A Heuristic Approach to Locating a Landfill Site in the Sekondi-Takoradi Metropolis of Ghana

Sarah-Lynn Mensah [*1] Rebecca Nduba Arhin [2] Famous Tumi-Acquah [3]
[1, 2, 3] Department of Mathematics and Statistics, Takoradi Polytechnic, P. O. Box 256, Takoradi, Ghana

Abstract
The rise in the urban population of developing countries in the past decade has brought the necessity to develop environmentally sustainable and efficient waste management systems. Sanitary landfill constitutes one of the primary methods of municipal solid waste disposal. Optimized siting has gained considerable importance in order to ensure minimum damage to the environment. Despite an increase in alternative techniques for disposing of waste, landfill site still remains the primary means of waste disposal. This study seeks to find the optimal location of a landfill site in the Sekondi -Takoradi metropolis. The problem was formulated as an Integer Programming model and the solution was presented through an ant colony based meta-heuristic for the Travelling Salesman Problem. The data on distances were taken from potential collection points and also Cartesian coordinates of the collection points were collected and used for each sub-metro. The optimal solutions were obtained with the aid of a MATLAB implementation codes. The Ant Colony results revealed that the best location for an additional landfill site is Apremedo with a route length of a 133.35miles.
Keywords: Ant colony, Travelling Salesman Problem, Landfill site, Optimization and Integer Programming.

1. INTRODUCTION

Landfill site also known as dump or rubbish dump is a site for the disposal of waste materials. Also, a landfill site is an area of the land that is used to dump rubbish either directly on the ground (landraising) or filling of unwanted hole in the ground (landfilling). We need land fill sites to dispose rubbish that cannot be reused or recycled. New technologies are being developed to reduce the amount of rubbish sent to land fill each year for instance Energy Recovery Facilities (ERF) and compositing.

Solid waste is a telltale sign of how citizens' lifestyles change as a result of economic development. Furthermore, the distribution of waste generation in the different regions of a country is indicative of its degree of urbanization. In cities, where standard of living is higher, there is usually a higher waste output compared to rural areas. This is reflective of the case of a developing country like Ghana where its Western Regional capital (Sekondi-Takoradi) generates almost a quarter of the country's total waste generation (STMA, 2010).

Landfill site contains both household and commercial refuse. Household refuse are mostly organic, which contains plastics, food, paper, tin packaging etc. Nowadays, Western countries generally rely on landfilling to overcome the problem of waste accumulation (Girling, 2005; Pacione, 2005). The landfill seems to have a special attraction for municipal waste managers because it offers a cheap and convenient option for waste disposal compared with other strategies such as reuse, recycling and energy recovery (Charzan, 2002).

Urban Waste Management (UWM) and by extension those of urban environment planning and management represent some of the major challenges facing urban managers (Attahi, 1999). This is being associated with the increasing rates of rural-urban migration in many parts of the world, especially Africa. Africa is said to be least urbanized continent but one currently experiencing the fastest rate of urbanization (Silitsheea, 1996), higher volumes of solid waste are produced from the home to the neighborhood, the city and the region as a whole. The high rate of urbanization in Africa implies a rapid accumulation of refuse, social and economic changes that most countries have witnessed since the 1960s have also contributed to the increase in waste generated per capita (Onibokunn, 2004). That is why the location of a landfill site is very important in the community.

Recent developments, however, seem to suggest that burying waste in landfills is not a sustainable solution to the mounting solid waste problem. Because of a number of factors including rising concerns about the polluting effects of landfills, land space for land filling is becoming increasingly scarce and difficult to acquire. By the mid-1990s, for example, half of the one million tons of solid waste generated by Central Londoners were being transported, more than 64 km to be dumped because landfill space within the Central London area had been exhausted (Kwawe, 1995).

Landfill siting has become the most contentious and difficult part of the solid waste since it is difficult to find sites that are both technically feasible and environmentally acceptable. The concentration of population and business activities in Ghana cities being accompanied by a rapid increase in the volume of solid waste generated from production and consumption activities. An observation within the city show visible aspects of the solid waste problem including accumulation of garbage, Heavy Street, litter, waste-clogged drains and waste bodies and stinking gutters. The increasing rate of unplanned urbanization in the developing countries of Africa has brought about environmental degradation. One of the most pressing issues of urbanization in the developing world, mostly in Africa, has been the problem of solid, liquid, and toxic-waste management.

Recently, in major urban centers in Africa have shown that the problem of waste management has become a monster that has aborted most efforts made by city authorities, state and federal governments, and professionals alike. In recent times, several large foreign loans have been secured to help tackle the problems of environmental sanitation. Visit any African city today will show aspects of the waste-management problem like heaps of uncontrolled garbage, roadsides littered with garbage, streams blocked with junk, disposal sites, and inappropriately disposed toxic wastes which pose public health risks and aesthetic burdens to the citizens they are meant to serve the country.

Since the Sekondi-Takoradi Metropolis is growing rapidly there is the need to locate an additional landfill site which has little negative impact to the population and the environment.

The cost of siting and keeping a dump site operational can be measured in monetary and non-monetary terms. The monetary cost may include the cost of acquiring the land, maintenance cost of the site, labour cost and the cost of transporting refuse to the landfill site. Thus, it is not doubtful that when the monetary cost is optimized, the cost of dumping waste to consumers will be minimized.

Our paper is focused on the optimal location of an additional landfill site in the Sekondi-Takoradi Metropolis, given three possible sites. The objectives include optimal ordering of all the routes linking the waste collecting points and to connect each of the landfill site to the optimal route. We will accomplish our objectives by employing the ant colony methodology.

2. METHODOLOGY

This section discusses the integer programming model of the landfill site location problem and the ant colony system for solving the problem

2.1 The Binary Integer Programming Model

The assumptions of the model are as follows:

• The alternative sites for the building of the landfills are known.

• The capacities of the collection trucks that carry the waste to the landfill sites are the same

• When a collection truck is emptied at the landfill site, it goes back to the garage if there is no waste to be collected in the sub metro.

• The landfill sites are incapacitated. Each sub metro sends its waste to the nearest landfill site.
• All waste should be brought to a designated collection point.
• There is one collection truck operating for each sub metro.
• The cost of opening a landfill site is the same for all candidate sites.

Parameters of the model are as follows:

n = Total number of the waste generation points from where the waste is collected
t =Total number of potential sites for the building of the transfer stations
l =Total number of potential sites for the building of the landfills

d_{ij} = The shortest path distance between the generation point *i* and the candidate transfer site *j* in kilometers

d_{jk}= The shortest path distance between the sub metro *j* and the candidate landfill site *k* in kilometers

g_i= Amount of waste generated by the generation point *i*

c_1=The total cost of loaded trips of a collection truck per km

c_2= Total cost of empty trips of a collection truck per km

c_3= Cost of a trip of a long haul truck per km

F_j= Fixed cost of building a landfill site *j*

C = Capacity of a long hauling truck
M = A sufficiently large number

The decision variables are as follows:

$$V_{ij} = \begin{cases} 1, if waste generated by submetro is transported to a landfill site \\ 0 , otherwise \end{cases}$$

Since, we assumed that there are enough number of long haul trucks to carry the waste to the landfills, n_{ij} can be considered as the number of long haul trucks that should be made available at the transfer station

The mathematical formulation of the model is as follows:

Minimize

$$\sum_{i\in D}\sum_{j\in T}(c_1+c_2)v_{ij}d_{ij}+\sum_{j\in T}\sum_{k\in T}c_3 n_{ij}\, d_{ik}+\sum_{j\in T}F_j \tag{1}$$

Subject to

$$\sum_{j \in T} V_{ij} = 1 \ \forall i \in D \tag{2}$$

$$n_{ij} \geq \frac{\sum_{i \in N} g_i V_{ij}}{C} \tag{3}$$

$$x_j = 0 \ or \ 1 \ for \forall j \in T \tag{4}$$

$$\left. \begin{array}{c} V_{ij} = 0 \ or \ 1 \ for \forall i \in D and j \in \\ n_{ij} = nonnegativeinteger \forall j \in T and k \in L \end{array} \right\} \tag{5}$$

There are other costs including the total cost of the trips of collection trucks from the garage to the districts, plus, the total cost of the return trips of collection trucks from the transfer stations to the garage, and the cost of collecting the waste within the districts. These costs add up to a constant which does not depend on or affect the decisions of the model.

The objective function represents the cost function to economically locate landfill sites. The first two sets of terms in (1) compute the total cost of short haul collections and long haul transfers. The third and the fourth terms add the capital cost of opening a landfill site. The first constraint (2) represents that no district can be served by more than one landfill site. Constraint (3) ensures that if a transfer does not exist between a generation point and a landfill site, then the number of the trips between them is zero. Constraint (4) represents the number of long haul trips that should be made in order to transfer all the collected garbage to a landfill site.

2.2 The Ant Colony System

The natural metaphor on which ant algorithms are based is that of ant colonies. Real ants are capable of finding the shortest path from a food source to their nest without using visual cues by exploiting pheromone information. While walking, ants deposit pheromone on the ground and follow, in probability, pheromone previously deposited by other ants. In Figure 1, we show a way ants exploit pheromone to find a shortest path between two points. Consider Figure 1 (a): ants arrive at a decision point in which they have to decide whether to turn left or right. Since they have no clue about which is the best choice, they choose randomly. It can be expected that, on average, half of the ants decide to turn left and the other half to turn right. This happens both to ants moving from left to right (those whose name begins with an L) and to those moving from right to left (name begins with an R). Figure 1 (b) and 1 (c) shows what happens in the immediately following instants, supposing that all ants walk at approximately the same speed. The number of dashed lines is roughly proportional to the amount of pheromone that the ants have deposited on the ground. Since the lower path is shorter than the upper one, more ants will visit it on average, and therefore pheromone accumulates faster. After a short transitory period the difference in the amount of pheromone on the two paths is sufficiently large so as to influence the decision of new ants coming into the system [this is shown by Figure 1 (d)]. From now on, new ants will prefer in probability to choose the lower path, since at the decision point they perceive a greater amount of pheromone on the lower path. This in turn increases, with a positive feedback effect, the number of ants choosing the lower, and shorter, path. Very soon all ants will be using the shorter path. The above behavior of real ants has inspired *ant* *system*, an algorithm in which a set of artificial ants cooperate to the solution of a problem by exchanging information via pheromone deposited on graph edges. The ant system has been applied to combinatorial optimization problems such as the traveling salesman problem and the quadratic assignment problem. The ant colony system (ACS), the algorithm presented in this article, builds on the previous ant system in the direction of improving efficiency when applied to symmetric and asymmetric Travelling Salesman Problem (TSP). The main idea is that of having a set of agents, called *ants*, search in parallel for good solutions to the TSP and cooperate through pheromone-mediated indirect and glob communication. Informally, each ant constructs a TSP solution in an iterative way: it adds new cities to a partial solution by exploiting both information gained from past experience and a greedy heuristic. Memory takes the form of pheromone deposited by ants on TSP edges, while heuristic information is simply given by the edge's length. The main idea introduced by ant algorithms is the synergistic use of cooperation among many relatively simple agents which communicate by distributed memory implemented as pheromone deposited on edges of a graph. We will estimate the optimal number of ants to be used, observe the effects of pheromone mediated cooperation, and evaluate the role that pheromone and the greedy heuristic have in ACS performance.

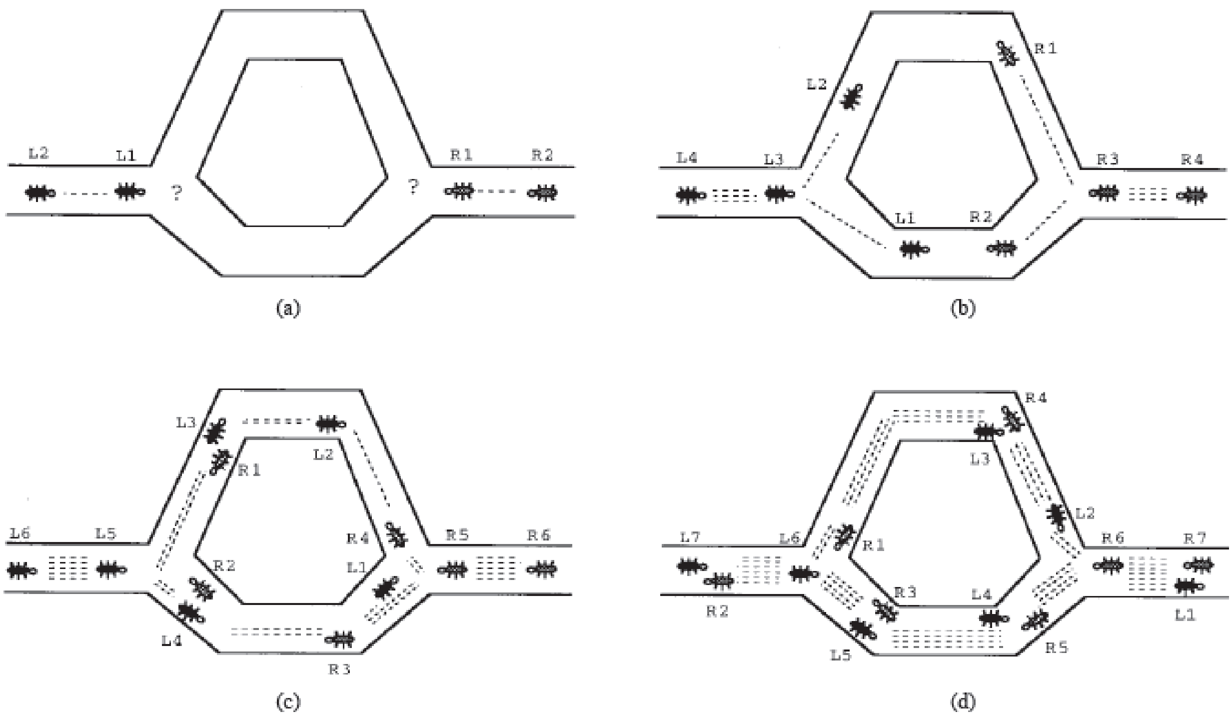

Figure 1: Exploitation of Pheromone by Ants

3. RESULTS AND DISCUSSION

This section displays ant colony results of the data taken from the various places in the sub-metros. Table 1 shows the distance matrix table which displays the x and y coordinates for each collecting point.

Figure 2 shows the ACO output of Sub-Metro 1 with Sofokrom as the landfill site area and the optimal route length is approximately 161.14miles.This shows that the best ant will cover an optimum course by the length of about 161.14miles, which is a better distance covered by truck of Sub-Metro 1. This means that the optimal route length displaced by truck of Sub-Metro 1 using Ant Colony is 161.14miles.

We observe from Figure 3 that the best ant will cover an optimum course by the length of about 138.9026miles, which is a better distance covered by Sub-Metro 2. This means that the optimal route length displaced by truck of Sub-Metro 2 using Ant Colony is approximately 138.90miles.

Finally, it can be seen in Figure 4 that the best ant will cover an optimum course by the length of about 133.3527miles, which is a better distance covered by the truck of Sub-Metro 3. This means that the optimal route length displaced by truck of Sub-Metro 3 using Ant Colony is approximately 133.35miles.

4 COCLUSIONS AND RECOMMENDATIONS

The ant colony optimization algorithm has shown that it is one of the most powerful tools that can be used to solve hard and complex combinatorial optimization problems. The results show the possibility of the ant colony optimization heuristic to converge the solution to optimality.

The main objective of the study was to use the Ant Colony Optimization to locate an additional landfill site in the Sekondi Takoradi Metropolitan Assembly.

Considering the Figures 2, 3 and 4 the landfill site can be located at any of these three nodes; node 20 (Sofokrom) or node 20 (Adeitsemu Highways) or node 20 (Apremedo) respectively. Using the Ant Colony Output in figures 2, 3 and 4, the best alternative found among the three places is Apremedo, which had an optimal length of about 133miles. This implies that the minimum distance from the collection points in the sub-metro 3 to the new landfill site at Apremedo is 133.35miles.

In respect of the results obtained in the research, we recommend that if the government of Ghana wants to establish landfill site in the Sekondi-Takoradi Metropolis, it will be advisable to locate it at Apremedo.

REFERENCES

Addor, J. A., Amponsah, S. K., Annan, J. and Sebil, C (2013). School Bus Routing: A Case Study of Wood Bridge School Complex, Sekondi-Takoradi, Ghana, *International Journal of Business and Social Research*, 3 (12): 26-36.

Attahi, K. (1999). Managing the Monster, *Urban Waste and Governance in Africa.* Pp. 11- 48. Ottawa, IDRC.

Dorigo, M. and Gambardella, L. M. (April 1997). Ant Colony System: A Cooperative Learning Approach to the Travelling Salesman Problem. IEEE Transactions on Evolutionary Computation 1(1): 53–66. ‘

Edmunson, R. (1981). Refuse Management in Kumasi. Land Administration Research Centre, Kwame Nkrumah University Ghana, Kumasi, Environmental Engineering, 122-10, 902-908.

Girling, R. (2005). Rubbish! Dirt on Our Hands and Crisis Ahead. Eden Project Books.

Kirkpatrick, S., Gelatte, C. D., Vecchi, M. P. (1983). Optimization by Simulated Annealing, science 220(4598):671-680

Kwawe, D. B. (1995). Culture of Waste Handling. *African and Asian Studies*, 30(1-2): 53-67

Malombe, J. M. (1993). *Sanitation and Solid Waste Disposal in Malindi, Kenya*, *19th Water, Sanitation, Environment and Development Conference Preprints, Ghana Management*. New York, McGraw Hill. Urban Waste and Governance in Africa Pp. 101-172. Ottawa, IDRC.

Nze, F.C. (1978). Managing Urban Waste in Nigeria for Social and Economic Development *journal of management studies*, Lagos vol.5 Nigeria

Onibokun, A. G. (Ed). (2004). Managing the Monster: Urban Waste and Governance in Africa.

Pacione, M. (2005). Urban Geography. A Global Perspective. 2nd. Edition. London and Principles and management issues / George Tchobanoglous, Hilary Theisen, Process, *Socio – Economic Planning Science* 25, 89-121.

Silitshena, R. M. K. (1996). Urban Environmental Management and Issues in Africa South of the Sahara, *Socio – Economic Planning Sciences*", 25(2): 89-102

Fisher, M. L. (1981). The Lagragian Relaxation Method for Solving Integer programming Problems'', *Management Science*, 27:1-18.

Schittekat, P., Sevaux, M., Sörensen, K. (2009). A Mathematical Formulation for a School Bus Routing Problem‖, IEEE, 1552-1556.

Table 1: Distance matrix for STMA

Collecting Point	Y	X	Collecting Point	Y	X
Effiakuma Night Market	90	620	Chapel Hill	75	622
Sekondi Anafo	92	630	Pipeano	89	621
Kwesiminstsim Bus Stop	89	614	Ketan	92	636
Housing New Site	92	624	Sofokrom	55	644
Saw Mill	88	616	Bankyease	83	610
Market Circle	93	650			
Tanokrom	90	610			
Adeitsemu Highways	87	623			
Assakae	90	621			
Mpatado	97	622			
Butumagyebu	85	633			
Adiembra Ridge	87	615			
Anaji Fie	96	618			
Apremedo	81	614			
Sika Duasi	75	645			
Zenith Area	80	615			

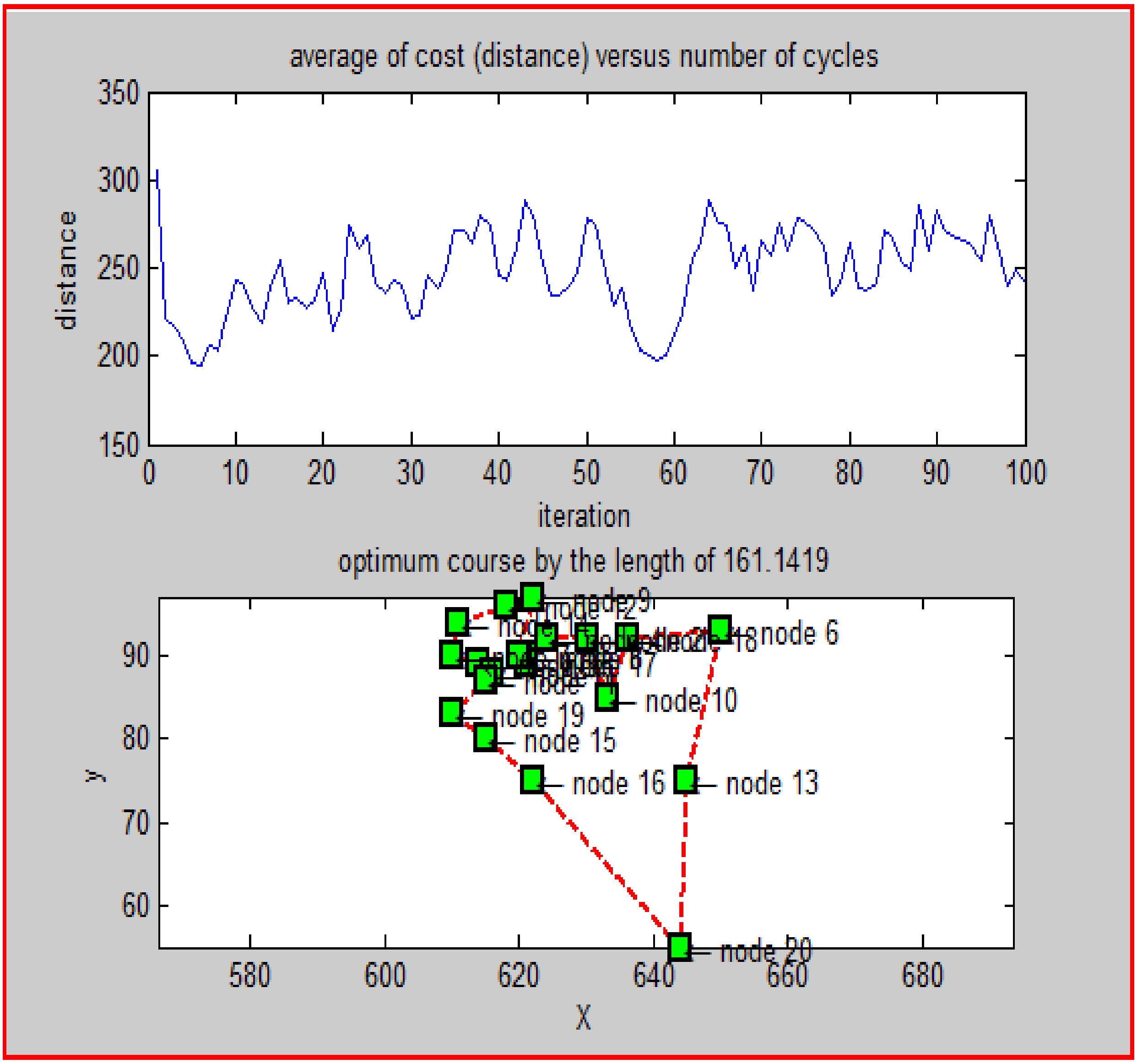

Figure 2: ACO output for sub metro 1with Sofokrom as landfill site

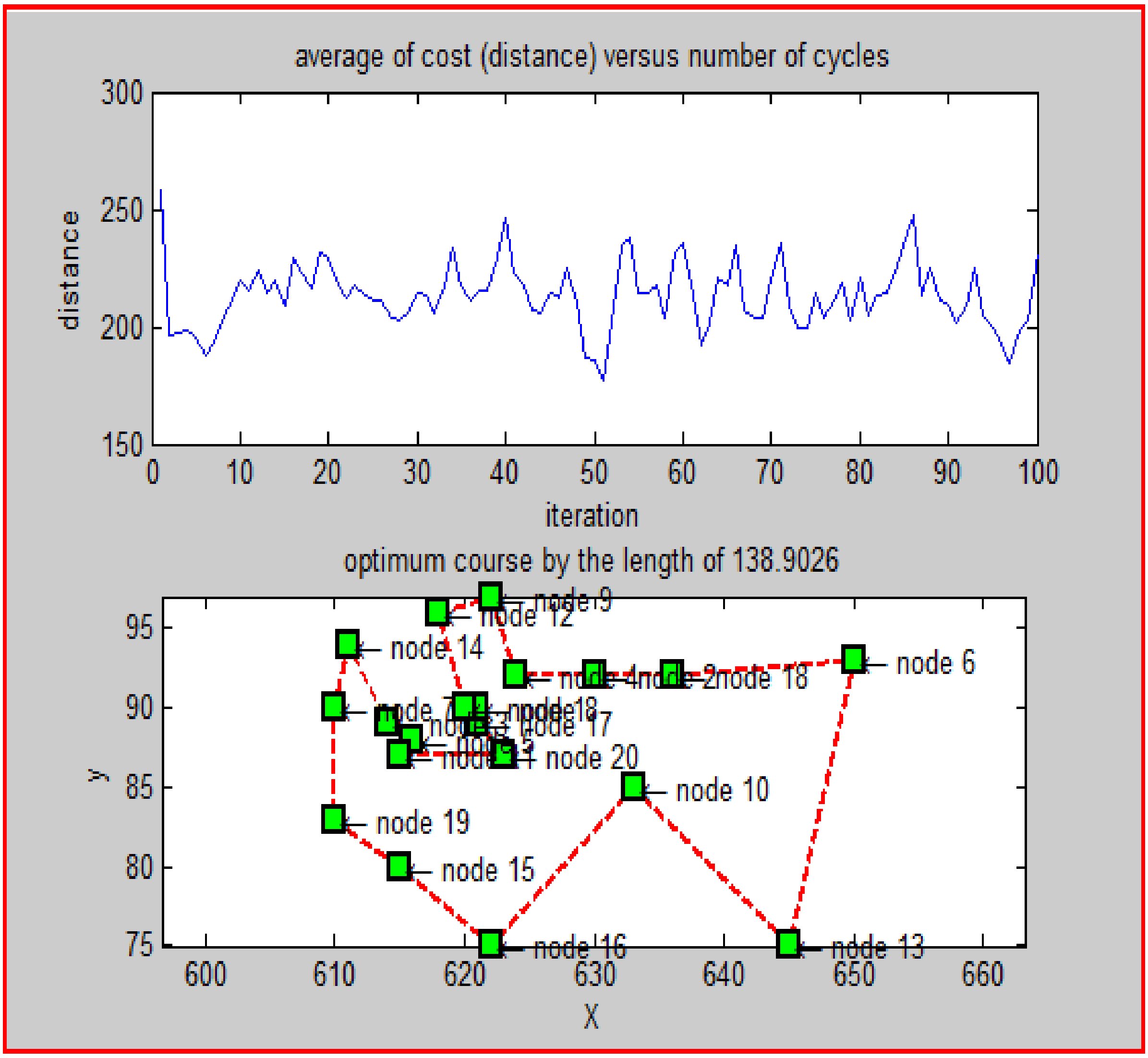

Figure 3: ACO Output for Sub Metro 2 with Adeitsemu Highways as landfill site area

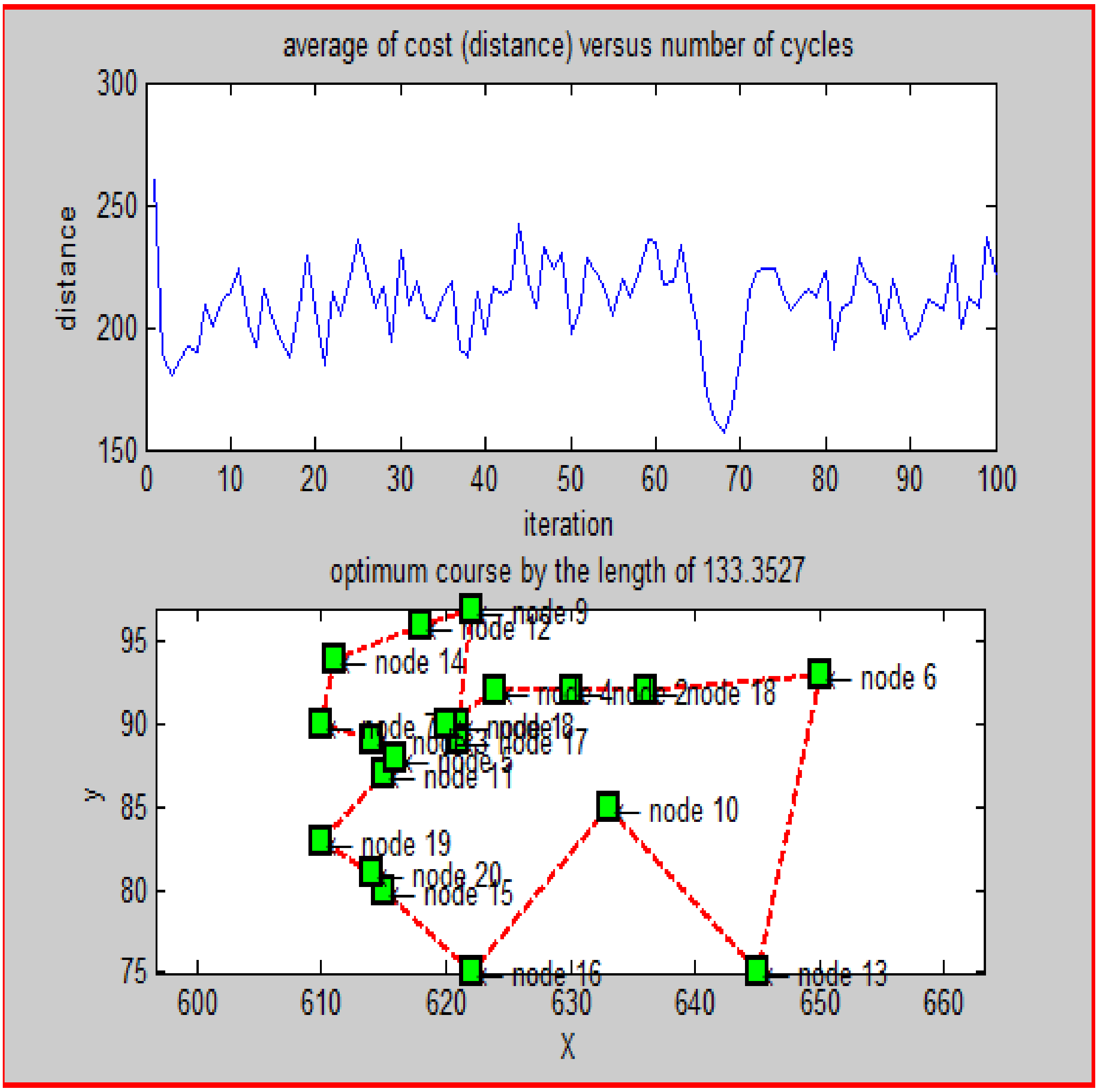

Figure 4: ACO output for Sub metro 3 with Apremedo as Landfill Site Area