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IN-TOWN TOUR OPTIMIZATION OF CONVENTIONAL MODE FOR MUNICIPAL SOLID WASTE COLLECTION

A. S. Aremu
DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF ILORIN, ILORIN, KWARA STATE, NIGERIA
E-mail address: aremu_adeniyi@yahoo.com

Abstract

This study illustrates the application of a simple and efficient Solver add-in tool in Microsoft Office Excel© 2010 software for in-town tour optimization of solid waste collection. Data required for tour optimization was obtained from the municipal authority, field studies, and a digitized map of Ilorin, Nigeria while collection operation was formulated as a Traveling Salesman Problem on Excel spreadsheet. The results obtained from the optimization of ten prominent routes revealed that two empirical routes had the same tour distance as the optimized tour. However, in the remaining eight routes, the optimization process reduced tour distance by 2.04-19.27 %, tour time by 0.33-22.80 %, and fuel consumption by 1.78-20.54 %. The cost incurred in purchasing diesel is also expected to decrease by US$0.11-US$1.65/vehicle/day. Therefore, the proposed method can serve as a valuable tool for reducing some socio-economic and environmental impacts associated with solid waste collection.

Keywords: Solid waste, hauled container, conventional mode, Traveling Salesman Problem, tour optimization

1. Introduction

Solid waste collection is widely recognized across the globe to account for majority of expenditure on solid waste management [1, 2]. Typically, collection costs represent 80-90% and 50-80% of municipal solid waste management budget in low income and middle income countries respectively [3]. In Nigeria, solid waste collection accounts for about 70-80 % of the total cost of solid waste management [4]. In a bid to reduce collection costs, municipal authorities have been forced to develop new strategies for the collection of solid wastes, particularly in urban centers.

The hauled container system for municipal solid waste collection using the conventional mode has gained prominence in areas with high waste generation and accessibility problems, especially in the developing world [5]. The system requires a large container to be stationed at a service or collection point where waste generators drop their wastes. Collection trips involve the movement of full containers to the disposal site and return of empty containers to service points. Each daily collection route begins at the garage, and after picking assigned number of waste containers, the collection vehicle returns to the garage. Daily collection routes are established based on collection requirements (fullness and location of waste containers).

Finding the optimal route to collect waste containers from dispersed service points within an urban center is an important aspect during solid waste collection. This is because substantial benefits in terms of social, economic and environmental gains accrue from route optimization. For example a route optimization process using Route View Pro™ Software [6] resulted in 4-59 %, 14-65 % and 24.7 % decrease in distance, time and monthly costs respectively. Also the heuristic method used by Ogwueleka and Agunwamba [7] for route optimization in two cities in Nigeria led to a savings of 19.08 and 28.17 km per day, reduction of 7.65 and 21.09 % collection costs, and improvement in collection efficiency by 12 and 20 %. Another study by Chakias and Lasaridi [8] which used GIS technology as the optimization tool resulted in 3-17 % and 5.5-12.5 % reduction in collection time and distance respectively. This could in turn decrease the economic, health and environmental burden of solid waste collection activities since they are related to collection time or distance travelled by the collection vehicle. Other significant advantages of route optimization include reduction in vehicle maintenance expenditure and improvement in traffic conditions [9], and reduction in emissions per route [10].

The optimal routing problem of collection vehicles can be classified as either a Chinese Postman Problem (CPP) or a Traveling Salesman Problem (TSP), formulated for vehicles to perform routing over essential nodes or arcs in a network with respect to some constraints [11]. In the CPP, the collection vehicle is routed over the branches of a network while in the TSP, it is routed over the nodes in a network. The routing problem in the use of conventional method for municipal solid waste collection is essentially a TSP. It requires the creation of the shortest tour through the assigned service points (container locations/nodes) such that for every collection operation, the full container in each service point is disposed and the empty container is brought back to the same location. General solutions to TSP include exact method (i.e branch-and-bound and cutting plane algorithms), heuristic method (i.e nearest neighbor and sub tour reversal algorithm), and metaheuristics such as tabu search, simulated annealing and genetic algorithms [12, 13].

This paper applies the widely used spreadsheet software; Microsoft Office Excel©, to solve a TSP in the conventional method for municipal solid waste collection. The add-in "Solver" tool in Microsoft Office Excel© is considered to be a fast and flexible tool for large and cumbersome TSPs [14]. Also, spreadsheets allow the integration and modification of several variables which is similar to route modeling with specialized software [15]. More importantly, the 2010 version of Microsoft Office Excel© contains the "alldifferent" constraint and "Evolutionary Solver" which significantly reduces computation time and provides efficient solutions based on genetic algorithms.

2. Materials and Methods

2.1 Description of the Case Study and Collection System

The city of Ilorin; the case study, is the largest urban centre in Kwara State, North central Nigeria. It is composed of three Local Government Areas: Ilorin West, Ilorin East, and Ilorin South. Ilorin has a population of about 800,000, lies at latitude 8°30'N and longitude 4°35' E, and occupies an area of 89 km^2 [16]. The estimated waste generation from residential land use types is 0.22 kg/capita/day, while waste generation from commercial land use types ranges from 0.038 kg/m^2/day to 0.155 kg/m^2/day [17].

The Kwara State Waste Management Company (KWMC), a public – private sector partnership, is the organization responsible for the distribution of waste bins and collection and disposal of wastes in the city. The waste bins are locally fabricated metallic Roll-on-roll-off waste bins of capacity 7.54 m^3. The waste bins are placed at predetermined positions along the shoulders of major roads within the metropolis. KWMC uses a fleet of medium sized collection vehicles; *Iveco Euro Cargo 100E18* manufactured by Iveco Company, Italy, to haul the waste bins. The mode of operation of the conventional method for municipal solid waste collection is presented in Figure 1. Each collection trip comprises of unit operations including a round trip to the disposal site. The vehicular movement in a collection route comprises of two flows:

(1) In-town movement: Garage → Waste bin locations →Garage
(2) Out-town movement: Waste bin location → Disposal Site → Waste bin location

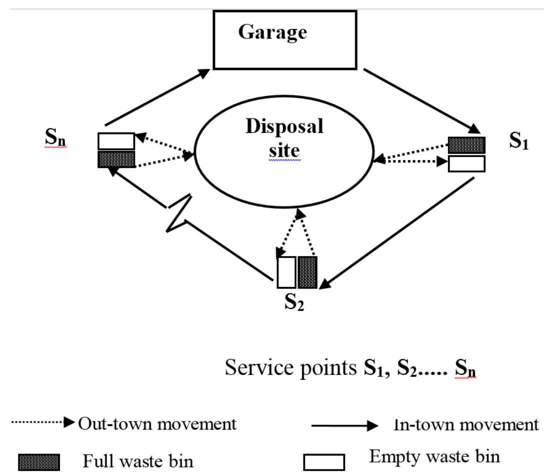


Figure 1: Operation sequence for the conventional mode

Flow (1) consists of a single origin and several destinations before getting back to the origin. Flow (2) consists of several origins and a single destination. Flow (1) and (2) make up a complete route. Flow (2) is usually straight forward especially if the destination is a single disposal site. Flow (1) requires the decision of the tour through the service points. Specifically it represents the movement of the collection vehicle from the garage through the service points and back to the garage to complete a day's work. This flow is similar to the curbside collection method but has no capacity limitation. The TSP in this study is to find the shortest travel distance to accomplish a collection tour in Flow (1), which is a subset of the total collection route.

2.2. Data Collection

Data on empirically developed daily collection routes for twelve months was obtained from the KWMC. The frequency of collection of the waste bins varies widely, hence a total of ten collection routes which showed a combined prominence of about 75 % out of the obtained data were selected for analysis. The spatial distribution of service points (waste bin locations) in the studied routes within Ilorin metropolis is shown in Figure 2. Each route consists of *n* waste bins to be picked in order to complete a day's work. Parameters such as waste bin location (for *i* = 1 to *n*) and vehicular movement during the collection of these waste bins were obtained from field study. Other data related to each collection route and required for the estimation of tour parameters were obtained from a digitized map of the city and literature. Basically the parameters examined under each tour are distance, time, fuel consumption and cost.

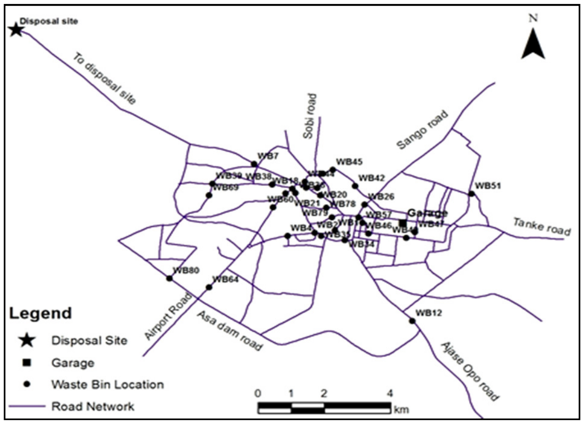


Figure 2: Spatial location of waste bins in the studied routes within Ilorin metropolis

2.3. Optimization of Collection Tour

The optimization model to solve the TSP using the Solver add-in tool available in standard Microsoft Excel© 2010 package was developed following the Premium Solver Platform procedure of Jiang [15]. The procedure entails three basic steps:

2.3.1. Creation of Excel worksheet and defining the initial tour sequence.

In this step, an origin-destination (O-D) matrix for each route which represents the Euclidean mileage matrix of all the nodes in the route is created in Excel spreadsheet. For example, as shown in Figure 3, the O-D matrix for Route 1 is I3:P10. Next the initial tour is defined such that the collection vehicle begins and ends the day's work at garage (G), i.e Cells A4:A11 contain integer values 1 to 8 while Cell A12 has the formula "=A4" and it assures that the tour ends at garage (G) where the tour began. The Excel function VLOOKUP() is then used to obtain the waste bins associated with the integer values (1-8) in the initial tour (A4:A11). For example the Excel formula for B4 is: =VLOOKUP(A4,$D$4:$E$11,2) and this function is also applied to fill Cell B5 to B12. The distance from one waste bin to the next is found using the Excel function INDEX and this instruction finds the associated distance from the O-D matrix. For example Cell C5=INDEX($I$3:$P$10,A4,A5) and this formula is equally used to fill Cell C6 to D12.The total distance of the initial tour (sum of Cell C5 to C12) is represented by Cell C13.

2.3.2 Operation of Solver dialogs

The solver dialogs are activated to define the objective, cells to change, constraints, and the solution method (Figure 4). The objective is defined by the spreadsheet cell to optimize; that is to minimize Cell C13, which contains the total tour distance. The cells to change in order to minimize the total distance are A4:A11, which hold the integer values assigned to the eight waste bin locations. The constraint in this problem is that there will be only one entry and one exit to each waste bin, and the tour will end where it began. This is implemented by declaring that the values in cells A4:A11 will be "all different" and this option is only available in Microsoft Excel 2010 and higher versions. The solution method selected is the "Evolutionary" method i.e using genetic algorithm.

2.3.3 Creation of the solution

The solution to TSP in Microsoft Excel using the Solver dialog box is obtained by clicking the *solve* button. In the example in Figure 4, once the *solve* button is clicked, the *Solver* performs some iterations by rearranging the tour sequence in Cells A4 to A11. Finally, the optimal solution is presented in Cell C13.

The optimized tours generated from the Microsoft Excel© Solver tool were then compared with empirical tours generated by officials of the waste management company. Euclidean distance from the empirically generated tour and the distance obtained from the Solver solution were used for analyses.

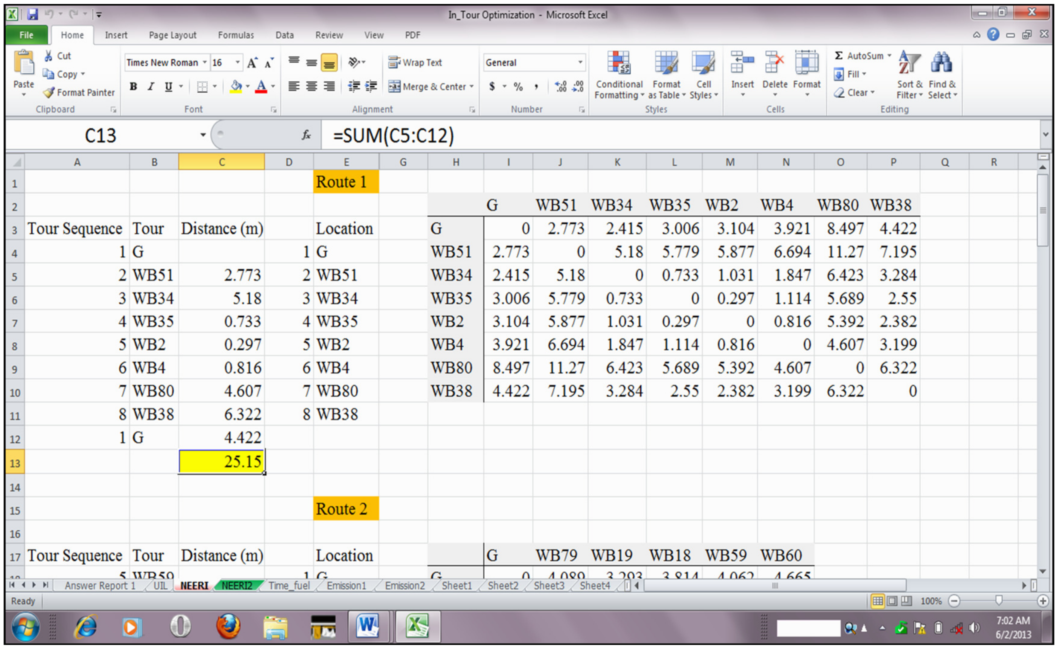
2.4 Estimation of Tour Time

The time required for a complete collection trip using the conventional mode is given by Aremu *et al.* [18] as:

$$T_{tt} = 1.02\left(0.081 + 0.034x_{ts} + 0.030x_{fs} + 0.003N_{turn} + 0.0064N_{inter}\right) \quad (1)$$

Where T_{tt} is the trip time for collecting solid waste from service point, hr/trip, x_{ts} is the haul distance from service point to disposal site, km/trip , x_{fs} is the haul distance from disposal site to the same service point km/trip, N_{turn} is the number of turns made during the collection trip and N_{inter} is the number of intersections encountered during the collection trip. From Figure (1) and Equation (1), the total collection time required to complete collection activities for an assigned route in a day is given as:

$$T_{tr} = 1.02\left[n(0.081) + 0.034\sum_{i=1}^{n} x_{ts_i} + 0.030\sum_{i=1}^{n} x_{fs_i} + \sum_{i=1}^{n}(0.003N_{turn_i} + 0.0064N_{\text{int}\,er_i}) + \sum_{i=1}^{n-1} x_{t_{i/i+1}} + x_{t1} + x_{t2} \right] \quad (2)$$



Tour Sequence	Tour	Distance (m)		Location
1	G		1	G
2	WB51	2.773	2	WB51
3	WB34	5.18	3	WB34
4	WB35	0.733	4	WB35
5	WB2	0.297	5	WB2
6	WB4	0.816	6	WB4
7	WB80	4.607	7	WB80
8	WB38	6.322	8	WB38
1	G	4.422		
		25.15		

	G	WB51	WB34	WB35	WB2	WB4	WB80	WB38
G	0	2.773	2.415	3.006	3.104	3.921	8.497	4.422
WB51	2.773	0	5.18	5.779	5.877	6.694	11.27	7.195
WB34	2.415	5.18	0	0.733	1.031	1.847	6.423	3.284
WB35	3.006	5.779	0.733	0	0.297	1.114	5.689	2.55
WB2	3.104	5.877	1.031	0.297	0	0.816	5.392	2.382
WB4	3.921	6.694	1.847	1.114	0.816	0	4.607	3.199
WB80	8.497	11.27	6.423	5.689	5.392	4.607	0	6.322
WB38	4.422	7.195	3.284	2.55	2.382	3.199	6.322	0

Figure 3: Screenshot of the TSP formulation on Excel worksheet

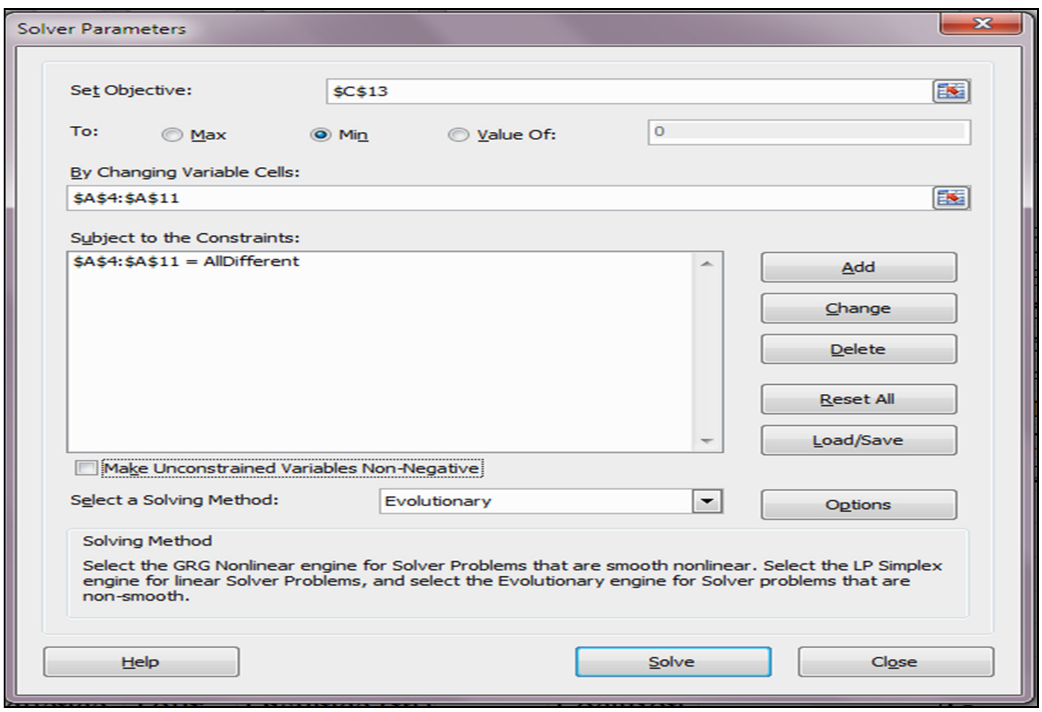


Figure 4: Solver dialog box in Microsoft Excel 2010

where T_{tr} is the Route time for collecting solid waste, hr/trip, n is the number of service points in the route, $x_{t_{i/i+1}}$ is the time required to drive from service point i to service point $i+1$, x_{t1} is the time required to drive from the garage to the first service point, and x_{t2} is the time required to drive from the last service point (n) to the garage

From Equation (2), the in-town tour time is:

$$T_{tr} = \sum_{i=1}^{n-1} x_{t_{i/i+1}} + x_{t1} + x_{t2} + (0.003N'_{turn} + 0.0064N'_{\text{int}\,er}) \quad (3)$$

In (3), N'_{turn} is the number of turns made during in-town movement and N'_{inter} is the number of intersections encountered during in-town movement

The equivalent of Equation (3), when time is correlated with distance travelled by the collection vehicle [5] is:

$$T_{tr} = 0.030\left[\sum_{i=1}^{n-1} x_{d_{i/i+1}} + x_{d1} + x_{d2}\right] + (0.003N'_{turn} + 0.0064N'_{inter}) \quad (4)$$

where the constant (0.030) is a multiplier which converts collection distance to time, $x_{d_{i/i+1}}$ is the distance from service point i to service point $i+1$, x_{d1} is the distance from the garage to the first service point, and x_{d2} is the distance from the last service point (n) to the garage

$x_{d_{i/i+1}}$, x_{d1}, and x_{d2} are obtained from the digitized map of the study area

2.5 Estimation of Fuel Consumption and Cost

The fuel consumed by the collection vehicle during each tour was estimated using values reported by Nguyen and Wilson [1]. The fuel consumed when the collection vehicle is stationary at turns and intersections was estimated as 3.15L/hr, while the fuel consumed during in-town tour movement was reported as 0.335L/km. The total amount of diesel consumed per tour (TD_t) is given as:

$$TD_t = 0.335\left[\sum_{i=1}^{n-1} x_{d_{i/i+1}} + x_{d1} + x_{d2}\right] + 3.15\left[0.003N'_{turn} + 0.0064N'_{inter}\right] \quad (5)$$

The average pump price of diesel in Nigeria is taken as US$1.05 per litre, therefore the cost of fuel consumed by the collection vehicle (TC_t) is:

$$TC_t = 1.05\,TD_t \quad (6)$$

3. Results and Discussion

The Solver tool in the standard Microsoft Excel© 2010 package rearranged empirical in-town tours and displayed optimized in-town tours for each route within 2 minutes. The empirical and optimized in-town tour for the ten routes is presented in Table 1. As observed from Table 1, the tour in Route 1 is the same for empirical and optimized tour while Routes 2 to 10 have different tour sequence for empirical and optimized tours. In Route 5, 8, 9 and 10, the reordering of empirical tours to optimized tours started right after leaving the garage. For instance in Route 5, the empirical tour sequence *SP47-SP57-SP78-SP21-SP20-SP19-SP18* was replaced with *SP18-SP20-SP19-SP2-SP78-SP47-SP57* in the optimized tour.

Route 2 and 7 maintained the same waste bin to be picked up first; Route 3 preserved the order in the first and second waste bin to be collected while the order in the first three waste bins to be collected is retained in Route 4 and 6. Therefore for all routes except Route 1, there is likelihood that the tour distance will be different in empirical and optimized tours.

Figure 5 shows a comparison of the total distance travelled by the collection vehicle to accomplish empirical and optimize[illegible]s. The distance for the empirical and optimize[illegible] is the same for Routes 1 and 10.

Table 1: Tour sequence for empirical and optimized tours

Route No.	No. of waste bins	Tour type	Tour sequence
1	7	Empirical Optimized	G-SP51-SP34-SP35-SP2-SP4-SP80-SP38-G G-SP51-SP34-SP35-SP2-SP4-SP80-SP38-G
2	5	Empirical Optimized	G-SP79-SP19-SP18-SP59-SP60-G G-SP79-SP18-SP60-SP59-SP19-G
3	5	Empirical Optimized	G-SP51-SP1-SP19-SP18-SP59-G G-SP51-SP1-SP18-SP59-SP19-G
4	7	Empirical Optimized	G-SP49-SP46-SP2-SP7-SP60-SP59-SP9-G G-SP49-SP46-SP2-SP59-SP60-SP9-SP7-G
5	7	Empirical Optimized	G-SP47-SP57-SP78-SP21-SP20-SP19-SP18-G G-SP18-SP20-SP19-SP21-SP78-SP47-SP57-G
6	8	Empirical Optimized	G-SP51-SP42-SP44-SP19-SP18-SP21-SP60-SP59-G G-SP51-SP42-SP44-SP60-SP59-SP18-SP19-SP21-G
7	7	Empirical Optimized	G-SP57-SP26-SP78-SP21-SP19-SP18-SP59-G G-SP57-SP78-SP18-SP59-SP19-SP21-SP26-G
8	7	Empirical Optimized	G-SP49-SP26-SP42-SP45-SP21-SP19-SP18-G G-SP26-SP42-SP45-SP18-SP19-SP21-SP49-G
9	7	Empirical Optimized	G-SP17-SP1-SP58-SP19-SP18-SP35-SP64-G G-SP19-SP18-SP64-SP58-SP35-SP1-SP17-G
10	7	Empirical Optimized	G-SP12-SP2-SP36-SP59-SP38-SP39-SP69-G G-SP38-SP39-SP69-SP59-SP36-SP2-SP12-G

G: Garage; SP: Service point (waste bin location), number after SP is the location identity

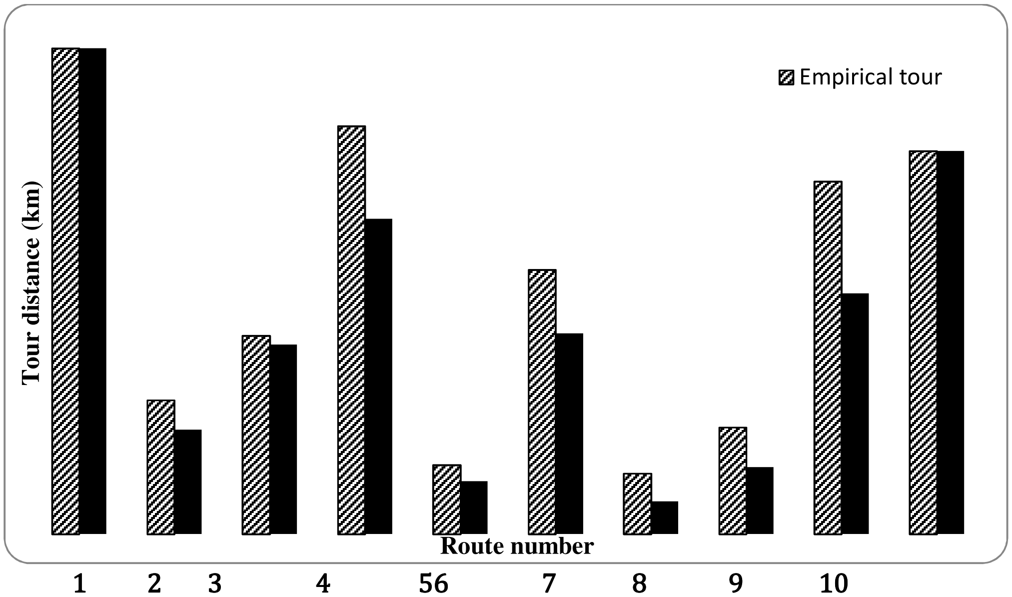


Figure 5: Distance covered to accomplish empirical and optimized tours

In all other routes, the optimized tour distances were lower than empirical tour distances. This reduction varied from 0.31 km in Route 3 to 3.94 km in Route 9 and this result indicates that the optimization process effectively minimized tour distance.

The calculated in-town tour time, and fuel consumption and cost are presented in Table 2. The tour time included the time taken during vehicular movement within the tour and the time spent on encountered turns and intersections (Equation 4). In each of the routes (except Route 1), the optimized tour had less tour time than the empirical tour even though in some instances the number of turns and intersections (i.e. Route 5 and 8) were more in the optimized tour. The least time saved by the optimized tour (0.03 minutes) occurred in Route 10 (though the distance covered is the same as empirical tour) while the greatest time saved was at Route 9 (11.93 minutes). Also from Table 2, the optimized tour was observed to have consumed less fuel (between 0.1 L and 1.57 L) than the empirical tour in Routes 2 to 9. It will in turn save between US$ 0.11 and US$1.65 from the budgeted costs for vehicle fueling. The cost savings may seem diminutive, however since collection efficiency is 75 % (about 274 times in a year), then the yearly cost savings on fuel alone could be between US$30 and US$452 per vehicle. Other cost savings may include reduction in other principal cost factors [7] such as overtime wages and some daily capital costs. Also time, fuel and cost savings are expected to increase when out-town optimization which involves long haul distance to the disposal site is included. Nevertheless this optimization technique is simple, efficient and fast, and could replace empirical decisions which often require several trial and error approaches. More so the results of this optimization method can be useful for budgeting and fuel allocation during the planning stage of municipal solid waste collection.

4. Conclusion

Empirical decisions by municipal authorities on the sequence of solid waste bins collection requires several trial and error approaches. This study proposes a simple and efficient method of solving TSPs and reports a real world in-town tour improvement of the convectional mode for municipal solid waste collection. The Solver tool in Microsoft Office Excel© 2010 was used to optimize in-town tour of ten selected collection routes in Ilorin, North central Nigeria. Tours in two empirical routes were found to be as efficient as the optimized tours.

However, in the remaining eight routes, the optimization process reduced tour distance by 2.04-19.27 %, tour time by 0.33-22.80 %, and fuel consumption 1.78-20.54 %. A cost savings of US$0.11-US$1.65/vehicle/day arising from reduced distance, time and fuel consumption is also expected to accrue when the optimized tours are implemented. As such, the outcome of this study suggests the implementation of optimized tours in municipal solid waste collection systems because of the possibilities of socio-economic and environmental benefits. Also the results of the in-town optimization process can find useful application when planning a coordinated approach for municipal solid waste collection.

Table 2: Estimated in-town collection time, fuel consumption and cost

Route No.	Empirical tour parameters		Optimized tour parameters		Tour time (Minutes)		Fuel consumed (Litres)		Fuel cost ($)	
	Inter	Turns	Inter	Turns	Emp	Opt	Emp	Opt	Emp	Opt
1	40	5	40	5	61.53	61.53	9.28	9.28	9.74	9.74
2	27	7	26	6	34.54	32.10	4.87	4.50	5.12	4.72
3	34	5	34	5	40.95	40.40	5.76	5.65	6.05	5.94
4	39	8	42	8	56.75	52.01	8.37	7.33	8.79	7.70
5	29	6	30	9	31.01	30.91	4.14	4.02	4.35	4.22
6	44	5	37	8	49.00	42.80	6.74	5.88	7.08	6.17
7	28	7	28	9	30.28	28.87	4.03	3.72	4.23	3.91
8	26	6	31	7	32.25	31.83	4.52	4.17	4.75	4.37
9	39	3	25	6	52.32	40.39	7.66	6.09	8.05	6.39
10	40	6	39	8	55.19	55.16	8.07	8.07	8.48	8.48

Inter= Intersections

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