Analysis & Development Of Solid Waste Management System Of Addis Ababa

Master's Thesis
(Draft)

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Abstract

Solid waste, which is a consequence of day-to-day activity of human kind, needs to be managed properly. Addis Ababa like other cities in developing countries, faces problems associated with poorly managed waste collection operation. This thesis deals with the city's current solid waste management problems, collection and disposal.

The city's refuse collection operation is modeled using queuing/simulation model. Spreadsheet Monte Carlo simulation technique is used to simulate the collection activities of the vehicles. In a similar manner, the average waite time of the customer(unit volume of waste) is also simulated. The result obtained shows that the collection operation is affected by the relative location of zonal centroid with reference Repi landfill site. Based on the simulation result, vehicle performance in collection operation is also evaluated. The number of vehicles that are required to carry out the operation has been calculated.

In regard to solid waste disposal, alternative models are evaluated to meet the city's disposal need. Land filling with other disposal options is found to be better alternative. The four proposed landfill sites are modeled using linear programming technique for optimized collection/disposal operation. Energy recovery potentials of various disposal options like landfill, incineration and anaerobic digestion have been assessed. Material recovery potential of the city's refuse is also evaluated for reprocessing. Better solid waste management option is also proposed.

Chapter I

Introduction

1.1 Background

From the days of primitive society humans and animals have used the resources of the earth to support and to dispose of wastes. Problems with disposal of wastes can be traced from the time when humans first began to congregate in tribes, villages, and communities and the accumulation of wastes became a consequence of life. In most developing countries, the practice of throwing wastes in the streets, roadways, and vacant lands led to the breeding of rats, with their attendant fleas carrying the germs of disease, and the outbreak of plague. The lack of any plan for the management of solid waste, leads to the epidemic of plague.

The research focuses on Addis Ababa's solid waste collection and disposal problems. The background information of the city is vital for thorough understanding of the existing problem. Solid waste collection and disposal has been a problem for A.A city. The population size is the main factor for the quantity of waste generated every day. Economic background and living standard also affects the daily refuse generation. To meet the changing demands of the city refuse collection, it is necessary to look closely the population size, density and distribution.

The city (Addis Ababa) has an area of 540 square kilometers and situated between 9 degrees latitude and 38 degrees east longitude in a plateau ranging from 2200-2800 meters of altitude above sea level. The city is divided in to 6 administrative zones, 28 woredas and 303 kebeles.

The population is estimated to be 2.5 million with house hold size of 5.2 person and growing at the rate of 3.8% per year. The population size of Addis Ababa has grown from 443,728 in 1961 to 683,530 in 1967, 1,167, 315 in 1978, 1,423,111 in 1984 and to dejure population of 2,112,737 in 1994. Compared to the 1984 census, the 1994 population size has shown 3.26 percent increase.

Urban-rural distribution of the population of Addis Ababa indicate that the over whelming majority of population is living in urban area. Urban part of Addis Ababa, which is 56.1 percent (297.48 km^2) of Addis Ababa in terms of area size, contains 98.7 percent of the population. The remaining, 1.3 percent of the population is living in rural areas, which covers 232.73 km^2. Thus, population density of Addis Ababa is 3984 persons per km^2 and that of urban and rural parts of Addis Ababa are 7008 and 121 per km^2, respectively.

Regarding spatial distribution of population by zone, the 1994 population and housing census result indicates that the population is not evenly distributed over the 6 zones. Zone 4 has the highest population size, constituting just above one fifth of the total population of the region, then follow zones 5 and 2 with about 21 percent and 20 percent, respectively. Zones 1 and 3 contains about 15 percent and 18 percent of the population while zone 6 contains the least number of population (only about 5 percent.)

Of total solid waste generated in the city, 76% is from households and the rest 5% from industries, 6% from street sweepings, 9% from commercial areas, 1% from hospital and 3% from hotels. At present the daily total solid waste generation is estimated to be 573 tones out of which 360-412 tones are collected and disposal in land fill.

The environmental hygiene department as a coordinating office leads the refuse management system and 6 zonal offices that are involved in direct waste management. There are many operational and capacity problems that hinder the city's refuse collection. Because of lack of sound system of waste management, the city dwellers are at risks of health hazards.

1.2 Research Problems Statement

The problems related to solid waste management activities still continue to get public health importance for the growing cities of many developing countries. The United Nations center for Human settlements (Habitat) branch for Africa estimated that over 80% of the cities of developing countries do not possess an adequate and meaningful refuse management. Ethiopia as one of the many developing countries comprises some major cities, which lack quality and quantity of services of solid waste management system. Addis Ababa city started its solid waste management some three decades back. The service cannot meet changing demands [2].

The social waste collection service coverage of Addis Ababa city is estimated to be 65%. Since the solid waste service is unsatisfactory, scenes of scattered waste is common in most part of the city. As a result, the population has the opinion that the municipal solid waste collection service is not functioning properly. Consequence to this, the willingness of the population to cooperate with waste collection operation and to pay for the service is low [2]. With respect to the organization of operations and management structure, collection and disposal are parts that are poorly organized. A disposal site situated at one corner of the city is also the main determining factors for collection and disposal of wastes in the city. With context to processing and recycling of social waste, nothing is done at all level of its management i.e. no source separation or sorting and at disposal site too. But some scavengers at landfill sites practice an informal type of waste recovery. Other options like energy recovery, composting are not practiced as alternatives for waste recovery.

In general problems of refuse collection and disposal has been associated with the city refuse management for the last two or three decades. The health risk of the city inhabitants is vital that requires due consideration at most under such circumstances [2].

1.3 Objectives Of The Research

The research objectives emanate from current problems existing in the solid waste management of Addis Ababa city. Hence, the main objectives are:

- To estimate quantity of waste collected by a vehicle from the six administrative zones of the city for operational decision.
- To estimate the number of vehicles required for collection.
- To minimize collection cost through optimization of disposal.
- To develop better system of SWM in terms of collection & disposal.

1.4 Summary of previous Research and Research gap

Researches have been done in the areas of waste management of major cities of the country. Poorly organized refuse collection system not only make the city filthy and untidy but also risks the health of the inhabitants. In this context, various researches especially on improvement and planning were made in the past. Researches, which have been made on Addis Ababa's solid waste management, mainly focus on quantitative analysis and waste characterization. These are studies by international consultants (only some for partial fulfillment of master's degree) were geared towards quantifying refuse generation units. The solid waste generation unit was very much unclear until two decades ago. Therefore studies and researches were made particularly in these areas. Various researchers and international consultants came up with figures, which shows daily waste generation unit.

Quantification of the waste generated was essential as all refuse management planning is based primarily on it. Even though plan is made based on annual generation, the performance of the collection operation is still very low. To this effect, few researches focused on the city's waste management problems. These few research efforts on the city's solid waste management in general were on transport, volume analysis etc. Therefore it can be concluded that there is a relative neglect of the specific research problem of the existing collection and disposal.

With regard to the research methodologies followed by previous researcher on the management of refuse collection and vehicle allocation, was based on quantity of waste to be disposed. It has the limitation that it didn't consider other variable that affects the collection process. The methodology of the author of this research (discussed in chapter III in detail) relies on a general model that represents the system as a whole. The model incorporates variables affecting the system, which makes it capable of simulating the real system. Besides this, the data used as an input for the model to see the effect is derived from actual observed vehicle collection performance.

Usefulness of potential application of the research's findings is based on the problems associated with collection and disposal. Improving the performance of the system as a whole for the benefit of the public is the main objective. As far as the problems exist and the condition gets worse, it is eminent that research needs to be done in this area.

1.4 Methodology overview and Definitions

1.4.1 Methodology overview

The methodology is primarily based on appropriate modeling of the whole system, which represents the actual activities. Refuse collection operation is modeled as queuing operation which suits situations where imbalance exist between the service and the customer. Modeling a system eases complexity so that factors and variables can be weighted against its effect. The system that is modeled as queuing operation is simulated to observe and analyze requirements for the operation. Monte Carlo simulation is applied to this effect. Spreadsheet Monte Carlo simulation using single sever queue model is done for each zone of the city to come up with necessary results.

Data collection is a primary activity next to model building. Secondary real data showing the service time of waste collection vehicles is collected. The collected data being processed, gives probability distribution of service time used in Monte Carlo simulation.

Landfill site allocation of waste quantity to new sites also modeled using linear programming techniques with appropriate mathematical representation for enhancement of the cities refuse management.

The methodology of the research is described in detail in chapter 3.

1.4.2 Definitions

Solid Waste: is the general term used to describe to a non-liquid waste materials arising from various social and economical activities in human settings. The current Addis Ababa Municipality operation health regulation (Legal Notice 1/1986 E.C) states solid waste as any thing discarded as public sweepings, food remains, ash, vegetable and grass remains, cigarette butts, papers of various sorts, discarded glass, metals, plastics, dead animal, and the like that poses environmental health risks.

Transfer stations are centralized facilities where waste is unloaded from smaller collection vehicles (containers) and re loaded into larger vehicles for transport to a disposal or processing site.

Landfill Secure landfill is carefully engineered depression in the ground (or built on top the ground, resembling a foot ball stadium) in to which wastes are put.

Container Is a material made of metallic substances used for storage of refuse.

Compactor trucks A truck that allow waste containers to be emptied in the vehicle from the rear, the front or the side. It compacts the waste to a high density using hydraulic or mechanical pressure.

Service time The time taken for waste collector truck to collect, load and transport to a landfill area.

Arrival time The time elapsed in between arrival of waste in specified amount.

Queue Refuse in specified amount waiting for service.

Simulation Refers to any analytical method meant to imitate a real-life system especially when other analyses are too mathematically complex or too difficult to reproduce.

Monte Carlo Simulation A technique, which randomly generates values for uncertain variables over and over to stimulate a model.

Chapter II

Literature Review

In the past many individual and consulting researchers have worked in the area of waste management. In the developed world, quite many researchers came up with sound solutions for the problem on which they dealt. In contrast to this, only few researches have made studies on Addis Ababa's solid waste management. The contributions of these authors can be put under the following categories.

(i) Waste characterization and quantification

(ii) Waste collection and modeling

(iii) Waste disposal systems

(iv) Energy recovery from municipal solid waste

In subsequent sections of this chapter, the contributions of some of the important authors are discussed.

2.1 Waste Characterization and Quantification

In order to design waste management systems and their various components, accurate data on quantity and composition as well as the chemical and physical properties of waste materials are required. Bilitewski *et al* [1] reported waste generation units and its management in some selected countries and emphasized the use of data on yearly averages, specific waste per capita quantities (kg/p/y), and waste composition estimates can only be used during the first steps of planning a refuse management.

Region 14 Environmental hygiene department report [2] tabulated per capita waste generation units of some cities around the world for the purpose of comparison with Addis Ababa city. The comparison shows that waste generation units of developed countries are higher than the developing ones. Tchobanoglous *et al* [3] attributes

difference of generation units to the effect of technological advances. Cities like New York have generation units of 18 liter/capita/day while most cities in developing countries have units less than 1 liter/capita/day.

Addis Ababa's solid waste generation unit was unknown until recently (1983). The first to publish its findings in 3 volumes was Norconsult, a private consultant company on waste management from Norway [2]. Nor consult reported that the weighted mean capita/day generation as 0.4 liters and 150 in grams. The 1982 study of Norconsult estimated the weighted mean density in kg/m^3 as 370.

A French mission in 1986 and Gordon study, a Louis Bergen expert consultant also reported their findings. Kumie has done some case studies on Addis Ababa's generation unit since 1994 [2].

Kume's volumetric method of study has been undertaken for high income group for more than a year on the basis of which the weight volume mean has been projected for the total population refuse generation, referring the unit weight and the density for high income groups.

The following table reported in Region 14 environmental hygiene department [2] summarizes level of Addis Ababa refuse generation as a function of income groups.

Table 2.1 Level of Addis Ababa refuse generation as a function of income groups.

Income group	Type of Study			
	Nor consult, 1982	Study Gordon June 1994	Study Gordon Nov. 1995	Abera Kumie April 1997
High income				
grm/capita/day	280	350	477	-
liter/capita/day	1.0	1.08	2.226	0.55
density, kg/m^3	280	322	220	-
Middle income				
grm/capita/day	110	280	236	-

liter/capita/day	0.28	0.70	1.246	0.50
density, kg/m^3	390	395	196	-
Low income				
grm/capita/day	150	170	260	-
liter/capita/day	0.4	0.55	1.316	-
density, kg/m^3	380	310	206	-
General Population				
grm/capita/day	150	221	252	-
liter/capita/day	0.40	0.65	1.23	0.45
density, kg/m^3	370	336	205	-

Kumie in one of his case studies [2] reported that his figure for per capita generation is twice less than that of the Gordon's study in 1994 and four times less than that of the figure for 1995. Kumie suggested that such significant variation could not be explained by population growth rate, nor by seasonal variations.

The effect of unit waste generation growth rate can be also excluded due to the fact that there has not been an absolute change in per capita income that should be seen as a function of the purchasing power of the supply (net income against the respective demand (actual needs) that may conclude the relative increase of income caused the increase of waste generation. Kumie attributed this to methodological differences in data quality control and the duration of the study. Such significant difference is even observed between the two cross-sectional studies of Gordon's study in a one-year time elapse.

Region 14 Environmental hygiene department uses the 1994 Gordon study result which is 0.221 kg/capita/day with average density of 336 kg/m^3 (0.65 liters) for planning purpose.

As to sources of the solid waste, Nor consult [2] in its study mission reported contributors of solid waste generation as: Domestic waste – 76% of the total generated; street sweepings 6%, commercial wastes 9%; industrial wastes 5%; hotels 3%, hospitals 1%. The data can be used for the present time generation analysis assuming that there had not been a potential socio economic growth since the study [2].

Therefore total waste generated in m^3 can be calculated as

$$X = \frac{[(0.65 lt/c/d) x (number\ of\ \ population)]}{1000} x \frac{100}{76} \quad \text{..............(Eq 2.1)}$$

In respect to characterization of waste, various studies have been made in the past. Nor consult and Gordon study [2] reported weighted percent composition by weight of waste constituents.

Therefore based on the study, organic matter (kitchen wastes) about 8%, recyclable fraction (leather, glass, metal, textile, paper, rubber, wood, plastics) above 10%, Combustible fraction (grass, leaves) 20%, non-combustible 3% ash 28%, and fines 30% all by weight.

The study of Norconsult & Gordon as reported in [2] classified 60% of waste by weight as organic matter (kitchen waste, vegetables, organic fines and grass); about 90% ash and fines contributing to high density of the refuse.

Table 2.2 Summary of Waste Characterization Study

Constituents	Weighted % composition by weight and source of study		
	Nor Consult 1982	Gordon, 1994*	Gordon, 1995**
Vegetable	8.7	4.185	2.90
Paper	2.2	2.47	3.37
Rubber	0.5	1.0	0.28
Wood	NA	2.33	2.29
Bone	NA	1.06	1.62
Plastics	0.7	1.93	1.98
Textile	1.5	2.37	1.41
Ferrous Metals	0.8	0.9	1.16
Aluminum	NA	NA	0.02
Glass	0.5	0.445	0.80
Combustibles-leaves, grass,	25.2	15.13	22.63
etc	6.3	2.52	2.96
Non Combustibles	NA	29.93	28.04
Fines <10mm	NA	35.65	31.40
10 < Fines < 55mm	53.6	65.58	59.44
All Fines			
	100	100	99.70
Total			

* Data represents for low-income group.

** Data represent for the weighted mean calculated for general public.

With regard to chemical composition of the waste, data for developing countries reveals that organic substances (C.N.H) comprised about 40-50%; inorganic substances (P,K) 20-30%, moisture about 30-40% by weight, with less than 1000 Kcal of heat value [2]. Since there is no available data for Addis Ababa, general estimates of the developing countries can be extended.

2.2 Waste Collection and Modeling

Collection of solid wastes in urban areas is difficult and complex because the generation of residential and commercial-industrial solid wastes is a mixed process that takes place in every home, every apartment streets, parks, and even in vacant areas of every community. As the generation patterns become more mixed and the total quality of wastes increases, the logistics problems associated with collection become complex.

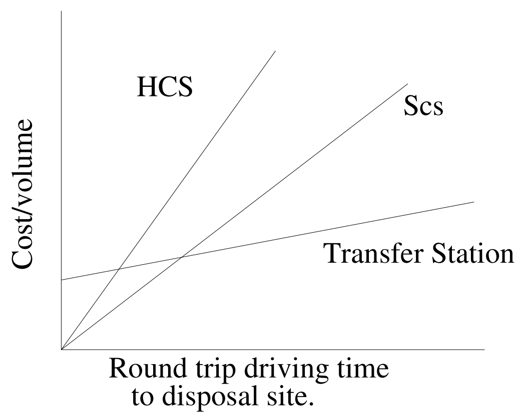
Solid waste collection systems may be classified from several points. Tchobanoglous *et al* [3] classified according to their mode of operation in two categories:

(i) *Hauled container system (HCS):* These are collection systems in which the containers used for the storage of wastes are hauled to the disposal site, emptied, and returned to either their original location or some other location.

(ii) *Stationary container systems (SCS):* These are collection system in which the containers used for the storage of wastes remain at the point of generation, except for occasional short trips to the collection vehicles. Under stationary container systems;

there are three main types (i) Systems in which self loading compactor are used, and [2] Systems in which manually loaded vehicles are used.

Bilitewski *et al* [1] reported that waste transportation is uneconomical if waste is transported over long distances in small vehicles. Therefore the use of transfer stations has become economical for urban areas that generate large waste quantities and which are a long distance away from the waste processing or disposal facilities. Tchobanoglous *et al* described that transfer operations may prove economical and put it as in the following Fig.



Where: HCS : Hauled container system
Scs : Stationary container system

Fig 2.1 Economics of transfer operations

Significant number of researchers and authors tried to model the waste collection system. Tchobanoglous *et al* [3] produced analytical model both for hauled and stationary container system.

The time required per trip, which also corresponds to the time required per container as:

$$T_{chs} = \frac{(P_{chs} + S + h)}{(1 - W)} \qquad \text{(Eq. 2.2)}$$

Where

T_{hcs} = time per trip for hauled container system, h/trip

P_{hcs} = pickup time per trip for hauled container system, h/trip

S = at – site time per trip, h/trip (time spent at disposal site)

h = haul time per trip, h/trip

w = off route factor, expressed as a fraction

The authors also found that the haul time h may be approximated by

h = a + bx

where h = total haul time, h/trip

a = empirical constant, h/trip

b = round-trip – haul distance, mi/trip

Therefore the time per trip can be expressed as

$$T_{chs} = \frac{(P_{chs} + S + a + bx)}{(1 - W)} \qquad \text{(Eq. 2.4)}$$

The pickup time per trip P_{hcs} for the hauled container system is then

P_{hcs} = Pc +uc +dbc

Where pc = time required to pickup loaded container

uc= time required to unload empty container, h/trip

dbc= time required to drive between container locations, h/trip.

Tchobanoglous *et al* [3] further related the number of trips that can be made per vehicle per day, time required per week and weekly number of trips as:

$$N_d = \frac{(1-W)H)}{(P_{chs} + S + a + bx)} \qquad \text{(Eq. 2.5)}$$

Where N_d = number of trips per day, trips/day

H = Length of workday, h/day.

$$D_w = \frac{t_w(P_{chs} + S + a + bx)}{[(1-W)H]} \qquad \text{(Eq. 2.6)}$$

Where D_w = time required per week, days/week.

T_w= integer number of trips per week, trips/week and

$N_w = V_w$ (CF)

Where N_w = number of trips per week, trips/wk

N_w = weekly waste generation rate

C = average container size

F = weighted average container utilization factor

As for stationery container systems, Tchobanoglous *et al* [3] reported the mathematical model for mechanically loaded vehicles of the time per trip, pickup time per trip as,

$$T_{scs} = (P_{scs} + s + a + bx) / (1- W) \qquad (Eq\ 2.7)$$

T_{scs} = time per trip of stationary container systems

P_{scs} = pick up time per trip for stationery container system

And;

$$P_{scs} = C_t(Uc) + (n_p-1)\ (d_{bc}) \qquad (Eq.\ 2.8)$$

Where C_t = number of containers emptied per trip, containers/trip

Uc = average unloading time per container for stationary

container systems/h/container

n_p = number of container pickup locations per trip, locations / trip

d_{bc} = average time spend driving to between container locations, h/ location

In an effort to operate existing systems and design new ones more efficiently, techniques and tools that where developed in related areas are now being applied to problems of waste collection. Terms such as systems analysis, operations research, system simulation, and systems and operations modeling are becoming part of the vocabulary in this field.

Researchers have also used advanced techniques of analysis for refuse collection problems. Quon *et al* were the first to apply simulation techniques to the solid waste collection problem. This model estimated the time required to complete a route of a given length. A similar model was developed for estimating the number of households that could be serviced in a fixed length working day (quon *et al*, truitt *et al*) proposed a simulation model, which examined the impact of transfer stations on collection costs [4].

Wilson *et al* [4] developed a discrete event Monte Carlo simulation model that can be used to estimate total collection time requirements for municipal curbside waste collection systems. Same Authors proposed derived probability model of curbside waste collection activities that allows for direct analysis of the stochastic aspects of municipal solid waste collection systems.

Queuing theory is a powerful tool for computing certain steady state queue performance measures. It has been used by researchers to model real systems.

In designing queuing systems we need to aim for a balance between service to customers (short queues implying many service) and economic considerations (not too many servers). In essence all queuing systems can be broken down in to individual sub-systems consisting of entities queuing for some activity.

JE Beasley *et al* [5] described the type of questions in which we are concerned with measures of system performance as:

- How long does a customer expect to wait in the queue before they are served, and how long will they have to wait before the service is complete?
- What is the probability of a customer having to wait longer than a given time interval before they are served?
- What is the average length of the queue?
- What is the probability that the queue will exceed a certain length?

Some of the problems that are often investigated in practice are:

- Is it worthwhile to invest effort in reducing the service time?
- How many servers ought to be employed?
- Should priorities for certain types of customers be introduced?
- Is the waiting area for customers adequate?

JE Beasly *et al* [5] further added that in order to get answers to above questions there are two basic approaches:

i) Analytic methods or queuing theory (formula based); and

ii) Simulation (computer based)

The reason for there being two approaches (instead of just one is that analytic methods are only available for relatively simple queuing systems.

Complex queuing systems are almost always analyzed using simulation (more technically know as discrete – event simulation.

2.3 Waste Disposal

The final Functional element in the solid waste management system is disposal. Disposal is the ultimate fate of all solid wastes, whether they are residential, commercial wastes collected and transported to landfill site, incinerator, compost, or other substances from the various solid waste processing plants that are of no further use to society.

Region 14 Environmental hygiene department report [2] states that currently there is only one landfill site in the south waste of the city where all collected waste is disposed off. Its location is about 13 kms from the center of the city. The area was adopted source 35 years ago. According to the report (1997), the landfill has a capacity of absorbing at least 10 years if all conditions are assumed to be not changing.

B. Bilitewski *et al* [1] described landfills as advantageous as the sole waste disposal method because the technology is rather simple. Furthermore, short-term operational considerations and the low associated cost, depending o the landfills location size and age, are also important.

Land filling of solid wastes is a method of waste disposal, which has been, practiced since very early times. Joseph Pavoni *et al* [6] reported, landfill as the most economical waste disposal techniques in current uses. It is often referred to as the only final solid waste disposal method since, unlike incineration or composting, it is not a processing operation, which yields a residue or end product, which requires disposal. The wastes deposited in a sanitary landfill are considered to be ultimately 'eliminated'; the landfill is their ultimate destination. Because of this, land filling of solid waste material is in some ways a very undesirable procedure; many potential useful materials, which could be recycled, are buried in the earth and lost [9].

In early fills (developed countries) and still in many developing countries, refuse is deposited in an open dump on a selected piece of land and allowed to decompose in the open air. The nuisances associated with such open dumping odors, airborne litter and waste paper, the preference of disease vectors such as rats and mice's, and other problems caused in alternation in land filing operations [6].

Tchobanoglous *et al* [3] reported various operational methods, which usually are used for unprocessed municipal solid wastes as follows.

i) *Area method*: operationally the wastes are unloaded and spread in long, narrow strips to the surface of the land in a series of layers that vary in depth from 16 to 30 in. Each layer is compacted as the filing progress during the course of the day until the thickness of the compacted wastes reaches a height varying from 6 to 10ft.

   At that time, and at the end of each day's operations, a 6 to 12 in layer of cover material is placed over the completed roll.

ii) *Trench method*: The trench method of landfill is ideally suited to areas where a adequate depth of cover material is available at the site and where the water table is near the surface.

A portion of the trench is dug and the dirt is stockpile to form an embankment behind the first trench. Wastes are the placed in the trench, spread in the thin layers (usually 18 to 24 in) and compacted. The operation continues until the desired height to fill is reached at the end of each day's operation. The length also should be sufficient to avoid costly delays for collection vehicles. Waiting to unload. Cover martial is obtained by excavating and adjacent trench or continuing the trench that is filled.

iii) *Depression method:* At locations where natural or artificial depressions exist, it is often possible to use then effectively for landfill operations. The techniques to place and compact solid wastes in depression landfills vary with the geometry of the site, the characteristics of the cover material, the hydrology and geology of the site, and the access to the site. Wastes are usually deposited on the canyon floor and from there are pushed up against the canyon face at a slope of about 2 & 1. In this way, a high degree of compaction can be achieved.

A landfill disposal site has to be located in appropriate place. Tchobanoglous *et al* [3] described the factors that must be considered in evaluating potential solid waste disposal sites. They are (1) available land area, (2) impact of processing and resource recovery (5) climatological condition, (6) Surface-water hydrology, (7) geologic and hydrologic condition, (8) local environmental conditions and (9) potential ultimate uses for the completed site. These factors also can be used to screen out suitable sites.

Final selection of disposal site usually is based o the results of a preliminary site survey results of engineering design and cost studies and an environmental impact assessment.

The haul distance is one of the important variables in the selection of a disposal site. Tchobanoglous *et al* [3] underlined that the length of the haul can significantly affect the overall design and operation of the waste management system. Although the minimum haul distances are desirable, other factors must also be considered. These include collection route location, local traffic patterns, and characteristics of the routes to and from the disposal site.

Economical site selection involves analytical analysis with respect to haul distance and cost. Same author put it mathematically as follows.

$$\text{Objective function} = \sum_{j=1}^{n} \sum_{i=1}^{m} X_{ij} C_{ij} \text{ --------------- (Eq 2.9)}$$

$$\text{Subject to: } \sum_{j=1}^{n} X_{ij} = R_i \quad i = 1 \text{ to } n \text{ --- (Eq 2.10)}$$

$$\sum_{i=1}^{m} X_{ij} <= D_j \quad j = 1 \text{ to } m \text{--- (Eq 2.11)}$$

$$X_{ij} >= 0 \text{ ----------------- (Eq 2.12)}$$

Where ; X_{ij} = the amount of wastes hauled from city area i to disposal site j.

R_i = the total amount of waste at city area i.

D_j = the total amount of waste that can be a accepted at disposal site j.

C_{ij} = the cost of hauling wastes from city area i to disposal site j.

A visitor to a landfill generally is appalled at the sight of so much material being wasted.

Joseph L. Pavoni *et al* [6] reported that the material which can be recovered from solid wastes (secondary materials) may be categorized in to their general groupings: those materials which can be directly recycled, directly put back in to use; and those materials which require considerable amounts of processing before they can be reused.

Region 14 Environmental hygiene department reported [2] that there is very little, less than 10% by weight, wastes to be recycled like paper, glass, metals, plastics, rubber, bone and wood. An informal type of waste recovery is managed by some 200 scavengers in the landfill using the recovered substances as a source of daily wages. Informal waste recoveries include plastics; rubber bottles, metals, and combustible materials used as traditional fuel. Some wastes are also recovered at their source of generation by informal groups [2].

In terms of preparation and collection of separate recyclable and mixed recyclable before they enter the waste stream, the organizational and technical effort is shifted to the waste producer. Joseph L. Pavoni *et al* [6] give emphasis to this and pointed that when any waste material is placed in the general municipal refuse stream, it is very difficult and expensive to separate that material from other wastes and reclaim it. Consequently, voluntary separation of valuable materials by the consuming public is very advantageous. Voluntary separation of waste components for recycling has been attempted in may localities with in the recent past.

Besides Land filling there are also other waste disposal options. Composting, being one among others, is a classic method of waste treatment. B. Bilitewski *et al* [1] reported that composting as an ecologically sound treatment method, because the organic share of the waste (generally about 40% by weight in household waste) is returned to the natural cycle. In comparison to other waste treatment methods, composting has only minor negative effects on the environment.

Joseph L. Pavoni *et al* [6] defined composting as the biochemical degradation of the organic fraction of solid waste material having as its end product a humus-like substance that is used, primarily for soil conditioning. Composting entails the degradation of organic compounds by naturally occurring microbes. Same author reported the microbiology of the composting process.

During initial composting development, the mesophilic flora (organism able to grow in the 77 to 113^0c range) predominates and is responsible for most of the metabolic activity that occurs. Raw compost should have a water content of approximately 55%, because microbes absorb nutrients in molecularly dissolved from through a semi permeable membrane. Below moisture content of 20%, no biological processes are possible. The water content of household waste is usually between 20 and 40%, which means that moisture must be added. The oxygen required for aerobic decomposition is about 1 gram O_2 /gm degradable organic substances. In the course of composting process, the decomposition of organic matter per unit of time and the respiratory activity declines. The highest oxygen consumption can be expected to occur in the temperature range around 60^{o}c. The PH value should be between 7 and 9. Especially important is the ratio of carbon and nitrogen (C/N ratio). The raw materials for aerobic decomposition should have an optimal C/N ratio of 35 to 1, since microorganisms prefer this ratio for metabolism.

The report [2] put composting with methane gas harvesting for energy recovery as one alternative for Addis Ababa's waste recovery. It further reported that composting has not been tried in the landfill due to its less economical and market variables operational costs are expected to be very high with little benefits because of less demand for compost in Addis Ababa. Although this seems the condition, there is still a way to introduce composting since 30% -35% by weight (equivalent to about 90% by volume) of the refuse constituent organic matters, mainly kitchen wastes and abandoned vegetables and grass. Organic, contents of the refuse (N_2, P, C) and market demand analysis need further to be studied for the implementation of the composting option for waste recovery [2].

UNEP source book [7] describes the practical differences in industrialized, transition, and developing countries. Accordingly, main differences relate to the waste stream to be composted, the agricultural traditions relate to the waste steam to be composted and the physical infrastructure of the built and nature environment. Back yard composting can be both an individual strategy from management of household kitchen and garden wastes and a formal strategy for the management of the organic waste stream in a region. The source book [10] discussion refers only to the second aspect. Backyard composting represents the smallest scale of composting and is a sound approach when.

- A significant member of households have individual or collective yards or gardens, and there is enough room for a compost pile;
- Composting is culturally familiar to most people; and
- The waste stream to be composted contains primarily insects when little animal matter is present.

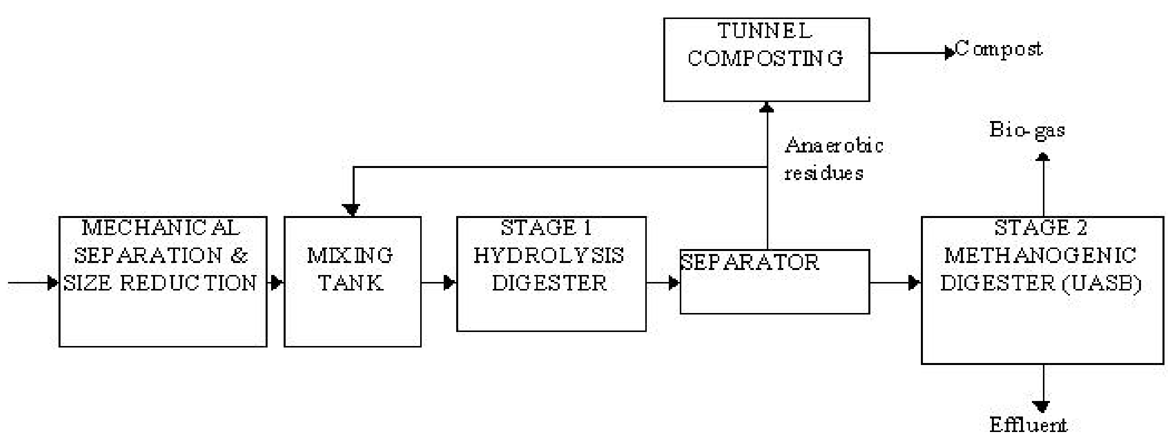
The next larger scale for composting is the neighborhood, block or business scale-composting site. Such facilities can provide a waste management opportunity to a small group of people at a relatively low cost. Small-scale composting uses the wastes of a number of households, shops, or institutions; the composting is done on unused land, beside community gardens, or in parks. UNEP source book [7] reported the sound practice for sitting neighborhood composting sites requires that they.

- Be accessible to all who want to use them;
- Be clearly designated with signs that all users can read or interpret;
- Be sited with agreement of the surrounding land users
- Have adequate financing or control to prevent their becoming an open dump; and
- Have appropriate soil to absorb.

Daniel Hoornmweg *et al* [8] (world bank report) assessed composting process: windrow composting, passively aerated windrow, aerated static pile, in vessel composting and vermin composting. Windrow composting is a simple and versatile method where organic matter builds in to large piles and physically turned to a regular basis. Passive Aerated windrows is very similar to windrow composting except that turning is not required for aeration. Air is supplied to the organic material through perforated pipes embedded in the pile. The aerated static pile method combines techniques from passive aerated widows with more advanced technology. In-vessel composting occurs inside and enclosed container or vessels and relies to various methods of aeration and mechanical turning to control the process. In other composting, the natural digestion process of red worms and earthworms to break down organic material.

Anaerobic digestion of solid wastes is currently becoming another potential option for disposal of solid wastes. The process of anaerobic digestion occurs naturally and is responsible for the degradation of organic matter in environments where oxygen is lacking. It is now over twenty years since the latent energy potential of solid waste landfills has been recognized and systems installed to collect methane gas rather than allowing its uncontrolled escape to atmosphere. Again, the energy benefits have been recognized and most modern sanitary landfill sites are now equipped to generate electricity from the methane slowly being released from the anaerobic degradation of solid wastes. The microbial processes within a landfill site are however slow and the stabilization of the waste may extend over a period of decades before the site can be returned to other uses. The focus here is on municipal solid wastes either collected as a mixed waste or source segregated, and those materials of interest as digester feedstock.

Different systems can handle different percentages of solid to liquid, and while average ratios are 15-25% (wet fermentation), certain technologies can cope with solids as high as 30% (dry fermentation); there is roughly an equal split between the 'wet' and 'dry' technologies in terms of installed capacity. Digestion can take place in one of two different temperature ranges around 35-37^{o}C (known as the mesophilic range) or at the higher (thermophilic) temperature of 55^{o}C. The waste is held in the digester for periods varying from 10-20 days, the duration being dictated by differing technologies, external temperature fluctuations, and other variables like the waste composition. In Europe both mesophilic and thermophilic processes are operating with about 63% of the capacity being operated in the mesophilic range. The main advantage of operating at the higher temperature is the added benefit of increasing the rate at which pathogens are killed in the process.



Most digesters comprise of a single reactor vessel (one phase system), but it is also possible to split the microbial phases of the digestion process and operate in a 2 phases, although the latter is not common practice with only about 10% of digesters working in this way.

The other solid waste disposal option is incineration. T. Rand *et al* [9] (The world bank report) describe incineration as the most expensive solid waste management options and which require highly skilled personnel and careful maintenance. For this reason, incineration tends to be good choice only when other, simpler, and less expensive choices are not a available. Accordingly since incineration plants are capital-intensive and require high maintenance costs and comparative higher technically trained operators, developed countries commonly adopt them.

All waste disposal alternatives eventually decompose organic materials in to simpler carbon molecules such as CO_2 and CH_4. The balance between these two gases and time frame for the reactions varies by alternative incineration provides the best way to eliminate material gas emissions from waste management process. One of the most alterative features of the incineration processes is that it can be used to reduce the original volume of combustible by 95 percent. Air pollution control remains a major problem in the implementation of incineration of solid waste disposal [9].

T. rand *et al* [12] pointed the following criteria for applicability of municipal solid waste incineration projects:

- A mature and well functioning waste management system has been in place for a number of years.
- Solid waste is disposed of at controlled and well operated land fills
- They supply of combustibles waste will be stable and amount to at least 50,000 metric tons/year.

- The lower calorific value must on average be at least 7MJ/kg of and must never fall below 6MJ/kg in any season
- The community is willing to absorb the increased treatment cost through management changes, tipping fees, and tax-based subsidies
- Skilled staff can be recruited and maintained
- The planning environment of the community is stable enough to allow a planning horizon of 15 years or more.

UNEP source book [7] reported that the two most widely used and technically proven incineration technologies are mass burn incineration and modular incineration. Fluidized bed incineration has been employed to a lessen extent, although its use has been expanding and experience with this relatively new technology increase. Refuse derived fuel production and incineration has also been used, primarily in Europe, but with limited success. Some facilities have also experimented with pyrolysis, gasification, and other related processes that cover solid waste to gaseous, liquid, or solid fuel through thermal processing.

Mass-burn systems are the predominant form of municipal solid waste incineration. The waste intake area usually includes a tipping floor, a pit, a crane, and some times conveyors. Trucks enter the tipping floor and tip their wastes either to the floor itself, or directly in the pit. From a feed chute, municipal solid waste is continuously fed to a grate system, which moves the waste through a combustion chamber using a tumbling motion. Modular incinerators employ a somewhat different process than mass burn incinerators, typically involving two combustion chambers. Gases generated in the Primary chambers flow to a after burner, which ensures more complete combustion and often serves as the primary means of pollution control.

Region 14 Environmental hygiene department report [2] states based on the data available for developing countries cities that the heat value of municipal waste is less than 1000 kcal (to be compared with 7000-9000 kcal/kg for methane gas, 9000-11,000 kcal/kg for naphtha, and 2000-2500 kcal/kg for wood) indicating that additional fuel is required if the refuse is to be incinerated.

2.4 Energy recovery from municipal solid waste

The enormous increase in the quantum and diversity of Waste materials generated by human activity and their potentially harmful effects on the general environment and public health, have led to an increasing awareness, world-wide, about an urgent need to adopt scientific methods for safe disposal of wastes. While there is an obvious need to minimize the generation of wastes and to reuse and recycle them, the technologies for recovery of energy from wastes can play a vital role in mitigating the problems. Besides recovery of substantial energy, these technologies can lead to a substantial reduction in the overall waste quantities requiring final disposal, which can be better managed for safe disposal in a controlled manner while meeting the pollution control standards.

Most of the Municipal Solid Wastes (MSW) are a mix of house-hold wastes, street wastes, commercial & institutional wastes, etc. containing organic as well as inorganic matter and offer good possibilities for recovery of energy in its organic fraction for gainful utilization through adoption of suitable processing and treatment technologies. Such recovery of energy from MSW offers a few additional benefits such as:

(i) The total quantity of waste gets reduced by nearly 60% to over 90%, depending upon the waste composition and the adopted technology;

(ii) Demand for land, which is already scarce in cities for land filling is reduced;

(iii) The cost of transportation of waste to far-away landfill sites also gets reduced proportionately;

(iv) There is a net reduction in environmental pollution.

The latent energy present in the organic fraction of the MSW (biodegradable as well as non-biodegradable) can be recovered through basically the following methods:

(i) Thermo-chemical conversion (Incineration/ Pyrolysis/ Gasification) - entailing thermal de-composition of organic matter to produce either heat energy or fuel oil or gas;

(ii) Bio-chemical conversion (Anaerobic Digestion or Bio-methanation/Alcohol Fermentation) - entailing biological decomposition of organic matter by microbial action to produce methane gas or alcohol.

The thermo-chemical conversion processes are useful for wastes with low moisture content. The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic biodegradable matter and high moisture content.

Parameters affecting Energy Recovery: the two main factors, which determine the potential of Recovery of Energy from Wastes are:

- The quantity, and
- Physico-chemical characteristics (quality).

The actual production of energy also depends upon specific treatment process employed, the selection of which is also critically dependent upon the above two factors. Accurate information on these factors, including variations thereof with time (daily/ seasonal) is, therefore, important.

Some of the important physico-chemical parameters requiring consideration include:

- Size of constituents
- Density
- Moisture content
- % Volatile Solids
- Fixed Carbon / Inerts content
- Calorific Value

Often, an analysis of waste to determine the proportion of carbon, hydrogen, oxygen, nitrogen and sulfur (ultimate analysis) is done to make mass balance calculations, for both thermo - chemical and bio-chemical processes. In case of Anaerobic Digestion, the parameters C/N ratio (a measure of nutrient concentration available for bacterial growth) and Toxicity (representing the presence of heavy metals/ other toxic/ hazardous materials, which inhibit bacterial growth), also require consideration**.**

Table 2.3: Desirable range of important waste parameters for technical viability of energy recovery.

Waste Treatment	Basic Principle	Important Waste Parameters	Desired Range

Method			
Thermo-chemical conversion • Incineration • Pyrolysis • Gasification	Decomposition organic matter by action of heat	•Moisture content •Organic / Volatile matter •Fixed Carbon •Total Inerts •Calorific Value(NCV)	<45% >40% <15% < 35% >1200 kcal/kg.
Bio-chemical conversion •Anaerobic Digestion Biomethanation	Decomposition of organic matter by microbial action	•Moisture content •Organic / Volatile matter •C/N ratio	>50% > 40% 25 – 30

Landfill gas (LFG) is another renewable source of energy. There are five main ways to recover energy from LFG: direct heating, electricity generation, chemical feedstock, purification to pipeline-quality gas, and heat recovery. Each of these methods has a variety of LFG applications. A complete list of applications and technologies is provided below.

1. Direct Heating Applications:
    - Use for industrial boilers
    - Space heating and cooling
    - Industrial heating/co-firing.
2. Electricity Generation Applications:
    - Processing and use in reciprocating internal combustion (RIC) engines (i.e., stoichiometric combustion or lean combustion)

- Processing and use in gas and steam turbines
- Processing and use in fuel cells.

3. Feedstock in Chemical Manufacturing Processes:
   - Conversion to methanol (and optional subsequent industrial or vehicular fuel use)
   - Conversion to diesel fuel (and subsequent use as vehicular fuel).
4. Purification to Pipeline-Quality Gas:
   - Utilization as vehicular fuel
   - Incorporation into local natural gas network.
5. Heat-Recovery from Landfill Flares:
   - Using organic Rankine cycle
   - Using Stirling cycle engines.

P.R.White *et al* [10] reported typical values used in energy recovery as;

- Landfill gas production per ton of biodegradable waste, 250m^3/tone
- Percentage of collectable landfill gas, 40%
- Calorific value of landfill & biogas, 5000kcal/m^3
- Conversion efficiency (waste to wire), 30%
- Conversion efficiency for incinerator, 25%
- Typical biogas yield ,0.1m^3/kgof volatile solids.
- *Digestion* efficiency 60%.

Chapter III

III. Methodology

3.1 Model building

Model building is knowing what to cut out, and the purpose of the model acts as the logical knife. It provides the criteria about what will be cut, so that only essential features necessary to fulfill the purpose are left. Clear purpose allows model users to ask questions that reveal whether a model is useful for solving the problem under consideration.

Every model is a representation of a system a group of functionally interrelated elements forming a complex whole. But for the model to be useful, it must address a specific problem and must simplify rather than attempting to mirror in detail an entire system.

3.2 Types of Models

There are many types of models, and they can be classified in many ways. Models can be static or dynamic, mathematical or physical stochastic or deterministic. One of the most useful classifications however divides models in to those that optimize versus those that simulate. The distinction between optimization and simulation models is particularly important since these types of models are suited for fundamentally different purpose.

3.2.1 Optimization

The output of an optimization model is a statement of the best way to accomplish some goal. Optimization model do not tell what will happen in a certain situation. Instead it tells what to do in order to make the best of the situation; it is normative or prescriptive models.

An optimization model typically includes three parts. The objective function specifies the goal or objective the decision variables the choices to be made. The constraints restrict the choices of the decision variable to those that are acceptable and possible.

Many optimization models have a variety of limitations made problems that potential users should bear in mind. These problems are: difficulties with the specification of the objective function, unrealistic linearity, lack of feedback, and lack of dynamics. A typical optimization problem is very complex; involving hundreds or thousands of variables and constraints, the mathematical problem of finding the optimum is extremely difficult. To render such problems tractable, modelers commonly introduce a number of simplifications. Among these is the assumption that the relationships in the system are linear. In fact, the most popular optimization technique, linear programming, requires that the objective function and all constraints be linear. Linearity is mathematically convenient but in reality it is almost always invalid.

Many optimization models are static. They determine the optional solution for a particular moment in time without regard for how the optimal state is reached or how the system will evolve in the future.

3.2.2 Simulation

The purpose of a simulation model is to mimic the real system so that its behavior can be studied. Simulations of physical systems are commonplace and range from wind tunnel tests of aircraft design to simulation of weather patterns and the depletion of oil reserves. There are many different simulation techniques, including stochastic modeling, system dynamics discrete simulation, and real playing games.

Despite the differences among them, all simulation techniques share a common approach to modeling. Optimization models are prescriptive but simulation models are descriptive. A simulation model does not calculate what should be done to reach a particular goal, but clarifies what would happen in a given situation.

The purpose of simulation may be fore sight (predicting how systems might behave in the future under assumed conditions) or policy design (designing new decision making strategies or organizational structures and evaluating their effects on the behavior of the system).

Every simulation model has two main components. First it must include a representation of the physical world relevant to the problem under study. How much detail a model requires about the physical structure of the system will of course, depend on the specific problem being addressed. Any model is only as good as its assumptions consist of the descriptions of the physical system and the decision rules. Adequately representing the physical system is usually not a problem; the physical environment can be portrayed with whatever detail and accuracy is needed for the model purpose. Also, simulation models can easily incorporate feedback effects, non-linearity, and dynamics they are not rigidly determined in their structure by mathematical limitations as optimization models often are.

3.3. Solid Waste Collection

3.3.1 System Description

Addis Ababa city is subdivided into 6 zonal administrations. Each zone has waste management office undertaking the collection of waste generated in the weredas with in the zone. Vehicles that collect wastes travel through the street in Kebele's of the zone to collect and finally dump the waste in Repi landfill area.

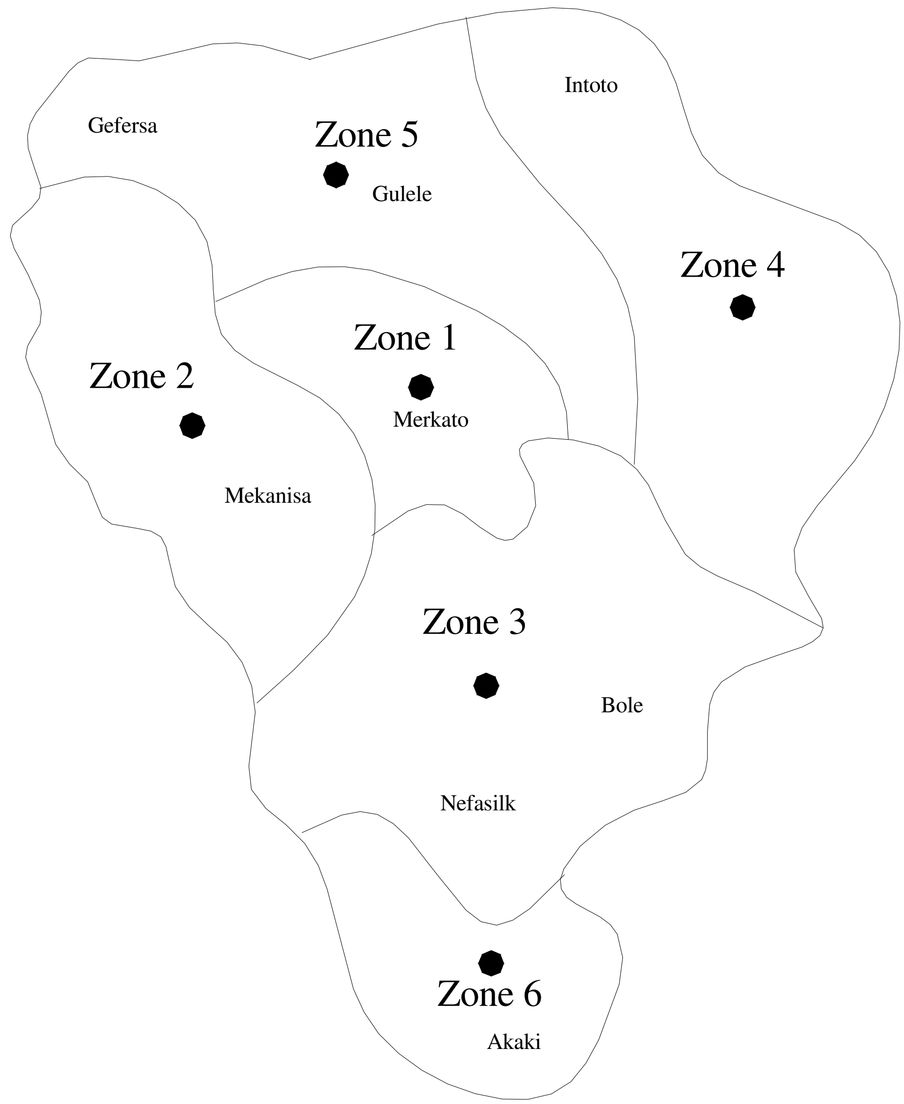


Fig Administrative zones of Addis Ababa

In zone 1, there are 4 weredas (wereda 03, 04, 05 ad 06), in zone 2 there are 5 weredas (wereda 20. 21, 22, 23, 24), in zone 3, there are 4 weredas (wereda 18, 19, 28); in zone 4, there are 7 weredas (wereda 1, 09, 11, 12, 13,115, 16); in zone 5 there are 6 weredas (wereda 02, 07, 08, 10, 14, 25) ad in zone 6 there are only two weredas, wereda 26 ad 27.

The city's waste collection system is undertaken in 3 broad type of collection system: container, door to door & block system.

3.3.1.1 Container System

The public at large gets collection services through a transfer station in a container collection system, which is composed of refuse containers of 4-8m^3 capacity located at accessible sites of kebeles (community) and where large waste generation is assumed.

3.3.1.2 Block system

The block collection system consists of large refuse containers ranging from 0.1-8m^3 located at the premise of the blocked houses or building, containers of 8m^3 size is made available by the municipality to the client upon his request for the service to be charged. When containers are full, the owner informs the zonal health officers for collection and disposal. Both types of trucks serve the block system: side loaders and lift trucks.

3.3.1.3 Door to Door Collection System

The side – loading and compacting trucks are usually designed to serve for door to door collection system where a 8m^3 transfer station are lacking and road accessibility is not limited.

In this collection system the disposing people and truck along accessible street, collection points meet at a defined time during the day. For this purpose, compactor trucks ad covered trucks are assigned.

3.3.2 System Representation, Justification and Model Selection

As described in the problem statement there is an in balance situation especially in the municipality waste collection system of the city. Few vehicles available collect the waste generated by the urban dwellers. Only 65% of the total waste can be collected. This clearly indicates the system is not in equilibrium. The waste piled near by full containers simply justifies this.

Imbalance in a system can be modeled using queuing/simulation model in which the waste as a customer and the vehicles as a service giver. The hypothesis of representing waste collection operation as a queuing model is based on wastes forming queue to be serve by the vehicles. As it is well known queue or waiting line problems arise either because:

(i) There is too much demand to the facilities so that we say there is an excess of waiting time or inadequate number of service facilities.

(ii) There is too less demand in which case there is too much idle facility time or too many facilities.

For the present situation of Addis Ababa city waste collection system, case (i), fully describes it as the in balance between the customer (waste) and the service (vehicles is due to insufficient collection vehicles. There are several factors that take the blame for poorly managed collection of wastes. Among the problems, insufficient collection vehicles, the distance traveled to cover a trip, the traffic density that delays a trip, infrastructure etc. Therefore the system is a complex system in which many variables affecting the situation in an interrelated manner. Though the collection system can be represented as a queuing model, due to its complexity it is difficult, to optimize the system.

However using queuing simulation model, it can be simulated the system as a queue to decide on the variables.

The city's waste collection is organized and led by the Environmental hygiene department under the region 14 health bureau. Zonal environmental hygiene offices carry out the daily plan and execution of waste collection operation. These offices look for status of waste accumulation and based on daily assessment, collection vehicles are assigned to pick full containers in the weredas. Since the numbers of vehicles are insufficient, a single vehicle is assigned in more than one wereda in the zone to collect wastes. Therefore the waste collection operation is not based on a single wereda in the zone but multiple combinations of weredas. Vehicle routing follows similar tend.

3.3.3 System Modeling

The Addis Ababa City refuse management has its own characteristics that make it unique. The system is so complex that the relationship and the impact of the variables that affect the refuse collection cannot be easily identified. In such complex system, optimization modeling plays a little role, as it needs thorough understanding of the effect of the system variables.

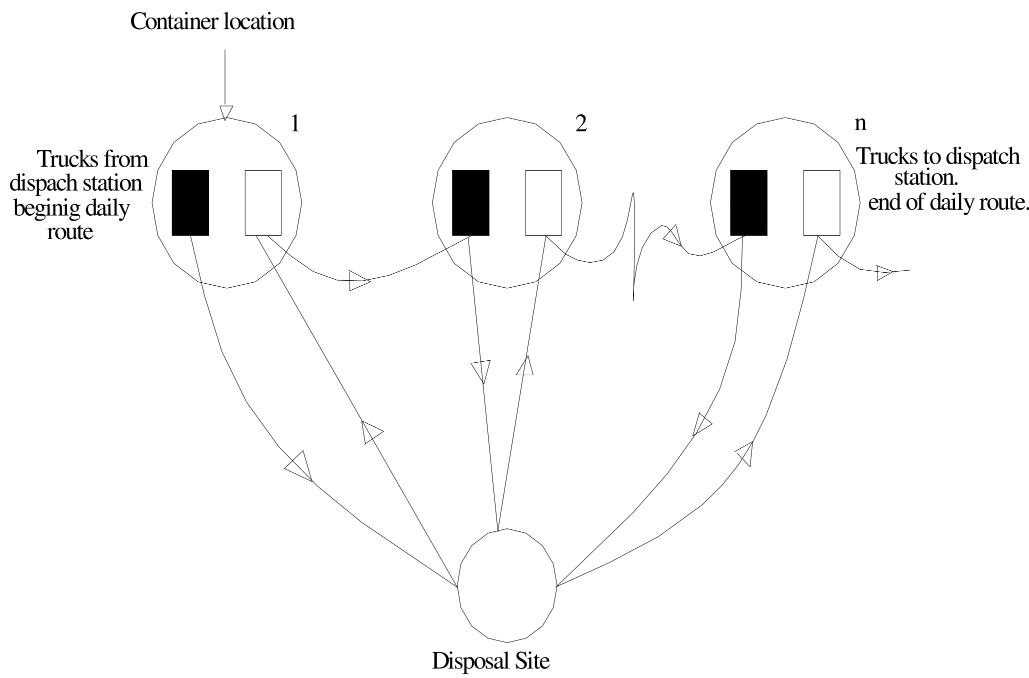


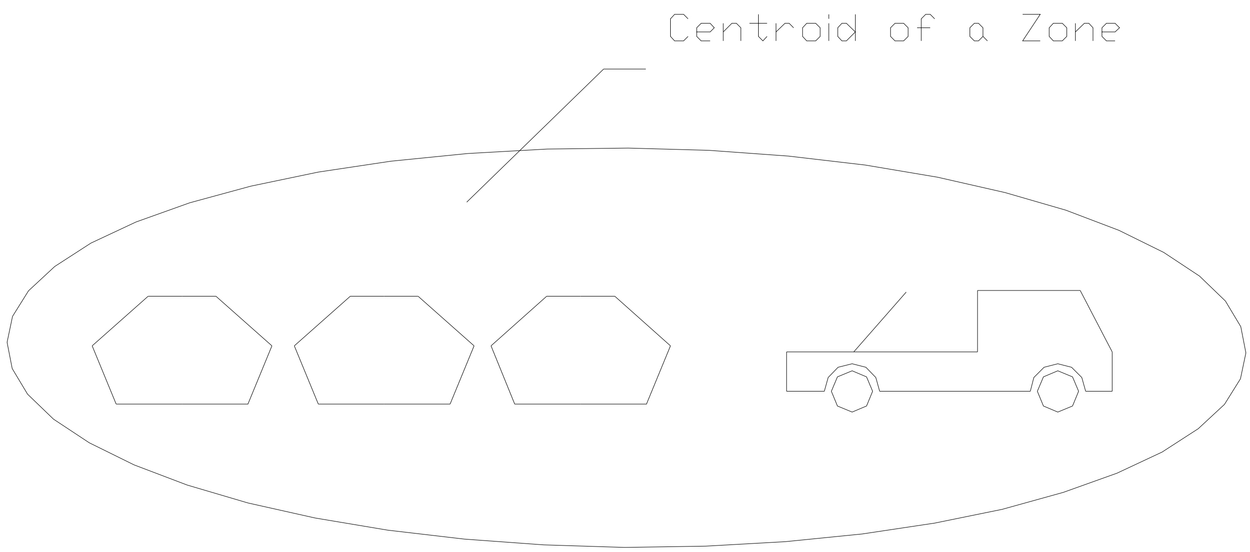
Fig Hauled Container system

As shown in the fig, the service time represents the time required to reach the disposal site, starting after a container whose content are to be emptied has been loaded on the truck, plus the time after leaving the disposal site until the truck arrives at the location where the empty container is to re-deposited. The in-between travel time from one container situation to the next is also included. As show in the fig the time spent traveling from container 1 to container 2 is accounted in service time for container 2.

Waste collection as a queuing model can be visualized in such a way that waste generated in the zone can be assumed to form a queue at a zonal centroid waiting for a service. The inter arrival time, which is the time elapsed between two arrivals of waste (of certain quantity) at zonal centroid point is not uniform.

The non-uniformity of the inter arrival time can be avoided by taking all factors (location etc) in the service time. Therefore the service time is not the same.

The three existing types of collection systems can be modeled in similar fashion. For the communal collection, which is the container system containers full of refuse can be assumed to form queue at zonal cetroid.



Similarly, volume of waste equivalent to the truck capacity is taken to form a waiting line for door-to-door collection system. The block-to-block system dissolves in either of the above two collection systems.

Modeling the system based on zonal collection, best represent the operation as described earlier under system description. Special characteristics of the operation need to incorporate in the mathematical model so as it can thoroughly describes it.

Since there are multiple collection vehicles in different routes in the zone, queuing model with multiple service channels can represent the system in which waiting line breaks down in to shorter lines in front of each service stations (multi-server serial queues). This can be shown by the fact that containers, which are placed at different locations in the zone, can be served simultaneously by vehicles that collects in different routes. In other words wastes can be in a queue for a single route. Therefore a single server queuing model shows the collection operation for a single route.

3.3.4 Model Properties

The waste collection operation to be presented by a model, it must have special characteristics that describe the system. The characteristics of waste collection as a queuing model follow the following assumptions.

1) Arrival properties

- There is an infinite population of customers

  (This is true especially for a single server of waste collection operation)

- Arrival process is regular that means the time between successive arrivals, which depend upon the daily per capita waste generation, is constant. Therefore, according to the demographic characteristics of the zone, hourly or per minute quantity of generated waste can form a queue. A Poisson distribution which is convenient mathematical model of many real life queuing systems, doesn't describe inter arrival time distribution of generated waste as it is regular.

2) Service properties

- The service time (the time taken to collect travel and dump) doesn't follow any known mathematical distribution (e.g. exponential). Service time is obtained from observed (collected)data.
- The service discipline is random.

(This is because collection operation does not necessarily follow similar route and service everyday.)

3) *Queue characteristics*

- There is no balking (customers deciding not to join the queue if it is too long)
- There is no reneging (customers leave the queue if they have waited too long for service)
- There is no jockeying (customers switch between queues, if they think they will get served by so doing)

3.3.5 Methods

The service time, which is not uniform, represents the time taken to collect, travel and dump. The difference in service time is attributed to the location of container in the zone, which is the vital factor for variation. The traffic density of the streets also affects the service time. Therefore the service time is not same even for a container located at a known point when served at different times. The collection time for door-to-door system varies as it depends on the people who bring the waste to the truck and performance of collection workers.

Compaction time that constitutes the collection time for compaction trucks also depends upon type of waste.

These and other factors make the service time to be uncertain (not deterministic). Nevertheless, the probability of a service time for a certain zone to fall in an interval time can be made known. This means that the probability of collecting waste, traveling and dumping from any location in a zone can be established. In other words, the service time, which depends upon complex interrelated factors, is stochastic. The variation in time of service is accounted for location and other factors so that inter arrival time for generated waste is uniform.

3.3.5.1 Data Collection and Compilation

Secondary data from Region 14 environmental hygiene department are taken for service time analysis. This is observed performance time for zonal collection of each vehicle. The daily performance report of waste collection shows the name of vehicle driver, quantity of waste serviced (collected & dumped), the zone from which waste is collected and the time taken.

A 3-month data (Tikmit, Hidar, and Tahsas 1994 E.C) is considered as observed data. (Sample data is shown as Annex-E)

The raw data (secondary data) using Microsoft access program is sorted by zone, collection and vehicle type. Further for each collection and vehicle type in a certain zone, an analysis is done to know the frequency of finishing a service within certain time limits. The frequency gives the probability of a service time to fall with in a known time interval.

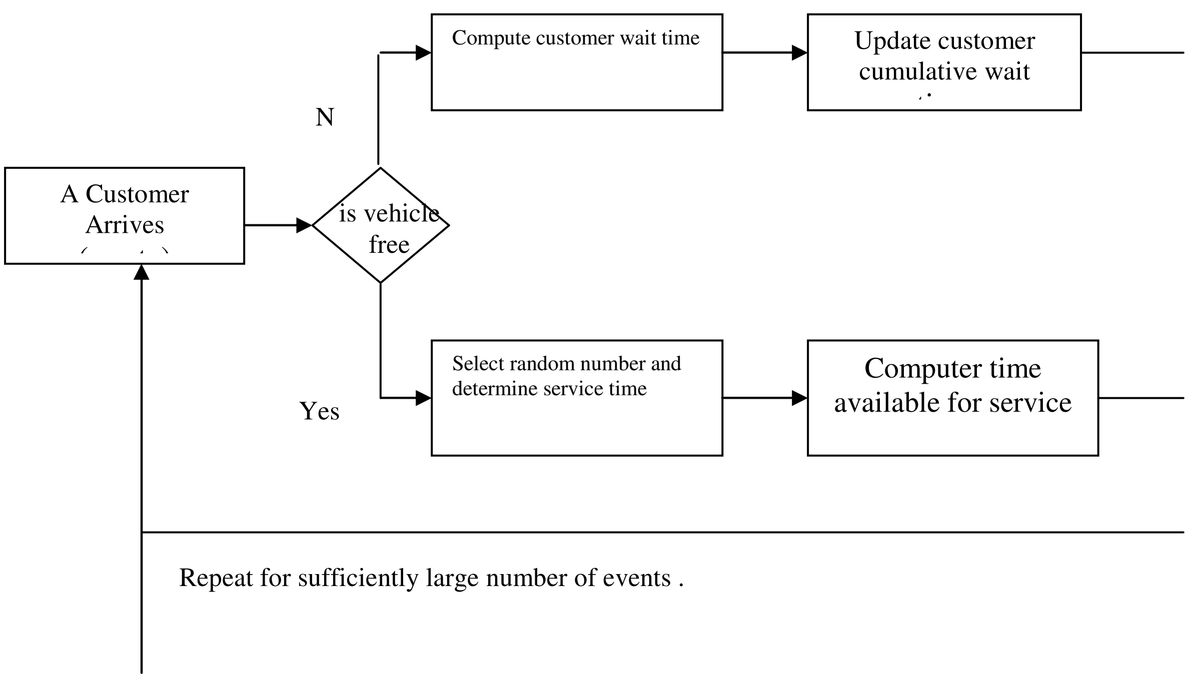
3.3.5.2 Spreadsheet Monte Carlo Simulation

Monte Carlo technique has been used to tackle a variety of problems involving stochastic situations and mathematical problems, which cannot be solved with mathematical techniques and where physical experimentation with the actual system is impracticable. The stochastic situations are usually a long sequence of probabilistic events or steps. We may able to write mathematical formulae for probability of a particular event, but to write a mathematical relationship for the probabilities of all events in the sequence is a difficult task.

In contrast to mathematical modeling where the results of the analysis yield a direct and overall solution to the problem, in simulation, the behavior of the system is observed over a sufficiently long period of time, and in process, the relevant information is collected. The system is first described by listing the various events in order of their occurrence. An event representing a point in time signifies the end of one or more activities and the beginning of the next activity. As each event occurs, certain actions are taken, resulting in the generation of new event, which are considered in sequence. For example, the arrival of waste at the centroid of a zone is the occurrence of an event, and action taken depends upon the availability of a facility (vehicle), which may be free or occupied.

The experimentation is performed on a simulated model of the real system. It is a sort of sampling technique in which, instead of drawing samples from real population, the samples are drawn from a theoretical equivalent of the real population. By making use of random numbers, Monte Carlo approach determines the probability distribution of the occurrence of the event under consideration, and then samples the data from this distribution.

Any random process can select the random numbers. For each service time, a random number is selected which will represent the percentage of frequency



corresponding to it.

Spreadsheet simulation refers to the use of a spreadsheet as a platform for representing simulation models and performing the simulation experiment. Engineers have been trained to use other software tools such as MATLAB that were written specifically for mathematical modeling. These tools are very powerful and can certainly be used to develop a broad range of simulation models, but in many cases a spreadsheet is simpler and more intuitive to use. Spreadsheet is used to develop, test and run a simulation experiment because it has the following capabilities.

- A way to represent mathematical and logical relationships between variable in the form of computations and assignment of values, and algorithms that describe how top do a series of computations.
- A way to generate random numbers. the random function, which is called" RAND()" in most spreadsheet produces a pseudo random sample from a uniform distribution between 0 and 1.
- A means to repeat a series of computations, thus implementing replications.

Generally, each cell in a spreadsheet model can be classified as containing one of the three types of quantities.

1. Inputs to the model: these can be parameters that are part of the model. They can also be random variables that represent uncertain quantities in the model
2. Intermediate computations: these are calculations that are involved in the model.
3. Out puts from the model: these are the observation on quantities of interest one seeks from the model.

Simulation of queues in spreadsheets can be grouped in to three classes; activity-driven, event driven, and process-driven.

An *activity-driven* simulation describes the activities that occur during fixed intervals of time (for example, an hour, day or week), typically using one row of the spreadsheet for each time interval.

An *event-driven* simulation describes the changes in the system at the moment of each stochastic event, typically using one row of the spreadsheet for each event.

A *process-driven* simulation models the logical sequence of events for each customer, typically using one row of the spreadsheet for each customer.

For the purpose of simulating queues of solid waste, a process-driven simulation best represent the system as it shows the logical sequence of events. This indicates clearly the service time events for various trips carried out in a day's time. Using the process driven simulation model, a type of solid waste transporter is simulated to see its performance with in a day.

Based on the result obtained, necessary analysis shall be done.

3.3.6 Execution

Based on the model which represents the system, generated and manipulated data for the service time and calculated result on the population for arrival time is executed on the simulation platform, which is the software environment. Spreadsheet is the software environment where zonal waste queue is simulated for the available collection systems (communal, door- to – door and block to block). The output is further analyzed for better system approach.

3.4 Solid Waste Disposal

Solid waste collection with out sound integration with disposal does not solve the problem of the city's waste management system. It has been stated in the problem statement that the city currently dumps the refuse collected from all areas in the city to Repi landfill site which is located in the south west of the city.

The Repi landfill area was adopted some 30 years ago and at present has a capacity of absorbing at least 10 years if all conditions are assumed to be not changing. Therefore developing another landfill site is mandatory. To alleviate this problem, the Addis Ababa city government, in the new master plan of the city, included four proposed new landfill sites: Filidoro,Dertu,Bole Arbasa and Yeka Abdo. According to the master plan, Repi landfill area will be a green area after closure. The proposed landfill sites are not yet developed.

3.4.1 System Alternatives

As it is discussed in the literature review section, there are a number of disposal options. From economic point of view and performance, all possibilities should be investigated. For the present Addis Ababa refuse management, the following system alternatives are identified.

1. Total waste land filling
2. Land filling combined with other disposal options

3.4.1.1 Total Waste Land filling System Description

As per the master plan of the city's refuse management, more landfill sites will be developed. But still there will be a problem of allocation of generated wastes in the city to the landfill sites. The following fig. describes the system with four landfill sites.

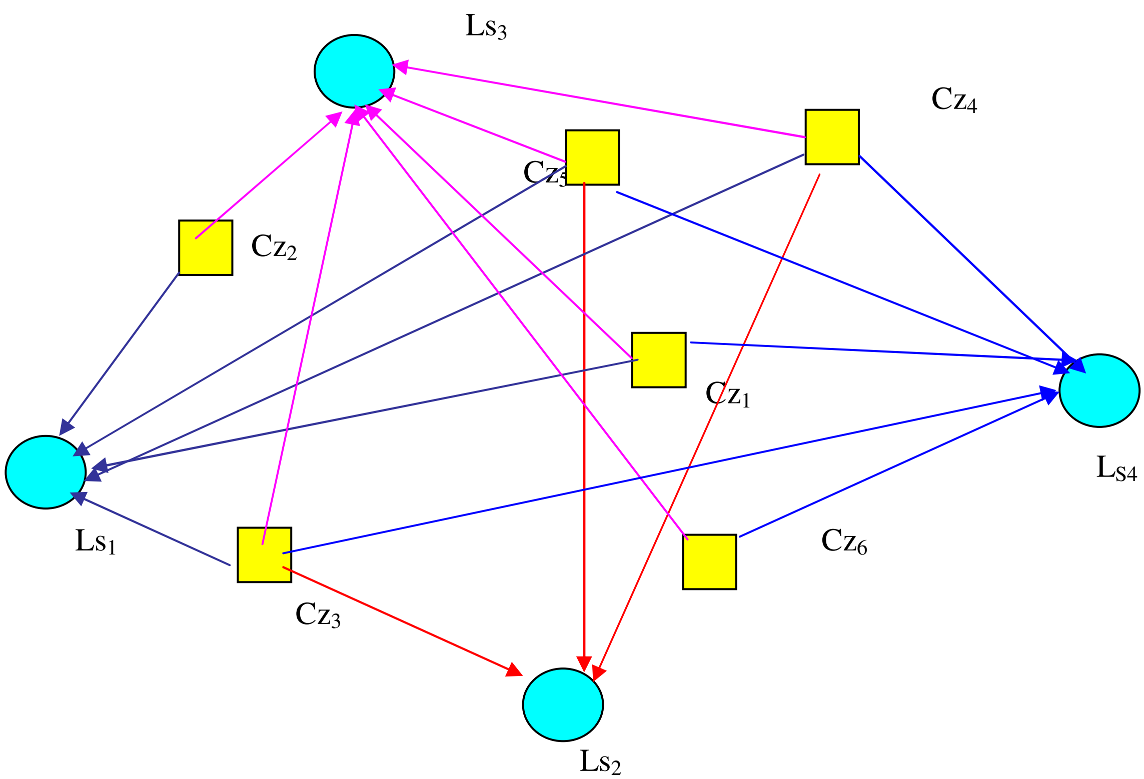


Fig Waste allocation System

Where: Cz_1,Cz2………..Cz6 are centroid of zone 1,2,…6

Ls_1,Ls_2,………..Ls_4 are landfill sites 1,2..4

3.4.1.2 System Modeling

The system of waste allocation problem as depicted in the fig above involves optimization. Therefore determination must be made of the amount of solid waste that should be hauled to each 4-disposal site from each of zonal centroid, so that the total haul cost will be minimum possible value. This is a linear programming model.

Assumptions:

1- The total amount of wastes hauled to all the disposal sites must be equal to the amount generated in the zone (material balance requirement)

2- Only specified amounts of wastes can be accepted at each disposal site (this constraint could arise as a result of limited highway access to a given disposal site)

3- The amount of wastes hauled from each zonal centroid is equal to or greater than zero.

Let;

i= index of the waste-generation centroid of the different parishes in Addis Ababa.

i.e 1 for zone-1, 2 for zone-2 etc.

j= index of different sites

X_{ij} = the amount of waste hauled from the zonal centroid i to disposal site j.

C_{ij} = cost of transporting one ton of waste from the waste generation centroid of parish i to landfill site j

W_i = Waste generated in parish i.

Capacity $_j$ = the total amount of waste that can be accepted at landfill site j.

$$\text{Objective function} = \sum_{j=1}^{4} \sum_{i=1}^{6} X_{ij} C_{ij}$$

Subject to the following constraints;

$$\sum_{j=1}^{4} X_{ij} = W_i \quad i = 1 \text{ to } 6$$

$$\sum_{i=1}^{6} X_{ij} <= Capacity_j \quad j = 1 \text{ to } 4$$

$$X_{ij} >= 0$$

3.4.1.3 Land filling Combined with Other Disposal Options Methods

The system description and modeling is similar except the amount of waste hauled to the disposal sites, in this case is less.

3.4.2 Methods

The alternatives are analyzed using linear programming technique.

Chapter IV

Model Analysis

4.1 Solid Waste Collection

The Queuing model, which represents the solid waste collection operation of Addis Ababa, discussed in chapter 3, has special properties. The properties are parameterized in subsequent section for model input and Analysis.

4.1.1 Arrival Properties

The inter- Arrival time depends on waste generation per unit time. That is, the time between subsequent arrival of 'Certain' quantities of waste emanates from generation units. The quantity of waste arriving at zonal centroid point at every unit of time, is based on the type of collection system. For communal collection system, the container lifter (service giver) transports refuse full of $8m^3$ container. Therefore according to the model, a volume of waste equal to $8m^{3,}$ forms a waiting line at zonal centroid. In addition to $8m^3$, 1.1 m^3 small skips also serves as a communal collection operation. The service giver (Vehicle), in this case, is

Renault (compactor truck), with a capacity of $15m^3$. Hence, refuse of $15m^3$ is assumed to form a queue.

The following table summarizes the type of collection system, quantity (volume) of waste and vehicle type.

Table 4.1 Collection systems, quantity of waste & vehicle type

Type of collection system	Volume of waste forming queue	Service giver vehicle
Communal		
Container	$8m^3$	Container – lifter
Small skips	$15m^3$	Renault compactor
Door- to Door	$9 m^3$	Covered side loader
	$10m^3$	Hino compactor

* Block to Block system dissolves in one of the two collection systems.

At present, the coverage of each collection system is as follows

Communal collection system: 64%

- Container ($8m^3$) = 33%[**]
- Container ($1.1m^3$) 15 m^3 = 31%[**] (including street sweepings)

Door – to Door collection system is 36%[**]

- $9m^3$ covered side loader = 22%[+]

[**] data from Region 14 Environmental hygiene department
[+] Estimated by the author of this thesis on the basis of vehicle number.

- $10m^3$ Hino- compactor = 14%[+]

Hence, for each collection system and service giver type, refuse allocation depends on the percentage coverage.

The refuse generation unit primarily depends on the population size of the zone. The following table shows projected urban population of each zone.

Table 4.2 Projected Total population of zones, Urban areas ,2002

Zone	Population size
1	399,282
2	542,300
3	460,183
4	588,552
5	551,722
6	106,961
Total A.A Urban Areas	2,646,000

Total waste generated as discussed in chapter II, is given by

Generated waste (m^3)/ day =

$$= \left(\frac{1}{1000}\right)\left[0.65\, lt/c/d\right]^{\clubsuit} \text{ (No of people) x } \frac{100}{76}$$

♣ 0.65 lt/day is equivalent to 0.22kg/day with ρ=336kg/m^3, region-14 EHD uses this for planning purpose.

The following table shows generated waste unit of each zone and allocated refuse quantity in m^3 according to collection systems coverage

Table 4.3 Generated waste and amount allocated to each collection system - 2002

Zone	Population size	Generated Waste (m^3/day	Communal Collection		Door – to Door	
			Container ($8m^3$) allocated waste (m^3/d)	Container ($1.1m^3$) 15m3- allocated waste (m^3/d)	Covered side loader allocated refuse (m^3/d)	Hino compactor allocated refuse (m^3/d)
1	399,282	341.49	112.69	105.86	75.13	47.81
2	542,300	463.81	153.06	143.78	102.04	64.93
3	460,183	393.58	129.88	122.01	86.59	55.10
4	585,552	500.80	165.26	155.25	180.29	-
5.	551,722	471.87	155.72	146.28	103.81	66.06
6.	106,961	91.48	91.48	-	-	-

1. In zone – 4, for door-to-door collection system, covered side loader type is the prevalent system.
2. In zone- 6, container system is the prevalent system.

Operations of collections are planned based on daily generation units. It has been described in chapter 3, that the arrival property is based on refuse generation. Therefore daily unit arrival of waste forms a queue at zonal centroid for each collection system. The collection operation involves different routes for same type of collection system in the zone. In this case, to meet the model, multi-serial queue system is assumed. Hence the number of unit arrival forming waiting line for daily service is essential to determine the inter- arrival time for each collection system. Unit arrival is the respective volume in table 4.1 for the existing types of collection operations.

The number of unit volume forming queue is given bellow in Table 4.4

For example for zone 1, communal collection system, number of $8m^3$ generated per day is equivalent to

$$= \frac{allocated\ waste(m^3/d)}{8m^3}$$

$$= \frac{112.69}{8}$$

= 14.09 units of $8m^3$ waste generated per day.

Similarly number of units that can form a queue for each zone is given in the table below.

Table 4.4. Generation units per unit of collection volume

Zone	Population size	Generated Waste (m^3/day	Communal	Collection	Door-to	Door
			No. of $8m^3$) generated per day	No. of $15m^3$ Generated per day	No. of 9 m^3 generated per day	No. of $10m^3$ generated per day
1	399,282	341.49	14.09	7.06	8.35	4.78
2	542,300	463.81	19.13	9.59	11.34	6.49
3	460,183	393.58	16.24	8.13	9.62	5.51
4	585,552	500.80	20.66	10.35	20.03	-
5.	551,722	471.87	19.46	9.75	11.53	6.61
6.	106,961	91.48	11.44	-	-	-

The arrival rate (customer per unit time) is determined from the number of unit arrivals that form queue. For example, for communal container collection systems (zone 1), the arrival rate (per hour) is:

$$\text{Arrival rate=}\ \frac{14.09 cust}{8hr} = 1.76\ cust\ \ /hr$$

Similarly the arrival rate for all other zones with the given collection type is given in the table bellow.

Table 4.5. Arrival-rate (customer or unit arrival/hr.)

Zone	Communal collection		Door- to- Door	
	$8m^3$ units of waste as a customer/hr	$15m^3$ units of waste as a customer/hr	$9m^3$ units of waste as a customer/hr	$10m^3$ units of waste as a customer/hr
1	1.76	0.88	1.04	0.60
2	2.39	1.20	1.42	0.81
3	2.03	1.02	1.20	0.69
4	2.58	1.29	2.50	-
5	2.43	1.22	1.44	0.83
6.	1.43	-	-	-

The inter - arrival time is given by the reciprocal of the arrival rate ($\frac{1}{\lambda}$, where λ is arrival rate). For example, the inter-arrival time for zone 1, $8m^3$ (communal system) is given by

$$\text{Inter-arrival time} = \frac{1}{\lambda} = \frac{1}{1.76\,cust/hr}$$

$$= 0.57\,hr/cust.$$

Hence the inter-arrival time in calculated in similar fashion for each collection system and is tabulated bellow.

Table 4.6 Inter-Arrival time(hr.) for unit volume of waste as a customer.

Zone	Inter-Arrival time for 8 working hours in a day	
	Communal collection	Door-to Door

	$8m^3$ units of waste (hr/customer)	$15m^3$ units of waste (hr/customer)	$9m^3$ units of waste (hr/customer)	$10m^3$ units of waste (hr/customer)
1	0.57	1.13	0.96	1.67
2	0.42	0.83	0.71	1.23
3	0.49	0.98	0.83	1.45
4	0.39	0.77	0.40	-
5	0.41	0.82	0.69	1.21
6	0.70	-	-	-

4.1.2 Service parameters

The service- time distribution is established from observed data. Data collected (shown as Annex-E), is the average time a vehicle spent to load, haul and dump at disposal site. The data after being sorted for zone, vehicle & collection type using Microsoft Access, distribution for service time is established. It is based on the frequency of service time bounded in selected time limits. The service time that depends on many factors (location or distance form land fill site, traffic density, infrastructure, driver behavior etc.) is not same even for waste located at same point in the zone on different operation day. Hence, service time distribution established from frequency of observed time, tells the probability of collecting & dumping to fall within a given time intervals. For instance, the probability for the time taken to pick, load etc of refuse in a container located at any place in a zone to be with in an interval of time is known. This, as described in chapter-3, is the basis for Monte Carlo simulation of the system. The service time range selection primarily depends on the frequency or repetition of data .The probability distribution established from observed data (Annex -E) are shown as follows.

Cumulative probability distribution (for each type of collection system)

Zone – 1

Table 4-7

Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.58	0.99	27	0.34	0.34	0	0.34	0.58
0.99	1.21	30	0.38	0.72	0.34	0.72	0.99
1.21	1.5	20	0.25	0.97	0.72	0.97	1.21
1.5	1.58	2	0.03	1.00	0.97	1.00	1.5
		79				1.00	1.58

Table 4.8

Covered- Side loader

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.81	1.25	11	0.18	0.18	0	0.18	0.81
1.25	1.5	29	0.48	0.67	0.18	0.67	1.25
1.5	1.72	14	0.23	0.90	0.67	0.90	1.5
1.72	2.04	6	0.10	1.00	0.90	1.00	1.72
		60				1.00	2.04

Table 4.9

Compactor-Hino

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.08	1.29	15	0.29	0.29	0	0.29	1.08
1.29	1.56	29	0.56	0.85	0.29	0.85	1.29
1.56	1.75	5	0.10	0.94	0.85	0.94	1.56
1.75	1.89	3	0.06	1.00	0.94	1.00	1.75
		52				1.00	1.89

Table 4.10

Compactor -Renault

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.88	1.17	8	0.24	0.24	0	0.24	0.88
1.17	1.33	11	0.32	0.56	0.24	0.56	1.17
1.33	1.56	9	0.26	0.82	0.56	0.82	1.33
1.56	2.29	6	0.18	1.00	0.82	1.00	1.56
		34				1.00	2.29

Zone –2

Table 4.11

Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.65	0.76	5	0.10	0.10	0	0.10	0.65
0.76	0.99	26	0.52	0.62	0.10	0.62	0.76
0.99	1.13	13	0.26	0.88	0.62	0.88	0.99
1.13	1.13	6	0.12	1.00	0.88	1.00	1.13
		50				1.00	1.33

Table 4.12

Covered-Side loader

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.67	1.11	8	0.14	0.14	0	0.14	0.67
1.11	1.39	24	0.43	0.57	0.14	0.57	1.11
1.39	1.67	20	0.36	0.93	0.57	0.93	1.39
1.67	1.75	4	0.07	1.00	0.93	1.00	1.67
		56				1.00	1.75

Table 4.13

Compactor-Hino

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.97	1.28	7	0.37	0.37	0	0.37	0.97
1.28	1.58	10	0.53	0.89	0.37	0.89	1.28
1.58	1.67	2	0.11	1.00	0.89	1.00	1.58
		19				1.00	1.67

Table 4.14

Compactor-Renault

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time

0.88	1.19	13	0.41	0.41	0	0.41	0.88
1.19	1.42	13	0.41	0.81	0.41	0.81	1.19
1.42	1.88	6	0.19	1.00	0.81	1.00	1.42
		32				1	1.88

Zone-3

Table 4.15

Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.82	1.2	26	0.37	0.37	0	0.37	0.82
1.2	1.44	32	0.46	0.83	0.37	0.83	1.2
1.44	1.58	8	0.11	0.94	0.83	0.94	1.44
1.58	2.04	4	0.06	1.00	0.94	1.00	1.58
		70				1.00	2.04

Table 4.16

Covered side loader

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.78	1.21	9	0.24	0.24	0	0.24	0.78
1.21	1.42	10	0.26	0.50	0.24	0.50	1.21
1.42	1.56	10	0.26	0.76	0.50	0.76	1.42
1.56	2.13	9	0.24	1.00	0.76	1.00	1.56
		38				1.00	2.13

Table 4.17

Compactor-Hino

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.21	1.64	9	0.27	0.27	0	0.27	1.21
1.64	2	15	0.45	0.73	0.27	0.73	1.64
2	2.33	4	0.12	0.85	0.73	0.85	2
2.33	2.83	5	0.15	1.00	0.85	1.00	2.83
		33				1.00	2.83

Table 4.18

Compactor-Renault

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.33	1.92	27	0.57	0.57	0	0.57	1.33
1.92	2.17	7	0.15	0.72	0.57	0.72	1.92
2.17	2.58	6	0.13	0.85	0.72	0.85	2.17
2.38	2.75	7	0.15	1.00	0.85	1.00	2.38

		47				1.00	2.75

Zone-4

Table 4.19
Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.68	1.2	32	0.40	0.40	0	0.40	0.68
1.2	1.5	35	0.43	0.83	0.40	0.83	1.2
1.5	1.62	9	0.11	0.94	0.83	0.94	1.5
1.62	1.77	5	0.06	1.00	0.94	1.00	1.62
		81				1.00	1.77

Table 4.20

Covered side loader

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1	1.2	4	0.04	0.04	0	0.04	1
1.2	1.53	42	0.45	0.49	0.04	0.49	1.2
1.53	1.75	31	0.33	0.82	0.49	0.82	1.53
1.75	2.17	17	0.18	1.00	0.82	1.00	1.75
		94				1.00	2.17

Table 4.21

Compactor-Renault

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.96	1.38	20	0.40	0.40	0	0.40	0.96
1.38	1.58	15	0.30	0.70	0.40	0.70	1.38
1.58	2.04	11	0.22	0.92	0.70	0.92	1.58
2.0	2.38	4	0.08	1.00	0.92	1.00	2.04
		50				1.00	2.38

Zone-5

Table 4.22

Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
0.71	1.71	40	0.45	0.45	0	0.45	0.71
1.17	1.35	30	0.34	0.80	0.45	0.80	1.17
1.35	1.88	16	0.18	0.98	0.80	0.98	1.35
1.88	2.08	2	0.02	1.00	0.98	1.00	1.88

88

Table 4.23

Covered side loader

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.19	1.39	14	0.33	0.33	0	0.33	1.19
1.39	1.64	13	0.31	0.64	0.33	0.64	1.39
1.64	1.72	3	0.07	0.71	0.64	0.71	1.64
1.72	2.25	12	0.29	1.00	0.71	1.00	1.72
		42					

Table 4.24

Compactor-Hino

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.11	1.44	13	0.30	0.30	0	0.30	1.11
1.44	1.69	21	0.48	0.77	0.30	0.77	1.44
1.69	2	5	0.11	0.89	0.77	0.89	1.69
2	2.28	5	0.11	1.00	0.89	1.00	2
		44				1.00	2.28

Table 4.25

Compactor-Renault

Time from	Interval to	Frequency	Probability	Cum.Prob	Lower-bound	Upper bound	Service time
1.27	2	23	0.68	0.68	0	0.68	1.27
2	2.56	7	0.21	0.88	0.68	0.88	2
2.56	3.67	4	0.12	1.00	0.88	1.00	2.56
		34				1.00	3.67

Zone-6

Table 4.26

Container-Lifter

Time from	Interval to	Frequency	Probability	Cum.Prob.	Lower-bound	Upper bound	Service time
0.71	1.25	18	0.51	0.51	0	0.51	0.71
1.25	1.53	12	0.34	0.86	0.51	0.86	1.25
1.53	1.89	5	0.14	1.00	0.86	1.00	1.53
		35				1.00	1.89

4.1.3 Algorithm for spreadsheet Monte Carlo simulation

Monte Carlo simulation involves sampling technique using random numbers. Once the service time distribution is established, a system of random number generation, picking the required service time from the distribution and simulation schemes has to be developed. Several inter-related variables have to be considered while using spreadsheet as a platform for performing computations. Separate data entry sheet is attached as to make the simulation user friendly and interactive.

The general structure used for simulation of collection operation is shown below.

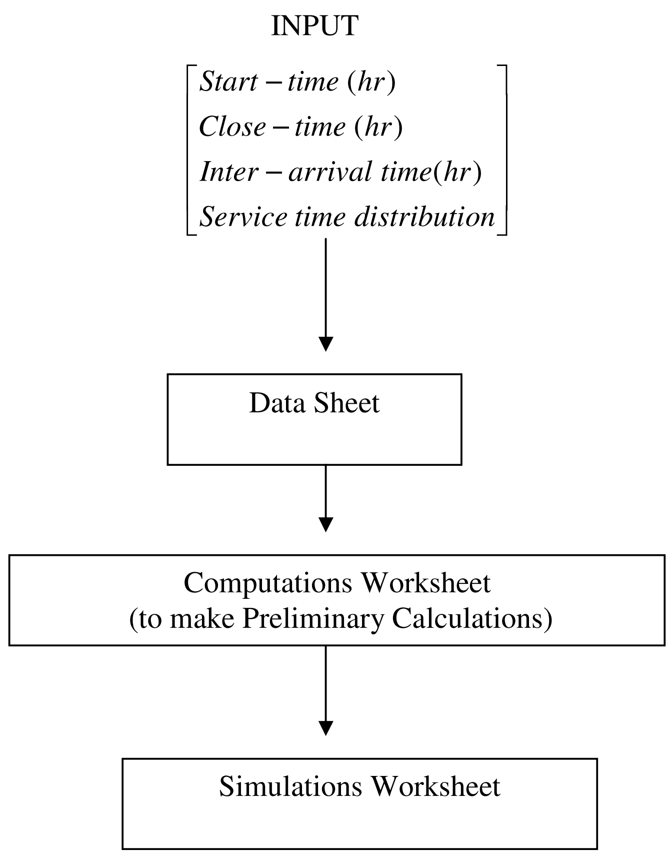


Fig 4.1 General structure of the spreadsheet simulation

Algorithm for Computations worksheet

The preliminary calculations, based on input data in the data sheet are made in this worksheet. The variable used for computations are customer number, inter-arrival time, service time, arrival time, potential start time, actual start time and next –server. Hence each variable are represented by cells for each customer number for service hour duration. As depicted in Fig 4.1, the worksheet automatically picks data from data sheet for subsequent computation and simulation. The steps involved for computations are.

Step 1- Record customer number until the closed hour if there is arrival.

Step 2- For each customer recorded, read inter-arrival time from data sheet.

Step 3- Generate random number for the customer with potential of getting service and pick service time related to the random number from data sheet.

Step 4- Calculate the arrival time of each customer considering inter-arrival time and service time.

Step 5- Identify potential start time of each customer comparing arrival time of the customer with service end time of predecessor customer.

Step 6- Based on step 6, list actual start-time of customer.

Step 7- Comparing potential and actual start-time, identify customer waiting for service.

The algorithm corresponding to computations steps mentioned above and to the foregoing and the associated flow chart is given bellow.

1. Record first customer and for other customers add 1 to previous customer number provided that there is potential starting customer.

   {IF (ISTEXT (cell number for potential start time), " ", ----+ 1)}

2. Read inter-arrival time for first customer cell from data sheet

   {Data ! (cell number for inter-arrival time)} for other customers cells,

- Check for predecessor customer cell, record and read data from data sheet.
- {If (Not ((predecessor customer number cell)=” “), Data! F ll,” “)}

3. Generate random number and pick the corresponding service time from data sheet for the first customer cell.

   {VLOOKUP (Rand ( ), Data (range), column number)}

   For other customers' cell, check for record of potential start time cell, if yes then generate random number and take corresponding service time from data sheet.

   If there is no potential starter write no character.

   {IF (NOT (Potential starter= “ “), V LOOKUP (Rand ( ), Data (range), “ “)}

4. Take the start-time from data sheet as arrival time for the first customer cell {Data! (Cell number for start time, Data sheet)}

   - For other customers cell, check if there is arrival and Sum of the arrival and inter-arrival time with close time. If there is no arrival write no character and if sum of the arrival & inter-arrival time is greater than close time, write closed. Otherwise calculate the sum as arrival time.
   - {(IF (ISTEXT (arrival), “ “, IF (SUM>Close time, ”closed”, SUM)}

5. Check for possible arrival and if there is, record potential start time taking the maximum out of end time (Sum of arrival time and service time), start & arrival time. If no possible arrival, write no character.

   {IF (ISTEXT (arrival), “ “, Max (end time, start time, arrival time)}

6. Record the actual start time for each customer if there is arrival.

{IF (ISTEXT (Arrival), " ", potential start time)}

7. Match actual start time and potential start time for each customer to identify waiting customer.

   {IF (IS TEXT (Potential start), " ", Match (start time, Potential start time)

Algorithm for Simulations Worksheet

Simulation worksheet is the one on which final simulation calculation is done. Based on arrival time, start time (actual) & service time for each customer calculated in the computations worksheet, simulations is done for actual customer number to be served in between start and closed time. This includes start, end time and wait time of each customer. Accordingly start, end and wait time variables are included in the simulations work sheet. Average wait time of a customer also included to determine the average waiting time for the queue.

The steps followed are:

Step 1 Record actual customer number if service time is complete.

Step2 For the actual customer recorded, designate inter-arrival time.

Step 3 Take arrival time data from computations worksheet for actual customers to be served.

Step 4 Record customer service time for potential customers.

Step 5 Record start time of actual customers if the arrival time is between start time and close time.

Step 6 Calculate end time for customers to be served.

Step 7 Calculate wait time for each customer for which service is given.

Step 8 Calculate Average wait time of a customer based on queue length.

The algorithm for simulations calculation is given bellow.

1. - Read customer number data for first customer from computations worksheet.

   {= Computations! (Cell no)}

   - For other customer, check if service is finished. If yes, read data from computations worksheet.

   Otherwise write no character.

   {=IF (ISTEXT (End time), " ", computations (Data))}

2. Read inter- arrival time data from computations worksheet.

3. - Read of the arrival time from corresponding computations worksheet cell for the first customer.

   {= Computations! (Cell number)}

   - For other customers, check the corresponding computations work sheet cell is "closed". If yes write closed. Otherwise take arrival & inter-arrival time from computation worksheet and SUM.

   {=IF (computations (cell number)="closed", computations!(Arrival time)+ computations (inter-arrival time), computations (SUM)}

4. Check for potential arrival. If yes read from corresponding cell in computations sheet. If no, write no character.

   {=IF(ISTEXT (Arrival), " ", computations! (Service time)}

5. - For first customer, check for possible next server in corresponding computations sheet, and sum of arrival & inter arrival time with close time.

   If there is next server and the sum is less than close time, take corresponding data from computations sheet. If no, write no character.

   {=IF(AND(Computations! (Next server)=1, Computations (actual start time)<close time, start time + service time,” “)}

   - For other customers, check predecessor cell, if empty write no character. If recorded, repeat step 5.

   {=IF (ISTEXT (Predecessor cell), “ “, ------------------------)}

6. Check for potential customer. If no, write no character. If there is potential customer, check for sum of start and service with close time. If sum is less than close time, record the sum as end time. If greater, write no character.

   {=IF (ISTEXT (starter), “ “, IF (AND (Start time+ computations (service time)<= close time, start time + service time, “ “)}

7. Check for service being finished. If finished subtract arrival time from actual start time for wait time. If service is not finished, write no character.

   {=IF(ISTEXT (end time), “ “, computations! (Actual start time)-computations (arrival time)}

8. Calculate the average of waiting time by dividing the sum of waiting time of customers to number of served customers.

   {=Average (cell for customer number 1: cell for last customer}

The complete developed module of spreadsheet simulation package (Data sheet, computations & simulations sheet) is attached as Annex-A.

4.1.4 Spread Sheet Simulation Run Result & Analysis

The refuse collection operation of each zone classified as per the collection systems (Communal, door-to- door) has been executed using the spreadsheet simulation. The service givers (container lifter& Renault compactor for communal collection, Covered side loader & Hino compactor for door to door) performance also simulated. Since Monte Carlo simulation result depends on the random number generated that decides the service time, a series of simulation run need to be made in order to estimate the number of customer served with in time interval (Start- close time). The average wait time for a customer also follows similar fashion. Hence, simulation run exercise is made 10 times for each service giver in each zone. The out come of each run is shown as Annex C.

The following table shows mean of the number of customer served out of the ten-simulation run for each service giver (vehicle) with the given variance.

Table 4.24 Number of customer that can be served.

Zone	Container lifter		Covered side loader		Compactor Hino		Compactor Renault	
	Mean of cust. That can be served	Variance	Mean of Cust. That can be served	Variance	Mean of cust that can be served	Variance	Mean of cust that can be served	Var.
1	8.1	0.54	5.8	0.4	5	0.0	5.9	0.1
2	8.8	0.18	6.8	0.18	5.9	0.1	6.9	0.32
3	6.7	0.23	5.9	0.32	4.1	0.54	4.2	0.18
4	6.9	0.54	5.3	0.23	-	-	5.5	0.28
5	7.1	0.32	5.1	0.1	5.3	0.23	4.4	0.7

6	7.1	0.54	-	-	-	-	-	-

The mean average waiting time of each customer is shown on the following table

Table 4.25 Average Waiting time for a customer

Zone	Container lifter		Covered side loader		Compactor Hino		Compactor Renault	
	Mean of Av. Waiting time of a cust. (hr)	Variance	Mean of Av. Waiting time of a cust. (hr)	Variance	Mean of Av. Waiting time of a cust. (hr).	Variance	Mean of Av. Waiting time of cust. (hr)	Var.
1	1.32	0.03	0.61	0.05	0.01	0.00	0.38	0.04
2	1.69	0.02	1.08	0.11	0.14	0.02	0.6	0.01
3	1.78	0.01	1.12	0.06	0.51	0.1	1.22	0.04
4	2.08	0.10	2.02	0.02	-	-	1.34	0.12
5	1.9	0.11	1.48	0.04	0.4	0.05	1.47	0.33
6	0.96	0.14	-	-	-	-	-	-

The simulation run result shown in the above (table 4.24) can further be used for analysis of the refuse collection operation in terms of number of vehicle required for collecting the daily-generated waste.

For instance, in zone 1, for communal collection system,

$8m^3$ container system,

Mean number of customers = 8.1

This implies that a container lifter vehicle in zone 1 can collect and dump quantity of waste equivalent to

= (8.1) x (Volume of unit Customer)

= (8.1) x ($8m^3$)

= 64.8 m^3 of refuse

Number of vehicle required taking vehicle availability rate of 72%[1],

$$= \left[\frac{Volume\ of\ waste\ allocated(table 4.3)}{Volume\ of\ waste\ colledted\ with\ single\ vehicle}\right] \Big/ (Vehicle\ availability\ rate)$$

$$= \frac{\left[\frac{112.69 m^3/d}{64.8 m^3/d/vehicle}\right]}{0.72}$$

$$= \frac{1.73}{0.72}$$

$$= \underline{\underline{3}}$$

Table 4.26, Summary of required number of vehicles

Zone	Communal collection		Door-to-Door collection	
	Container-Lifter	Renault Compactor	Covered side loader	Hino-Compactor
1	3	2	2	2
2	3	2	3	2
3	4	3	3	2
4	4	3	5	-
5	4	3	3	2
6	3	-	-	-
	21	13	16	8

In order to verify and validate the result, it is essential to compare with region-14 environmental hygiene department vehicle allocation for the purpose of planning waste collection operation in Addis Ababa.

[1] data from Region 14 environmental hygiene department(average)

The allocation of vehicle is tabulated[2] as follows.

Table 4.27, Vehicle allocation plan (Region-14, EHD)

Zone	Communal collection		Door-to-Door collection	
	Container-Lifter	Renault Compactor	Covered side loader	Hino-Compactor
1	5	2	2	2
2	3	1	2	2
3	4	2	2	2
4	4	2	2	-
5	4	2	2	2
6	1	-	-	-
	21	9	10	8

Hence, waste collection coverage for communal system (Renault compactor):

$$= \frac{Number\ of\ vehicles\ allocated}{number\ of\ vehicles\ required} x\, 100$$

$$= \frac{9}{13} x\, 100$$

[2] Used for planning purpose by environmental hygiene department for zonal offices.

$$= \quad 69.2\%$$

For door-to-door, collection coverage (covered side loader):

$$= \quad \frac{10}{16} x\, 100$$

$$= \quad 62.5\%$$

Therefore, overall waste collection coverage:

$$= \quad \frac{62.5 + 69.2}{2}$$

$$= \quad 65.85\%$$

4.2 Solid Waste Disposal

4.2.1 Total Waste land filling

As discussed in chapter III, one of the alternatives for disposal of solid waste is total waste land filling. This is a type of disposal system where all generated waste of Addis Ababa is taken to sanitary landfill for disposal. Unlike Repi, the only dump area for the city's refuse, sanitary landfill is a better disposal systems in which gas emission from decomposition of organic waste and leachate are managed properly.

In total waste land filling alternative, determining the quantity of waste that need to be disposed and the contribution of the different parishes of the city has to be known. Hence, a waste allocation model system, represented by the objective function is developed.

$$= \sum_{j=1}^{4} \sum_{i=1}^{6} x_{ij}\ C_{ij} \quad \text{(Minimization)}$$

Subject to the following constraints

$$\sum_{j=1}^{4} x_{ij} = W_i, i = 1 \text{ to } 6$$

$$\sum_{i=1}^{6} x_{i_j} <= capacity, j = 1 \text{ to } 4$$

$$x_{ij} >= 0$$

Where

i = index of the waste generation centroid of the different parishes in Addis Ababa. i.e. 1 for zone1, 2 for zone 2 etc.

j = index of different land fill sites.

X_{ij} = the amount of waste hauled from the zonal centroid i to disposal site j.

C_{ij} = Cost of transporting one ton or m^3 of waste from the waste generation centroid of parish i to land fill site j.

W_i = Waste generated in parish i.

Capacity $_j$= the total amount of waste that can be accepted at landfill site j.

4.2.1.1 Solution Techniques For The Linear Programming Model

Among the widely used techniques for solving linear programming problems, brief description of the two wieldy used techniques is discussed bellow.

I. Extreme-Point Solutions

Extreme-point solution method is based on extreme point of the convex set K (K is a convex polyhedron having finite number of extreme points) that the objective function assumes its minimum generated by the set of feasible solutions to the linear programming problems. Further the method assumes that if the objective function assumes its minimum at more than one extreme point, then it takes on the same value for every convex combination of those particular points.

There fore X= $(x_1, x_{2,} .... x_n)$ is an extreme point of K if and only if the positive X_j are coefficients of linearly independent vectors p_j in $\sum_{j=1}^{n} x_j p_j p_o$

As a result of the assumptions,

1. There is an extreme point of K at which the objective function takes on its minimum.
2. Every basic feasible solution corresponds to an extreme point of K.
3. Every basic feasible point of K has m linearly independent vectors of the given set of associated with it.

From the above, the method investigates extreme point solutions and hence only those feasible solutions generated by m linearly independent vectors. Since there are at most $\left(\frac{n}{m}\right)$ sets of m linearly independent vectors from the given set of n, the value $\left(\frac{n}{m}\right)$ is an upper bound to the number of possible solutions to the problem. For large n and m, it would be an impossible task to evaluate all possible solutions and select one that minimizes the objective function.

II Simplex Method

This method finds an extreme point and determines whether it is minimum. If it is not, the Procedures finds an adjacent extreme point whose corresponding value of the objective function is less than or equal to the preceding value. In a finite number of such steps (usually, between m and 3m), a minimum feasible solution is found. It is a powerful scheme for solving any linear-programming problem. Therefore, for the LP model and discussion, simplex method is chosen.

4.2.1.2 Algorithm Development Of Waste Allocation LP Problem

The LP model of waste allocation can be written as:

$Min(z)= X_{11}C_{11}+\dots +X_{61}C_{61}+ X_{12} C_{12} + \dots + X_{62}C_{62}+X_{13} + \dots \dots +X_{63}C_{63}+ X_{14}C_{14}+ \dots X_{64}C_{64}$

Subject to

$W_1 = X_{11} + X_{12} + X_{13} + X_{14}$

$W_2 = X_{21} + X_{22} + X_{23} + X_{24}$

$W_3 = X_{31} + X_{32} + X_{33} + X_{34}$

$W_4 = X_{41} + X_{42} + X_{43} + X_{44}$

$W_5 = X_{51} + X_{52} + X_{53} + X_{54}$

$W_6 = X_{61} + X_{62} + X_{63} + X_{64}$

$Cap_1 \geq X_{11}+X_{21}+X_{31}+X_{41}+X_{51}+X_{61}$

$Cap_2 \geq X_{12}+X_{22}+X_{32}+X_{42}+X_{52}+X_{62}$

$Cap_3 \geq X_{13}+X_{23}+X_{33}+X_{43}X+_{53}+X_{63}$

$Cap_4 \geq X_{14}+X_{24}+X_{34}+X_{44}+X_{54} +X_{64}$

And

$X_{11},X_{12} \dots\dots X_{64} \geq 0$

Let m= number of zonal centriod and n = number of landfill sties.

The number of constraint equations =n + m. The number slacks = n & number of artificial variables = m. Hence, objective equation and constraint equation can be put like

$C_1 \; C_2 \; \dots\dots\dots \; C_{(nm+n+m+1)}$

a_{11} a_{12} …………………………… $a_{(nm+n+m+1)}$

.

.

$a_{n+m,1}$ $a_{n+m,2}$ ……………………………….. $a_{n+m, (nm+n+m+1)}$

Column 1 2 3 4. . ……………………………………………… nm+n+m+1

index

Where $C_{1,}$ C_2 are coefficients of objective function (i.e. transport cost)

a_{11}, a_{12} are coefficients of constraint equations.

To use simplex method to solve the waste allocation problem, variable designation has to be made to avoid complexity.

Therefore the steps involved are

Step 1- To minimize an objective function, maximize its negative

Step 2- For Artificial Variables used, give large negative coefficient in the objective function row.

Step 3- Given an initial basic feasible solution, choose the pivot column in subsequent iterations, that column whose variable has the largest simplex criterion.

Step 4- Choose as the pivot row, in subsequent iterations, that row is in which the ratio of the constant index and the coefficient in the pivot column is the smallest positive, none zone ratio.

Step 5- When there are no positive, non-zone simplex criteria associated with any variable, no further iterations required.

The algorithm for waste allocation problem based on the above basic steps is as follows

1. Read the number of land fill sites, sites

   Read the number of zones, centroid

   Read cost of transport per m^3 of waste, j= 1 to m, i =1 to n, CC(i,j)

   Read waste generated in zone i,j=1 to m, w (i)

   Read land fill site j can accept, j=1, n, Cap (j)

2. Store cost parameters (coefficients of objective function) in single array according to column index. Multiply by –1 for minimization j=1,n i =1, m

   Co (L)= CC (i,j)

3. Assign zero coefficients of slack variables to objective function.

   i=(mxn)+n to (mxn)+n, Co (i) = 0

4. Assign negative big number for coefficients of artificial variables to objective function.

   i=(mxn)+n to (mxn)+n+m+1 : Co(i)= -999999

5. Initialize Constraint matrix

   XC (i,j)=0

6. Assign coefficients of constraint equations having slack variables (excluding slacks) XC (i,j)=1

7. Assign coefficients of slacks

   XC (i,j)=1

8. Assign coefficients of constraint equations with artificial variables (excluding artificial variables)

   XC (i,j)=1

9. Assign coefficients of artificial variables.

   XC(i,j)=1

10. Assign the last column of constraint matrix.

    XC (i,j)=Cap(i)   or   XC(i,j)=W(i)

11. Search the right side of the initial matrix for the basic variable and store in

    IBV (i)

    If (XC(i,j).EQ.1)IBV(i)=j

12. Calculate simplex criteria and identify initial solution.

13. Divide each of the positive elements in the pivot column and store in the variable IPVRO the number yielding the smallest quotient (quont).

14. Divide all the elements in the pivot row by the elements in the pivot position to make 1.

15. Assign all other elements in the pivot column zero and assign values to complete Iterations.
    If (Scmax. LE.0). Iterations finished.

16. Rearrange column number to describe variable index similar to in put variables. CN(i).

17. End

The flow chart shows the algorithm flow. The program source code written in FOTRAN is shown As Annex-C.

4.2.1.3 Total Waste land filling Model Analysis for Energy Recovery

Landfill gas is only produced from the biodegradable fractions of municipal solid waste. Other fractions such as glass, plastics and metals affect the rate of decomposition, since their presence is likely to facilitate water percolation of the waste and diffusion of gases, but they will not markedly affect the total level of decomposition over time.

To estimate the landfill gas recovered for energy from all sites,

Let

Total waste quantity	=	W tones
Fraction of organic waste[3]	=	60%
Organic waste	=	0.6xW
Typical land fill gas [4] Production per tone of Biodegradable waste	=	$250m^3$ /tone
Typical percentage of [4] Collectable gas	=	40%
Total Gas that can be collected	=	0.6x0.4 x 250xW
	=	60W
Calorific value of LFG (55% CH_4)	=	5000 $Kcal/m^3$
Energy rec[3]overy potential (kwh)	=	$60W \text{ x } (5000 \text{ x } 4.183)\frac{K \quad (J)}{(3600s)} x1hr$
	=	$60W \text{ x } \frac{5000}{860} = 345W$
Power generation potential (kw)	=	$345 \text{ x } \frac{w}{24} = 14.5 \text{ W}$

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[4] P.R. White *et al*[10] PP 285,284 & 221respectively.

[3] Based on Gordon's Study (literature survey section 2.1)

Typical conversion efficiency [Φ] = 30%

(Burning of landfill gas in a gas engine to generate electricity, which is then exported in to gird)

Net power generation(KW) = <u>4.35W</u>

For Addis Ababa, W = 760 tones/ day[5]

Hence, Net power generation (MW) = 760x4.35

= 3.3MW

\

4.2.2 Land Filling Combined With Other Disposal Options

The second option is similar to total waste landfilling alternative except that waste materials that can be recycled, composted, digested or incinerated are utilized instead of disposed at the landfill sites. Hence the amount of waste quantity that needs to be transported at the landfill site is lower which result in lower transportation cost. Therefore, the quantity of waste that can be transported to landfill sites is equivalent to

$$X'_{ij} = X_{ij} - \text{(usable wastes)}$$

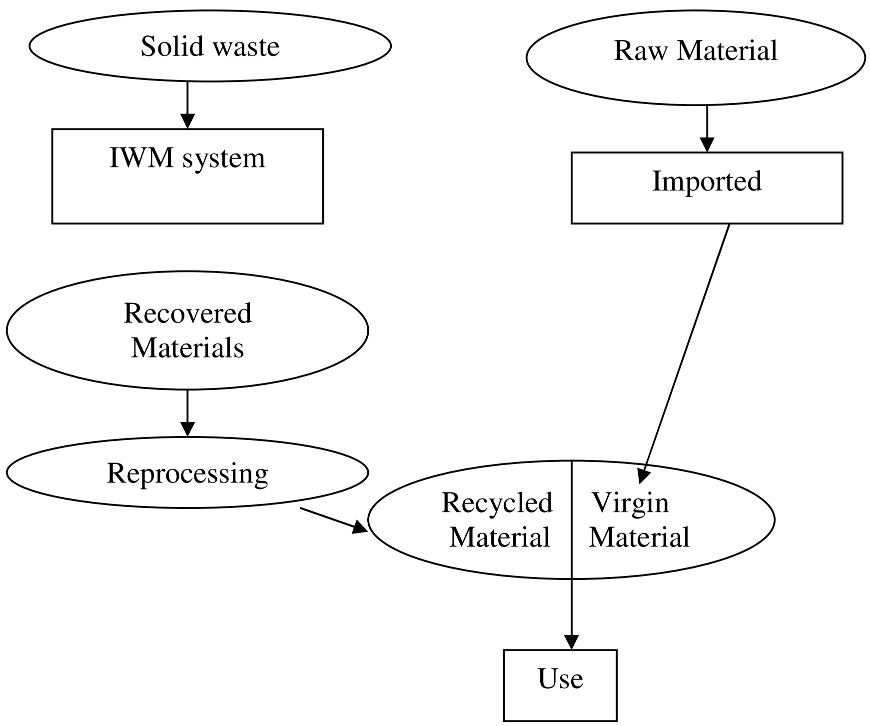
Usable wastes include waste that can be recycled, digested etc.

4.2.2.1 **Recycling**

[Φ] B.Bilitewski *et al* [1] PP 312

[5] From table 4.3 summing generated waste (m^3/d) and multiplying by 336kg/m^3

Recycling includes the reprocessing of the recovered materials with in the waste management system boundary. Recycling process in most case is integrated in to the normal production process for the virgin material.



Plastic

Plastic is a general term covering a host of different resins, but only thermoplastic resins are suitable for materials recycling. Thermo set plastics (duro plastics) cannot be reprocessed in this way. Within the thermoplastics, there are as many different production processes for the Virgin materials as there are resin types. There is less variety, however, in the reprocessing, as there are resin types. Most used reprocessing method is mechanical recycling, where the plastic is shredded or crumbled to a flake and contaminants such as paper labels are removed using cyclone separation.

The flake is then generally washed (this stage may also be used to separate different resins on the basis of density), dried and then the flake extruded as pellets ready for blending with virgin material.

According to 1994, Gordon's weighted % composition study, plastics amount to 1.93%.

Hence, assuming no substantial socio economic growth, recyclable plastics can be estimated.

Let

W=Total annual waste quantity	=	W (tones)
Fraction of plastic by weight [6]	=	1.93%
Recyclable plastic	=	$\frac{1.93}{100}w = 0.0193w$
	=	0.0193x760 = 14.7tones/day

Other than the return value from recycling plastics, gain due to absence of land filling.

i) Gain from transport cost (compared to present situation)

recyclable plastics	=	0.00193 w tone
Typical density of plastics[7]	=	0.96 tones/m^3
Volume of recyclable plastics	=	$\frac{0.019}{0.96}w = 0.02w\ m^3$
Cost of transport [8]	=	21 birr/m^3

Gain due to

[7] P.R.White *et al* [10] PP 293

[8] source Region-14 environmental hygiene department.

Recycling (excluding return from reuse)	=	0.22 X 21 XW
		0.42 w birr
	=	0.42x760 = 319.2birr/day

ii) Landfill space:

= 0.2wm^3 of landfill space can be saved.

= 0.2x760 = 152m^3/day can be saved.

Paper

Waste paper reprocessing varies according to the type of recycled paper product, which will in turn determine the type of waste paper that is used as the process feed stock. Basic stages of reprocessing includes soaking, pulping to separate the fiber, screening to remove contaminants, de-inking, thickening and washing.

Estimation of recyclable paper following same assumptions made for plastic:

Let W= total annual waste quantity	=	W (tones)
Fraction of paper by weight [9]	=	2.47%
Recyclable paper	=	0.0247 W
Typical Losses due to reprocessing[10]	=	15%
Paper ready for blending	=	(1- 0.15) x 0.0247 W
	=	0.02W
	=	0.02x760
	=	15.2 tones/day

[9] From Gordon's Study for Addis Ababa waste,1994 (table 2.2, literature survey)
[10] P.R.White *et al* [10] PP 162

Since paper is biodegradable, it can be land filled for production of landfill gas as paper mill factory (wonji paper mill) is located some 112 km away from the city.

Glass

The use of recovered glass cullet in glass making has the advantage of lowering the furnace temperature needed to melt the other raw ingredients.

Estimation of recyclable glass:

Let W= Total Annual Waste quantity = W (tones)

Fraction of glass by weight[11] = 0.445%

Recyclable glass = $\frac{0.445}{100}$ x W= 0.00445W

= 0.00445 x760 = 3.38 tones/day

Excluding the return value from recycling, gain due to absence of land filling:

i) Gain from transport cost (companied with present Situation)

Recyclable glass = 0.00445W

Typical density of glass[12] = 1.96 tonnes/m_3

Volume of recyclable glass = $\frac{0.00445W}{1.96}$ = 0.0023Wm^3

Cost of transport = 21 birr/m^3

= 21x 0.0023W = <u>0.0483W</u>

ii) Landfill space:

---

[11] From Gordon's Study for Addis Ababa waste,1994 (table 2.2, literature survey)

[12] P.R.White *et al* [10] PP293

=0.0023 Wm^3 landfill space can be saved.

= 0.0023 x 760 = 1.748 m^3 landfill space can be saved.

iii) Energy Saving

Recyclable glass	=	0.00445W tone
Typical energy saving♣	=	3.7GJ/tonne of recovered material
Energy saving	=	0.00445 x 3.7
	=	0.016WGJ
	=	0.016 x 760 = 12.16GJ

4.2.2.2 Incineration

Energy recovery assessment of the Potential of recovery of energy from municipal solid waste through diffident treatment methods can be made from knowledge of its calorific Value and organic fraction.

In thermo-chemical conversion (incineration, pyrolysis), all of the organic matter, bio degradable as well as non-biodegradable contributes to the energy out put:

Let	Total waste quantity	=	W tones
	Net Calorific value	=	NCV kca/1kg.
	Energy recovery potential (KWh)	=	NCV x W x1000/860
		=	1.16 x NCV x W
	Power generation potential (KW)	=	1.6 x NCV x W/24
		=	0.048 x NCV x W
	Typical waste to wire conversion efficiency	=	25%
	Net power generation potential (KW)	=	0.012 x NCV x W

♣ P.R White *et al*[10] PP 177

NCV for waste generated from developing countries is about 1000 Kcal/kg. Hence,

Power generation potential (KW) = 12xW

Generated Electrical power consumption [14] = 14%

on site(for moving grates etc.)

Net power generation potential (MW) = (1-0 .14) x12 x 760/1000 = 7.84 MW

4.2.2.3 Anaerobic digestion of waste

In bio-chemical conversion (Anaerobic digestion), only the biodegradable fraction of the organic matter can contribute to the energy out put:

Total waste quantity: = W (tones)

Total organic /volatile solids: VS[13] = 60%

Typical digestion efficiency [14] = 60%

Typical Biogas yield = B (m^3)[14] = 100 m^3/tone of VS destroyed

100 x 0.6 x W = 60xW

Calorific value of bio-gas[14] = 5000 kcal /m^3 (typical)

Energy recovery potential (KWh) = Bx5000/860 = 348.5W

Power generation potential (KW) = $348.5\text{x}\dfrac{W}{24} = 14.5\text{W}$

Typical conversion efficiency = 30%

Net power generation (KW) = 4.35W

Consumption on site (for heating) [14] = 35%

---

[13] From Gordon's Study for Addis Ababa waste, 1994 (table 2.2 , literature review)

[14] P.R.White *et al* [10] PP 220

Net power generation (MW) = (1-0.35) x 4.35 x 760/1000 = 2.15 MW

Compost, from anaerobic digestion of waste

= 0.4xW

= 0.4W tones

= 0.4 x 760

= 304 tones/day

4.2.2.4 Cost of Disposal Options

Landfill Gas To Energy

As shown in Annex-D, Internal combustion engine / electricity generation holds the minimum cost among the listed landfill gas energy recovery options with Capital cost (dollars per kilowatt) of 900 -1200. The operating and maintenance cost per kilowatt-hour is in the range of 0.013 -0.020 dollars.

Hence, for 3.3MW = 3300kW:

Capital Cost = 1050 x 3300 = 3,465,000 dollar.

Operating Cost = 0.033 x 3300 = 108.9 dollar.

Incineration

From the graph shown in Annex-D (estimated cost of incineration plants):

Investment cost for a plant with capacity of 2263.03♣ m^3 per day

= 250 million US dollar.

♣ Daily generation unit for Addis Ababa (sum from all zones, table 4.3)

IV. Anaerobic digestion

Biodegradable waste = 0.6 x 760 = 456 tones

Annual capacity of a plant = 365 x 456 = 166,440 tones.

From the graph showing trend in cost of anaerobic digestion of municipal waste, for annual capacity of 166,440 tones, 29 ECU = 29 X 1.13 US dollar = 32.77 per ton of treatment cost is incurred .

The investment cost generally is higher than landfill gas recovery options.

Chapter V

Conclusion And Recommendations

5.1 Conclusion

Based on the foregoing chapters, the following inferences are made.

5.1.1. Solid Waste Collection

- The refuse collection operation of Addis Ababa city couldn't meet the quantity of waste generated by the city dwellers for the following reasons.

  i) *The disposal point (Repi landfill area) is not located in such a way that it considers all zonal centroid location.*

  That is, the proximity of the zonal centroid to the landfill site is not uniform.

  The simulation result of waste collection operation summarized in table 4.24 (Chapter IV) verifies this in that the number of customers (Quantity of waste designated according to the collection system) that can be collected daily is different for each zone and type of collection system.

  From comparison of the result (table 4.24) with zonal centroid location (Fig 3.1, Chapter III), it can be concluded that zones with good proximity to the landfill site, can have more quantity of waste collected (e.g. zone 1&2). Contrary to this, zones located faraway from the disposal site, have lower quantity of waste collected (e.g. zone 4).

Similarly from the simulation result for average waiting time of a customer (table 4.25), it can be concluded that zonal location with reference to the disposal site is the major factor for time interval between collections. The more close the zonal centroid to the landfill site, the less the time it takes between subsequent operations, which result in cleaned environment.

ii) *Lack of Choice of efficient collection system.*

Coverage of collection systems (communal & door-to- door with further classification according to vehicle type) has to be based on the performance and type of vehicle that suits the collection system.

The Simulation result tabulated (table 4.24) indicated that for door -to door collection system, covered side loader has higher performance in terms of customers served (refuse collected) than Hino - compactor vehicle. Hence, availing more covered side loader vehicle or replacing Hino compactor gradually with covered side loader, improves the waste collection operation.

iii) *Number of vehicles required for carrying out the collection operation is higher than the existing ones.*

iv) Lack of choice of convenient time of operation for collection systems.

The refuse collection operation coordinated by zonal offices is undertaken during the day time. As discussed in previous chapters, the service time depends not only on location but also on traffic density and other factors. Carrying out collection operation during the nighttime decreases the service time, which result in more number of customers served (quantity of waste). Since door-to door collection involves interaction with people, is not subject to change. Hence, undertaking Communal collection operation during night time and door -to-door operation during day time by far improves the collection efficiency as communal collection takes the lion share.

5.1.2 Solid waste Disposal

The following conclusions are made based on previous chapters.

- To obtain real environmental improvements in the management of solid waste, it is essential to get the economics right. Responsible economic management ensures that economic costs are minimized with in overall waste managements system that seeks to deliver a real environmental improvement.

  Collection of the waste usually represents a significant part of the economic cost of a waste management system, and it can also be a significant source of environmental impacts. Optimizing the collection system will therefore improve the overall performance of most systems, in both economic and environmental terms.

  To this effect, total waste land filling model (waste allocation) allows collection operation to be undertaken with minimum cost provided that numbers of landfill sites are available and recycling is done. The Linear-programming model of waste allocation not only minimizes economic costs but also strengthen planning of collection operation for better performance as compared to the present situation.

- Effective system for solid waste management must be both environmentally and economically sustainable. By environmentally sustainable, it must reduce as much as possible the environmental impacts of waste management, including energy consumption, pollution of land air and water, and loss of amenity. The system must also be economically sustainable in that it must operate at cost acceptable to the community, which includes private citizens, businesses and government. The costs of operating an effective solid waste system will depend on existing local infrastructure, but ideally should be little or no more than existing waste management costs.

As to make the Addis Ababa solid waste management system both environmentally and economically sustainable, landfill combined with other disposal option model analysis (integrated waste management approach) forwarded the following points.

- Recycling of recovered material from solid waste management system anchors sustainability of environmental and economical aspects in terms of sound disposal alternative and reduction of cost.
- Energy recovery from landfill gas using internal combustion engine to generate electricity help the overall refuse management systems cost effective.

➢ From Energy recovering analysis the following points can be concluded.

- Thermo- chemical conversion (incineration, pyrolysis) of solid waste renders pretty good power generation potential (7.84MW). But these types of equipment needs higher investment and trained personnel for operation (as it is shown in cost estimation). Unless it is equipped with good emission control devices pollute the environment.

- Bio- Chemical conversion (anaerobic digestion) of solid waste has lower power generation potential (2.15MW) than thermo - chemical conversion. But produces compost (304 tones/day) for fertilizer use.
- Energy recovery potential of landfill is attractive from investment cost perspective.

5.2 Recommendations

Recommendations in regard to developing an effective waste management system of Addis Ababa which are environmentally and economically sustainable and application of decision support system (waste allocation) and simulation technique are stipulated as follows.

- The simulation technique developed for Addis Ababa solid waste management can be used as a bench mark for planning and controlling the collection operations.

- To handle all waste in an environmentally sustainable way requires a range of disposal options. Landfill is the only method that can handle all waste alone with lower cost. Hence, landfill sites have to be developed in order to make the collection operation optimized. The decision support (waste allocation) model can be incorporated in the planning and designing routes for the operation.

- Other than landfill, integrating potential disposing options such as recycling (Plastic, glass) , renders economic reward to the present Addis Ababa solid waste management system provided that region 14 health bureau play a part in building markets for the out puts working with material processors

(thermoplastic factory for plastic recycling, Addis glass factory for glass recycling,)

- Collection lies at the very hub of all integrated waste management system. The way that waste material are collected (and subsequently sorted) determines which waste management option can be subsequently used. Therefore, either the collection method defines the subsequent disposal option, or taking the reverse case, the existing or potential markets will defines how material should be collected and sorted if they are to be used. With regard to Addis Ababa solid waste management, so as to meet the above recycling and energy recovery options, the collection methods need to be designed in subsequent disposal option. Therefore
    - Some form of separation of waste in the different fractions at source, i.e. with home, prior to collection is essential. At its simplest this might involve removing recyclable materials, e.g. glass bottle and plastics for delivery to collector vehicle.

    - The degree of home sorting achieved in any scheme will be a function of both the ability and especially the motivation of householders. The household's behavior in generating, and separating the waste and also in its use of vehicle transport (meeting vehicles characteristics like collection bags) will have major effects on the overall system performance. Region 14-health bureau, in this aspect has to work with the community to make integrated waste management a reality in Addis Ababa.

- Collection of sorted refuse for subsequent treatment can start with door -to door collection system with appropriate bin or bags provided to the households for purpose of storage and delivery to collection vehicles (side loader & compactor trucks). The communal collection system, particularity refuse that comes from commercial institutions (Hotels, bar etc) can also be made sorted at source to suit the disposal options.

- People are important to the effective running of solid waste management systems. All integrated waste management system must be set up to enable each person involved in the system to meet the needs of their customers and to have their needs as a customer met by their suppliers. Thus Region 14, health bureau need to work with householders to make them know clearly and exactly how they should present their waste material to the collector.

- Partnerships are required to make real progress. Effective partnerships will have people with different skills and responsibilities, entrepreneurs & businessmen working together against the shared goals of environmental and economic sustainability.

5.3 Summary of Contributions

- A simulation technique for collection operation performance has been developed.
- A decision support tool has been developed for waste allocation problem.
- Energy recovery potential of alternative disposal options has been assessed.
- Better waste management system has been proposed.

5.4 Scope of Further investigation

In addition to the recommendations suggested by the author of this thesis, the following can be taken up for further investigation.

1. Life cycle inventory model approach to predict and compare disposal options.
2. A total quality management approach for sound environmental and economic improvements.
3. Computerized solid waste management system for efficient operation.

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Annex-A

Spreadsheet Simulation (waste collection operation)

(Zerayakob Belete)

Start Time(hr)	***Close Time(hr)***	***Inter-Arrival Time(hr)***
1.00	9.00	0.57

Service Time Distribution

Cum.Probability	Service Time(hr)
0	0.58
0.34	0.99
0.72	1.21
0.97	1.5
1	1.58

Computations Worksheet

Cust. #	Inter-Arrival Time(hr)	Service Time(hr)	Arrival Time(hr)	Potential #1 Start Time(hr)	Actual Start Time(hr)	Next Server
Start			1.00			
1	0.57	0.58	1.00	1	1	1
2	0.57	1.21	1.57	1.58	1.58	1
3	0.57	0.99	2.14	2.79	2.79	1
4	0.57	1.21	2.71	3.78	3.78	1
5	0.57	0.99	3.28	4.99	4.99	1
6	0.57	0.99	3.85	5.98	5.98	1
7	0.57	0.58	4.42	6.97	6.97	1
8	0.57	0.58	4.99	7.55	7.55	1
9	0.57	1.5	5.56	8.13	8.13	1
10	0.57	1.21	6.13			
	0.57		6.7			

Simulation Worksheet

Cust. #	Inter-Arrival Tme(hr)	Arrival Tme(hr)	Service Time(hr)	Start Time (hr)	End Time (hr)	Wait Time (hr)
Start		1.00				
1	0.57	1	0.58	1	1.58	0
2	0.57	1.57	1.21	1.58	2.79	0.01
3	0.57	2.14	0.99	2.79	3.78	0.65
4	0.57	2.71	1.21	3.78	4.99	1.07
5	0.57	3.28	0.99	4.99	5.98	1.71
6	0.57	3.85	0.99	5.98	6.97	2.13
7	0.57	4.42	0.58	6.97	7.55	2.55
8	0.57	4.99	0.58	7.55	8.13	2.56
9	0.57	5.56	1.5	8.13		
	0.57	6.13				
	0.57	6.7				
					Av.wait Tme (hr)	1.34