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Research Article

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Solid Waste Inventory Management Theory

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Abstract The paper aims at presenting and leading discussions on a theory termed, "Theory of solid waste inventory management" following the conventional inventory management ideology. The theory is centered on developing models for determining quantities of waste generated and the quantities that should be evacuated to maintain a minimum inventory level of waste in a given location. It also provides methods of estimating costs of waste evacuation and for evaluating a waste manager's performance for sustainable solid waste management, using full cost accounting and economic order quantity approach. Models developed in the study were validated using data collected from a consecutive sixty one day field study conducted on Ogbalingba roadside dumpsite in Awka metropolis of Anambra State, Nigeria. Simulation results show that going by the rate at which solid waste were generated and dumped at the dumpsite, waste evacuation lead time should be fixed at every three days and should not exceed a fourth day, if delayed. Reducing this frequency of evacuation will lead to stocks of excess inventory of waste, occupying more space at the site and littering the area. Besides, it is hopeful that the model application to solid waste management will contribute to knowledge enhancement in the academic world.

Keywords Development, inventory management, models, solid waste, theory

1. Nomenclature

Symbol	*Meaning*
=	"is equal to" or "represents"
Q	Total quantity of waste in a specified location
D	Expected quantity of waste removed/ evacuated from a stated location
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
L_w	Expected queue length, i.e. expected quantity of waste in queue at a morning check of a waste dumpsite
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 disposal rate when μ_q is constant for all $q > 0$
q_R	Quantity of waste remaining in the system at the end of a stated period
V_b	Volume of waste container
I	a percentage of the purchase/evacuation/ disposal cost
k_1	a parameter that essentially lumps together the costs of working capital for the inventory itself and the storage costs
k_2	a setup cost parameter and denotes a fixed cost of evacuation
$k_3 = k_4$	an operating cost parameter, and the operating cost is assumed to be proportional to the quantity (bin load-counts) of waste evacuated/ disposed
D^{opt}	optimal quantity of solid waste disposed (evacuated) to keep a minimal inventory of waste generated in a given area
C^{opt}	cost of evacuating D^{opt}
∂	symbol used for partial differentiation
Avg	Average or mean
cb	chain-up bins
cbpd	chain-up bins per day
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
MAWES	maximum allowable waste excess stock
MAWIL	maximum allowable waste inventory level
MAWSS	maximum allowable waste safety stock
NCWC	Normal capacity of waste container
NGR	Normal generation rate
NET	Normal evacuation (disposal) time or evacuation lead time

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 refers 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 or acronym not defined in this column is defined in the body of the text.

2. Introduction

A new way of looking at waste and its management is needed. Otherwise, the process of achieving an environmentally sound industry may be unacceptably slow. The paradigm shift that is argued for here involves equating industrial waste with normal products in terms of the allocation of revenues and costs, an approach that is termed the equality principle [1]. Consequently, a theory of Solid Waste Inventory Management (SWIM) is proposed and discussed herein this report following the conventional inventory management methodology.

2.1 Meaning and scope of SWIM and its management

Solid Waste Inventory refers to any heap or quantity of waste (including reusable and recyclable materials, general waste, etc.) that is under the control of a waste manager. Excessive waste inventory levels constitute a risk to the environment, while small waste inventory levels, which the society requires, may lead to loss of revenue/job by waste workers.

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

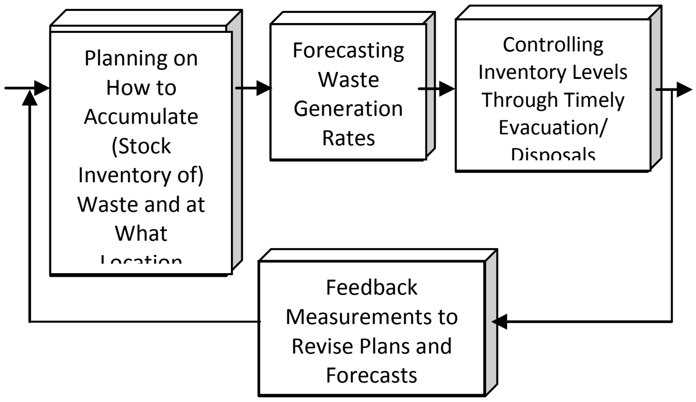

Figure 1: Waste inventory control system with a feedback mechanism

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

Proper solid waste inventory control should be a close loop system as depicted in Fig. 1 and should also lend its support to sustainable integrated solid waste management and development.

2.2. SWIM Decisions and terms used

Objective: Minimize waste generation and total cost of waste evacuation

Decisions: How much waste to evacuate/dispose?

When to evacuate/dispose waste?

Terms used in SWIM:

- Waste generation rate: This is the quantity of waste produced per period in a named geographical area. Waste generation is the most critical, yet an uncontrollable component of waste management; without waste generation there would be no need for keeping waste inventory or establishing a waste management unit in the first place.
- Waste evacuation/disposal rate: This is the quantity of waste removed from a pile of waste existing in a given area per period. Waste disposal is dependent on waste generation and management decision. In places where waste production rate exceeds its disposal rate, waste accumulates at such spots.
- Waste lead time: This refers to the time between when waste starts accumulating and when it is evacuated/disposed. It may be assumed deterministic or probabilistic. Waste lead time has two components which are *Waste Generation Lead Time* (WGLT) and *Waste Evacuation Lead Time* (WELT). Waste generation lead time is the time taken to fill an empty container of known size or volume with waste. Waste evacuation lead time on the other hand is the inter-disposal time of a disposal vehicle in its visits to a given dumpsite. That is to say, it is the length of time taken from the last time a waste container of known capacity is emptied of its contents to the next time it is full and re-emptied. Waste evacuation lead time can be classified further as *waste inspection lead time* which is the time in-between two consecutive inspection visits to a dumpsite to determine the state of waste in stock at the site, *waste administrative lead time* which is the period in-between the last point a waste manager takes decision on a quantity of waste due for evacuation and the next point when a similar decision is made, and *waste transportation lead time* which is the period from the time the management made a decision on waste to be evacuated or transferred (from one point to another) to the time it takes a waste disposal truck to execute/implement the decision.

  Consideration of lead time is a very important factor in waste inventory management.
- Quantity discount/economy of scale: Is defined as an allowance granted by a vendor to a purchaser of certain materials for encouraging large size orders. In a waste management system, commercial waste transporters act as the vendors while the waste manager assumes the position of the purchaser of transportation service. Some-

times there is an agreement between the waste manager and the waste transporter that quantity discount will be allowed by the latter on evacuation of certain specified quantity of waste. Two main types of quantity discounts are: 1). all-units, and 2). incremental [2].

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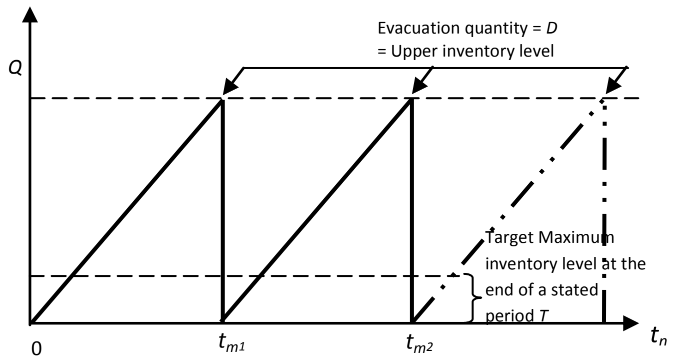

Figure 2: Waste inventory level over time based on EWEQ assumptions

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

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

✓The average rate of waste generation/ production in an area
✓The average time taken to fill a given size of waste container or space.
✓Normal capacity of waste container
✓Waste evacuation requirements
✓The optimum quantity of waste which could be evacuated advantageously

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

MAWES = MAWSS = NCWC + (NGR x NET) (1)

2.3 Overview of economic waste evacuation quantity and the underlying assumptions

Economic Waste Evacuation Quantity (EWEQ) or Economic Waste Disposal Lot Size (EWDLS), is the quantity of waste that a waste manager should evacuate in order to minimize the total costs of waste disposal - such as holding costs, setup costs, transportation costs, and environmental (damage or havoc) costs. It refers to the lot size of waste for which the total cost per disposal run is minimum. In other words, EWEQ is the disposal quantity that minimizes total waste inventory holding costs, setup costs and evacuation costs. Fig. 2 displays waste inventory levels over time based on EWEQ principles.

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

Therefore, EWEQ can be applied to determine the optimal quantity of waste to evacuate so as to minimize the total cost associated with the generation, storage and transportation of some quantity of waste. The required parameters to the solution include:

- ✓the total generation for a specified period,
- ✓the evacuation cost per disposal truck run,
- ✓the optimum waste evacuation quantity,
- ✓the fixed cost of storage per given unevacuated quantity of waste per the specified period.

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

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

The cost per evacuation run is a linear function of the optimum evacuation quantity

3 Materials and Methods

3.1 EWEQ variables and models

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

The Total Cost of Evacuation

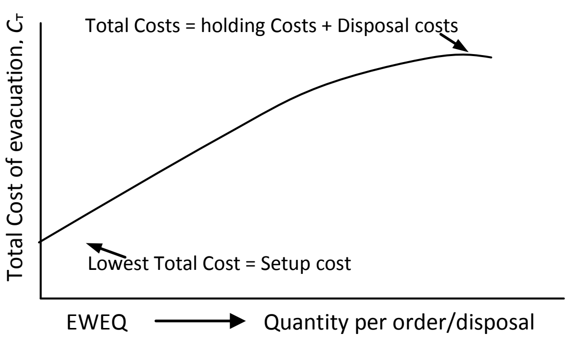

Figure 3: Variation in costs of evacuation with waste disposal lot size

Fig. 3 shows the variation of costs of waste evacuation and the evacuated quantity.

Vital notes in this theory include:

i. Minimizing EWEQ model costs

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

ii. EWEQ total cost

Components of EWEQ total cost:

✓Cost of waste evacuation

✓Cost of carrying or holding waste inventory

✓Setup costs (C_s)

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

iii. Two methods for carrying cost in SWIM

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

1. As a fixed cost, such as
   C_h = ₦2000 per unit quantity per year
2. As a percentage (I) of the cost of evacuated quantity of waste
   $C_h = I \times C_E$ (2)

iv. Average waste inventory value

After D is found, the average value of inventory of waste on hand can be calculated.

Average inventory value = $C_n \times (D/2)$ (3)

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

It may be a little difficult to estimate C_h in a given dumpsite. However, the EOQ formula in form of eqn (4) can be applied to calculate the value of C_h that would make a given Q optimal [3].

$$D^{opt} = \{(k_1)^{-1}k_2Q\}^{½} \quad (4)$$

3.2 Determining disposal lot size or EWEQ: average waste inventory level and total cost of evacuation

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

MAWIL = $[\lambda t_{GL} + \lambda(t_n - t_m)]$ (5a) $= [D + q_{ES}] = Q$ (5b)

Average waste inventory = $½Q$ (6)

Setup cost (C_s) = $(D/Q) \times C_n$ (7)

Carrying cost = $I \times (Q/D)$ (8)

Total cost of evacuation, $C_T = C_n \times Q/D$ (9)

Assuming that eqn (10) holds true, the C_T resulting from quantity of waste generated over a given period is given by the sum of the carrying cost and the total cost of evacuation made within the period [3]; which for a linear cost function, eqn (11a) holds, and for the non-linear cost function, eqn (11b) holds.

$$C_h = k_1D \quad (10)$$

$$(C_T)_L = k_1D + r(k_2 + k_3D) \quad (11a)$$

$$(C_T)_{NL} = k_1D + r(k_2 + k_4D^{½}) \quad (11b)$$

Values for the parameters in k may be approximated from the relation:

$$k_1 = k_2 \times 10^{-3} \quad (12a)$$

$$k_2 = k_3D \times 10^{-1}, \quad (12b)$$

$$k_4 = k_3 \quad (12c)$$

where the value of k_3 is first determined/fixed by the waste manager or by act of law.

3.3 Application of the EWEQ model in Awka Municipality, Anambra State

Ihueze and Chukwumuanya [3] showed application of some of the developed EWEQ models in solid waste management costs analysis, using a thirty six month data collected on Awka City solid waste management, Anambra State, Nigeria. The analysis clearly showed the approximate quantities of solid waste produced in Awka city and the amounts of money paid in the months of January 1, 2012 to December 31, 2014 for disposing them.

3.4 Determining how much to evacuate (dispose) and when to evacuate

As already noted, in applying the EWEQ model, it has to be assumed that waste evacuation is instantaneous, and that inventory is replenished at a fixed rate until it reaches the maximum capacity of the containing vessel or the allowable excess stock level. This assumption is illustrated in Fig. 4. This implies that a specific quantity of waste arrive after evacuation to return the inventory to its full level within the set waste generation lead time. In reality waste may be seen as arriving exponentially at the dumpsites and in some cases it is evacuated in smaller batches at the waste crew members discretion or as the capacity of the disposal truck's bucket (or container) may allow. In considering waste evacuation to be instantaneous, the EWEQ model also assumes that waste are always in stock and that there is always some associated costs with the waste in stock. Consequently, the cost of inventory under the EWEQ model involves a

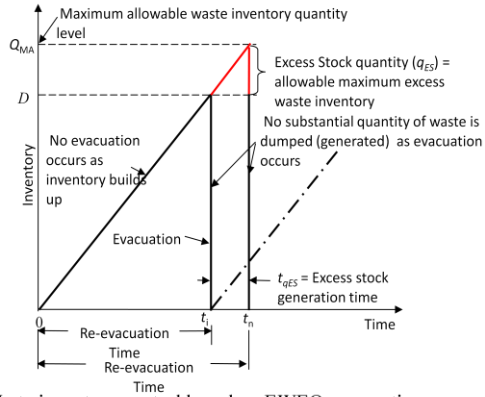

Figure 4: Waste inventory control based on EWEQ assumptions

tradeoff between inventory holding costs (the cost of storage, as well as the cost of tying up capital in inventory rather than investing it or using it for other purposes) and other costs represented under the full cost accounting (FCA) strategy. Evacuating a large amount of waste at one time will reduce holding costs paid by the state or a waste manager, while making fewer evacuations will increase holding costs and costs of damages to environment. The EWEQ model aims at finding the quantity that minimizes the sum of these costs.

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

Meanwhile, waste generation cycle will last until Q units have been generated and generating waste at a rate of D units per day means that it will last (Q/D) days. After D is determined, the second decision is when to evacuate the waste. Evacuation should usually be done when inventory reaches container capacity or before it exceeds the MAWES quantity. The waste generation lead time (WGLT) should be determined and fixed. This will help in determining when to fix the time for evacuation (evacuation lead time). That is to say, re-evacuation depends on the WGLT. Re-evacuation point (REP) also illustrated in Figure 4 is expressed as:

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

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

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

4. Simulation of Waste Generation and Evacuation Lead Times for Ogbalingba Dumpsite

Some assumptions in application of EWEQ principles in SWIM models include:

- ✓ The state (quantity) of waste at the dumpsite(s) is always monitored.
- ✓ Rate of waste generation is known or relatively uniform
- ✓ Waste evacuation lead time is fixed.

- ✓ Waste evacuation is made instantaneously; the whole batch is disposed/transported at once.

Time taken to fill a set of waste bin kept at any given dumpsite is considered herein this discussion as the WGLT (t_{GL}) for that dumpsite. Taking the above assumptions into consideration, data in Tables 1 were used in determining the WGLT Ogbalingba dumpsites.

Table 1: Simulation of waste generation and evacuation lead times at Ogbalingba dumpsite of Awka city, Anambra State

Ogbalingba Dumpsite: No. Of Chain-up Bins = 3 and WELT = 5 days										
Time Days	L_q **(cb)**	q_d	$(N_{q=0})_d$	q_N **(cb)**	$(N_{q=0})_N$	$q_{(d+N)}$ **(cb)**	N_{tgL}	λ_q **(cbpd)**	D	$N_{\mu=1}$ **days**
1	2.0	0.2	0	0.3	0	0.5	0	2.2	0	0
2	2.5	0.2	0	0.5	0	0.7	0	2.7	0	0
3	3.2	0.5	0	0.0	1	0.5	0	3.7	0	0
4	3.7	0.2	0	0.4	0	0.6	0	3.9	0	0
5	4.3	0.4	0	0.5	0	0.9	1	4.7	4.7	5
6	0.5	0.0	1	0.8	0	0.8	0	0.5	0	0
7	1.3	0.2	0	0.0	1	0.2	0	1.5	0	0
8	1.5	0.9	0	0.8	0	1.7	0	2.4	0	0
9	3.2	0.4	0	0.0	1	0.4	1	3.6	0	0
10	3.6	0.2	0	0.6	0	0.8	0	3.8	3.8	5
11	0.6	0.2	0	0.5	0	0.7	0	0.8	0	0
12	1.3	0.0	1	0.5	0	0.5	0	1.3	0	0
13	1.8	0.2	0	0.6	0	0.8	1	2.0	0	0
14	2.6	0.4	0	0.4	0	0.8	0	3.0	0	0
15	3.4	0.2	0	0.5	0	0.7	0	3.6	3.6	5
16	0.5	0.2	0	0.8	0	1.0	0	0.7	0	0
17	1.5	0.4	0	0.2	0	0.6	1	1.9	0	0
18	2.1	0.0	1	0.7	0	0.7	0	2.1	0	0
19	2.8	0.4	0	0.0	1	0.4	0	3.2	0	0
20	3.2	0.2	0	0.5	0	0.7	0	3.4	3.4	5
21	0.5	0.3	0	0.3	0	0.6	0	0.8	0	0
22	1.1	0.2	0	0.5	0	0.7	1	1.3	0	0
23	1.8	0.3	0	0.0	1	0.3	0	2.1	0	0
24	2.1	0.1	0	0.8	0	0.9	0	2.2	0	0
25	3.0	0.3	0	0.7	0	1.0	0	3.3	3.3	5
26	0.7	0.2	0	0.3	0	0.5	0	0.9	0	0
27	1.2	0.1	0	0.0	1	0.1	1	1.3	0	0
28	1.3	0.3	0	0.3	0	0.6	0	1.6	0	0
29	1.9	0.2	0	0.2	0	0.4	0	2.1	0	0
30	2.3	0.2	0	0.4	0	0.6	0	2.5	2.5	5
31	0.4	0.2	0	0.0	1	0.2	0	0.6	0	0
32	0.6	0.3	0	0.4	0	0.7	0	0.9	0	0
33	1.3	0.2	0	0.0	1	0.2	0	1.5	0	0
34	1.5	0.2	0	0.6	0	0.8	1	1.7	0	0
35	2.3	0.4	0	0.0	1	0.4	0	2.7	2.7	5
36	0.0	0.7	0	0.8	0	1.5	0	0.7	0	0
37	1.5	0.3	0	0.0	1	0.3	0	1.8	0	0
38	1.8	0.1	0	0.6	0	0.7	1	1.9	0	0
39	2.5	0.3	0	0.5	0	0.8	0	2.8	0	0
40	3.3	0.2	0	0.5	0	0.7	0	3.5	3.5	5

41	0.5	0.1	0	0.6	0	0.7	0	0.6	0	0
42	1.2	0.3	0	0.4	0	0.7	1	1.5	0	0
43	1.9	0.2	0	0.5	0	0.7	0	2.1	0	0
44	2.6	0.2	0	0.8	0	1.0	0	2.8	0	0
45	3.6	0.4	0	0.2	0	0.6	0	4.0	4	5
46	0.2	0.0	1	0.7	0	0.7	1	0.2	0	0
47	0.9	0.4	0	0.0	1	0.4	0	1.3	0	0
48	1.3	0.2	0	0.5	0	0.7	0	1.5	0	0
49	2.0	0.2	0	0.3	0	0.5	0	2.2	0	0
50	2.5	0.0	1	0.5	0	0.5	0	2.5	2.5	5
51	0.5	0.2	0	0.0	1	0.2	0	0.7	0	0
52	0.7	0.4	0	0.8	0	1.2	1	1.1	0	0
53	1.9	0.4	0	0.7	0	1.1	0	2.3	0	0
54	3.0	0.0	1	0.3	0	0.3	0	3.0	0	0
55	3.3	0.2	0	0.0	1	0.2	0	3.5	3.5	5
56	0.0	0.9	0	0.3	0	1.2	1	0.9	0	0
57	1.2	0.4	0	0.2	0	0.6	0	1.6	0	0
58	1.8	0.2	0	0.4	0	0.6	0	2.0	0	0
59	2.4	0.2	0	0.5	0	0.7	0	2.6	0	0
60	3.1	0.5	0	0.9	0	1.4	1	3.6	3.6	5
61	0.9	0.2	0	0.6	0	0.8	0	1.1	0	0

Let it also be assumed that the numerical data contained in the above said table is the mean values of the quantities of waste generated daily in the referenced dumpsites for a given length of time, say one year. Number of waste containers kept at Ogbalingba dumpsite is 3. The WGLTs (t_{GL}) for the dumpsite was calculated using eqn. (4a) and entered in Table 1 as 5 days. Taking the total volumes of the containers kept in the dumpsite as the maximum allowable (upper limit) stocks for the site, and by varying the WELT (t_{EL}) it is easy to visualize the stability of the SWM system at the dumpsite. It should be noted that in actual practice *D* has inverse relationship with the waste lead times. Starting with the assumption that WELT = WGLT for the dumpsite, the data in Table 1 was generated and plotted in Fig. 5.

Fig. 5 is a plot of *D* against t_{EL} for Ogbalingba dumpsite. The figure shows that if t_{EL} is delayed upto 5 days due to some considerations made such as costs, server failure, administrative bottle neck, etc. the system will be unstable. This claim is supported by the points of *D* above the dashed reference line representing the maximum allowable stock of waste at the dumpsite.

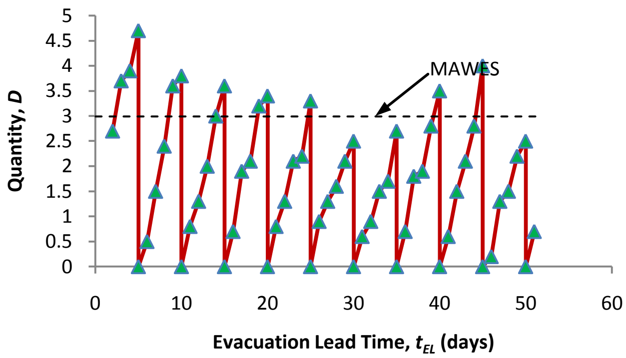

Figure 5: Ogbalingba SWM system stability when WELT = 5 days

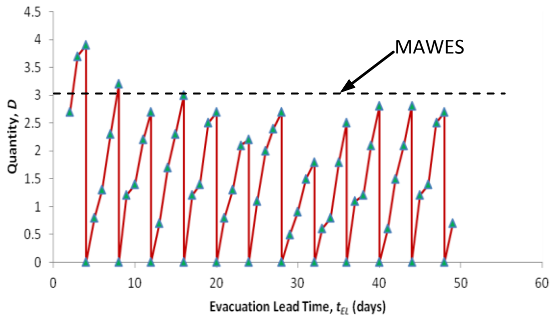

Figure 6: Ogbalingba SWM system stability when WELT = 4 days

Figs. 6 and 7 show the system plots for Ogbalingba dumpsite when the mean WELTs are reduced by a certain amount.

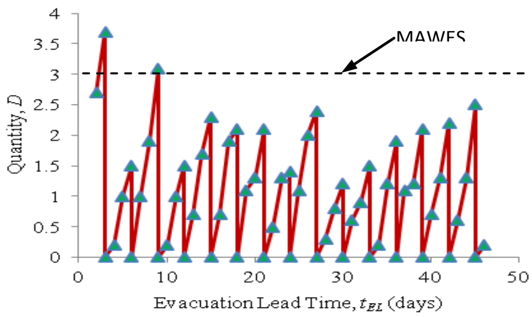

Figure 7: Ogbalingba SWM system stability when WELT = 3 days

In Figures 6, the WELT is reduced by one day; whereas in Fig. 7, the WELT is reduced by two days.

Of course, these reductions in number of days implies increase in frequency of waste evacuation. The two plots show clearly that as the unit reductions in t_{EL} continues, more of the points of D go below the upper reference line indicating that the system gets more and more stabilized (the location under discussion is kept cleaner), though not without some financial costs.

5. Conclusion and Recommendations

The following conclusions are drawn from this study:

- Models for monitoring rates of solid waste discard and evacuation rates at a given dumpsite have been presented in the paper and demonstrated by way of simulation.
- The study models were generated based on the functional relationships among waste production and evacuation rates parameters.
- The simulation model can also be used as a monitoring tool for determining waste generation lead time and in fixing the waste evacuation/disposal lead time of a given dumpsite.
- The models can also assist in evaluating the performances of a waste manager and for estimating financial transactions made over time.
- Results also show that there will be improvement in the system, in terms of cleaner environment, as the waste evacuation lead times gets smaller, but with some additional costs.
- 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 known locality.
- It is recommended, as the simulation results have shown, that Anambra State Waste Management Agency (ASWAMA) should deploy its disposal trucks to Ogbalingba dumpsite every three to four days to evacuate stock of waste deposited there to avoid excess accumulation and littering of the area with garbage.

- As earlier stated, 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 plan. 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 attention of the agency. This will give the public the opportunity of participating in solid waste management in the state and also save ASWAMA the costs of employing some workers to do this, among other benefits. This method was used during the field study to monitor both the waste bin site and the evacuator trucks that went to the bin site in any day.
- 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.
- As recommended in Chukwumuanya and Ihueze [4], 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 develop-ment. This entails that the waste manager concerned should open up phoning programme in which the public is given opportunity of participating in solid waste management in their locality. It will also save the manager the costs of employing some workers to the costs of employing some workers to monitor the various waste dump sites, among other benefits. This method was used during the field study in monitoring 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 8. This programme should be linked to a computer based data collection and database management system.

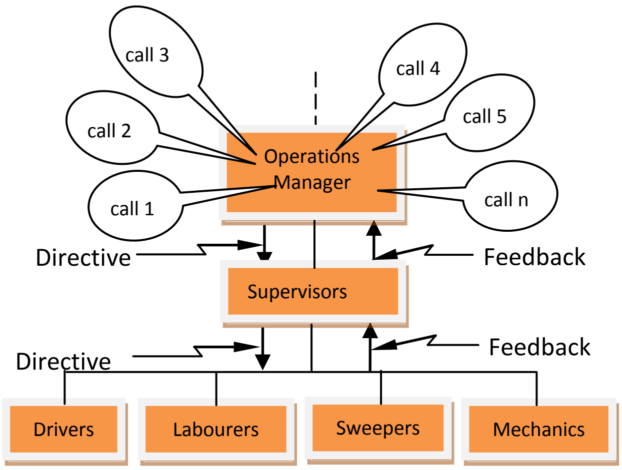

Figure 7: An information flow structure for solid waste management

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