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Research Paper

Mathematical Modeling of Solid Waste Management Processes A Case of Solid Waste Management In Awka City, Anambra State, Nigeria

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ABSTRACT: *Virtually all waste managers in developing countries do not have any well defined method of collecting and keeping data on solid wastes (or any other form of waste) in their localities. Consequently, the required basic data on their waste management systems are lacking; the existing ones are not organized and cannot be relied upon for proper engineering analysis and adequate policy making. This claim is supported by both published reports and findings resulting from this study. The study aimed at developing mathematical models of waste generation and disposal processes as tools for use by waste managers. The developed models were applied in evaluating the performance of the Anambra State Waste Management Authority using a consecutive thirty one days data collected on solid waste management in Awka, the Anambra State Capital. Results show that the models are ideal and can be used when making economic considerations and in scheduling waste disposal vehicles. A phoning programme is recommended as a vital component in the use of the models in waste management. The phoning programme could save Anambra State Waste Management Authority some costs it incurs in managing solid waste in the state; distributing the said costs indirectly among the informant callers.*

Keywords: *accumulation, disposal, dumpsite, evacuators, generation, Queuing theory, solid waste*

Nomenclature

Symbol	*Meaning*
=	"is equal to" or "represents"
Q	Total quantity of waste in a specified location
D	Expected annual waste evacuation or quantity of waste removed from a stated location in a given time.
N_b	Number of waste bins (containers) installed in a given dumpsite
N	Number of simulation runs or the n^{th} term of a serial occurrence
$a_{M,0j} = a_{0j}$	Initial quantity of waste found at roadside dumpsite j at the beginning (morning or evening check of the very 1^{st} day) of an experiment.
L_w	Expected queue length, i.e. expected quantity of quantity of waste in queue at a morning check of a waste dump site
L_q	Expected queue length, i.e. expected quantity of quantity of waste in queue at an evening check of a waste dump site
L_s	Expected queue size, i.e. expected quantity of quantity of waste in the system
λ_d	Quantity of waste generated/dumped in the system during the morning hours (6:00 am - 6:00 pm) of each study days period
$(N_{\lambda=0})_d$	State of no waste or negligible quantity of waste in a given dumpsite at a morning check of the site. If such state exists, $(N_{\lambda=0})_d = 1$.
λ_N	Quantity of waste generated/dumped in the system during the night hours (6:00 pm - 6:00 am) of each day of the study period
$(N_{\lambda=0})_N$	State of no waste or negligible quantity of waste in a given dumpsite at a evening check of the site. If such state exists, $(N_{\lambda=0})_N = 1$.
$\lambda_{(d+N)}$	Total quantity of waste deposited/dumped in the system in each day of the study period
λ_q	Mean waste arrival rate (expected quantity per unit time) when there are q units in the system
μ_q	Mean waste disposal (service) rate (expected quantity evacuated per unit time) when there are q units are in the system
λ	Mean waste arrival rate when λ_q is constant for all q
μ	Mean waste arrival rate when λ_q is constant for all $q > 0$
$(N_s)_o$	Number of unit times/days the server is found idle in a given period

q_R	Quantity of waste remaining in the system at the end of a stated period
R	Number of evacuator/disposal truck runs in a stated location
W_a	Expected waiting time of waste at a given dumpsite (= server mean service time)
W_q	Expected waiting time per given quantity of waste in the queue
W_s	Expected waiting time per given quantity of waste in the system
η	Disposal system evacuation efficiency .i.e. percentage of waste removed from the system in a given period
s	Number of parallel servers facility (disposal vehicles/trucks)
ρ	$\lambda/s\mu$ = ratio of arrival (dump) rate to service (evacuation) rate of waste in the system in a given period. It is a measure of traffic intensity (accumulation rate) of waste in the system
$P_q(t)$	Steady state probability of having q units in the system
P_o	Probability of zero quantity of waste in the system
$P_{s,o}$	:obability of server being idle (zero disposal service in the system)
P_w	Probability that waste in the system must wait for service
P_λ	Probability that new waste arrives in the system
V_b	Volume of waste container
Avg	Average or mean
mod	Mode or highest frequency
pd	per day
cb	chain-up bins
cbpd	chain-up bins per day
pp	per period
Σ	Sum of, add all, or total up
ASWAMA	Anambra State Waste Management Authority (or Agency)
SWM	Solid waste management
MSW	Municipal solid management
USW	Urban solid waste

N.B: If any of the above symbols is a subscript of another it implies its meanings with respect to the item to which it is attached.
Each subscript of the lower letters *i, j,* and *z* refer to a set of serial numbers 1, 2, 3, … to the n^{th}, k^{th} and m^{th} terms respectively, say.
A bar "-" on top of a symbol refer the symbol to the mean value of the variable the symbol represents
Any other symbol not defined in this column are defined in the body of the text.

I. INTRODUCTION

Several researchers have identified solid waste management as an uphill task for many communities of the globe. Many factors have also been identified by some these researchers, [2],[3],[4],[5],[6],[7],[8] and [9], among others as constraints in providing effective waste management in the concerned localities. In an effort to minimize/eliminate these constraints, various models have developed. Mathematical methods of analyzing data which will assist in their policy making and economic considerations will always be readily accepted by waste managers that sincerely seek for solutions to the challenges posed by solid waste produced in their states.[1].
Meanwhile, for one to make a meaningful contribution or discussion about a system, he/she must have had some substantial knowledge about the system and its operations. Hence, the researchers commenced this study by making several pre-visits to different waste managers offices and dump sites in Awka, Onitsha, Nnewi and Ekwulobia Urban Centres of Anambra State to enable them appreciate the structure and nature of waste management practices in the state. Accumulation is a natural phenomenon and another form of queue. Waste, like any other thing in life increases (accumulates) in volume at some rate in a given system when there exists inability to dispose them at the same rate at which they are generated. Accumulation of waste in our environment makes the environment untidy and leads to many societal problems, which includes environmental, economic and public health problems.

Waste accumulation structure is dynamic in discipline, with the waste dumped discretely at the sites both in the day and in the night hours The structure of waste management system in Anambra State is depicted in Figs 1 and 2. The entire structure can be approximated to what is obtainable in a queuing system.

Fig 1 shows that solid waste generated in different residential homes and other sources are discarded at the various roadside waste dumpsites (as storage containers) in the area. The dumped waste are later collected by waste evacuating vehicles (as serving/disposing elements) and sent to the final dump site (as sink element) located at some points at the outskirts of the urban centres.

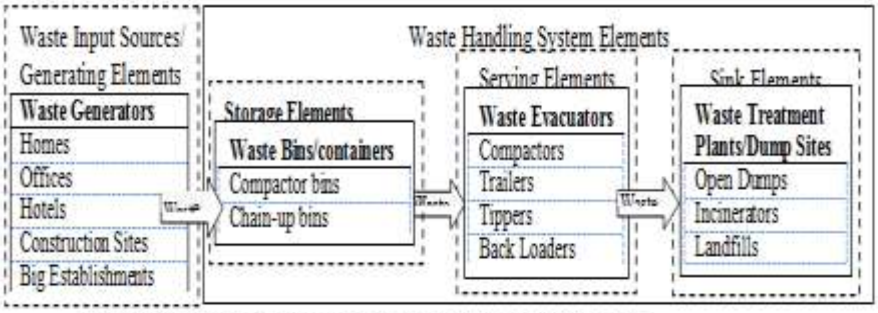


Figure 1: Basic waste handling processes in a waste management system

As Fig 2 illustrates, waste bins kept at the various dump stations in each of the zones constituting the study area are considered as customers in a single queue and randomly served by the server/evacuator trucks who go to any of them that is free and waiting for service. A server truck could visit more than one waste dump station in a single trip if waste at the first station were not enough to fill up the vehicle's container. Although waste evacuation takes place almost on daily bases, most of the dumpsites were still not served for days leading to refuse piling up at those sites and causing some environmental and social problems.

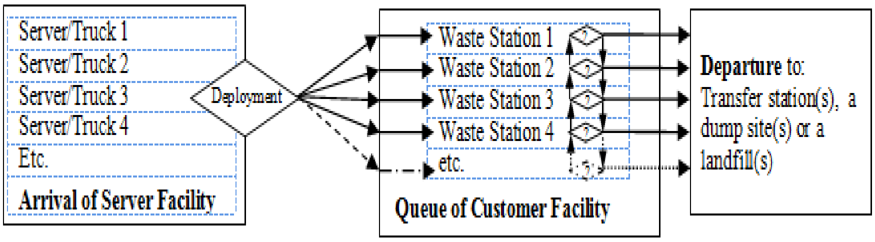


Figure 2: Flow diagram of a typical Multiple Servers-Multiple Waste Depot System

II. MATERIALS AND METHODS

In the analysis, solid waste generation and evacuation in Awka, Anambra State, was viewed in the thinking that waste containers kept at different locations in Awka formed a queue with many servers (ASWAMA disposal vehicles) visiting them and rendering disposal services. This assumption should be right, since in reality a customer can either go to a service center to receive some service or have a worker(s) from the servicing firm come to him/her to render the service. Once the waste in a dumpsite was evacuated (whether totally or partially), the dumpsite or waste container(s) stationed therein was taken as having been served and departed. New waste dumped at the served dumpsite makes the container(s) at the dumpsite a new customer(s) to be served. By this consideration, the queue length is unknown, infinite and unrestricted. Number of servers that operated in the study area varied from 0 to 15 disposal trucks of different capacities per day. Also average number of chain-up bin loads of waste evacuated daily varied from 0 to 63. Variation in the number of servers was caused, among other reasons, by administrative bottlenecks and incessant breakdown of most of the disposal vehicles.

A consecutive thirty one (31) days data on solid waste generation and evacuation in three roadside dump sites (Ogbalingba, Eke Awka Market and Ifite Market) in Awka Metropolitan city of Anambra State were used to show the applications of the models developed in the study. Actually, different disposal trucks of various capacities serviced the three dumpsites under review, but it is taken in this exercise that only one disposal truck (server) worked in the three dumpsites within the thirty one (31) day study period such that the data obtained in TABLES 2, 4 and 5 hold true. Data in the said tables contain the estimated quantities of waste found at the three dumpsites during the morning and evening checks of the study period, which act as the input (independent) variables from which other parameters, as the output (dependant) variables, derive their values. Waste dumped between 6 am - 6 pm at the sites were considered as day arrivals, while the ones deposited between 6 pm - 6 am were termed night arrivals. As these refuse arrived, they built up and filled the containers. Collated data were first organized and descriptive statistics used to compute the combined average waste bin loads generated (i.e. waste production/dump rates) and the quantities discharged (i.e. waste evacuation/disposal service rates) in each of the three dumpsites in the month of December, 2014. Also computed were the approximate waste disposal system utilization in the same period. Summary of the analysis are contained in TABLES 2 to 7. Microsoft Excel was very helpful in achieving this fit.

3.1 Waste Queuing and Evacuation Models Development

3.1.1 Assumptions

- ✓The number of waste containers (bins) in use is known but in terms of the quantities of waste to be generated it is unknown, infinite and unrestricted. That is to say, there are many batched quantities (measured in terms of bin sizes) to be evacuated (served) in a given period (hourly, daily, weekly, etc)
- ✓The service/unloading time of bins is controllable
- ✓The waste bins are arbitrarily but strategically distributed (placed) at various locations within the research area.
- ✓Quantity of solid waste found at roadside dumpsites at any given time is the total waste generated by the people living/operating within the area.
- ✓Waste existing at various public used roadside dumpsites are in queue
- ✓Waste generation and disposals are stochastic, dynamic and man-machine-material interaction processes of the system
- ✓The system is non-fully automated
- ✓Arrival rate of waste at the dump sites is stochastic, but the evacuation is executed according to management plans.
- ✓State (quantity) of waste before and after evacuation at a given dumpsite in a given period(s) is always recorded.
- ✓Cost of waste evacuation is dependent on the quantity of waste disposed (transported) in a stated period, say, daily, weekly, monthly or annually.
- ✓Waste not brought to a public dumpsite is negligible/not considered at all.
- ✓Unit of measurement is the unit volume (full load) of the waste container kept at a dump site under consideration
- ✓Size and number of waste bins (containers) and bin locations (dumpsites) may vary, but such data is recorded and treated from the point of such a variation
- ✓For purposes of the present study, unless where otherwise stated, loading of an evacuator at a waste bin/dump site is measured by the fraction of full loaded chain-up bins carried by the truck per its trip from the site.
- ✓Any indisposed waste at a given waste bin site, after a truck's visit to the site on a day is considered a new joiner to the line of bins waiting for service during the truck's next visit to the site.
- ✓For a recording that starts at evening check of day i = 1, c_{ij} = 0 and d_{ij} > 0; if recording starts at morning check: d_{ij} = 0 and c_{ij} > 0.

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

Table 1: Simulation table for queue model development, demonstration and validation

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

In estimating the quantities of waste generated and evacuated in a given dumpsite, the following relations could be established:

$$q_i = Q_{p,\,j} - Q_i \tag{1}$$

Rewriting (1) to show the number of evacuator runs and the mean disposable quantity:

$$q_j = Q_{p,\,j} - r_j \overline{D_j} \tag{2a}$$

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

$$\overline{D_j} = r_j^{-1} Q_j \qquad (2b)$$

So, $$q_j = Q_{p,j} - r_j \overline{D_j} \qquad (2c)$$

For all the dumpsites in the area under consideration:

$$Q_{p,j} = q_j + r_j \underline{D_j} \qquad (3a)$$

Or $$Q = Q_{rem} + Q_{eva} \qquad (3c)$$

$$\Sigma Q_{p,i\,j} = \Sigma q_{ij} + \Sigma(\underline{r\,D})_{ij} \qquad (3b)$$

For all the dumpsites, it was assumed that check starts in the morning of day $i = 1$, with $L_{w,(i-1)j} \geq 0$, $q_{N,(i-1)j} \geq 0$, $\mu_{q,ij} = 0$, $q_{d,ij} = 0$, $q_{N,ij} = 0$ and $\mu_{q,(i-1)j} = (r\,D)_{(i-1)j}$. Thus, in accordance with (3):

$$q_{M,ij} = (Q - rD)_{(i-1)j} + q_{N,(i-1)j} = q_{M,oj} \qquad (4a)$$

Or rewriting (4a) in terms of queue parameters

$$L_{q,oj} = q_{M,ij} = L_{w,(i-1)j} + q_{N,(i-1)j} \qquad (4b)$$

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

$$q_{d,ij} = \left(L_{w,ij} + \mu_{q,ij}\right) - q_{M,oj} \qquad (4c)$$

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

$$L_{q,(i+1)j} = \left(L_{w,ij} + q_{N,ij}\right) \qquad (5a)$$

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

$$q_{d,(i+1)j} = (L_w + \mu_q)_{(i+1)j} - q_{M,(i+1)j} \qquad (5b)$$

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

$$q_{(d+N)j} = (q_d + q_N)_{ij} \qquad (5c)$$

A waste container is considered full if only:

$$V_b = \sum_{i=1}^{m} q_{(d+N)} \geq 1 \quad (\text{where } 1 \leq m \leq n) \qquad (6a)$$

And number of fully and/or over loaded bins:

$$N_{Bf} = \sum_{i=1}^{n} \left(\frac{q_{(d+N)}}{V_b}\right) \geq 0 \qquad (6b)$$

For k number of dumpsites, daily quantity of waste arriving (deposited) in a period i to n days is obtained thus:

$$\lambda_q = (L_q + q_d)_{ij} \qquad (7a)$$

While the combined mean quantity of waste arriving in a period i to n days is obtained thus:

$$\lambda = \frac{1}{nk} \sum_{i=1}^{n} \sum_{j=1}^{k} \lambda_{q,ij} \qquad (7b)$$

Combined mean number of waste bins served over a given period:

$$\mu = \frac{1}{nk} \sum_{i=1}^{n} \sum_{j=1}^{k} \mu_{q,ij} \qquad (8)$$

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

$$L_{q,n} = L_{q,o} + \left(\sum_{i=1}^{n-1} q_{(d+N)} - \sum_{i=1}^{n-1} \mu_q\right)_{ij} \qquad (9a)$$

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

$$L_{s,n} = L_{q,o} + \left(\sum_{i=1}^{n-1} q_{(d+N)} - \sum_{i=1}^{n-1} \mu + q_d\right)_{ij} \qquad (9b)$$

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

$$L_s = \frac{1}{nk} \sum_{j=1}^{k} \left(L_{q,o} + \sum_{i=1}^{n-1} q_{(d+N)} - \sum_{i=1}^{n-1} \mu + q_d\right)_{ij} \qquad (9c)$$

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

$$L_{w,n} = L_{q,o} + \left(\sum_{i=1}^{n-1} q_{(d+N)} - \sum_{i=1}^{n} \mu_q + q_d\right)_{ij} \qquad (9d)$$

From the general queuing theory, we obtain:

$$W_q = L_q \lambda^{-1} \quad (10a)$$
$$W_s = L_s \lambda^{-1} \quad (10b)$$
$$W_a = \sum_{i=1}^{n-1} N_{(\mu=0)} \quad (10c)$$

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

$$\eta_{ij} = \frac{\mu_{q,ij}}{\lambda_{q,i,j}} \times 100\% \quad (11$$

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

$$\eta = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}\mu_{q,ij}}{(\sum L_{q,oj} + \sum_{i=1}^{n}\sum_{j=1}^{k} q_{(d+N)})_{ij}} \quad (11b)$$

The waste disposal system utilization:

$$\rho = \frac{\lambda}{s\mu} \quad (12)$$

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

$$\left.\begin{aligned} \mu &= 0 \\ q_{(d+N)} &\geq 0 \\ t_{os} &= t_{\mu=0} \\ N_{\mu=0} &= 1 \text{ (say)} \end{aligned}\right\} N_{Bf} \geq 1 \quad (13)$$

and

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

$$N_{s,o} = \sum_{i=1}^{n}\sum_{j=1}^{k} N_{(\mu=0),ij} \quad (14)$$

Therefore, probability that a server is idle:

$$(P_o)_s = (N_s)_o \times n^{-1} \quad (15)$$

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

$$P_{Bf} = \sum_{i=1}^{n}\sum_{j=1}^{k}\left(\frac{N_{Bf}}{n}\right)_{ij} \quad \{\text{where } NBf: NBf = (NBf + NBof)\} \quad (16)$$

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

$$\left.\begin{aligned} N_{\mu>0} &\geq N_b \\ q_{(d+N)} &= 0 \\ N_{\lambda=0} &= 1 \text{ (say)} \end{aligned}\right\} \quad (17)$$

and

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

$$P_{o,d,j} = \left(\frac{N_{\lambda=0}}{n}\right)_{d,ij} \leq 0.5 \quad (18a)$$

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

$$P_{o,N,j} = \left(\frac{N_{\lambda=0}}{n}\right)_{N,ij} \leq 0.5 \quad (18b)$$

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

$$P_{o,j} = \left(\frac{N_{\lambda=0}}{2n}\right)_{d,ij} + \left(\frac{N_{\lambda=0}}{2n}\right)_{N,ij} \leq 1 \quad (18c)$$

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

$$P_o = \frac{1}{k}\sum_{j=1}^{k}\left\{\left(\frac{N_{\lambda=0}}{2n}\right)_d + \left(\frac{N_{\lambda=0}}{2n}\right)_N\right\}_{ij} \leq 1 \quad (18d)$$

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

$$P_{\lambda} = \frac{\sum_{i=1}^{n} q_{(d+N)}}{\left(L_{q,oj} + \sum_{i=1}^{n} q_{(d+N)}\right)} \quad (19)$$

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

III. MODELS APPLICATION, RESULTS AND DISCUSSIONS

4.1 Waste dump and disposal data presentation and discussions

The input data in TABLES 2 and 4 to 6 enable derivation of more information (responses from the input variables) for evaluating the performance of the waste management system. The three dumpsites were juxtaposed in columns set as shown in TABLE 1 but have been presented here in separate tables for want of space. As can be seen from TABLE 2, even though the overall waste evacuation efficiency (80.6%) at Ogbalingba dumpsite is commendable, the system still showed not to be stable as λ > μ.

Table 2: Data collected on solid waste generation and evacuation processes in Ogbalingba dumpsite of Awka city, Anambra State

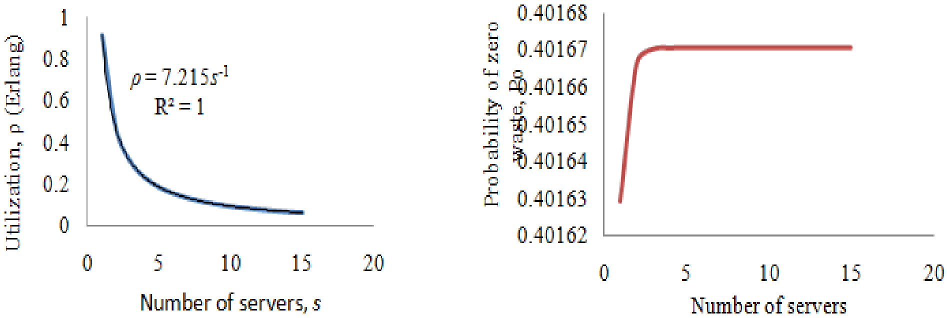
Time	Ogbalingba Dumpsite (No. Of Chain-up Bins = 3)																
	L_q	q_d		q_N		$q_{(d+N)}$	λ_q	μ_q		L_∞	L_s	W_a	W_q	W_s			
Days	(cb)		$(N_{q=0})_d$	(cb)	$(N_{q=0})_N$	(cb)	(cbpd)		$N_{\mu=0}$	(cb)		(hrs)			η (%)	$P_d(t)$	Cum $P_d(t)$
1	3.7	0.2		0.0	1	0.2	3.9	0	1	3.9	3.9	24.0	22.8	24.0	0.0	0.03	0.03
2	3.9	0.3		0.4		0.7	4.2	3		1.2	4.6	24.0	22.3	26.3	71.4	0.03	0.06
3	1.6	0.2		0.0	1	0.2	1.8	0	1	1.8	1.8	48.0	21.3	48.0	0.0	0.01	0.07
4	1.8	0.2		0.6		0.8	2.0	0	1	2.0	2.6	72.0	21.6	93.6	0.0	0.01	0.08
5	2.6	0.4		0.0	1	0.4	3.0	0	1	3.0	3.0	96.0	20.8	96.0	0.0	0.02	0.10
6	3.0	0.7		0.8		1.5	3.7	2		1.7	4.5	24.0	19.5	29.2	54.1	0.03	0.13
7	2.5	0.3		0.0	1	0.3	2.8	0	1	2.8	2.8	48.0	21.4	48.0	0.0	0.02	0.15
8	2.8	0.1		0.6		0.7	2.9	0	1	2.9	3.5	72.0	23.2	86.9	0.0	0.02	0.17
9	3.5	0.3		0.5		0.8	3.8	0	1	3.8	4.3	96.0	22.1	108.6	0.0	0.03	0.19
10	4.3	0.2		0.5		0.7	4.5	2		2.5	5.0	24.0	22.9	26.7	44.4	0.03	0.23
11	3.0	0.1		0.6		0.7	3.1	0	1	3.1	3.7	48.0	23.2	57.3	0.0	0.02	0.25
12	3.7	0.3		0.4		0.7	4.0	0	1	4.0	4.4	72.0	22.2	79.2	0.0	0.03	0.28
13	4.4	0.2		0.5		0.7	4.6	2		2.6	5.1	24.0	23.0	26.6	43.5	0.03	0.31
14	3.1	0.2		0.8		1.0	3.3	0	1	3.3	4.1	48.0	22.5	59.6	0.0	0.02	0.33
15	4.1	0.4		0.2		0.6	4.5	0	1	4.5	4.7	72.0	21.9	75.2	0.0	0.03	0.36
16	4.7	0.0	1	0.7		0.7	4.7	0	1	4.7	5.4	96.0	24.0	110.3	0.0	0.03	0.39
17	5.4	0.4		0.0	1	0.4	5.8	0	1	5.8	5.8	120.0	22.3	120.0	0.0	0.04	0.43
18	5.8	0.2		0.5		0.7	6.0	0	1	6.0	6.5	144.0	23.2	156.0	0.0	0.04	0.48
19	6.5	0.2		0.3		0.5	6.7	3		3.7	7.0	24.0	23.3	25.1	44.8	0.05	0.52
20	4.0	0.0	1	0.5		0.5	4.0	0	1	4.0	4.5	48.0	24.0	54.0	0.0	0.03	0.55
21	4.5	0.2		0.0	1	0.2	4.7	0	1	4.7	4.7	72.0	23.0	72.0	0.0	0.03	0.58
22	4.7	0.4		0.8		1.2	5.1	0	1	5.1	5.9	96.0	22.1	111.1	0.0	0.04	0.62
23	5.9	0.4		0.7		1.1	6.3	0	1	6.3	7.0	120.0	22.5	133.3	0.0	0.04	0.66
24	7.0	0.0	1	0.3		0.3	7.0	2		5.0	7.3	24.0	24.0	25.0	28.6	0.05	0.71
25	5.3	0.2		0.0	1	0.2	5.5	0	1	5.5	5.5	48.0	23.1	48.0	0.0	0.04	0.75
26	5.5	0.9		0.3		1.2	6.4	0	1	6.4	6.7	72.0	20.6	75.4	0.0	0.04	0.79
27	6.7	0.4		0.2		0.6	7.1	3		4.1	7.3	24.0	22.6	24.7	42.3	0.05	0.84
28	4.3	0.2		0.4		0.6	4.5	0	1	4.5	4.9	48.0	22.9	52.3	0.0	0.03	0.87
29	4.9	0.2		0.5		0.7	5.1	0	1	5.1	5.6	72.0	23.1	79.1	0.0	0.04	0.91
30	5.6	0.5		0.9		1.4	6.1	0	1	6.1	7.0	96.0	22.0	110.2	0.0	0.04	0.95
31	7.0	0.2		0.6		0.8	7.2	3		4.2	7.8	24.0	23.3	26.0	41.7	0.05	1.00
	Σ=	8.5	3	12.6	7	21.1	144.3	20	23						80.6		

Waste accumulated at Ogbalingba dumpsite at an average rate of 4.654 cbpd, while the server operated at an average rate of 0.645 cbpd. Data on this relationship are contained in TABLE 3 and plotted in Figs 3a and 3b for visual appreciation.

Table 3: Determination of best system utilization at Ogbalingba dumpsite

s	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
p	7.215	3.6075	2.405	1.8038	1.443	1.2025	1.0307	0.9019	0.8017	0.7215

A trendline equation generated on plot of Fig 3a shows that the function has a power distribution/relationship: $\rho = 7.215s^{-1}$, with $R^2 = 1$. Figure 3b shows that going by the present service rate at the dumpsite, it would be very rear not to see dumped waste at the site.



(a): Server Utilization at Ogbalingba dumpsite **(b):** Probability of no waste in Ogbalingba dumpsite

Figure 3: Performance evaluation on Ogbalingba dumpsite

Again in TABLE 4, the overall waste evacuation efficiency (90.8) at Eke Awka dumpsite is quite impressive. However, the system still showed not to be stable. Waste generation/dump rate at the site was estimated as an average rate of 8.308 cbpd, while the waste containers were served at an average rate of 2.968 cbpd. By the same reasoning as in discussing the waste management at Ogbalingba dumpsite, data plot on Eke Awka Market gave the relation: $\rho = 2.7978s^{-1}$ and $R^2 = 1$ and requires a service rate, $\mu = 8.9$ cbpd to stabilize the subsystem.

Table 4: Data collected on solid waste generation and evacuation processes in Eke Awka Market dumpsite of Awka city, Anambra State

Time	Eke Awka Market Dumpsite (No. Of Chain-up Bins = 3)																
Days	L_q (cb)	q_d (cb)	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$q_{(d+N)}$ (cb)	λ_q (cbpd)	μ_q (cbpd)	$N_{\rho=0}$	L_w (cb)	L_s (cb)	W_a (hrs)	W_q (hrs)	W_s (hrs)	η (%)	$P_d(t)$	Cum $P_d(t)$
1	2.6	1.0		3.1		4.1	3.6	3		0.6	6.7	24.0	17.3	44.7	83.3	0.01	0.01
2	3.7	1.7		2.7		4.4	5.4	0	1	5.4	8.1	24.0	16.4	36.0	0.0	0.02	0.03
3	8.1	2.3		2.7		5.0	10.4	8		2.4	13.1	24.0	18.7	30.2	76.9	0.04	0.08
4	5.1	0.4		1.6		2.0	5.5	0	1	5.5	7.1	48.0	22.3	62.0	0.0	0.02	0.10
5	7.1	0.9		3.1		4.0	8.0	0	1	8.0	11.1	72.0	21.3	99.9	0.0	0.03	0.13
6	11.1	1.4		1.4		2.8	12.5	8		4.5	13.9	24.0	21.3	26.7	64.0	0.05	0.18
7	5.9	0.0	1	1.6		1.6	5.9	0	1	5.9	7.5	48.0	24.0	61.0	0.0	0.02	0.20
8	7.5	0.1		1.7		1.8	7.6	0	1	7.6	9.3	72.0	23.7	88.1	0.0	0.03	0.23
9	9.3	2.0		2.0		4.0	11.3	8		3.3	13.3	24.0	19.8	28.2	70.8	0.04	0.27
10	5.3	0.5		0.7		1.2	5.8	0	1	5.8	6.5	48.0	21.9	53.8	0.0	0.02	0.30
11	6.5	1.5		1.1		2.6	8.0	0	1	8.0	9.1	72.0	19.5	81.9	0.0	0.03	0.33
12	9.1	0.0	1	1.2		1.2	9.1	0	1	9.1	10.3	96.0	24.0	108.7	0.0	0.04	0.36
13	10.3	1.1		2.5		3.6	11.4	9		2.4	13.9	24.0	21.7	29.3	78.9	0.04	0.41
14	4.9	1.7		0.7		2.4	6.6	0	1	6.6	7.3	48.0	17.8	53.1	0.0	0.03	0.43
15	7.3	0.0	1	2.6		2.6	7.3	4		3.3	9.9	24.0	24.0	32.5	54.8	0.03	0.46
16	5.9	1.8		0.0	1	1.8	7.7	3		4.7	7.7	24.0	18.4	24.0	39.0	0.03	0.49
17	4.7	0.5		3.5		4.0	5.2	0	1	5.2	8.7	48.0	21.7	80.3	0.0	0.02	0.51

18	8.7	1.6		0.0	1	1.6	10.3	0	1	10.3	10.3	72.0	20.3	72.0	0.0	0.04	0.55
19	10.3	0.0	1	3.6		3.6	10.3	8		2.3	13.9	24.0	24.0	32.4	77.7	0.04	0.59
20	5.9	0.7		4.5		5.2	6.6	0	1	6.6	11.1	48.0	21.5	80.7	0.0	0.03	0.62
21	11.1	1.2		3.0		4.2	12.3	9		3.3	15.3	24.0	21.7	29.9	73.2	0.05	0.66
22	6.3	0.6		2.8		3.4	6.9	0	1	6.9	9.7	48.0	21.9	67.5	0.0	0.03	0.69
23	9.7	1.9		0.9		2.8	11.6	0	1	11.6	12.5	72.0	20.1	77.6	0.0	0.05	0.74
24	12.5	0.6		4.0		4.6	13.1	10		3.1	17.1	24.0	22.9	31.3	76.3	0.05	0.79
25	7.1	0.5		2.7		3.2	7.6	0	1	7.6	10.3	48.0	22.4	65.1	0.0	0.03	0.82
26	10.3	2.2		0.2		2.4	12.5	8		4.5	12.7	24.0	19.8	24.4	64.0	0.05	0.86
27	4.7	0.2		2.4		2.6	4.9	0	1	4.9	7.3	48.0	23.0	71.5	0.0	0.02	0.88
28	7.3	0.0	1	3.2		3.2	7.3	8		0.0	10.5	24.0	24.0	34.5	109.6	0.03	0.91
29	3.2	1.5		2.5		4.0	4.7	0	1	4.7	7.2	48.0	16.3	73.5	0.0	0.02	0.93
30	7.2	4.4		0.0	1	4.4	11.6	6		5.6	11.6	24.0	14.9	24.0	51.7	0.05	0.98
31	5.6	0.8		3.6		4.4	6.4	0	1	6.4	10.0	48.0	21.0	75.0	0.0	0.02	1.00
		33.1	5	63.6	3	98.7	237.4	92	18						90.8		

Tables 5, 6 and 7 are explained in the same reasoning as in TABLES 2 and 4.

Table 5: Data collected on solid waste generation and evacuation processes in Ifite Market dumpsite of Awka city, Anambra State

Time	Ifite Market Dumpsite (No. Of Chain-up Bins = 2)																
Days	L_q (cb)	q_d	$(N_{q=0})_d$	q_N (cb)	$(N_{q=0})_N$	$q_{(d+N)}$ (cb)	λ_q (cbpd)	μ_q	$N_{\mu=0}$	L_w (cb)	L_s	W_a (hrs)	W_q	W_s	η (%)	$P_t(t)$	Cum $P_t(t)$
1	2.4	0.1		0.1		0.2	2.5	0	1	2.5	2.6	24.0	23.0	25.0	0.0	0.02	0.02
2	2.6	0.4		0.3		0.7	3.0	0	1	3.0	3.3	24.0	20.8	26.4	0.0	0.02	0.04
3	3.3	0.3		0.6		0.9	3.6	2		1.6	4.2	24.0	22.0	28.0	55.6	0.03	0.07
4	2.2	0.4		0.3		0.7	2.6	0	1	2.6	2.9	48.0	20.3	53.5	0.0	0.02	0.09
5	2.9	0.3		0.8		1.1	3.2	0	1	3.2	4.0	72.0	21.8	90.0	0.0	0.02	0.11
6	4.0	0.2		0.3		0.5	4.2	0	1	4.2	4.5	96.0	22.9	102.9	0.0	0.03	0.14
7	4.5	0.5		0.3		0.8	5.0	0	1	5.0	5.3	120.0	21.6	127.2	0.0	0.04	0.18
8	5.3	0.3		0.4		0.7	5.6	0	1	5.6	6.0	144.0	22.7	154.3	0.0	0.04	0.22
9	6.0	0.1		0.7		0.8	6.1	3		3.1	6.8	24.0	23.6	26.8	49.2	0.05	0.27
10	3.8	0.0	1	0.3		0.3	3.8	0	1	3.8	4.1	48.0	24.0	51.8	0.0	0.03	0.30
11	4.1	0.3		0.6		0.9	4.4	0	1	4.4	5.0	72.0	22.4	81.8	0.0	0.03	0.33
12	5.0	0.0	1	0.1		0.1	5.0	0	1	5.0	5.1	96.0	24.0	97.9	0.0	0.04	0.37
13	5.1	0.3		0.4		0.7	5.4	0	1	5.4	5.8	120.0	22.7	128.9	0.0	0.04	0.41
14	5.8	0.6		0.4		1.0	6.4	0	1	6.4	6.8	144.0	21.8	153.0	0.0	0.05	0.45
15	6.8	0.0	1	0.5		0.5	6.8	4		2.8	7.3	24.0	24.0	25.8	58.8	0.05	0.50
16	3.3	0.4		0.4		0.8	3.7	0	1	3.7	4.1	48.0	21.4	53.2	0.0	0.03	0.53
17	4.1	0.2		0.5		0.7	4.3	0	1	4.3	4.8	72.0	22.9	80.4	0.0	0.03	0.56
18	4.8	0.6		0.8		1.4	5.4	3		2.4	6.2	24.0	21.3	27.6	55.6	0.04	0.60
19	3.2	0.1		0.1		0.2	3.3	0	1	3.3	3.4	48.0	23.3	49.5	0.0	0.02	0.63
20	3.4	0.3		0.5		0.8	3.7	0	1	3.7	4.2	72.0	22.1	81.7	0.0	0.03	0.66
21	4.2	0.3		0.5		0.8	4.5	2		2.5	5.0	24.0	22.4	26.7	44.4	0.03	0.69
22	3.0	0.5		0.6		1.1	3.5	0	1	3.5	4.1	48.0	20.6	56.2	0.0	0.03	0.72
23	4.1	0.4		0.4		0.8	4.5	0	1	4.5	4.9	72.0	21.9	78.4	0.0	0.03	0.75
24	4.9	0.5		0.3		0.8	5.4	0	1	5.4	5.7	96.0	21.8	101.3	0.0	0.04	0.79
25	5.7	0.1		0.1		0.2	5.8	0	1	5.8	5.9	120.0	23.6	122.1	0.0	0.04	0.83
26	5.9	0.0	1	0.3		0.3	5.9	4		1.9	6.2	24.0	24.0	25.2	67.8	0.04	0.88
27	2.2	0.1		0.1		0.2	2.3	0	1	2.3	2.4	48.0	23.0	50.1	0.0	0.02	0.89
28	2.4	0.2		0.2		0.4	2.6	0	1	2.6	2.8	72.0	22.2	77.5	0.0	0.02	0.91
29	2.8	0.3		0.3		0.6	3.1	0	1	3.1	3.4	96.0	21.7	105.3	0.0	0.02	0.94
30	3.4	0.6		0.3		0.9	4.0	0	1	4.0	4.3	120.0	20.4	129.0	0.0	0.03	0.97
31	4.3	0.2		0.2		0.4	4.5	0	1	4.5	4.7	144.0	22.9	150.4	0.0	0.03	1.00
		8.6	4	11.7	0	20.3	134.1	18	25						73.9		

TABLE 6 contains summary of the analysis made for the overall system performance. The table depicts the combined effects of TABLES 2, 4 and 5. Also shown in the table are the overall system's server daily evacuation efficiency (η_d) and the transient state probabilities of quantities of waste in the three dumpsites.

Table 6: Summary of daily waste management data on Ogbalingba, Eke Awka Market and Ifite Market dumpsites in Awka Capital
City of Anambra State, Nigeria collected from 1st - 31st December, 2015.

Time	All The Three Dumpsite (No. Of Chain-up Bins = 9)																
Days	ΣL_q (cb)	Σq_d	$\Sigma(N_{q=0})_d$	Σq_N (cb)	$\Sigma(N_{q=0})_N$	$\Sigma q_{(d+N)}$ (cb)	Σ □$_q$ (cbpd)	Σ □$_q$	$\Sigma N_{\mu=0}$	L_w (cb)	L_s	W_a (hrs)	W_q	W_s	η (%)	$P_t(t)$	Cum $P_t(t)$

1	8.7	1.3		3.2	1	4.5	10.0	3		7.0	10.0	24.0	20.9	24.0	24.0	30.0	0.02
2	10.2	2.4		3.4		5.8	12.6	3		9.6	12.6	24.0	19.4	24.0	24.0	23.8	0.02
3	13.0	2.8		3.3	1	6.1	15.8	10		5.8	15.8	24.0	19.7	24.0	24.0	63.3	0.03
4	9.1	1.0		2.5		3.5	10.1	0	1	10.1	10.1	48.0	21.6	48.0	48.0	0.0	0.02
5	12.6	1.6		3.9	1	5.5	14.2	0	1	14.2	14.2	72.0	21.3	72.0	72.0	0.0	0.03
6	18.1	2.3		2.5		4.8	20.4	10		10.4	20.4	24.0	21.3	24.0	24.0	49.0	0.04
7	12.9	0.8	1	1.9	1	2.7	13.7	0	1	13.7	13.7	48.0	22.6	48.0	48.0	0.0	0.03
8	15.6	0.5		2.7		3.2	16.1	0	1	16.1	16.1	72.0	23.3	72.0	72.0	0.0	0.03
9	18.8	2.4		3.2		5.6	21.2	11		10.2	21.2	24.0	21.3	24.0	24.0	51.9	0.04
10	13.4	0.7	1	1.5		2.2	14.1	2		12.1	14.1	24.0	22.8	24.0	24.0	14.2	0.03
11	13.6	1.9		2.3		4.2	15.5	0	1	15.5	15.5	48.0	21.1	48.0	48.0	0.0	0.03
12	17.8	0.3	2	1.7		2.0	18.1	0	1	18.1	18.1	72.0	23.6	72.0	72.0	0.0	0.03
13	19.8	1.6		3.4		5.0	21.4	11		10.4	21.4	24.0	22.2	24.0	24.0	51.4	0.04
14	13.8	2.5		1.9		4.4	16.3	0	1	16.3	16.3	48.0	20.3	48.0	48.0	0.0	0.03
15	18.2	0.4	2	3.3		3.7	18.6	8		10.6	18.6	24.0	23.5	24.0	24.0	43.0	0.03
16	13.9	2.2	1	1.1	1	3.3	16.1	3		13.1	16.1	24.0	20.7	24.0	24.0	18.6	0.03
17	14.2	1.1		4.0	1	5.1	15.3	0	1	15.3	15.3	48.0	22.3	48.0	48.0	0.0	0.03
18	19.3	2.4		1.3	1	3.7	21.7	3		18.7	21.7	24.0	21.3	24.0	24.0	13.8	0.04
19	20.0	0.3	1	4.0		4.3	20.3	11		9.3	20.3	24.0	23.6	24.0	24.0	54.2	0.04
20	13.3	1.0	1	5.5		6.5	14.3	0	1	14.3	14.3	48.0	22.3	48.0	48.0	0.0	0.03
21	19.8	1.7		3.5	1	5.2	21.5	11		10.5	21.5	24.0	22.1	24.0	24.0	51.2	0.04
22	14.0	1.5		4.2		5.7	15.5	0	1	15.5	15.5	48.0	21.7	48.0	48.0	0.0	0.03
23	19.7	2.7		2.0		4.7	22.4	0	1	22.4	22.4	72.0	21.1	72.0	72.0	0.0	0.04
24	24.4	1.1	1	4.6		5.7	25.5	12		13.5	25.5	24.0	23.0	24.0	24.0	47.1	0.05
25	18.1	0.8		2.8	1	3.6	18.9	0	1	18.9	18.9	48.0	23.0	48.0	48.0	0.0	0.04
26	21.7	3.1	1	0.8		3.9	24.8	12		12.8	24.8	24.0	21.0	24.0	24.0	48.4	0.05
27	13.6	0.7		2.7		3.4	14.3	3		11.3	14.3	24.0	22.8	24.0	24.0	21.0	0.03
28	14.0	0.4	1	3.8		4.2	14.4	8		7.1	14.4	24.0	23.3	24.0	24.0	55.6	0.03
29	10.9	2.0		3.3		5.3	12.9	0	1	12.9	12.9	48.0	20.3	48.0	48.0	0.0	0.02
30	16.2	5.5		1.2	1	6.7	21.7	6		15.7	21.7	24.0	17.9	24.0	24.0	27.6	0.04
31	16.9	1.2		4.4		5.6	18.1	3		15.1	18.1	24.0	22.4	24.0	24.0	16.6	0.03
		50.2	12	89.9	10	140.1	535.8	130	13						87.4		

Table 7 is derived from TABLES 2, 4, 5 and 6. The table shows a summary report on the mean values obtained for the various dependent variables by applying the relevant developed models. A close look at the table reveals that almost all the variables in the models developed from the study are well represented.

Table 7: Awka waste management system performance evaluation

Table 31: Data on the new combined system's performance for the three sample dumpsites

		Dumpsite Obtainable			**Computed Values for All Dumpsites**		
		Ogbalingba	**Eke Awka Market**	**Ifite Market**			
Parameter/ Symbol	**Source/Ref. Eqn.**	**Mean values per demonstration run ($t = i$ to n)**			**Over-all**	**Mean**	**Unit of Measure**
N_b	-	3	4	2	9	3	bins
n	-	31	31	31	31	31	days
L_q	4b, 5a	4.38	7.24	4.05	15.7	5.22	cb
q_d	(4c), (5b), TABLES 2, 4, 5 & 6	0.27	1.07	0.28	1.6	0.54	cb
$(N_{\lambda=0})_d$	TABLES 2, 4, 5 & 6	3	5	4	12	-	-
q_N	(4c), (5b), Tables 2, 4, 5 & 6	0.41	2.12	0.38	2.9	0.97	cb
$(N_{\lambda=0})_N$	TABLES 2, 4, 5 & 6	7	3	0	10	-	-
$q_{(d+N)}$	(5c)	0.68	3.18	0.65	4.5	1.51	cb
λ	(7a), (7b)	4.65	8.30	4.33	17.3	5.76	cbpd
μ	(51), TABLES 2, 4, 5 & 6	0.65	2.97	0.58	4.2	1.40	cbpd
$N_{s,o}$	(14)	23	18	25	13	4.33	-
L_w	(9d)	0.0	5.4	3.7	9.1	3.03	cb
$\boldsymbol{L_s}$	(9b), (9c)	4.3	6.4	4.0	14.7	4.90	cb
W_a	(10c)	61.9	42.6	71.2	175.7	58.58	hrs
W_q	(10a)	22.5	20.9	22.3	65.7	21.90	hrs
W_s	(10b)	63.1	40.5	73.7	177.3	59.10	hrs
η	(11a), (11b)	13.86	35.74	13.42	24.26	24.26	%
ρ	(12)	7.215	2.798	7.450	4.122	-	Erlang
P_o	(18c)	0.161	0.129	0.065	0.355	-	-
$(P_o)_d$	(18a)	0.048	0.081	0.065	0.065	-	-
$(P_o)_N$	(18b)	0.113	0.048	0.000	0.054	-	-
$(P_s)_o = P_w$	(15)	0.742	0.581	0.806	0.419	-	-
P_λ	(19)	0.851	0.974	0.894	0.991	-	-

Summary of the waste management system's performance data of TABLE 7 gives the λ and μ for each of the three dumpsites. For the entire system (i.e. the mean of means), λ = 17.3 cbpd and μ = 4.2 cbpd, showing that there is instability in the system. For the system to be considered stable, the waste service (disposal/removal/ evacuation) rate must be greater than the waste arrival (dump/generation/production) rate, i.e. $\mu > \lambda$. The mean values obtained for these parameters were used in coding a single line multi-server queuing system based on (12) to estimate the optimum number of servers (***s***) that should make the system stable. TABLE 8 refers.

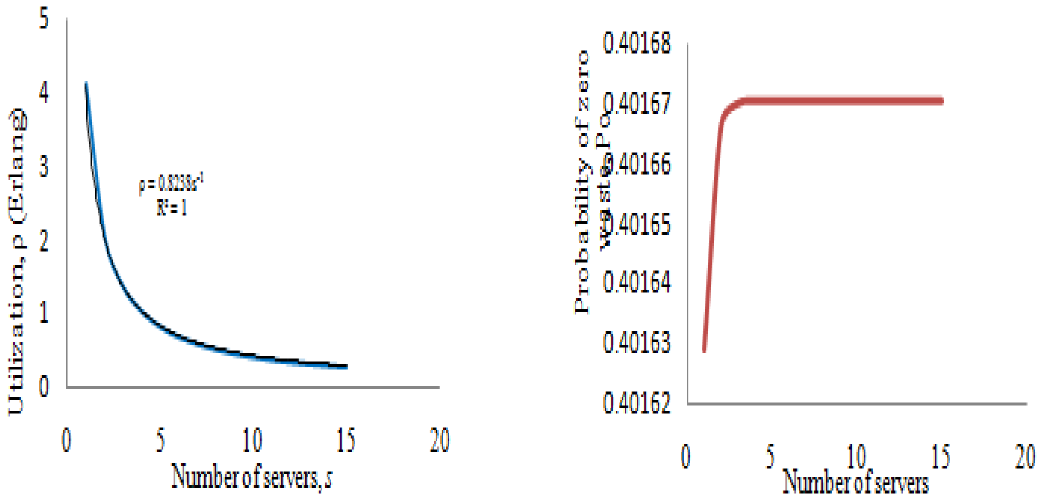
Table 8: Evaluation of the queue system performance when λ and μ are constant and s is varied

s	1	2	3	4	5	6	7	8	9	10
ρ	4.119	2.0595	1.373	1.0298	0.8238	0.6865	0.5884	0.5149	0.4577	0.4119
P_0	0.0107	0.0145	0.0157	0.0161	0.0162	0.0162	0.0163	0.0163	0.0163	0.0107

From the data in TABLE 8, it could be observed that as s increases the system becomes more stable. However from s = 1 to s = 4 the system still remains unstable with $\rho > 1$. From s >= 5 servers, $\rho < 1$ and the system becomes more stable . Implying that $\mu > \lambda$. But employing more number of servers (disposal trucks) keeps the facilities underutilized. Five (5) of such trucks working in the entire system or by increasing the present service rate by 5 times will make $\rho \approx 0.8238$ and suggests to be the best option among those provided in TABLE 8.

TABLE 9 contains a new set of data generated based on the new scenario: λ = 17.3 cbpd and μ = 21 cbpd. A plot of the server system utilization factor against the number of servers (Figure 51) shows clearly that ρ decreases as s increases. A trendline equation generated from this plot shows that ρ relates with s as: $\rho = 0.8238s^{-1}$ and gives the R^2 value of 1. Also of interest is the possibility of not having huge piles of waste as we see them in the three dumpsites studied in the present course when these five trucks work at the dumpsites. This possibility of having no waste in the system is illustrated in Figure 4b. The plot shows a positive possibility of such a condition as the number of servers increases. The five trucks of choice give almost the same probability ≈ 0.016 as 6 to 9 servers.

s	1	2	3	4	5	6	7	8	9	10
ρ	0.8238	0.4119	0.2746	0.206	0.1648	0.1373	0.1177	0.103	0.09153	0.0824
P_0	0.4387	0.4388	0.4388	0.4388	0.4388	0.4388	0.4388	0.4388	0.43876	0.4388



a: Plot of combined server system utilization against number of servers.

b: Plot of probability of having no waste in the system against number of servers

Figure 4: Performance evaluation on the three sample dumpsites

A careful perusal of the values in TABLES 2 through 7 reveals the most of reasons why waste containers in Awka municipality and other areas in Anambra State are always fully loaded, and in some cases, overflowing with waste; appearing to the uninformed passersby in the street as if ASWAMA is not doing much work. But the study has shown from both the subsystems and the overall systems efficiencies that the agency is really performing, and that its service facilities are in fact, being over utilized. The over utilization could be the major reason for the incessant breakdowns of these facilities.

4.2 Flow chart for systematic application of the waste queuing models

Flow chart for application of the waste queuing models developed in this study in Excel spreadsheet is depicted in Figure 5. Values for two basic queuing parameters - λ and μ - for i = 1 to n and j = 1 to k are required as input data which Excel uses to generate values for other parameters based on coded models of interest.

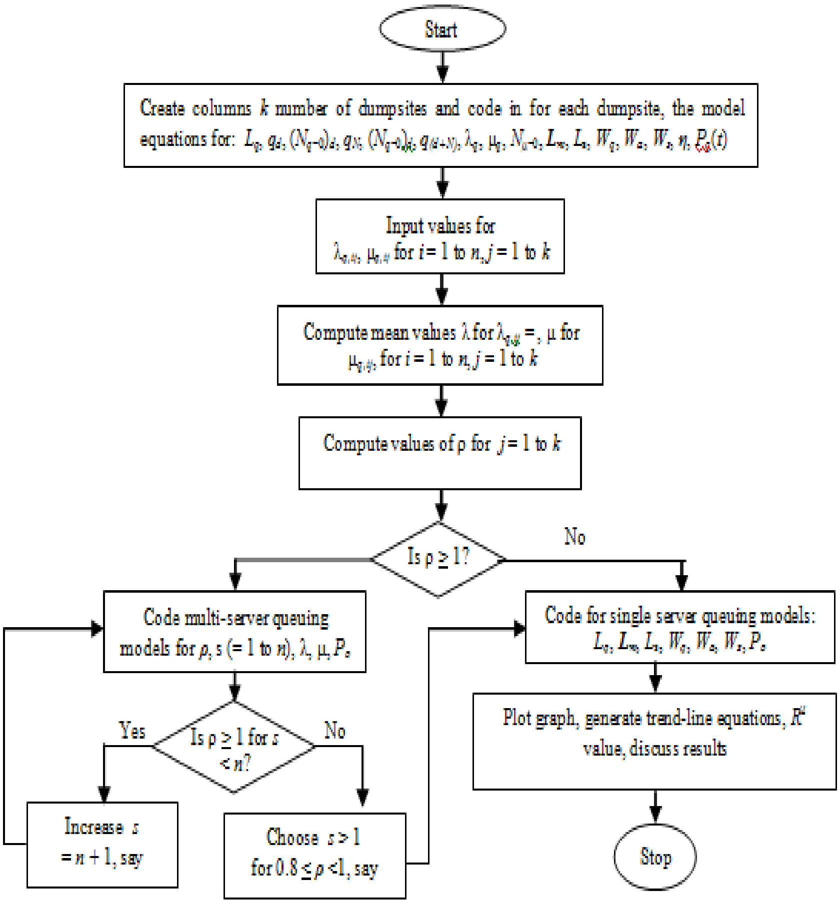


Figure 5: Flow chart for application of the study waste queuing models

IV. CONCLUSION

The following conclusions are drawn from this study:

- Models based on the functional relationships existing among waste production and evacuation rates parameters in solid waste management have been developed and presented in this paper by applying queuing theory in the system..
- The models can be used as monitoring/assessment tools for evaluating the performances and estimating the financial transactions made by a waste manager over time.
- The study provides a systematic method of collecting, analyzing and keeping quantitative data on quantity of solid waste generated and the quantity disposed to a landfill, transfer station or final dumpsite in a locality.
- Application of the models in the study showed that the three dumpsites used as case study had different waste generation and evacuation/disposal lead times, which can be used in making far reaching waste management decisions.
- Results also show that improvement exists in the system as the waste evacuation lead times gets closer to or equals the waste generation lead times.
- It is hoped that application of these models will in no small measure assist the ASWAMA and other solid waste managers in making economic decisions when scheduling their disposal trucks for waste evacuation.

V. RECOMMENDATION

During the period the field study was conducted, it was observed that waste evacuators routing was left at the discretion of the vehicles drivers and the members of their crew, who drive about town collection waste randomly. This random search/operation increases the costs of waste evacuation. A well conducted solid waste inventory management system should be a close loop system and should also lend its supports to sustainable integrated solid waste management and development. To achieve this fit, ASWAMA should open up customers phone calls centre/programme where the public can feed the agency with information about the state of their environment, especially the waste bin locations that need evacuation atten-tion of the agency. This will give the public the opportunity of participating in solid waste management in the state and also save ASWAMA the costs of employing some workers to do this, among other benefits. This method was used during the field study to monitor both the waste bin sites and the evacuator trucks that went to the bin sites in any day. A sample of the information flow structure is depicted in Figure 6. This programme should be linked to a computer based data collection and database management system.

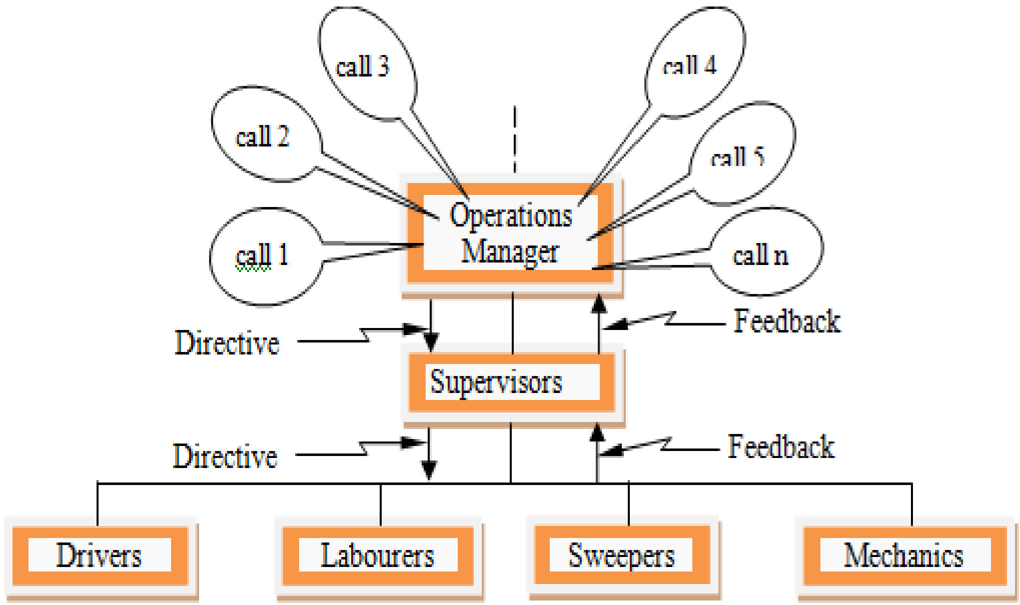


Figure 6: An information flow structure for solid waste management

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REFERENCES

[1]. Ihueze CC and Chukwumuanya EO. Cost estimation and waste production forecast models for sustainable solid waste management: A Study on Anambra State Waste Management System. Inter J Appl Sci Engr, 3(1), 2015, 14-18. www.ijapscengr.com

[2]. Ihueze, Christopher Chukwutoo & Chukwumuanya, Emmanuel Okechukwu (2015). Statistical Modeling of Anambra State Solid Waste Management Constraints. Global Journal of Engineering, Design and Technology, Vol. 4(6), Nov. - Dec., 2015, 1-7.

[3]. Olorunfemi J.F, Odiata C.O (1998). Land use and solid waste generation in Ilorin, Kwara State. The Environmentalists. 2: 67-75.

[4]. UNICEF (2006). Solid and Liquid Waste Management in Rural areas. A Technical Note, 2006.

[5]. World Bank, (1992). World Development Report, Development and Environment, New York. Paper No 13

[6]. Ezigbo, C.A (2012), "Management Of Solid Waste In Nigeria: challenges and proposed solutions ". Sacha Journal of Environmental Studies, Volume 2 Number 1 (2012) pp. 159-169, ISSN 2045-8479 (Print), ISSN 2045-8487 (Online), www.sachajournals.com

[7]. Kaila J (1987). "Mathematic Model for Strategic Evaluation of Municipal Solid Waste management system". Technical research centre of Finland Publication 40, Espoo. Finland.

[8]. Chukwuemeka, Emma E. O., Osisioma, B. C., Onwuka, Ebele and Ugwu, Joy (2012). "The challenges of waste management to Nigeria sustainable development: A study of Enugu State". International Journal of Research Studies in Management 2012 October, Volume 1 Number 2, 79-87, ISSN: 2243-7770, Online ISSN: 2243-7789

[9]. Ezema, T. O. (2009). "The problems of managing solid waste in a depressed economy". Journal of Sustainable Development, 5(2) 45-55.

[10]. Emeka Chiakwelu (2011). "Poor management bedeviled refuse disposal in Onitsha and Anambra state".www.afripol.org/archive/item/282-poor-management-bedeviled-refuse-disposal-in-onitsha -and-anambra-state.html