_{94} & P_{95} & P_{96} & P_{97} & P_{98} & P_{99} & P_{910} & P_{911} & P_{912} \\ P_{101} & P_{102} & P_{103} & P_{104} & P_{105} & P_{106} & P_{107} & P_{108} & P_{109} & P_{1010} & P_{1011} & P_{1012} \\ P_{111} & P_{112} & P_{113} & P_{114} & P_{115} & P_{116} & P_{117} & P_{118} & P_{119} & P_{1110} & P_{1111} & P_{1112} \\ P_{121} & P_{122} & P_{123} & P_{124} & P_{125} & P_{126} & P_{127} & P_{128} & P_{129} & P_{1210} & P_{1211} & P_{1212} \end{pmatrix} \end{array} = M \qquad (75)$$

represented by the rows and columns numbers 1, 2, 3, ..., 12. This same information is shown in the ICCE solar-tree diagram of Figure 17 and the ICCE artificial neural network diagram of Figure **XXII** in the Appendices. Meanwhile, matrix M can be seen as representing the probability of a change in monthly waste generation (production) in the twelve zones. We used the notation P_{ij} to denote the change from state i to state j.



Definitions:

Zone 1 = 1; Zone 2 = 2; Zone 3 = 3;
Zone 4 = 4; Zone 5 = 5; Zone 6 = 6;
Zone 7 = 7; Zone 8 = 8; Zone 9 = 9;
Zone 10 = 10; Zone 11 = 11;
Zone 12 = 12
Jan = 1'; Feb = 2'; Mar = 3';
Apr = 4'; May = 5'; Jun = 6'
Jul = 7'; Aug = 8'; Sep = 9';
Oct = 10'; Nov = 11'; Dec = 12';
Year = 0

Figure 17: An ICCE solar-tree diagram showing the probability distribution of waste production states at the end of different months in a year.

To forecast the probable future waste percentage productions in the twelve zones under review, we raise M to an index number greater than unity. For example, we can investigate what percentage contributions each of these zones will likely make to the total waste in the next one year. To achieve the result, we square M and solve the matrix by method of matrix multiplication. That is to say,

$$M^2 = M \, . \, M \qquad (76)$$

In doing so, we must have utilized the memoryless property of the Markov chain, i.e we used the data for only the given year to predict the outcome of the subsequent year(s). Therefore, we summarize this work as follows:

M^n gives the probabilities of a transition from one state to another after n repetitions of an experiment.

An alternative approach to arriving at the same result as above is to multiply matrix M with the final probability vector. We recall that a probability vector is a matrix with only one row, having non-negative entries, with the sum of the entries equal to 1. In the study, it is assumed that the final probability vector, X_0, is the matrix that represents the annual total productions from each of the twelve zones. Let this final vector be:

$$X_0 = [P_{1'0}, P_{2'0}, P_{3'0}, P_{4'0}, P_{5'0}, P_{6'0}, P_{7'0}, P_{8'0}, P_{9'0}, P_{10'0}, P_{11'0}, P_{12'0}] \qquad (77)$$

From the foregoing, we can safely find the distribution of states after a number of years (future productions) from the relations:

$$M^2 = X_0 . M \qquad (78a)$$

$$M^3 = X_0 . M^2 \qquad (78b)$$

.

.

$$M^n = X_0 . M^n \qquad (78c)$$

3.3.8.3 Algorithm for implementation of Markov chain in waste management

Following are the steps for application of Markov chain in waste management. It is an easy, straight forward and self explanatory process.

Step 1: Divide the study area into ***n*** number of zones and the study period, into ***n*** number of equal parts. Assign unique names, numbers or codes to each division of the zones and to each division of the study time periods. Using serial numbers 1, 2, 3, …, n as codes is recommended.

Step 2: In a spreadsheet (or any other of such) create a table that has n + 3 number of columns and n+3 number of rows

Step 3: Label cell of row 1, column 1 as "Time" (or "Periods") and insert a horizontal arrow pointing rightwards into cells of row 1, columns 2 and 3. Insert another arrow pointing downwards into cell of rows 2 and 3, column 1 and serially number column 4 to ***n*** of row 1 and rows 4 to ***n*** of column 1 as are the names or codes given to the time periods in step 1.

Step 4: Label cell of row 2, column 2 as "Zone" and insert a horizontal arrow pointing rightwards into cells of row 2, column 3. Insert another arrow pointing downwards into cell of row 3, column 2 and serially number column 4 to ***n*** of row 2 and rows 4 to ***n*** of column 2 as are the names or codes given to the zones in step 1.

Step 5: Label cell of row 3, column 3 as "States" and serially number column 4 to ***n*** of row 2 and rows 4 to ***n*** of column 2 as 1, 2, 3. …, ***n***.

Step 6: For each zone, enter its percentage contribution to the total waste stream in periods 1 to n in row 5 of columns 5 to ***n*** and sum up these values in column n+1, which should be equal to 1.

Step 7: Write the ***n*** x ***n*** (i.e. rows 5 to n x columns 5 to n) part of the table as a transition matrix M raised to an index number k greater than unity and solve until all the values in each column of the matrix converge to the same unique numbers at the k^{th} transposition of the matrix. Matlab, Scilab or any of such application software may be very helpful in doing this.

Step 8: Stop the matrix operations and write out the various converged numbers as the probable future waste percentage productions in k^{th} (future) time from each of the respective ***n*** number of zones under review.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Field Qualitative Data and Discussions

4.1.1 Departmentalization and organizational Structure of ASWAMA

As at the time this information was collected from ASWAMA, its Head Office was located inside the Anambra State Government House, along Enugu-Onitsha Express- way, Awka. There were six main departments in the establishment. These departments are contained in **Table 13**, while Figure 43 shows the organigram, both of which are shown the Appendix session. The Managing Director (M/D) and most of the other members of the Board are political appointees (strangers) to the agency.

4.1.2 Stakeholders in waste management of Anambra State

The persons known to ASWAMA as its stakeholders in the state are:

1. The Anambra State Government
2. The Federal Government of Nigeria
3. The residents of the state
4. Civil societies/organizations
5. Non-governmental Organizations (NGOs)
6. Community-based Organizations (CBOs)

4.1.3 A causal loop analysis of Awka municipal solid waste management system at the Moment

Effort is made in this section to analyze the current SWM system in Awka metropolitan city by use of a casual loop. The causal loops currently perceived to be major drivers in Anambra State SWM system based on qualitative/descriptive emphasis in the literature, previous studies, as well as in the present research are indicated in bold. The trends highlighted in the causal loop diagram were drawn strictly from qualitative/ descriptive data of the study. The Causal Loop Diagrams are shown in Figures 18 and 19.

According to Kasozi and Blottnitz(2010), the generation of waste is generally a product of the City residents' day to day living activities and the City's economic activity expressed in business enterprise, commerce, industry and various public institutions (Figure 18: loops 1 & 2). These in turn are fed by the respective population and economic/commer-

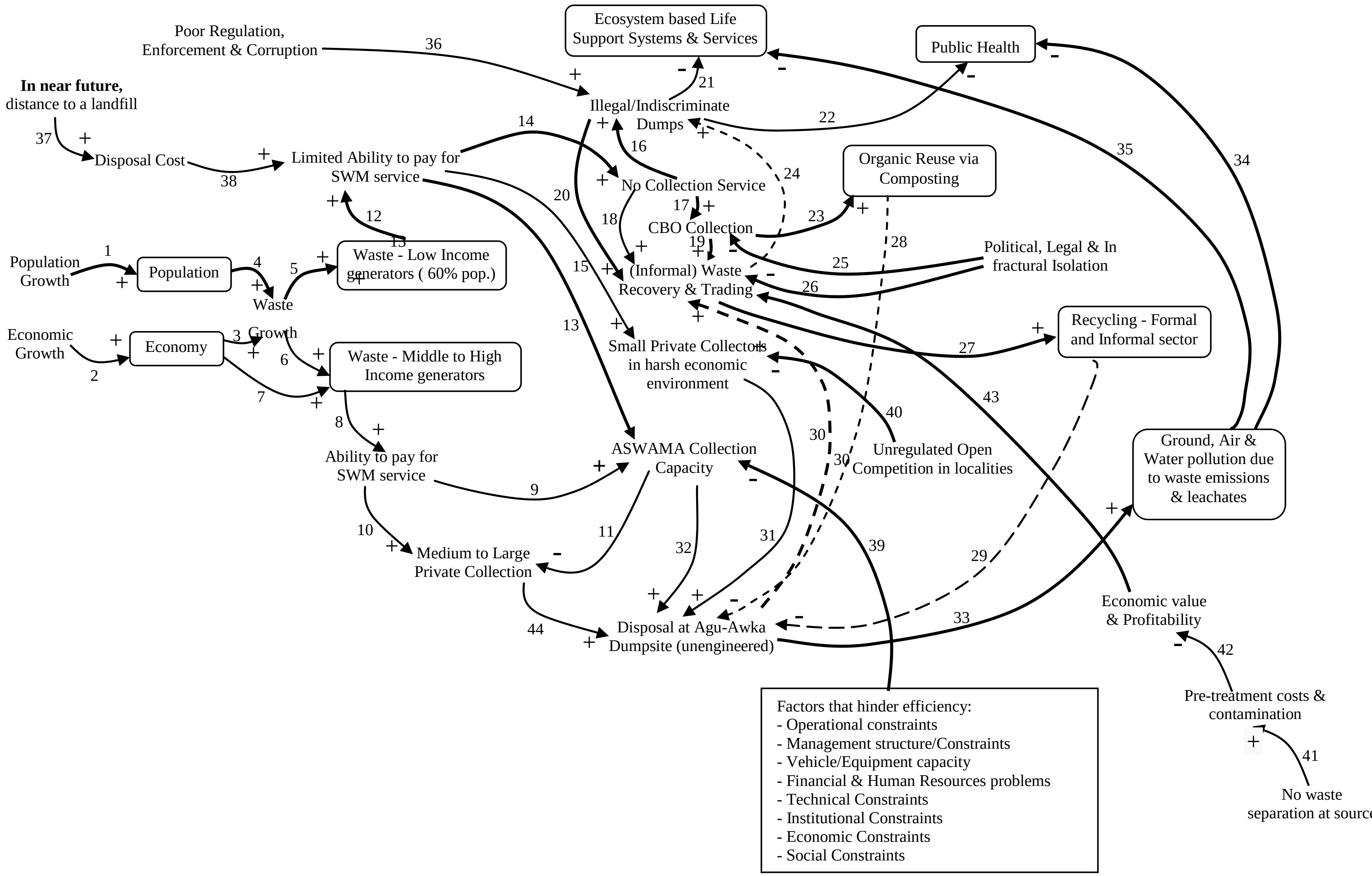


Figure 18: A Causal Loop Diagram showing the solid waste management system currently in place in Awka

cial growths prevalent in the city at the time (loops 3 & 4).

In Awka, the waste generated generally falls into two broad categories, that from low income and informal settlement areas (loop 5), and that from middle to high income areas and whose residents comprise the remainder (loops 6). A third general category of generators not explicitly shown in the diagram but one that behaves similarly to the two already mentioned is Commerce/Business and general non-domestic waste generators, with smaller enterprises, kiosks etc synonymous with lower income owners and larger establishments associated with more affluent ownership.

Low income residents by nature only have a limited ability to pay for Solid Waste Management (SWM) Services, while middle to higher income residents on the other hand are better able to pay for these services (loops 8 & 12). In Anambra State, the general total waste collection service by ASWAMA has been consistently declining due to various factors including declining resourcing and facilitation from central government leading to internal operational constraints; inefficiencies in management structure; under-billing for collection service; inefficiencies in human resourcing as well as in revenue collection and other issues (loop 39). If more of the residents of Awka are willing, ready and pay their waste service charges (loop 9), ASWAMA is empowered to collect the waste generated in the area; else, ASWAMA and other waste managers are constrained to give an efficient and effective service to the people (loop 13). General direct service charge collections by ASWAMA have always been criticized and protested against by traders and allied workers. Also poor performance by ASWAMA, and politicking with the agency, coupled with the factors mentioned above have severely crippled the ASWAMA's ability to effectively meet the city's collection and disposal needs while meeting own operational costs over time. Loops 39 and 13 may be argued to be the most dominant causes for the ASWAMA's declining performance. Several previous studies have comprehensively investigated and noted the various causes of ASWAMA's declining capacity to range from corruption to poor management. The general resulting consensus however, reaching its culmination in the recommendations of the UN-Habitat and the US EPA, is the involvement of private sector in SWM services in the state. This has led to the rapid emergence of various private waste collectors in the city (loop 10 and more recently loop 15). The limited ability of residents of the state especially in the lower income areas to pay for SWM services however has to date been largely unattractive to the medium and to the large, more established, private collectors, and over the years these areas have remained under serviced due to low ASWAMA collection ability/capacity and low medium-to-large private collector interest (loop 14). This lack of service delivery in low income areas led to the emergence of Community Based Organizations (CBOs) in the form of Market Groups and general Self Help Organisations involving community members in the cleanup of their communities (loop 17). While many were initially formed for the major purpose of keeping neighborhoods clean, income generation was needed to sustain these activities. As a result a number of these are increasingly simultaneously involved in the active collection, sorting, recovery, and sale of recyclables to waste dealers and to larger scale recyclers in what is currently a largely informal industry (loop 19, Figure 18). On cleaning up of neighborhoods, residual waste collected by the groups are ideally either taken to designated ASWAMA communal waste collection points or left at the side of the roads for further transport to final disposal sites, complaints abound however of irregular ongoing waste collection by ASWAMA.

4.1.3.1 Observations in the study

Specific factors identified as being responsible for the failure of the various waste management boards formed in Anambra State in particular, and Nigeria in general, to perform their expected basic function include:

1. Absence of adequate technology for proper waste management
2. Inadequate policy making and poor implementation of existing Government policies
3. Absence of enabling legislation
4. Corruption
5. Poor public enlightenment programmes on the needs for proper waste management. Public enlightenment programmes lacked the coverage, intensity and continuity required to correct the apathetic attitude which the public has toward the environment.
6. Abandonment/Lack of continuity in policy implementation by new administrations. State elections which usually call for change of administration in the state every four/eight years lead to a tendency for the previous policies to be either turned upside down, totally abandoned or attempts made to thwart efforts to arrive at sustainable, long term solutions.
7. Poor funding, poor data management inadequate taxation, and lack of human resources.

At the various dumpsites, it was observed among others things that:

8. The various servers (disposal trucks) were assigned specific areas (Zones) to ply in a day, but the routing was left at the discretion of the drivers and their co-workers (the labourers). This practice is uneconomical as these drivers travel about the city seeking for waste at dumpsites to collect - both time and some order resources are wasted in the process. ASWAMA management should device a means of determining the states of the waste at various dumpsites in the state in any day and use such knowledge in scheduling work (routing) for its waste disposal truck drivers.
9. In some days, waste at different roadside dumpsites were partially evacuated (i.e. only a small fraction of the large heap of waste that accumulated at such stations were collected and disposed) by the waste disposal trucks.
10. Inter-service time of many of the waste dumpsites varied from zero to one or more times per day or less than seven times in a week. The latter case usually led to chaotic (over accumulation and illegal dumping) situations with their attend ant problems. The waste generation lead time at every waste dump station should be scientifically deter-mined as to enable the waste manager fix the evacuation lead time for such a location.
11. One or more of the disposal trucks never visited any of the bin stations in a number of days; instead they routed the town collecting waste directly from the generation sources (homes, offices etc) for some token fees. This was one of the reasons why high volumes of waste accumulated in the said dumpsites.
12. There is no modern landfill constructed in the state, only open dumpsites exist and no ground-water protection, leachate recovery, or waste treatment systems.
13. Reduction and recycling of waste for profitability are not yet part of the state's management policy.
14. There is no urban/municipal composting program in any of the urban centers of the state, and anaerobic digestion to produce methane is not applied either.
15. While waste recovery and reuse of materials is generally for personal use, there are also many professional waste pickers. These waste pickers (including little children and women) are seriously threatened by disease organisms, sharp objects and other hazards in the waste, especially since they generally lack protective equipment.
16. There is no clear cut state policy on sanitation and environmental education in the state is very poor as observed during the field investigation. The only envi ronmental education programme known to the state is the clean-up exercise fixed for every last Saturday of every month. Many of the residents of Awka (mostly the youths) never

participated in the programme, instead they used the period (6.00 a.m to 10.00 a.m) to play football, sleep, attend to personal needs, etc.

17. Furthermore, some of the waste management staff were poorly trained and no plan in the future to give them further training or to improve already acquired skill.

4.1.4 Investigation into the capabilities of ASWAMA

Capabilities of the Anambra State Waste Management Authority in delivering its primary duty to the state were also investigated using both SWOT and causal loop analyses. The results are shown in **Table 6** and Figure 19 respectively.

4.1.4.1 A conduct of SWOT analysis on ASWAMA

The Anambra State Waste Management Authority is a legal entity formed by the state government. The SWOT analysis made on the organization is contained in **Table 6**.

Table 6: Performed SWOT analysis on ASWAMA

STRENGTHS	**WEAKNESSES**
Established and backed by law Has day-to-day direct contact with waste producers Charges some token over waste producers Receives annual subvention from government Awareness raising potential Availability over a range of vehicles	Political influence Capacity gaps and shortfalls Priority conflict Implementation of imposed policies (the effects are pronounced) Performance level still low Creation of public awareness campaign still very low Partial or no understanding of real own emissions and external costs No proper method for measuring actual quantities of waste generated/evacuated No practice of 3R principle.
OPPORTUNITIES	THREATS
Funding schemes (state govt., EU, private sector, etc) Public Private Partnership (anids) Clustering/grouping PAYT "mix"	PAYT failure, leading to increased littering Existence of private waste managing contractors High costs of collection and disposal Lack of recycling plants No means of lychete recovery Global warming Fire outbreak at dump sites Outbreak of a disease(s)

4.1.4.2 Causal loop analysis of ASWAMA and private waste managers' capabilities in solid waste management of Anambra State

From the causal loop shown in Figure 19, it could be seen that when ASWAMA receives its budgetary allocation from the state government, it is empowered and motivated to go into waste collection and disposal activities that should be commensurate with the available resources. This calls for continuously monitoring and evaluating the performance of ASWAMA by the state government. Therefore, before the state government gives the next budgetary allocation to ASWAMA, it should ensure that the previous allocation was judiciously utilized at maximum benefits.

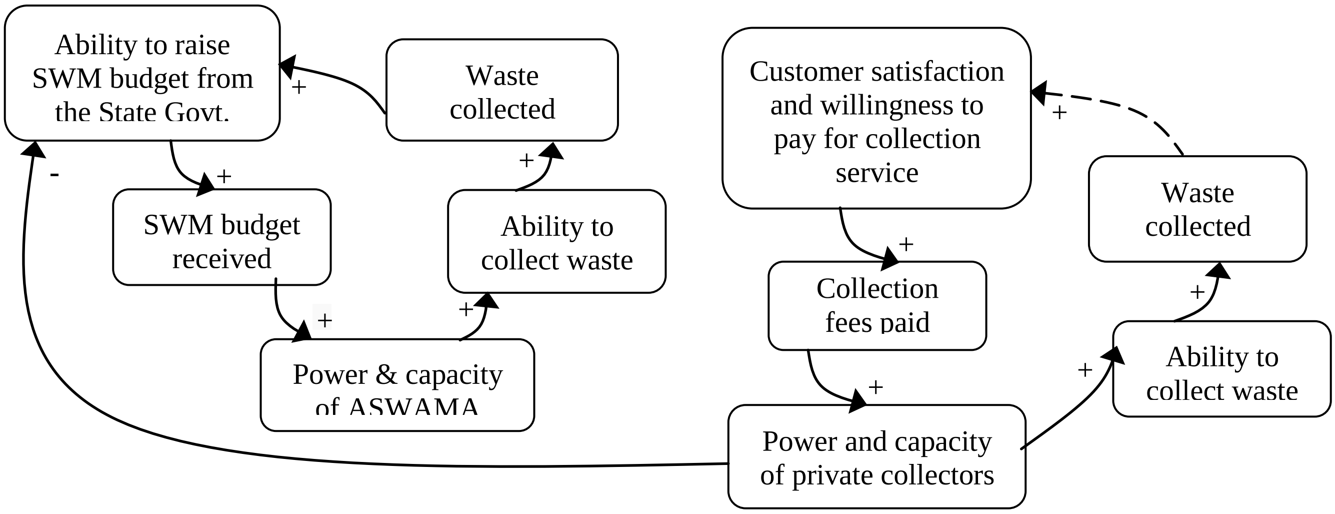


Figure 19: A causal loop diagram showing the requirements/processes that improves the capabilities of waste managers in Anambra State [Adapted from Kasozi and Blottnitz, 2010]

On the part of private waste collectors, when the customers pay for waste collection services they expect quality and effective service to be delivered. When they are satisfied with the previous services, they will be willing to pay for the next collection services. Anambra State government does not consider or give budgetary allocation to private waste collectors as such, when their customers make payments for disposal of their waste, the private collectors are further encouraged and motivated to render the services within the limits of the available resources.

The foregoing analyses show the need for the waste management system in Anambra State to be continuously monitored, evaluated and adequately sponsored for sustainability and continuous improvement.

4.1.5 Factors constraining development of effective SWM system

Many factors constrain the development of effective solid waste management system in various countries round the globe, especially in developing countries, leading to some public health, environmental and management problems. A typical solid waste management system in a developing country displays an array of such problems as low collection coverage and irregular collection services, crude open dumping and burning without air and water control, the breeding of flies and vermin, and the handling and control of informal waste picking and scavenging activities(Hisashi, 2012). Hisashi also broadly categorized and discussed these constraining factors as follows:

(a) Technical constraints

In most developing countries, there is typically a lack of human resources at both the national and local levels with technical expertise necessary for solid waste management planning and operation. Many officers in charge of solid waste management, particularly at the local level, have little or no technical background or training in engineering or management. Without adequately trained personnel, a project initiated by external consultants could not be continued. Therefore, the development of human resources in the recipient country of external support is essential for the sustainability of the collaborative project.

Another technical constraint in developing countries is the lack of overall plans for solid waste management at the local and national levels. As a result, a solid waste technology is often selected without due consideration to its appropriateness in the overall solid waste management system. In some cases, foreign assistance is given to a component of a solid waste management system for which the use of resources may not be most cost-effective. For instance, an external support agency provided its support to improve a general disposal site.

However, the coverage of solid waste collection service is so low that solid waste generated is dumped at many undesignated sites (e.g., open areas, water channels, streets, etc.). As a result, improving the disposal site, although it may not be a bad project, would have little impact on the overall solid waste management effectiveness. In such a case, the low collection coverage is a bottleneck in the overall solid waste management system in the city, and it would be most cost-effective to provide resources to upgrade the collection service.

Research and development activities in solid waste management are often a low priority in developing countries. The lack of research and development activities in developing countries leads to the selection of inappropriate technology in terms of the local climatic and physical conditions, financial and human resource capabilities, and social or cultural acceptability. As a result, the technology selected can never be used, wasting the resources spent and making the project unsustainable. Several guides/manuals on appropriate solid waste management technologies in developing countries are available in the literature, and the selection of technology could be made sometimes based on these guides/manuals. However, in most cases, these guides/manuals must be modified to the local conditions prevailing in the country, and therefore local studies are normally still needed. Such studies can be relatively easily incorporated into a collaborative project and, to the extent possible, should involve local research institutions.

(b) Financial constraints

In general, solid waste management is given a very low priority in developing countries, except perhaps in capital and large cities. As a result, very limited funds are provided to the solid waste management sector by the governments, and the levels of services required for protection of public health and the environment are not attained.

The problem is acute at the local government level where the local taxation system is inadequately developed and, therefore, the financial basis for public services, including solid waste management, is weak. This weak financial basis of local governments can be supplemented by the collection of user service charges.

However, users' ability to pay for the services is very limited in poorer developing countries, and their willingness to pay for the services which are irregular and ineffective is not high either. An effective strategy for raising funds needs to be searched in any collaborative project to ensure its sustainability.

In addition to the limited funds, many local governments in developing countries lack good financial management and planning. For instance, in a town in a developing country, over 90% of the annual budget provided for solid waste management was used up within the first six months. The lack of financial management and planning, particularly cost accounting, depletes the limited resources available for the sector even more quickly, and causes the solid waste management services to halt for some periods, thus losing the trust of service users.

(c) Institutional constraints

Several agencies at the national level are usually involved at least partially in solid waste management. However, there are often no clear roles/functions of the various national agencies defined in relation to solid waste management and also no single agency or committee designated to coordinate their projects and activities. The lack of coordination among the relevant agencies often results in different agencies becoming the national counterpart to different external support agencies for different solid waste management collaborative projects without being aware of what other national agencies are doing. This leads to duplication of efforts, wasting of resources, and unsustainability of overall solid waste management programmes.

The lack of effective legislation for solid waste management, which is a norm in most developing countries, is partially responsible for the roles/functions of the relevant national agencies not being clearly defined and the lack of coordination among them. Legislation related to solid waste management in developing countries is usually fragmented, and several laws (e.g., Public Health Act, Local Government Act, Environmental Protection Act, etc.) include some clauses on rules/regulations regarding solid waste management. The rules and regulations are enforced by the different agencies. However, there are often duplication of responsibilities of the agencies involved and gaps/missing elements in the regulatory provisions for the development of effective solid waste management systems. It should be also noted that legislation is only effective if it is enforced. Therefore, comprehensive legislation, which avoids the duplication of responsibilities, fills in the gaps of important regulatory functions, and is enforceable is required for sustainable development of solid waste management systems. Because of a low priority given to the sector, the institutional capacity of local government agencies involved in solid waste management is generally weak, particularly in small cities and towns. Local ordinance/by-laws on solid waste management is not also well developed. These weak local government institutions are not provided with clear mandates and sufficient resources to fulfill the mandates. In large metropolitan areas where there are more than one local government, coordination among the local governments is critical to achieve the most cost-effective alternatives for solid waste management in the area. For instance, the siting of a solid waste transfer station or disposal facility for use by more than one local governments is cost-effective due to its economy of scale. However, as these facilities are usually considered unwanted installations and create not-in-my-backyard (NIMBY) syndromes among the residents, no local government is willing to locate them within its boundary. The lack of a coordinating body among the local governments often leads to disintegrated and unsustainable programmes for solid waste management.

(d) Economic constraints

Economic and industrial development play key roles in solid waste management. Obviously, an enhanced economy enables more funds to be allocated for solid waste management, providing a more sustainable financial basis. However, by definition, developing countries have weak economic bases and, hence, insufficient funds for sustainable development of solid waste management systems.

Local industry which produces relatively inexpensive solid waste equipment and vehicles will reduce, or in some cases could eliminate totally, the need for importing expensive foreign equipment/vehicles and therefore foreign exchange. Such local industry can also supply associated spare parts, lack of which is often responsible for irregular and insufficient solid waste collection and disposal services. However, the lack of industry manufacturing solid waste equipment and spare parts and a limited foreign exchange for importing such equipment/spare parts are the rule rather than exception in developing countries.

Also, in small developing countries, waste recycling activities are affected by the availability of industry to receive and process recycled materials. For instance, the recycling of waste paper is possible only when there is a paper mill within a distance for which the transportation of waste paper is economical. The weak industry base for recycling activities is a common constraint for the improvement of solid waste management in developing countries, such as those in the Pacific region where a large volume of package waste is generated.

(e) Social Constraints

The social status of solid waste management workers is generally low in both developed and developing countries, but more so in developing countries then developed countries. This owes much to a negative perception of people regarding the work which involves the handling of waste or unwanted material. Such people's perception leads to the disrespect for the work and in turn produces low working ethics of laborers and poor quality of their work.

Because of insufficient resources available in the government sector, collaborative projects often have attempted to mobilize community resources and develop community self-help activities. Results are a mixture of success and failures. Failed projects with inactive communities usually did not provide people in the community with economic as well as social incentives to participate in activities. The social incentive is based on the responsibility of individuals as part of the community for the improvement of the community, and is created by public awareness and school education programmes. The lack of public awareness and school education about the importance of proper solid waste management for health and well-being of people severely restricts the use of community-based approaches in developing countries.

At dump sites, transfer stations, and street refuse bins, waste picking or scavenging activities are common scenes in developing countries. People involved have not received school education and vocational training to obtain knowledge and skills required for other jobs. They are also affected by limited employment opportunity available in the formal sector. The existence of waste pickers/scavengers creates often an obstacle to the operation of solid waste collection and disposal services. However, if organized properly, their activities can be effectively incorporated into a waste recycling system. Such an opportunistic approach is required for sustainable development of solid waste management programmes in developing countries.

4.1.5.1 Constraints of external support

External support provided to solid waste management in developing countries has its own limitations and constraints. As constraints in developing countries, they can be divided into technical, financial, institutional, economic, and social constraints and are discussed below.

(a) Technical Constraints

Industrialized countries, which provide external support to developing countries, usually have technical expertise and human resources suitable for solid waste management in these countries. Their school and university education and subsequent on-the-job training are targeted for the technologies of solid waste management applicable to these countries.

However, there is the lack of human resources with sufficient experiences and knowledge of solid waste management in developing countries. Opportunities to learn solid waste management problems and practices in developing countries through regular training programmes and seminars are rarely provided in industrialized countries.

The lack of knowledge and experience in solid waste management situations in developing countries leads to a tendency to support and provide the technologies available in the donor country regardless of their applicability to the developing country situation. In some cases, the solid waste management equipment and facilities, which are obsolete and outdated in the donor country, are provided as foreign aid to the recipient country.

Communication between consultants provided by the external support agency and the local counterpart in the developing country sometimes becomes a constraint in implementing an effective collaborative project. The communication difficulty occurs in two different situations: (i) no common spoken language exists between the external consultants and the local counterpart; and (ii) the local counterpart does not understand technical terms. Efforts by both sides to improve communication ability are being made in a number of countries.

As mentioned earlier, the lack of an overall plan for solid waste management leads to a solid waste management system which is not cost-effective. It also encourages a piece-meal approach by the external support agency. Referring to the earlier example of support for improvement of a disposal site, it can be easily seen that the external support agency made the decision to support without sufficient consideration to other components of solid waste management. Piecemeal, or not comprehensive approaches taken by external support agencies, often result in unsustainable solid waste management projects.

(b) Financial Constraints

Obviously, all donor agencies have their own upper limits to financial support. Solid waste management is one of many sectors for which an external agency provides its resources. For some donor agencies, solid waste management may not be a priority sector for support. As a result, there is a finite (and often limited) amount of funds that can be allocated to the sector.

Because of its inherent nature, solid waste management does not render itself to an operation which can easily generate revenues. This is particularly true in developing countries where the willingness and ability to pay for solid waste management services are low. For external lending agencies, this means that the risk of providing a loan to such a project is generally high. The high risk of loan projects can be lessened by building into the projects revenue raising systems (e.g., user charges, sales of recycled materials).

(c) Institutional Constraints

External support agencies have their own organizational mandates and structure that limit their activities to certain operations such technical cooperation, loan/lending of capital funds, training, and so on. Even in the same donor country, there are usually different external support agencies, each specializing in one area of support. The extent of their geographical coverage is also limited to certain countries for their support. These organizational mandates and operational coverage of external support agencies determine the levels and types of resources provided to solid waste management projects in developing countries. As mentioned earlier, in many cases their support is piece-meal and not comprehensive as individual projects to be effective in introducing substantial and lasting impacts on solid waste management in the recipient countries. There is also lack of coordination among the various external support agencies to complement each other's efforts, although it is gradually improving recently. With better coordination and communication among them, the sustainability of solid waste management projects in recipient countries will be improved.

(d) Economic Constraints

The economic situation of the donor is a determinant to the amount of funds that can be allocated for foreign aid to developing countries. Thus, it influences the levels of resources provided to solid waste collaborative projects. However, the economic situation of one donor country is not so critical for the sustainability of solid waste management projects in developing countries.

External support agencies in industrialized countries tend to promote solid waste management technologies developed in their countries and use consultants from their countries. It is understood and often accepted that there is a bias in the selection of equipment, facilities, and consultants for solid waste management collaborative projects. As mentioned earlier, the provision of solid waste equipment was done from the point of view of the donor agency, instead of the need of the recipient country. For instance, two large compactor trucks of 8-tonne capacity each were provided to the capital town of a small island country where an estimated 7 tonnes per day of solid waste was generated and there were many narrow streets. In another developing country where solid waste is wet and has a low calorific value, the construction of an incinerator was recommended by a group of consultants from a developed country where incineration is very common. Often, the appropriateness of a technology to be used in a developing country is not fully assessed, and the technology is adopted based on the norm and experience of the donor country.

(e) *Social Constraints*

In any country, developed or developing, there are social or cultural norms accepted only by the society. Such norms affect designs of solid waste management systems. Where the society allows only a certain social class or group to deal with solid waste, the availability of work force for solid waste collection and disposal becomes constrained by this rule. In some countries, directly handling human waste is a traditional taboo, which then prohibits the application of co-composting of refuse and human waste. The lack of understanding of local cultures and ways of life by the external support agency is often a cause of failure of a collaborative project.

Communication difficulty was cited as a constraint earlier. In addition to the language-related communication problem, the lack of decent attitude and experience of external consultants in working with officials of developing countries results in unnecessary tension between the consultants and local counterpart.

4.1.5.2 Factors militating against effective SWM system in Nigeria

Many factors have been identified as the constraints in developing an effective solid waste management system in Nigeria. Ezigbo(2012) identified some of the factors as high rate of growth in urban population coupled with increased commercial and industrial activities which result to phenomenal increase in the volume and diversity of solid waste being generated; lack of adequate physical planning, functional drainage system, proper housing condition, and environmental pollution which result from high industrial activities; poorly planned road network and lack of adequate parking space resulting in perpetual traffic congestion. Adeshina(2000) added to these factors, inadequate public toilets and sewage systems.

In their findings, Chukwuemeka *et al*(2012) reported that the resources normally voted by government annually for managing was very small and there was no adequate environmental education; that some of the waste management staff were poorly trained with no plan in future to give them further training or to improve their already acquired skills. They also saw non-participation of local communities in SWM and non-inclusion of detailed topics on SWM in primary, secondary and tertiary institutions as constituting part of the problems. Ogwueleka(2009), in his own report pointed at inefficient collection methods, insufficient coverage of the SWM collection system, improper disposal of solid wastes, lack of institutional arrangement, insufficient financial resources, absence of by-laws and standards on SWM, inflexible work schedules, insufficient information on quantity and composition of waste and inappropriate technology as being the major causes of poor solid waste management in Nigeria.

Meanwhile, Olorunfemi and Odiata(1998) also reported that lack of data on solid wastes in Nigeria, which is at all levels (from wards, through the local government areas/districts/urban centres, the state to the federal) has remained the most conspicuous and probably, the most important problem militating against the successful and effective management of solid wastes by their respective waste management authorities. Even where such data exist, they are generally unreliable, scattered and unorganized(World Bank, 2003). The above mentioned constraints have been summarized and categorized into six major groups as represented in the Fishbone diagram of Figure 20.

Fishikawa Diagram

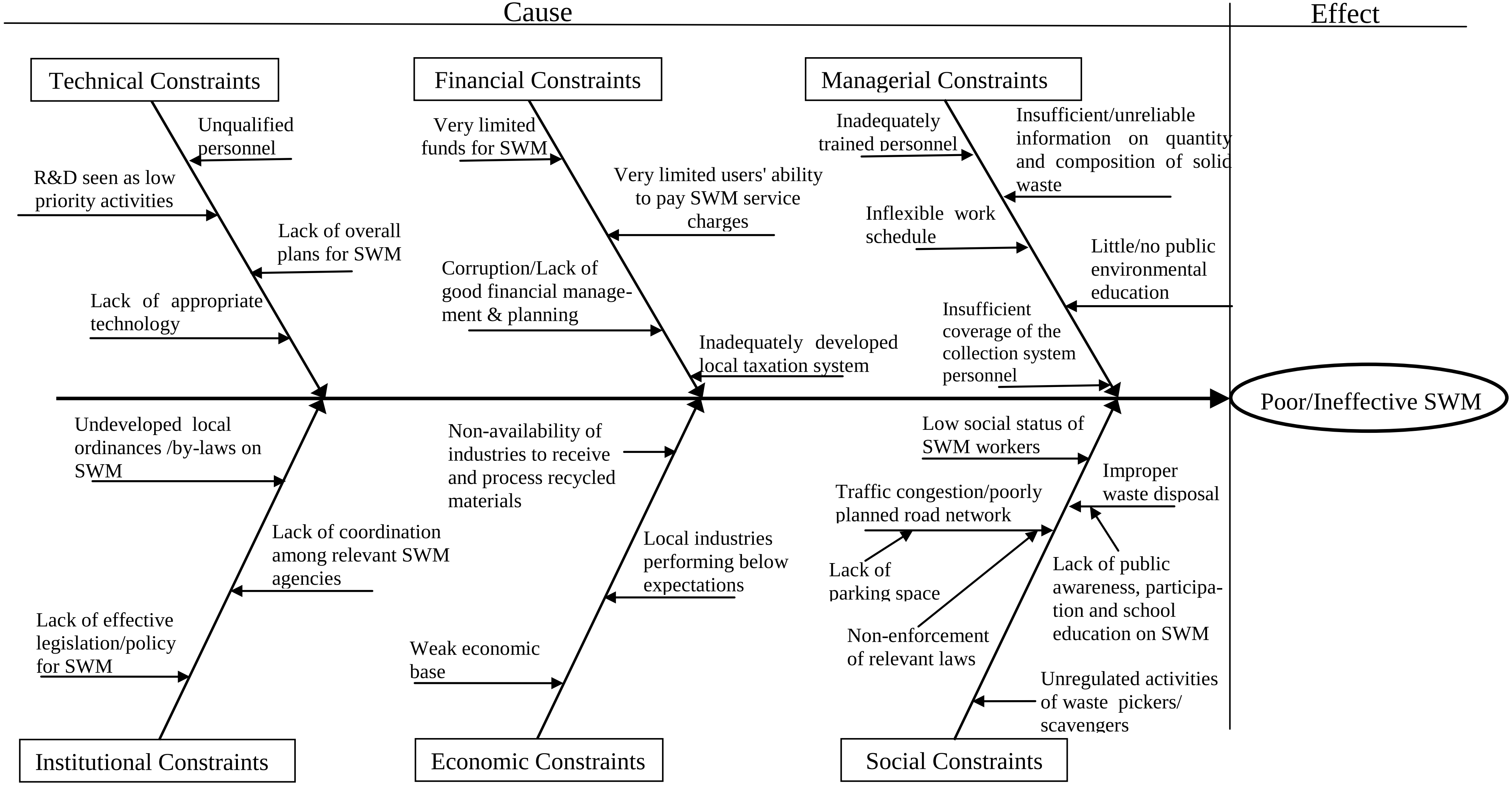


Figure 20: Causes of poor/ineffective solid waste management

4.2 Quantitative Data Presentation and Discussions

Quantitative data are very important in operations research and systems analysis. They form the bases for determining the size of a product, the possible outcome of an event(s), making of economic considerations and used as tools in most management decision making processes.

4.2.1 Statistical modeling of ASWAMA performance constraints

Responses given by ASWAMA workers to the questionnaire shared to them show that the major factors which cause poor or ineffective and inefficient solid waste management in Anambra State can be summarized in six folds:

1. The overhead costs of managing solid waste in an effective, efficient and sustainable manner is high;
2. Nonexistence of proper method for data management of the waste produced in the state.
3. Standard tools for evaluating past performances, scheduling for waste evacuation, and forecasting future productions of these waste so as to enable proactive management measures to be taken are lacking.
4. inability (or lack of means) to acquire the needed technology to convert the generated waste into wealth.
5. No clear cut policy on solid waste management exist in the state
6. Other factors such as absence of waste reprocessing/recycling plants, poorly planned road network resulting in perpetual traffic congestion, lack of adequate physical planning, functional drainage systems, proper housing condition, high industrial activities, et cetera.

Table 7 depicts the various classes of ASWAMA staff to whom the questionnaire were shared. Out of the 200 copies of the questionnaire distributed, only 135 were filled and returned.

Table 7: Responses to questionnaire distributed to ASWAMA staff
[Source: Field survey]

Category By Rank	Estimated Size of Population	Number Of Questionnaires Issued	Number Of Questionnaires Filled & Returned	No. Of Years Of Work Experience		
				Below 3 Yrs	3 – 6 Yrs	Above 6 Yrs
TLM	19	19	10	0	2	8
LLM	38	38	22	0	10	12
OSC	143	143	103	39	30	34
Total:	200	200	135	39	42	54

Now, having presented the above data, what is left for one to do next is to check if the sample size of 135 workers is scientifically acceptable to represent the target population of 200 solid waste workers. To verify the acceptability of our sample size, we employ the use of Yaro Yamen's formula, eqn (*xlv*) of the Appendices. If after calculating the sample size from this formula and the value obtained is less than or equal to the sample size of 135 workers in **Table 7**, the sample size of 135 workers will be accepted; otherwise, it is rejected. Having taken this decision, we substitute the following values into eqn (*xlv*) of the Appendices: N = 200 (estimated population), e = 5% (say), and obtained $\boldsymbol{n}$ (the sample size) = 133 workers (say)

Since the sample size (133 workers) obtained from using the Yaro Yamen's formula is less than the 135 workers obtained in **Table 7**, the 135 workers, therefore, is scientifically acceptable as our sample size.

On the question, "What are the reasons for ASWAMA's inefficient solid waste management in the state?" that led to the responses in **Table 8**, the workers were given the privilege of marking as many of the options as they considered appropriate, however, none should be repeated (marked or selected more than once). After collation, with little statistics, it was discovered that a total of 219 (43.75%) of the respondents considered insufficient funding as the major reason why ASWAMA was performing below expectation. 106 respondents (21.25%) indicated that standard tools for evaluating past performances, scheduling for waste evacuation, and for forecasting future productions of the waste so as to enable proactive management measures to be taken was the main cause; whereas 56 (11.25%) of the respondents claimed that inability (or lack of means) to acquire the needed technology to convert the generated waste into wealth was the major cause of their inability to perform as expected. 44 (21.28%) respondents said that the major cause was non-existence of proper method for data management of the waste produced in the state; In their own opinion, 31 respondents (about 6.25%) insisted that the major cause of their poor performance was non-existence of clear-cut policy on solid waste management in the state; whereas 19 respondents (about 3.75%) pointed at corruption as the major cause of the problem in question; and 25 respondents (about 5.00%) were convinced that some other reasons not included in the options could be among the major causes.

These information are shown in **Table 8** and Figure 21.

Table 8: Respondents' views on the causes of ASWAMA's poor solid waste management practices

Enquiry Index	No. of Respondents	Percentage Representation
Insufficient funding	219	43.75
Non-availability of vital tools	106	21.25
Lack of modern technology	56	11.25
Poor data management	44	8.75
No clear-cut policy on SWM	31	6.25
Corruption	19	3.75
Others factors	25	5.00
Total =	**501**	**100.00%**

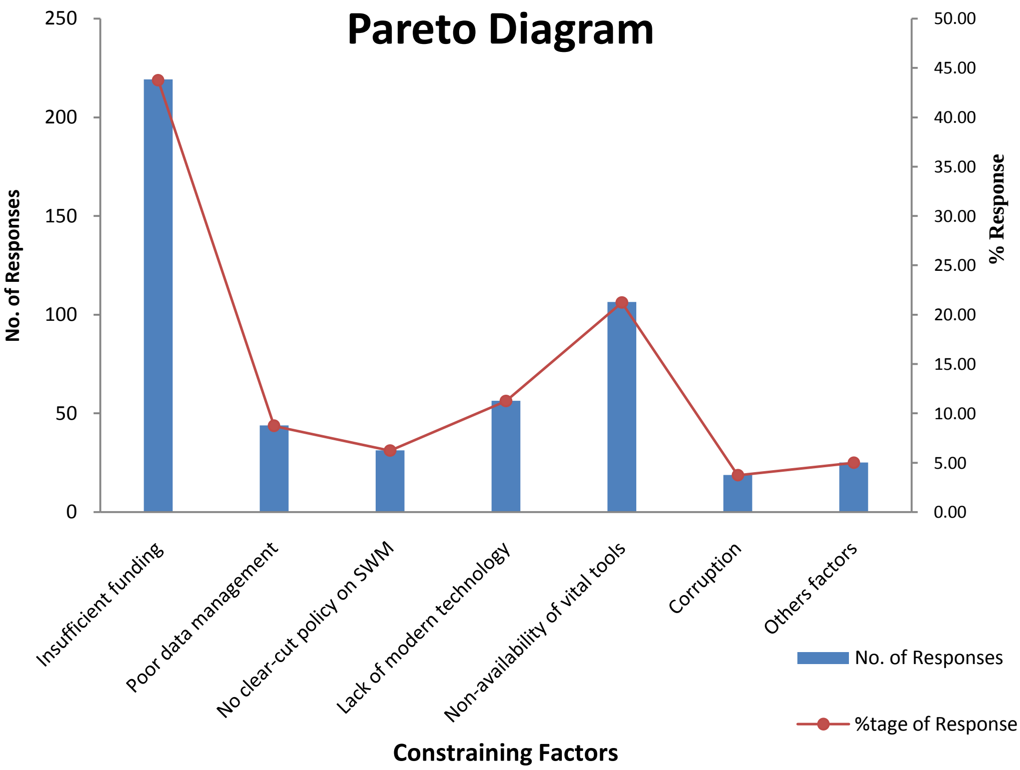


Figure 21: Waste management workers' views on the causes of ASWAMA's poor performances [Source: Field survey]

4.2.2 Application of Pareto 80:20 rule

From the foregoing detailed discussions, it can be seen that many factors militate against ASWAMA's performances in the state. However, existence of the Pareto law reminds us that among these lot there are still few critical ones. As such, the Pareto (80:20) Principle is used in this section to identify these most nagging few among the many number of causes (constraints). The analysis is done in **Table 9** and depicted in Figure 22.

Table 9: Respondents' views on the causes of poor solid waste management system in Anambra State

Enquiry Index	No. of Responses	% Responses	Cumulative No. of Responses	Cumulative %
Insufficient funding	219	43.75	219	43.75
Non-availability of vital tools	106	21.25	325	65.00
Lack of modern technology	56	11.25	382	76.25
Poor data management	44	8.75	426	85.00
No clear-cut policy on SWM	31	6.25	457	91.25
Corruption	19	3.75	476	95.00
Other factors	25	5.00	501	100.00

Table 9 and Figure 22 clearly show that inadequate funding constitutes nearly 44% of the reasons why ASWAMA is performing below expectation in its SWM service delivery; while poor data management assumes about 8.75% of the causes. By implication of the results obtained from the analysis, therefore, adequate provision of fund, necessary tools and equipment, modern technology and proper data (information) management will eliminate about 85% of the factors causing the low productivity/performance in ASWAMA. The results also suggest that poor data management (or lack of data) is not "... the most conspicuous and probably, the most important problem militating against the successful and effective management of solid wastes by..." ASWAMA as identified by Olorunfemi and Odiata (1998).

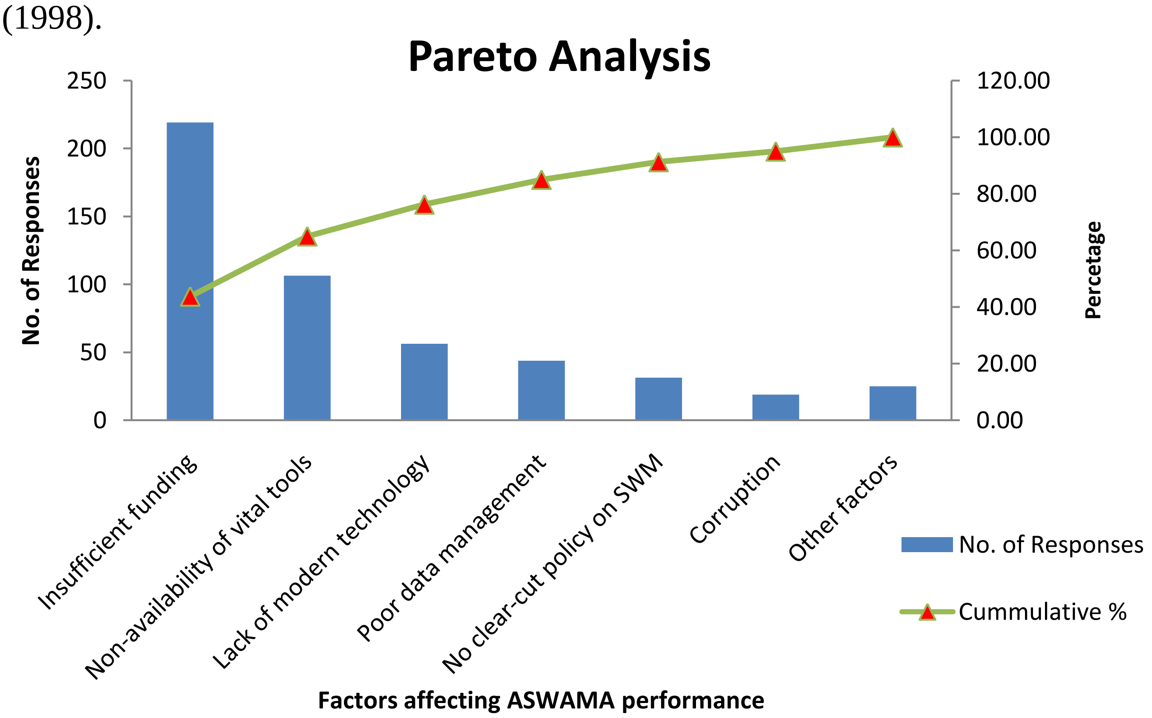


Figure 22: Result of the Pareto analysis

4.2.3 Population of each local government area in Anambra State

The final results of 1991 and 2006 population censuses of Nigeria released by the National Population Commission shows that the population of each L.G.A. in Anambra State had a total number of people resident in it as depicted in **Table N** of the appended tables. A careful look at the values in this latter table reveals that between 1991 and 2006, the population of Anambra State grew by 1.5128%), with a projection factor of approximately, 1.1542% for the years 1992 to 1996. It is worthy to state that the 2006 census conducted in the state was seriously marred by irregularities and activities of the members of MASSOB; especially in Onitsha and its environs. Consequently, many of the residents did not participate in the exercise. Nevertheless, NPC, Anambra State, has directed that a growth rate factor of ***3.2%*** be used for projecting the future population of the state from the 2006 population census.

4.2.4 Summary of Awka roadside dumpsite agents report and discussion

The Street Dumpsite Agents reports showed that a total of ***42956*** chain-up bin loads and ***120339*** compactor bin loads (≡ ***24068*** chain-up bin loads) of solid waste were dumped at the monitored sites in Awka within the period of the study. A summary of the agents' reports is shown in **Table J** and the graph plotted in Figure 23. From both the data in the table and plot of Figure 23 it is easily seen that the highest number of bin loads of solid waste was generated (dumped) at the roadside dumpsites in the 36th month (December 2014) of study period; whereas ASWAMA made its highest transfer function (evacuation) of the waste in the 32nd month (October 2014). It is also vividly seen that both waste generation and disposal operations kept fluctuating (varying) from month to month, which proves these waste management processes to be stochastic.

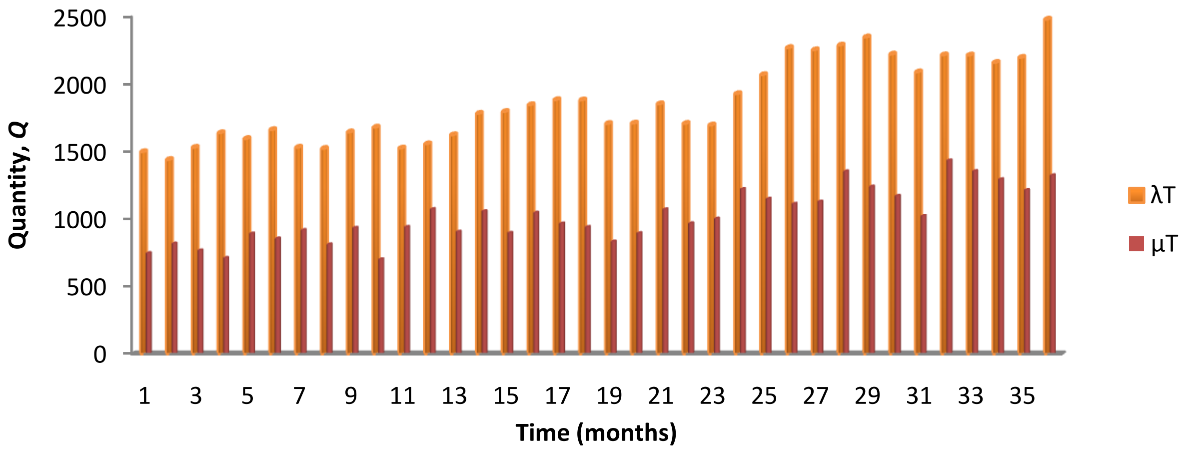


Figure 23: Approximate quantities of solid waste generated in and the quantities evacuated from Awka metropolitan city within the 36-months study period

Table 10: Approximate quantities of monthly solid waste generation rate and evacuation rate in twelve zones of Awka metropolis from Jan. 1, 2012 - Dec. 31, 2014

Year	Month	Mnt_ Code	Amawbia		Zik's Ave.		Amaikwo		Amaenyi/ Amaku		Udoka Estate		Nibo/ Umuawulu		Iyiagu Estate		Okpuno		Enugu-Onitsha Express Way		Emma Nnaemeka Axis		Ifite		Govt. House		Monthly Totals	
			λ_1	μ_1	λ_2	μ_2	λ_3	μ_3	λ_4	μ_4	λ_5	μ_5	λ_6	μ_6	λ_7	μ_7	λ_8	μ_8	λ_9	μ_9	λ_{10}	μ_{10}	λ_{11}	μ_{11}	λ_{12}	μ_{12}	λ_T	μ_T
2012	Jan	1	119.2	59	210.6	105	134.2	67	133.0	66	133.6	67	117.9	59	93.0	46	120.4	60	84.0	42	74.6	37	144.4	72	132.9	66	***1497.8***	***746***
	Feb	2	123.9	70	189.0	107	126.5	72	114.9	65	131.3	75	110.5	63	103.1	58	112.8	64	87.9	50	80.3	46	132.3	75	126.8	72	***1439.3***	***817***
	Mar	3	112.2	56	208.4	104	138.5	69	144.0	72	137.4	69	96.9	48	94.7	47	133.7	67	101.6	51	72.1	36	148.7	74	142.0	71	***1530.1***	***766***
	Apr	4	136.6	59	237.0	103	141.0	61	119.6	52	151.0	65	128.9	56	114.8	50	130.2	56	107.1	46	78.3	34	143.5	62	149.9	65	***1637.9***	***710***
	May	5	117.4	66	206.4	115	144.2	81	156.9	88	143.1	80	111.5	62	109.6	61	136.4	76	92.3	52	92.7	52	153.3	86	131.3	73	***1594.8***	***891***
	Jun	6	145.5	75	241.3	124	152.1	78	143.8	74	118.8	61	118.3	61	86.9	45	139.5	72	115.9	60	91.0	47	143.0	74	164.8	85	***1660.9***	***855***
	Jul	7	116.8	70	210.3	126	140.2	84	128.5	77	151.8	91	105.1	63	93.5	56	128.5	77	93.5	56	70.1	42	140.2	84	151.8	91	***1530.3***	***917***
	Aug	8	142.8	76	214.4	114	116.7	62	136.1	73	135.8	72	107.0	57	104.7	56	121.1	65	99.8	53	68.3	36	142.4	76	132.7	71	***1521.9***	***811***
	Sep	9	118.6	67	229.5	130	142.2	81	131.2	75	144.0	82	129.4	74	114.8	65	146.2	83	97.5	55	87.5	50	155.1	88	148.3	84	***1644.3***	***934***
	Oct	10	147.1	61	244.0	102	153.9	64	145.5	61	120.1	50	119.6	50	87.8	37	141.1	59	117.2	49	92.0	38	144.6	60	166.6	69	***1679.6***	***700***
	Nov	11	131.6	81	195.7	121	120.3	74	135.2	83	150.8	93	110.2	68	111.9	69	114.9	71	88.0	54	85.1	52	143.8	89	137.1	85	***1524.5***	***940***
	Dec	12	144.8	100	224.7	155	136.6	94	130.4	90	135.7	93	108.4	75	107.5	74	122.0	84	94.3	65	88.1	61	137.1	94	126.3	87	***1555.8***	***1072***
2013	Jan	13	153.9	86	227.1	127	122.5	68	143.5	80	144.8	81	119.3	67	111.7	62	127.6	71	106.5	59	72.9	41	151.9	85	141.5	79	***1623.1***	***905***
	Feb	14	130.6	77	242.7	144	161.3	96	167.7	99	160.0	95	112.8	67	110.3	65	155.7	92	118.3	70	83.9	50	173.2	103	165.4	98	***1781.9***	***1057***
	Mar	15	157.3	78	260.8	130	164.4	82	155.5	78	128.4	64	127.8	64	93.9	47	150.8	75	125.3	63	98.4	49	154.6	77	178.1	89	***1795.2***	***896***
	Apr	16	171.8	97	266.5	151	162.0	92	154.7	88	160.9	91	128.6	73	127.5	72	144.7	82	111.8	63	104.5	59	162.6	92	149.9	85	***1845.5***	***1045***
	May	17	149.9	77	264.8	136	168.7	87	167.2	86	168.0	86	148.2	76	116.9	60	151.4	78	105.6	54	93.8	48	181.5	93	167.0	86	***1883.1***	***966***
	Jun	18	138.5	69	243.4	122	170.1	85	185.1	92	168.8	84	131.5	66	129.2	65	160.9	80	108.9	54	109.3	55	180.8	90	154.8	77	***1881.3***	***940***
	Jul	19	147.2	72	219.1	107	134.6	66	151.3	74	168.7	82	123.4	60	125.2	61	128.6	63	98.4	48	95.2	46	160.9	78	153.4	75	***1706.2***	***832***
	Aug	20	142.6	75	247.4	129	147.2	77	124.8	65	157.6	82	134.6	70	119.9	63	135.9	71	111.8	58	81.7	43	149.8	78	156.4	82	***1709.8***	***894***
	Sep	21	133.6	77	258.6	149	160.2	93	147.8	85	162.3	94	145.8	84	129.3	75	164.7	95	109.9	63	98.6	57	174.7	101	167.1	97	***1852.6***	***1070***
	Oct	22	130.3	74	234.6	133	156.4	89	143.4	81	169.4	96	117.3	66	104.3	59	143.4	81	104.3	59	78.2	44	156.4	89	169.4	96	***1707.2***	***967***
	Nov	23	145.9	86	222.6	132	149.0	88	135.3	80	154.6	91	130.2	77	121.4	72	132.9	79	103.6	61	94.6	56	155.8	92	149.3	88	***1695.0***	***1002***
	Dec	24	168.9	107	280.1	177	176.6	112	166.9	106	137.8	87	137.3	87	100.8	64	161.9	103	134.6	85	105.6	67	166.0	105	191.2	121	***1927.8***	***1221***
2014	Jan	25	174.6	97	301.4	167	180.0	100	146.9	82	188.9	105	162.8	90	145.0	81	164.5	91	135.3	75	98.9	55	181.2	101	189.3	105	***2068.7***	***1149***
	Feb	26	198.8	97	329.7	161	207.8	102	196.5	96	162.2	79	161.5	79	118.7	58	190.6	93	158.4	78	124.3	61	195.4	96	225.1	110	***2268.9***	***1111***
	Mar	27	179.3	90	316.7	159	201.8	101	200.0	100	200.9	101	177.3	89	139.9	70	181.1	91	126.4	63	112.2	56	217.1	109	199.8	100	***2252.5***	***1128***
	Apr	28	167.7	99	311.6	184	207.0	122	215.3	127	205.4	121	144.8	86	141.6	84	199.9	118	151.9	90	107.8	64	222.4	131	212.3	125	***2287.7***	***1352***
	May	29	169.3	89	327.7	173	203.1	107	187.3	99	205.7	109	184.8	98	163.9	86	208.7	110	139.2	73	124.9	66	221.4	117	211.8	112	***2347.7***	***1239***
	Jun	30	163.5	86	287.4	151	200.8	106	218.5	115	199.2	105	155.2	82	152.6	80	189.9	100	128.6	68	129.0	68	213.4	112	182.8	96	***2220.8***	***1170***
	Jul	31	180.3	88	268.2	131	164.8	81	185.3	91	206.6	101	151.0	74	153.3	75	157.5	77	120.5	59	116.6	57	197.0	96	187.8	92	***2088.9***	***1021***
	Aug	32	169.0	109	304.4	197	202.9	131	186.1	120	219.7	142	152.2	98	135.3	88	186.1	120	135.3	88	101.5	66	202.9	131	219.7	142	***2215.1***	***1433***
	Sep	33	190.6	117	290.7	178	194.6	119	176.7	108	201.9	123	170.0	104	158.5	97	173.6	106	135.3	83	123.5	76	203.4	124	195.0	119	***2213.7***	***1354***
	Oct	34	201.0	120	311.7	187	189.5	114	180.9	108	188.2	113	150.5	90	149.2	89	169.2	101	130.8	78	122.2	73	190.2	114	175.3	105	***2158.7***	***1293***
	Nov	35	192.4	106	319.2	176	201.2	111	190.2	105	157.1	87	156.4	86	114.9	63	184.5	102	153.3	85	120.4	67	189.1	105	217.9	120	***2196.6***	***1214***
	Dec	36	235.0	125	346.9	185	187.2	100	219.2	117	221.2	118	182.2	97	170.6	91	194.9	104	162.6	87	111.3	59	232.1	124	216.2	115	***2479.4***	***1323***
		Averages:	***154.13***	***84.39***	***258.18***	***141.44***	***162.78***	***89.33***	***160.14***	***87.72***	***163.66***	***89.86***	***135.26***	***74.06***	***121.01***	***66.42***	***152.94***	***83.81***	***116.55***	***63.81***	***96.93***	***53.17***	***171.17***	***93.81***	***169.08***	***92.58***	***1861.79***	***1021***

4.2.5 Multiple regression analysis: Total monthly waste production versus individual zones monthly productions

Data in **Table 10** clearly show that the total quantities of waste generated monthly is dependent on a number of identified predictor variables (number of dumpsites grouped into zones). It is desired in the study to investigate how these predictors combine to affect total quantities of waste generated daily, weekly, monthly and yearly. The aim here is to influence ASWAMA management decisions in planning and budgeting as to maintain high service delivery regardless of seasonal variations. To achieve this, Fit Regression Model of Minitab 17.0 statistical software and Excel Statistical ToolsPack were used as tools to investigate the relationships between both the total monthly generation (response variable) and the predictor variables (inputs from the various zones).

Minitab 17.0 gave the outputs of the regression analysis made as shown in **Table 11**; while the multiple regression model coefficients are displayed in **Table 12**.

Table 11: Minitab Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	12	3057973	254831	23669895.83	0.000
Amawbia	1	417	417	38691.67	0.000
Ziks Ave	1	691	691	64205.44	0.000
Amaikwo	1	18	18	1644.70	0.000
Amaenyi/Amaku	1	32	32	2932.10	0.000
Udoka Est	1	7	7	668.92	0.000
Nibo/Umuawu	1	65	65	6047.18	0.000
Iyiagu	1	3	3	299.64	0.000
Okpuno	1	49	49	4525.58	0.000
Enugu Onitsha Exp	1	7	7	638.94	0.000
Emma Nnaemeka	1	8	8	714.15	0.000
Ifite	1	28	28	2619.31	0.000
Govt House	1	9	9	849.59	0.000
Error	23	0	0		
Total	35	3057974			

Table 12: Minitab generated regression model coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	- 0.048	0.116	- 0.41	0.685	
Amawbia	0.99652	0.00507	196.70	0.000	65.88
Ziks Ave	1.00808	0.00398	253.39	0.000	96.14
Amaikwo	1.0123	0.0250	40.55	0.000	1548.10
Amaenyi/Amaku	1.0133	0.0187	54.15	0.000	951.67
Udoka Est	0.9721	0.0376	25.86	0.000	3818.33
Nibo/Umuawu	0.9886	0.0127	77.76	0.000	285.88
Iyiagu	1.0429	0.0603	17.31	0.000	5914.20
Okpuno	0.9800	0.0146	67.27	0.000	476.81
Enugu Onitsha Expr	0.9727	0.0385	25.28	0.000	2089.15
Emma Nnaemeka	0.9781	0.0366	26.72	0.000	1334.58
Ifite	0.9929	0.0194	51.18	0.000	981.85
Govt House	1.0285	0.0353	29.15	0.000	3455.65

Table 13: Excel regression analysis - summary output

Regression Statistics

Multiple R	0.99999996
R Square	0.999999919
Adjusted R Square	0.999999877
Standard Error	0.103759542
Observations	36

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	12	3057973.291	254831.1076	23669896	1.45638E-78
Residual	23	0.247618981	0.010766043		
Total	35	3057973.539			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.047793025	0.116219951	-0.411229091	0.684711	-0.288212309	0.192626	-0.28821	0.192626
Amawbia	0.996516069	0.005066121	196.7019741	1.31E-38	0.986035999	1.006996	0.986036	1.006996
Zik's Ave.	1.00807991	0.003978406	253.387923	3.87E-41	0.999849951	1.01631	0.99985	1.01631
Amaikwo	1.012326477	0.024961863	40.55492406	6.68E-23	0.960688929	1.063964	0.960689	1.063964
Amaenyi/Amaku	1.013291068	0.018713054	54.14888688	9.25E-26	0.974580165	1.052002	0.97458	1.052002
Udoka Estate	0.972118956	0.037586513	25.86350464	1.67E-18	0.89436533	1.049873	0.894365	1.049873
Nibo/ Umuawulu	0.988628283	0.012713246	77.76364286	2.35E-29	0.962328931	1.014928	0.962329	1.014928
Iyiagu Estate	1.042943083	0.060250609	17.31008359	1.1E-14	0.918305203	1.167581	0.918305	1.167581
Okpuno	0.980019402	0.014567925	67.27241034	6.48E-28	0.949883354	1.010155	0.949883	1.010155
Enugu-Onitsha Express Way	0.972695805	0.038480933	25.27734453	2.78E-18	0.89309193	1.0523	0.893092	1.0523
Emma Nnaemeka Axis	0.978083464	0.036600048	26.72355656	8.05E-19	0.902370496	1.053796	0.90237	1.053796
Ifite	0.992861217	0.019399688	51.17923588	3.35E-25	0.952729905	1.032993	0.95273	1.032993
Govt. House	1.028535627	0.035287022	29.14770281	1.15E-19	0.955538861	1.101532	0.955539	1.101532

4.2.5.1 Regression equation

Minitab used the data in **Table 11** to generate the following regression equation:

$$y_T = 0.99652x_1 + 1.00808x_2 + 1.0123x_3 + 1.0133x_4 + 0.9721x_5 + 0.9886x_6 + 1.0429x_7$$
$$+ 0.9800x_8 + 0.9727x_9 + 0.9781x_{10} + 0.9929x_{11} + 1.0285x_{12} + e \quad (79)$$

Where x_1, x_1, x_1, …, x_{12} represent monthly waste contributions from Amawbia, Zik's Avenue, Amaikwo, …, Govt. House Zones in Awka area respectively, y_T is the monthly total waste production and e is an error term. Microsoft Excel gave the same equation, when written with the values for the coefficients in **Table 13**.

As can be seen, the regression equation is of a general linear type. The same model can be used to generate predictions. General Regression gives us an additional piece of output that is crucial for prediction, the predicted R-squared. The predicted R-squared indicates how well the model predicts new observations. The closer the predicted R-sq is to the R-sq, the better the result. Here's the summary of the model as provided by Minitab and Microsoft Excel spreadsheet.

S	***R*-sq**	***R*-sq(adj)**	***R*-sq(pred)**
0.103760	100.00%	100.00%	100.00%

Fits and diagnostics for unusual observations

Obs	**Totals**	**Fit**	**Resid**	**Std Resid**
5	1594.80	1595.00	-0.20	-2.22 R

R has large residual

Excel gives the values R-sq as 0.999999919, the R-sq(adj) as 0.999999877 and the Multiple R or R-sq (pred) as 0.99999996 (**Table 13** refers) which have all been rounded up to 100% each. It can be seen that the regression model is a good fit and may be used for predictions.

4.2.5.2 Residual plots for monthly total quantities of solid waste generated

Minitab used the data in **Table 11** to generate the various residual plots shown in Figure 24.

Excel Regression statistical tool gave similar plots as in Figure 24. The residuals in the Normal Probability Plot above follow a straight line, which indicates they are normally distributed. In the Versus Fits plot, the residuals appear to be randomly scattered about zero.

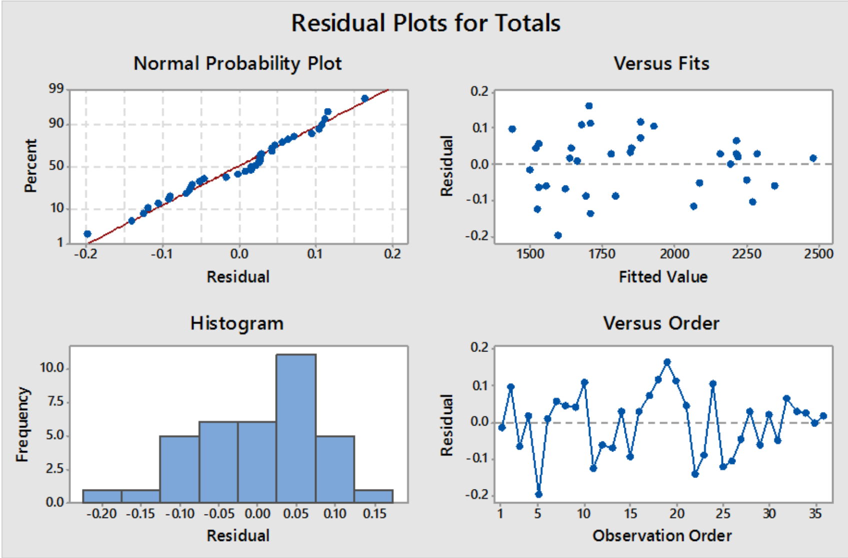


Figure 24: Residual plots for combined quantities of solid waste generated monthly

These data were not recorded in time-order so we can ignore the Versus Order plot. The histogram can help detect outliers, but none are evident. (We know it is wrong to use histograms to assess normality, because they can be deceptive for that purpose).

4.2.6 Waste queuing and SWIM models applications, results and discussions

In the analysis, solid waste generation and evacuation in Awka, Anambra State, was viewed in the thinking that waste containers kept at different locations in Awka formed a queue with many servers (ASWAMA disposal vehicles) visiting them and rendering disposal services. This assumption should be right, since in reality a customer can either go to a service center to receive some service or have a worker(s) from the servicing firm come to him/her to render the service. Once the waste in a dumpsite was evacuated (whether totally or partially), the dumpsite or waste container(s) stationed therein was taken as having been served and departed. New waste dumped at the served dumpsite makes the container(s) at the dumpsite a new customer(s) to be served. By this consideration, the queue length is unknown, infinite and unrestricted. Number of servers that operated in the study area varied from 0 to 15 disposal trucks of different capacities per day. Also average number of chain-up bin loads of waste evacuated daily varied from 0 to 63. Variation in the number of servers was caused, among other reasons, by administrative bottlenecks and incessant breakdown of most of the disposal vehicles.

A consecutive thirty one (61) day data on solid waste generation and evacuation in three roadside dump sites (Ogbalingba, Eke Awka Market and Ifite Market) in Awka Metropolitan city of Anambra State are used in this section to show the sample applications of the queuing and SWIM models developed in the study. Actually, different disposal trucks of various capacities serviced the three dumpsites under review, but it is taken in this exercise that only one disposal truck (server) worked in the three dumpsites within the sixty one (61) day study period such that the data obtained in **Tables 25**, **27** and **28** hold true. Data in the said tables contain the estimated quantities of waste found at the three dumpsites during the morning and evening checks of the study period, which act as the input (independent) variables from which other parameters derive their values as the output (dependant) variables. Waste dumped between 6 am - 6 pm at the sites were considered as day arrivals, while the ones deposited between 6 pm - 6 am were termed night arrivals. As they arrived, they built up and filled the containers. Collated data were first organized and descriptive statistics used to compute the combined average waste bin loads generated (i.e. waste production/dump rates) and the quantities discharged (i.e. waste evacuation/disposal service rates) in each of the three dumpsites in the month of December, 2014. Also computed were the approximate waste disposal system utilization in the same period. Summary of the analysis are contained in **Tables 14** to **19**.

4.2.6.1 Waste dump and evacuation data presentation and discussions

The input data in **Tables 14** and **16** to **19** enable derivation of more information (responses from the input variables) for evaluating the performance of the waste management system. The three dumpsites were juxtaposed in columns set as shown in **Table 4** but have been presented here in separate tables for want of space.

As can be seen from Table 14, even though the overall waste evacuation efficiency (88.8%) at Ogbalingba dumpsite is commendable, the system still showed not to be stable as $\lambda > \mu$.

Table 14: Data collected on solid waste generation and evacuation processes in Ogbalingba ' dumpsite of Awka city, Anambra State

Time	Ogbalingba Dumpsite (No. Of Chain-up Bins = 3)																	
Days	L_q (cb)	q_d (cb)	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$q_{(d+N)}$ (cb)	N_{tGL}	λ_q (cbpd)	μ_q (cbpd)	$N_{\mu=0}$	L_w (cb)	L_s (cb)	W_a (hrs)	W_q (hrs)	W_s (hrs)	η (%)	$P(t)_\lambda$	Cum $P(t)_\lambda$
1	2.0	0.2	0	0.3	0	0.5	0	2.2	0	1	2.2	2.5	24	21.8	27.3	0.0	0.008	0.008
2	2.5	0.2	0	0.5	0	0.7	0	2.7	0	1	2.7	3.2	48	22.2	28.4	0.0	0.010	0.018
3	3.2	0.5	0	0.0	1	0.5	0	3.7	0	1	3.7	3.7	72	20.8	24.0	0.0	0.014	0.032
4	3.7	0.2	0	0.4	0	0.6	0	3.9	3	0	0.9	4.3	24	22.8	26.5	76.9	0.015	0.047
5	1.3	0.4	0	0.5	0	0.9	1	1.7	0	1	1.7	2.2	24	18.4	31.1	0.0	0.006	0.054
6	2.2	0.0	1	0.8	0	0.8	0	2.2	0	1	2.2	3.0	48	24.0	32.7	0.0	0.008	0.062
7	3.0	0.2	0	0.0	1	0.2	0	3.2	0	1	3.2	3.2	72	22.5	24.0	0.0	0.012	0.074
8	3.2	0.9	0	0.8	0	1.7	0	4.1	2	0	2.1	4.9	24	18.7	28.7	48.8	0.015	0.089
9	2.9	0.4	0	0.0	1	0.4	1	3.3	0	1	3.3	3.3	24	21.1	24.0	0.0	0.012	0.102
10	3.3	0.2	0	0.6	0	0.8	0	3.5	0	1	3.5	4.1	48	22.6	28.1	0.0	0.013	0.115
11	4.1	0.2	0	0.5	0	0.7	0	4.3	2	0	2.3	4.8	24	22.9	26.8	46.5	0.016	0.131
12	2.8	0.0	1	0.5	0	0.5	0	2.8	0	1	2.8	3.3	24	24.0	28.3	0.0	0.011	0.142
13	3.3	0.2	0	0.6	0	0.8	1	3.5	0	1	3.5	4.1	48	22.6	28.1	0.0	0.013	0.155
14	4.1	0.4	0	0.4	0	0.8	0	4.5	0	1	4.5	4.9	72	21.9	26.1	0.0	0.017	0.172
15	4.9	0.2	0	0.5	0	0.7	0	5.1	0	1	5.1	5.6	96	23.1	26.4	0.0	0.019	0.191
16	5.6	0.2	0	0.8	0	1.0	0	5.8	3	0	2.8	6.6	24	23.2	27.3	51.7	0.022	0.213

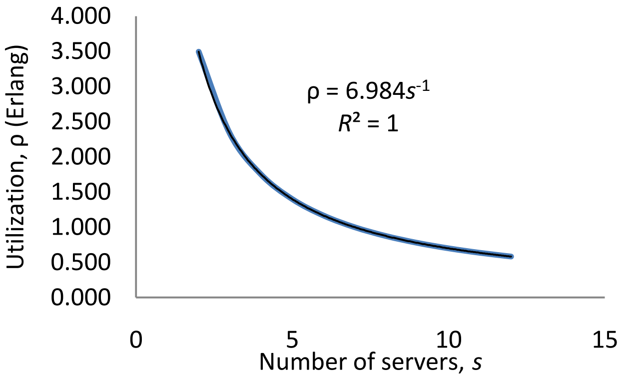
17	3.6	0.4	0	0.2	0	0.6	1	4.0	0	1	4.0	4.2	24	21.6	25.2	0.0	0.015	0.228
18	4.2	0.0	1	0.7	0	0.7	0	4.2	0	1	4.2	4.9	48	24.0	28.0	0.0	0.016	0.244
19	4.9	0.4	0	0.0	1	0.4	0	5.3	0	1	5.3	5.3	72	22.2	24.0	0.0	0.020	0.264
20	5.3	0.2	0	0.5	0	0.7	0	5.5	3	0	2.5	6.0	24	23.1	26.2	54.5	0.021	0.284
21	3.0	0.3	0	0.3	0	0.6	0	3.3	0	1	3.3	3.6	24	21.8	26.2	0.0	0.012	0.297
22	3.6	0.2	0	0.5	0	0.7	1	3.8	0	1	3.8	4.3	48	22.7	27.2	0.0	0.014	0.311
23	4.3	0.3	0	0.0	1	0.3	0	4.6	1	0	3.6	4.6	24	22.4	24.0	21.7	0.017	0.329
24	3.6	0.1	0	0.8	0	0.9	0	3.7	0	1	3.7	4.5	24	23.4	29.2	0.0	0.014	0.343
25	4.5	0.3	0	0.7	0	1.0	0	4.8	0	1	4.8	5.5	48	22.5	27.5	0.0	0.018	0.361
26	5.5	0.2	0	0.3	0	0.5	0	5.7	1	0	4.7	6.0	24	23.2	25.3	17.5	0.021	0.382
27	5.0	0.1	0	0.0	1	0.1	1	5.1	0	1	5.1	5.1	24	23.5	24.0	0.0	0.019	0.401
28	5.1	0.3	0	0.3	0	0.6	0	5.4	0	1	5.4	5.7	48	22.7	25.3	0.0	0.020	0.422
29	5.7	0.2	0	0.2	0	0.4	0	5.9	3	0	2.9	6.1	24	23.2	24.8	50.8	0.022	0.444
30	3.1	0.2	0	0.4	0	0.6	0	3.3	0	1	3.3	3.7	24	22.5	26.9	0.0	0.012	0.456
31	3.7	0.2	0	0.0	1	0.2	0	3.9	0	1	3.9	3.9	48	22.8	24.0	0.0	0.015	0.471
32	3.9	0.3	0	0.4	0	0.7	0	4.2	3	0	1.2	4.6	24	22.3	26.3	71.4	0.016	0.487
33	1.6	0.2	0	0.0	1	0.2	0	1.8	0	1	1.8	1.8	24	21.3	24.0	0.0	0.007	0.494
34	1.8	0.2	0	0.6	0	0.8	1	2.0	0	1	2.0	2.6	48	21.6	31.2	0.0	0.008	0.501
35	2.6	0.4	0	0.0	1	0.4	0	3.0	0	1	3.0	3.0	72	20.8	24.0	0.0	0.011	0.512
36	3.0	0.7	0	0.8	0	1.5	0	3.7	2	0	1.7	4.5	24	19.5	29.2	54.1	0.014	0.526
37	2.5	0.3	0	0.0	1	0.3	0	2.8	0	1	2.8	2.8	24	21.4	24.0	0.0	0.011	0.537
38	2.8	0.1	0	0.6	0	0.7	1	2.9	0	1	2.9	3.5	48	23.2	29.0	0.0	0.011	0.548
39	3.5	0.3	0	0.5	0	0.8	0	3.8	0	1	3.8	4.3	72	22.1	27.2	0.0	0.014	0.562
40	4.3	0.2	0	0.5	0	0.7	0	4.5	2	0	2.5	5.0	24	22.9	26.7	44.4	0.017	0.579
41	3.0	0.1	0	0.6	0	0.7	0	3.1	0	1	3.1	3.7	24	23.2	28.6	0.0	0.012	0.591
42	3.7	0.3	0	0.4	0	0.7	1	4.0	0	1	4.0	4.4	48	22.2	26.4	0.0	0.015	0.606
43	4.4	0.2	0	0.5	0	0.7	0	4.6	2	0	2.6	5.1	24	23.0	26.6	43.5	0.017	0.623
44	3.1	0.2	0	0.8	0	1.0	0	3.3	0	1	3.3	4.1	24	22.5	29.8	0.0	0.012	0.636
45	4.1	0.4	0	0.2	0	0.6	0	4.5	0	1	4.5	4.7	48	21.9	25.1	0.0	0.017	0.653
46	4.7	0.0	1	0.7	0	0.7	1	4.7	0	1	4.7	5.4	72	24.0	27.6	0.0	0.018	0.670
47	5.4	0.4	0	0.0	1	0.4	0	5.8	0	1	5.8	5.8	96	22.3	24.0	0.0	0.022	0.692
48	5.8	0.2	0	0.5	0	0.7	0	6.0	0	1	6.0	6.5	120	23.2	26.0	0.0	0.023	0.715
49	6.5	0.2	0	0.3	0	0.5	0	6.7	3	0	3.7	7.0	24	23.3	25.1	44.8	0.025	0.740
50	4.0	0.0	1	0.5	0	0.5	0	4.0	0	1	4.0	4.5	24	24.0	27.0	0.0	0.015	0.755
51	4.5	0.2	0	0.0	1	0.2	0	4.7	0	1	4.7	4.7	48	23.0	24.0	0.0	0.018	0.773
52	4.7	0.4	0	0.8	0	1.2	1	5.1	0	1	5.1	5.9	72	22.1	27.8	0.0	0.019	0.792
53	5.9	0.4	0	0.7	0	1.1	0	6.3	0	1	6.3	7.0	96	22.5	26.7	0.0	0.024	0.816
54	7.0	0.0	1	0.3	0	0.3	0	7.0	2	0	5.0	7.3	24	24.0	25.0	28.6	0.026	0.842
55	5.3	0.2	0	0.0	1	0.2	0	5.5	0	1	5.5	5.5	24	23.1	24.0	0.0	0.021	0.863
56	5.5	0.9	0	0.3	0	1.2	1	6.4	0	1	6.4	6.7	48	20.6	25.1	0.0	0.024	0.887
57	6.7	0.4	0	0.2	0	0.6	0	7.1	3	0	4.1	7.3	24	22.6	24.7	42.3	0.027	0.914
58	4.3	0.2	0	0.4	0	0.6	0	4.5	0	1	4.5	4.9	24	22.9	26.1	0.0	0.017	0.931
59	4.9	0.2	0	0.5	0	0.7	0	5.1	0	1	5.1	5.6	48	23.1	26.4	0.0	0.019	0.950
60	5.6	0.5	0	0.9	0	1.4	1	6.1	0	1	6.1	7.0	72	22.0	27.5	0.0	0.023	0.973
61	7.0	0.2	0	0.6	0	0.8	0	7.2	3	0	4.2	7.8	24	23.3	26.0	41.7	0.027	1.000
	∑ =	16.1	6.0	24.7	13.0	40.8	13.0	265.4	38.0	45.0						88.8		

Table 14 shows that while the daily waste evacuation efficiencies are low, the overall evacuation efficiency of 88.8% is quite impressive. Waste accumulated at Ogbalingba dumpsite at an average rate of 4.35 cbpd, while the server operated at an average rate of 0.62 cbpd. Using eqns (11) and (12) of the Appendices, data on this relationship were calculated and entered in **Table 15**.

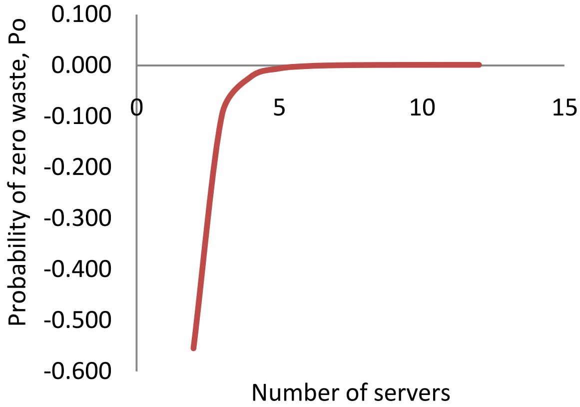
Table 15: Determination of best system utilization at Ogbalingba dumpsite

s	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
ρ	3.492	2.328	1.746	1.397	1.164	0.998	0.873	0.776	0.698	0.635	0.582
P_0	-0.555	-0.096	-0.023	-0.006	-0.002	0.000	0.001	0.001	0.001	0.001	0.001
P_w	5.429	4.119	3.039	2.172	1.498	0.993	0.630	0.381	0.219	0.120	0.062
L_q	-7.608	-7.220	-7.111	-7.645	-10.631	439.327	4.333	1.321	0.508	0.208	0.086
L_s	-0.624	-0.236	-0.127	-0.661	-3.647	446.311	11.317	8.305	7.492	7.192	7.070
W_q	-1.749	-1.659	-1.634	-1.757	-2.444	100.976	0.996	0.304	0.117	0.048	0.020
W_s	-0.143	-0.054	-0.029	-0.152	-0.838	102.581	2.601	1.909	1.722	1.653	1.625
W_a	-0.322	-0.403	-0.538	-0.809	-1.631	101.667	1.580	0.796	0.532	0.400	0.320

It can be seen clearly from **Table 14** that SWM at Ogbalingba Dumpsite will remain chaotic even if the present mean service rate is increased upto about six times. The system would start stabilizing from s = 7. However, at s = 7, it is still imposible to find the system empty; P_w is almost certain (0.993). L_q, L_s, W_q, W_s and W_a also show large values. A close and better system utilization factor for the dumpsite is s = 0.873 Erlang (87.3%). Values of P_0 and P_w against s are plotted in Figures 25a and 25b for visual appreciation.



(a): Server Utilization at Ogbalingba dumpsite



(b): Probability of no waste in Ogbalingba dumpsite

Figure 25: Performance evaluation on Ogbalingba dumpsite

A trendline equation generated on plot of Figure 25a shows that the function has a power distribution relationship: $\rho = 6.984s^{-1}$, with R^2 = 1. Figure 25b shows that going by the present service rate at the dumpsite, it would be very rear not to see any waste at the dumpsite. Therefore increasing the average service rate to about 5 cbpd may be ideal for making the system stable.

Again in **Table 16**, the overall waste evacuation efficiency (95.2%) at Eke Awka dumpsite is quite impressive. However, the system still shows not to be stable. Waste generation/dump rate at the site was estimated as an average rate of 7.26 cbpd, while the waste containers were served at an average rate of 3.02 cbpd. By the same reasoning as in discussing the waste management at Ogbalingba dumpsite, data plot on Eke Awka Market gave the relation: $\rho = 2.408s^{-1}$ and R^2 = 1 and requires a service rate, μ, of 8 cbpd to stabilize the subsystem.

Table 16: Data collected on solid waste generation and evacuation processes in Eke Awka Market dumpsite of Awka city, Anambra State

Time	Eke Awka Market Dumpsite (No. Of Chain-up Bins = 4)																	
Days	L_q (cb)	q_d	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$q_{(d+N)}$ (cb)	N_{tGL}	λ_q (cbpd)	μ_q	$N_{\mu=0}$	L_w (cb)	L_s	W_a (hrs)	W_q	W_s	η (%)	$P(t)_\lambda$	Cum. $P(t)_\lambda$
1	0.7	0.0	1	3.6	0	3.6	0	0.7	0	1	0.7	4.3	24	24.0	147.4	0.0	0.002	0.002
2	4.3	1.5	0	4.5	0	6.0	1	5.8	0	1	5.8	10.3	48	17.8	42.6	0.0	0.013	0.014
3	10.3	2.4	0	3.0	0	5.4	1	12.7	12	0	0.7	15.7	24	19.5	29.7	94.5	0.028	0.043
4	3.7	0.8	0	1.2	0	2.0	1	4.5	0	1	4.5	5.7	24	19.7	30.4	0.0	0.010	0.053
5	5.7	1.9	0	2.5	0	4.4	1	7.6	0	1	7.6	10.1	48	18.0	31.9	0.0	0.017	0.069
6	10.1	0.6	0	0.7	0	1.3	1	10.7	11	0	0.0	11.4	24	22.7	25.6	100.0	0.024	0.093
7	0.7	0.5	0	3.1	0	3.6	1	1.2	0	1	1.2	4.3	24	14.0	86.0	0.0	0.003	0.096
8	4.3	2.2	0	1.4	0	3.6	1	6.5	0	1	6.5	7.9	48	15.9	29.2	0.0	0.014	0.110
9	7.9	0.2	0	1.6	0	1.8	0	8.1	8	0	0.1	9.7	24	23.4	28.7	98.8	0.018	0.128
10	1.7	1.6	0	1.7	0	3.3	1	3.3	0	1	3.3	5.0	24	12.4	36.4	0.0	0.007	0.135
11	5.0	0.0	1	2.0	0	2.0	1	5.0	0	1	5.0	7.0	48	24.0	33.6	0.0	0.011	0.146
12	7.0	0.7	0	0.7	0	1.4	0	7.7	0	1	7.7	8.4	72	21.8	26.2	0.0	0.017	0.164
13	8.4	1.2	0	1.1	0	2.3	1	9.6	9	0	0.6	10.7	24	21.0	26.8	93.8	0.021	0.185
14	1.7	0.6	0	1.2	0	1.8	0	2.3	0	1	2.3	3.5	24	17.7	36.5	0.0	0.005	0.190
15	3.5	1.1	0	2.5	0	3.6	1	4.6	0	1	4.6	7.1	48	18.3	37.0	0.0	0.010	0.200
16	7.1	1.7	0	0.7	0	2.4	1	8.8	9	0	0.0	9.5	24	19.4	25.9	100.0	0.020	0.220
17	0.7	0.0	1	2.6	0	2.6	0	0.7	0	1	0.7	3.3	24	24.0	113.1	0.0	0.002	0.221
18	3.3	1.8	0	0.0	1	1.8	1	5.1	0	1	5.1	5.1	48	15.5	24.0	0.0	0.011	0.232
19	5.1	0.5	0	3.5	0	4.0	1	5.6	0	1	5.6	9.1	72	21.9	39.0	0.0	0.012	0.245
20	9.1	1.0	0	0.0	1	1.0	0	10.1	0	1	10.1	10.1	96	21.6	24.0	0.0	0.022	0.267
21	10.1	1.7	0	3.6	0	5.3	1	11.8	12	0	0.0	15.4	24	20.5	31.3	100.0	0.026	0.293
22	3.6	2.3	0	4.5	0	6.8	1	5.9	0	1	5.9	10.4	24	14.6	42.3	0.0	0.013	0.307
23	10.4	0.0	1	3.0	0	3.0	1	10.4	0	1	10.4	13.4	48	24.0	30.9	0.0	0.023	0.330
24	13.4	0.1	0	2.8	0	2.9	1	13.5	12	0	1.5	16.3	24	23.8	29.0	88.9	0.030	0.359
25	4.3	2.0	0	0.9	0	2.9	1	6.3	0	1	6.3	7.2	24	16.4	27.4	0.0	0.014	0.373
26	7.2	0.5	0	4.0	0	4.5	1	7.7	8	0	0.0	11.7	24	22.4	36.5	100.0	0.017	0.391
27	4.0	1.5	0	2.7	0	4.2	1	5.5	0	1	5.5	8.2	24	17.5	35.8	0.0	0.012	0.403
28	8.2	0.0	1	0.2	0	0.2	0	8.2	8	0	0.2	8.4	24	24.0	24.6	97.6	0.018	0.421
29	0.4	1.1	0	2.4	0	3.5	1	1.5	0	1	1.5	3.9	24	6.4	62.4	0.0	0.003	0.424
30	3.9	1.7	0	2.6	0	4.3	1	5.6	6	0	0.0	8.2	24	16.7	35.1	100.0	0.012	0.437
31	2.6	1	0	3.1	0	4.1	1	3.6	3	0	0.6	6.7	24	17.3	44.7	83.3	0.008	0.445
32	3.7	1.7	0	2.7	0	4.4	1	5.4	0	1	5.4	8.1	24	16.4	36.0	0.0	0.012	0.457
33	8.1	2.3	0	2.7	0	5.0	1	10.4	8	0	2.4	13.1	24	18.7	30.2	76.9	0.023	0.480
34	5.1	0.4	0	1.6	0	2.0	1	5.5	0	1	5.5	7.1	24	22.3	31.0	0.0	0.012	0.492
35	7.1	0.9	0	3.1	0	4.0	1	8.0	0	1	8.0	11.1	48	21.3	33.3	0.0	0.018	0.510
36	11.1	1.4	0	1.4	0	2.8	1	12.5	8	0	4.5	13.9	24	21.3	26.7	64.0	0.028	0.537
37	5.9	0	1	1.6	0	1.6	0	5.9	0	1	5.9	7.5	24	24.0	30.5	0.0	0.013	0.550
38	7.5	0.1	0	1.7	0	1.8	1	7.6	0	1	7.6	9.3	48	23.7	29.4	0.0	0.017	0.567
39	9.3	2	0	2	0	4.0	1	11.3	8	0	3.3	13.3	24	19.8	28.2	70.8	0.025	0.592
40	5.3	0.5	0	0.7	0	1.2	0	5.8	0	1	5.8	6.5	24	21.9	26.9	0.0	0.013	0.605
41	6.5	1.5	0	1.1	0	2.6	1	8.0	0	1	8.0	9.1	48	19.5	27.3	0.0	0.018	0.623
42	9.1	0	1	1.2	0	1.2	0	9.1	0	1	9.1	10.3	72	24.0	27.2	0.0	0.020	0.643
43	10.3	1.1	0	2.5	0	3.6	1	11.4	9	0	2.4	13.9	24	21.7	29.3	78.9	0.025	0.668
44	4.9	1.7	0	0.7	0	2.4	1	6.6	0	1	6.6	7.3	24	17.8	26.5	0.0	0.015	0.683
45	7.3	0	1	2.6	0	2.6	0	7.3	4	0	3.3	9.9	24	24.0	32.5	54.8	0.016	0.699
46	5.9	1.8	0	0	1	1.8	1	7.7	3	0	4.7	7.7	24	18.4	24.0	39.0	0.017	0.716
47	4.7	0.5	0	3.5	0	4.0	1	5.2	0	1	5.2	8.7	24	21.7	40.2	0.0	0.012	0.728
48	8.7	1.6	0	0	1	1.6	0	10.3	0	1	10.3	10.3	48	20.3	24.0	0.0	0.023	0.750
49	10.3	0	1	3.6	0	3.6	1	10.3	8	0	2.3	13.9	24	24.0	32.4	77.7	0.023	0.773
50	5.9	0.7	0	4.5	0	5.2	1	6.6	0	1	6.6	11.1	24	21.5	40.4	0.0	0.015	0.788
51	11.1	1.2	0	3	0	4.2	1	12.3	9	0	3.3	15.3	24	21.7	29.9	73.2	0.027	0.815
52	6.3	0.6	0	2.8	0	3.4	1	6.9	0	1	6.9	9.7	24	21.9	33.7	0.0	0.015	0.830
53	9.7	1.9	0	0.9	0	2.8	1	11.6	0	1	11.6	12.5	48	20.1	25.9	0.0	0.026	0.856
54	12.5	0.6	0	4	0	4.6	1	13.1	10	0	3.1	17.1	24	22.9	31.3	76.3	0.029	0.885
55	7.1	0.5	0	2.7	0	3.2	1	7.6	0	1	7.6	10.3	24	22.4	32.5	0.0	0.017	0.902
56	10.3	2.2	0	0.2	0	2.4	0	12.5	8	0	4.5	12.7	24	19.8	24.4	64.0	0.028	0.930
57	4.7	0.2	0	2.4	0	2.6	1	4.9	0	1	4.9	7.3	24	23.0	35.8	0.0	0.011	0.941
58	7.3	0	1	2.6	0	2.6	1	7.3	8	0	0.0	9.9	24	24.0	32.5	100.0	0.016	0.957
59	2.6	1.5	0	2.5	0	4.0	1	4.1	0	1	4.1	6.6	24	15.2	38.6	0.0	0.009	0.966
60	6.6	2.4	0	2.6	0	5.0	1	9.0	6	0	3.0	11.6	24	17.6	30.9	66.7	0.020	0.986
61	5.6	0.8	0	3.6	0	4.4	1	6.4	0	1	6.4	10.0	24	21.0	37.5	0.0	0.014	1.000
		62.3	10	131.9	4	194.2	48	451.2	187.0	38						95.9		

Table 17 is explained in the same reasoning as **Tables 14** to **16** were discussed. See

Table 19 also.

Table 17: Data collected on solid waste generation and evacuation processes in Ifite Market dumpsite of Awka city, Anambra State

Time	Ogbalingba Dumpsite (No. Of Chain-up Bins = 2)																	
Days	L_q (cb)	q_d (cb)	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$q_{(d+N)}$ (cb)	N_{tGL}	λ_q (cbpd)	μ_q (cbpd)	$N_{\mu=0}$	L_w (cb)	L_s (cb)	W_a (hrs)	W_q (hrs)	W_s (hrs)	η (%)	$P(t)_\lambda$	Cum. $P(t)_\lambda$
1	1.2	0.2	0	0.1	0	0.3	0	1.4	0	1	1.4	1.5	24	20.6	25.7	0.0	0.007	0.007
2	1.5	0.3	0	0.5	0	0.8	0	1.8	0	1	1.8	2.3	48	20.0	30.7	0.0	0.009	0.015
3	2.3	0.6	0	0.5	0	1.1	1	2.9	0	1	2.9	3.4	72	19.0	28.1	0.0	0.014	0.029
4	3.4	0.2	0	0.1	0	0.3	0	3.6	3	0	0.6	3.7	24	22.7	24.7	83.3	0.017	0.046
5	0.7	0.4	0	0.4	0	0.8	0	1.1	0	1	1.1	1.5	24	15.3	32.7	0.0	0.005	0.051
6	1.5	0.5	0	0.4	0	0.9	1	2.0	0	1	2.0	2.4	48	18.0	28.8	0.0	0.009	0.061
7	2.4	0.1	0	0.8	0	0.9	0	2.5	0	1	2.5	3.3	72	23.0	31.7	0.0	0.012	0.072
8	3.3	0.0	1	0.3	0	0.3	0	3.3	2	0	1.3	3.6	24	24.0	26.2	60.6	0.016	0.088
9	1.6	0.1	0	0.3	0	0.4	0	1.7	0	1	1.7	2.0	24	22.6	28.2	0.0	0.008	0.096
10	2.0	0.6	0	0.4	0	1.0	1	2.6	0	1	2.6	3.0	48	18.5	27.7	0.0	0.012	0.108
11	3.0	0.1	0	0.7	0	0.8	0	3.1	2	0	1.1	3.8	24	23.2	29.4	64.5	0.015	0.123
12	1.8	0.3	0	0.3	0	0.6	1	2.1	0	1	2.1	2.4	24	20.6	27.4	0.0	0.010	0.133
13	2.4	0.3	0	0.4	0	0.7	0	2.7	0	1	2.7	3.1	48	21.3	27.6	0.0	0.013	0.146
14	3.1	0.5	0	0.1	0	0.6	0	3.6	0	1	3.6	3.7	72	20.7	24.7	0.0	0.017	0.163
15	3.7	0.3	0	0.4	0	0.7	1	4.0	0	1	4.0	4.4	96	22.2	26.4	0.0	0.019	0.182
16	4.4	0.4	0	0.4	0	0.8	0	4.8	3	0	1.8	5.2	24	22.0	26.0	62.5	0.023	0.205
17	2.2	0.0	1	0.5	0	0.5	0	2.2	0	1	2.2	2.7	24	24.0	29.5	0.0	0.010	0.215
18	2.7	0.4	0	0.4	0	0.8	1	3.1	0	1	3.1	3.5	48	20.9	27.1	0.0	0.015	0.230
19	3.5	0.2	0	0.5	0	0.7	0	3.7	0	1	3.7	4.2	72	22.7	27.2	0.0	0.018	0.247
20	4.2	0.1	0	0.5	0	0.6	0	4.3	3	0	1.3	4.8	24	23.4	26.8	69.8	0.020	0.268
21	1.8	0.4	0	0.1	0	0.5	1	2.2	0	1	2.2	2.3	24	19.6	25.1	0.0	0.010	0.278
22	2.3	0.2	0	0.5	0	0.7	0	2.5	0	1	2.5	3.0	48	22.1	28.8	0.0	0.012	0.290
23	3.0	0.5	0	0.5	0	1.0	0	3.5	1	0	2.5	4.0	24	20.6	27.4	28.6	0.017	0.306
24	3.0	0.3	0	0.6	0	0.9	1	3.3	0	1	3.3	3.9	24	21.8	28.4	0.0	0.016	0.322
25	3.9	0.1	0	0.4	0	0.5	0	4.0	0	1	4.0	4.4	48	23.4	26.4	0.0	0.019	0.341
26	4.4	0.0	1	0.3	0	0.3	0	4.4	1	0	3.4	4.7	24	24.0	25.6	22.7	0.021	0.362
27	3.7	0.3	0	0.1	0	0.4	0	4.0	0	1	4.0	4.1	24	22.2	24.6	0.0	0.019	0.381
28	4.1	0.0	1	0.3	0	0.3	1	4.1	0	1	4.1	4.4	48	24.0	25.8	0.0	0.019	0.400
29	4.4	0.3	0	0.1	0	0.4	0	4.7	3	0	1.7	4.8	24	22.5	24.5	63.8	0.022	0.423
30	1.8	0.4	0	0.2	0	0.6	0	2.2	0	1	2.2	2.4	24	19.6	26.2	0.0	0.010	0.433
31	2.4	0.1	0	0.1	0	0.2	0	2.5	0	1	2.5	2.6	48	23.0	25.0	0.0	0.012	0.445
32	2.6	0.4	0	0.3	0	0.7	1	3.0	0	1	3.0	3.3	72	20.8	26.4	0.0	0.014	0.459
33	3.3	0.2	0	0.6	0	0.8	0	3.5	2	0	1.5	4.1	24	22.6	28.1	57.1	0.017	0.476
34	2.1	0.4	0	0.3	0	0.7	0	2.5	0	1	2.5	2.8	24	20.2	26.9	0.0	0.012	0.487
35	2.8	0.3	0	0.8	0	1.1	1	3.1	0	1	3.1	3.9	48	21.7	30.2	0.0	0.015	0.502
36	3.9	0.2	0	0.3	0	0.5	0	4.1	0	1	4.1	4.4	72	22.8	25.8	0.0	0.019	0.522
37	4.4	0.5	0	0.3	0	0.8	0	4.9	0	1	4.9	5.2	96	21.6	25.5	0.0	0.023	0.545
38	5.2	0.3	0	0.4	0	0.7	1	5.5	0	1	5.5	5.9	120	22.7	25.7	0.0	0.026	0.571
39	5.9	0.1	0	0.7	0	0.8	0	6.0	3	0	3.0	6.7	24	23.6	26.8	50.0	0.028	0.599
40	3.7	0	1	0.3	0	0.3	0	3.7	0	1	3.7	4.0	24	24.0	25.9	0.0	0.018	0.617
41	4.0	0.3	0	0.4	0	0.7	1	4.3	0	1	4.3	4.7	48	22.3	26.2	0.0	0.020	0.637
42	4.7	0	1	0.1	0	0.1	0	4.7	0	1	4.7	4.8	72	24.0	24.5	0.0	0.022	0.659
43	4.8	0.3	0	0.4	0	0.7	0	5.1	0	1	5.1	5.5	96	22.6	25.9	0.0	0.024	0.684
44	5.5	0.4	0	0.4	0	0.8	1	5.9	0	1	5.9	6.3	120	22.4	25.6	0.0	0.028	0.712
45	6.3	0	1	0.5	0	0.5	0	6.3	4	0	2.3	6.8	24	24.0	25.9	63.5	0.030	0.741
46	2.8	0.4	0	0.4	0	0.8	0	3.2	0	1	3.2	3.6	24	21.0	27.0	0.0	0.015	0.757
47	3.6	0.2	0	0.5	0	0.7	1	3.8	0	1	3.8	4.3	48	22.7	27.2	0.0	0.018	0.775
48	4.3	0.6	0	0.5	0	1.1	0	4.9	3	0	1.9	5.4	24	21.1	26.4	61.2	0.023	0.798
49	2.4	0.1	0	0.1	0	0.2	0	2.5	0	1	2.5	2.6	24	23.0	25.0	0.0	0.012	0.810
50	2.6	0.3	0	0.5	0	0.8	1	2.9	0	1	2.9	3.4	48	21.5	28.1	0.0	0.014	0.823
51	3.4	0.3	0	0.5	0	0.8	0	3.7	2	0	1.7	4.2	24	22.1	27.2	54.1	0.018	0.841
52	2.2	0.5	0	0.6	0	1.1	1	2.7	0	1	2.7	3.3	24	19.6	29.3	0.0	0.013	0.854
53	3.3	0.4	0	0.4	0	0.8	0	3.7	0	1	3.7	4.1	48	21.4	26.6	0.0	0.018	0.871
54	4.1	0.5	0	0.3	0	0.8	0	4.6	0	1	4.6	4.9	72	21.4	25.6	0.0	0.022	0.893
55	4.9	0.1	0	0.1	0	0.2	0	5.0	0	1	5.0	5.1	96	23.5	24.5	0.0	0.024	0.917
56	5.1	0	1	0.3	0	0.3	1	5.1	4	0	1.1	5.4	24	24.0	25.4	78.4	0.024	0.941
57	1.4	0.1	0	0.1	0	0.2	0	1.5	0	1	1.5	1.6	24	22.4	25.6	0.0	0.007	0.948
58	1.6	0.2	0	0.2	0	0.4	0	1.8	0	1	1.8	2.0	48	21.3	26.7	0.0	0.009	0.956
59	2.0	0.3	0	0.3	0	0.6	0	2.3	0	1	2.3	2.6	72	20.9	27.1	0.0	0.011	0.967
60	2.6	0.6	0	0.3	0	0.9	1	3.2	0	1	3.2	3.5	96	19.5	26.3	0.0	0.015	0.982
61	3.5	0.2	0	0.2	0	0.4	0	3.7	0	1	3.7	3.9	120	22.7	25.3	0.0	0.018	1.000
	∑ =	16.4	8.0	22.3	0.0	38.7	19.0	211	36	47						90.2		

Table 18 contains summary of the analysis made for overall system performance of the three sample dump sites. The table depicts the combined effects of **Tables 14**, **16** and **17**. Also shown in the table are the overall system's server daily evacuation efficiency (η_d) and the transient state probabilities of quantities of waste in the three dumpsites.

Table 18: Summary of data collected on solid waste generation and evacuation processes in all the three sample dump sites of Awka city, Anambra State

Time	All the three Sample Dumpsites (No. Of Chain-up Bins = 9)																	
	ΣL_q	Σq_d		Σq_N (cb)		Σq $_{(d+N)}$		$\Sigma\lambda_q$	$\Sigma\mu_q$		L_w	L_s	W_a	W_q	W_s			
Days	(cb)		$\Sigma(N_{q=0})_d$		$\Sigma(N_{q=0})_N$	(cb)	N_{tGL}	(cbpd)		$N_{\mu=0}$	(cb)		hrs			η (%)	$P(t)_\lambda$	Cum $P_t(t)$
1	3.9	0.4	1	4.0	0	4.4	0	4.3	0	1	4.3	8.3	24	21.8	46.3	0.0	0.005	0.005
2	8.3	2.0	0	5.5	0	7.5	1	10.3	0	1	10.3	15.8	48	19.3	36.8	0.0	0.011	0.011
3	15.8	3.5	0	3.5	1	7.0	1	19.3	12	0	7.3	22.8	24	19.6	28.4	62.2	0.021	0.021
4	10.8	1.2	0	1.7	0	2.9	1	12.0	6	0	6.0	13.7	24	21.6	27.4	50.0	0.013	0.013
5	7.7	2.7	0	3.4	0	6.1	1	10.4	0	1	10.4	13.8	24	17.8	31.8	0.0	0.011	0.011
6	13.8	1.1	1	1.9	0	3.0	1	14.9	11	0	3.9	16.8	24	22.2	27.1	73.8	0.016	0.016
7	6.1	0.8	0	3.9	1	4.7	0	6.9	0	1	6.9	10.8	24	21.2	37.6	0.0	0.007	0.007
8	10.8	3.1	1	2.5	0	5.6	1	13.9	4	0	9.9	16.4	24	18.6	28.3	28.8	0.015	0.015
9	12.4	0.7	0	1.9	1	2.6	0	13.1	8	0	5.1	15.0	24	22.7	27.5	61.1	0.014	0.014
10	7.0	2.4	0	2.7	0	5.1	1	9.4	0	1	9.4	12.1	24	17.9	30.9	0.0	0.010	0.010
11	12.1	0.3	1	3.2	0	3.5	0	12.4	4	0	8.4	15.6	24	23.4	30.2	32.3	0.013	0.013
12	11.6	1.0	1	1.5	0	2.5	0	12.6	0	1	12.6	14.1	24	22.1	26.9	0.0	0.014	0.014
13	14.1	1.7	0	2.1	0	3.8	0	15.8	9	0	6.8	17.9	24	21.4	27.2	57.0	0.017	0.017
14	8.9	1.5	0	1.7	0	3.2	0	10.4	0	1	10.4	12.1	24	20.5	27.9	0.0	0.011	0.011
15	12.1	1.6	0	3.4	0	5.0	1	13.7	0	1	13.7	17.1	48	21.2	30.0	0.0	0.015	0.015
16	17.1	2.3	0	1.9	0	4.2	0	19.4	15	0	4.4	21.3	24	21.2	26.4	77.3	0.021	0.021
17	6.5	0.4	2	3.3	0	3.7	0	6.9	0	1	6.9	10.2	24	22.6	35.5	0.0	0.007	0.007
18	10.2	2.2	1	1.1	1	3.3	0	12.4	0	1	12.4	13.5	48	19.7	26.1	0.0	0.013	0.013
19	13.5	1.1	0	4.0	1	5.1	0	14.6	0	1	14.6	18.6	72	22.2	30.6	0.0	0.016	0.016
20	18.6	1.3	0	1.0	1	2.3	0	19.9	6	0	13.9	20.9	24	22.4	25.2	30.2	0.021	0.021
21	14.9	2.4	0	4.0	0	6.4	1	17.3	12	0	5.3	21.3	24	20.7	29.5	69.4	0.019	0.019
22	9.5	2.7	0	5.5	0	8.2	1	12.2	0	1	12.2	17.7	24	18.7	34.8	0.0	0.013	0.013
23	17.7	0.8	1	3.5	1	4.3	1	18.5	2	0	16.5	22.0	24	23.0	28.5	10.8	0.020	0.020
24	20.0	0.5	0	4.2	0	4.7	1	20.5	12	0	8.5	24.7	24	23.4	28.9	58.5	0.022	0.022
25	12.7	2.4	0	2.0	0	4.4	1	15.1	0	1	15.1	17.1	24	20.2	27.2	0.0	0.016	0.016
26	17.1	0.7	1	4.6	0	5.3	1	17.8	10	0	7.8	22.4	24	23.1	30.2	56.2	0.019	0.019
27	12.7	1.9	0	2.8	1	4.7	1	14.6	0	1	14.6	17.4	24	20.9	28.6	0.0	0.016	0.016
28	17.4	0.3	2	0.8	0	1.1	0	17.7	8	0	9.7	18.5	24	23.6	25.1	45.2	0.019	0.019
29	10.5	1.6	0	2.7	0	4.3	0	12.1	6	0	6.1	14.8	24	20.8	29.4	49.6	0.013	0.013
30	8.8	2.3	0	3.2	0	5.5	1	11.1	6	0	5.1	14.3	24	19.0	30.9	54.1	0.012	0.012
31	8.7	1.3	0	3.2	1	4.5	1	10.0	3	0	7.0	13.2	24	20.9	31.7	30.0	0.011	0.011
32	10.2	2.4	0	3.4	0	5.8	1	12.6	3	0	9.6	16.0	24	19.4	30.5	23.8	0.014	0.014
33	13.0	2.7	0	3.3	1	6.0	1	15.7	10	0	5.7	19.0	24	19.9	29.0	63.7	0.017	0.017
34	9.0	1.0	0	2.5	0	3.5	1	10.0	0	1	10.0	12.5	24	21.6	30.0	0.0	0.011	0.011
35	12.5	1.6	0	3.9	1	5.5	1	14.1	0	1	14.1	18.0	48	21.3	30.6	0.0	0.015	0.015
36	18.0	2.3	0	2.5	0	4.8	1	20.3	10	0	10.3	22.8	24	21.3	27.0	49.3	0.022	0.022
37	12.8	0.8	1	1.9	1	2.7	0	13.6	0	1	13.6	15.5	24	22.6	27.4	0.0	0.015	0.015
38	15.5	0.5	0	2.7	0	3.2	1	16.0	0	1	16.0	18.7	48	23.3	28.1	0.0	0.017	0.017
39	18.7	2.4	0	3.2	0	5.6	0	21.1	11	0	10.1	24.3	24	21.3	27.6	52.1	0.023	0.023
40	13.3	0.7	1	1.5	0	2.2	0	14.0	2	0	12.0	15.5	24	22.8	26.6	14.3	0.015	0.015
41	13.5	1.9	0	2.1	0	4.0	1	15.4	0	1	15.4	17.5	24	21.0	27.3	0.0	0.017	0.017
42	17.5	0.3	2	1.7	0	2.0	0	17.8	0	1	17.8	19.5	48	23.6	26.3	0.0	0.019	0.019
43	19.5	1.6	0	3.4	0	5.0	0	21.1	11	0	10.1	24.5	24	22.2	27.9	52.1	0.023	0.023
44	13.5	2.3	0	1.9	0	4.2	0	15.8	0	1	15.8	17.7	24	20.5	26.9	0.0	0.017	0.017
45	17.7	0.4	2	3.3	0	3.7	0	18.1	8	0	10.1	21.4	24	23.5	28.4	44.2	0.020	0.020
46	13.4	2.2	1	1.1	1	3.3	1	15.6	3	0	12.6	16.7	24	20.6	25.7	19.2	0.017	0.017
47	13.7	1.1	0	4.0	1	5.1	0	14.8	0	1	14.8	18.8	24	22.2	30.5	0.0	0.016	0.016
48	18.8	2.4	0	1.0	1	3.4	0	21.2	3	0	18.2	22.2	24	21.3	25.1	14.2	0.023	0.023
49	19.2	0.3	1	4.0	0	4.3	1	19.5	11	0	8.5	23.5	24	23.6	28.9	56.4	0.021	0.021
50	12.5	1.0	1	5.5	0	6.5	1	13.5	0	1	13.5	19.0	24	22.2	33.8	0.0	0.015	0.015
51	19.0	1.7	0	3.5	1	5.2	1	20.7	11	0	9.7	24.2	24	22.0	28.1	53.1	0.022	0.022
52	13.2	1.5	0	4.2	0	5.7	1	14.7	0	1	14.7	18.9	24	21.6	30.9	0.0	0.016	0.016
53	18.9	2.7	0	2.0	0	4.7	0	21.6	0	1	21.6	23.6	48	21.0	26.2	0.0	0.023	0.023
54	23.6	1.1	1	4.6	0	5.7	1	24.7	12	0	12.7	29.3	24	22.9	28.5	48.6	0.027	0.027
55	17.3	0.8	0	2.8	1	3.6	1	18.1	0	1	18.1	20.9	24	22.9	27.7	0.0	0.020	0.020

56	20.9	3.1	1	0.8	0	3.9	1	24.0	12	0	12.0	24.8	24	20.9	24.8	50.0	0.026	0.026
57	12.8	0.7	0	2.7	0	3.4	0	13.5	3	0	10.5	16.2	24	22.8	28.8	22.2	0.015	0.015
58	13.2	0.4	1	3.2	0	3.6	0	13.6	8	0	5.6	16.8	24	23.3	29.6	58.8	0.015	0.015
59	9.5	2.0	0	3.3	0	5.3	0	11.5	0	1	11.5	14.8	24	19.8	30.9	0.0	0.012	0.012
60	14.8	3.5	0	3.8	0	7.3	1	18.3	6	0	12.3	22.1	24	19.4	29.0	32.8	0.020	0.020
61	16.1	1.2	0	4.4	0	5.6	0	17.3	3	0	14.3	21.7	24	22.3	30.1	17.3	0.019	0.019
		94.8	24	178.9	17	273.7	33	927.7	261.0	27						94.0		

Table 19 is derived from **Tables 14**, **16**, **17** and **18**. The table shows a summary report on the mean and mean of mean values obtained for the various dependent variables by applying the relevant developed models. A close look at the table reveals that almost all the variables in the models developed from the study are well represented.

Table 19: Summary of Awka solid waste management system performance evaluation

Para-meter/ Symbol	**Source/Ref. Eqn.**	**Dumpsite Obtainable**			**Computed Values for All Dumpsites**		**Unit of Measure**	Comment
		Ogbali-ngba	**Eke Awka Market**	**Ifite Market**				
		Mean values per demonstration run						
		($t = i$ to n)			**Overall**	**Mean**		
N_b	-	3	4	2	9	3	bins	
n	-	61	61	61	61	61	days	
L_q	(51b), (52a)	4.1	6.4	3.2	13.7	4.6	cb	
q_d	(51c), (52b), Tables 14, 16, 17 & 18	0.3	1.0	0.3	1.6	0.5	cb	
$(N_{\lambda=0})_d$	Tables 13, 15, 16 & 17	0.1	0.2	0.1	0.4	0.1	days	
q_N	(51c), (52b), Tables 13, 15, 16 & 17	0.4	2.2	0.4	2.9	1.0	cb	
$(N_{\lambda=0})_N$	Tables 13, 15, 16 & 17	0.2	0.1	0.0	0.3	0.1	days	
$q_{(d+N)}$	(52c)	0.7	3.2	0.4	4.5	1.5	cb	
λ	(54a), (54b)	4.35	7.40	3.46	15.21	5.07	cbpd	ρ >1, makes system unstable
μ	(55), Tables 13, 15, 16 & 17	0.62	3.07	0.59	4.28	1.43	cbpd	
ρ	(60)	6.984	2.413	5.864	3.554	3.554	Erlang	
ρ'	(54), Tables 14, 16, 17 & 18	0.873	0.931	0.963	0.940	0.923	Erlang	ρ <1, makes system stable
μ'		5	8	4	16	5	cbpd	
$\mathbf{N_{tqL}}$	(53e)	13	48	19	33	27	-	
$\mathbf{t_{GL}}$	(53d)	5	1	3	2	2	days	
$N_{s,o}$	(62)	45	38	47	27	27	days	
L_w	(57d)	3.7	4.4	2.9	10.9	3.7	cb	
$\mathbf{L_s}$	(56b), (56c)	4.8	9.6	3.8	18.1	6.0	cb	
W_a	(60c)	17.7	15.0	18.5	10.6	10.6	hrs	
W_q	(58a)	22.4	20.1	21.8	21.4	21.4	hrs	
W_s	(58b)	26.5	36.1	26.8	29.3	29.3	hrs	

η	(59a), (59b)	88.8	95.9	90.2	94.0	91.7	%	
P_o	(66c)	0.156	0.115	0.066	0.336	-	-	
$(P_o)_d$	(66a)	0.098	0.164	0.131	0.393	-	-	
$(P_o)_N$	(66b)	0.213	0.066	0.000	0.279	-	-	

Summary of the waste management system's performance data of **Table 19** gives the λ and μ for each of the three dumpsites. For the all three dumpsites (the mean): λ = 15.02 cbpd and μ = 4.23 cbpd, showing that there is instability in the system. For the system to be considered stable, the waste service (disposal/removal/evacuation) rate must be greater than the waste arrival (dump/generation/production) rate, i.e. $\mu > \lambda$. The mean values obtained for these parameters were used in coding a single line multi-server queuing system based on eqns (64) (or (15)) and (16) to estimate the optimum number of servers (***s***) that should make the system stable. **Table 20** refers.

Table 20: Evaluation of queue system performance when λ and μ are constant and *s* is Varied

s	2	3	4	5	6	7	8	9	10	11	12
ρ	1.775	1.184	0.888	0.710	0.592	0.507	0.444	0.395	0.355	0.323	0.296
P_0	-0.279	-0.034	0.013	0.024	0.027	0.028	0.029	0.029	0.029	0.029	0.029

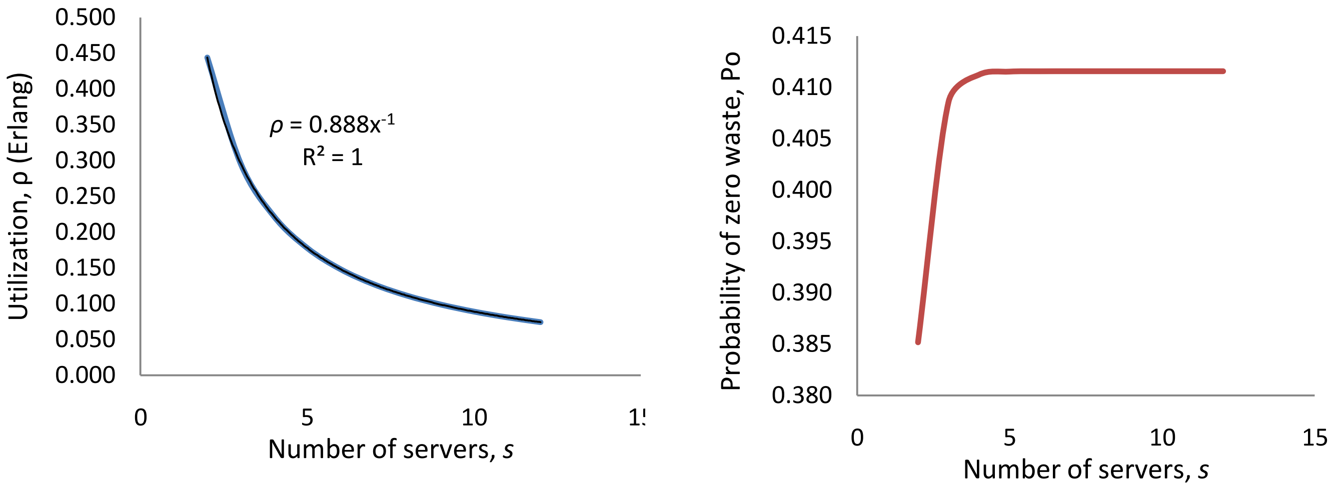
From the data in **Table 20**, it could be observed that as *s* increases the system becomes more stable. However from *s* = 1 to *s* = 3 the system still remains unstable with $\rho > 1$. From *s* >= 4 servers, $\rho < 1$ and the system becomes more stable . Implying that $\mu > \lambda$. But employing more number of servers (disposal trucks) keeps the facilities underutilized. Increasing the present service rate by interpolation to optimal number of 16 cbpd will make $\rho \approx 0.940$ and may be the best option among those provided in **Table 21**.

Table 21 contains a new set of data generated based on the new scenario: λ = 15.02 cbpd and μ = 16 cbpd. A plot of the server system utilization factor against the number of servers (Figure 26) shows clearly that ρ decreases as *s* increases. A trendline equation generated from this plot shows that ρ relates with s as: $\rho = 0.888s^{-1}$ and gives the $R^2 = 1$.

Table 21: Data on the new combined system's performance for the three sample dumpsites

s	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
ρ	0.444	0.296	0.222	0.178	0.148	0.127	0.111	0.099	0.089	0.081	0.074
P_0	0.385	0.409	0.411	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412

Also of interest is the possibility of not having huge piles of waste as we see them in the three dumpsites studied in the present course when the server trucks work on the three dumpsites at the rate of 32 cbpd, 48 cbpd, 64 cbpd, etc. This possibility of having no waste in the system is illustrated in Figure 26. The plot shows a positive possibility of such a condition as the number of servers increases and settles at 0.412.



(a): Plot of combined server system utilization against number of servers.

(b): Plot of probability of having no waste in the system against number of servers

Figure 26: Performance evaluation on the three sample dumpsites

The same analysis was made with the data on the entire Awka MSWM presented in **Table 10**. Total number of days in the 36 month study period = 1096, total quantity of waste generated in the base period λ_T = 67024.6 cb and total quantity evacuated μ_T = 36741cb. These values gave average values: $\lambda \approx 61.15$ cbpd and $\mu \approx 33.52$ cbpd. Analysis made shows that the entire system would be stable if the number of the present service rate is doubled which gives $\rho = 0.912$ Erlang. This new value of ρ shows $\mu \approx 67$ cbpd.

If the values in **Tables 14** through **21** are carefully perused, they seem to suggest the reasons why waste containers in Awka municipality and other dumpsites in Anambra State are always fully loaded, and in some cases, overflowing with waste; appearing to the uninformed passersby in the street as if ASWAMA is not doing much work. But the study has shown from both the subsystems and the overall systems efficiencies that the agency is really performing, and that its service facilities are in fact, being over utilized. The over utilization could be a major reason for the incessant breakdowns of these facilities.

4.2.7 Simulation of Waste Generation and Evacuation Lead Times for Awka MSW Dumpsites

In section 3.2.3, a good number of assumptions were made for application of EWEQ principles in SWIM models, some of which include the following:

a. The state (quantity) of waste at the dumpsite(s) is always monitored.
b. Rate of waste generation is known or relatively uniform
c. Waste evacuation lead time is fixed.
d. Waste evacuation is made instantaneously, the whole batch is disposed/transported at once.

Time taken to fill a set of waste bins kept at any given dumpsite is considered herein this discussion as the WGLT (t_{GL}) for that dumpsite. Taking the above assumptions into consideration, data in **Tables 14, 16** and **17** were used in determining the WGLTs for the sample three dumpsites as contained in **Table 18**. Let it also be assumed that the numerical data contained in the above said three tables are the mean values of the quantities of waste generated daily in the referenced dumpsites for a given length of time, say one year. Number of bins kept at Ogbalingba, Eke Awka Market and Ifite Market dumpsites are 3, 4 and 2 respectively. The WGLTs (t_{GL}) for the three dumpsites were evaluated and depicted in **Table 18** as 5, 1 and 3 respectively. Taking the total volumes of the containers kept in each of the dumpsites as the maximum allowable (upper limit) stocks for the sites, and by varying the WELT (t_{EL}) it is easy to visualize the stablibilty of the SWM systems at the dumpsites. It should be note that in actual practice *D* has inverse relationship with the waste lead times. Starting with the assumption that WELT = WGLT for the three dumpsites, the data in **Tables 22** to **24** were generated and plotted in Figures 27, 28 and 29 respectively for Ogbalingba, Eke Awka and Ifite Markets dumpsites.

Table 22: Simulation of waste evacuation lead times at Ogbalingba dumpsite of Awka city, Anambra State

Ogbalingba Dumpsite: No. Of Chain-up Bins = 3 and WELT = 5 days

Time Days	L_a (cb)	q_d (cb)	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	q $(d+N)$ (cb)	N_{tgL}	λ_a (cbpd)	D (cbpd)	$N_{\mu=1}$ days	L_w (cb)	L_s (cb)	W_a (hrs)	W_q (hrs)	W_s (hrs)	η (%)	$P(t)_\lambda$	Cum. $P(t)_\lambda$
1	2.0	0.2	0	0.3	0	0.5	0	2.2	0	0	2.2	2.5	24	21.8	27.3	0.0	0.017	0.017
2	2.5	0.2	0	0.5	0	0.7	0	2.7	0	0	2.7	3.2	48	22.2	28.4	0.0	0.021	0.038
3	3.2	0.5	0	0.0	1	0.5	0	3.7	0	0	3.7	3.7	72	20.8	24.0	0.0	0.029	0.067
4	3.7	0.2	0	0.4	0	0.6	0	3.9	0	0	3.9	4.3	96	22.8	26.5	0.0	0.030	0.097
5	4.3	0.4	0	0.5	0	0.9	1	4.7	4.7	5	0.0	5.2	24	22.0	26.6	100.0	0.037	0.134
6	0.5	0.0	1	0.8	0	0.8	0	0.5	0	0	0.5	1.3	24	24.0	62.4	0.0	0.004	0.138
7	1.3	0.2	0	0.0	1	0.2	0	1.5	0	0	1.5	1.5	48	20.8	24.0	0.0	0.012	0.150
8	1.5	0.9	0	0.8	0	1.7	0	2.4	0	0	2.4	3.2	72	15.0	32.0	0.0	0.019	0.168
9	3.2	0.4	0	0.0	1	0.4	1	3.6	0	0	3.6	3.6	96	21.3	24.0	0.0	0.028	0.196
10	3.6	0.2	0	0.6	0	0.8	0	3.8	3.8	5	0.0	4.4	24	22.7	27.8	100.0	0.030	0.226
11	0.6	0.2	0	0.5	0	0.7	0	0.8	0	0	0.8	1.3	24	18.0	39.0	0.0	0.006	0.232
12	1.3	0.0	1	0.5	0	0.5	0	1.3	0	0	1.3	1.8	48	24.0	33.2	0.0	0.010	0.242
13	1.8	0.2	0	0.6	0	0.8	1	2.0	0	0	2.0	2.6	72	21.6	31.2	0.0	0.016	0.258
14	2.6	0.4	0	0.4	0	0.8	0	3.0	0	0	3.0	3.4	96	20.8	27.2	0.0	0.023	0.281
15	3.4	0.2	0	0.5	0	0.7	0	3.6	3.6	5	0.0	4.1	24	22.7	27.3	100.0	0.028	0.309
16	0.5	0.2	0	0.8	0	1.0	0	0.7	0	0	0.7	1.5	24	17.1	51.4	0.0	0.005	0.315

17	1.5	0.4	0	0.2	0	0.6	1	1.9	0	0	1.9	2.1	48	18.9	26.5	0.0	0.015	0.330
18	2.1	0.0	1	0.7	0	0.7	0	2.1	0	0	2.1	2.8	72	24.0	32.0	0.0	0.016	0.346
19	2.8	0.4	0	0.0	1	0.4	0	3.2	0	0	3.2	3.2	96	21.0	24.0	0.0	0.025	0.371
20	3.2	0.2	0	0.5	0	0.7	0	3.4	3.4	5	0.0	3.9	24	22.6	27.5	100.0	0.027	0.398
21	0.5	0.3	0	0.3	0	0.6	0	0.8	0	0	0.8	1.1	24	15.0	33.0	0.0	0.006	0.404
22	1.1	0.2	0	0.5	0	0.7	1	1.3	0	0	1.3	1.8	48	20.3	33.2	0.0	0.010	0.414
23	1.8	0.3	0	0.0	1	0.3	0	2.1	0	0	2.1	2.1	72	20.6	24.0	0.0	0.016	0.430
24	2.1	0.1	0	0.8	0	0.9	0	2.2	0	0	2.2	3.0	96	22.9	32.7	0.0	0.017	0.447
25	3.0	0.3	0	0.7	0	1.0	0	3.3	3.3	5	0.0	4.0	24	21.8	29.1	100.0	0.026	0.473
26	0.7	0.2	0	0.3	0	0.5	0	0.9	0	0	0.9	1.2	24	18.7	32.0	0.0	0.007	0.480
27	1.2	0.1	0	0.0	1	0.1	1	1.3	0	0	1.3	1.3	48	22.2	24.0	0.0	0.010	0.490
28	1.3	0.3	0	0.3	0	0.6	0	1.6	0	0	1.6	1.9	72	19.5	28.5	0.0	0.012	0.503
29	1.9	0.2	0	0.2	0	0.4	0	2.1	0	0	2.1	2.3	96	21.7	26.3	0.0	0.016	0.519
30	2.3	0.2	0	0.4	0	0.6	0	2.5	2.5	5	0.0	2.9	24	22.1	27.8	100.0	0.019	0.539
31	0.4	0.2	0	0.0	1	0.2	0	0.6	0	0	0.6	0.6	24	16.0	24.0	0.0	0.005	0.543
32	0.6	0.3	0	0.4	0	0.7	0	0.9	0	0	0.9	1.3	48	16.0	34.7	0.0	0.007	0.550
33	1.3	0.2	0	0.0	1	0.2	0	1.5	0	0	1.5	1.5	72	20.8	24.0	0.0	0.012	0.562
34	1.5	0.2	0	0.6	0	0.8	1	1.7	0	0	1.7	2.3	96	21.2	32.5	0.0	0.013	0.575
35	2.3	0.4	0	0.0	1	0.4	0	2.7	2.7	5	0.0	2.7	24	20.4	24.0	100.0	0.021	0.596
36	0.0	0.7	0	0.8	0	1.5	0	0.7	0	0	0.7	1.5	24	0.0	51.4	0.0	0.005	0.602
37	1.5	0.3	0	0.0	1	0.3	0	1.8	0	0	1.8	1.8	48	20.0	24.0	0.0	0.014	0.616
38	1.8	0.1	0	0.6	0	0.7	1	1.9	0	0	1.9	2.5	72	22.7	31.6	0.0	0.015	0.631
39	2.5	0.3	0	0.5	0	0.8	0	2.8	0	0	2.8	3.3	96	21.4	28.3	0.0	0.022	0.652
40	3.3	0.2	0	0.5	0	0.7	0	3.5	3.5	5	0.0	4.0	24	22.6	27.4	100.0	0.027	0.680
41	0.5	0.1	0	0.6	0	0.7	0	0.6	0	0	0.6	1.2	24	20.0	48.0	0.0	0.005	0.684
42	1.2	0.3	0	0.4	0	0.7	1	1.5	0	0	1.5	1.9	48	19.2	30.4	0.0	0.012	0.696
43	1.9	0.2	0	0.5	0	0.7	0	2.1	0	0	2.1	2.6	72	21.7	29.7	0.0	0.016	0.712
44	2.6	0.2	0	0.8	0	1.0	0	2.8	0	0	2.8	3.6	96	22.3	30.9	0.0	0.022	0.734
45	3.6	0.4	0	0.2	0	0.6	0	4.0	4	5	0.0	4.2	24	21.6	25.2	100.0	0.031	0.765
46	0.2	0.0	1	0.7	0	0.7	1	0.2	0	0	0.2	0.9	24	24.0	108.0	0.0	0.002	0.767
47	0.9	0.4	0	0.0	1	0.4	0	1.3	0	0	1.3	1.3	48	16.6	24.0	0.0	0.010	0.777
48	1.3	0.2	0	0.5	0	0.7	0	1.5	0	0	1.5	2.0	72	20.8	32.0	0.0	0.012	0.789
49	2.0	0.2	0	0.3	0	0.5	0	2.2	0	0	2.2	2.5	96	21.8	27.3	0.0	0.017	0.806
50	2.5	0.0	1	0.5	0	0.5	0	2.5	2.5	5	0.0	3.0	24	24.0	28.8	100.0	0.019	0.825
51	0.5	0.2	0	0.0	1	0.2	0	0.7	0	0	0.7	0.7	24	17.1	24.0	0.0	0.005	0.831
52	0.7	0.4	0	0.8	0	1.2	1	1.1	0	0	1.1	1.9	48	15.3	41.5	0.0	0.009	0.839
53	1.9	0.4	0	0.7	0	1.1	0	2.3	0	0	2.3	3.0	72	19.8	31.3	0.0	0.018	0.857
54	3.0	0.0	1	0.3	0	0.3	0	3.0	0	0	3.0	3.3	96	24.0	26.4	0.0	0.023	0.881
55	3.3	0.2	0	0.0	1	0.2	0	3.5	3.5	5	0.0	3.5	24	22.6	24.0	100.0	0.027	0.908
56	0.0	0.9	0	0.3	0	1.2	1	0.9	0	0	0.9	1.2	24	0.0	32.0	0.0	0.007	0.915
57	1.2	0.4	0	0.2	0	0.6	0	1.6	0	0	1.6	1.8	48	18.0	27.0	0.0	0.012	0.928
58	1.8	0.2	0	0.4	0	0.6	0	2.0	0	0	2.0	2.4	72	21.6	28.8	0.0	0.016	0.943
59	2.4	0.2	0	0.5	0	0.7	0	2.6	0	0	2.6	3.1	96	22.2	28.6	0.0	0.020	0.963
60	3.1	0.5	0	0.9	0	1.4	1	3.6	3.6	5	0.0	4.5	24	20.7	30.0	100.0	0.028	0.991
61	0.9	0.2	0	0.6	0	0.8	0	1.1	0	0	1.1	1.7	24	19.6	37.1	0.0	0.009	1.000

Figure 28 is plot of *D* against t_{EL} for Ogbalingba dumpsite. The figure shows that if t_{EL} = 5 days due to some considerstions made such as costs, server failure, administrative bottle neck, etc the system will still be unstable. This claim is supported by the points of *D* above the dashed reference line representing the maximum allowable stock of waste at the dumpsite.

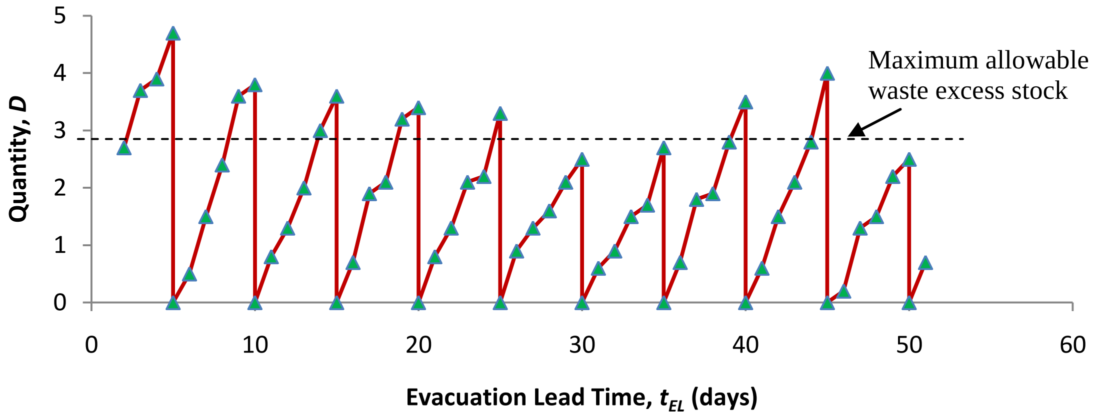


Figure 27: Ogbalingba SWM system stability when WELT = 5 days

The same explanations made on Ogbalingba dumpsite still holds for Eke Awka Market dumpsite with t_{EL} = 1 day (see **Table 23** and Figure 28).

Table 23: Simulation of waste evacuation lead time at Eke Awka Market dumpsite of Awka city, Anambra State

Eke Awka Market Dumpsite: No. Of Chain-up Bins = 4 and WELT = 1 day																		
Time	L_q	q_d				q		λ_q	D	$N_{\mu=1}$	L_w	L_s	W_a	W_q	W_s			
Days	(cb)		$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$(d+N)$ (cb)	N_{tqL}	(cbpd)		days	(cb)		(hrs)			η (%)	$P(t)_\lambda$	Cum. $P(t)_\lambda$
1	0.7	0.0	1	3.6	0	3.6	0	0.7	0.7	0	0.0	4.3	24	24.0	147.4	100.0	0.004	0.004
2	3.6	1.5	0	4.5	0	6.0	1	5.1	5.1	0	0.0	9.6	24	16.9	45.2	100.0	0.027	0.030
3	4.5	2.4	0	3.0	0	5.4	1	6.9	6.9	0	0.0	9.9	24	15.7	34.4	100.0	0.036	0.066
4	3.0	0.8	0	1.2	0	2.0	1	3.8	3.8	0	0.0	5.0	24	18.9	31.6	100.0	0.020	0.086
5	1.2	1.9	0	2.5	0	4.4	1	3.1	3.1	0	0.0	5.6	24	9.3	43.4	100.0	0.016	0.102
6	2.5	0.6	0	0.7	0	1.3	1	3.1	3.1	0	0.0	3.8	24	19.4	29.4	100.0	0.016	0.119
7	0.7	0.5	0	3.1	0	3.6	1	1.2	1.2	0	0.0	4.3	24	14.0	86.0	100.0	0.006	0.125
8	3.1	2.2	0	1.4	0	3.6	1	5.3	5.3	0	0.0	6.7	24	14.0	30.3	100.0	0.028	0.153
9	1.4	0.2	0	1.6	0	1.8	0	1.6	1.6	0	0.0	3.2	24	21.0	48.0	100.0	0.008	0.161
10	1.6	1.6	0	1.7	0	3.3	1	3.2	3.2	0	0.0	4.9	24	12.0	36.8	100.0	0.017	0.178
11	1.7	0.0	1	2.0	0	2.0	1	1.7	1.7	0	0.0	3.7	24	24.0	52.2	100.0	0.009	0.187
12	2.0	0.7	0	0.7	0	1.4	0	2.7	2.7	0	0.0	3.4	24	17.8	30.2	100.0	0.014	0.201
13	0.7	1.2	0	1.1	0	2.3	1	1.9	1.9	0	0.0	3.0	24	8.8	37.9	100.0	0.010	0.211
14	1.1	0.6	0	1.2	0	1.8	0	1.7	1.7	0	0.0	2.9	24	15.5	40.9	100.0	0.009	0.220
15	1.2	1.1	0	2.5	0	3.6	1	2.3	2.3	0	0.0	4.8	24	12.5	50.1	100.0	0.012	0.232
16	2.5	1.7	0	0.7	0	2.4	1	4.2	4.2	0	0.0	4.9	24	14.3	28.0	100.0	0.022	0.254
17	0.7	0.0	1	2.6	0	2.6	0	0.7	0.7	0	0.0	3.3	24	24.0	113.1	100.0	0.004	0.257
18	2.6	1.8	0	0.0	1	1.8	1	4.4	4.4	0	0.0	4.4	24	14.2	24.0	100.0	0.023	0.280
19	0.0	0.5	0	3.5	0	4.0	1	0.5	0.5	0	0.0	4.0	24	0.0	192.0	100.0	0.003	0.283
20	3.5	1.0	0	0.0	1	1.0	0	4.5	4.5	0	0.0	4.5	24	18.7	24.0	100.0	0.024	0.306
21	0.0	1.7	0	3.6	0	5.3	1	1.7	1.7	0	0.0	5.3	24	0.0	74.8	100.0	0.009	0.315
22	3.6	2.3	0	4.5	0	6.8	1	5.9	5.9	0	0.0	10.4	24	14.6	42.3	100.0	0.031	0.346
23	4.5	0.0	1	3.0	0	3.0	1	4.5	4.5	0	0.0	7.5	24	24.0	40.0	100.0	0.024	0.370
24	3.0	0.1	0	2.8	0	2.9	1	3.1	3.1	0	0.0	5.9	24	23.2	45.7	100.0	0.016	0.386
25	2.8	2.0	0	0.9	0	2.9	1	4.8	4.8	0	0.0	5.7	24	14.0	28.5	100.0	0.025	0.411
26	0.9	0.5	0	4.0	0	4.5	1	1.4	1.4	0	0.0	5.4	24	15.4	92.6	100.0	0.007	0.418
27	4.0	1.5	0	2.7	0	4.2	1	5.5	5.5	0	0.0	8.2	24	17.5	35.8	100.0	0.029	0.447
28	2.7	0.0	1	0.2	0	0.2	0	2.7	2.7	0	0.0	2.9	24	24.0	25.8	100.0	0.014	0.461
29	0.2	1.1	0	2.4	0	3.5	1	1.3	1.3	0	0.0	3.7	24	3.7	68.3	100.0	0.007	0.468
30	2.4	1.7	0	2.6	0	4.3	1	4.1	4.1	0	0.0	6.7	24	14.0	39.2	100.0	0.021	0.489
31	2.6	1	0	3.1	0	4.1	1	3.6	3.6	0	0.0	6.7	24	17.3	44.7	100.0	0.019	0.508
32	3.1	1.7	0	2.7	0	4.4	1	4.8	4.8	0	0.0	7.5	24	15.5	37.5	100.0	0.025	0.533
33	2.7	2.3	0	2.7	0	5.0	1	5.0	5	0	0.0	7.7	24	13.0	37.0	100.0	0.026	0.559
34	2.7	0.4	0	1.6	0	2.0	1	3.1	3.1	0	0.0	4.7	24	20.9	36.4	100.0	0.016	0.576
35	1.6	0.9	0	3.1	0	4.0	1	2.5	2.5	0	0.0	5.6	24	15.4	53.8	100.0	0.013	0.589
36	3.1	1.4	0	1.4	0	2.8	1	4.5	4.5	0	0.0	5.9	24	16.5	31.5	100.0	0.024	0.612
37	1.4	0	1	1.6	0	1.6	0	1.4	1.4	0	0.0	3.0	24	24.0	51.4	100.0	0.007	0.619
38	1.6	0.1	0	1.7	0	1.8	1	1.7	1.7	0	0.0	3.4	24	22.6	48.0	100.0	0.009	0.628
39	1.7	2	0	2	0	4.0	1	3.7	3.7	0	0.0	5.7	24	11.0	37.0	100.0	0.019	0.648
40	2	0.5	0	0.7	0	1.2	0	2.5	2.5	0	0.0	3.2	24	19.2	30.7	100.0	0.013	0.661
41	0.7	1.5	0	1.1	0	2.6	1	2.2	2.2	0	0.0	3.3	24	7.6	36.0	100.0	0.012	0.672
42	1.1	0	1	1.2	0	1.2	0	1.1	1.1	0	0.0	2.3	24	24.0	50.2	100.0	0.006	0.678
43	1.2	1.1	0	2.5	0	3.6	1	2.3	2.3	0	0.0	4.8	24	12.5	50.1	100.0	0.012	0.690
44	2.5	1.7	0	0.7	0	2.4	1	4.2	4.2	0	0.0	4.9	24	14.3	28.0	100.0	0.022	0.712
45	0.7	0	1	2.6	0	2.6	0	0.7	0.7	0	0.0	3.3	24	24.0	113.1	100.0	0.004	0.716
46	2.6	1.8	0	0	1	1.8	1	4.4	4.4	0	0.0	4.4	24	14.2	24.0	100.0	0.023	0.739
47	0	0.5	0	3.5	0	4.0	1	0.5	0.5	0	0.0	4.0	24	0.0	192.0	100.0	0.003	0.741
48	3.5	1.6	0	0	1	1.6	0	5.1	5.1	0	0.0	5.1	24	16.5	24.0	100.0	0.027	0.768
49	0	0	1	3.6	0	3.6	1	0.0	0	1	0.0	3.6	24	0.0	0.0	100.0	0.000	0.768
50	3.6	0.7	0	4.5	0	5.2	1	4.3	4.3	0	0.0	8.8	24	20.1	49.1	100.0	0.022	0.790
51	4.5	1.2	0	3	0	4.2	1	5.7	5.7	0	0.0	8.7	24	18.9	36.6	100.0	0.030	0.820
52	3	0.6	0	2.8	0	3.4	1	3.6	3.6	0	0.0	6.4	24	20.0	42.7	100.0	0.019	0.839
53	2.8	1.9	0	0.9	0	2.8	1	4.7	4.7	0	0.0	5.6	24	14.3	28.6	100.0	0.025	0.864
54	0.9	0.6	0	4	0	4.6	1	1.5	1.5	0	0.0	5.5	24	14.4	88.0	100.0	0.008	0.871
55	4	0.5	0	2.7	0	3.2	1	4.5	4.5	0	0.0	7.2	24	21.3	38.4	100.0	0.024	0.895
56	2.7	2.2	0	0.2	0	2.4	0	4.9	4.9	0	0.0	5.1	24	13.2	25.0	100.0	0.026	0.921
57	0.2	0.2	0	2.4	0	2.6	1	0.4	0.4	0	0.0	2.8	24	12.0	168.0	100.0	0.002	0.923
58	2.4	0	1	2.6	0	2.6	1	2.4	2.4	0	0.0	5.0	24	24.0	50.0	100.0	0.013	0.935
59	2.6	1.5	0	2.5	0	4.0	1	4.1	4.1	0	0.0	6.6	24	15.2	38.6	100.0	0.021	0.957
60	2.5	2.4	0	2.6	0	5.0	1	4.9	4.9	0	0.0	7.5	24	12.2	36.7	100.0	0.026	0.982
61	2.6	0.8	0	3.6	0	4.4	1	3.4	3.4	0	0.0	7.0	24	18.4	49.4	100.0	0.018	1.000

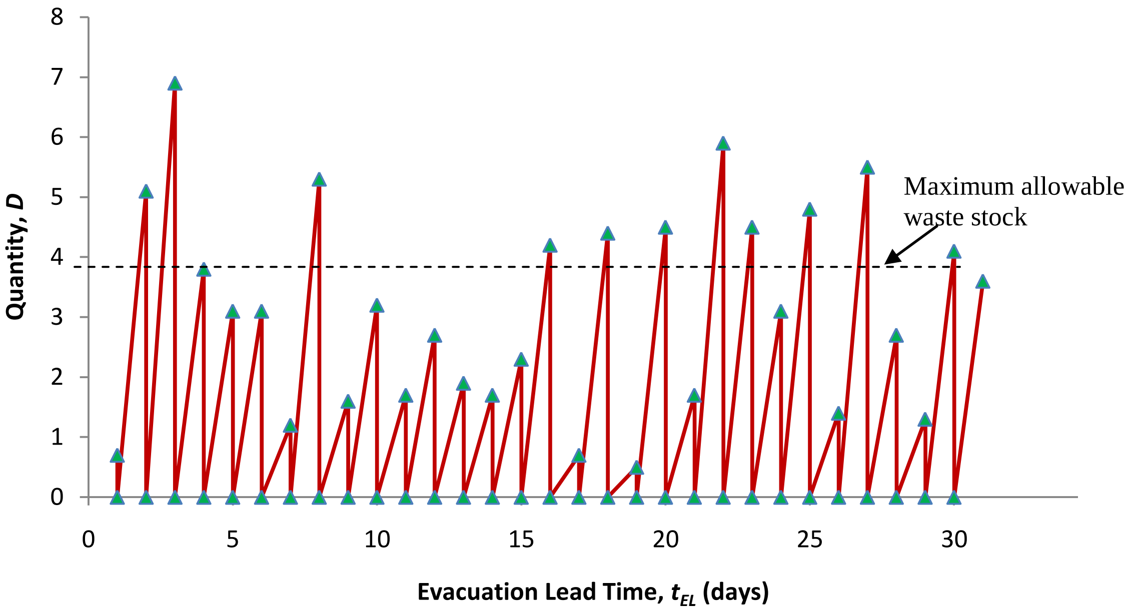


Figure 28: Eke Awka Market SWM system stability when WELT = 1 day

With the t_{EL} for Eke Awka Market set to hold on daily basis, the system still shows instability. If the t_{EL} is reduced further the system will definitely become more stable, but not without more financial implications being involved.

For Ifite Market dumpsite, with t_{EL} = 3 days, **Table 24** and Figure 29 refer.

Table 24: Simulation of waste evacuation lead times at Ifite Market dumpsite of Awka city, Anambra State

Ifite Market Dumpsite: No. Of Chain-up Bins = 2 and WELT = 3 day																		
Time	L_q	q_d				q		λ_q	D	$N_{\mu=1}$	L_w	L_s	W_a	W_q	W_s			
Days	(cb)		$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$(d+N)$ (cb)	N_{tgL}	(cbpd)		days	(cb)		(hrs)			η (%)	$P(t)_\lambda$	Cum. $P(t)_\lambda$
1	1.2	0.2	0	0.1	0	0.3	4	0.3	0	1.4	0	1	1.4	1.5	24	20.6	25.7	0.0
2	1.5	0.3	0	0.5	0	0.8	4	1.1	0	1.8	0	1	1.8	2.3	48	20.0	30.7	0.0
3	2.3	0.6	0	0.5	0	1.1	4	2.2	0	2.9	2.9	0	0.0	3.4	24	19.0	28.1	100.0
4	0.5	0.2	0	0.1	0	0.3	4	2.5	0	0.7	0	1	0.7	0.8	24	17.1	27.4	0.0
5	0.8	0.4	0	0.4	0	0.8	4	3.3	0	1.2	0	1	1.2	1.6	48	16.0	32.0	0.0
6	1.6	0.5	0	0.4	0	0.9	4	0.2	1	2.1	2.1	0	0.0	2.5	24	18.3	28.6	100.0
7	0.4	0.1	0	0.8	0	0.9	4	1.1	0	0.5	0	1	0.5	1.3	24	19.2	62.4	0.0
8	1.3	0.0	1	0.3	0	0.3	4	1.4	0	1.3	0	1	1.3	1.6	48	24.0	29.5	0.0
9	1.6	0.1	0	0.3	0	0.4	4	1.8	0	1.7	1.7	0	0.0	2.0	24	22.6	28.2	100.0
10	0.3	0.6	0	0.4	0	1.0	4	2.8	0	0.9	0	1	0.9	1.3	24	8.0	34.7	0.0
11	1.3	0.1	0	0.7	0	0.8	4	3.6	0	1.4	0	1	1.4	2.1	48	22.3	36.0	0.0
12	2.1	0.3	0	0.3	0	0.6	4	0.2	1	2.4	2.4	0	0.0	2.7	24	21.0	27.0	100.0
13	0.3	0.3	0	0.4	0	0.7	4	0.9	0	0.6	0	1	0.6	1.0	24	12.0	40.0	0.0
14	1.0	0.5	0	0.1	0	0.6	4	1.5	0	1.5	0	1	1.5	1.6	48	16.0	25.6	0.0
15	1.6	0.3	0	0.4	0	0.7	4	2.2	0	1.9	1.9	0	0.0	2.3	24	20.2	29.1	100.0
16	0.4	0.4	0	0.4	0	0.8	4	3.0	0	0.8	0	1	0.8	1.2	24	12.0	36.0	0.0
17	1.2	0.0	1	0.5	0	0.5	4	3.5	0	1.2	0	1	1.2	1.7	48	24.0	34.0	0.0
18	1.7	0.4	0	0.4	0	0.8	4	0.3	1	2.1	2.1	0	0.0	2.5	24	19.4	28.6	100.0
19	0.4	0.2	0	0.5	0	0.7	4	1.0	0	0.6	0	1	0.6	1.1	24	16.0	44.0	0.0
20	1.1	0.1	0	0.5	0	0.6	4	1.6	0	1.2	0	1	1.2	1.7	48	22.0	34.0	0.0
21	1.7	0.4	0	0.1	0	0.5	4	2.1	0	2.1	2.1	0	0.0	2.2	24	19.4	25.1	100.0
22	0.1	0.2	0	0.5	0	0.7	4	2.8	0	0.3	0	1	0.3	0.8	24	8.0	64.0	0.0
23	0.8	0.5	0	0.5	0	1.0	4	3.8	0	1.3	0	1	1.3	1.8	48	14.8	33.2	0.0
24	1.8	0.3	0	0.6	0	0.9	4	0.7	1	2.1	2.1	0	0.0	2.7	24	20.6	30.9	100.0
25	0.6	0.1	0	0.4	0	0.5	4	1.2	0	0.7	0	1	0.7	1.1	24	20.6	37.7	0.0
26	1.1	0.0	1	0.3	0	0.3	4	1.5	0	1.1	0	1	1.1	1.4	48	24.0	30.5	0.0
27	1.4	0.3	0	0.1	0	0.4	4	1.9	0	1.7	1.7	0	0.0	1.8	24	19.8	25.4	100.0
28	0.1	0.0	1	0.3	0	0.3	4	2.2	0	0.1	0	1	0.1	0.4	24	24.0	96.0	0.0
29	0.4	0.3	0	0.1	0	0.4	4	2.6	0	0.7	0	1	0.7	0.8	48	13.7	27.4	0.0

30	0.8	0.4	0	0.2	0	0.6	4	3.2	0	1.2	1.2	0	0.0	1.4	24	16.0	28.0	100.0
31	0.2	0.1	0	0.1	0	0.2	4	3.4	0	0.3	0	1	0.3	0.4	24	16.0	32.0	0.0
32	0.4	0.4	0	0.3	0	0.7	4	0.1	1	0.8	0	1	0.8	1.1	48	12.0	33.0	0.0
33	1.1	0.2	0	0.6	0	0.8	4	0.9	0	1.3	1.3	0	0.0	1.9	24	20.3	35.1	100.0
34	0.6	0.4	0	0.3	0	0.7	4	1.6	0	1.0	0	1	1.0	1.3	24	14.4	31.2	0.0
35	1.3	0.3	0	0.8	0	1.1	4	2.7	0	1.6	0	1	1.6	2.4	48	19.5	36.0	0.0
36	2.4	0.2	0	0.3	0	0.5	4	3.2	0	2.6	2.6	0	0.0	2.9	24	22.2	26.8	100.0
37	0.3	0.5	0	0.3	0	0.8	4	4.0	0	0.8	0	1	0.8	1.1	24	9.0	33.0	0.0
38	1.1	0.3	0	0.4	0	0.7	4	0.7	1	1.4	0	1	1.4	1.8	48	18.9	30.9	0.0
39	1.8	0.1	0	0.7	0	0.8	4	1.5	0	1.9	1.9	0	0.0	2.6	24	22.7	32.8	100.0
40	0.7	0	1	0.3	0	0.3	4	1.8	0	0.7	0	1	0.7	1.0	24	24.0	34.3	0.0
41	1	0.3	0	0.4	0	0.7	4	2.5	0	1.3	0	1	1.3	1.7	48	18.5	31.4	0.0
42	1.7	0	1	0.1	0	0.1	4	2.6	0	1.7	1.7	0	0.0	1.8	24	24.0	25.4	100.0
43	0.1	0.3	0	0.4	0	0.7	4	3.3	0	0.4	0	1	0.4	0.8	24	6.0	48.0	0.0
44	0.8	0.4	0	0.4	0	0.8	4	0.1	1	1.2	0	1	1.2	1.6	48	16.0	32.0	0.0
45	1.6	0	1	0.5	0	0.5	4	0.6	0	1.6	1.6	0	0.0	2.1	24	24.0	31.5	100.0
46	0.5	0.4	0	0.4	0	0.8	4	1.4	0	0.9	0	1	0.9	1.3	24	13.3	34.7	0.0
47	1.3	0.2	0	0.5	0	0.7	4	2.1	0	1.5	0	1	1.5	2.0	48	20.8	32.0	0.0
48	2	0.6	0	0.5	0	1.1	4	3.2	0	2.6	2.6	0	0.0	3.1	24	18.5	28.6	100.0
49	0.5	0.1	0	0.1	0	0.2	4	3.4	0	0.6	0	1	0.6	0.7	24	20.0	28.0	0.0
50	0.7	0.3	0	0.5	0	0.8	4	0.2	1	1.0	0	1	1.0	1.5	48	16.8	36.0	0.0
51	1.5	0.3	0	0.5	0	0.8	4	1.0	0	1.8	1.8	0	0.0	2.3	24	20.0	30.7	100.0
52	0.5	0.5	0	0.6	0	1.1	4	2.1	0	1.0	0	1	1.0	1.6	24	12.0	38.4	0.0
53	1.6	0.4	0	0.4	0	0.8	4	2.9	0	2.0	0	1	2.0	2.4	48	19.2	28.8	0.0
54	2.4	0.5	0	0.3	0	0.8	4	3.7	0	2.9	2.9	0	0.0	3.2	24	19.9	26.5	100.0
55	0.3	0.1	0	0.1	0	0.2	4	3.9	0	0.4	0	1	0.4	0.5	24	18.0	30.0	0.0
56	0.5	0	1	0.3	0	0.3	4	0.2	1	0.5	0	1	0.5	0.8	48	24.0	38.4	0.0
57	0.8	0.1	0	0.1	0	0.2	4	0.4	0	0.9	0.9	0	0.0	1.0	24	21.3	26.7	100.0
58	0.1	0.2	0	0.2	0	0.4	4	0.8	0	0.3	0	1	0.3	0.5	24	8.0	40.0	0.0
59	0.5	0.3	0	0.3	0	0.6	4	1.4	0	0.8	0	1	0.8	1.1	48	15.0	33.0	0.0
60	1.1	0.6	0	0.3	0	0.9	4	2.3	0	1.7	1.7	0	0.0	2.0	24	15.5	28.2	100.0
61	0.3	0.2	0	0.2	0	0.4	4	2.7	0	0.5	0	1	0.5	0.7	24	14.4	33.6	0.0

Figure 29 shows the data obtained by simulating the waste generation and evacuation processes of Ifite Market dump site. In this simulation, the accumulating wastes were evacuated every 3 days. It can be seen that the system shows evidence of instability, which the points above the MAWES reference line represent.

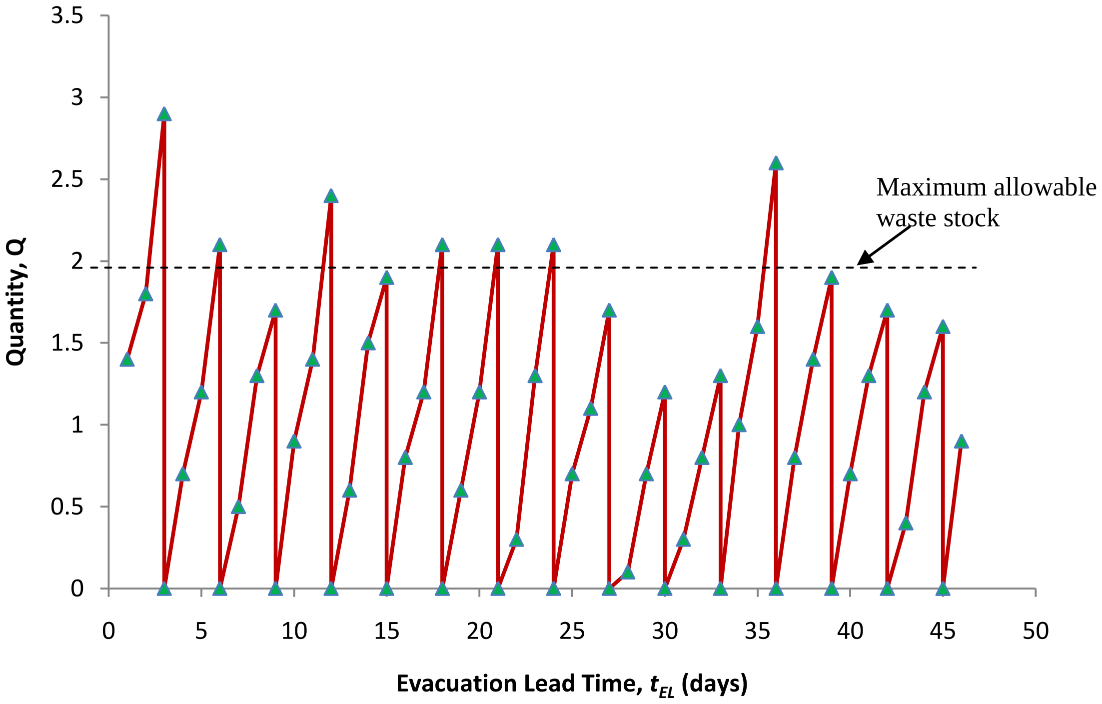


Figure 29: Ifite Market SWM system stability when WELT = 3 days

Figures 30a and 30b show the system plots for Ogbalingba dumpsite when its mean WELT is reduced by certain amounts. In Figures 30a, the WELT is reduced by one day; whereas in Figure 30b, the WELT is reduced by two days. Ofcourse, these reduction in number of days implies increase in frequency of waste evacuation. The two plots show clearly that with the unit reductions in t_{EL}, more of the points of D go below the upper (MAWES) reference line indicating that the systems gets more and more stabilized (the location is kept cleaner), though not without some financial costs.

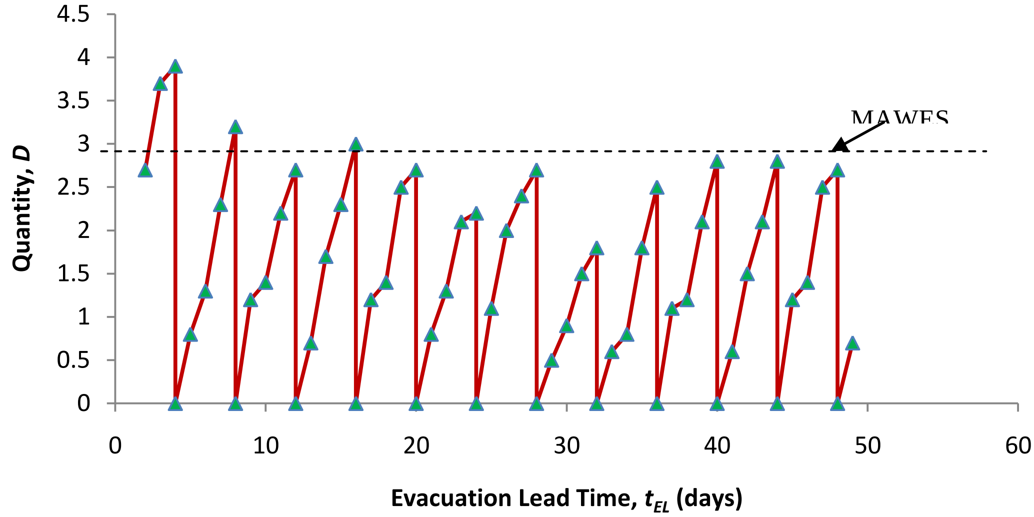


Figure 30a: Ogbalingba SWM system stability when WELT = 4 days

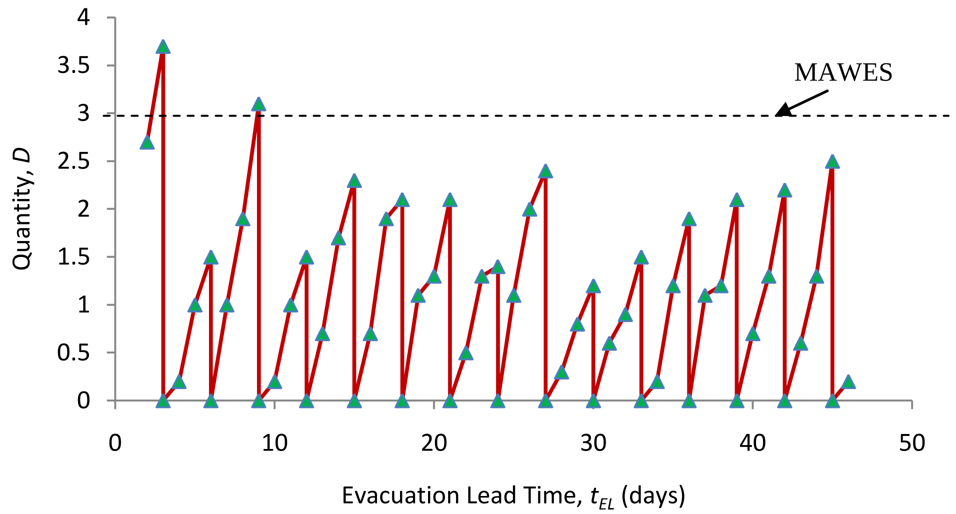


Figure 30b: Ogbalingba SWM system stability when WELT = 3 days

Figures 31 shows the system plot for Ifite Market dumpsite when its mean WELT is reduced by two days. The two plots show clearly that reducting the t_{EL} to 2 days makes more of the points of D to go below the upper (MAWES) reference line. Hence, the systems is stabilized.

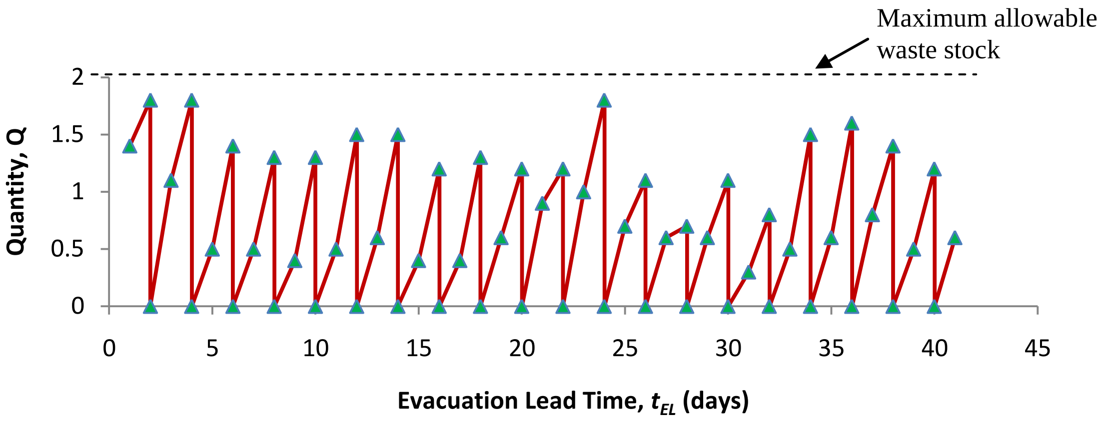


Figure 31: Ifite Market SWM system stability when WELT = 2 days

4.2.8 Summary of Agu-Awka dumpsite agents report and discussion

Contrary to the Street Dumpsite Agents reports, though expected, the research agents at Agu-Awka final dumpsite reported that approximately a total of ***142391*** chain-up bin loads of solid waste were deposited at the final dumpsite as against the 67024 chain-up bin loads reported by the Street Dumpsite Agents within the period under review. Nevertheless, the entire quantity of waste was assumed to had been generated within Awka, the study area. Consequently, the data was used in designing Awka municipal solid waste system and in conducting some regression analysis as presented shortly.

4.2.8.1 Awka municipal solid waste system design

Design Problem

Data gathered in the course of this research revealed that the total population of Awka urban area in 1996 was 301846 (Awka North = 112192 and Awka South= 189654) with annual growth rate of 3.2% (NPC, 2014). The Final Dumpsite Agents' records on the activities that transpired at Agu-Awka dumpsite in each week of the thirty six months observation period gave the following data.

Average numbers of different waste disposal vehicles that brought solid waste to the dumpsite each week are:

a. Compactor trucks = 7
b. Chain-up trucks = 3
c. Small bucket tipper trucks = 6
d. Double bucket tipper trucks = 4

e. Small bucket tipper trucks without tailboards = 5
f. Individual residents' private cars, trucks, etc = 3

Average number of each disposal truck run to the dumpsite per week:

a. Compactor truck = 16
b. Chain-up truck = 28
c. Number of tipper SB truck loads = 12
d. Number of tipper DB truck loads = 7
e. Number of tipper SB trucks without tailboards = 3
f. Number of loads from individual residents' private cars and trucks = 5

Average (estimated) volume of the disposal trucks are follows:

i. Compactor truck = 4 chain-up bin loads
ii. Chain-up truck = 1 chain-up bin loads
iii. Tipper truck = 2.5 chain-up bin loads
iv. Tipper (double bucket) truck = 5 chain-up bin loads
v. Tipper (without tailboard) truck = 2 chain-up bin loads
vi. Others = 1 chain-up bin load = 1 chain-up bin loads

What is the unit or per capita disposal rate in Awka area, assuming that the specific weight of full loaded chain-up bin is 74.16 kg/m^3?

Table 25 contains the summary of the analysis made in solving the present problem.

Table 25: Computation of the per capita waste disposal rate in Awka metropolis

Waste source	**Total Number of Loads (chain-up bins)**	**Unit Volume (m^3)**	**Specific Weight (kgm^{-3})**	**Total weight (kg)**
Compactor truck	69888	17.2	297.0	78706084.83
Chain-up truck	13104	4.3	74.16	4178708.35
Tipper truck	28080	10.75	186.0	55964844.00
Tipper (double bucket) truck	21840	21.5	370.8	174112848.00
Tipper (without tailboard) truck	4680	8.6	148.32	5969583.36
Others	2320	4.3	74.16	739820.16
Waste in stock at the end of 2014 (see Table 10)	2479.4	4.3	74.16	790650.91
			Total =	***320468917.37***

From **Table 12** of the Appendices, the projected total population of Awka area in 2012, 2013 and 2014 are 499644, 515632 and 532133 respectively. Grand total population for the three year period = 1547409. Assume 156 weeks and 1096 days of continuous disposals in the 3-year period. Substituting the actual values into eqn. (72b) and solving, we obtain:

$$PCDR \approx \underline{\mathbf{0.189}\ \text{kg/(capita.day)}}$$

4.2.9 Cost Estimation and Waste Inventory Minimization Models Application, Results and Discussions - *Awka City solid waste management costs analysis*

In the years 2012, 2013 and 2014, the cost per run of solid waste evacuation in Awka city were N3000, N5000 and N8000 respectively. A full loaded tipper truck carried about three full loads of chain-up waste bins per trip. Values of the parameters in k used in the data analysis were assumed to relate such that $k_2 = k_3D \times 10^{-1}$, $k_1 = k_2 \times 10^{-3}$ and $k_4 = k_3$.

With these information, monthly costs of evacuating various quantities of waste produced in Awka city in the 36 months of the said three year period were calculated and recorded in **Table 26**. Let it be noted that the amounts of money quoted under the "Field Data" column in **Table 26** are the cash supposedly paid to commercial waste disposal truck (tipper 911) drivers for transporting the stated quantities of waste from the points of their collation in the streets to the final dumpsite at Agu-Awka by Ring Road in Awka South Local Government Area of Anambra State; the amounts excludes other costs addressed in full cost accounting analysis which the Researcher is also presenting for consideration in financial management of the solid waste generated in the state.

Table 26: Quantities of solid waste produced in Awka city and the approximate amounts of money paid for disposing them in the months of January 1, 2012 to December 31, 2014

Time		**Field Data**					**Costs Obtained From Study Models Application**			
Year	**Mnt Cod**	**Q [Bin loads]**	**Q_{eva} [Bin loads]**	**r**	**C_n (₦)**	**C_E (₦)**	**$(C_E)_L$ (₦) [Eqn. 20]**	**$(C_T)_L$ (₦) [Eqn. 23]**	**$(C_E)_{NL}$ (₦) [Eqn. 22]**	**$(C_T)_{NL}$ (₦) [Eqn. 24]**
2012	1	1497.8	746	249	3000	747000	971100	971771	82839	306039
	2	1439.3	817	272	3000	816000	1060800	1061535	86650	330550
	3	1530.1	766	255	3000	765000	994500	995189	83930	312530
	4	1637.9	710	237	3000	711000	924300	924939	80837	293237
	5	1594.8	891	297	3000	891000	1158300	1159102	90449	356849
	6	1660.9	855	285	3000	855000	1111500	1112270	88621	344221
	7	1530.3	917	306	3000	918000	1193400	1194225	91746	366246
	8	1521.9	811	270	3000	810000	1053000	1053730	86334	328434
	9	1644.3	934	311	3000	933000	1212900	1213741	92584	371584
	10	1679.6	700	233	3000	699000	908700	909330	80273	289073
	11	1524.5	940	313	3000	939000	1220700	1221546	92878	373678
	12	1555.8	1072	357	3000	1071000	1392300	1393265	99124	419524
2013	13	1623.1	905	302	5000	1510000	1963000	1964358	151916	603416
	14	1781.9	1057	352	5000	1760000	2288000	2289586	164058	690558
	15	1795.2	896	299	5000	1495000	1943500	1944844	151166	598166
	16	1845.5	1045	348	5000	1740000	2262000	2263568	163132	683632
	17	1883.1	966	322	5000	1610000	2093000	2094449	156903	638403
	18	1881.3	940	313	5000	1565000	2034500	2035910	154797	622797
	19	1706.2	832	277	5000	1385000	1800500	1801748	145722	559722
	20	1709.8	894	298	5000	1490000	1937000	1938341	150999	596499
	21	1852.6	1070	357	5000	1785000	2320500	2322105	165054	699054
	22	1707.2	967	322	5000	1610000	2093000	2094451	156983	638483
	23	1695	1002	334	5000	1670000	2171000	2172503	159772	659272
	24	1927.8	1221	407	5000	2035000	2645500	2647332	176214	785214

2014	25	2068.7	1149	383	8000	3064000	3983200	3985958	273575	1190375
	26	2268.9	1111	370	8000	2960000	3848000	3850666	269053	1154653
	27	2252.5	1128	376	8000	3008000	3910400	3913107	271086	1171086
	28	2287.7	1352	451	8000	3608000	4690400	4693645	296556	1376556
	29	2347.7	1239	413	8000	3304000	4295200	4298174	283995	1272795
	30	2220.8	1170	390	8000	3120000	4056000	4058808	276042	1209642
	31	2088.9	1021	340	8000	2720000	3536000	3538450	258025	1071625
	32	2215.1	1433	478	8000	3824000	4971200	4974639	305240	1450040
	33	2213.7	1354	451	8000	3608000	4690400	4693650	296774	1376774
	34	2158.7	1293	431	8000	3448000	4482400	4485503	290066	1322066
	35	2196.6	1214	405	8000	3240000	4212000	4214914	281140	1250740
	36	2479.4	1323	441	8000	3528000	4586400	4589575	293385	1349385

Figure 32 shows a graph plot (data series) of the quantities of solid waste produced and quantities evacuated in Awka metropolitan city as contained in **Table 26**. The two trendlines added to the data series in the figure seem to diverge, suggesting that waste generation rate exceeds the evacuation rate - the reason why in spite of ASWAMA's efforts to evacuate the waste the latter keep accumulating. This accumulation problem suggests the need to determine the optimum quantity of waste that should be evacuated in a given period as to ensure that the quantities of waste left as inventory in the area at the end of the period is always kept at a minimal level. In other words, something should be done to stop the widening gap between the produced and the evacuated waste quantities if a clean environ-

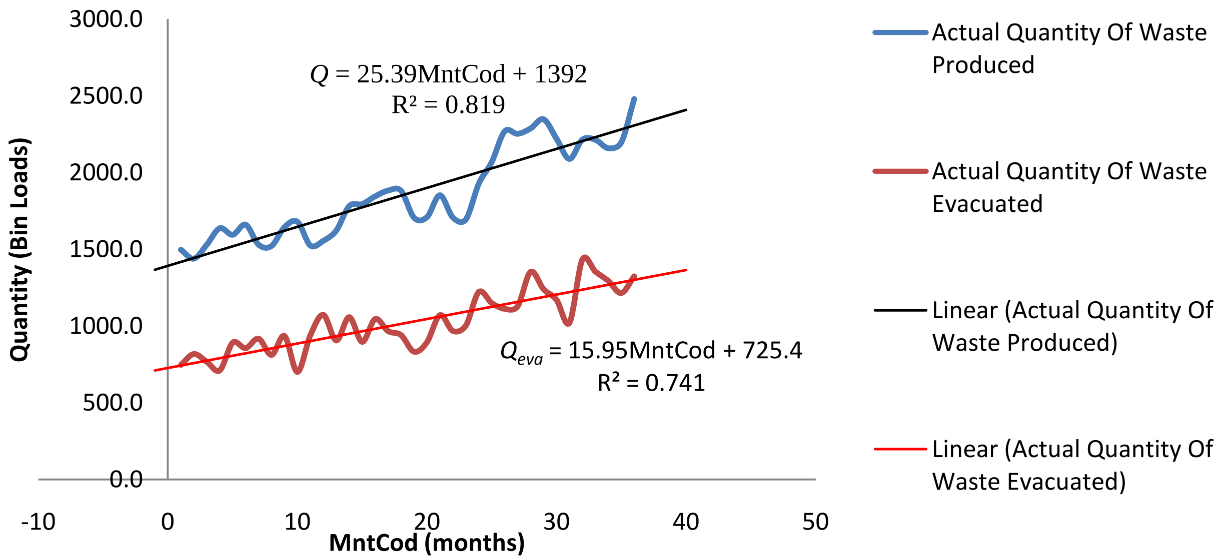


Figure 32: Trends of solid waste production and evacuation in Awka city in the thirty six months period.

ment is to be maintained. An equation generated on the waste production trendline makes prediction of waste production for management decision making in Awka possible. The trendline equation is written out as waste production forecasting model 1 (81). Thus,

$$Q = 25.39MntCod + 1392 \quad (81)$$

4.2.10 Forecasting solid waste generation and cost of its evacuation in Awka

Equation 81 was used to predict the quantities of waste that would be produced in Awka city in the next five months - January to May, 2015. Eqns 33 and 37 were used in determining the optimum quantities of the predicted waste evacuated which minimized the cost of evacuation and the minimum inventory of solid waste that remained at the dumpsites at the end of each month of the said period. It is assumed that there would be no increase in C_r in the next six months of January to June 2015 consequently, the values of C_E and C_T in the first five months of 2015 were predicted. Following the assumptions made under sub-section 4.2.9, with the value of C_r already known as ₦8000, the values of k_1, k_2 and k_3 were evaluated as 2.4, 2400 and 8000 respectively. Finally, FCA recommendations were applied by substituting the values of k into eqns (24), (26), (27), and (28) which are solved to obtain the forecast costs of evacuating the predicted D^{opt}. The results are shown in **Table 27**.

Table 27: Predicted values for the next five months (Jan - May 2015) period

Time	Forecast Quantity			Forecast Costs				
	Field Data			Field Cost Model	Linear Function Model		Non-Linear Function Model	
Mnt Cod	Q (81)	D^{opt} (Eqn 29)	r	$(C_r)_{TF}$, (Eqn 19b)	$(C_E)_L$, (Eqn 20)	$(C_T)_L$, (Eqn 23)	$(C_E)_{NL}$, (Eqn 22)	$(C_T)_{NL}$ (Eqn 24)
37	2422.2	1556	519	4150284	5395370	5399105	949216	2191902
38	2462.6	1569	523	4184693	5440100	5443867	953133	2206141
39	2503.7	1582	527	4219484	5485329	5489127	957077	2220522
40	2545.6	1595	532	4254650	5531045	5534874	961047	2235042
41	2588.3	1609	536	4290180	5577234	5581095	965042	2249696

4.2.11 Costs of evacuation for optimum quantities of solid waste evacuation

By varying the values in parameter k slightly such that $k_1 = 1$, $k_2 = 1224$, and $k_3 = k_4$ = ₦ 3000 for the year 2012, $k_3 = k_4$ = ₦ 5000 for the year 2013 and , $k_3 = k_4$ = ₦ 8000 for the year 2014, values of the various cost items in **Table 28** for the monthly optimum evacuated quantities of solid waste were determined using the model equations shown in the second row of the column headings. Other calculated values not shown in the table include: for 2012 C_r = ₦9000, $(C_r)_{TL}$ = ₦10224, and $(C_r)_{TNL}$ = ₦6420; for 2013 C_r = ₦1500, $(C_r)_{TL}$ = ₦16224, and $(C_r)_{TNL}$ = ₦9884 and for 2014 C_r = ₦2400, $(C_r)_{TL}$ = ₦25224, and $(C_r)_{TNL}$ = ₦15080. When compared with the ₦3000 charged per run (from the field data), it can be said that the values obtained from the models for the same service have satisfied the requirements of the FCA approach in the aspect of waste evacuation.

Table 28: Cost items for the calculated optimal evacuated quantities

Field Data		Models Generated Data (Optimization Results)										
Mnt Cod	Q	D^{opt} [Eqn. 29]	$(C_E)_L$ [Eqn. 23]	$(C_E)_{NL}$ [Eqn. 22]	$(C_T)_L$ [Eqn. 20]	$(C_T)_{NL}$ [Eqn. 24]	r [Eqn. 25]	$(C_T)_L$ [Eqn. 26]	$(C_T)_{NL}$ [Eqn. 27]	C^{opt} [Eqn. 34]	dC_T/dD [Eqn. 28]	d^2C_T/dD^2 [Eqn. 30]
1	1497.8	1354	2542368	304799	2542371	304802	499	5104505	611970	4496108	0.0000	0.0015
2	1439.3	1327	2784336	333808	2784339	333811	480	4905175	588073	4320588	0.0000	0.0015
3	1530.1	1369	2610528	312970	2610531	312973	510	5214559	625164	4593015	0.0000	0.0015
4	1637.9	1416	2419680	290090	2419683	290093	546	5581966	669212	4916532	0.0000	0.0014
5	1594.8	1397	3036528	364042	3036531	364045	532	5434943	651586	4787073	0.0000	0.0014
6	1660.9	1426	2913840	349334	2913843	349337	554	5660350	678609	4985552	0.0000	0.0014
7	1530.3	1369	3125136	374665	3125139	374668	510	5215248	625247	4593622	0.0000	0.0015
8	1521.9	1365	2763888	331356	2763891	331359	507	5186638	621817	4568430	0.0000	0.0015
9	1644.3	1419	3183072	381611	3183075	381614	548	5603710	671819	4935678	0.0000	0.0014
10	1679.6	1434	2385600	286004	2385603	286007	560	5724046	686245	5041637	0.0000	0.0014
11	1524.5	1366	3203520	384063	3203523	384066	508	5195471	622876	4576208	0.0000	0.0015
12	1555.8	1380	3653376	437995	3653379	437998	519	5302169	635668	4670160	0.0000	0.0014
13	1623.1	1409	3084240	369763	3084243	369766	541	5531502	663162	4872096	0.0000	0.0014
14	1781.9	1477	3602256	431866	3602259	431869	594	6072834	728061	5348755	0.0000	0.0014
15	1795.2	1482	3053568	366085	3053571	366088	598	6117951	733470	5388482	0.0000	0.0013
16	1845.5	1503	3561360	426963	3561363	426966	615	6289316	754014	5539373	0.0000	0.0013
17	1883.1	1518	3292128	394686	3292131	394689	628	6417542	769387	5652278	0.0000	0.0013
18	1881.3	1517	3203520	384063	3203523	384066	627	6411407	768652	5646877	0.0000	0.0013
19	1706.2	1445	2835456	339936	2835459	339939	569	5814751	697120	5121507	0.0000	0.0014
20	1709.8	1447	3046752	365268	3046755	365271	570	5827031	698592	5132319	0.0000	0.0014
21	1852.6	1506	3646560	437178	3646563	437181	618	6313664	756933	5560812	0.0000	0.0013
22	1707.2	1446	3295536	395094	3295539	395097	569	5818157	697528	5124506	0.0000	0.0014
23	1695.0	1440	3414816	409395	3414819	409398	565	5776563	692542	5087881	0.0000	0.0014
24	1927.8	1536	4161168	498873	4161171	498876	643	6569895	787652	5786428	0.0000	0.0013
25	2068.7	1591	3915792	469455	3915795	469458	690	7050133	845227	6209283	0.0000	0.0013
26	2268.9	1666	3786288	453929	3786291	453932	756	7732288	927009	6809922	0.0000	0.0012
27	2252.5	1660	3844224	460875	3844227	460878	751	7676378	920306	6760693	0.0000	0.0012
28	2287.7	1673	4607616	552397	4607619	552400	763	7796610	934720	6866557	0.0000	0.0012
29	2347.7	1695	4222512	506227	4222515	506230	783	8000854	959207	7046393	0.0000	0.0012
30	2220.8	1649	3987360	478035	3987363	478038	740	7568589	907384	6665785	0.0000	0.0012
31	2088.9	1599	3479568	417157	3479571	417160	696	7118903	853472	6269836	0.0000	0.0013
32	2215.1	1647	4883664	585491	4883667	585494	738	7548981	905033	6648520	0.0000	0.0012
33	2213.7	1646	4614432	553214	4614435	553217	738	7544293	904471	6644392	0.0000	0.0012
34	2158.7	1626	4406544	528291	4406547	528294	720	7356923	882007	6479413	0.0000	0.0012
35	2196.6	1640	4137312	496013	4137315	496016	732	7486016	897484	6593079	0.0000	0.0012
36	2479.4	1742	4508784	540548	4508787	540551	826	8449663	1013013	7441565	0.0000	0.0011

4.2.12 Application of sensitivity analysis and results obtained

Parameter values are known to contain errors and for this reason, sensitivity analyses were conducted to see the responses of the optimum cost values to these parameters. **Table 29** contains results obtained from such analysis with parameters C^{opt} and D^{opt} in the 36 months study period.

Table 29: Sensitivity analysis on the optimal total cost and optimal evacuation quantity parameter for minimum waste inventory

Field Data		Optimal Values		Sensitivity Analysis Parameter Values							
Mnt Cod	Q (Bin loads)	D^{opt} (Bin loads) [Eqn. 29]	C^{opt} (₦) [Eqn. 34]	$(S^C)_{k1}$ (Eqn. 35)	$(S^C)_{k2}$ (Eqn. 36)	$(S^C)_{k3}$ (Eqn. 37)	$(S^C)_Q$ [Eqn. 38]	$(S^D)_{k1}$ [Eqn. 39]	$(S^D)_{k2}$ [Eqn. 40]	$(S^D)_{k3}$ [Eqn. 41]	$(S^D)_Q$ (Eqn. 42]
1	1497.8	1354	4496108	1354.00	1.11	1497.80	3000.90	-677.00	677.00	0.00	1.81

2	1439.3	1327	4320588	1327.30	1.08	1439.31	3000.92	-663.65	663.65	0.00	1.84
3	1530.1	1369	4593015	1368.52	1.12	1530.09	3000.89	-684.26	684.26	0.00	1.79
4	1637.9	1416	4916532	1415.91	1.16	1637.90	3000.86	-707.95	707.95	0.00	1.73
5	1594.8	1397	4787073	1397.13	1.14	1594.76	3000.88	-698.57	698.57	0.00	1.75
6	1660.9	1426	4985552	1425.81	1.16	1660.90	3000.86	-712.91	712.91	0.00	1.72
7	1530.3	1369	4593622	1368.61	1.12	1530.29	3000.89	-684.30	684.30	0.00	1.79
8	1521.9	1365	4568430	1364.85	1.12	1521.90	3000.90	-682.42	682.42	0.00	1.79
9	1644.3	1419	4935678	1418.66	1.16	1644.28	3000.86	-709.33	709.33	0.00	1.73
10	1679.6	1434	5041637	1433.81	1.17	1679.59	3000.85	-716.91	716.91	0.00	1.71
11	1524.5	1366	4576208	1366.01	1.12	1524.49	3000.90	-683.00	683.00	0.00	1.79
12	1555.8	1380	4670160	1379.96	1.13	1555.80	3000.89	-689.98	689.98	0.00	1.77
13	1623.1	1409	4872096	1409.49	1.15	1623.09	5000.87	-704.75	704.75	0.00	1.74
14	1781.9	1477	5348755	1476.85	1.21	1781.93	5000.83	-738.43	738.43	0.00	1.66
15	1795.2	1482	5388482	1482.33	1.21	1795.17	5000.83	-741.16	741.16	0.00	1.65
16	1845.5	1503	5539373	1502.94	1.23	1845.46	5000.81	-751.47	751.47	0.00	1.63
17	1883.1	1518	5652278	1518.19	1.24	1883.08	5000.81	-759.09	759.09	0.00	1.61
18	1881.3	1517	5646877	1517.46	1.24	1881.28	5000.81	-758.73	758.73	0.00	1.61
19	1706.2	1445	5121507	1445.13	1.18	1706.21	5000.85	-722.56	722.56	0.00	1.69
20	1709.8	1447	5132319	1446.65	1.18	1709.81	5000.85	-723.33	723.33	0.00	1.69
21	1852.6	1506	5560812	1505.85	1.23	1852.60	5000.81	-752.92	752.92	0.00	1.63
22	1707.2	1446	5124506	1445.55	1.18	1707.20	5000.85	-722.78	722.78	0.00	1.69
23	1695.0	1440	5087881	1440.37	1.18	1695.00	5000.85	-720.19	720.19	0.00	1.70
24	1927.8	1536	5786428	1536.10	1.25	1927.79	5000.80	-768.05	768.05	0.00	1.59
25	2068.7	1591	6209283	1591.25	1.30	2068.70	8000.77	-795.63	795.63	0.00	1.54
26	2268.9	1666	6809922	1666.46	1.36	2268.86	8000.73	-833.23	833.23	0.00	1.47
27	2252.5	1660	6760693	1660.42	1.36	2252.46	8000.74	-830.21	830.21	0.00	1.47
28	2287.7	1673	6866557	1673.38	1.37	2287.74	8000.73	-836.69	836.69	0.00	1.46
29	2347.7	1695	7046393	1695.15	1.38	2347.67	8000.72	-847.58	847.58	0.00	1.44
30	2220.8	1649	6665785	1648.73	1.35	2220.83	8000.74	-824.36	824.36	0.00	1.48
31	2088.9	1599	6269836	1599.00	1.31	2088.88	8000.77	-799.50	799.50	0.00	1.53
32	2215.1	1647	6648520	1646.59	1.35	2215.08	8000.74	-823.29	823.29	0.00	1.49
33	2213.7	1646	6644392	1646.08	1.34	2213.70	8000.74	-823.04	823.04	0.00	1.49
34	2158.7	1626	6479413	1625.51	1.33	2158.72	8000.75	-812.75	812.75	0.00	1.51
35	2196.6	1640	6593079	1639.71	1.34	2196.60	8000.75	-819.85	819.85	0.00	1.49
36	2479.4	1742	7441565	1742.05	1.42	2479.36	8000.70	-871.02	871.02	0.00	1.41

From the numerical values in **Table 29**, it can be seen that D^{opt} in each month appears to have a very high sensitivity to k_1 and k_2, but not to other parameters, especially to Q. However, it should be noted that a unit change in Q is quite different from a unit change in k_1 or k_2 (0.5), see eqns (39) and (40) . Therefore, in order to put the sensitivities on a more meaningful basis, the relative sensitivity analysis were computed for the same problem and presented in **Table 30**.

Table 30: Relative Sensitivity analysis on the optimal total cost and optimal evacuation quantity parameter for minimum waste Inventory

Field Data		Optimal Values		Relative Sensitivity Analysis Parameter Values							
Mnt Cod	**Q (cb)**	**D^{opt} (cb) Eqn. 29**	**C^{opt} (₦) Eqn. 34**	**$(S_r^C)_{k1}$ Eqn. 43**	**$(S_r^C)_{k2}$ Eqn. 44**	**$(S_r^C)_{k3}$ Eqn. 45**	**$(S_r^C)_Q$ Eqn. 46**	**$(S_r^D)_{k1}$ Eqn. 47**	**$(S_r^D)_{k2}$ Eqn. 48**	**$(S_r^D)_{k3}$ Eqn. 49**	**$(S_r^D)_Q$ Eqn. 50**
1	1497.8	1354	4496108	0.0003	0.0003	0.9034	0.4511	-0.50	0.50	0.00	0.50

2	1439.3	1327	4320588	0.0003	0.0003	0.9216	0.4422	-0.50	0.50	0.00	0.50
3	1530.1	1369	4593015	0.0003	0.0003	0.8939	0.4559	-0.50	0.50	0.00	0.50
4	1637.9	1416	4916532	0.0003	0.0003	0.8640	0.4717	-0.50	0.50	0.00	0.50
5	1594.8	1397	4787073	0.0003	0.0003	0.8756	0.4654	-0.50	0.50	0.00	0.50
6	1660.9	1426	4985552	0.0003	0.0003	0.8580	0.4750	-0.50	0.50	0.00	0.50
7	1530.3	1369	4593622	0.0003	0.0003	0.8938	0.4559	-0.50	0.50	0.00	0.50
8	1521.9	1365	4568430	0.0003	0.0003	0.8963	0.4547	-0.50	0.50	0.00	0.50
9	1644.3	1419	4935678	0.0003	0.0003	0.8623	0.4726	-0.50	0.50	0.00	0.50
10	1679.6	1434	5041637	0.0003	0.0003	0.8532	0.4777	-0.50	0.50	0.00	0.50
11	1524.5	1366	4576208	0.0003	0.0003	0.8955	0.4551	-0.50	0.50	0.00	0.50
12	1555.8	1380	4670160	0.0003	0.0003	0.8865	0.4597	-0.50	0.50	0.00	0.50
13	1623.1	1409	4872096	0.0003	0.0003	1.4465	0.4696	-0.50	0.50	0.00	0.50
14	1781.9	1477	5348755	0.0003	0.0003	1.3806	0.4920	-0.50	0.50	0.00	0.50
15	1795.2	1482	5388482	0.0003	0.0003	1.3755	0.4938	-0.50	0.50	0.00	0.50
16	1845.5	1503	5539373	0.0003	0.0003	1.3566	0.5007	-0.50	0.50	0.00	0.50
17	1883.1	1518	5652278	0.0003	0.0003	1.3430	0.5058	-0.50	0.50	0.00	0.50
18	1881.3	1517	5646877	0.0003	0.0003	1.3436	0.5055	-0.50	0.50	0.00	0.50
19	1706.2	1445	5121507	0.0003	0.0003	1.4108	0.4814	-0.50	0.50	0.00	0.50
20	1709.8	1447	5132319	0.0003	0.0003	1.4094	0.4819	-0.50	0.50	0.00	0.50
21	1852.6	1506	5560812	0.0003	0.0003	1.3540	0.5017	-0.50	0.50	0.00	0.50
22	1707.2	1446	5124506	0.0003	0.0003	1.4104	0.4816	-0.50	0.50	0.00	0.50
23	1695.0	1440	5087881	0.0003	0.0003	1.4155	0.4799	-0.50	0.50	0.00	0.50
24	1927.8	1536	5786428	0.0003	0.0003	1.3273	0.5118	-0.50	0.50	0.00	0.50
25	2068.7	1591	6209283	0.0003	0.0003	2.0502	0.5301	-0.50	0.50	0.00	0.50
26	2268.9	1666	6809922	0.0002	0.0002	1.9577	0.5552	-0.50	0.50	0.00	0.50
27	2252.5	1660	6760693	0.0002	0.0002	1.9648	0.5532	-0.50	0.50	0.00	0.50
28	2287.7	1673	6866557	0.0002	0.0002	1.9496	0.5575	-0.50	0.50	0.00	0.50
29	2347.7	1695	7046393	0.0002	0.0002	1.9246	0.5648	-0.50	0.50	0.00	0.50
30	2220.8	1649	6665785	0.0002	0.0002	1.9787	0.5493	-0.50	0.50	0.00	0.50
31	2088.9	1599	6269836	0.0003	0.0003	2.0402	0.5327	-0.50	0.50	0.00	0.50
32	2215.1	1647	6648520	0.0002	0.0002	1.9813	0.5486	-0.50	0.50	0.00	0.50
33	2213.7	1646	6644392	0.0002	0.0002	1.9819	0.5484	-0.50	0.50	0.00	0.50
34	2158.7	1626	6479413	0.0003	0.0003	2.0070	0.5416	-0.50	0.50	0.00	0.50
35	2196.6	1640	6593079	0.0002	0.0002	1.9896	0.5463	-0.50	0.50	0.00	0.50
36	2479.4	1742	7441565	0.0002	0.0002	1.8728	0.5804	-0.50	0.50	0.00	0.50

Looking at the monthly data in **Table 30**, it can be seen that a change in k_3 has the largest sensitivity influence on C^{opt}, followed by a change in Q. Changes in k_1 and k_2 have no significant influence on C^{opt}. Also, it can be seen that the relative sensitivities for D^{opt} (in terms of absolute value of fractional changes) show that only k_3 has no influence on D; whereas other parameters k_1, k_2 and Q have equal influence on D.

4.3 Comparison of the Field Data with Theoretical Results

Table 31 contains the actual data obtained from the field study and the ones obtained as outcome of applying the EWEQ and the SWIM models in Awka municipal solid management. It can be seen from these data that for the same quantities of solid waste generated in the given months, applying the models shows that maximum inventory of waste (left in stock) at the various street dumpsite is kept at $\leq$ 30% of the total generation at the end of each month. Compare D with D^{opt} and q with q^{opt}.

Table 31: Comparison of field study data with theoretical (model application) results

Time			Field Data (Before Optimization)					Model Result (After Optimization)			
Year	**Month**	**Mnt Cod**	**Qty Of Waste Generated, *Q***	**Actual Quantity Of Waste Evacuated, *D***	**Actual No. Of Evacuator Runs, *r***	**Actual Waste In Stock, *q***	**Percentage Waste Left In Stock, *q* (%)**	**Qty Of Waste Evacuated, D^{opt}**	**No. Of Evacuator Runs, r^{opt}**	**Waste In Stock, q^{opt}**	**Percentage Waste Left In Stock, q^{opt} (%)**
2012	Jan	1	1497.8	746	249	751.8	50.19	1354	451	143.8	9.60
	Feb	2	1439.3	817	272	622.3	43.24	1327	442	112.3	7.80
	Mar	3	1530.1	766	255	764.1	49.94	1369	456	161.1	10.53
	Apr	4	1637.9	710	237	927.9	56.65	1416	472	221.9	13.55
	May	5	1594.8	891	297	703.8	44.13	1397	466	197.8	12.40
	Jun	6	1660.9	855	285	805.9	48.52	1426	475	234.9	14.14
	Jul	7	1530.3	917	306	613.3	40.08	1369	456	161.3	10.54
	Aug	8	1521.9	811	270	710.9	46.71	1365	455	156.9	10.31
	Sep	9	1644.3	934	311	710.3	43.20	1419	473	225.3	13.70
	Oct	10	1679.6	700	233	979.6	58.32	1434	478	245.6	14.62
	Nov	11	1524.5	940	313	584.5	38.34	1366	455	158.5	10.40
	Dec	12	1555.8	1072	357	483.8	31.10	1380	460	175.8	11.30
2013	Jan	13	1623.1	905	302	718.1	44.24	1409	470	214.1	13.19
	Feb	14	1781.9	1057	352	724.9	40.68	1477	492	304.9	17.11
	Mar	15	1795.2	896	299	899.2	50.09	1482	494	313.2	17.45
	Apr	16	1845.5	1045	348	800.5	43.38	1503	501	342.5	18.56
	May	17	1883.1	966	322	917.1	48.70	1518	506	365.1	19.39
	Jun	18	1881.3	940	313	941.3	50.03	1517	506	364.3	19.36
	Jul	19	1706.2	832	277	874.2	51.24	1445	482	261.2	15.31
	Aug	20	1709.8	894	298	815.8	47.71	1447	482	262.8	15.37
	Sep	21	1852.6	1070	357	782.6	42.24	1506	502	346.6	18.71
	Oct	22	1707.2	967	322	740.2	43.36	1446	482	261.2	15.30
	Nov	23	1695	1002	334	693.0	40.88	1440	480	255	15.04
	Dec	24	1927.8	1221	407	706.8	36.66	1536	512	391.8	20.32
2014	Jan	25	2068.7	1149	383	919.7	44.46	1591	530	477.7	23.09
	Feb	26	2268.9	1111	370	1157.9	51.03	1666	555	602.9	26.57
	Mar	27	2252.5	1128	376	1124.5	49.92	1660	553	592.5	26.30
	Apr	28	2287.7	1352	451	935.7	40.90	1673	558	614.7	26.87
	May	29	2347.7	1239	413	1108.7	47.22	1695	565	652.7	27.80
	Jun	30	2220.8	1170	390	1050.8	47.32	1649	550	571.8	25.75
	Jul	31	2088.9	1021	340	1067.9	51.12	1599	533	489.9	23.45
	Aug	32	2215.1	1433	478	782.1	35.31	1647	549	568.1	25.65
	Sep	33	2213.7	1354	451	859.7	38.84	1646	549	567.7	25.64
	Oct	34	2158.7	1293	431	865.7	40.10	1626	542	532.7	24.68
	Nov	35	2196.6	1214	405	982.6	44.73	1640	547	556.6	25.34
	Dec	36	2479.4	1323	441	1156.4	46.64	1742	581	737.4	29.74

Figure 33 is a plot of the data from **Table 31**. In an effort to ensure that the quantities of waste evacuated from the dumpsites were maximized (by applying EWEQ and SWIM models), quantities of waste left in stock at the various street dumpsite as inventory were kept low at the end of each month. This is shown by the graph of D^{opt} which is at a higher level and closer to Q than D, and the graph plot of q^{opt} which is at a lower level and further away from Q than the plot of q. All this clearly shows that the system is improved.

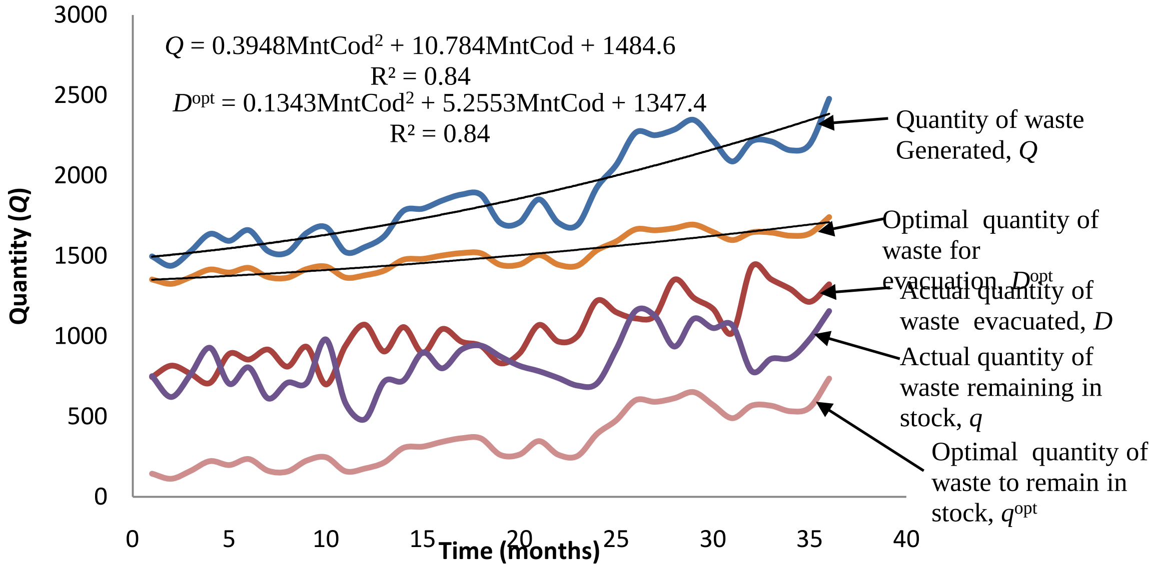


Figure 33: Plots for comparison of field study data and models application results

Trendline equations of order two generated on the curves with (their R^2 values) provide us with more forecasting tools. These forecasting models (82) and (83) can respectively be used for predicting a short term future total quantities of waste that will be dumped at the various street dumpsites in Awka area and the quantities that should be evacuated to keep waste in stock minimized. Copying out these models from Figure 32,

$$Q = 0.3948\text{MntCod}^2 + 10.784\text{MntCod} + 1484.6 \quad (R^2 = 0.84) \qquad (82)$$

$$D^{opt} = 0.1343\text{MntCod}^2 + 5.2553\text{MntCod} + 1347.4 \quad (R^2 = 0.84) \qquad (83)$$

4.4 Application of Markov Model in SWIM, Discussion and Results

Tables 32 to **34** give the distributions (percentage of total contribution) of solid waste in three roadside dumpsites in Zik's Avenue Zone at the end of each day for days 1 to 3 respectively (i.e. for three days).

Table 32: States of waste containers at the dumpsites for day 1

Dumpsite	Proportion
Eke Awka	15%
Dike Park	67%
St. Pauls	18%

Readings recorded on the second day are shown in **Table 33**.

Table 33: States of waste containers at the dumpsites for day 2

Dumpsite	State	Proportion
Eke Awka	1	12%
Dike Park	2	36%
St. Pauls	3	52%

Readings recorded on the third day are shown in **Table 34**.

Table 34: States of waste containers at the dumpsites for day 3

Dumpsite	State	Proportion
Eke Awka	1	65%
Dike Park	2	28%
St. Pauls	3	7%

Table 35 depicts the summary of the distributions (percentage of total contribution) of solid waste deposited at the three roadside dumpsites for the three days

Table 35: Contributions from the three waste containers at the end of the three days

Dumpsite	State	Proportion
Eke Awka	1	68%
Dike Park	2	11%
St. Pauls	3	21%

Figure 15 refers. To see how these proportions would change after each day generation, we use the tree diagram in Figure 16. For example, to find the initial proportion of waste in Eke Awka (state 1) as at the commencement of the experiment (before the three day generation), we add the numbers indicated with arrows as shown in Figure 34.

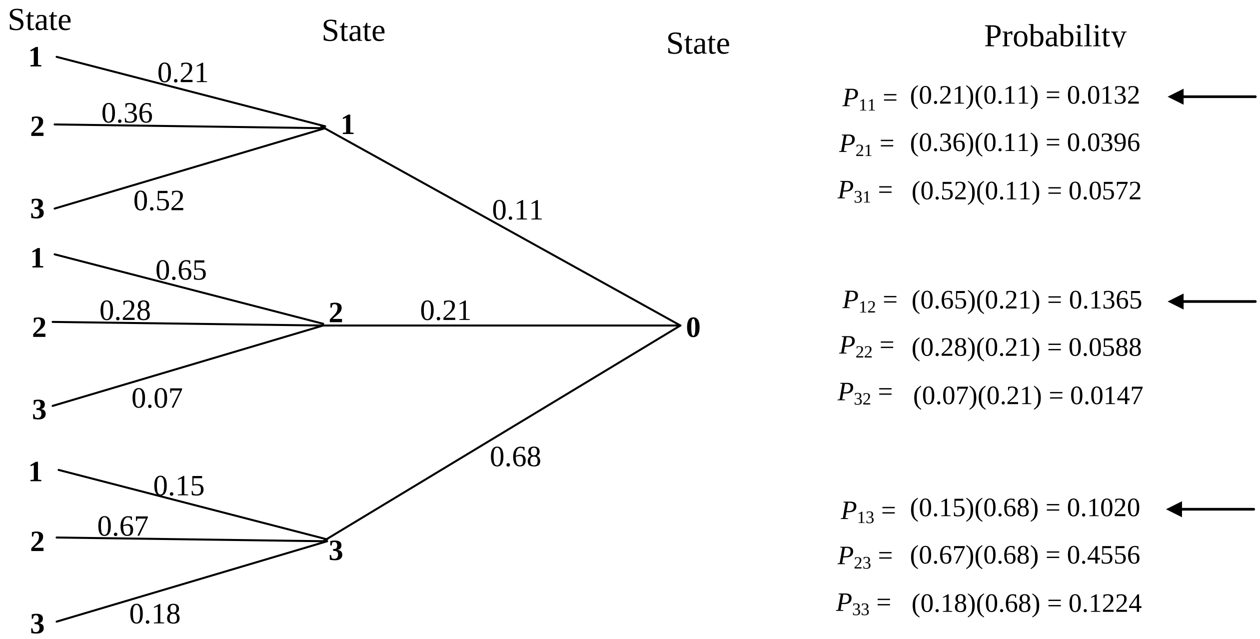


Figure 34: A tree diagram of the state distribution

$$0.0132 + 0.1365 + 0.1020 = 0.2517$$

In the same way, the proportion of waste in Dike Park (state 2) at the beginning of the three day study is

$$0.0572 + 0.0147 + 0.1224 = 0.1943$$

and the proportion of waste at St. Pauls (state 3) at the beginning of the three day study is

$$0.0396 + 0.0588 + 0.4556 = 0.5540$$

The final distribution of states, 21%, 68% and 11% came, after one (three day) generation, which emanated from the initial waste dump proportions of 25.17% in state 1, 55.4% in state 2, and 19.43% in state 3. These distribution can be written as probability vectors (where the percents have been changed to decimals rounded to the nearest hundredth) [0.68 0.11 0.21] and [0.25 0.19 0.55] respectively. A probability vector is a matrix of only one row, having nonnegative entries, with sum of the entries equal to 1.

Awka Urban City of Anambra State was divided into twelve Zones to enable effective solid waste management in the area. Of all the quantities of solid waste produced in the zones and dumped at Agu-Awka final dumpsite during a thirty six month field study, it was noticed that each zone contributed a certain quantity every month. The data on such contributions are depicted in **Table 10**. Meanwhile, one of the initial problems that arose because of monthly and seasonal variations in waste production was determining which of the months of the year would serve as the best time to start the field study. Nevertheless, the researcher later decided to start the research on 1st January (the first month of) 2012. The field study ended on 31st December, 2014, lasting for 1096 days. Assuming that the various quantities of waste contributed by the zones represent the transition states of the waste, what is the long-range trend of the Markov chain in the waste generation? Verify if the month of January, or any other month of the year, chosen by the researcher is the most appropriate period to start the research.

In order to use the memoryless property of the Markov model in attending to the above stated problem, it seems reasonable to work with the averages of the data given in **Table 10**. The average quantity of solid waste contributed by each of the zones in the corresponding months $^1/_3$(Jan 2012 + Jan 2013 + Jan 2014), $^1/_3$(Feb 2012 + Feb 2014 + 2014), ..., $^1/_3$(Dec 2012 +Dec 2013 + Dec 2014) of the three year-period are calculated and copied into Table 36

.

Table 36: Average monthly waste generation calculated for the same months of Jan 1, 2012 to Dec 31, 2014

Year	Month Code	1 Ama-wbia	2 Zik's Ave.	3 Ama-ikwo	4 Amaenyi/ Amaku	5 Udoka Estate	6 Nibo/ Umuawulu	7 Iyiagu Estate	8 Okpuno	Enugu-Onitsha Express Way	10 Emma Nnaemeka Axis	11 Ifite	12 Govt. House	Average Total Dump
		$\bar{\lambda}_1$	$\bar{\lambda}_2$	$\bar{\lambda}_3$	$\bar{\lambda}_4$	$\bar{\lambda}_5$	$\bar{\lambda}_6$	$\bar{\lambda}_7$	$\bar{\lambda}_8$	$\bar{\lambda}_9$	$\bar{\lambda}_{10}$	$\bar{\lambda}_{11}$	$\bar{\lambda}_{12}$	
2012 to 2014	1	149.2	246.4	145.6	141.1	155.8	133.3	116.6	137.5	108.6	82.1	159.2	154.6	1729.9
	2	151.1	253.8	165.2	159.7	151.2	128.3	110.7	153.0	121.5	96.2	167.0	172.4	1830.1
	3	149.6	262.0	168.2	166.5	155.6	134.0	109.5	155.2	117.8	94.2	173.5	173.3	1859.3
	4	158.7	271.7	170.0	163.2	172.4	134.1	128.0	158.3	123.6	96.9	176.2	170.7	1923.7
	5	145.5	266.3	172.0	170.5	172.3	148.2	130.1	165.5	112.4	103.8	185.4	170.0	1942.0
	6	149.2	257.4	174.3	182.5	162.3	135.0	122.9	163.4	117.8	109.8	179.1	167.5	1921.0
	7	148.1	232.5	146.5	155.0	175.7	126.5	124.0	138.2	104.1	94.0	166.0	164.3	1775.1
	8	151.5	255.4	155.6	149.0	171.0	131.3	120.0	147.7	115.6	83.8	165.0	169.6	1815.5
	9	147.6	259.6	165.7	151.9	169.4	148.4	134.2	161.5	114.2	103.2	177.7	170.1	1903.6
	10	159.5	263.4	166.6	156.6	159.2	129.1	113.8	151.2	117.4	97.5	163.7	170.4	1848.5
	11	156.6	245.8	156.8	153.6	154.2	132.3	116.1	144.1	115.0	100.0	162.9	168.1	1805.5
	12	182.9	283.9	166.8	172.2	164.9	142.6	126.3	159.6	130.5	101.7	178.4	177.9	1987.7

These calculated average values are taken as data in the present for determining the ones in the future in accordance with the memoryless property of the Markov model. The actual values of the data in **Table 36** are plotted in graph of Figure 35; while Figure 36 is a plot of the same data represented as the monthly fractional contributions from respective zones.

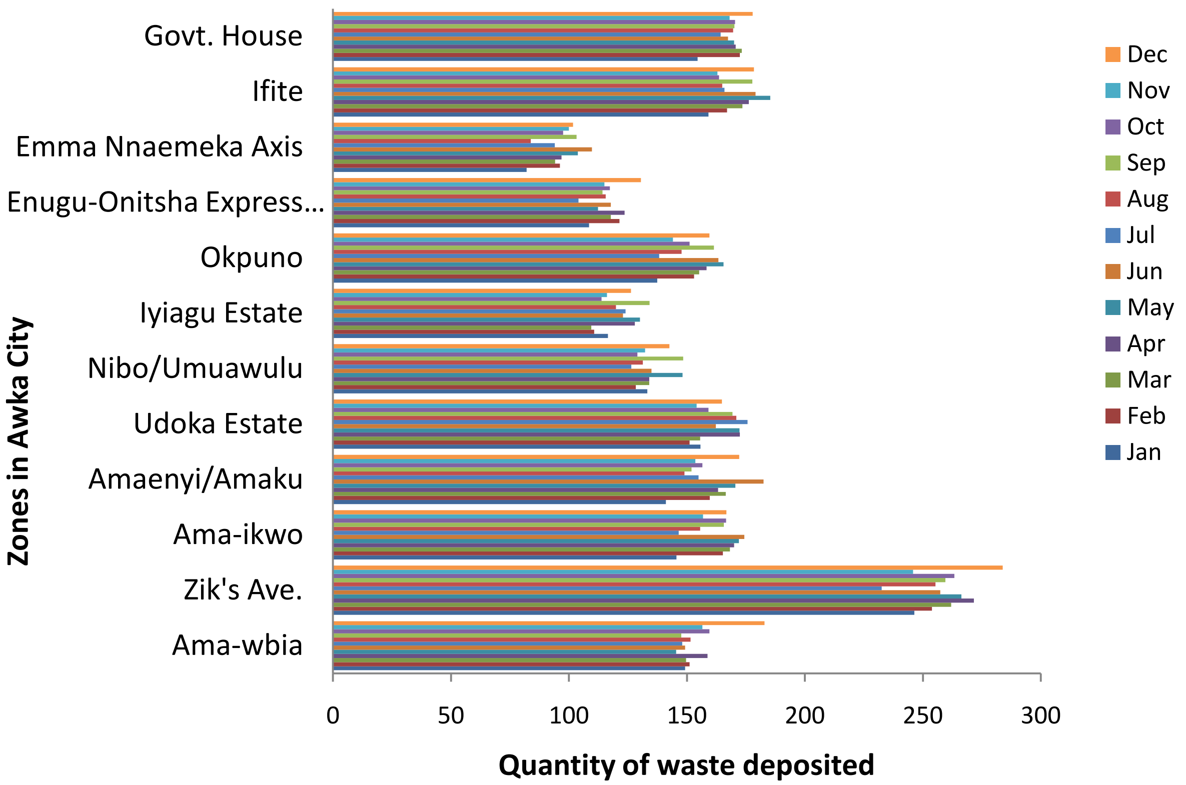


Figure 35: Average monthly solid waste generation in each of the twelve zones of Awka Urban City

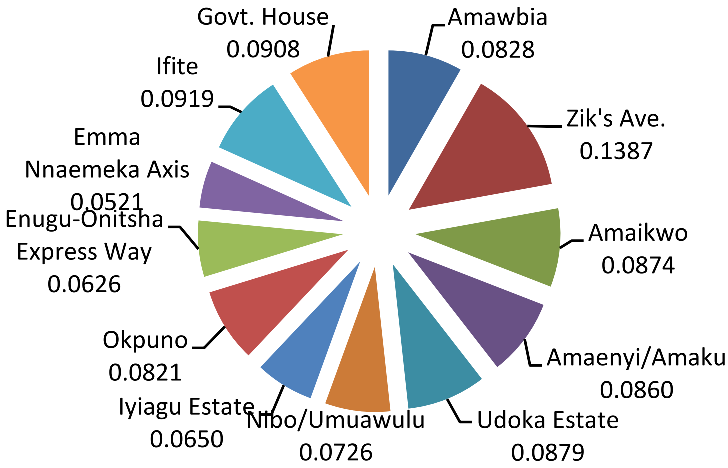


Figure 36: Fractional contribution from the various zones of Awka city

4.4.1 Determining long-range trend of Awka Urban waste generation

Table 37 contains the data in **Table 36** which have been converted to percentages, expressed as probability vectors of the average monthly total generations, with the transition states defined. The percents have been changed to decimals rounded up to the nearest one-thousandth. A Markov chain is then formulated from **Table 37** as shown in the transition matrix *M* that follows the table.

Table 37: Average percentage monthly contributions by each ASWAMA Zone to the average total solid waste produced in Awka city annually.

States	1	2	3	4	5	6	7	8	9	10	11	12	Total
1	0.086	0.142	0.084	0.082	0.090	0.077	0.067	0.079	0.063	0.047	0.092	0.089	1.000
2	0.083	0.139	0.090	0.087	0.083	0.070	0.060	0.084	0.066	0.053	0.091	0.094	1.000
3	0.080	0.141	0.090	0.090	0.084	0.072	0.059	0.083	0.063	0.051	0.093	0.093	1.000
4	0.082	0.141	0.088	0.085	0.090	0.070	0.067	0.082	0.064	0.050	0.092	0.089	1.000
5	0.075	0.137	0.089	0.088	0.089	0.076	0.067	0.085	0.058	0.053	0.095	0.088	1.000
6	0.078	0.134	0.091	0.095	0.084	0.070	0.064	0.085	0.061	0.057	0.093	0.087	1.000
7	0.083	0.131	0.083	0.087	0.099	0.071	0.070	0.078	0.059	0.053	0.094	0.093	1.000
8	0.083	0.141	0.086	0.082	0.094	0.072	0.066	0.081	0.064	0.046	0.091	0.093	1.000
9	0.078	0.136	0.087	0.080	0.089	0.078	0.070	0.085	0.060	0.054	0.093	0.089	1.000
10	0.086	0.143	0.090	0.085	0.086	0.070	0.062	0.082	0.064	0.053	0.089	0.092	1.000
11	0.087	0.136	0.087	0.085	0.085	0.073	0.064	0.080	0.064	0.055	0.090	0.093	1.000
12	0.092	0.143	0.084	0.087	0.083	0.072	0.064	0.080	0.066	0.051	0.090	0.090	1.000

Formulation of *M* from **Table 37** gives

M =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	0.086	0.142	0.084	0.082	0.090	0.077	0.067	0.079	0.063	0.047	0.092	0.089
2	0.083	0.139	0.090	0.087	0.083	0.070	0.060	0.084	0.066	0.053	0.091	0.094
3	0.080	0.141	0.090	0.090	0.084	0.072	0.059	0.083	0.063	0.051	0.093	0.093
4	0.082	0.141	0.088	0.085	0.090	0.070	0.067	0.082	0.064	0.050	0.092	0.089
5	0.075	0.137	0.089	0.088	0.089	0.076	0.067	0.085	0.058	0.053	0.095	0.088
6	0.078	0.134	0.091	0.095	0.084	0.070	0.064	0.085	0.061	0.057	0.093	0.087
7	0.083	0.131	0.083	0.087	0.099	0.071	0.070	0.078	0.059	0.053	0.094	0.093
8	0.083	0.141	0.086	0.082	0.094	0.072	0.066	0.081	0.064	0.046	0.091	0.093
9	0.078	0.136	0.087	0.080	0.089	0.078	0.070	0.085	0.060	0.054	0.093	0.089
10	0.086	0.143	0.090	0.085	0.086	0.070	0.062	0.082	0.064	0.053	0.089	0.092
11	0.087	0.136	0.087	0.085	0.085	0.073	0.064	0.080	0.064	0.055	0.090	0.093
12	0.092	0.143	0.084	0.087	0.083	0.072	0.064	0.080	0.066	0.051	0.090	0.090

Using matrix *M* we can predict the probable future monthly percentage waste contributions from the various Zones of Awka city. As stated earlier, it is taken that ***M*** is for the present year (2014) as the first year and the second year in our prediction is 2015, the third year is 2016, et cetera. This prediction will assist the state waste manager, ASWAMA, in making decision on how to schedule its disposal trucks to the Zones and if variable charges are to apply in the area, which zone pays what?

Using *M*, the waste production distribution of states in the months of 2015, 2020 and in the next 50th year were obtained as M^2, M^7 and M^{50} respectively. It should be noted that the positions of the zones as contained in **Table 10** have not changed in the transitions. That is to say, data for Amawbia Zone are still retained in column 1, data for Zik's Avenue are still retained in column 2, et cetera. Hence, we have

M^2 =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0826	0.1384	0.0873	0.0861	0.0874	0.0724	0.0645	0.0819	0.0628	0.0518	0.0917	0.0908
2	0.0829	0.1389	0.0875	0.0862	0.0875	0.0725	0.0646	0.0821	0.0630	0.0518	0.0918	0.0910
3	0.0828	0.1387	0.0875	0.0861	0.0873	0.0724	0.0645	0.0820	0.0630	0.0518	0.0918	0.0909
4	0.0828	0.1388	0.0875	0.0862	0.0876	0.0725	0.0646	0.0821	0.0629	0.0519	0.0919	0.0910
5	0.0828	0.1388	0.0876	0.0863	0.0875	0.0724	0.0646	0.0821	0.0630	0.0519	0.0919	0.0910
6	0.0828	0.1387	0.0875	0.0861	0.0875	0.0723	0.0645	0.0820	0.0629	0.0518	0.0918	0.0909
7	0.0829	0.1389	0.0876	0.0863	0.0877	0.0726	0.0648	0.0821	0.0630	0.0519	0.0920	0.0911
8	0.0827	0.1386	0.0874	0.0861	0.0874	0.0724	0.0646	0.0820	0.0629	0.0518	0.0918	0.0909
9	0.0827	0.1386	0.0874	0.0862	0.0875	0.0724	0.0645	0.0820	0.0629	0.0519	0.0918	0.0909
10	0.0831	0.1392	0.0877	0.0863	0.0877	0.0726	0.0647	0.0823	0.0631	0.0519	0.0920	0.0912
11	0.0828	0.1387	0.0874	0.0861	0.0874	0.0724	0.0645	0.0820	0.0629	0.0518	0.0918	0.0909
12	0.0831	0.1391	0.0877	0.0863	0.0877	0.0727	0.0648	0.0822	0.0631	0.0519	0.0920	0.0912

M^7 =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0826	0.1384	0.0873	0.0859	0.0873	0.0722	0.0644	0.0818	0.0628	0.0517	0.0916	0.0907
2	0.0828	0.1387	0.0874	0.0861	0.0874	0.0724	0.0645	0.0820	0.0629	0.0518	0.0918	0.0909
3	0.0827	0.1385	0.0873	0.0860	0.0873	0.0723	0.0645	0.0819	0.0628	0.0517	0.0917	0.0908
4	0.0828	0.1387	0.0874	0.0861	0.0874	0.0724	0.0645	0.0820	0.0629	0.0518	0.0918	0.0909
5	0.0828	0.1387	0.0874	0.0861	0.0874	0.0724	0.0645	0.0820	0.0629	0.0518	0.0918	0.0909
6	0.0827	0.1385	0.0873	0.0860	0.0873	0.0723	0.0645	0.0819	0.0628	0.0517	0.0917	0.0908
7	0.0829	0.1388	0.0875	0.0862	0.0875	0.0725	0.0646	0.0821	0.0630	0.0518	0.0919	0.0910
8	0.0827	0.1385	0.0873	0.0860	0.0873	0.0723	0.0645	0.0819	0.0628	0.0517	0.0917	0.0908
9	0.0827	0.1385	0.0873	0.0860	0.0873	0.0723	0.0645	0.0819	0.0628	0.0517	0.0917	0.0908
10	0.0829	0.1389	0.0876	0.0863	0.0876	0.0725	0.0647	0.0822	0.0630	0.0519	0.0920	0.0911
11	0.0827	0.1385	0.0873	0.0860	0.0873	0.0723	0.0645	0.0819	0.0628	0.0517	0.0917	0.0908
12	0.0829	0.1389	0.0876	0.0863	0.0876	0.0725	0.0647	0.0822	0.0630	0.0519	0.0920	0.0911

A close look at the values in each of the columns in *M* for the 2nd and 7th years seem to converge to certain specific values. After many (say, 50) years the values in the columns (rounded up to the nearest 1000^{th}) seem to have almost fully converged to their target end numbers.

M^{50} =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
2	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
3	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
4	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
5	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
6	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
7	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
8	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
9	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
10	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
11	0.083	0.137	0.087	0.085	0.087	0.073	0.065	0.082	0.063	0.052	0.092	0.090
12	0.082	0.138	0.087	0.086	0.087	0.072	0.064	0.081	0.062	0.051	0.092	0.090

The results obtained in M^{50} provides ASWAMA with the formulae in **Table 38** for sharing its responsibilities (job scheduling, revenue generation and expenditure, just name it) among the twelve zones of Awka municipality in the approximated ratio.

Table 38: Sharing formula for allocation of ASWAMA resources and job scheduling in Awka area.

1 Ama-wbia	2 Zik's Ave.	3 Ama-ikwo	4 Amaenyi/ Amaku	5 Udoka Estate	6 Nibo/Umu awulu	7 Iyiagu Estate	8 Okpuno	Enugu-Onitsha Express Way	10 Emma Nnaemeka Axis	11 Ifite	12 Govt. House
8.3%	13.7%	8.8%	8.6%	8.8%	7.2%	6.4%	8.2%	6.3%	5.2%	9.2%	9.1%

4.4.2 Determination of the month of best fit to start a research in SWM

The last column of **Table 10** gives the approximate values of the monthly total quantities of solid waste generated in all the zones in Awka city. It is assumed here that these quantities are the actual generations in the area and that the waste were allowed to keep accumulating till the end of the year. These assumptions enabled **Table 39** to be constructed. The table shows the transition states of the total waste generated monthly in the area. At the end of the month of January of a given year, only the quantity of waste generated in the month is recorded; no waste is generated in the future months. At the end of the month of February of the same year, only the quantity of waste generated in the months of January and February accumulated and were recorded; no waste is generated in the future months. By the same line of thinking, at the end of the month of March only the waste generated in the months of January to March were recorded, future monthly generations had null values, and so on.

Table 39: Stepwise consideration of data collected on waste generated monthly in Awka city

Future →

Present ↓

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Total Dump
Jan	1729.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1729.9
Feb	1729.9	1830.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3560.0
Mar	1729.9	1830.1	1859.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5419.3
Apr	1729.9	1830.1	1859.3	1923.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7343.0
May	1729.9	1830.1	1859.3	1923.7	1942.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9285.0
Jun	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	0.0	0.0	0.0	0.0	0.0	0.0	11206.0
Jul	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	0.0	0.0	0.0	0.0	0.0	12981.1
Aug	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	1815.5	0.0	0.0	0.0	0.0	14796.6
Sep	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	1815.5	1903.6	0.0	0.0	0.0	16700.2
Oct	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	1815.5	1903.6	1848.5	0.0	0.0	18548.7
Nov	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	1815.5	1903.6	1848.5	1805.5	0.0	20354.2
Dec	1729.9	1830.1	1859.3	1923.7	1942.0	1921.0	1775.1	1815.5	1903.6	1848.5	1805.5	1987.7	22341.9

The data in **Table 39** were converted into percentages, expressed as probability vectors and represented in **Table 40**.

Table 40: Values in Table 39 converted into percentages for application in Markovian analysis

States	1	2	3	4	5	6	7	8	9	10	11	12	Total
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
2	0.4859	0.5141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
3	0.3192	0.3377	0.3431	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
4	0.2356	0.2492	0.2532	0.2620	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
5	0.1863	0.1971	0.2002	0.2072	0.2092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
6	0.1544	0.1633	0.1659	0.1717	0.1733	0.1714	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
7	0.1333	0.1410	0.1432	0.1482	0.1496	0.1480	0.1367	0.0000	0.0000	0.0000	0.0000	0.0000	1.000
8	0.1169	0.1237	0.1257	0.1300	0.1312	0.1298	0.1200	0.1227	0.0000	0.0000	0.0000	0.0000	1.000
9	0.1036	0.1096	0.1113	0.1152	0.1163	0.1150	0.1063	0.1087	0.1140	0.0000	0.0000	0.0000	1.000
10	0.0933	0.0987	0.1002	0.1037	0.1047	0.1036	0.0957	0.0979	0.1026	0.0997	0.0000	0.0000	1.000
11	0.0850	0.0899	0.0913	0.0945	0.0954	0.0944	0.0872	0.0892	0.0935	0.0908	0.0887	0.0000	1.000
12	0.0774	0.0819	0.0832	0.0861	0.0869	0.0860	0.0795	0.0813	0.0852	0.0827	0.0808	0.0890	1.000

Finally, **Table 40** is converted to a regular transition matrix P as shown hereunder:

$P =$

States	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.4859	0.5141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.3192	0.3377	0.3431	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.2356	0.2492	0.2532	0.2620	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.1863	0.1971	0.2002	0.2072	0.2092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.1544	0.1633	0.1659	0.1717	0.1733	0.1714	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.1333	0.1410	0.1432	0.1482	0.1496	0.1480	0.1367	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.1169	0.1237	0.1257	0.1300	0.1312	0.1298	0.1200	0.1227	0.0000	0.0000	0.0000	0.0000
9	0.1036	0.1096	0.1113	0.1152	0.1163	0.1150	0.1063	0.1087	0.1140	0.0000	0.0000	0.0000
10	0.0933	0.0987	0.1002	0.1037	0.1047	0.1036	0.0957	0.0979	0.1026	0.0997	0.0000	0.0000
11	0.0850	0.0899	0.0913	0.0945	0.0954	0.0944	0.0872	0.0892	0.0935	0.0908	0.0887	0.0000
12	0.0774	0.0819	0.0832	0.0861	0.0869	0.0860	0.0795	0.0813	0.0852	0.0827	0.0808	0.0890

Following the same steps as used for the transition matrix M, P^2, P^{18}, P^{25} *and* P^{50} were determined as follows:

P^2 =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0000	0	0	0	0	0	0	0	0	0	0	0
2	0.7357	0.2643	0	0	0	0	0	0	0	0	0	0
3	0.5928	0.2895	0.1177	0	0	0	0	0	0	0	0	0
4	0.4992	0.2789	0.1532	0.0686	0	0	0	0	0	0	0	0
5	0.4338	0.2618	0.1630	0.0976	0.0438	0	0	0	0	0	0	0
6	0.3859	0.2449	0.1635	0.1103	0.0660	0.0294	0	0	0	0	0	0
7	0.3514	0.2307	0.1607	0.1155	0.0774	0.0456	0.0187	0	0	0	0	0
8	0.3226	0.2176	0.1565	0.1173	0.0840	0.0559	0.0311	0.0151	0	0	0	0
9	0.2976	0.2053	0.1513	0.1170	0.0877	0.0627	0.0397	0.0257	0.0130	0	0	0
10	0.2773	0.1947	0.1462	0.1157	0.0894	0.0668	0.0453	0.0329	0.0219	0.0099	0	0
11	0.2602	0.1853	0.1413	0.1138	0.0899	0.0692	0.0490	0.0379	0.0283	0.0171	0.0079	0
12	0.2439	0.1761	0.1362	0.1114	0.0897	0.0707	0.0517	0.0418	0.0333	0.0229	0.0144	0.0079

P^{18} =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	1.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.9998	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.9999	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P^{25} =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

P^{50} =

States	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The implication of the result obtained in P^{50} is that it does not really matter in which month of the year the present studies was started, provided the same length of time is maintained. This claim is what all the values in the first column (representing the present states) that have converged to unity indicate.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of a research is to describe what a research is set to achieve. Once the objectives of the research are achieved, the aim is achieved also. The main aim of this study was to develop models for use as tools in and MSWM. (Module 1.3 refers). Each of the stated objectives has been logically and vigorously pursued and concluded. In summary, the following conclusion are drawn from this study:

The study provides a systematic method of collecting, analyzing and keeping both qualitative and quantitative data on solid waste generation in a locality.

Models for optimizing cost of waste evacuation and forecasting of solid waste production were developed in the report following Baumol(1972) and Thomas *et al*(2001) methods, and by using calculus and Newton-Raphson iteration methods in determining optimum quantities of waste that minimized the objective function.

Models generated based on the functional relationships between waste generation and waste evacuation cost parameters are presented for use as monitoring/assessment tools for evaluating the performances of a waste manager and for estimating the financial transactions made over time.

A forecast made in the study revealed that a total of 2422 to 2588 chain-up bins of solid waste was generated in Awka in each month of January to May 2015 and ASWAMA must have used about N2.2m to N5.6m in each of these months to keep $\boldsymbol{Q}$ in the city at $\leq$ 30% of the total generation at the end of the month.

A Markov chain prediction gave a long time percentage monthly solid waste contributions to total waste stream from each of the twelve zones of Awka city in future years as: Amawbia = 8.3%, Zik's Avenue = 13.9%, Amaikwo = 8.8%, Amaenyi/Amaku = 8.6%, Udoka Estate = 8.8%, Nibo/Umuawulu = 7.2%, Iyiagu Estate = 6.4%, Okpuno = 8.2%, Enugu/Onitsha Expressway = 6.3%, Emma Nnaemeka Axis = 5.2%, Ifite = 9.2% and Government House = 9.1%.

A multiple regression analysis made to see how waste predictors combine to affect total quantities generated monthly gave a regression model:

$y_T = 0.99652x_1 + 1.00808x_2 + 1.0123x_3 + 1.0133x_4 + 0.9721x_5 + 0.9886x_6 + 1.0429x_7 + 0.9800x_8 + 0.9727x_9 + 0.9781x_{10} + 0.9929x_{11} + 1.0285x_{12} - e$. Where y is the total waste generation; x_1, x_1, x_1, …, x_{12} represent monthly waste contributions from Amawbia, Zik's Avenue, Amaikwo, …, Govt. House Zones in Awka area respectively; while e is an error term. .

Hopefully, the various models developed in the study will be beneficial to Anambra State in particular, wastes policy makers and managers in other states of the globe who may apply them in their waste management services. Also hoped for is that the analyses made and the results obtained from the study will contribute to knowledge enhancement in the academic world.

5.2 Recommendations

From the foregoing observations, it is seen that solid waste management in Anambra State should be taken more seriously than a technical issue. There should be inputs from a range of disciplines: institutional, social, legal and financial bodies and other stakeholders, as well as the general public. This implies coordinating, managing and collaborating with a large workforce, and considerations should also be made of local conditions.

Other recommendations of the study include:

a. Participation of the local communities in solid waste management should be encouraged.

c. Environmental education should be intensified by both the state and local government authorities, and management staff should be adequately trained. .

d. Primary, secondary and tertiary schools curricula should inculcate detailed topics on solid waste management.

e. Efforts should be made toward diverting most of the waste generated in the state for material and resource recovery. This practice will result to a substantial reduction in final volumes of wastes and the recovered material and resources could be utilized to generate revenue to fund waste management.

f. Disposed materials that are organic in nature, such as plant material, food scraps, and paper products, should be recycled using biological composting and digestion processes to decompose the organic matter. The resulting organic material should then be further recycled as mulch or compost for agricultural or landscaping purposes. In addition, waste gas from the process (such as methane) can be captured and used for generating heat and electricity. The intention of biological processing is to control and accelerate the natural process of decomposition of organic matter.

g. In accordance with the discussions made in section 3.2.1, ASWAMA should open up customers phone calls centre/programme where the public can feed the agency with information about the state of their environment, especially the waste bin locations that need evacuation attention of the agency. This will give the public the opportunity of participating in solid waste management in the state and also save ASWAMA the costs of employing some workers to do this, among other benefits. This method was used during the field study to monitor both the waste bin sites and the evacuator trucks that went to the bin sites in any day. A sample of the information flow structure is depicted in Figure XXI in the Appendices.

In the area of further research, the following recommendations are made:

1. There should be further investigations into ways of using the principles of inventory management to further develop the theory of SWIM, as a new way of looking at and handling municipal solid waste management problems.
2. Research should be made on how to apply artificial neural network in solid waste management, using the webbed model designed in the course of this study. The model is named Chukwutoo Christopher Chukwumuanya Emmanuel (ICCE) artificial neural network and shown as Figure XXII of the Appendices.

5.3 Contribution to Knowledge

Appropriate models have been developed for enhancing the performance of the Anambra State Waste Management Agency. In particular, the models are for determining the quantity of waste generated and the quantities that should be evacuated to maintain a minimal inventory of waste in given location of the study area. They also facilitate methods of estimating the costs of waste evacuation as well as enhancing a waste manager's performance.

5.3.1 Articles Published from this Study

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2. Ihueze C. C. and Chukwumuanya E. O. (2015). Statistical Modeling of Anambra State Solid Waste Management Constraints. *Global Journal of Engineering, Design & Technology*. Vol 4 (6) 1-7. www.gifre.Org

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APPENDICES

Tables:

Table A: Patterns of composition, characteristics and quantities of solid wastes

Composition (% by weight)	Low Income Countries (1)	Middle Income Countries (2)	High Income Countries (3)
Metal	0.2 – 2.5	1 – 5	3 – 13
Glass, Ceramics	0.5 – 3.5	1 – 10	4 – 10
Food and Garden waste	40 – 65	20 – 60	20 – 50
Paper	1 – 10	15 – 40	15 – 40
Textiles	1 – 5	2 – 10	2 – 10
Plastics/Rubber	1 – 5	2 – 6	2 – 10
Misc. Combustible	1 – 8	–	–
Misc. Incombustible	–	–	–
Inert	20 – 50	1 – 30	1 – 20
Density (kg/m3)	250 – 500	170 – 330	100 – 170
Moisture Content (% by wt)	40 – 80	40 – 60	20 – 30
Waste Generation (kg/cap/day)	0.4 – 0.6	0.5 – 0.9	0.7 – 1.8

(1) Countries having a per capita income less than US$360 (1978 prices)

(2) Countries having a per capita income US$360-3500 (1978 prices)

(3) Countries having a per capita income greater than US$3500 (1978 prices)

[Source: Holmes, J : Managing Solid Waste in Developing Countries]

Table B: Composition of waste stream characteristics

Waste Type	Nsukka β	Lagos µ	Makurdi ±	Kano µ	Onitsha ¥	Ibadan α	Maiduguri #
Putrescrible	56	56	52.2	43.0	30.7	76	25.8
Plastics	8.4	4	8.2	4.0	9.2	4.0	18.1
Paper	13.8	14.0	12.3	17.0	23.1	6.6	7.5
Textile	3.1	-	2.5	7.0	6.2	1.4	3.9
Metal	6.8	4.0	7.1	5.0	6.2	2.5	9.1
Glass	2.5	3.0	3.6	2.0	9.2	0.6	4.3
Others	9.4	19.0	14.0	22.0	15.4	8.9	31.3

Others = dust, ash, ceramics, rubber, soil, bones

α Diaz and Golueke (1985), β Ogwueleka (2003), ± Ogwueleka (2006), ¥ Agunwamba et al (1998), µ Cointreau (1982), # Dauda and Osita (2003)

[Source: Ogwueleka (2009)]

Table C: Urban solid waste generation

City	Population	Agencies	Tonnage per month	Density (kg/m^3)	Kg/capita/day
Lagos	8,029,200	Lagos Waste Management Authority	255,556	294	0.63
Kano	3,248,700	Kano State Environmental Protection Agency	156,676	290	0.56
Ibadan	307,840	Oyo State Environmental	135,391	330	0.51

		Protection Commission			
Kaduna	1,458,900	Kaduna State Environmental Protection Agency	114,433	320	0.58
Port Harcourt	1,053,900	Rivers State Environmental Protection Agency	117,825	300	0.60
Makurdi	249,000	Urban Development Board	24,242	340	0.48
Onisha	509,500	Anambra State Environmental Protection Agency	84,137	310	0.53
Nsukka	100,700	Enugu State Environmental Protection Agency	12,000	370	0.44
Abuja	159,900	Abuja Environmental Protection Agency	14,785	280	0.66

Table D: Ability of different waste management models to accommodate the procedures of CBA

Model	Calculation Of Costs Incurred When Implementing A Scheme	Estimation Of Financial Benefits When Implementing A Scheme	Accounting Of Environmental Effects When Implementing A Scheme	Collation Of Cost And Benefits
Waste Plan (Goldstein & Siecher, 2003)	Full cost accounting (FCA): Waste Plan facilitates the use of FCA, an approach aimed at accounting for and allocating all the cost for solid waste management to appropriate programmes (i.e. recycling, composting, collection, disposal) and management categories	Economic benefits: - Avoided cost disposal ($); - Source reduction: avoided cost of finished goods ($); - Recycling: Values of recycled commodities ($); - Energy Benefits: Avoided use of energy in material extraction, production, and disposal processes (MMBTU).	Air and water pollution benefits: - Avoided emissions in material extraction, production, and disposal processes (reduced pounds emitted); Land use benefits: - Landfill space preserved through source reduction and recycling (cubic yards, actres); - Avoided resource extraction (forest acreage).	CBA, least-cost system planning, capacity analysis/system mass balance assessment, sensitivity/scenario analysis
IWM-2 (McDougali et al, 2001)	Inputs: - operating cost - energy requirements	Outputs: - energy; - recovered materials; - compost Avoided burdens from recovered materials and energy	Outputs: - air emmissions; Residual solid waste (landfill volume)	The inputs and outputs are all done on a mass balance
WISARD (PWC and URS, 2001)	The calculation of cost is presented for each type of collection system: Capital	Revenue from energy, compost, recycling.	Air emissions, water emissions, emission to soil.	CBA Mass balance.

	expenditure and financing; operating expenditure: site management, administration, monitoring, closure and aftercare, insurance, etc.			
EPIC/CSR model (EPIC & CSR, 2000)	Collection, processing and administration costs. (the tipping fee charged at facility, actual capital costs of equipment and infrastructure and operating costs).	Revenue: - energy from waste programme; - recycling programme; - composting programme	Environmental impacts: - energy consumption; - greenhouse gas emissions (climate change); - emissions of acid gases (acid precipitation); - emission of smog precursors (smog formation); - air emissions of lead, cadmium, mercury and trace organics (health risk); - water emissions of heavy metals, dioxins and biological oxygen demand (impact on water quality); - residual solid waste (land use disruption.	The environmental impact is determined by the model's life cycle inventory module. The economic implications are ascertained by an economic analysis module. These modules can be used together or independently.
MSW-DST (Solano et al, 2002a, Solano et at 2002b)	Typical capital and operating costs for residential, commercial, institutional and industrial actors.	Revenues generated through the sale of recovered materials (recylable revenues), compost, fuels (gas) energy.	Environmental emissions (air, water), energy demands, landfilling of ashes.	Balancing the cost and environmental aspects to provide a win-win solution. Minimum-cost strategy. The most cost-effective strategy.
EUGENE (Berger et at, 1998)	The annual collection and transportation costs, the annual operating and maintenance costs, the investment costs, the importation costs (from the external	The annual revenue from sales to the markets.	The environmental and spatial indicators (will be integrated)	Total Discounted Net System Cost

	sources), the salvage values of the technologies.			
ORWARE (Erikson, 2000, Bjorklund, 2000)	Net costs include costs for investment and operation, spreading of residuals, and gas utilization. Costs for compensatory production of functional units are included as well.	Recovered energy is valued at market prices for compensatory generation of heat and power.	Emissions to air, water, and soil. Calculation of degradation products, energy output, primary energy carriers, heavy metals, nutrients.	Life Cycle Cost Analysis
MARKAL (Gielen, 1998)	The investment costs (which are proportional to the installed capacity), fixed annual costs (proportion-al to the installed capacity), variable costs (proportion-al to production volume), delivery costs	Energy recovery, waste recycling.	Greenhouse gas emissions, resource use, land use, waste volume.	The identification of least-cost system configuration, the evaluation of the effects of prices. The identification of cost effective responses to restrictions on emissions.
MWS (Ljunggren, 1997, Ljunggren, 1998)	Total annualized cost for the national waste management system	Revenues: - recovered materials; - compost; - recovered energy (heat)	The environmental assessment: - the accounting of the emissions to air and residual content of harmful substances in the waste or recovered material; - the introduction of emission constraints and fees.	The effect of different levels of costs increase, revenues for energy (heat), for compost and for recovered materials.

Table E: The cost structure for a SWM scheme

Cost category	Cost item
C_c Capital outlays	- Costs for land acquisition (purchasing and changing) - Costs for construction of main facilities, subsidiary industrial and service facilities, temporary buildings and constructions - Costs for acquisition of buildings, premises and constructions - Costs for acquisition of trucks and machinery and their setup - Costs for acquisition of intangible assets (know-how transfer, software, databases, patents, trademarks, licenses, know-how, etc) - Tax and other obligatory payments on investment activities

	- Other capital outlays
C_{op} Operating costs	- Material expenditures - Energy costs - Depreciation costs - Salaries of operating personnel - Tax and insurance costs - Rental payments - Administration costs - Costs for working environment of operating personnel - Costs for organization of work - Decommissioning costs (taking into account return of means from close-out sale) including retirement benefits of operating and service personnel - Other costs
C_r Costs for extensive and routine repairs	- Costs for repair of buildings and constructions such as offices - Costs for repair of used and unused equipment, trucks and machinery - Costs for repair of industrial premises
C_{en} Costs for creating engineering networks (infrastructure)	- Costs for construction of water supply, sewage, power supply, gas supply, communication, telecommunication, and signaling facilities, for example, cabling costs - Costs for hook-up of engineering networks such as connection fees
C_t Costs for creating the transport scheme servicing a MSW management scheme	- Costs for construction of stationary transportation management facilities - Costs for construction of roads including marking-out and installation of means ensuring safety of traffic and pedestrians
C_i Costs for investment project services	- Costs for research and design works - Costs for technical-economic substantiation including costs for legal and public hearings - Costs for investigations related to a project and documentation process - Preliminary organization expenses (costs for registration, advertisement, capital issue, marketing, banking and legal services, etc - Payment of long-term consulting and auditing services - Costs for scientific and engineering information and certification, for example, by ISO and EMAS etc. - Costs for creation of a supply network - Costs for training and retraining of personnel - Other costs
C_{ec} Costs for current	- Costs related to remediation of use of natural resources

Table F: Full Cost Accounting concept

Cost Category	Types and Examples Of Costs
Up-front costs	Public education and outreach; Land acquisition; Permitting Building construction/modification
Operating costs	Normal costs (operation and maintenance, capital costs, debt service); Unexpected costs
Back-end costs	Site closure; Building/equipment decommissioning; Post-closure care; Retirement/health benefits for current employees
Remediation costs	Investigation, containment, and cleanup of known releases; Closure and post-closure care at inactive sites
Contingent costs	Remediation costs (undiscovered and/or future releases); Liability costs (e.g., property damage, personal injury, natural resources damage)
Environmental costs	Environmental degradation; Use or waste of upstream resources; Downstream impacts
Social costs	Effects on property values Community image; Aestethic impacts Quality of life
economic damage	- Costs for elimination of consequences of environmental caused by pollution of pollution such as wind littering
the environment	- Health damage compensations to the population including compensations to the operating and service personnel
C_{tax} Environmental taxes	- Costs for environmental taxes due to current waste assortment grade and toxicity etc.
C_o Other costs	- Other unanticipated costs such as sabotage and earth quake damages and other force majeure kind of costs

Table G: Breakdown of capital investment items

Cost	**Cost Designation**	**Comments**
DIRECT PLANT COST DPC	Delivered equipment cost (DEC)	Processing equipment Product handling Waste reception equipment Maintenance equipment Include freight charges, taxes, insurance, duties
	Equipment installation	Materials and labour Structural supports (foundations, platforms), insulation (materials required for insulating), paint
	Installed equipment cost (IEC)	
	Instrumentation and controls	Purchase, installation, caliberation, computer tie-in
	Electrical equipment and materials (installed)	Electrical equipment-switches, motors, conduit, wire, fittings, feeders, grounding, instrument and control wiring, lighting, panels, electrical materials and labour

	Buildings (including services)	Process building Auxiliary building Maintenance shops Include electrical equipment
	Utilities	Steam, waster, power, refrigeration, compressed air, fuel, waste disposal include substation and transformer costs
	Services	Services or outside lines includes all piping, electrical works, waster, and sewers beyond battery limit
INDIRECT PLANT COST IPC	Architectural and engineering fees	Engineering costs-administrative, process, design and general engineering, drafting, cost engineering, procuring, expediting, reproduction, communications, scale models, consulting fees
	Contractor overheads	Includes all fringe benefits such as vocation, sick leave retirement benefits; labour burden such as social security and unemployment insurance; and salaries and overhead for supervisory personnel
	Contingency	A factor to compensate for unpredictable events, such as storms, floods, strikes, price
	Fixed-capital cost, C_{FC}	
NON PLANT COST (NPCC)	Start-up	Expenses for changes that have to be made before the plant can operate at maximum design conditions
	Working capital	Total amount of money invested in raw materials and supplies carried in stock, finished products in stock, accounts receivable, cash kept on hand for monthly payment and operating expenses, accounts payable and taxes payable
	Yard improvement	Site development-site clearing, grading, roads, walkaways, railroads, fenses, parking areas, wharves and piers, recreational facilities, landscaping
	Land	Surveys and fees property cost
	Total capital cost C_T	

Table H: Breakdown of operating cost items [Source: EMSEA, 2013-14]

Component		Comment
Direct Costs (DC)	Raw materials	Reagent, and other feed stocks required for the process
	Energy and other utilities	Costs of utility streams required by process: fuel gas, oil, coal, electric power, stream, cooling water, etc.
	Labour	Cost of personnel required for plant operations
	Supervision	Cost of engineering and support personnel
	Payroll charge	Payroll and accounting services
	Maintenance	Reserve account for maintenance, repairs and replacing, equipment exactly as it is.
	Operating supplies	Costs of miscellaneous supplies that support daily operation not considered to be raw materials: chart paper, lubricant, filters, protective clothing for operators, etc.
	Laboratory	Cost of routine and special laboratory tests required for product quality control and troubleshooting.
	Royalty	Cost of using patented or licensed technology
Indirect Costs (IC)	Rates	
	Insurance	Cost associated with property taxes and liability insurance based on plant location and severity on the process
	Overhead/ Administrative	Fire protection and safety services, medical services, cefeteria and any recreation facilities, payroll overhead and employee benefits, general engineering, etc. Includes salaries, other administration, buildings and other related activities.
	Research	

	Distribution/selling	Costs of sales and distribution
	Residual disposable	

Table I: SWOT analysis of a market position of a small business firm
[Source: Wikipedia]

Strengths	Weaknesses	Opportunities	Threats
Reputation in marketplace	Shortage of consultants at operating level rather than partner level	Well established position with a well defined market niche	Large consultancies operating at a minor level
Expertise at partner level in HRM consultancy	Unable to deal with multi-disciplinary assignments because of size or lack of ability	Identified market for consultancy in areas other than HRM	Other small consultancies looking to invade the marketplace

Table J: ASWAMA Zones, dump sites, number and type of waste bins identified in Awka area

Name of Zone	Waste Bin Locations										No. Of Bins In Zone	
											Comp-actor	Chain-up
Amaw-bia	Ugwu Tank	KHBE	St. Peters	Primary Sch.	Cheleku Hotel	Agulu Rd/ NAFDAC	-	-	-	-	9	15
Zik's Ave.	Ukwu Orji/ St. Pauls	Master Burger	NIHS/ Former CBN	Ogbugba-nkwa	Prof. Ken Dike Park	Eke Awka	-	-	-	-	-	12
Ama-ikwo	Bishop Crowder	Ogbali-ngba	Life & Light Ministries	New Mille-nium	Prof. Ken. Dike Street		-	-	-	-	3	6
Amaenyi / Amaku	Amaenyi Girls	Majuo Junction	Man 'O' War	Nwoka Street	Araba	Ejiabu	-	-	-	-	6	15
Udoka Estate	Rd. 1	Rd. 2	Rd. 15	Rd. 16	Gate 17	Estate Gate/ Express	Chief Emek Onuah Close	Ikebuba Nzewi Close	Markos Drive	Grac Court Drive	21	15
Nibo/ Umu-awulu	Govt. Lodge	Trig Point	Eke Nibo	Umuawulu Rd.	Nibo Ring Rd.	-	-	-	-	-	27	1
Iyiagu Estate	Hon. Uche Ekwunife Str.	Mama Africa Restraunt	Iyiagu Estate	Queen's Suit Close	St. Joseph d' Walker	Park-tonian Hotels	-	-	-	-	12	-
Okpuno	Y-Junction	Behind Mille-nium	Choice Hotels	Choice Hotels Close	Old INEC Building	-	-	-	-	-	-	12
Enugu-Onitsha Express Way	Nnedioramma Hostel	Acon Filling Station	Lagos Park	Old Unizik Temp. Site Junct.	-	-	-	-	-	-	3	4
Emma Nnaemeka Axis	Cona Hotels	Emma Nnaemeka Str.	Arthur Eze Ave./ Express	-	-	-	-	-	-	-	-	3
Ifite	Plaza	5-Deckin	$3^1/_2$ Storey	St. Anthony	2nd Market	Unizik/ Ifite Rd.	-	-	-	-	10	8

Govt. House	Ukwuorji Market	Ezenwanyi Axis	Govt. House	Ester Obiakor	-	-	-	-	-	-	8	6

Table K: Departments In ASWAMA [Source: Field survey]

Name Of Department	**Headed By (Officer)**	**Basic Qualification of Heading Officer**	**No. of Staff In the Dept.**
Administration Dept.	Administrative Officer	B. Sc/HND	5
Operations Dept.	Operations Officer	B. Sc/HND	10
Revenue Dept.	Head Of Department	B. Sc/HND	5
Litigation Dept.	Litigation Officer	B. Sc/HND	3
Accounts Dept.	Head of Department	B. Sc/HND	2
Enforcement Dept.	Enforcement Officer	B. Sc/HND	5

Table L: 1991 and 2006 population census of Anambra State, Nigeria [Source: NPC, Awka 2014]

S/N	LGA	Total Population (1991)	Projected Population (1996)	Total Population (2006)
1.	Aguata	286897	331151	369972
2.	Anambra East	81445	94008	152149
3.	Anambra West	113132	130583	167303
4.	Anaocha	157682	182004	284215
5.	Awka North	60728	70095	112192
6.	Awka South	130664	150819	189654
7.	Ayamelum	85812	99048	158152
8.	Dunukofia	64106	73994	96517
9.	Ekwusigo	89024	102756	158429
10	Idemili North	278632	321610	431005
11	Idemili South	124133	143280	206816
12	Ihiala	179734	207457	302277
13.	Njikoka	125239	144557	148394
14.	Nnewi North	121065	139739	155443
15.	Nnewi South	147428	170168	233362
16.	Ogbaru	191761	221340	223317
17.	Onitsha North	121157	-	125918
18.	Onitsha South	135290	-	137191
19.	Orumba North	92716	107017	172773
20.	Orumba South	92716	107017	184548
21.	Oyi	82350	95052	168201
	Totals =	2761711	2891696	4177828

Plates:

(a) A billboard found at a solid waste managers' Head Office at Onitsha.

(b) A waste container kept at the entrance gate into Laga International Ltd. company in Onitsha

Plate 1: Some information about the waste managers in Onitsha, Anambra State [Source: Field survey]

(a) A refuse dump inside Ekwulobia Motor Park, Aguata L. G. A

(b) A refuse dump at Eke Awka Market in Eke Awka Zone, Awka City

(c) A refuse dump behind Ekwulobia Motor Park, Aguata L. G. A

(d) A refuse dump at Ogbalingba in Amaikwo Zone, Awka city

Plate 2: Roadside dumpsites at different locations in Anambra State.
[Source: Field survey]

(a) A compactor truck in a reverse drive into the Agu-Awka dumpsite

(b) A chain-up (back loader) truck unloading solid waste at Enugu-Onitsha Express Way Dumpsite

(c) A wheel barrow loaded with solid waste and heading to Agu-Awka dumpsite, Awka South LGA, Anambra State.

(d) A tipper truck unloading solid waste at Enugu-Onitsha Express Way dumpsite, Onitsha North LGA of Anambra State.

Plate 3: Waste disposal/transportation vehicles [Source: Field survey]

(a) Loaded large (chain-up) bins at Eke-Awka dumpsite waiting for evacuation

(b) Loaded small (compactor) bins in Udoka Estate waiting to be discharged of its content - i.e. rubbish

Plate 4: Pictures of stationary type waste containers loaded with solid waste materials
[Source: Field survey]

Plate 5: An open refuse dumpsite in Onitsha, Anambra State
[Source: UN-Habitat, 2012]

Figures:

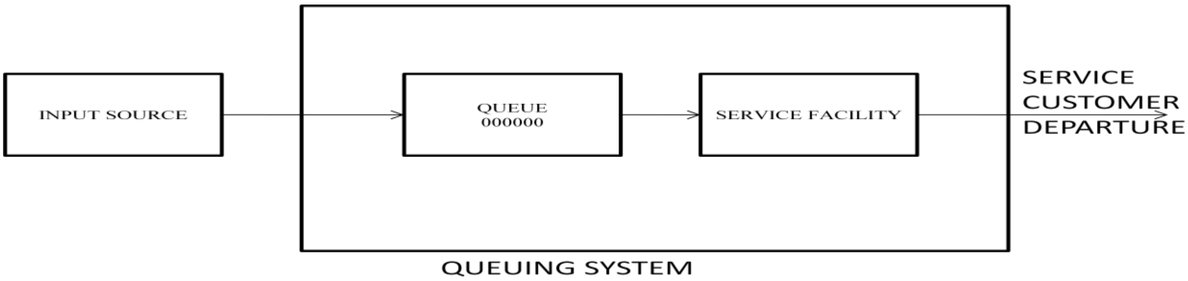

Figure I: A High-Level View of a Basic Queuing Process

[Source: Davis et al., 2003]

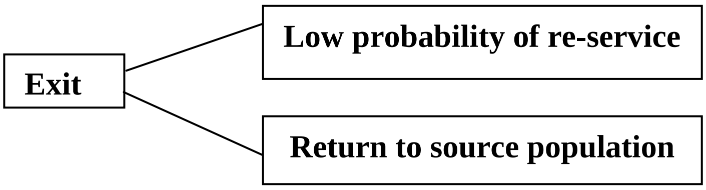

Figure II: Departure from a queuing system *[Source: Davis R. and Davis H. (2005)]*

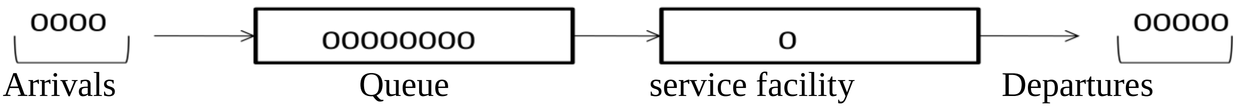

Figure III: Single-server, Single phase System. *[Source: Obamiro (2003)]*.

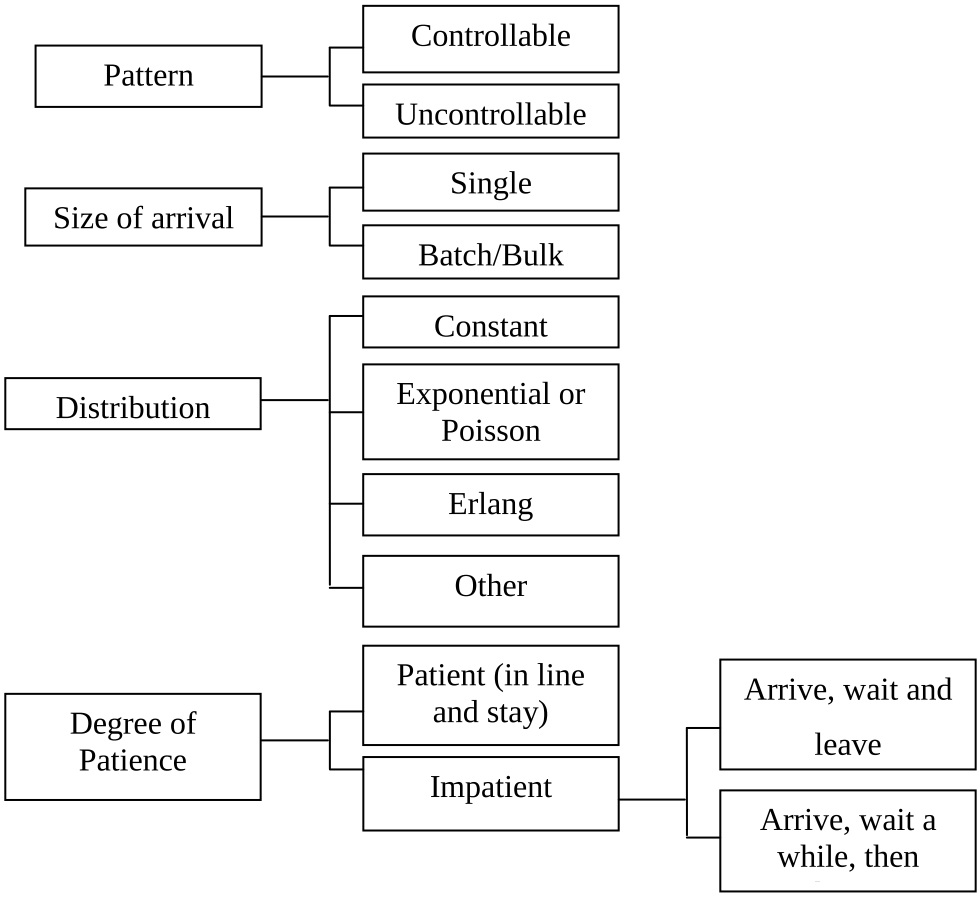

Figure IV: Arrival Characteristics in a Queue [*Source: Davis et al.*,

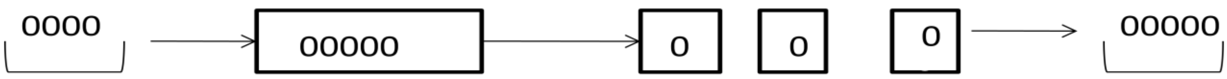

Figure V: Single-server, multiple phases System

[Source: Adopted from Obamiro (2003)]

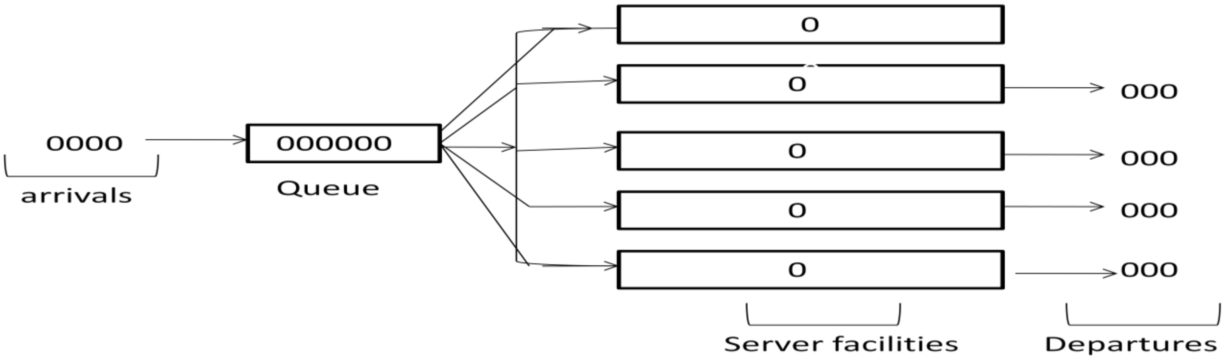

Figure VI: Multiple-servers, Single phase System *[Source: Obamiro (2003)]*

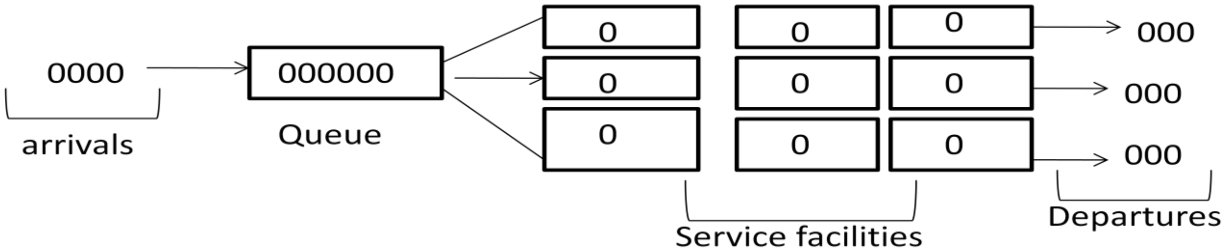

Figure VII: Multiple-servers, Multiple-phase System *[Source: Obamiro (2003)]*

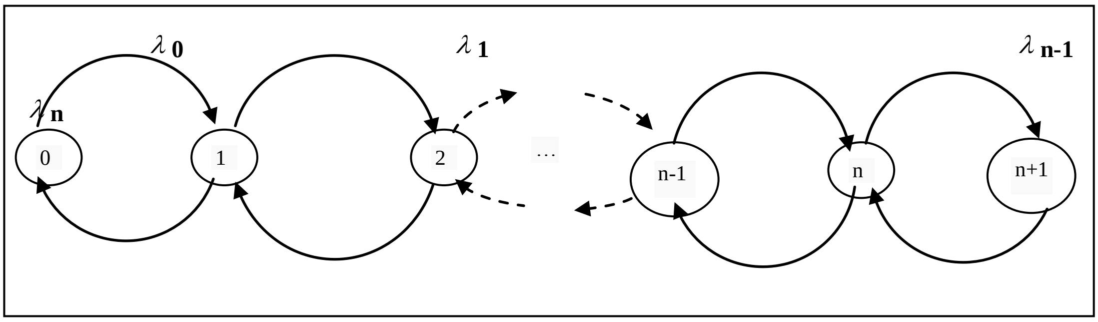

Figure VIII: Rate Diagram for the Birth-and-Death Process

[Source: Medhi (2003)]

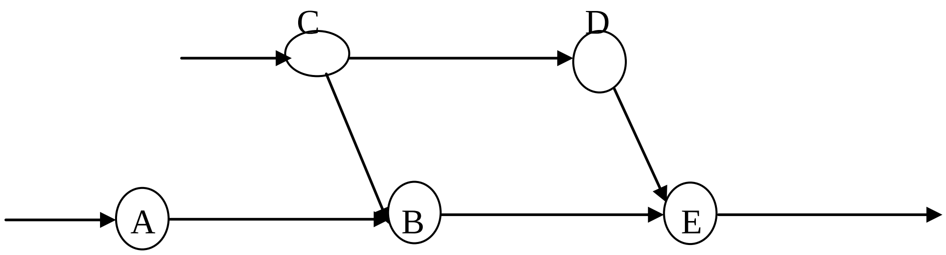

Figure IX: Example of a Queues Network

[Source: Medhi (2003)]

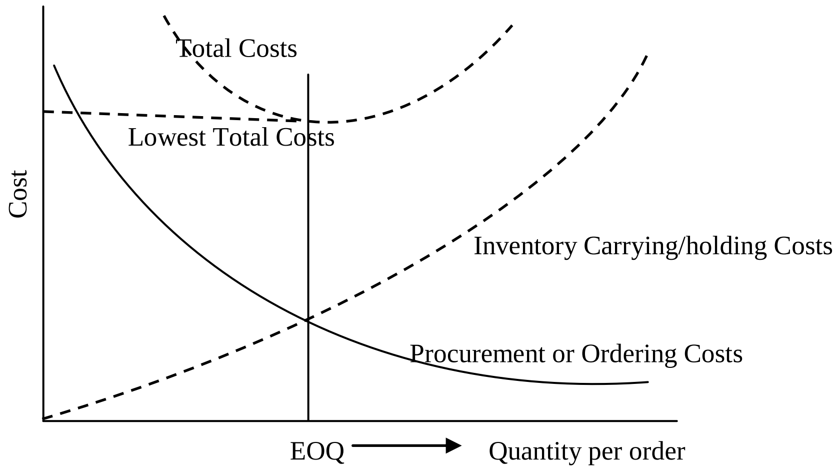

Figure X: Variation in different costs with lot size

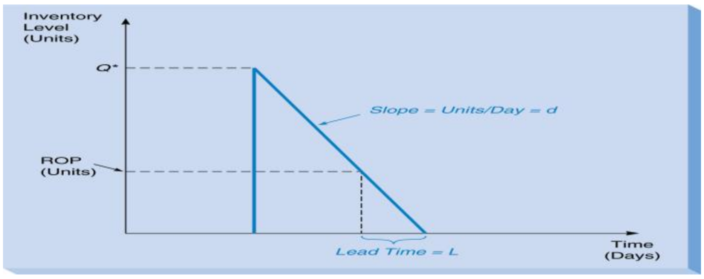

Figure XI: Reorder point [Source: Pearson, 2007]

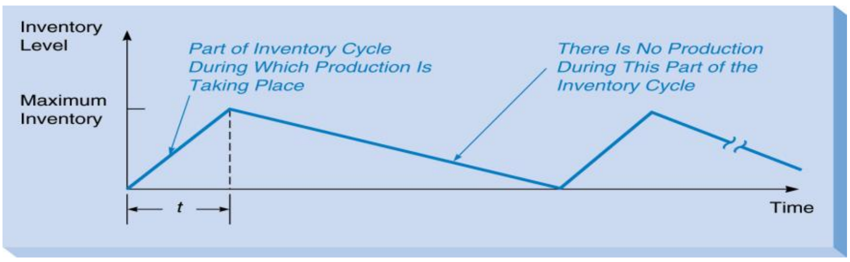

Figure XII: Inventory control with production
[Source: Pearson, 2007]

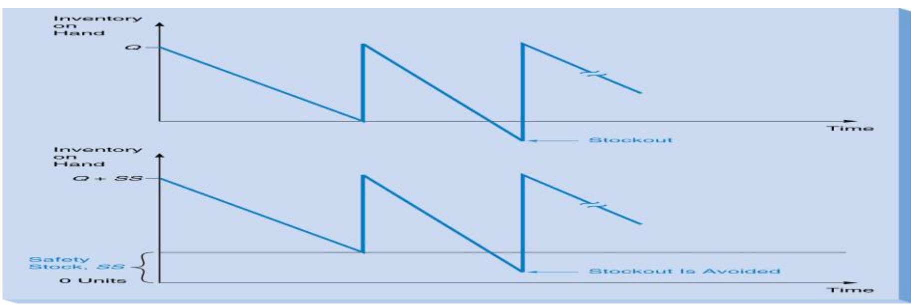

Figure XIII: Use of Safety Stock [Source: Pearson, 2007]

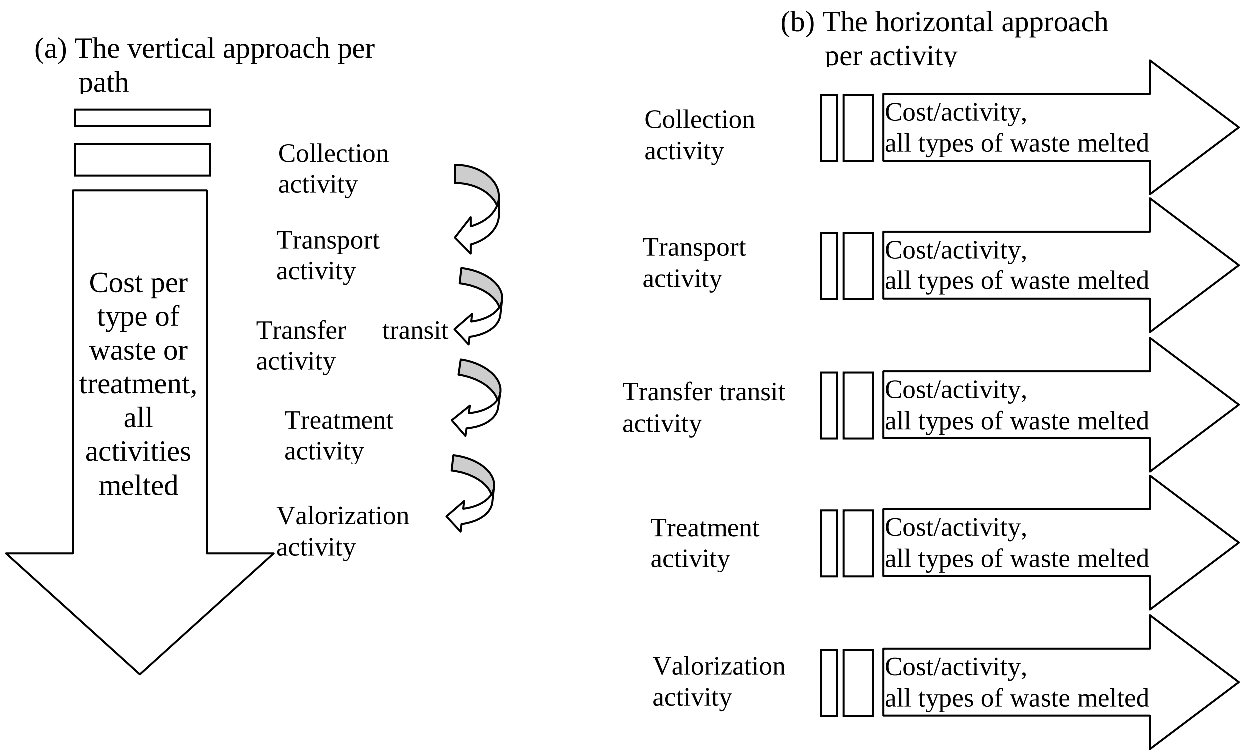

Figure XIV: Explicative scheme of activity and path distinction [Source: AWAST, 2004]

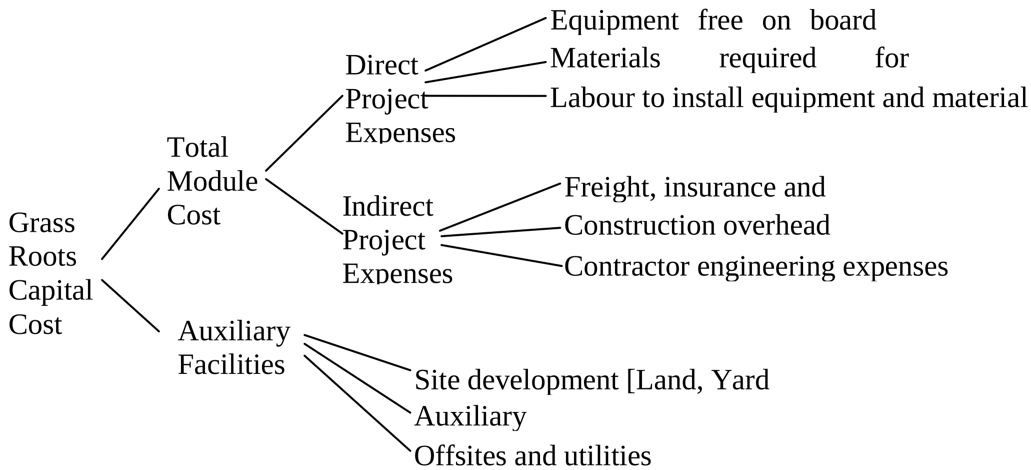

Figure XV: Capital costs classification by Turton

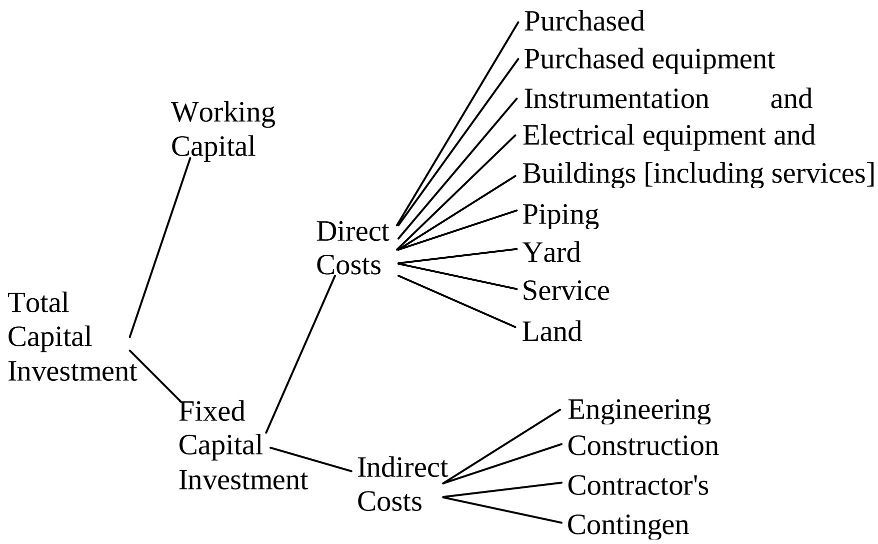

Figure XVI: Capital costs classification by Timmerhaus

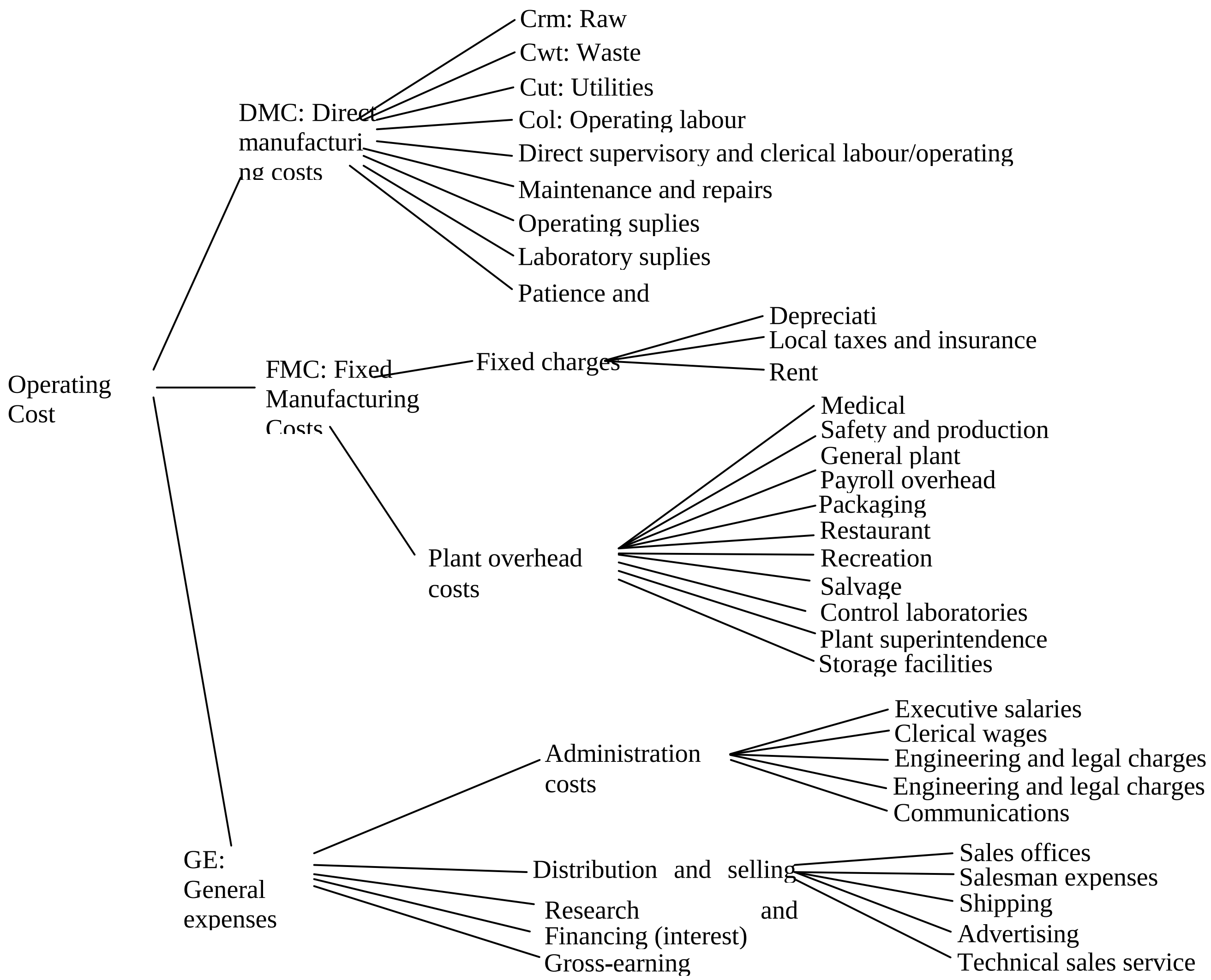

Figure XVII: Components of operating cost

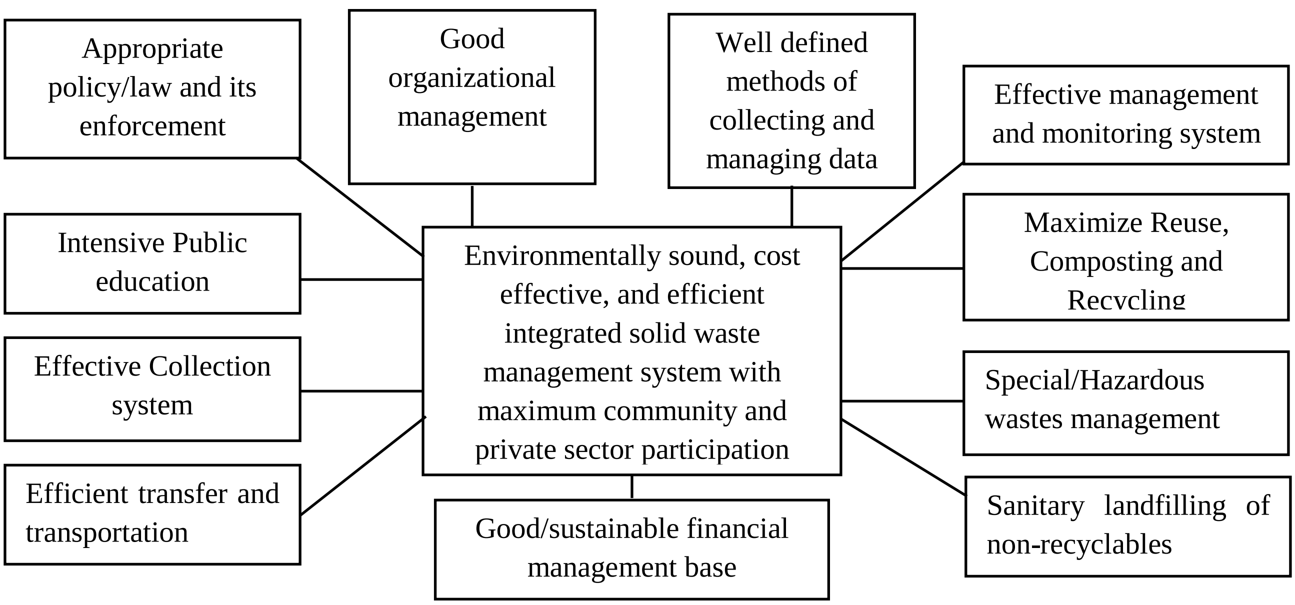

Figure XVIII: Strategy for Integrated Solid Waste Management
[Source: Klundert and Anschiitz, 2000]

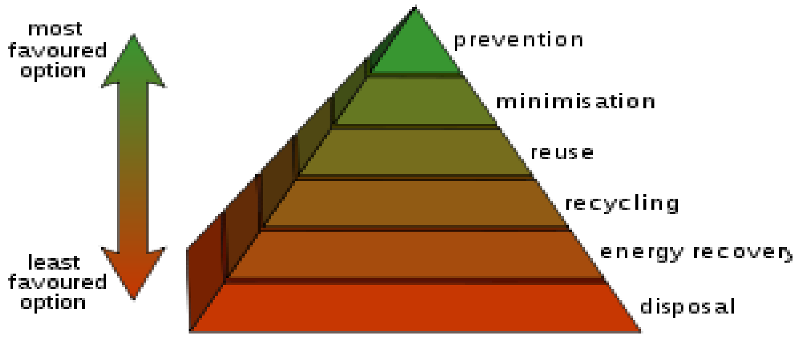

Figure XIX: Waste management hierarchy [Source: Wikipedia]

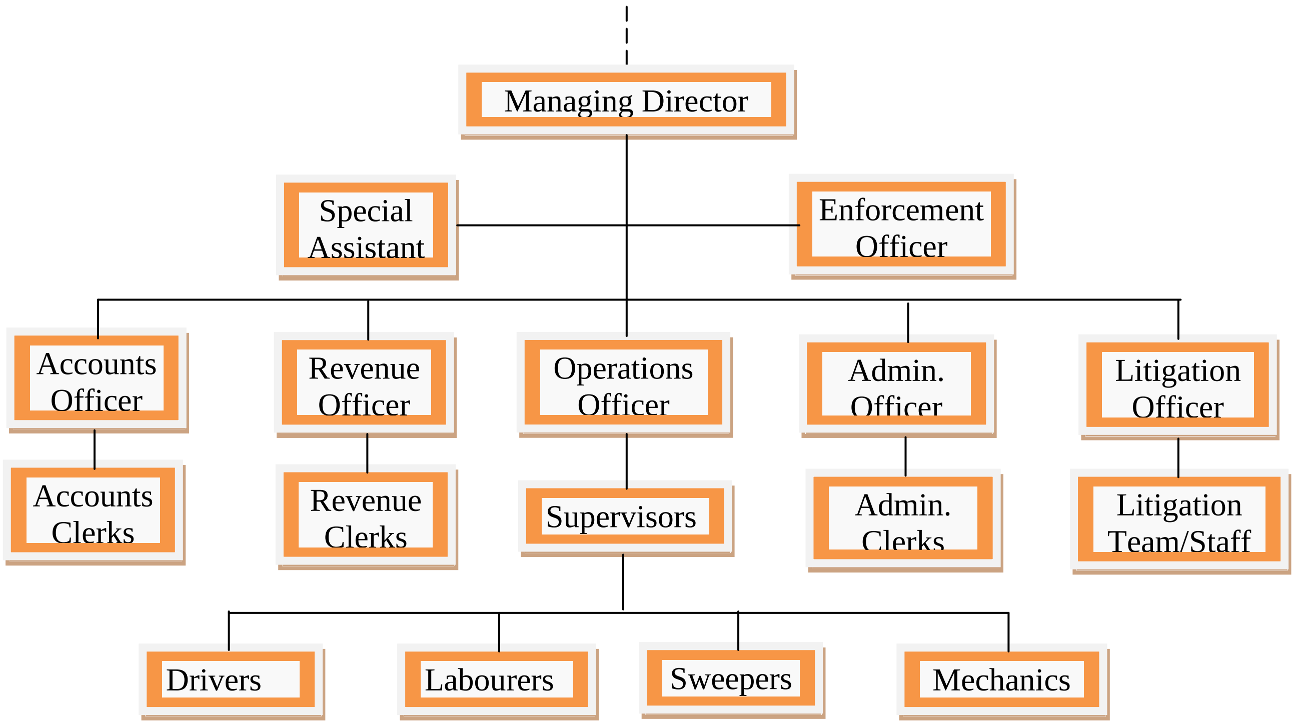

Figure XX: Organizational structure of ASWAMA [Source: ASWAMA]

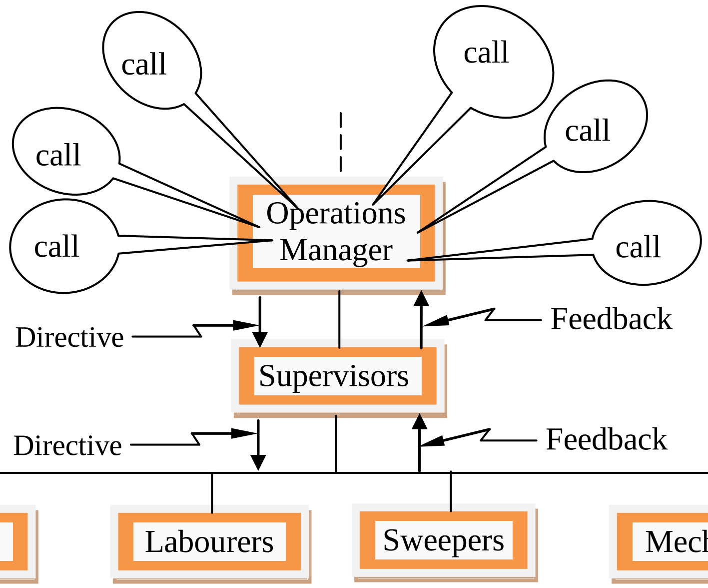

Figure XXI: An information flow structure for solid waste management

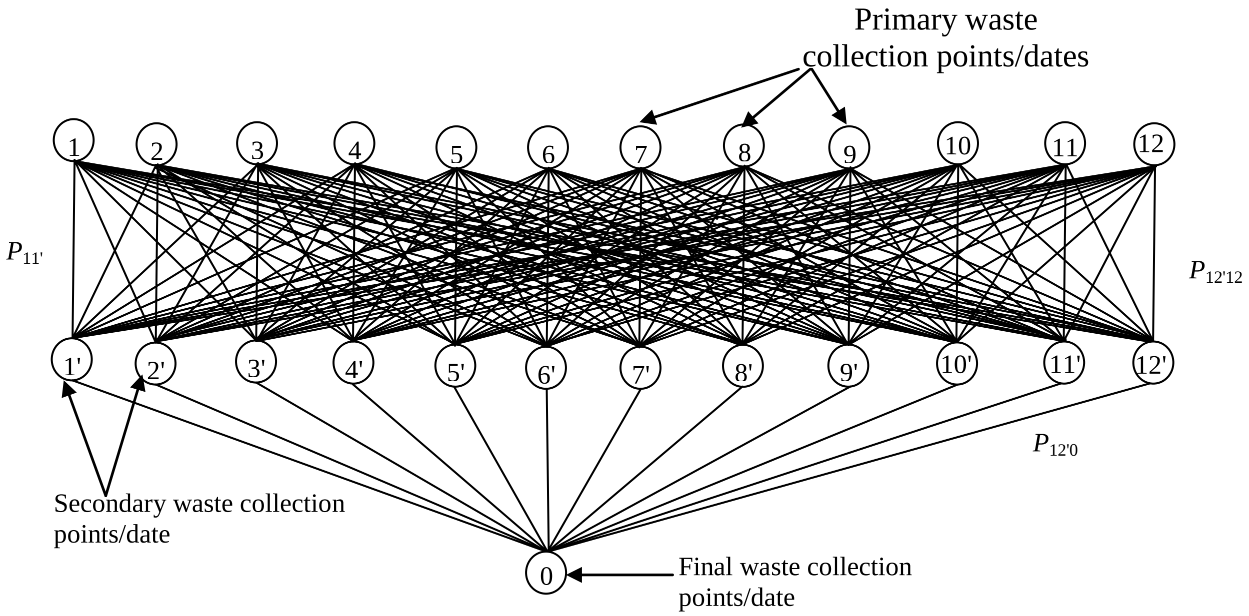

Figure XXII: An ICCE artificial neural network showing the probability distribution of waste production states at the end of different periods in a year.

Equations:

$$P^{P}_{\lambda,} = \frac{(\bar{\lambda})^{\lambda} e^{-\bar{\lambda}}}{\lambda!} \qquad (i)$$

$$f(t) = \bar{\mu} e^{-\bar{\mu} t} \qquad t \geq 0 \qquad (ii)$$

$$L_s = \frac{\lambda}{\mu - \lambda} \qquad (iii)$$

$$W_s = \frac{1}{\mu - \lambda} \qquad (iv)$$

$$\mathrm{L_q} = \frac{\lambda^2}{\mu(\mu - \lambda)} \qquad (v)$$

$$\mathrm{W_q} = \frac{\lambda}{\mu(\mu - \lambda)} \qquad (vi)$$

$$\rho = \frac{\lambda}{\mu} \qquad (vii)$$

$$P_0 = 1 - \frac{\lambda}{\mu} \qquad (viii)$$

$$P_n = \rho^n (1 - \frac{\lambda}{\mu}) \qquad (ix)$$

For the waiting time, *w*, of a unit which has to wait such that $w \leq W < w\ dw$,

$$P(w) = \int_{w}^{\infty} \lambda \left(1 - \frac{\lambda}{\mu}\right) e^{-(\mu - \lambda)w}\, dw \qquad (x)$$

$$\rho = \frac{\lambda}{m(\mu)} \qquad (xi)$$

$$p_0 = \left[\sum_{n=0}^{m-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{\left(\frac{\lambda}{\mu}\right)^m}{m!\left(1-\frac{\lambda}{m\mu}\right)}\right]^{-1} \qquad (xii)$$

$$L_q = \frac{\lambda\mu\left(\frac{\lambda}{\mu}\right)^m}{(m-1)!(m\mu-\lambda)^2} \; P_0 \qquad (xiii)$$

$$L_s = L_q + (\bar{\lambda}/\bar{\mu}) \qquad (xiv)$$

$$W_a = \frac{1}{m\mu - \bar{\lambda}} \qquad (xv)$$

$$W_q = \frac{L_q}{\bar{\lambda}} \qquad (xvi)$$

$$W_s = \frac{L_s}{\bar{\lambda}} \qquad (xvii)$$

$$P_w = \frac{W_q}{W_a} \qquad (xviii)$$

[Source: Blanc (2011), Sztrik (2011) and Nain (2004)]

$$L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)} \qquad (xix)$$

$$W_q = \frac{\lambda}{2\mu(\mu-\lambda)} \qquad (xx)$$

$$L_s = L_q + \frac{\lambda}{\mu} \qquad (xxi)$$

$$W_s = W_q + \frac{1}{\mu} \qquad (xxii)$$

Medhi, (2003); Hillier and Lieberman, (2005); Tutuncu and Newland, (2009).

$$X = \frac{T}{T+U} \qquad (xxiii)$$

$$L = N(1-F) \qquad (xiv)$$

$$W = \frac{L(T+U)}{N-L} = \frac{T(1-F)}{XF} \qquad (xxv)$$

$$J = NF(1-X) \qquad (xxvi)$$

$$H = FNX \qquad (xxvii)$$

$$N = J + L + H \qquad (xxviii)$$

[Source: Stevenson (2005)]

Total ordering cost = $(D/Q) \times C_o$ (*xxix*-a)

Total carrying cost = $(Q/2) \times C_h$ (*xxix*-b)

Total purchase cost = $p \times D$ = Total cost (*xxix*-c)

$(D/Q^*) \times C_o = (Q^*/2) \times C_h$ (*xxx*)

$Q^* = \sqrt{(2DC_o / C_h)}$ (*xxxi*)

$C_h = I \times p$ (*xxxii*)

Average inventory value = $p \times (Q^*/2)$ (*xxxiii*)

$C_o = Q^2 \times C_h/(2D)$ (*xxxiv*-a)

$C_h = 2DC_o/Q^2$ (*xxxiv*-b)

ROP = D x L (*xxxv*)

Max inventory = $Q \times (1- D/p)$ (*xxxvi*)

Ave inventory = $\frac{1}{2}Q \times (1- D/p)$ (*xxxvii*)

Setup cost = $(D/Q) \times C_s$ (*xxxviii*)

Carrying cost = $[\frac{1}{2}Q \times (1- D/p)] \times C_h$ (*xxxix*)

Production cost = P x D = Total cost (*xl*)

$(D/Q^*) \times C_s = [\frac{1}{2}Q^* \times (1- D/p)] \times C_h$ (*xli*)

$Q^* = \sqrt{(2DC_s / [C_h(1 - d / p)]}$ (*xlii*)

$x^2 = \sum[\frac{(f_o - f_e)^2}{f_e}]$ (*xliii*)

$f_e = \frac{(TR \times TC)}{GT}$ (*xliv*-a)

$df = (R – 1)(C – 1)$ (*xliv*-b)

$\mathbf{n} = \frac{N}{1 + N\boldsymbol{e}^2}$ 1 = a constant (*xlv*)