PRINT ISSN 1119-8362
Electronic ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://ww.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 23 (7) 1371-1376 July 2019

Conceptual and Simulated Semi-Automatic Urban Waste Management System using Global Systems for Mobile Communication and Customer Reliability Indices

***OGUNWOLU, L; OMIYALE, AD; AJIBOLA, OOE**

Department of Systems Engineering, Faculty of Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria
**Corresponding Author Email: fogunwolu@unilag.edu.ng; Other Authors Email: omiyaleabolade@yahoo.com; oajibola@unilag.edu.ng*

ABSTRACT: Municipal Solid Waste Management (MSWM) poses great challenges to many cities around the world. The challenges are fuelled by population explosions all over the world, especially in the major urban centres, against the backdrop of limited resources to manage wastes efficiently. In this paper, a conceptual and simulated semi-automatic approach to MSWM is considered using the prevalent Global Systems for Mobile Communication (GSM) technology to engage both the waste generators and collectors. This system connects users into a central database where data about their waste bin levels are harnessed. Users are prompted via GSM handsets daily for the level of the waste bin. Waste Collection Vehicles are routed based on the responses while an updatable Reporting Reliability Index (RRI) is computed for each user based on estimate of actual level of waste collected as against the reported level to factor future reporting. With history of collection volume at a location known, forecast is made as to the generated waste level when a customer's response to prompt is not available. The system is tested on a simulated 30-node housing estate and two dump sites with vehicles routed to optimize distance covered and volume of waste collected. Customers report when prompted with 0, 1, 2, 3, 4 for waste levels ranging from empty to full bin fills. Vehicles are routed to collect wastes at locations with a minimum threshold level of 2. Results obtained showed statistically insignificant differences in distribution of means of collection distance covered weekly but 13.31 volume units/km collected with this method compared with 3.08 volume units/km run of fixed routing scheme, at $\alpha = 0.05$. The cost saving potential and environmental benefits of timely waste disposal of this scheme is thus demonstrable.

DOI: https://dx.doi.org/10.4314/jasem.v23i7.28

Dates: Received: 12 May 2019; Revised: 24 June 2019; Accepted 12 July 2019

Keywords: Municipal Solid Waste, Waste Management, SMS Gateway, GSM, Reporting Reliability Index.

Waste management is a plethora of activities including collection, keeping, treatment and disposal of waste in such a way as to render them harmless to human and animal life as well as the ecology and environment. until it reaches its final destination – a treatment plant or disposal site (UN-HABITAT, 2010). Waste must be handled systematically to ensure that they are disposed of with acceptable public health and environmental safeguarding measures. (Alemma-Ozioruva Aliu 2017). The reckless disposal of waste has led to unimaginable damages such as blockage of sewers and drainage networks, and choking of water bodies (Bakare 2016). Sometimes, the problem of waste management may be institutional. In Lagos, Nigeria, although government allocates huge funds to waste management on yearly basis, not much of the waste is collected (Achankeng, 2003). Effective waste management is expensive, often comprising 20-50% of municipal budgets. In 2015, it is estimated that about 12,000 metric tonnes of waste are generated averagely on daily basis in Lagos State, Nigeria (Oresanya, 2014). Per capital waste generation in Lagos has been projected to rise to 1.42 kg in the next fifteen years. This presents a serious cause for concern for waste management strategies to match rate of generation. In the past, most attempts to improve solid waste management in cities have focused on the technical aspects of different means of collection and disposal (Manual, S, 2010). According to Cointreau (1994), more attention has been paid to enhancing institutional arrangement for service delivery with a special emphasis on privatization in the recent times. Several factors contribute to the poor waste management administration in most developing economies. In most developing economies, there is lack of relevant and adequate legislation, little or no enforcement of the existing regulations (Li 2007), little or no investment in infrastructure, inadequate human capacity for administrative and technical issues, low linkages of academic research and industry, lack of genuine data to aid waste managers on planning. For instance, the composition, the density of waste generated in each locality which can assist in infrastructural planning is not known in most cases, lack of the needed political will on the part of the leaders to mention but a few (Alemma-Ozioruva Aliu

**Corresponding Author Email: fogunwolu@unilag.edu.ng*

2017). Others include lack of willingness to pay for waste management services by the waste generators because of the public perception of waste management services as public service to be provided by the government at no cost to the waste generators. Furthermore, the unplanned and often congested natures of low-income communities with narrow roads which make it difficult for waste collection vehicles to navigate. These has resulted into a behemoth and a haven for rodents, cats and dogs, a situation that can lead to outbreaks of epidemic of unimaginable dimension if not arrested urgently.

Table 1. Waste generation and density in major cities in Nigeria

City	Tons per month	Density (Kg/m^3)	Volume/capita/day (m3)
Lagos	255,556	294	0.63
Kano	156,676	290	0.56
Ibadan	135,391	330	0.51
Kaduna	114, 433	320	0.58
Portharcout	117, 825	300	0.60
Makurdi	24,242	340	0.48
Onitsha	84,137	310	0.53
Nsukka	12,000	370	0.44
Abuja	14,785	280	0.66

Ogwueleka, 2009

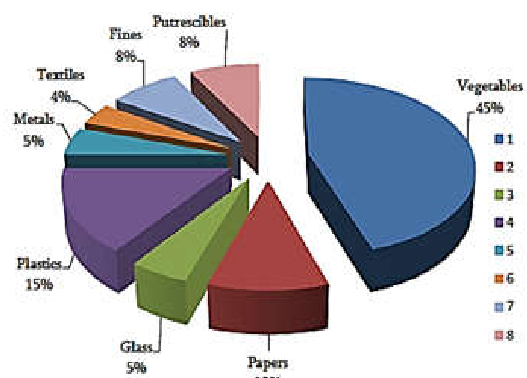

Fig 1: Composition of Solid Waste Generated in Lagos (LAWMA Report, 2016)

Several waste collection schemes have been developed among which are House-to-House, Community Bins, Self-Delivered, Contracted or Delegated Service etc. The waste collection modes also differ. There is automated collection, semi-automated collection and the manual collection modes. Solid waste collection is a labour-intensive business, often requiring as many as three workers per vehicle to lift and dump disposal containers. According to Rogoff *et al* (2010), automated collection has proven to significantly reduce collection worker injuries resulting in reduced workers compensation costs, decreasing disability claims, decreasing the number and cost of light duty assignments, and reducing salary fringe benefit costs in the future. The work on hand here is a semi-automatic intervention at the process dimension of waste management using customer reports through the GSM in place of smart dust-bins and thus planning for routing of collection vehicles.

MATERIALS AND METHODS

The proposed semi-automatic waste management system (WMS) in this work automates the process of waste level reporting at the generation stage to engender informed and optimal waste collection scheduling and vehicle routing. In addition, given the erratic nature of human beings to manipulate things in their favour when freely allowed to intervene in a system of this nature and especially when, as it is being proposed in the parent-research from where this work emanates, a pay-as-you generate system is in place, a system of waste reporting reliability and penalisation is introduced.

The Semi-Automatic Waste Management Concept: The Semi-automated WMS proposes a management system whereby individual subscribers to a waste collection system in an urban community is linked by GSM communication to a central waste management system and is expected when prompted at daily or other regular intervals to indicate the level of the waste generated in his waste-bin on a given pre-determined and agreed scaling, 0, 1, 2, …, r which indicate level of bin content such as empty, quarter-filled, half-filled, three-quarter-filled, completely-filled etc. Using this communicated indicator, the waste management body then schedules the locations of bins in its network that are ripe to collect at that point in time and effectively plan for collection vehicle-routing in the network. To ensure accurate and sanity in reporting, reliability indices of every customer's reporting is computed and updated regularly based on what is reported and what the waste collection team meets at collection point. The individual customer's reporting index is used to penalise his immediate future report and in a pay-as-you-generate system, it can affect the customer's bill.

Customer Reporting and Reliability Indices Computation: As indicated above, the customers' reporting reliability indices are based on the difference of waste level reported by customers (waste-generators) and the actual waste level found and reported by field officers at the point of collection. Based on n-reporting intervals, the customer reporting index can be computed as:

$$R_{ij} = \begin{cases} 1 & \text{if } R_{ij} > 1 \\ R_{(i-1)j} + \dfrac{(V_{ij}^R - V_{ij}^c)}{n} & \text{if } 0 \le R_{ij} \le 1 \\ 0 & \text{if } R_{ij} < 0 \end{cases}$$

Where $V_{ij}^R =$ Level of volume of waste reported at reporting interval i at collection location j; $V_{ij}^c =$ level of waste collected at interval i at location j ; $R_{ij}\left(R_{(I-1)j}\right) =$ Reporting Reliability Index for reporting interval i (reporting interval $i - 1$) at location j

This reporting reliability index is used to penalise the reported level of waste generated to obtain the scheduled waste, C_{ij} used for scheduling and vehicle routing purposes.

$$C_{ij} = R_{(i-1)j} V_{ij}^R$$

The collection vehicle routing is done as in the algorithm in the next sub-section.

The Reported Waste Routing Algorithm – Multi-Source Spanning Trees Approach (MUSSTA): The reported waste routing algorithm is a routing in an ad-hoc network within its parent-network for waste collection at any instance of collection since, in this system, only pre-qualified collection points or nodes and those which can enhance smooth routing are used. For this purpose, the following algorithm is used in the routing.

At each collection/routing interval i,: (1) With GSM prompt, obtain waste reports, V_{ij}^R from waste-generators (customers), $j = 1, 2, ., N$ in the network;, based on waste level ratings, 0, 1, 2, . . . , r. Where response is not received from a generator, use a p-period moving average of past collection details of concerned customer to predict. (2) Using the penultimate Reporting Reliability Index, $R_{(i-1)j}$ obtain scheduled waste level for current collection/scheduling,

$$C_{ij} = R_{(i-1)j} V_{ij}^R$$

Where $R_{(i-1)j}$ is the reliability index of the location as of the last collection/routing interval.

(3) Obtain actual waste collected, V_{ij}^c from field report. (4) Compute a current Reporting Reliability Index R_{ij} for each node/customer/location;

$$R_{ij} = \begin{cases} 1 & \text{if } R_{ij} > 1 \\ R_{(i-1)j} + \dfrac{(V_{ij}^R - V_{ij}^c)}{n} & \text{if } 0 \le R_{ij} \le 1 \\ 0 & \text{if } R_{ij} < 0 \end{cases}$$

1. Select qualified nodes/customer locations, S_i for collection based on a threshold value, c_t of level of waste such that,

$S_i = \{j \mid C_{ij} \ge c_t\}$

2. Now to route vehicles for waste collection using MUSSTA

a. Initialize set of selected nodes, S_i, linked nodes, $L_i = \emptyset$, and connected nodes to dump sites as $D_{ik} = n_k$ for $k = 1, 2, . . . , d$ where d is the total number of dumpsites in the network and $n_1, n_2, . . ., n_k, . . ., n_d$ the node numbers of the dump sites in the network. P = 0.

b. Let $p = p + 1$.

i. Connect the direct node, $j \in S_i$ with the optimal link cost in the network with each of last node connected to D_{ik}; $k = 1, 2, . . . , d$. Break ties arbitrarily.

ii. Update, $S_i = S_i \setminus j$ and $L_i = L_i \cup j$ for each j so chosen. $D_{ik} = D_{ik} \cup j$. If $S_i = \emptyset$. STOP

iii. Where there is no direct connection $j \in S_i$ linked to the last node connected in $D_{ik} \in N$; $k = 1, 2, . . . , d$, ($j \nrightarrow t, \forall t \in S_i$), select an intermediate node $q \in N \setminus S_i$ such that $q \rightarrow j$ (q linked to j) and $q \rightarrow$ any $t \in S_i$. Break ties arbitrarily.

Update, $S_i = S_i \setminus j$ and $L_i = L_i \cup j$ for each j so chosen. Update $D_{ik} = D_{ik} \cup \{q, t\}$ for each such k. If $S_i = \emptyset$. STOP

iv. Depending on precision and the vastness of network, 2, 3 or more intermediate nodes can be connected as iii. above in cases where a particular last node in D_{ik} is not connected.

iv. If $S_i = \emptyset$. STOP, otherwise, GO TO 2b(i).

3. Obtain route optimal costs and list out connecting nodes of routes to different dump sites.

A Simulated Test Waste Collection Network: For the purpose of testing the conceptual network, a simulated network of subscribed 30 waste generating households/houses and two dumpsites was conceived. Figure 2 shows the network configuration of the simulated network and the relative arc lengths (in kilometres).

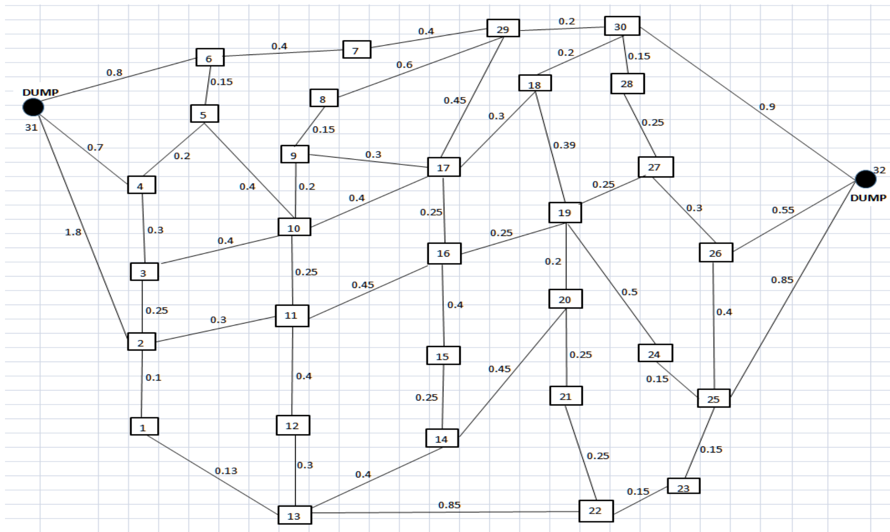

Fig 2: Configuration of Simulated Waste Management Network

It is a simulated waste collection system in which users are prompted via GSM daily to indicate the level of their waste bins for scheduling of trucks for collection on daily basis. Users were prompted to respond (0, 1, 2, 3 and 4 for completely empty, one-quarter filled, half-filled, three-quarter filled and completely-filled levels of their dust-bins respectively). Qualification of collection points/nodes for scheduling on a particular day was based on a threshold reporting waste bin level $c_t \geq 2$. Two vehicles, each with a capacity 40 (based on reporting waste level rating) were assumed. For example, where the unit size of bin is 250 litre-capacity, the vehicle capacity amounts to 10,000 litres. Furthermore, the waste bin sizes were assumed uniform. There was no attempt at crew-scheduling. Since this network was simulated, the waste reported levels and actual waste levels collected were partially and wholly generated randomly respectively. The waste reported levels were generated randomly as an integer number between 0 and 4 and added to the balance of waste from the previous collection interval to account for waste level simulated to be generated at the nodes. The actual levels of waste collected were purely generated as random integer numbers between 0 and 4. This simulated waste management network was simulated for one week for daily collection of solid wastes. Four objectives of network optimization were adopted:

a. Maximization of total carted waste volumes subject to the capacity of the collection vehicles.

b. Minimization of total distance travelled in waste collection

c. Maximization of Total Volume of Waste collected per kilometer

d. Minimization of the hybrid (or bi-objectives (a) and (b) above. This was accomplished by normalizing each of the objectives, converting the maximization objective to the normal complement of the values obtained and finding the average of the two normalized means.

In order to be able to compare the results obtained using the semi-automated approach with a case without it, the network was divided into two zones contiguous with the two dumpsites and comprising of 15 nodes each. Using the randomly generated Actual Volume of Waste collected as explained earlier, the waste collection routing was simulated for fixed daily collection of wastes based on the same objectives defined for semi-automated collection system.

RESULTS AND DISCUSSION

A casual perusal of the results obtained shows that more volumes of waste were collected (432.75 compared to 429.77 unit vol.) during the week using the fixed daily routing and collection compared to the semi-automated system approach. However, because under the former system, the whole network needed to be traversed daily (a constant distance of 20.05 km and

140.35 km for the week run), the Volume collected per kilometre run (13.31/km) was more under the semi-automated system than under the fixed route scenario (3.08/km). This is a veritable advantage of the semi-automated system of management proposed here. Statistical analysis were also carried out on the results with an objective to examine whether there are statistically significance in the difference of means and distributions of the streams of data in relation to volume collected and distance travelled day by day using one-factor Analysis of Variance (ANOVA) statistical method. Comparing the volume of waste collected under the semi-automated system simulation and that of the fixed routing system shows that there is no statistically significant difference in the means and distribution of the two volume streams of values. This is evident form Table 3 as the p-value (0.916063) is far greater than the $\alpha - level$ of significance (0.05) used and further confirmed by the fact that the calculated F-statistic (0.011586) is also far less than the F-critical (4.747225) for degrees of freedom 12 (for within the group and 1 (between the groups).

Table 2 shows the values obtained simulating under different objectives enumerated in the last section.

Table 2: Optimal Objective Values for 7-day Simulation run

Day	**Semi-Automated**				**Fixed Routing**			
	Volume	**Distance**	**Vol./km**	**Hybrid**	**Volume**	**Distance**	**Vol./km.**	**Hybrid**
1	67.00	4.60	14.57	0.42	75.46	20.05	3.76	0.76
2	62.34	5.15	12.10	0.31	65.04	20.05	3.24	0.64
3	64.19	5.15	12.46	0.28	58.19	20.05	2.90	0.65
4	67.42	5.2	12.97	0.32	56.55	20.05	2.82	0.54
5	67.87	4.35	15.60	0.42	63.71	20.05	3.18	0.67
6	51.43	4.45	11.56	0.39	59.02	20.05	2.94	0.71
7	49.52	3.4	14.56	0.29	54.78	20.05	2.73	0.62
TOTAL	429.77	32.30	13.31	2.43	432.75	140.35	3.08	4.59

Table 3: One-Way ANOVA Results for Volume Comparison

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.634314	1	0.634314	0.011586	0.916063	4.747225
Within Groups	657.0057	12	54.75047			
Total	657.64	13				

The result is an indication that the semi-automated waste management system as proposed can perform equally well as the fixed routing daily collection system which because it visits all nodes on daily basis is expected to attract heavy collection of wastes although at the expense of more distance covered. Comparing the distance covered by collection vehicles for the two systems of routing and waste collection however amply demonstrates the cost-saving potential of the proposed semi-automated waste management system. One-Way ANOVA statistical test conducted on the two streams of distance covered values as in Table 2, returned a p-value of (1.57×10^{16}) far more than the $\alpha - level$ of significance (0.05) used and a calculated F-statistic of 4021.172 which is far more than the critical value of F (4.747225).

Table 4: One-Way ANOVA Results for Distance Comparison

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	833.9145	1	833.9145	4021.172	1.57E-16	4.747225
Within Groups	2.488571	12	0.207381			
Total	836.403	13				

This shows that the semi-automated waste management system can enhance reduced travel distance of collection and by extension reduced collection time as compared to the trial and error fixed routing and collection system in which it is compulsory to visit all collection nodes because there is no a-priori knowledge of the state of waste generation in bin locations.

Conclusions: This paper examined a conceptual framework of a system of semi-automated waste management system using a simulated waste collection and routing network. The simulation results as compared to the case of fixed routing collection system amply justified the proposed system especially in terms of reduction in distance covered which also has bearing on time used in collection and by extension, routing and collection cost while it was also proved that the system can also perform as well as typical fixed route collection system in terms of volume of waste collected.

REFERENCES

Achankeng E., (2003). Globalization, urbanization and municipal solid waste management in Africa, African Studies Association of Australasia and the Pacific 2003 Conference Proceedings—African on a Global Stage, University of Adelaide, Adelaide, Australia.

Alemma-Ozioruva Aliu (2017) https://guardian.ng/saturday-magazine/challenges-of-managing-waste-disposal-in-nigeria/ Challenges of managing waste disposal in Nigeria. Nigeria: The guardian newspaper. August 2017.

Bakare, W. (2016) Solid Waste Management in Nigeria. BioEnergy Consult, Powering Clean Energy Future. https://www.bioenergyconsult.com/tag/nigeria/

Cointreau-Levine, S., (1994). Private Sector Participation in Municipal Solid Waste Management Service in Developing Countries. Vol. 1. The formal sector-UNDP/UNCHS/ The World Bank-Urban Management Programme. 52 pp.

LAWMA (2016). Action Plan for Sustainable Waste Management in Lagos State. LAWMA Report 2016.

Li, K. (2007). Study of Influence Factors in Municipal Solid Waste Management Decision Making. Master of Science Thesis, Royal Institute of Technology, Sweden

Manual, S. (2010). A Guide for Sustainable Urban Development in the 21st Century. *Shanghai, China*.

Ogwueleka, T. (2009). Municipal Solid Waste Characteristics and Management in Nigeria. *Iran. J. Environ. Health. Sci. Eng.*, 2009, 6(3), pp. 173-18

Onwuemele A. (2015). Determinants of Solid Waste Generation and Disposal Systems among Neighbourhoods in Benin City. *Inter. J. Soc. Sci. Hum. Rev.,* .5(2), 1– 10

Oresanya O. (2014). Waste control measures and responsibility of a waste manager within the framework of recent management methods and development in municipal and industrial wastes, *In Proceedings of the Workshop on Effective Waste Management in Nigeria, The Nigerian Society of Engineers, Lagos*, Nigeria.

Rogoff, MJ, Ross, D., & Wood, JL. (2010). Automated waste collection–how to make sure it makes sense for your community. *American Public Works Association (APWA) Reporter*, *77*(3), 44-48.

Un-Habitat. (2010). *Solid waste management in the world's cities*. UN-HABITAT.