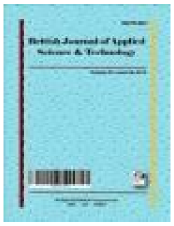


British Journal of Applied Science & Technology
10(2): 1-19, 2015, Article no.BJAST.18907
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

Application of Ant Colony Optimisation Algorithm on Solid Waste Collection: A Case of University of Port Harcourt

Oghenefejiri Bovwe[1] and Ify L. Nwaogazie[1*]

[1]Centre for Occupational Health, Safety and Environment, Institute of Petroleum Studies, Graduate School of Engineering and Technology, University of Port Harcourt, Choba, Rivers State, Nigeria.

Authors' contributions

Author OB designed the study, carried out site visits, computational aspect, wrote the protocol and the first draft of the manuscript. Author ILN supervised the study, provided guidance on data collection, analysis and modelling, confirmed the accuracy of results and documentation. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/18907
Editor(s):
(1) Wei Wu, Applied Mathematics Department, Dalian University of Technology, China.
Reviewers:
(1) Ahmet Sayar, Computer Engineering Department, Kocaeli University, Turkey.
(2) Anonymous, BMS College of Engineering, India.
Complete Peer review History: http://sciencedomain.org/review-history/9821

Original Research Article

Received 16th May 2015
Accepted 11th June 2015
Published 18th June 2015

ABSTRACT

Ants are social insects and their behaviour is geared towards the survival of the colony rather than the survival of the individual. Because ants are almost blind, they move along by building chemical trails using a chemical substance called *pheromone*. These trails are used by ants to find the way to food or back to the colony, using the shortest or otherwise optimised path. This informed the development of The Ant Colony Optimization (ACO) Algorithm. This algorithm was applied to the waste collection system of the University of Port Harcourt so as to optimize the route for solid waste collection within the Institution. University of Port Harcourt has three campuses, namely Choba, Delta and University Park campuses which are networked within a radius of about 1.5 km, separated by two expressed ways. University Park was split into two, Section 1 and Section 2 for this study. The primary data used for this study was gotten with the help of the Global Information System, personal observation and monitoring of waste collection points and tours within the Institution. At the end of the optimization process, the ACO was able to reduce the tour path for

**Corresponding author: E-mail: ifynwaogazie@yahoo.com, ifylnwaogazie@ipsng.org;*

Choba Park by 937.66 m, Delta Park by 1255.99 m, Abuja Park section 1 by 3779.89 m and Abuja Park Section 2 by 1875.15 m representing 33.5%, 31.43%, 51.48% and 32.16%, respectively. However, considering the physical nature of the built environment, a Best Tour Path (BTP) rather than the optimized path was chosen. This gave a total distance reduction of about 16% cumulatively.

Keywords: Solid waste; waste collection route; ant colony optimization (ACO); pheromones; observed route; optimized route; best tour path (BTP); uniport.

1. INTRODUCTION

Few decades ago, solid wastes were defined as consisting of wastes that are unwanted and useless arising from human and animal activities but now, due to advances in recycling and resource recovery technologies the concept of solid waste has changed. Some of what are known previously to be useless and unwanted are now processed into different valuable products [1]. The term *solid waste* as used in this research is all-inclusive, encompassing the heterogeneous mass of throwaways from the urban community as well as the more homogeneous accumulation of domestic, industrial and educational waste.

The increase in human activities coupled with the increasing rate of population growth has resulted to a significant rise in solid waste generation [2, 3]. This poses a challenge on waste management authorities to develop effective ways to manage waste. Route optimization of solid waste collection process remains the most likely option among other solutions. This is likely given its impact on the economic, environment and society at large is very positive when compared with other options. Minimizing waste collection routes are the prime objectives when optimizing waste collection. This implies that for a distinct collection area, waste collection trucks will have to optimize both travelling distance and time. Therefore a major factor in cutting down waste collection cost is by reducing the route time for a waste collection route [4].

In order to properly manage solid waste generated at the University of Port Harcourt, a unit known as the Campus Environmental Beautification and Sanitation (CEBAS) was created [5]. This unit ensures that refuse are collected by contracted waste managers from locations which have been classified into three zones. Each zone has a number of collection points with a final disposal site. With the recent level of economic growth and consumption as a result of increased population, there has been tremendous pressure on the environment and the unhealthy disposal of solid waste is one of the greatest challenges facing the institution and perhaps other developing countries.

2. MATERIALS AND METHODS

2.1 Study Area

The University of Port Harcourt is located in Choba, Rivers State, Nigeria within the coordinates of Latitude 4°5’19.24’’ and Longitude 6°55’25.41’’.The University of Port Harcourt has three campuses: Choba, Delta and University Parks respectively.

i. **Choba Park Campus:** this comprises majorly lecture halls with few hostel accommodations and has the largest commercial business center. It has about 12 waste collections points located within the vicinity and a central dump site;
ii. **Delta Park Campus:** this comprises mainly residential quarters for the University Staff, few administrative buildings and hostel accommodation for female students. It has the least number of commercial business centers among the Campuses and has about 17 waste collection points and a central dump site; and
iii. **University Park Campus:** this is also known as the Abuja Park which comprises the main Administrative Unit of the University, residential quarters for the University Staff, the main health center, various hostel accommodations, business centers, Colleges and it is the Largest of all the Campuses having about 33 waste collection points with the largest waste dump site among the campuses.

Presented in Fig. 1 is the road network, collection points and central dump sites within the University. Sections of the road network, collection points and central dump sites within the University are presented in Appendixes B1-B4.

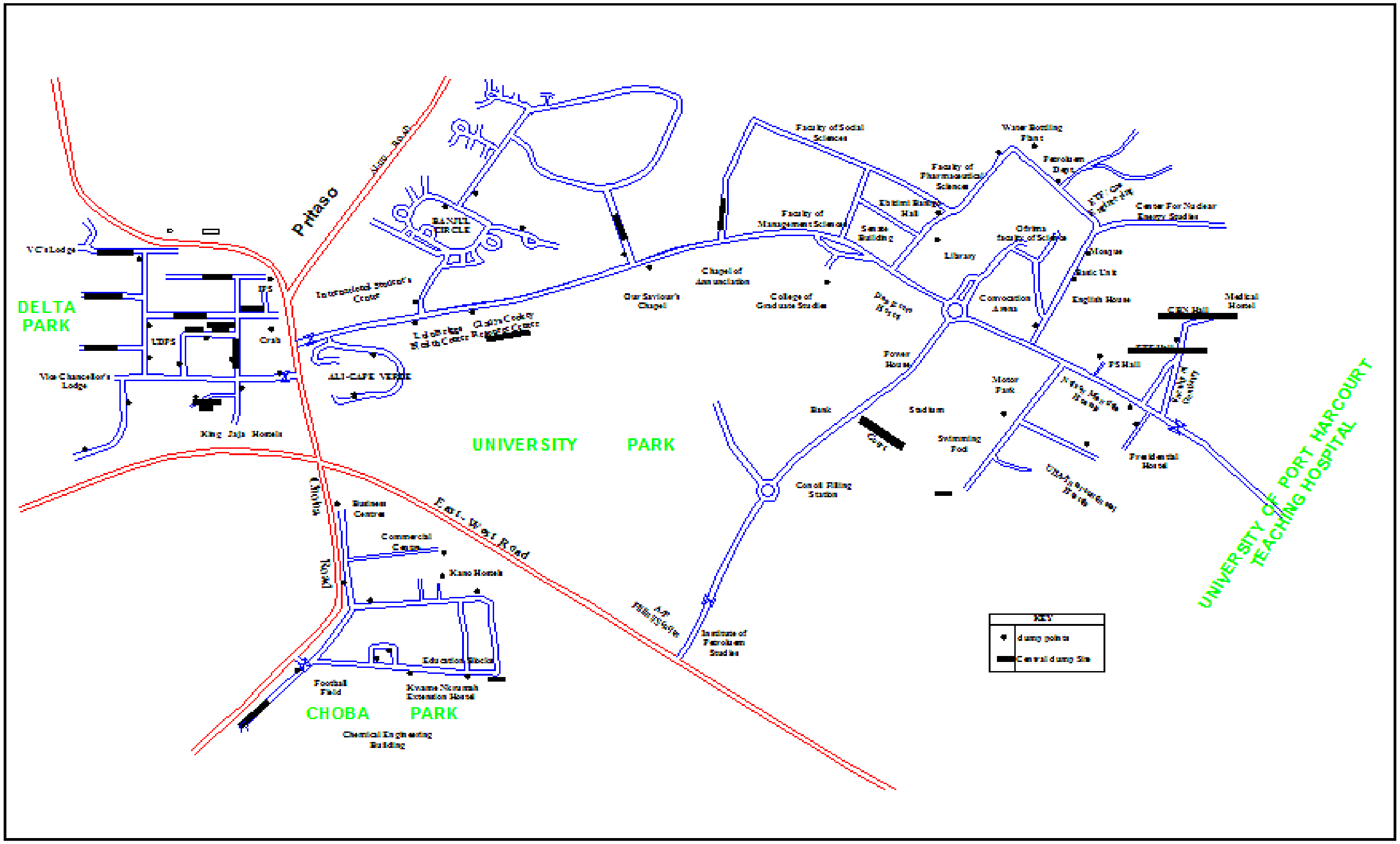


Fig. 1. Road network of the University of Port Harcourt *(AutoCAD & Revit)*

2.2 Data Collection and Analyses

Semi-structured scheduled interview and study group discussion were employed in data collection. Data were collected also from both primary and secondary sources. The location of the disposal sites and collection points, serviceable streets, collection routes, number of trips per day, number and capacities of solid waste collection vehicles were collected. The data were validated by joining some of the trips and by observing same activities within the University. The distance was obtained by computing the Euclidean (or taxicab) distance between each pair of the nodes using the Global Information System (GIS) with the help of the worldwide web and Global Positioning System (GPS) software, Google Earth.

2.3 Floyd-Warshall's Algorithm

The Floyd-Warshall's Algorithm (Table 1) was used to obtain pairs of the shortest distances between the various collection points and the Ant Colony Algorithm was then used to analyze the data in order to arrive at an optimal route for the waste collection points within the University.The pseudo code for Floyd-Warshall's Algorithm is as presented in the Table 1.

2.4 Ant Colony Optimisation (ACO)

The basic idea of ACO algorithms was inspired through the observation of swarm colonies and specifically ants [6]. Most species of ants are virtually considered to be blind but while moving around searching for food they deposit a chemical substance called ***pheromone*** [7]. Ants do smell *pheromone* and when choosing their paths around searching for food, they tend to choose, in probability, paths with high *pheromone* density [8]. Karadimas, Papatzelou and Loumos [9] presented an ant colony system (ACS) for determining waste collection routes for the Municipality of Athens (MoA). The collection involves 72 loading spots. When compared with empirical model the improvement obtained was approximately 25.6%. Also, Bell and McMullen [6] applied Ant Colony Optimization Technique on Vehicle Routing problem.

According to Dominic [10] the algorithm has two fundamental components:

i. the amount of *pheromone* on arc *(i, j)*,τ_{ij}
ii. desirability of arc *(i, j)*,η_{ij}
   Where: arc *(i, j)* denotes the connection between nodes *i* and *j*.

At the start of the algorithm an initial amount of *pheromone,* $\tau_0$is deposited on each arc:

$$\tau_{ij} = \tau_0 = \frac{k}{L_0} \qquad (1)$$

Where: L_0 is the length of an initial feasible tour and k is the number of ants.

Table 1. Pseudo code for Floyd-Warshall's Algorithm

```
    This pseudo code assumes an input graph of N vertices.
START
    for i = 1 to N
    for j = 1 to N
    if there is an edge from i to j
    dist [0][i][j] = the length of the edge from i to j
    else
    dist [0][i][j] = ∞
    for k = 1 to N
    for i = 1 to N
    for j = 1 to N
    dist [k][i][j] = min(dist[k-1][i][j], dist[k-1][i][k] + dist[k-1][k][j])
END
```

Source:Hemalatha and Valsalal [11]

The desirability value (also referred to as visibility or heuristic information) between a pair of nodes is the inverse of their distances;

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{2}$$

Where: d_{ij} is the distance between nodes *i* and *j*. So, if the distance on the arc (*i, j*) is long, visiting city *j* after city *i* (or vice-versa) will be less desirable.

Each ant constructs its own tour utilizing a transition probability: an ant *k* positioned at a city *i* selects the next city *j* to visit with a probability given by Equation (3):

$$p_{ij}^{k} = \begin{cases} \dfrac{\tau_{ij}^{\alpha}\eta_{ij}^{\beta}}{\sum_{l \in N_l^k} \tau_{ij}^{\alpha}\eta_{ij}^{\beta}} & , \quad j \in N_l^k \\ 0 & , \quad otherwise \end{cases} \tag{3}$$

Where: N_l^k denotes the set of collection points (nodes) not yet visited; α and β are positive parameters which controls the relative weight of the *pheromone* information (τ_{ij}) and heuristic information (η_{ij}). These positive parameters were assigned the values 1 and 2 respectively as regards to this research. After each ant has completed its tour, the *pheromone* levels are updated. The *pheromone* update consists of the *pheromone* evaporation and *pheromone* reinforcement. The *pheromone* evaporation refers to uniformly decreasing the *pheromone* values on all arcs. The aim is to prevent the rapid convergence of the algorithm to a local optimal solution by reducing the probability of repeatedly selecting certain nodes. The *pheromone* reinforcement process, on the other hand, allows each ant to deposit a certain amount of pheromone on the arcs belonging to its tour. The aim is to increase the probability of selecting the arcs frequently used by the ants that construct short tours. The *pheromone* update rule is as follows:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_{k=I}^{k} \Delta\tau_{ij}^{k} \ \forall (i,j) \tag{4}$$

In this formulation ρ (ranges from 0 to ≤ 1) is the *pheromone* evaporation parameter and $\Delta\tau_{ij}^{k}$ is the amount of *pheromone* deposited on arc *(i, j)* by ant *k* and is computed as follows:

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{1}{L_k} & , \quad if\ k^{th}\ uses\ path(i,j)\ in\ its\ tour \\ 0 & , \quad otherwise \end{cases} \tag{5}$$

Where: L_k is the tour length constructed by the *k-th* ant.

Equation (5) can also be taken as [10].

$$\Delta\tau_{ij}^{k} = \frac{Q}{L_k} \tag{6}$$

Where Q = (maximum distance observed between pairs of nodes) X (total number of nodes)

In most of the ant colony based algorithms to Vehicle Routing Problem(VRP), initial *pheromone* trails, τ_0 is set equal to the inverse of the best known route distances found for the particular problem. However, it was found that:

$$\tau_0 = \frac{1}{n}. \tag{7}$$

Where: n = total number of nodes (dump points) considered [10].

A summary of the ACO algorithm is presented in the flow chart (Fig. 2).

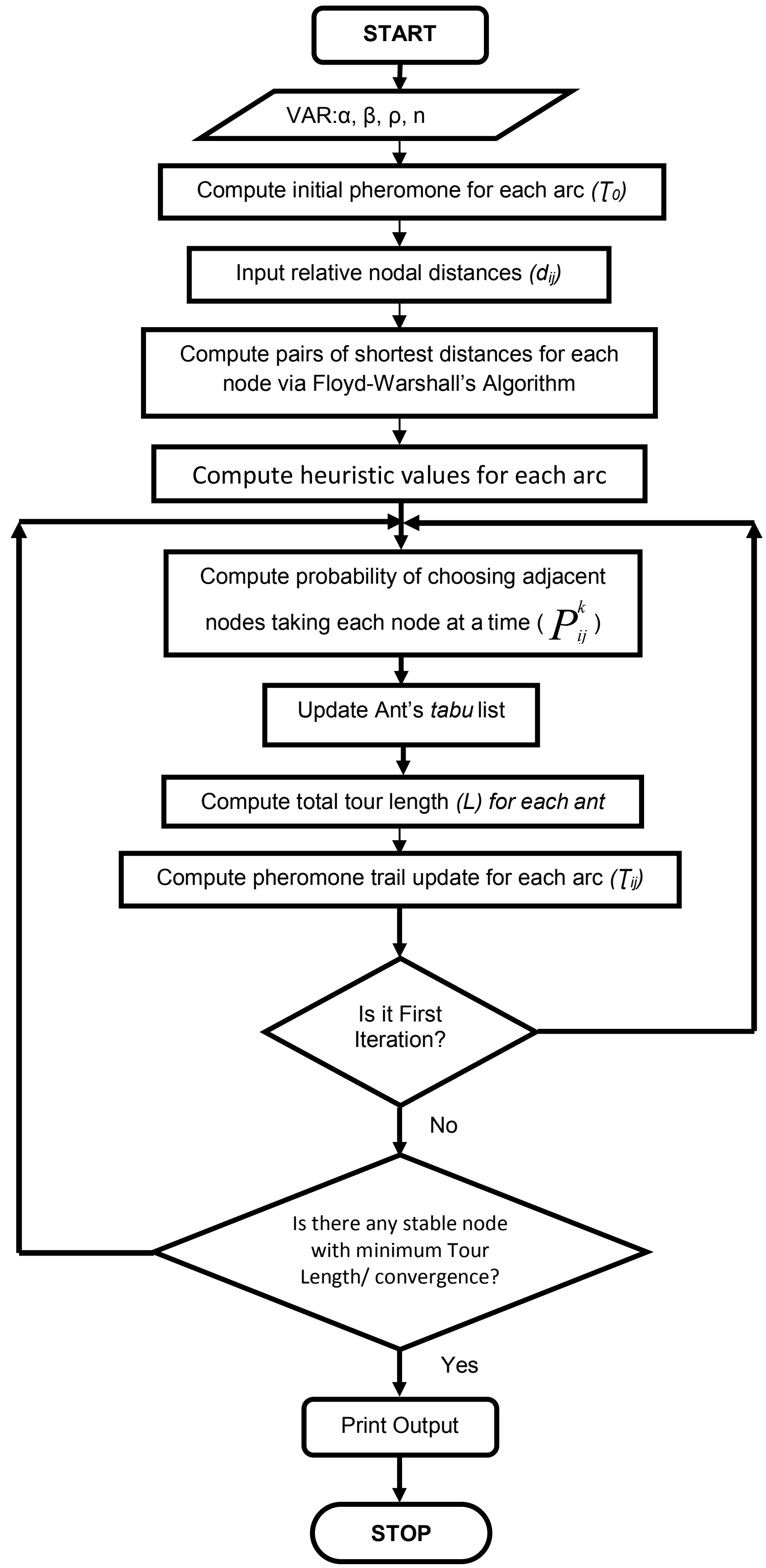


Fig. 2. A flow chart of the Ant colony algorithm

3. RESULTS

The results from the analyses of the data collected from the three campuses on applying Floyd-Warshall's algorithm is presented in Tables A1–A4 *(Appendix A)*, representing the shortest distance between collection points (nodes) of the three campuses (Choba Park Campus, Delta Park Campus and University Park Campus). Note that the University Park Campus was divided into two sections as a matter of convenience.

Taking the Choba Campus, for illustration on flow chart (Fig. 2) computation outputs, an initial pheromone (Table A1.1) was computed for all the nodes using Equation (6) and the heuristic values (Table A1.2) for the various nodes were computed by applying the resulted shortest distance between collection points (nodes) presented in Table A1 into Equation (2). On applying the computed initial pheromone and heuristic values for the various nodes into Equation (3), the resulted routes (Table A1.3) were obtained. After the first iteration, the initial pheromone for each node was updated (Table A1.4) using Equation 4. Also the resulted routes with respect to these updated pheromone on each arc trail is presented in Table A1.5; when reapplied into Equation (3) for the second iteration. The route with the minimum stable distance is taken as the proposed optimised route for the waste collection crew.

Similar to the results exemplified by Choba Park campus in Tables A1.1- A1.6, are those of the other two campuses (Delta Park and University Park in two sub-campuses or sections). The results printed out for Delta Park and University Park except for Tables A2 – A4 are unnecessary, given the result details as provided by Choba Park campuses illustration.

The summary of the resulting optimum route for each campus on the application of the Ant Colony Optimization algorithm (ACO) is represented in Table 2. However, considering the physical nature of the system (the feasibility of these paths and vehicle capacity), the **Best Tour Path** (BTP) for each campus was obtained.

The plot of the optimal route on relative co-ordinates for the various campuses are as shown in Figs. 3-6.

Table 2. Summary of results on applying ACO algorithm

Route	Choba park	Delta park	Univ. park (Section 1)	Univ. park (Section 2)
Observed route (m)	2641.00	3996.67	7342.56	5830.25
Optimized route (m)	1703.34	2740.68	3562.67	3955.10
Best tour path (m)	2556.75	3726.48	4994.67	5370.35

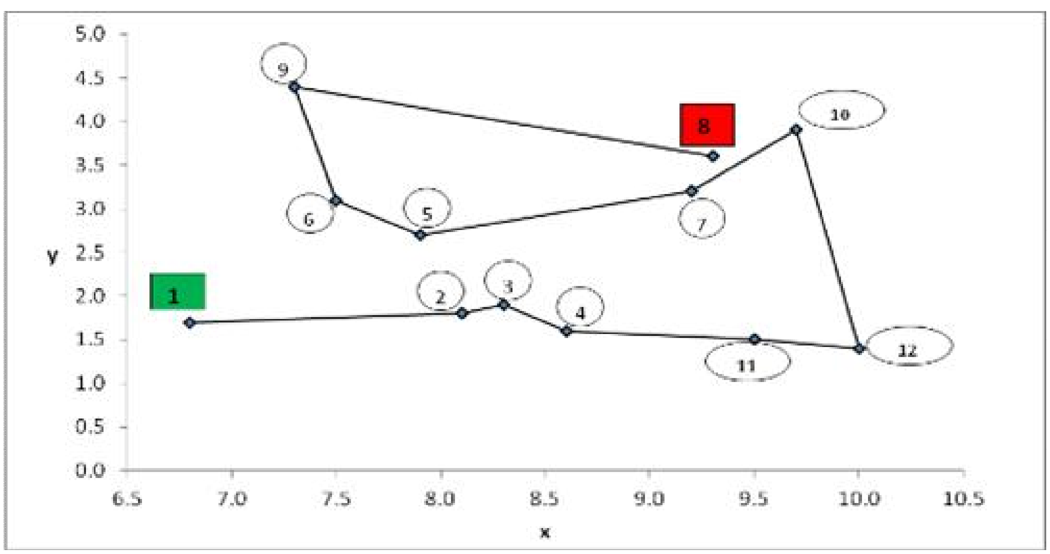


Fig. 3. Plot of Optimum Tour Path for Choba Campus (1→2→3→4→11→12→10→7→5→6→9→8)

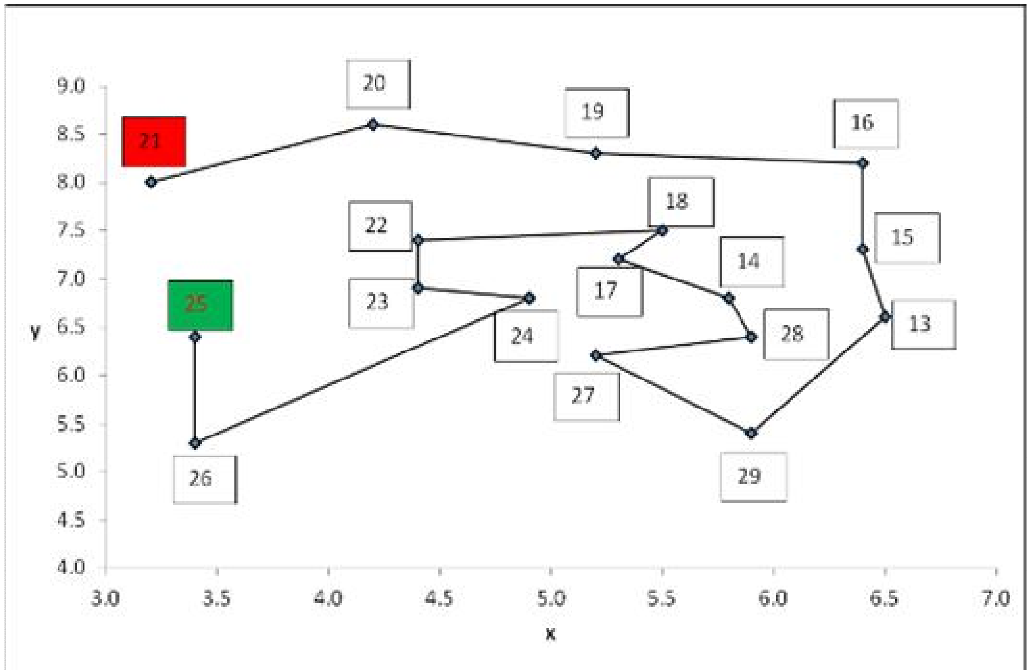


Fig. 4. Plot of Optimum Tour Path for Delta Campus
(25→26→24→23→22→18→17→14→28→27→29→13→15→16→19→20→21

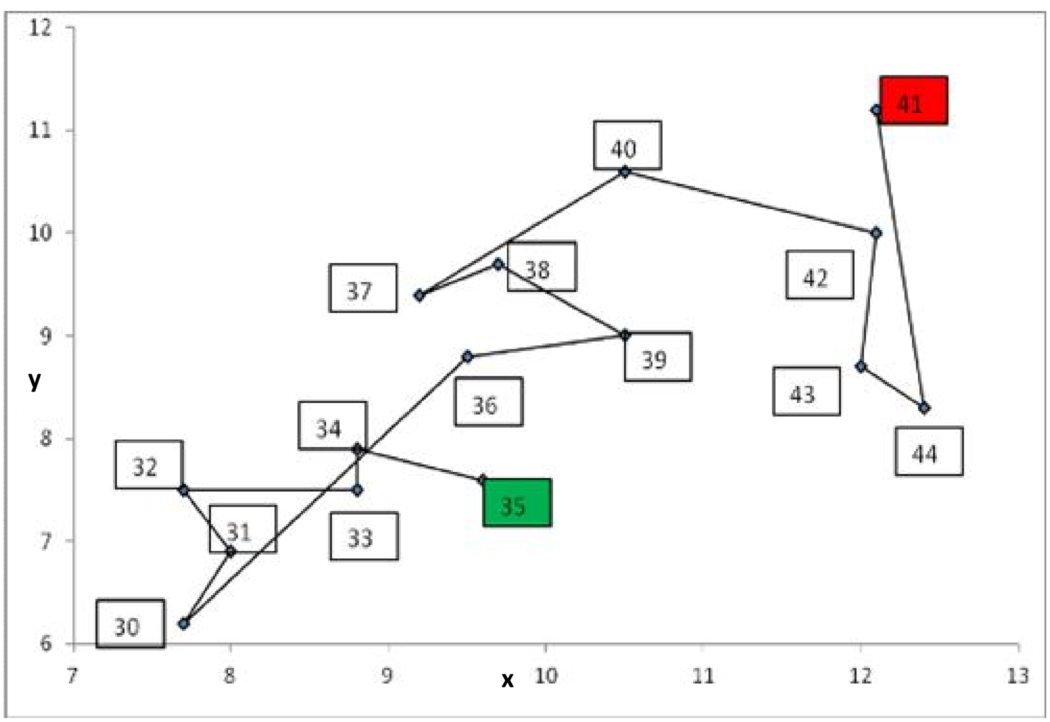


Fig. 5. Plot of Best Tour Path for University Park Section-1
(35→34→33→32→31→30→36→39→38→37→40→42→43→44→41)

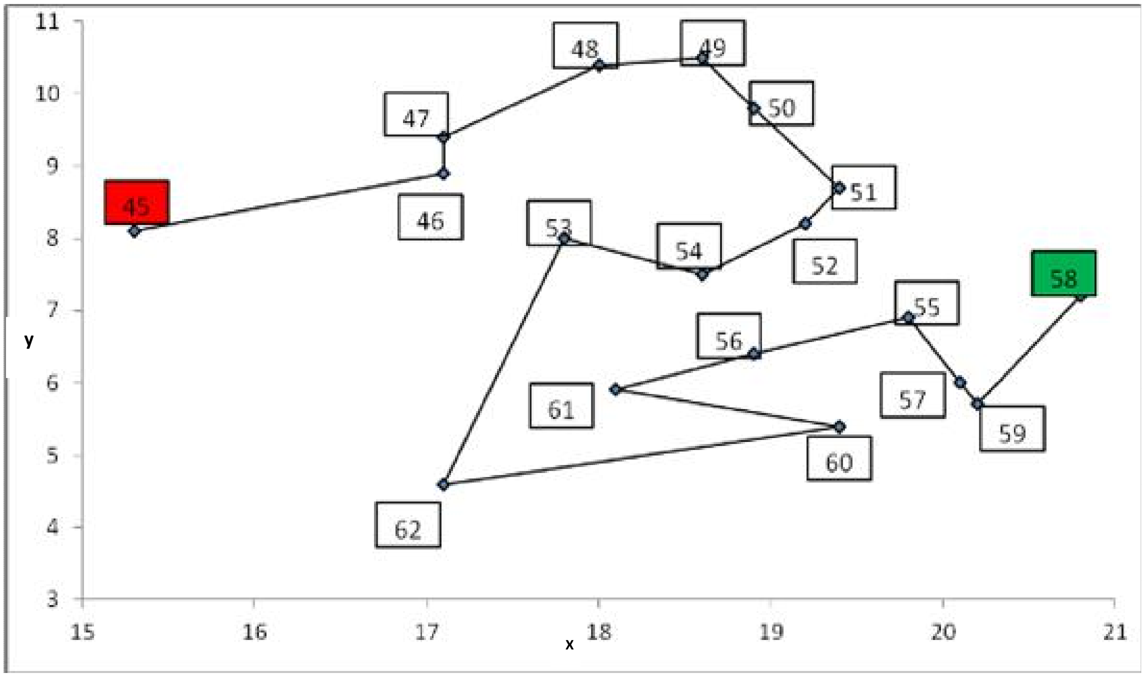


Fig. 6. Plot of Best Tour Path for University Park Section-2 (58→59→57→55→56→61→60→62→53→54→52→51→50→49→48→47→46→45)

4. DISCUSSION

It can be seen from Tables A1-A4 (which represent the pair of the shortest distance between each nodes within each campuses of the institution as analyzed using Floyd-Warshall's algorithm), that the nodes are numbered from 1, 2, 3…61 representing the total waste collection points within the Institution but with exception of nodes 12, 29, 62 which represent the dump site within Choba, Delta and University Park campuses, respectively. Waste collection points (nodes) within Choba campus are labeled 1, 2, 3…11. Delta Park campus has nodes labeled 13, 14, 15…28. While the University Park has nodes labeled 20, 31, 32…61.

The result obtained from the application of Floyd-Warshall's algorithm (Tables A1-A4) usually result to the formation of a kind of graph, whose vertices is equal to the number of collection points having its major diagonals equal to zero. This is so because the shortest distance between a collection point and itself will always be zero.

As seen in Table 2 there is significant reduction in the total distance travelled along the routes in the various campuses when the ACO was applied. For the case of Choba Park, the optimum tour path started with node 1 and ended with node 8 giving a total reduction in length of about 937.66 m representing 33.5% reduction in total length of tour path when compared with the tour path usually used by the waste collectors within the campus.

In Delta Park, the optimal tour started with node 25 and terminates with node 21 giving a total reduction in length of about 1255.99 m, representing 31.43% reduction in total length of tour path when compared with the tour path usually used by the waste collectors within the campus.

In University Park, Section 1 and Section 2 recorded 3779.89 m and 1875.15 m reduction in length representing 51.48% and 32.16% reduction in total length of tour path when compared with the tour path usually used by the waste collectors within the campus.

Given the availability of the road network, the vehicle capacity and nearness to the various dump sites the Best Tour Path (BTP) for each of the three campuses gave the percentage reduction. The BTP gave a total distance reduction of 2%, 6%, 32% and 8%, respectively for Choba, Delta, University Park sections 1 and 2, respectively. Cumulatively, a total distance reduction of about 16% was obtained when considering the Best Tour Path.

5. CONCLUSION

The following conclusion can be made from the application of the Ant Colony Optimization Algorithm in the optimization of Solid waste Collection within the University of Port Harcourt:

i. The Ant Colony Optimization (ACO) is very powerful tool in network or route optimization in general; and
ii. The Ant Colony Optimization (ACO) was able to achieve approximately40% reduction in total route distance travelled by solid waste collectors cumulatively for the whole institution.

The implication of this reduction in distance is that it has a direct relationship with time and overall reduction in both operational and maintenance (O & M) cost which in turn would mean an increase in profit for the waste management firm or company involved in the daily collection of waste for the University.

6. RECOMMENDATION

Solid waste collection is one of the six functional elements of Municipal Solid Waste Management (MSWM) System. In some cases it has been referred to as the most sensitive or important of the entire elements. Based on the results from this research it is recommended that:

i. The solid waste collection process within the University of Port Harcourt should be properly routed using the application of the Ant Colony Optimization algorithm;
ii. The capacity of the solid waste collection trucks should be increased so as to reduce the number of collection trips and perhaps reduce the overall operation and maintenance cost; and
iii. The University management should use the Ant Colony Optimization algorithm as a decision tool to aid the siting of solid waste collection points and dump sites within the campuses.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nwaogazie IL. Solid waste management: ETM 606.1 Lecture Note. Centre for Occupational Health, Safety and Environment (COHSE), Institute of Petroleum Studies, University of Port Harcourt, COHSE Library; 2011. (In press).
2. Imad AK. Municipal solid waste management in developing countries: Future challenges and possible opportunities. In: Kumar S, editor. Integrated Waste Management (II), InTech; 2011.
3. Rawal N, Singh RM, Vaishya RC. Waste characterisation and route optimization for solid wastes in urban areas. 2011; 4(6):438-442.
4. Gukhool O, Bokhoree C, Mohee R, Jamnejad G. Solid waste collection optimization using a route time approach: A case study for an urban area of Mauritius. Proceeding of the 23rd International Conference on Solid Waste Technology and Management. Philadelphia PA; 2008. ISSN 1091-8043.
5. Momoh YLO, Odonghanro B, Diemuodeke E. Physical composition and energy content approximation of solid waste at the University of Port Harcourt, Nigeria. J. Sus. Tech. 2010;1(1):29-36.
6. Bell JE, McMullen PR. Ant colony optimization techniques for the vehicle routing problem. Advanced Engineering Informatics. 2004;18:41–48.
7. Dorigo M, Di Caro G, Gambardella LM. Ant algorithms for discrete optimization. Artificial Life. 1999;5(2):137-172.
8. Blum C. Ant Colony Optimization: Introduction and recent trends. Physics of Life Reviews. 2005;2:353–373.
9. Karadimas NV, Papatzelou K, Loumos VG. Optimal solid waste collection routes identified by the Ant Colony System algorithm. Waste Management & Research. 2007;25(2):139-147.
10. Dominic O. Capacitated Arc routing problem: Collection of solid waste at Kwadaso Estate, Kumasi. MPhil. Thesis Submitted To The Graduate School Board Kwame Nkrumah University Of Science And Technology, Kumasi, Ghana; 2012.
11. Hemalatha S, Valsalal P. Restorative path selection for power system network using Floyd-Warshall algorithm. ARPN Journal of Engineering and Applied Sciences. 2012;7(4):472-477.

APPENDIXES

APPENDIX A

Table A1.0. Pair of shortest distance (m) between nodes for Choba park

Node	1	2	3	4	5	6	7	8	9	10	11	12
1	0	164.34	224.94	250.69	217.31	307.31	428.83	565.11	480.70	504.06	340.54	465.17
2	164.34	0	60.60	110.12	381.65	471.65	484.25	729.45	645.04	464.26	199.97	324.60
3	224.94	60.60	0	97.84	442.25	532.25	471.97	790.05	705.64	451.98	187.69	312.32
4	250.69	110.12	97.84	0	468.00	558.00	374.13	815.80	731.39	354.14	89.85	214.48
5	217.31	381.65	442.25	468.00	0	90.00	211.57	347.80	263.39	286.75	380.98	505.61
6	307.31	471.65	532.25	558.00	90.00	0	301.52	257.80	173.39	376.75	470.98	595.61
7	428.83	484.25	471.97	374.13	211.57	301.52	0	559.32	474.91	194.81	284.28	408.91
8	565.11	729.45	790.05	815.80	347.80	257.80	559.32	0	250.84	634.55	728.78	853.41
9	480.70	645.04	705.64	731.39	263.39	173.39	474.91	250.84	0	550.14	644.37	769.00
10	504.06	464.26	451.98	354.14	286.75	376.75	194.81	634.55	550.14	0	264.29	245.47
11	340.54	199.97	187.69	89.850	380.98	470.98	284.28	728.78	644.37	264.29	0	124.63
12	465.17	324.60	312.32	214.48	505.61	595.61	408.91	853.41	769.00	245.47	124.63	0

Table A1.1. Initial Pheromone *(T_0)* for Nodes (Choba Park)

Node	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
2	0.083	0	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
3	0.083	0.083	0	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
4	0.083	0.083	0.083	0	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
5	0.083	0.083	0.083	0.083	0	0.083	0.083	0.083	0.083	0.083	0.083	0.083
6	0.083	0.083	0.083	0.083	0.083	0	0.083	0.083	0.083	0.083	0.083	0.083
7	0.083	0.083	0.083	0.083	0.083	0.083	0	0.083	0.083	0.083	0.083	0.083
8	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0	0.083	0.083	0.083	0.083
9	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0	0.083	0.083	0.083
10	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0	0.083	0.083
11	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0	0.083
12	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0

Table A1.2. Heuristic Value (η_{ij}) for Nodes (Choba Park)

Nodes	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0.00608	0.00445	0.00399	0.0046	0.00325	0.00233	0.00177	0.00208	0.00198	0.00294	0.00215
2	0.00608	0	0.0165	0.00908	0.00262	0.00212	0.00207	0.00137	0.00155	0.00215	0.005	0.00308
3	0.00445	0.0165	0	0.01022	0.00226	0.00188	0.00212	0.00127	0.00142	0.00221	0.00533	0.0032
4	0.00399	0.00908	0.01022	0	0.00214	0.00179	0.00267	0.00123	0.00137	0.00282	0.01113	0.00466
5	0.0046	0.00262	0.00226	0.00214	0	0.01111	0.00473	0.00288	0.0038	0.00349	0.00262	0.00198
6	0.00325	0.00212	0.00188	0.00179	0.01111	0	0.00332	0.00388	0.00577	0.00265	0.00212	0.00168
7	0.00233	0.00207	0.00212	0.00267	0.00473	0.00332	0	0.00179	0.00211	0.00513	0.00352	0.00245
8	0.00177	0.00137	0.00127	0.00123	0.00288	0.00388	0.00179	0	0.00399	0.00158	0.00137	0.00117
9	0.00208	0.00155	0.00142	0.00137	0.0038	0.00577	0.00211	0.00399	0	0.00182	0.00155	0.0013
10	0.00198	0.00215	0.00221	0.00282	0.00349	0.00265	0.00513	0.00158	0.00182	0	0.00378	0.00407
11	0.00294	0.005	0.00533	0.01113	0.00262	0.00212	0.00352	0.00137	0.00155	0.00378	0	0.00802
12	0.00215	0.00308	0.0032	0.00466	0.00198	0.00168	0.00245	0.00117	0.0013	0.00407	0.00802	0

Table A1.3. Resulted Path with total length of path and change in pheromone for Choba Park (1st iteration)

Ant (Path)	**Length of path *(L)***	**$\Delta\tau$=*(10240.9/L)***
Ant 1 (1-2-3-4-11-12-10-7-5-6-9-8)	1703.34	6.012258269
Ant 2 (2-3-4-11-12-10-7-5-6-9-8-1)	2104.11	4.867102956
Ant 3 (3-2-4-11-12-10-7-5-6-9-8-1)	2116.39	4.838862402
Ant 4 (4-11-12-10-7-5-6-9-8-1-2-3)	2170.61	4.717991717
Ant 5 (5-6-9-8-7-10-12-11-4-3-2-1)	2051.09	4.992915962
Ant 6 (6-5-7-10-12-11-4-3-2-1-9-8)	2010.65	5.093337975
Ant 7 (7-10-12-11-4-3-2-1-5-6-9-8)	1709.08	5.992065907
Ant 8 (8-9-6-5-7-10-12-11-4-3-2-1)	1703.34	6.012258269
Ant 9 (9-6-5-7-10-12-11-4-3-2-1-8)	2017.61	5.075767864
Ant 10 (10-7-5-6-9-8-1-2-3-4-11-12)	2022.98	5.062294239
Ant 11(11-4-3-2-1-5-6-9-8-7-10-12)	2143.77	4.777060972
Ant 12(12-11-4-3-2-1-5-6-9-8-7-10)	2022.93	5.062419362

Table A1.4. Pheromone (T_1) for Nodes after first iteration (Choba Park)

Node	1	2	3	4	5	6	7	8	9	10	11	12
1	0	52.898	0.100	0.100	15.932	0.100	0.100	24.662	5.193	0.100	0.100	0.100
2	52.898	0	62.604	4.939	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
3	0.100	62.604	0	53.047	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
4	0.100	4.939	53.047	0	0.100	0.100	0.100	0.100	0.100	0.100	62.604	0.100
5	15.932	0.100	0.100	0.100	0	62.604	41.780	0.100	0.100	0.100	0.100	0.100
6	0.100	0.100	0.100	0.100	62.604	0	0.100	0.100	57.411	0.100	0.100	0.100
7	0.100	0.100	0.100	0.100	41.780	0.100	0	14.932	0.100	57.429	0.100	0.100
8	24.662	0.100	0.100	0.100	0.100	0.100	14.932	0	57.529	0.100	0.100	0.100
9	5.193	0.100	0.100	0.100	0.100	57.411	0.100	57.529	0	0.100	0.100	0.100
10	0.100	0.100	0.100	0.100	0.100	0.100	57.429	0.100	0.100	0	0.100	52.480
11	0.100	0.100	0.100	62.604	0.100	0.100	0.100	0.100	0.100	0.100	0	57.827
12	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	52.480	57.827	0

Table A1.5. Resulted Path with total length of path for Choba Park (2nd iteration)

Nodes	Tour Path	Length (m)
1	1-2-3-4-11-12-10-7-5-6-9-8	1703.34
2	2-3-4-11-12-10-7-5-6-9-8-1	2104.11
3	3-2-4-11-12-10-7-5-1-8-9-6	2243.7
4	4-11-12-10-7-5-6-9-8-1-2-3	2170.61
5	5-6-9-8-1-2-3-4-11-12-10-7	2056.88
6	6-5-7-10-12-11-4-3-2-1-9-8	2095.06
7	7-10-12-11-4-3-2-1-5-6-9-8	1709.08
8	8-9-6-5-7-10-12-11-4-3-2-1	1703.34
9	9-6-5-7-10-12-11-4-3-2-1-8	2017.61
10	10-7-5-6-9-8-1-2-3-4-11-12	2022.98
11	11-4-3-2-1-5-6-9-8-7-10-12	2143.77
12	12-11-4-3-2-1-5-6-9-8-7-10	2022.93

Table A2. Pair of Shortest Distance (m) between Nodes for Delta Park

Node	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
13	0	141.12	318.66	517.80	252.11	428.54	691.13	703.76	746.93	543.29	436.90	323.22	573.65	529.67	207.84	109.08	304.51
14	141.12	0	177.54	376.68	110.99	287.42	550.01	562.56	605.73	402.09	295.78	182.10	432.53	436.67	153.28	54.52	249.95
15	318.66	177.54	0	256.46	158.37	334.80	407.78	590.08	672.37	468.73	425.71	312.03	562.46	566.60	330.82	232.06	427.49
16	517.80	376.68	256.46	0	265.69	264.62	151.32	333.62	457.77	393.35	499.74	419.35	641.69	673.92	529.96	431.20	626.63
17	252.11	110.99	158.37	265.69	0	176.43	493.02	470.83	514.00	310.36	267.34	153.66	404.09	408.23	264.27	165.51	360.94
18	428.54	287.42	334.80	264.62	176.43	0	262.59	294.40	337.57	133.93	240.32	330.09	377.07	424.70	440.70	341.94	537.37
19	691.13	550.01	407.78	151.32	493.02	262.59	0	182.30	306.45	242.03	348.42	462.10	485.17	532.80	703.29	604.53	799.96
20	703.76	562.56	590.08	333.62	470.83	294.40	182.30	0	213.00	160.47	266.86	380.54	403.61	451.24	645.32	546.56	741.99
21	746.93	605.73	672.37	457.77	514.00	337.57	306.45	213.00	0	203.64	310.03	423.71	446.78	494.41	688.49	589.73	785.16
22	543.29	402.09	468.73	393.35	310.36	133.93	242.03	160.47	203.64	0	106.39	220.07	243.14	290.77	484.85	386.09	581.52
23	436.90	295.78	425.71	499.74	267.34	240.32	348.42	266.86	310.03	106.39	0	113.68	136.75	184.38	378.46	279.70	475.13
24	323.22	182.10	312.03	419.35	153.66	330.09	462.10	380.54	423.71	220.07	113.68	0	250.43	254.57	264.78	166.02	361.45
25	573.65	432.53	562.46	641.69	404.09	377.07	485.17	403.61	446.78	243.14	136.75	250.43	0	168.49	515.21	416.45	611.88
26	529.67	436.67	566.60	673.92	408.23	424.70	532.80	451.24	494.41	290.77	184.38	254.57	168.49	0	519.35	420.59	616.02
27	207.84	153.28	330.82	529.96	264.27	440.70	703.29	645.32	688.49	484.85	378.46	264.78	515.21	519.35	0	98.76	96.67
28	109.08	54.52	232.06	431.20	165.51	341.94	604.53	546.56	589.73	386.09	279.70	166.02	416.45	420.59	98.76	0	195.43
29	304.51	249.95	427.49	626.63	360.94	537.37	799.96	741.99	785.16	581.52	475.13	361.45	611.88	616.02	96.67	195.43	0

Table A3. Pair of Shortest Distance (m) between Nodes for University Park (Section 1)

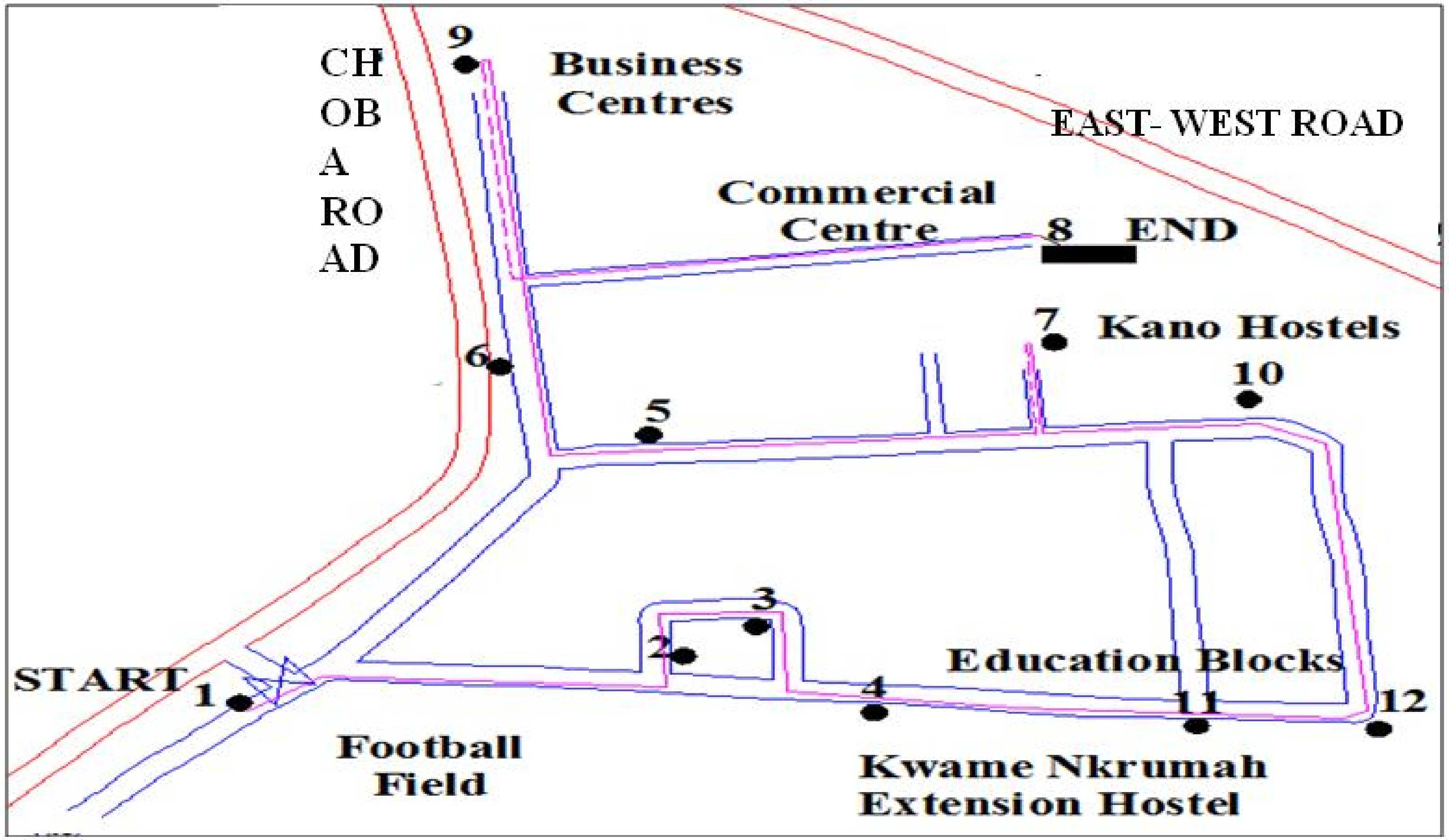
Node	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
30	0	314.54	215.20	374.17	431.19	453.31	639.45	867.20	866.82	860.38	1055.47	1398.76	1162.02	952.67	959.35
31	314.54	0	160.22	319.19	376.21	398.33	584.47	812.22	811.84	805.40	1000.49	1343.78	1129.04	897.62	904.37
32	215.20	160.22	0	158.97	215.99	238.11	424.25	652.00	651.62	645.18	840.27	1183.56	968.82	737.47	744.15
33	374.17	319.19	158.97	0	57.02	79.14	265.28	493.03	492.65	486.21	681.30	1024.59	809.85	578.50	585.18
34	431.19	376.21	215.99	57.02	0	77.44	208.26	436.01	435.63	429.19	624.28	967.57	808.16	576.80	583.48
35	453.31	398.33	238.11	79.14	77.44	0	285.70	513.45	513.07	506.63	701.72	1045.01	730.72	499.36	506.04
36	639.45	584.47	424.25	265.28	208.26	285.70	0	227.75	227.37	220.93	416.02	759.31	740.02	785.06	791.74
37	867.20	812.22	652.00	493.03	436.01	513.45	227.75	0	106.11	376.04	294.76	638.05	618.76	715.54	781.79
38	866.82	811.84	651.62	492.65	435.63	513.07	227.37	106.11	0	269.93	188.65	531.94	512.65	609.43	675.68
39	860.38	805.40	645.18	486.21	429.19	506.63	220.93	376.04	269.93	0	458.58	801.87	782.58	879.36	945.61
40	1055.50	1000.50	840.27	681.30	624.28	701.72	416.02	294.76	188.65	458.58	0	343.29	324.00	420.78	487.03
41	1398.76	1343.78	1183.56	1024.59	967.58	1045.00	759.31	638.05	531.94	801.87	343.29	0	344.10	575.45	641.70
42	1162.02	1129.04	968.82	809.85	808.16	730.72	740.02	618.76	512.65	782.58	324.00	344.10	0	231.35	297.60
43	952.67	897.62	737.47	578.50	576.80	499.36	785.06	715.54	609.43	879.36	420.78	575.45	231.35	0	66.25
44	959.35	904.37	744.15	585.18	583.48	506.04	791.74	781.79	675.68	945.61	487.03	641.70	297.60	66.25	0

Table A4. Pair of Shortest Distance (m) between Nodes for University Park (Section 2)

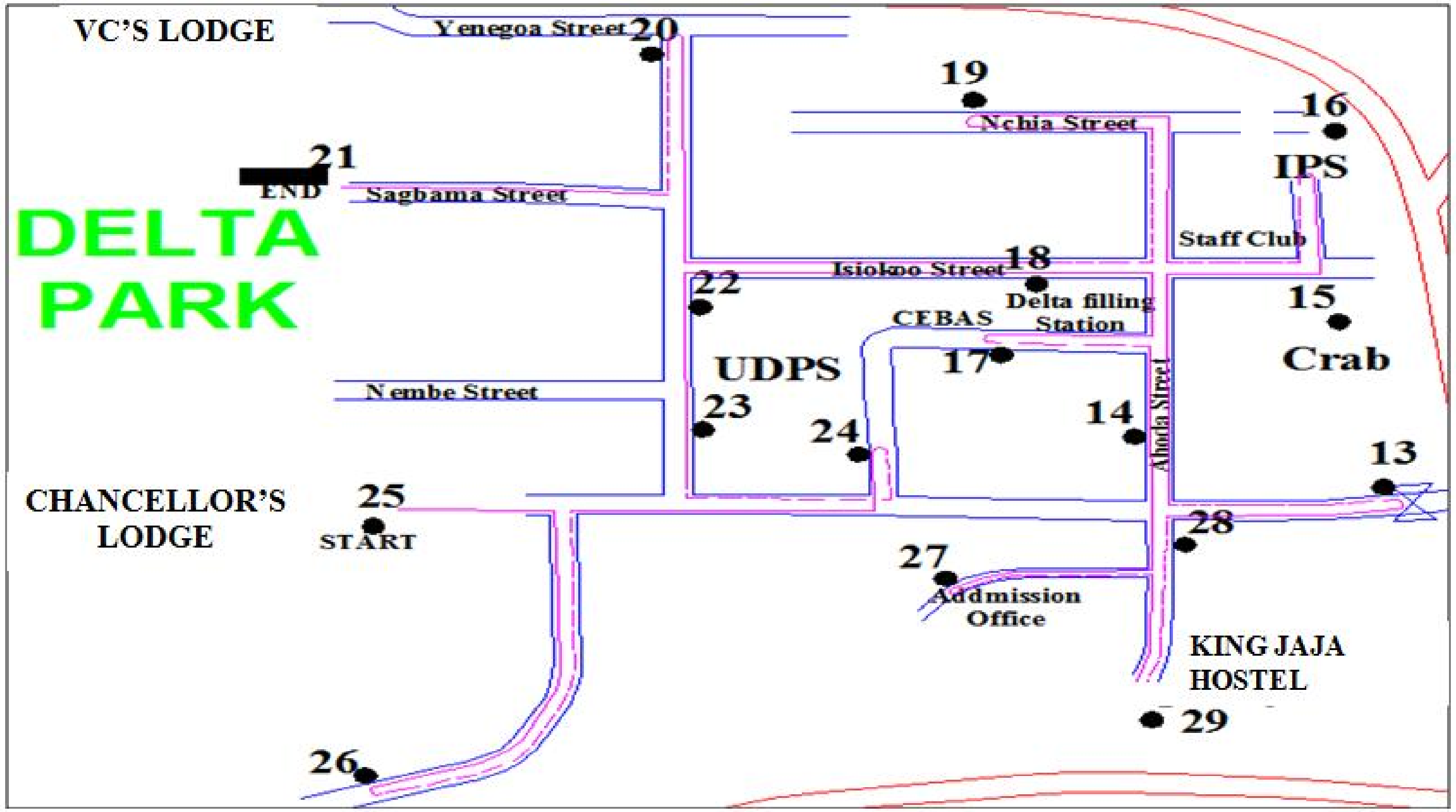
Node	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
45	0	372.45	512.99	636.31	739.36	916.40	1073.38	1001.63	494.81	846.92	1196.33	898.52	1193.18	1555.16	1359.07	1219.70	1045.64	1415.27
46	372.45	0	140.54	263.86	366.91	543.95	720.01	791.76	549.48	901.59	1251.00	953.19	1247.85	1609.83	1413.74	1274.37	1100.31	1295.88
47	512.99	140.54	0	123.32	226.37	403.41	579.47	651.22	690.02	805.93	1155.34	1093.73	1305.29	1667.27	1471.18	1414.91	1240.85	1436.42
48	636.31	263.86	123.32	0	103.05	280.09	456.15	527.90	813.34	682.61	1032.02	1217.05	1181.97	1543.95	1347.86	1538.23	1364.17	1559.74
49	739.36	366.91	226.37	103.05	0	177.04	353.10	424.85	916.39	579.56	928.97	1182.12	1078.92	1440.90	1244.81	1503.30	1329.24	1524.81
50	916.40	543.95	403.41	280.09	177.04	0	176.06	247.81	754.62	402.52	751.93	1005.08	901.88	1263.86	1067.77	1326.26	1152.20	1347.77
51	1073.38	720.01	579.47	456.15	353.10	176.06	0	71.75	578.57	226.46	575.87	829.02	725.82	1087.80	891.71	1150.20	976.14	1171.71
52	1001.63	791.76	651.22	527.90	424.85	247.81	71.75	0	506.82	154.71	504.12	757.27	654.07	1016.05	819.96	1078.45	904.39	1100.96
53	494.81	549.48	690.02	813.34	916.39	754.62	578.57	506.82	0	352.11	701.52	403.71	698.37	1060.35	864.26	724.89	550.83	746.40
54	846.92	901.59	805.93	682.61	579.56	402.52	226.46	154.71	352.11	0	349.41	602.56	499.36	861.34	665.25	923.74	749.68	945.25
55	1196.33	1251.00	1155.34	1032.02	928.97	751.93	575.87	504.12	701.52	349.41	0	253.15	149.95	511.93	315.84	574.33	400.27	595.84
56	898.52	953.19	1093.73	1217.05	1182.12	1005.08	829.02	757.27	403.17	602.56	253.15	0	294.66	656.64	460.55	321.18	147.12	342.69
57	1193.18	1247.85	1305.29	1181.97	1078.92	901.88	725.82	654.07	698.37	499.36	149.95	294.66	0	361.98	165.89	615.84	441.78	637.35
58	1555.16	1609.83	1667.27	1543.95	1440.90	1263.86	1087.80	1016.05	1060.35	861.34	511.93	656.64	361.98	0	323.34	977.82	803.76	999.33
59	1359.07	1413.74	1471.18	1347.86	1244.81	1067.77	891.71	819.96	864.26	665.25	315.84	460.55	165.89	323.34	0	781.73	607.67	803.24
60	1219.70	1274.37	1414.91	1538.23	1503.30	1326.26	1150.20	1078.45	724.89	923.74	574.33	321.18	615.84	977.82	781.73	0	174.06	324.13
61	1045.64	1100.31	1240.85	1364.17	1329.24	1152.20	976.14	904.39	550.83	749.68	400.27	147.12	441.78	803.76	607.67	174.06	0	195.57
62	1415.27	1295.88	1436.42	1559.74	1524.81	1347.77	1171.71	1100.96	746.40	945.25	595.84	342.69	637.35	999.33	803.24	324.13	195.57	0

APPENDIX B

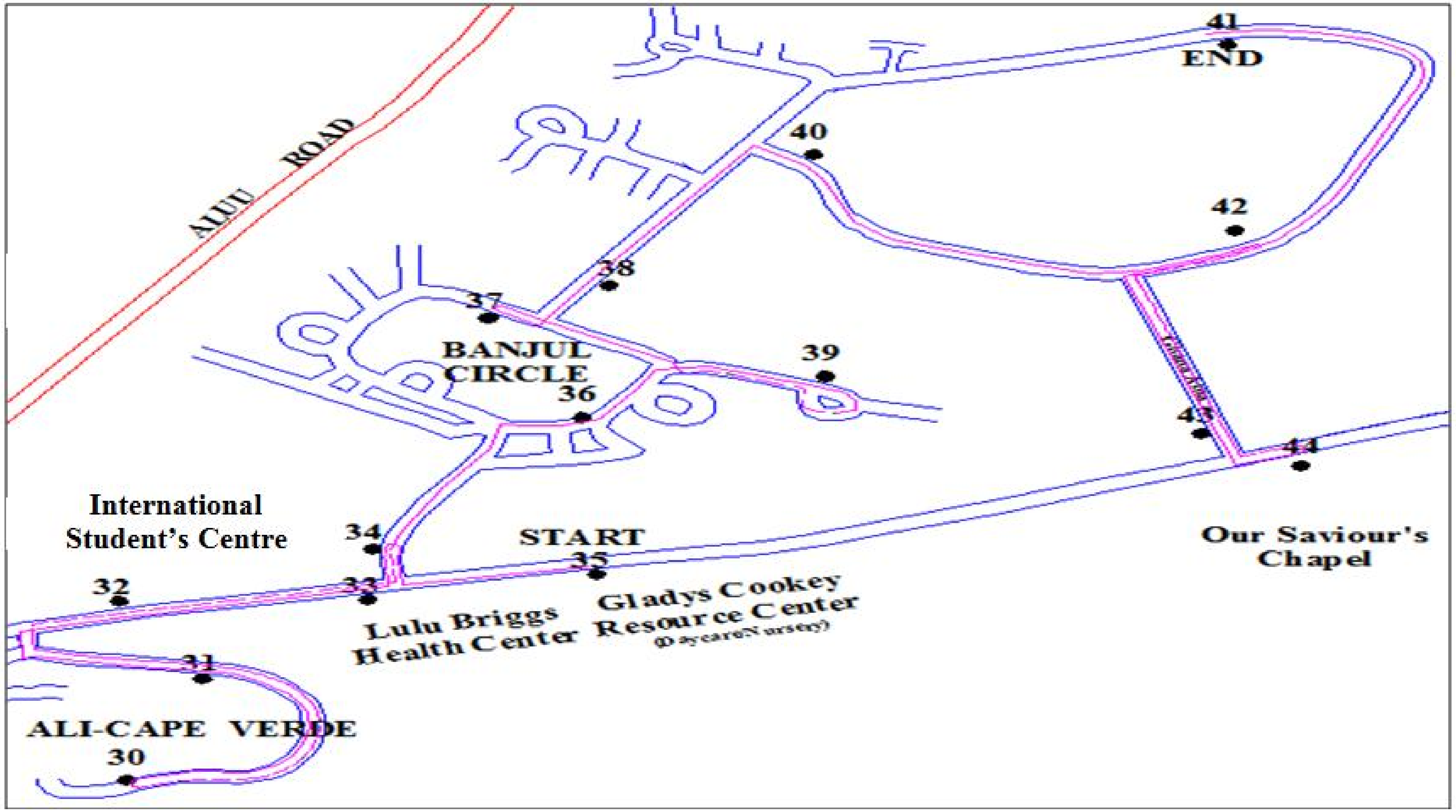
APPENDIX B1. Choba campus optimized route



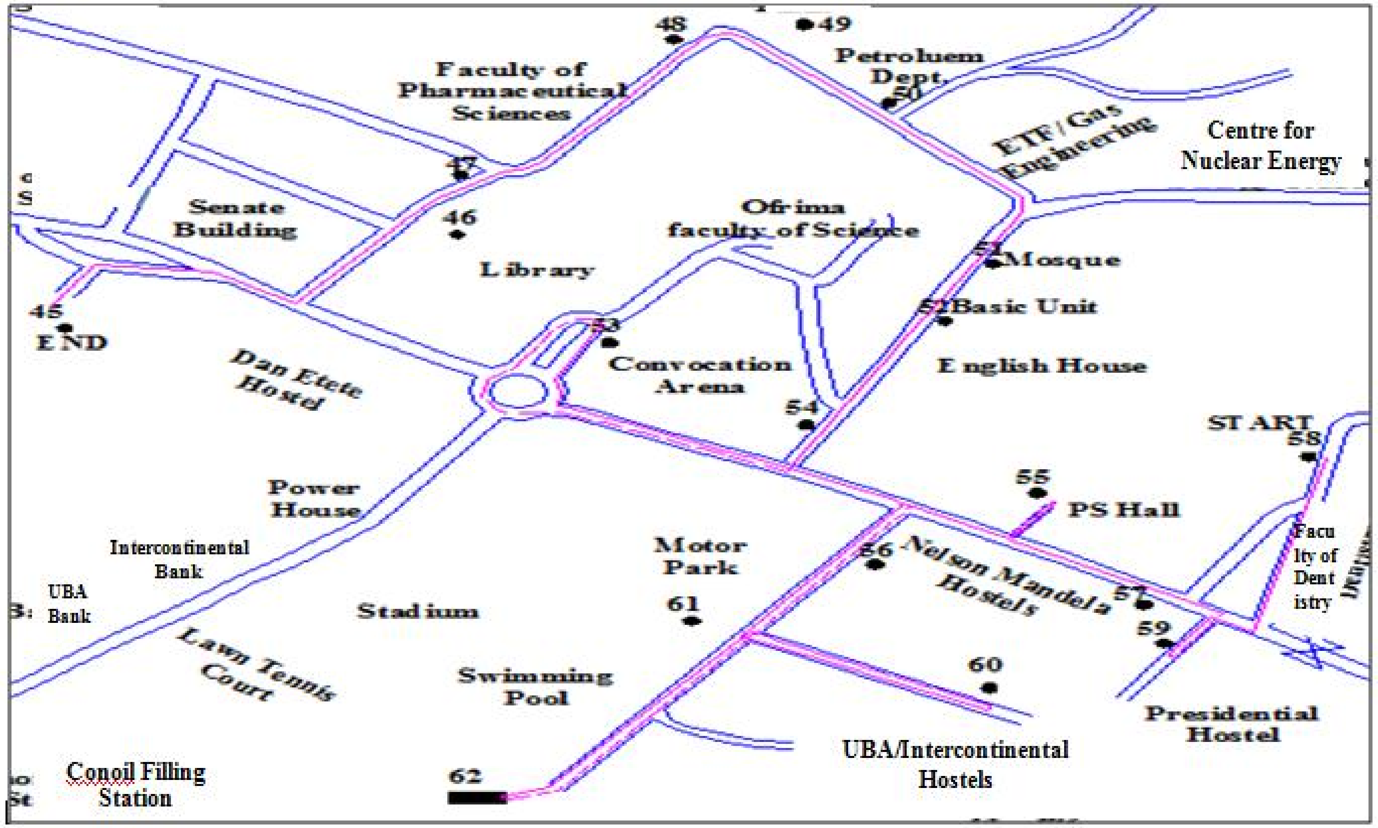
APPENDIX B2. Delta campus optimized route



APPENDIX B3. University park section 1 optimized route



APPENDIX B4. University Park section 2 optimized route



Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/9821