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Article

Rational Approach To Optimization Of Solid Waste Collection Routing Using GIS: A Case Study Of Adentan West Residential Area Of Accra

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Abstract: Vehicle routing is a critical factor in municipal solid waste (MSW) collection planning and operations. Poor routing can introduce inefficiencies and cause targeted levels of services or performance to be missed irrespective of the level of resource application. Trial and error approaches have been proven to be not the best in the planning and prediction of expected performance. This study explores various Geographic Information System (GIS) tools and analysis techniques, and how they can be applied to optimizing vehicle routes in light of challenging site conditions. Using Adentan West residential area, suburb of Accra Ghana as a case study, current performance of the trial and error method was measured and a GIS computer model was used to evaluate various optimization scenarios to determine the level of savings that can be made. Field measurements were taking with Global Positioning System (GPS) devices for waste collection activities in areas with varying characteristics and conditions, and data analysed for one selected vehicle operating four days per week. It was found that, for a scenario where only the bin collection order was optimized while route selection was restricted by the ArcGIS Network Analyst, 2.6% of travel distance and 2.21% of travel time were saved. For the second scenario where only the route selection was optimized while order of bin collection was restricted, 4.1% and 1.5% of travel distance and time respectively were saved. For a third scenario where both the order of collection and route selection were together optimized, 10.9% and 3.7% of travel distance and time respectively were saved. Lastly, by regrouping all the bins for daily collection, 4.5% and 1.2% of travel distance and time respectively were saved. The results demonstrated that there is always room for optimization of solid waste collection routing irrespective of site constraints and other challenges that the nature of bin distribution pose to drivers. In developing countries like Ghana, where there is high demand for services in the face of limited road network access, application of GIS in optimization of routes will guide providers in planning and subsequently make more savings in fuel consumption, vehicle maintenance and cost of man-hours.

Keywords: GIS in solid waste collection; waste vehicle routing; ArcGIS Network Analyst; waste bin allocation; municipal solid waste management

1. Introduction

Solid waste collection and disposal is increasingly becoming expensive in Ghana in response to population growth and changing lifestyles. Improved economic conditions have contributed to increased production and consumption of manufactured and packaged goods resulting in the massive production of solid waste. A critical issue to waste collection is the high cost of haulage, mostly due to long distances between generation points to final dumping sites as well as heavy vehicular traffic resulting in increased travel times. This contributes to higher capital investment requirements and recurrent costs for service providers, ultimately leading to higher service charges. Transportation

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accounts for a significant operational cost in waste management in developing countries like Ghana [11]. Thus, it is important to keep costs of transportation low when planning for a sustainable waste management. This is especially important for local authorities, the main providers of waste management services either directly or indirectly through subcontracting part or the entire operation. Optimisation of collection and transport routing systems for municipal solid waste has thus become very necessary to achieve effective and efficient solid waste management system. The problem of vehicle routing is similar to the classic Travelling Salesman Problem (TSP), where a vehicle travelling in a study area must visit all waste bins in a way that minimises total travel cost in terms of time and distance [17]. However, due to the network restrictions, optimising routing of solid waste collection networks becomes an asymmetric TSP (ATSP) which requires adapting to TSP algorithm. The growing interest in the relevance of Geographic Information Systems (GIS) models in decision making and the many related benefits have caused several authors to investigate route optimisation in waste collection transport [18]. Some benefits that may be generated as a result of GIS optimization of are reduction of travel time, distance, fuel consumption and pollutants emissions [19,21–23]. In Ghana and other developing countries in Africa, GIS has been extensively applied in optimization of MSW management. [8] used GIS and remote sensing to estimate the population at the settlement level, in addition to solid waste generation, waste spread and waste density. The study concluded by proposing an approach which is primarily based on fieldwork, primary and secondary data and the result of the spatial analysis. [7] attempted to map out and analyze the spatial distribution of solid waste collection points in Urban Katsina using GIS approach. The Study revealed a strong relationship between the amount of illegal disposal points and population density. They therefore recommended for more authorized collection points in the medium population density areas and population to be used as a criterion for facility allocation. They stressed on the need to institutionalize the use of GIS in waste management. In Tanzania, [10] demonstrated the effectiveness of GIS in assisting in increasing information and efficiency of solid waste collection system in an urban settlement. [12] and [24] applied GIS in the selection of suitable places that could be used as waster transfer stations. [15] went further to include break-even analysis and economic justification for the evaluation of possible location for transfer stations. A transport analysis was done in a GIS, which showed the difference in transportation distances between having decentralized and centralized composting and waste sorting stations in Kumasi [11]. [1] analysed Wa Municipality's waste collection system efficiency and pollution risk due to proximity of communal containers to hand-dug wells drinking water sources were using a GIS model. Fuzzy Logic and Multi-criteria Evaluation (MCE) in GIS environment was applied in the selection of landfill site in the Sekondi-Takoradi Metropolis [5]. [4] were able to identify two main forms of solid waste collection. These were found to be the house-to-house and communal container collection. The house-to-house was for the middle to high income communities and low-density suburbs. The communal container collection was for the low income and high-density haphazard suburbs where infrastructural facilities are in bad state and in some cases none existent. They argued for a comprehensive approach that combines infrastructure improvement and solid waste management processes that can improve the inefficiencies to ensure quality sanitation. To measure the actual level of service and performance achieved in light of these infrastructure constraints, [14] investigated the efficiency of companies involved with solid waste collection services within the Kumasi Metropolis. This was achieved through the assessment of their scope of operations, operational efficiency regarding time spent and trips made, and operational cost as it related to customers' satisfaction. The results from the customer satisfaction survey showed that companies whose services were found satisfactory where those with high overall efficiencies. [14] succeeded in establishing methodologies for obtaining all parameters necessary for efficiency estimation. Most importantly, it clearly demonstrated the application of GIS in solid waste collection operation and performance evaluation.

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This Study has demonstrated ways to optimize routing performance through the application of GIS techniques. In 2012, the Ghana Youth Engagement in Service Delivery (YES) Program introduced GIS system training to companies to improve their ability to track their collections, decrease lost revenue from missed collection points, decrease fuel costs and route times through optimized collection routes. It was reported that some contractors applying GIS recorded improvement in their services, hence others have shown interest in using GIS in their planning [25]. To increase knowledge in this area, this Study has gone further to model and assess typical field conditions to see how much their resulting inefficiencies can be reduced or eliminated. The underlying objectives of the Study are to measure performance of existing trial and error routing; analyze and quantify losses due to non-rational routing; and to evaluate optimization techniques and estimate the amount of monetary savings that can be made. Various GIS tools and analysis techniques and how they can be applied to optimizing vehicle routes in light of challenging site conditions are explored. The results from this study should guide service providers with adequate information on how to determine the optimum performance that can be achieved from vehicle routing for a selected service area. Using Adentan West residential area as a case study, current performance of the trial-and-error method was measured and a GIS computer model was used to evaluate various optimization scenarios to determine the level of saving that can be made.

2. Materials and Methods

2.1. The study area and existing conditions

The name Adentan West Area as used in this study is adopted from the name given to this area by the service provider for operational purposes. Geographically, the name can also be deduced from its relative West position to the Adentan Municipal. As shown in Figure 1, the study area lies within two districts of the Greater Accra Region. These are Ga East District and La Nkwantanang-Madina Municipal. The study area covers mostly these rural communities which are urbanizing rapidly through the development of residential accommodation and commercial entities on the land due to its proximity to commercial and administrative centers of Madina and Accra. As much as 84% of the population live in urban areas with the rest occupying the vanishing rural areas.

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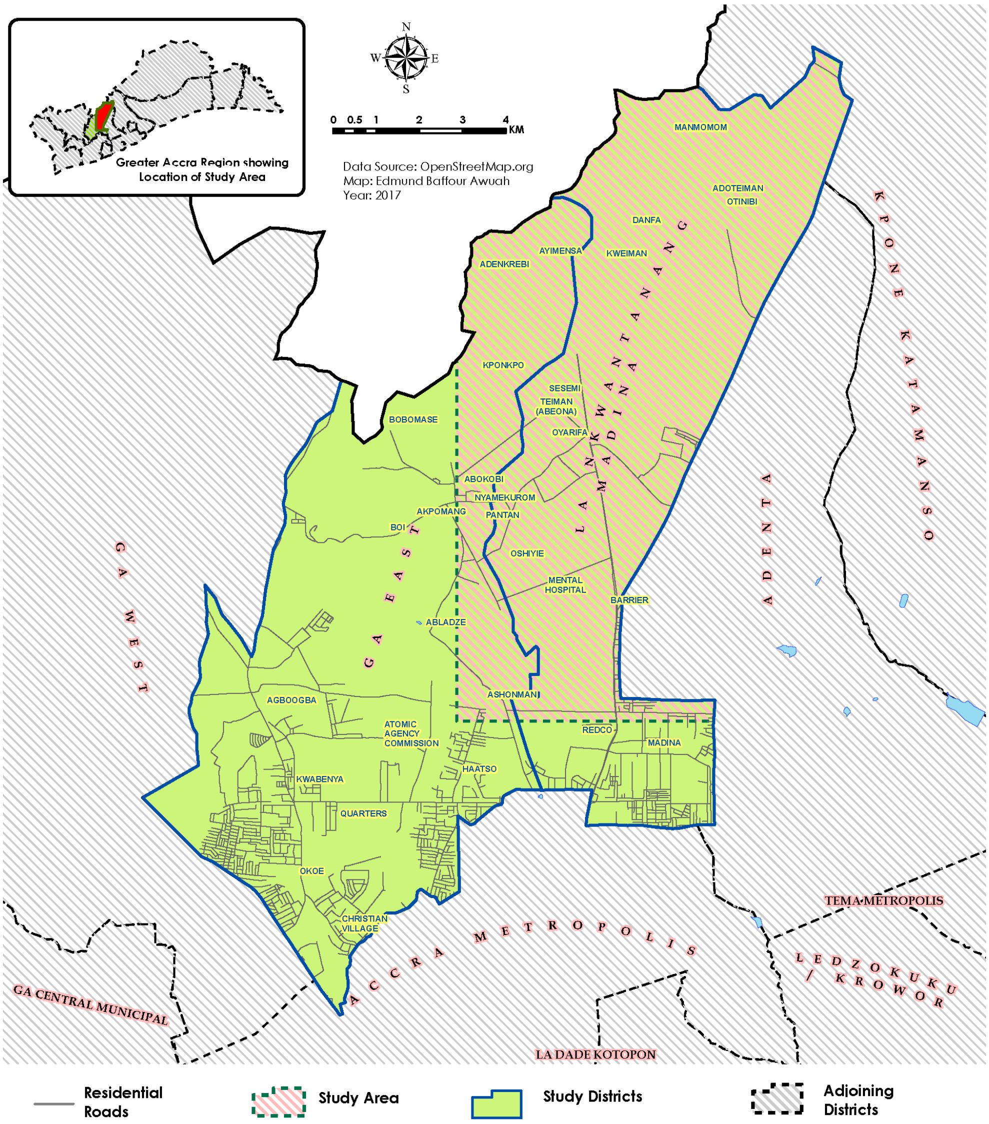

Figure 1. Location of study area.

It has three main major roads of very significant daily traffic volumes. All other roads are considered residential due to their current status and not their expected functional classification. Over 80% of the residential network is unpaved and in fair to poor condition. Some are only earth roads yet to be engineered and improved. Most housing developments within the area are very recent and therefore yet to receive the right level of road infrastructure. Door-to-door collection is the dominant solid waste collection type practiced in the area. The landuse is mainly residential in nature with the exception of some few factories like the Special Ice Company which produces mineral water and drinks within the area. Therefore, the waste type collected are mainly domestic in nature. All the households are served either by the formal or informal collectors. About six formal waste collection companies operate within the Municipal and all can access customers from the study area. Alliance Waste Limited, the service provider used for this study, is the largest collector within the area. The area also has the Abokobi landfill site which is just about 3 km from the N4 highway and about 7 minutes' drive from the study area. This is the only landfill site available within a radius of over 15 km and therefore attracts waste from even other districts and municipals. For the purpose of this study, the area was divided into four service areas based on the daily coverage of the 4-day collection services provided per week by the collection company (Alliance Waste Ltd.). The service areas are as defined in Table 1. All these four service areas are served by the same truck, from the same parking spot and dumps waste collected at the same landfill site. These made it easier to conduct comparative analysis to see how physical characteristics of these areas affect performance of service delivery.

Table 1. Location and operational days of service areas.

Service Area (SA)	Communities Served	Operational Days
SA1	Shalom, Pantang PnT, Abokobi	Wednesday
SA2	Adentan New Site	Thursday
SA3	Adentan, Oyarifa	Monday
SA4	Oyarifa, Damfa	Tuesday

Figure 2 shows the general methodology used for this research.

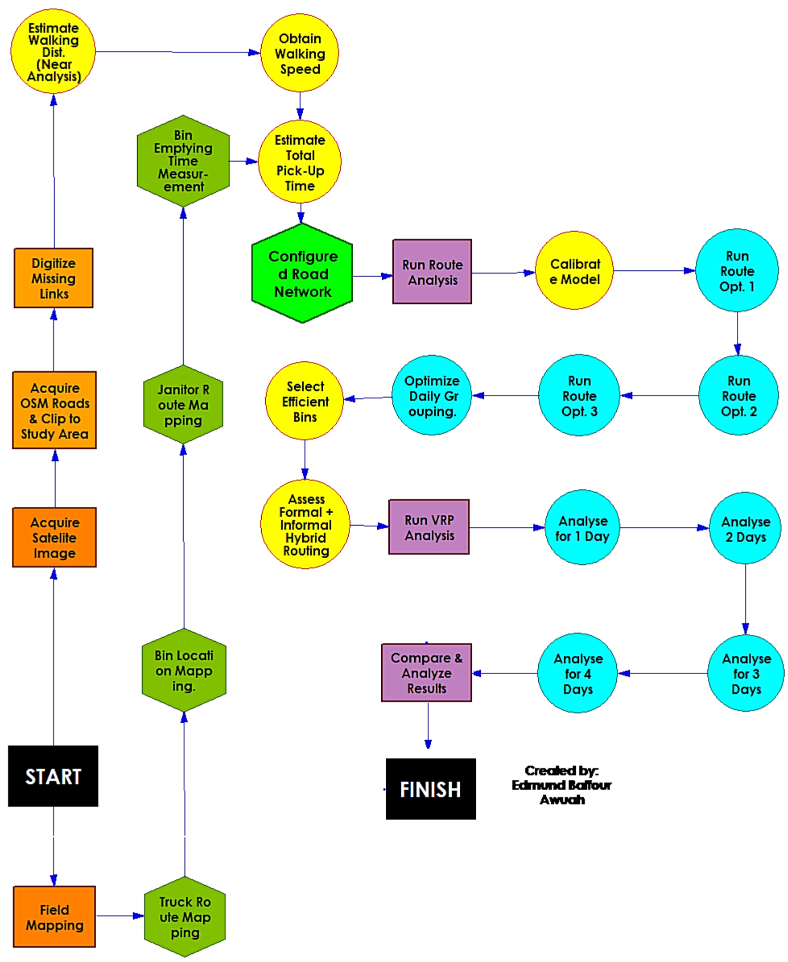

Figure 2. Methodology flow chart.

Trial mapping was done for 1 day for one service area to confirm and modify, where necessary, planned approach to the field measurements. Actual field data collection was done for 3 months (April to June 2017). For each service area, data was collected for 12 weeks and this was done once per week following the regular frequency of service for the area. Two Garmin handheld GPS devices were used for the recording and capturing of all field GIS data. One was hanged in the driver's compartment of the vehicle to track and record distances and durations as the vehicle moves including the path of travel. One was also hanged on one of the janitors to track and record walking lengths, durations and path of travel as they walk to pick and return bins from their locations. The locations of all bins were mapped using the GPS including any stored waste for which the truck stops or janitor walks to collect. The number of bins at each location was also taking into consideration during the mapping. Also, the mapping was done to follow the exact sequence of collection of the bins. For each measured track of a particular trip, the following values of relevance are generated by the Expert GPS 5.15 software;

- Distance covered in meters;
- Duration of travel in seconds; and
- Minimum, maximum and average speeds measured in km/h.

Figure 3 shows the various bins and roads measured at the four service areas.

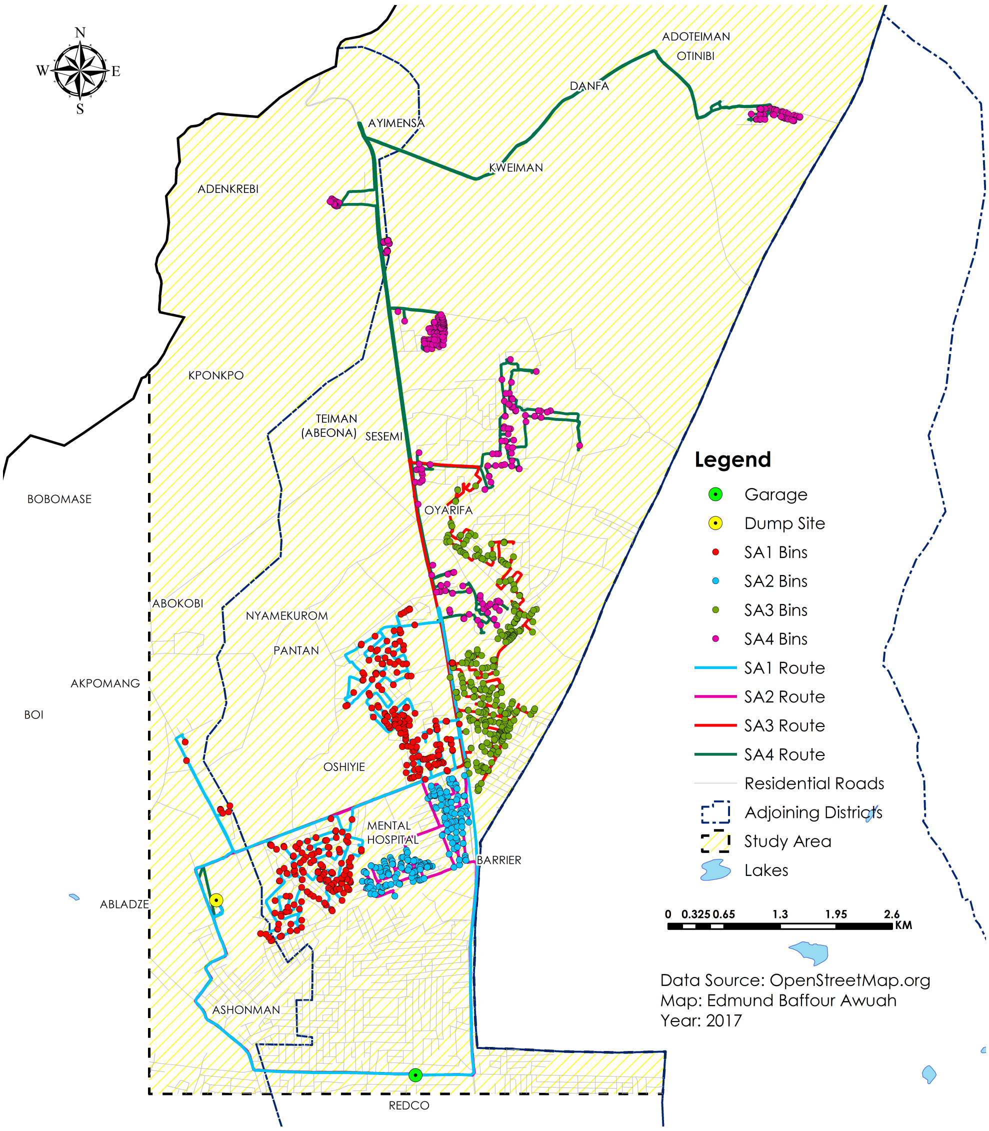

Figure 3. Truck routes and bin locations for service areas.

2.2. Road Network Centrelines

Due to the usual outdated state of the network data, missing road segments or links are digitized manually to cover all relevant portions of the project area. Some road links are realigned to current shape and length as seen on the satellite image or recorded by

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the GPS devices. The coverage of the network was clipped to the area of interest to reduce the volume of links and nodes for quicker running of the model (see Figure 4).

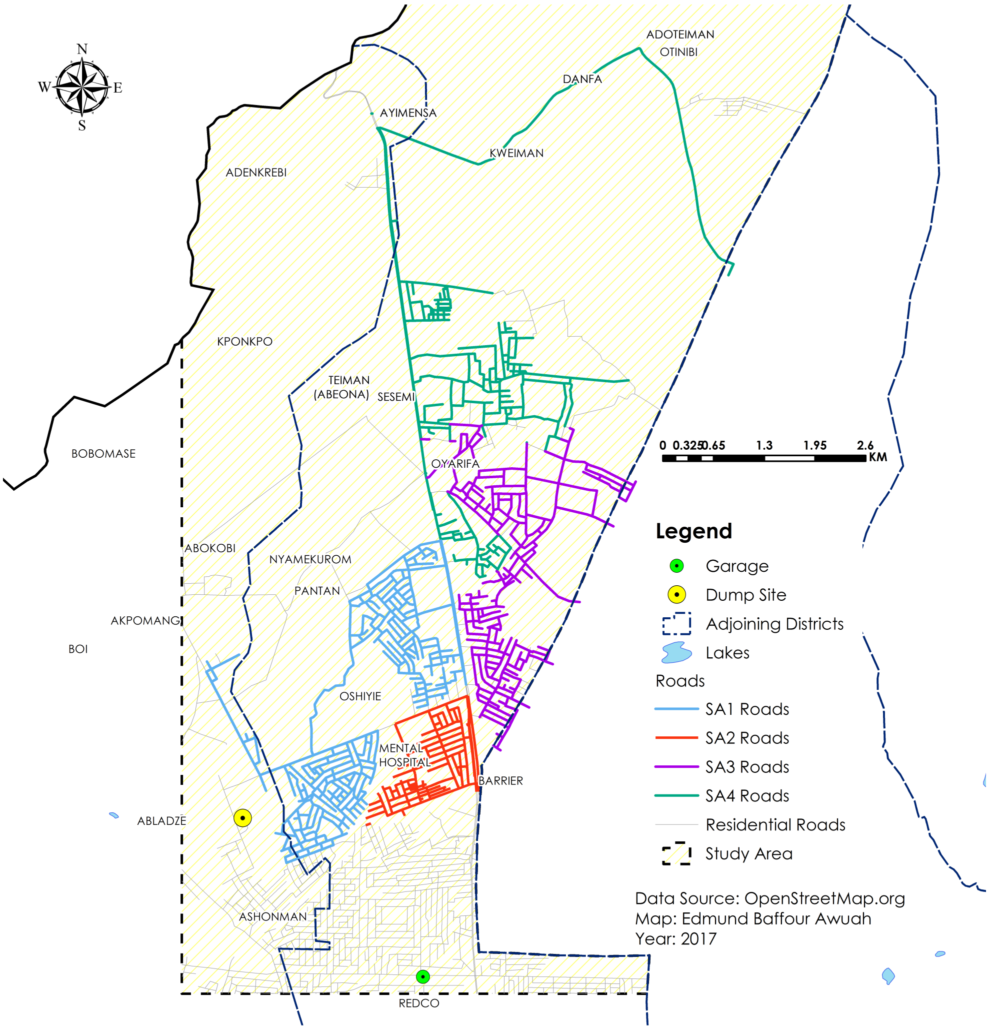

Figure 4. Road network within service areas.

2.3. Road Classifications

To appreciate the level of delay during collection, the classification of road segments had to be accomplished. All road segments were classified and coded based on Ghana Highway Authority's Functional Classification system (Figure 5). Adherence to this classification system was closely followed except for a few modifications necessary to fit the study. Table 2 shows a list of the functional classifications, their definitions and the number of road segments associated with each classification. Table 2: Urban area functional classification system

Table 2. Urban area functional classification system

Functional Classification	Basic Functional Classification Definition	Road Segments	Design Speed (KPH)
Primary or National	Link Ghana to neighboring countries	13	80
Residential or Urban Collector	Circulation within and into residential neighborhoods, commercial and industrial areas. Collects from local streets and channels to arterial	1820	30
Secondary or Inter-Regional Roads	Connect 2 or more region. Connect big towns to primary system	40	60
Tertiary or Regional Roads	Serves as collector roads between the road system and the secondary and primary system	163	40

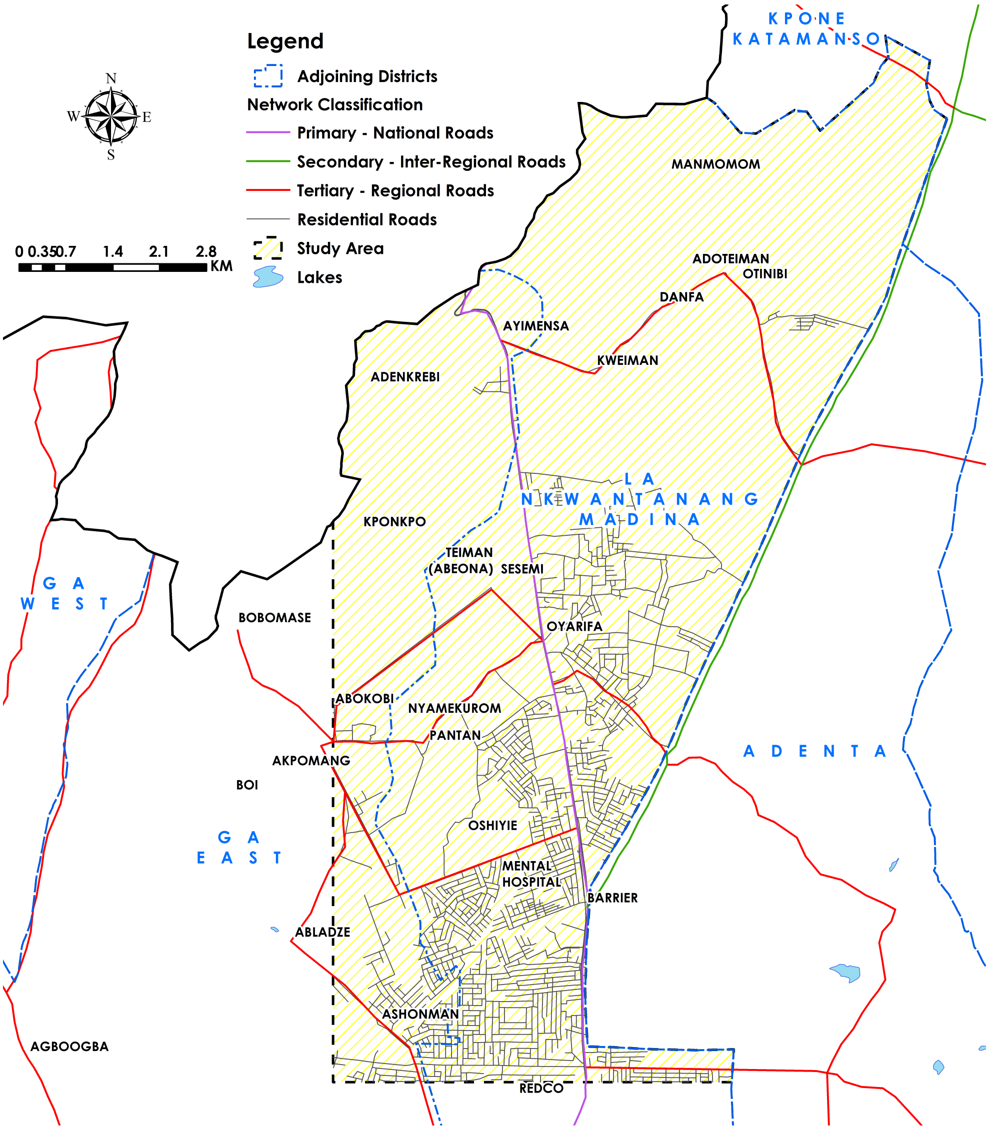

Figure 5. Road network and functional classification system.

2.4. Configuration the Network Analyst Tool and Calibration of the Road Network Dataset

The main objective of the calibration is to get the computer network model to simulate realistic travel times and distances as achieved at field. The Network Analyst tool of the ArcMap 10.1 software was used to create, modify and run the model. The main measured parameters that were needed for the calibration are;

- Pick-up time per bin;
- Coordinates of bin locations;
- Collection route of vehicle;
- Road network model configured with average speeds of vehicle;
- Sequence or order of collection; and
- Average duration at dump site.

The main parameter that reflects the level of delay on routes and varies is the average speed (Table 3) that the truck moves on the routes. Challenges and constraints on various routes are reflected in its attained speeds. Road segments that trucks did not use for measurements to be taken were given average values of other measured roads that they are connected to.

Table 3. Classes of Roads and Speeds Measured

Road Type	Speed Limit (KPH)	Minimum Vehicle Speed (KPH)	Maximum Vehicle Speed (KPH)	Average Vehicle Speed (KPH)	Speed Level Achieved
Primary Roads	80	7.30	68.00	48.45	60.60%
Residential Roads	30	0.60	62.50	12.63	42.10%
Secondary Roads	60	6.00	46.60	32.03	53.40%
Tertiary Roads	40	4.50	62.50	19.46	48.60%

In configuring the network dataset, some parameters like length, turns and restrictions of the routes are fixed and cannot be varied in any way. After selecting New Route Analysis from the Network Analyst toolbar, point and line barriers were used to guide the vehicle to start from the same point, use the same route in the same order of visits to bins, landfill site and finally return home. The average speeds selected for network links are then adjusted, varying the values between the minimum and maximum till the travel times and distances achieved by the route is approximately as attained from field measurements. The network is then considered calibrated since the level of impedance assigned allows it to closely mimic real field conditions. Using this calibrated network, the model was then used to run other scenarios to meet the objectives of the project. At the end of the calibration, the results shown in Table 4 were achieved.

Table 4. Summary of Measured and Calibrated Results

Service Area	Measured Distance (m)	Measured Duration (min)	Calibration Distance (m)	Calibration Duration (min)
SA1	49,094.12	483.5	49,093.7	487.06
SA2	26,374.49	353.4	26,374.56	350
SA3	40,214.67	563.7	40,214.65	564.2
SA4	63,327.87	462	63,326.14	464.36

2.5. Cost Data

In order to express savings in time and distances in monetary terms, cost values were selected from estimates done by [15] for a typical waste compacter vehicle operating in Ghana. The unit costs of time and distance for the waste compactor truck estimated from the data are as shown in Table 5.

Table 5. Summary of Cost Data and Estimated Unit Costs

Cost	Time-Based	Distance-Based	Total
Total (GH¢/yr)	14,309.0	77,821.0	92,130.0
Total (GH¢/month)	1,192.0	6,485.0	7,677.0
Total (US$/yr)	7,155.0	38,910.0	46,065.0
US$/hr	3.7	-	-
US$/km	-	2.4	-

Source: [15]

2.6. Measuring Geographic Patterns of Bin Locations

The tools considered in the pattern analysis of bin locations were Average Nearest Neighbour and High/Low Clustering toolsets. These tools are inferential statistics which start with the null hypothesis that the features exhibit a spatially random pattern. The p-value is then computed to indicate the probability of the null hypothesis being correct. The questions that these tools were needed to answer were;

1. Are the locations of bins generally spatially clustered or dispersed?
2. Which areas are the clustering intense and what is the degree of intensity?

The z-scores and p-values returned by the pattern analysis tell whether the null hypothesis can be rejected or not. A confidence level of 95% was selected for the analyses and at this level, to reject the null hypothesis, the z-score must be either less than -1.96 or greater than +1.96 and the p-value must be less than 0.05 (5%).

2.6.1. Average Nearest Neighbor

This tool calculates a nearest neighbor index based on the average distance from each feature to its nearest neighboring feature. The Nearest Neighbor index is expressed as the ratio of the Observed Mean Distance to the Expected Mean Distance. The expected distance is the average distance between neighbors in a hypothetical random distribution. If the index is less than 1, the pattern exhibits clustering; if it is greater than 1, the trend is toward dispersion.

2.6.2. High/Low Clustering

This tool measures the degree of clustering for either high values or low values using the Getis-Ord General G statistic. The higher (or lower) the z-score, the stronger the intensity of the clustering. A z-score near zero indicates no apparent clustering within the study area. A positive z-score indicates clustering of high values. A negative z-score indicates clustering of low values.

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3. Results

3.1. Baseline Results from Current Trial and Error Approach to Waste Collection Routing

The results have been summarized into service and journey trips. Journey trip comprises of site, landfill, roaming and home trips. The distances and travel times measured for trips covered in the various service areas are as shown in Table 6. A linear regression analysis showed a strong positive correlation between service distance and the spatial factors, with NB, OMD and z-score values explaining about 88%, 95% and 91% of the variations in the SD values respectively (Table 6). This explains why although SA1 had the highest number of bins but SA4 had the highest service distance and highest OMD value. The bins in SA4 are relatively farther away from each other compared to those of the other service areas and therefore more distance covered to reach bins.

Table 6. Nearest Neighbor Analysis Results for Bins

Measure	SA1 Bins	SA2 Bins	SA3 Bins	SA4 Bins
Service Distance, SD (km)	35.46	13.06	22.73	37.83
Journey Distance, JD (km)	12.3	13.84	25.02	25.5
Total Distance, TD (km)	47.76	26.9	47.75	63.33
Service Time, ST (hrs)	7.21	4.55	7.65	6.35
Journey Time, JT (hrs)	0.85	1.34	1.75	1.35
Total Time, TT (hrs)	8.06	5.89	9.4	7.7
No. of Bins, NB	370	241	323	348
Observed Mean Distance, OMD	25.5	16	21.7	29
Expected Mean Distance, EMD	158.6	196.8	170	185.3
Nearest Neighbor Ratio, NNR	0.161	0.081	0.128	0.157
z-score	5.57	2.02	4.07	7.87

The relationships were generally positive between service time and the spatial factors. Most significantly, about 65% of the variations in the service time (ST) values were explained by the variations in number of bins (NB), but the correlations were not strong for effects of z-score and OMD on service time (Table 7).

Table 7. Results of Regression Analysis

Analysis	Intercept	Slope	R Square
SD against NB	-34692	194.099	0.885
SD against OMD	-19664	2030.18	0.954
SD against Z-Score	5212.45	4488.38	0.906
ST against NB	1319.29	68.118	0.653
ST against Z-Score	18347.2	955.931	0.246
ST against OMD	11152	514.69	0.36

3.2. Optimization of Bin Collection Routing

Although current routing is assumed to be trial and error but this study recognizes the fact that it has evolved over time with the increasing level of familiarization of the driver with the terrain. In light of the many constraints that exist, the driver learns to achieve the best performance that the everyday trial and error system can allow him to. Various scenarios have therefore been assessed, taking into consideration some possible conditions that may pertain to the site to see how the computer's routing models will also perform after configuring it to mimic exact conditions. The optimization scenarios were run using the Route Analysis tool of ArcGIS Network Analyst.

3.2.1. Scenario 1 (Opt1): Optimization of Collection Sequence Only

After selecting a New Route from the Network Analyst toolbar, point barriers were placed on all roads within the service areas that were not assessed by the driver during field mapping but allowed the analysis to reorder travel paths to find optimal routes. The strategy was to avoid any unused road as the driver does at the field but changing the order of collection for less service duration and distance. The assumption was that these unused roads could be completely inaccessible and therefore the driver has very little room to select any other route other that the current. However, the order of collection is due to the driver's own judgement and could be optimized. The best route selected for SA2 from this scenario is as shown in Figure 6 which is the same as current route since no unused route was selected. SA2 gave the highest savings in distance (2.6%) and SA1 gave the highest savings in duration (2.21%) (Table 8). With all values of savings being positive, they show that even with the tightest conditions or constraints as in Scenario 1, computer optimization can achieve a better performance than the trial and error system. A total annual savings of US$ 336.71 was made on trip distances and durations.

Table 8. Results of Optimization Scenario 1

Service Area	Savings per Week	Level of Weekly Savings	Annual Cost Savings
SA1 Distance (km)	0.786	1.60%	$90.55
SA2 Distance (km)	0.687	2.60%	$79.14
SA3 Distance (km)	0.594	1.48%	$68.41
SA4 Distance (km)	0.315	0.50%	$36.25
SA1 Duration (mins)	10.74	2.21%	$31.85
SA2 Duration (mins)	3.72	1.06%	$10.95
SA3 Duration (mins)	5.22	0.92%	$15.39
SA4 Duration (mins)	1.44	0.30%	$4.17
Total	-	-	$336.71

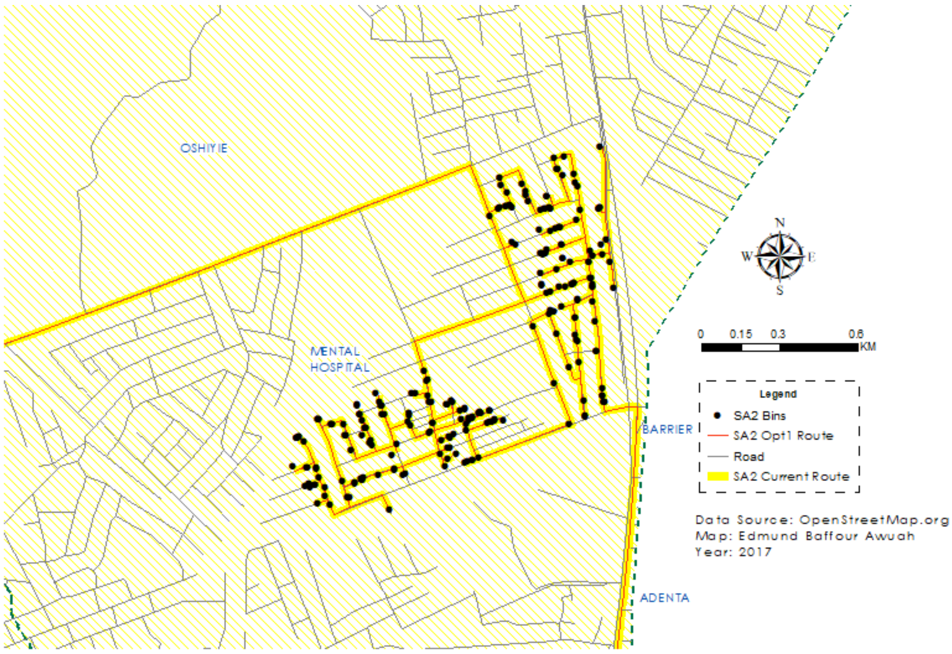

Figure 6. Map of SA2 Showing Current Route and Opt1 Route.

3.2.2. Scenario 2 (Opt2): Optimization of Route Selection Only

The strategy was to use all roads within the service area but follow the exact order of collection that the driver did at the field. The assumption was that due to the position of the car park and the dumping site, it only made sense to follow the current sequence of collection which was to start with the farthest bin from the dumping site but easily reachable from the car park. The driver then works his way towards the dumping site with the last bin served being the closest to the dumping site. The best route selected for

SA2 from this scenario is as shown in Figure 7. SA2 gave the highest savings in distance (4.06%) and SA1 gave the highest savings in duration (1.49%) (Table 9). A total annual savings of US$ 540 was made on trip distances and duration.

Table 9. Results of Optimization Scenario 2

Service Area	Savings per Week	Level of Weekly Savings	Annual Savings	Cost
SA1 Distance (km)	1.283	2.61%	$147.83	
SA2 Distance (km)	1.071	4.06%	$123.36	
SA3 Distance (km)	1.111	2.76%	$128.03	
SA4 Distance (km)	0.762	1.20%	$87.73	
SA1 Duration (mins)	7.26	1.49%	$21.49	
SA2 Duration (mins)	3.78	1.07%	$11.10	
SA3 Duration (mins)	4.68	0.83%	$13.85	
SA4 Duration (mins)	2.58	0.55%	$7.58	
Total	-	-	$540.97	

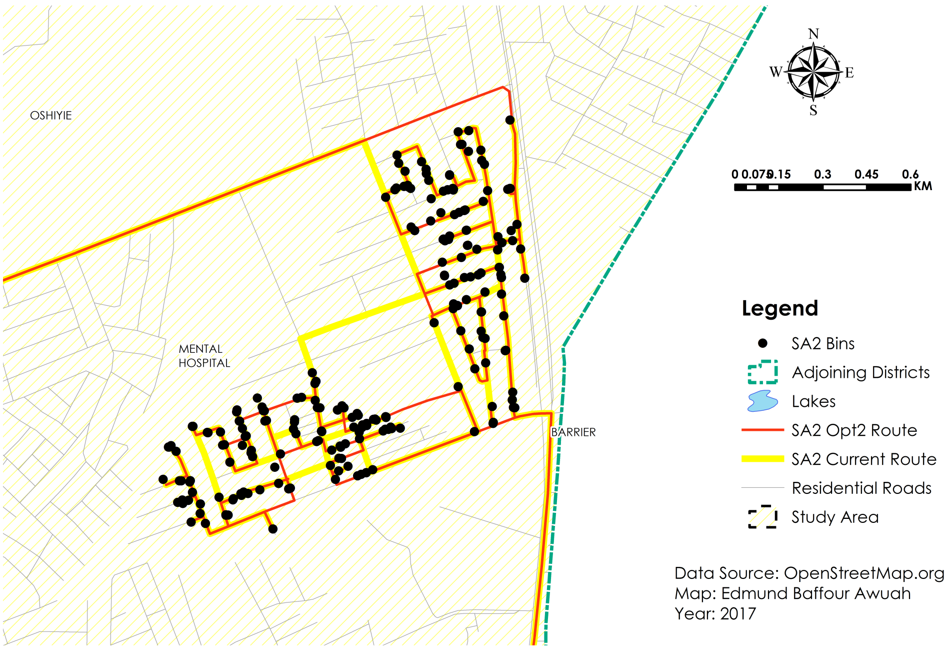

Figure 7. Map of SA2 Showing Current Route and Opt2 Route.

3.2.3. Scenario 3 (Opt3): Optimization of Both Collection Sequence And Route Selection

The strategy was to use all roads within the service area and also change the order of collection. The assumption was that all opportunities were available to the driver and his decision for the current route was just what he had judged to be the best. The best route selected for SA2 from this scenario is as shown in Figure 8. SA1 gave the highest savings in distance (10.9%) and SA2 gave the highest savings in duration (3.71%) (Table 10). To save as high as 14m on each bin as can be seen for SA1 shows that the computer can give a significant and better performance. Even for the lowest saving of 8m per bin made for SA4, this can be considered as quite significant since this can translate into savings in fuel and maintenance cost of the vehicle. A total annual savings of US$ 1,583.88 was made on trip distances and durations.

Table 10. Results of Optimization Scenario 3

Service Area	Savings per Week	Level of Weekly Savings	Annual Cost Savings
SA1 Distance (km)	5.356	10.91%	$617.05
SA2 Distance (km)	1.944	7.37%	$223.92
SA3 Distance (km)	2.666	6.63%	$307.16
SA4 Distance (km)	2.548	4.02%	$293.49
SA1 Duration (mins)	15.06	3.09%	$44.58
SA2 Duration (mins)	13.02	3.71%	$38.48
SA3 Duration (mins)	14.22	2.52%	$42.03
SA4 Duration (mins)	5.82	1.25%	$17.17
Total	-	-	$1,583.88

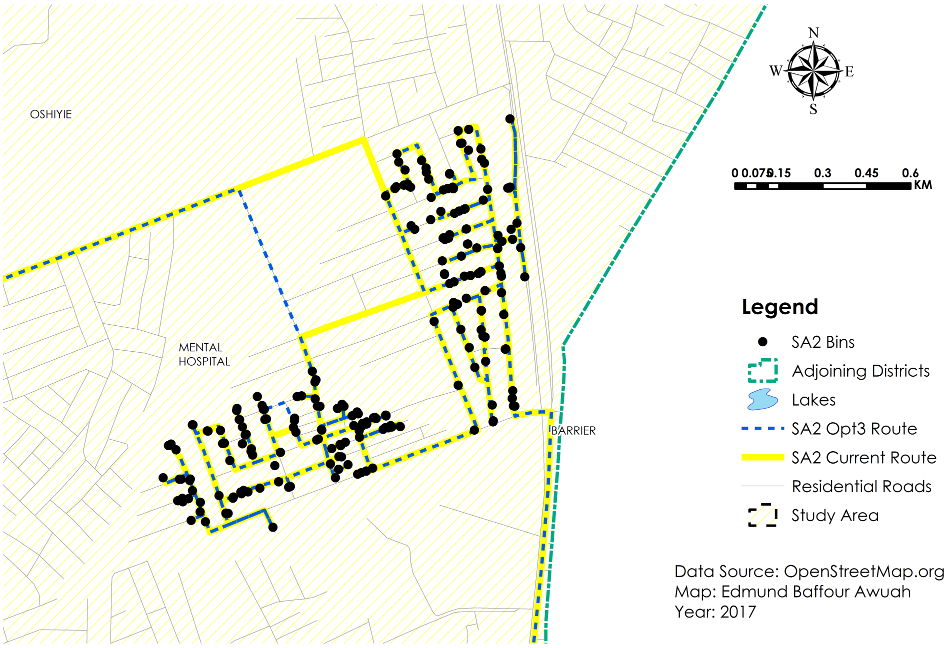

Figure 8. Map of SA2 Showing Current Route and Opt3 Route.

3.3. Optimization of Bin Grouping

Since the group of bins served in each day by the truck defined the service area (as termed for the purpose of this study), it was necessary to assess how the bins within the study area have been grouped for daily collection and to see how much savings can be made after optimization into new groups. The selection of bins for a group is normally guided by the following;

- Number of bins and quantity of waste to be picked;
- Order or sequence of collection; and
- Capacity of truck.

The Route Solver tool in ArcGIS Network Analyst was first used to establish the optimum sequence of collection by allowing the model to consider all bins as one group. The pickup quantity of waste at each location was then used to select the group of bins that make up the 15-ton capacity of the truck. Selection of bins followed the generated sequence of bin collection and the selected group of bins is considered as the daily group of bins to be served if one trip is to be made per day for the 4-day available period. Figure 9 and Figure 10 show the distribution of daily grouping as existing currently and as optimized for better performance respectively. The average distance per bin was reduced from 95.3 m to 91 m representing 4.5% savings in distance as a result of the optimization (Table 11 and Table 12).

Table 11. Service Distance Results for Existing Grouping

Day	**Bins Collected**	**Distance Covered (km)**	**Distance (m) per Bin**
Day1	372	36.26	97.47
Day2	242	14.85	61.35
Day3	326	28.75	88.19
Day4	323	43.3	134.05
Daily Average	316	30.79	95.3
Weekly Total	1263	123.15	381.1

Table 12. Service Distance Results for Existing Grouping

Day	**Bins Collected**	**Distance Covered (km)**	**Distance (m) per Bin**	**Savings**
Day1	313	20.96	66.97	-
Day2	323	24.21	74.96	-
Day3	308	40.1	130.21	-
Day4	319	29.25	91.69	-
Daily Average	316	28.63	91	-
Weekly Total	1263	114,53	363.8	-
Level of Weekly Savings	-	-	-	0.045
Savings per Week	-	-	-	8.62 km/wk
Annual Cost Savings	-	-	-	US$ 993.34

Also, the total duration to serve all bins was reduced from 424 minutes to about 417 minutes, representing 1.2% savings in duration as a result (Table 13 and Table 14). A total annual savings of US$ 1,078.78 was made on both distance and duration of service after optimization of bin grouping.

Table 13. Service Duration Results for Existing Grouping

Day	**Bins Collected**	**Duration (mins)**	**Duration (mins) per Bin**
Day1	372	448.4	1.21
Day2	242	291.8	1.21
Day3	326	550	1.69
Day4	323	406.2	1.26
Daily Average	316	424.1	1.3
Weekly Total	1263	1696.4	5.4

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Table 14. Service Duration Results for Existing Grouping

Day	Bins Collected	Duration (mins)	Duration (mins) per Bin	Savings
Day1	313	372.2	1.19	-
Day2	323	396.8	1.23	-
Day3	308	497.3	1.61	-
Day4	319	401.2	1.26	-
Daily Average	316	416.9	1.3	-
Weekly Total	1263	1667.6	5.3	-
Level of Weekly Savings	-	-	-	0.012
Savings per Week	-	-	-	28.86 mins/wk
Annual Cost Savings	-	-	-	$ 85.45

Figure 9: Map showing Current Bin Grouping

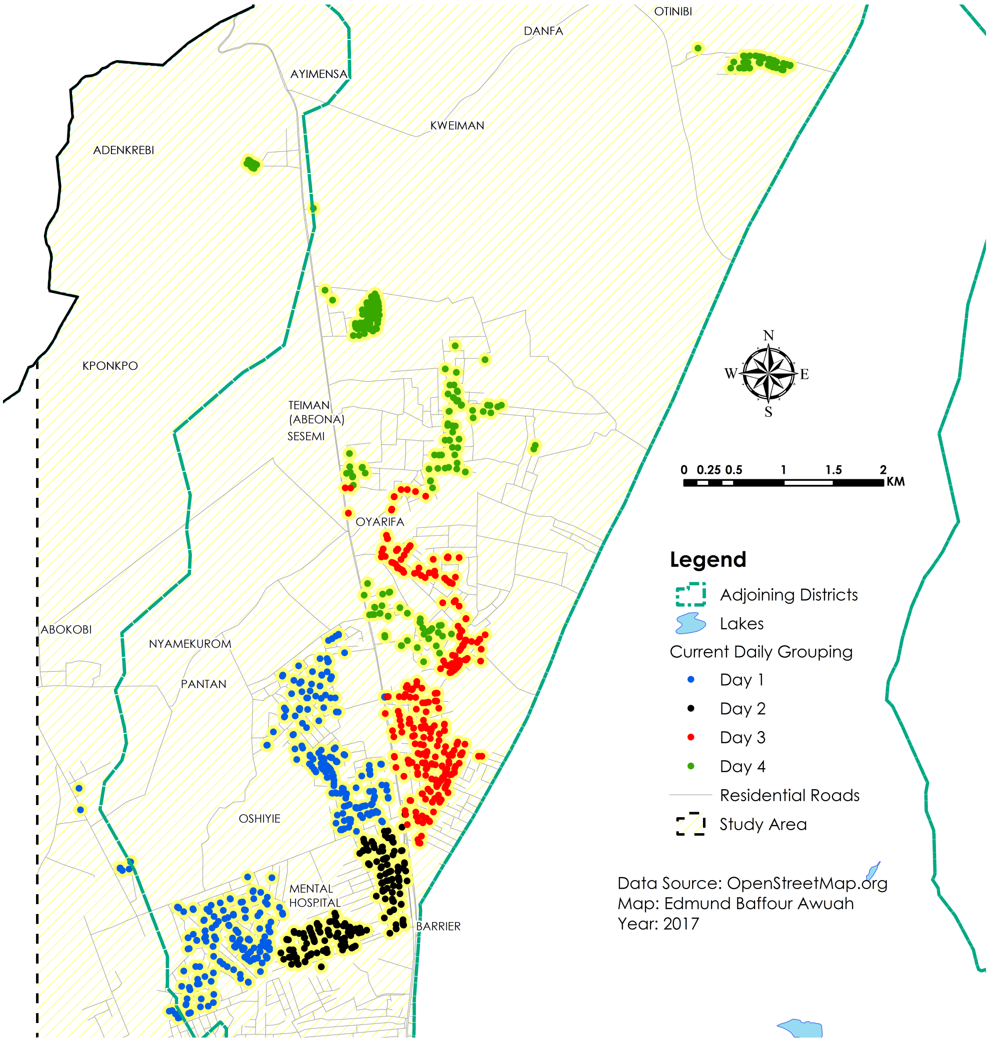

Figure 9. Map showing Current Bin Grouping.

Figure 10: Map showing Optimized Bin Grouping

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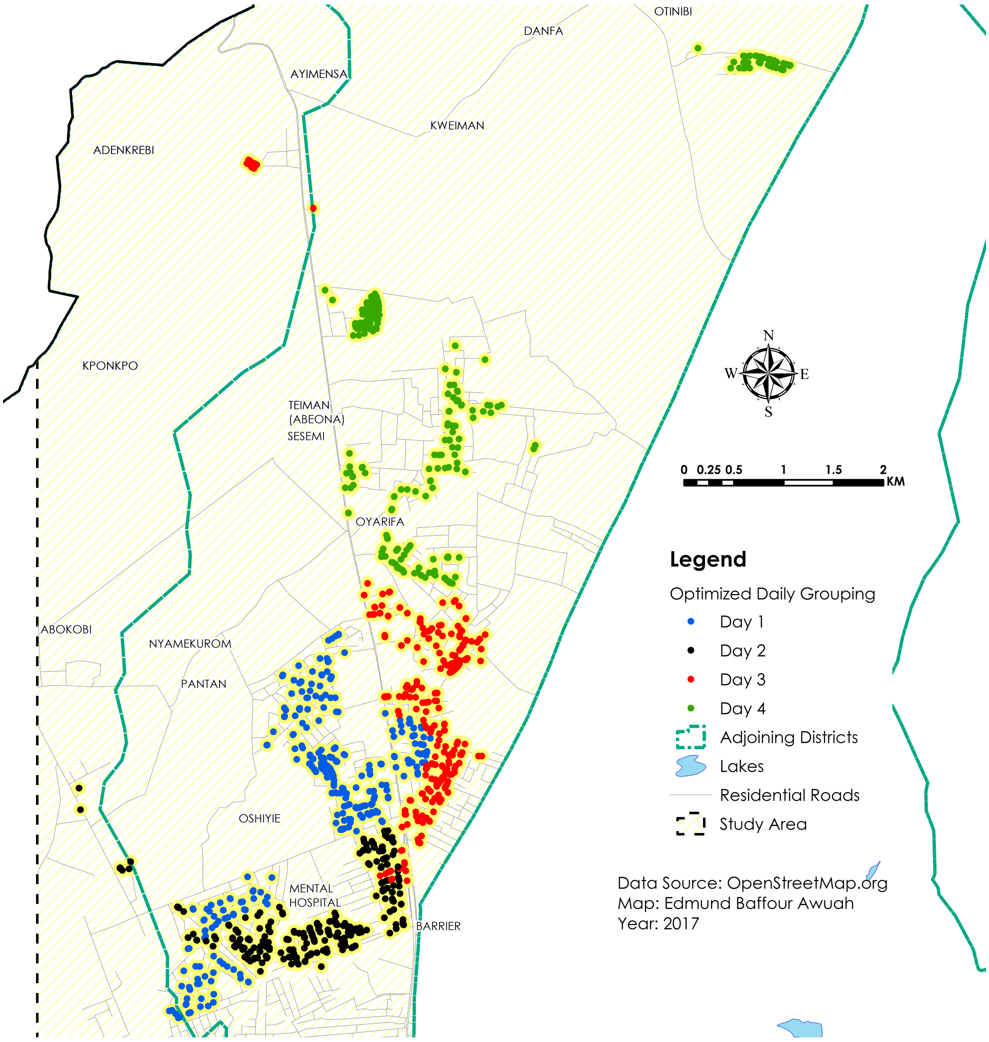

Figure 10. Map showing Optimized Bin Grouping.

4. Conclusions

Simulation of field performance has been successfully achieved after calibrating the road network model with real travel time and distance results collected from the field. All bin placements exhibited clustering pattern and could be described as highly clustered. A total distance of 185.74 km was covered and 31.05 hours spent in collection routing every week. A strong positive linear correlation was established between service distance and intensity of clustering. However, correlation between service duration and intensity of clustering was not significant. In terms of routing efficiency, an average of 82 m/bin was measured for routing distance and 1.2 min/bin for routing duration. The model was then used to run various optimization scenarios too see how much savings can be made. The study demonstrated the value of GIS technology as a waste collection optimization tool, capable of supporting decision making, in the context of residential area with poor and inadequate road network like the Adentan West area. The adoption of this technology could provide significant financial and environmental benefits for local communities as even with the tightest conditions or constraints at the field as in the case of Scenario 1, computer optimization can achieve a better performance than the trial and error system. Where there is enough room like in Scenario 3, savings as high as 14m were made on trips to each bin this is considered significant since this can translate into a total annual savings of US$ 1,583.88 in fuel and maintenance cost of the vehicle.

Abbreviations

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The following abbreviations are used in this manuscript:

MSW	Municipal Solid Waste
GIS	Geographic Information System
GPS	Global Positioning System
TSP	Travelling Salesman Problem
ATSP	Asymmetric TSP
MCE	Multi-criteria Evaluation
YES	Youth Engagement in Service Delivery
SA	Service Area
KPH	Kilometer per Hour
NB	Number of Bins
OMD	Observed Mean Distance
SD	Service Distance
TD	Total Distance
ST	Service Time
JT	Journey Time
TT	Total Time
EMD	Expected Mean Distance
NNR	Nearest Neighbor Ratio
wk	Week
yr	Year
Opt	Optimization
Dur	Duration
Dist	Distance
m	Meter
km	Kilometer
mins	Minutes
hr	Hour

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