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Solid Waste Collection Systems Optimization Using the Vehicle Routing Problem (VRP) Solver

Ilaboya, I.R, Aibangbee, O and Ehiorobo, J.

Department of Civil Engineering, Faculty of Engineering, University of Benin, P.M.B 1154, Benin City, Edo State, Nigeria

Abstract

In Nigeria and many other African countries, the volume of solid waste generated continues to increase coupled with lack of infrastructure for adequate waste treatment. Nigeria with a population growth rate of about 2.8% per annum and an urban growth rate of about 5.5 % per annum generates about 0.58 kg solid waste per person per day. The focus of this study is to evaluate the capability of VRP (vehicle routing problem solver) in optimizing solid waste collection systems in selected communities in Edo State, Nigeria. The study took a comprehensive evaluation of the solid waste composition in seven communities in Benin City; Edo State Nigeria. The communities include; Evbuotubu, Ekenwan, Ikpoba- Hill, Ogbebuya, New Benin Oko-Central and Ugbowo. Solid waste survey/ collection using the stratified random sampling approach was done on a daily bases for a period of eight (8) weeks in order to generate data for the analysis. For the optimization of the collection process a spatial geodatabase was designed and implemented, using a standard commercial GIS environment (ESRI, ArcGIS). Using the network analysis routines available from the software, previous spatial data for road network, existing routes, bins pickup and service times to load and unload bins were considered. The Vehicle Routing Problem (VRP) solver which is a component of Esri ArcGIS Network Analyst software extension was employed to optimize the solid waste collection system in order to estimate the optimum number of bins required to maximize the collection process. With reference to the current solid waste management practice in the study area, it was observed from the outcome of the study that; the total time spent for solid waste collection reduced from the initial 8.163hrs to 6.567hrs. The distance traveled per day reduced from 8,581.649m to 3, 282.339m. The total number of bins picked increased from 410tons to 510tons while the quantity of waste picked daily also increased from 20.5tons to 102tons. The findings of this study can serve as baseline document for government and other stakeholders responsible for solid waste collection for the establishment of a more sustainable solid waste management technique.

Keywords

Solid waste, Optimization, Collection systems, Solid waste survey

Article History

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1. Introduction

At present, municipal solid waste (MSW) generated in Nigerian cities are dumped into borough pits while some are disposed along road sides, causing threat to health of the citizens. This is simply because the waste management system has not attained acceptable standards (Onwughara et al., 2010). Efforts have been made by researchers to develop techniques to manage municipal solid waste in Nigeria and other developing countries with a view to reducing health hazards associated with poor management of solid wastes Odianna and Olorunfemi, 2021; Eze, 2010, Ogwueleka, 2009). Solid waste which is regarded as discarded, unwanted material which evolves from human activities of various kinds has increased globally in quantity due to the introduction of new products with new packaging materials; change in income; change in living standards; and life style (Maheshi and Udayangani, 2021; Kaushal et al., 2012). Ineffective solid waste management is a problem plaguing the environments of urban dwellings in Nigeria including Benin City. This is intrinsic to high volume of waste generated, lack of management funding and lack of expertise on the part of management personnel (Atikpo and Erameh, 2019). The menace of solid wastes managements is a common challenge faced in urban communities in the globe (Oyinloye, 2013). The current management level is considered ineffective in numerous African communities - rural and urban (World Health Organization - WHO, 1997; Atikpo and Erameh, 2019). Lack of good solid waste management system results in numerous problems - among which are health challenges, damage to environmental aesthetics, air quality degradation, flooding of highways and useful land mass, water contamination, and release of objectionable gases rendering ecosystems disharmonious and sickly (Ramiz and Yahya, 2017, Iro et al., 2012; Remigios and Wiseman, 2012). Some diseases associated with poor solid waste management are cholera, typhoid fever, malaria and laser fever (Sincero and Sincero, 2016). The above enumerated problems associated with poor solid waste management are also the occurrences in all communities in Benin City. In the light of these, sustainable solid waste management system is a solution which is the engineering approach (Atikpo and Erameh, 2019). The Engineering approach to this problem is a good solid waste survey and a more effective collection approach, hence the need for solid waste collection optimization (Sincero and Sincero, 2016; Intharathirat et al., 2015).

An attempt was made in this study to address the MSW collection optimization problem in in some selected communities in Benin City, Nigeria. The solid waste collection issue was modelled as a VRP with the ultimate target of finding the total distance travelled, total bins picked up and the amount of solid waste collected.

2. Research Methodology

Study Area Description

The study area includes selected communities in Benin City, namely; Ekenwan, Evbuotubu, Ogbebuya and Ugbowo. Others are; Ikpoba-Hill, New Benin and Oko-Central. The study area map is presented in Figure 1. Benin City lies between Latitude 6°20′17″ N and Longitude 5°37′32″ E with an elevation of 88 m above sea level. The city is influenced by two seasons, which are wet season (March to October) and dry season (October to March). Benin City has a borderline tropical savanna climate bordering upon a tropical monsoon climate. The weather is uncomfortably hot and humid year-round, and generally very dull, especially between July and September. It is one of the largest cities in Nigeria, located in southwestern part of the country, about 40 miles from the Gulf of Guinea.

The City has been experiencing rapid rural-urban migration and influx of displaced citizens from Northern Nigeria as a result of insurgency in recent times. Balogun and Onokerhoraye (2017) reported that population and spatial growth of Benin City are faster than the pace of infrastructure provision and that the lag between the growth of Benin City and infrastructure provision is impacting negatively on the quality of lives of the residents and threatens the sustainability of urban environment. Such a rapid growth leads to rapid increase in solid waste generation. With the exception of a few major streets swept daily within the urban agglomeration during week days, most neighborhoods in Benin City streets remain littered with solid wastes thus rendering the landscape insightful (Ogboi and Okosun, 2003).

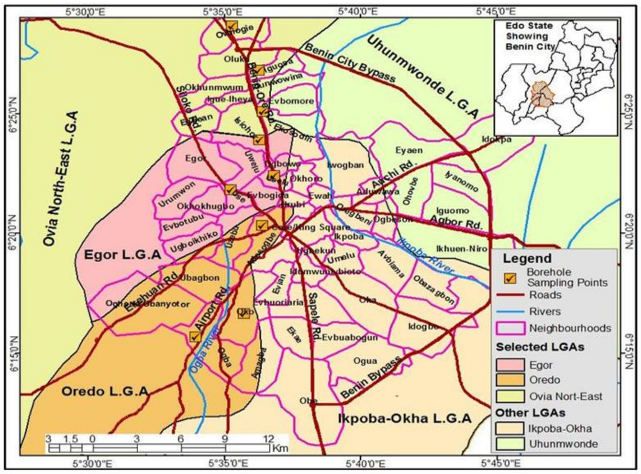

Figure 1: Map of study area

2.2. Materials/Equipment

2.2.1 Equipment for Data Collection

These include weighing scale, waste buckets, drums, dustbins, wheel barrows, bags, pencils, biros, notebooks, screening equipment, and a pick-up vehicle, hand gloves, face masks, hand trowels, hand forks, shovels, safety boots, helmets.

2.2.2 Household Survey

A survey questionnaire (400) per community was administered to 400 households in each community. The questionnaire was aimed at acquiring information about residents' attitudes towards waste, socio-economic characterization, waste management behavior (disposal and waste separation), problem faced with current management system, and how much they are willing to pay for waste management services, and whether they are aware of the possibility of converting waste to wealth.

2.2.3 Route Optimization Methodology

For the optimization of the collection process a spatial geodatabase was designed and implemented, using a standard commercial GIS environment (ESRI, ArcGIS). Using the network analysis routines available from the software, previous spatial data for road network, existing routes, bins pickup and service times to load and unload bins were considered. The Vehicle Routing Problem (VRP) solver which is a component of Esri ArcGIS Network Analyst software extension was employed to optimize the solid waste collection system in order to estimate the optimum number of bins required to maximize the collection process. The work flow diagram of the vehicle routing methodology which was designed based on GIS technology to highlight all the stages involved in a sequential order is presented in Figure 2.

The optimum network generated using the VRP was solved using the Network Dataset in Arcmap 10.1. The basic steps involved in solving the Vehicle Routing problem are as follows:

i. A Network analysis layer called vehicle routing problem analysis layer was created.

ii. To the newly created vehicle routing problem analysis layer, network analysis objects were added.

iii. VRP analysis layer properties were configured in the next step.

iv. Finally, the VRP solver solves the analysis layer.

The vehicle routing problem analysis layer is made up of 11 network analysis classes. They are orders, depots, routes, depot visits, breaks, route zones, route seed points, route renewals, specialties, order pairs, and barriers. These are either feature layers or tables stored within the VRP analysis layer. They contain the network analysis objects used in solving the vehicle routing problem. They also have various attributes that specify the inputs and outputs for a given vehicle routing problem. Input fields are used by the VRP solver to configure the problem, and we need to enter data into these fields (Chatzouridis and Komilis, 2012)

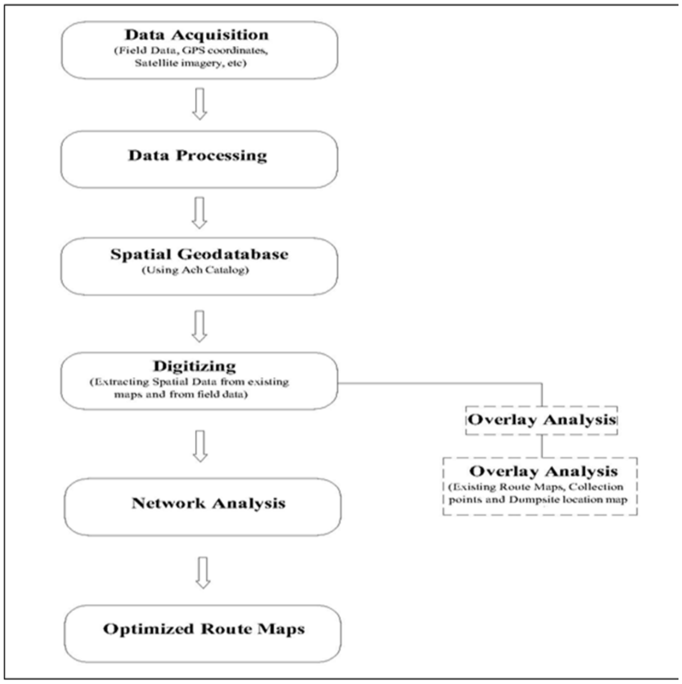

Figure 2: Route Optimization Algorithm

The output fields are used to store results and the solver itself writes into them. Input/output fields can either be edited or we can let the solver find the optimal value. To effectively carry out the optimization of waste collection route, the VRP solver required certain parameters which are presented in Table 1

Table 1: VRP solution parameters

S/N	Parameter	Time	Description
1	Start Time	8:00am	Time for work to commence
2	End Time	5pm	Closing time for the day
3	Break	30min	Morning /Launch break
4	Service time	15mins	Time required for transferring a waste bin into the truck and clearing up the area.
5	Volume	30Kg	Size of waste Bin
6	Volume 2	5000Kg (5 tons)	Size of truck
7	Route	10	Number of trucks owned by vendor (Average of 10).
8	Service time 2	30min	Time required to off load waste at dump site.
9	Route Zone	Area (m^2)	Area coverage of waste vendor

The base map showing the collection route network and the grouping of the different communities into zone is presented in Figure 3

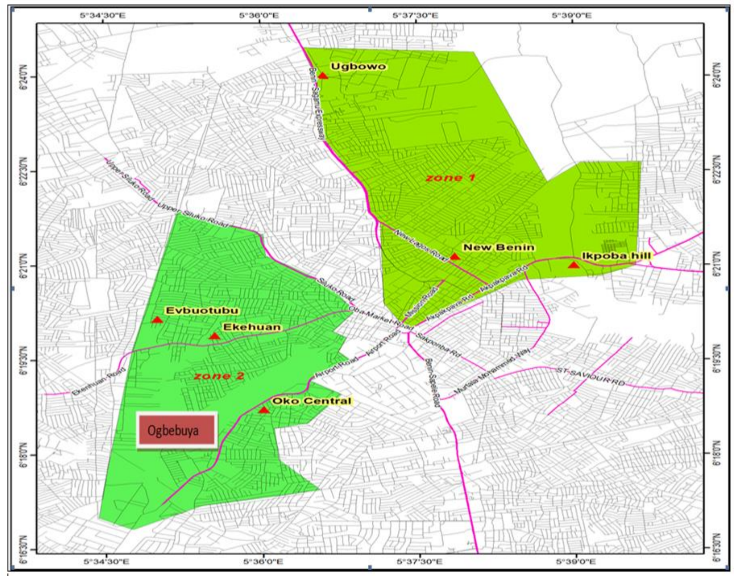

Figure 3: Network analyst base map showing the collection routs

From the base map of Figure 3, it was observed that two zones were created, namely; zone one and zone two. Zone one comprises of Ugbowo, New Benin and Ikpoba Hill while zone two comprises of Evbuotubu, Ekenwan, Oko Central and Ogbebuya. The assumption is that communities within the same zone will use the same dumpsite since it will make no sense to collect waste from Ekenwan (zone two) dump them in Otofure which is located in zone one. This assumption was first captured in the VRP solver before commencement of analysis.

The route solver analysis was run for two different scenarios. In the first scenario, bins were distributed at 60m apart as shown in Figure 4

Figure 4: Typical waste bin distribution at 60m interval

Under this scenario, the bin size was taken as 50kg, and a total of 12409 bins were used. In addition, each household was allowed to drop their waste in any of the bins and pick up was done at regular interval. The constraint here is that; because the bins are many, pickup may not be effective. In addition, some of the bins may not even be used and even when used, they may not be used optimally. This arrangement were bins are not effectively used will also affect the transportation process since it will also make no sense to transport waste to dumpsite when the trucks are not completely filled as this may eventually result to loss of man hour, underutilization of the bins and collection truck which will subsequently affect the efficiency of the collection process.

In scenario two, which is the optimized route systems, bins were located at major junctions of streets. In which case, fewer number of wastes collection points were adopted. This reduction in the collection points was meant to reduce the number of start-move-stop-slow movements of the collection vehicle. To achieve this, larger capacity waste collection bins of 200Kg size were used instead of the initial 50Kg capacity bins resulting in a total of 3263 bins. The bins were placed at major junctions along the collection route across all zones in the study area as presented in Figure 5.

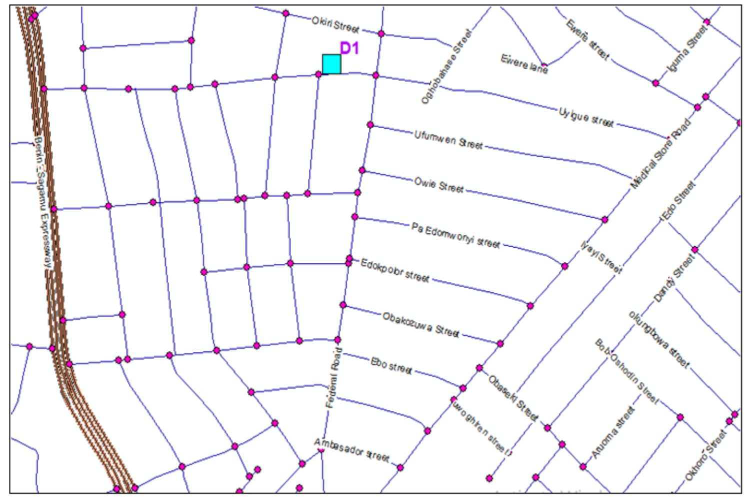

Figure 5: Optimized waste Bin at major Junctions

3.0 Results and Discussion

The breakdown of bin location for scenario 1 and 2 is presented in Table 2

Table 2: Breakdown of bin points for waste collection zones

	Normal Bins	Optimized Bins	Difference
Zone 1	6108	1581	4527
Zone 2	6301	1682	4619
Total	12,409	3263	9146

The result of Table 2 shows a difference of 4527 for zone 1 and 4619 for zone 2, this allows for less drive time and more effective pick-up system for each zone. In optimization of bin point the size of each bin at junction was 200Kg bin size which will allow for bulk collection of waste and easy pick-up and hence, drastic reduction in the service time. Information regarding the bin characteristics and the service time for pick-up for scenario one and two is presented in Table 3.

Table 3: Bin Characteristics for each scenario

	Number of Bins	Weight of Bins (Kg)	Service time for Pick up (min.)
Scenario 1	12409	50	15
Scenario 2	3263	200	10

Result of Table 3 revealed that fewer numbers of bins were required under the optimized systems compared to the unoptimized systems. In addition, service time for pick up reduced from 15 minutes for the unoptimized system to 10 minutes when the system was optimized. The implication is that the man-hour for collection had reduced, more waste was collected and more money will be saved. The vehicle routing solution is presented in Figure 6.

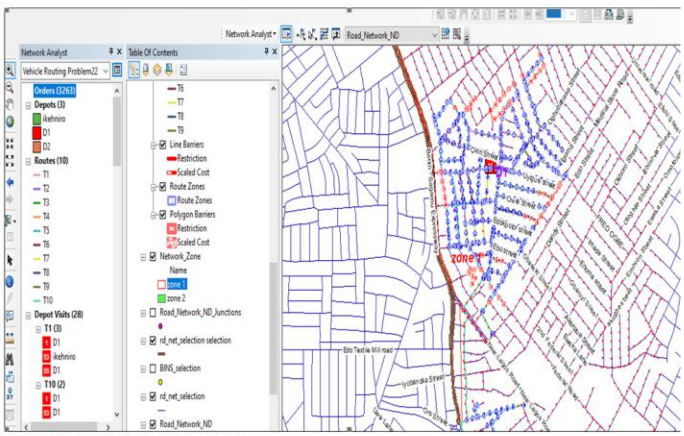

Figure 6: Vehicle Route solution in Arcmap

The final result of the route optimization is presented in Tables 5 and 6 respectively.

Table 5: Amount of waste Picked in Scenario 1 and 2.

	Zone 1		Zone 2	
	Scenario 1	Scenario 2	Scenario 1	Scena
Total Bin	6108	1581	6301	16
Total Bin Picked	410	508	410	51
Weight of Waste Picked (tons)	20.5	101.6	20.5	1(

Comparison between the result of scenario 1 and scenario 2 shows that for scenario 1 an average of 410 bins were picked up at an average return time of 6:55pm. For Scenario 2 an average of 51 bins were picked daily with a typical 10tonne truck which was seen to visit the waste dump site at least once, with an average depot return time of 6:55pm. The amount of waste picked during the optimized (scenario 2) and unoptimized (scenario 1) shows that in the optimized model (scenario 2), more than 500 bins were picked using 10 trucks of 10tons in a day amounting to about 101.6 tons of solid waste in zone 1 and 102 tons of solid waste in zone 2 compare to the unoptimized system in which less than 420 bins were picked using 10 trucks of 5 tons per day amounting to about 21 tons of solid waste picked. The difference between the optimized and the unoptimized system in terms of the total waste picked was estimated to be about 81 tons.

Table 6: Comparison of Unoptimized and Optimized Collection Systems

S/N	Route Component (Single Truck)	Unoptimized Systems	Optimised Systems
1.	Total Distance Covered (m)	8,581.649	3,282.339
2.	Total Time spent (Hr)	8.163	6.567
3.	Total Number of Bins Picked daily	410	510
4.	Quantity of waste Picked Up daily (tons)	20.5	102

Comparing the unoptimized waste collection systems with the optimized waste collection systems shows that the difference between the total distances travelled between both systems is 5,299km. The value shows that more points will be picked up within the 8hr daily working schedule of the collection crew. Also, the difference in total bins picked up is 100 and this is attributed to the time spent in scooping waste with shovels and head pans and loading of the truck in the unoptimized collection systems. While the optimized collection system picks an average of 102tons of waste and dispose at the dump site before closing hour, the unoptimized collection system does approximately one fifth of this in the same day.

In the case of the present unoptimized practice, 410 waste bins are likely to be evacuated in a day and this make up 6.7% of the total bins. In which case, an average of 14 days will be required to collect all the bins at that rate. In addition, since 5 ton truck cannot be filled in a single day under this present practice, there is the need for solid waste to be collected in truck over the night and to be filled the next day. This will further lead to waste of man hour and increase the collection cost in addition to increased fuel consumption. More also, since time is a critical factor in solid waste management, it will suffix to say therefore that the optimized systems is a far better technique for the achievement of sustainable waste management strategy compared to the unoptimized systems.

4.0 Conclusion

An attempt was made in this study to evaluate the performance of the VRP problem solver for the optimization of solid waste collection systems in selected communities in Benin City Nigeria with the view of determining the optimum number of bins required for the effective collection of solid waste generated. Comparing the unoptimized waste collection systems with the optimized waste collection systems, it was observed that; there is a reasonable difference in terms of total distance travelled, total bins picked up and the amount of solid waste collected.

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