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A Vehicle Routing Problem for Efficient Waste Transportation Using Ant Colony Algorithm: Marang Region

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Abstract: The study aimed to address the pressing issue of waste collection in Marangregion and provide a comprehensive solution to maintain a clean and liveableenvironment for the residents. Improper waste management can lead to a degraded quality of life and cause difficulties in daily activities, making effective waste collection a critical aspect of urban planning and management. The study focused onthe vehicle routing problem of household waste transportation, with the objective of minimizing the total distance and cost of waste collection. Given the NP-hard natureof the problem, the ant colony optimization (ACO) algorithm was employed to find the optimal solution, with the assistance of Python programming language. To accurately depict the waste collection scenario in Marang region, the latitude and longitude data for 18 residential locations and the disposal center located at Kampung Sungai Serai were obtained directly from the Global Positioning System (GPS). Thelocations were divided into two zones, with 10 locations in Zone 1 and 8 in Zone 2, to ensure a comprehensive analysis of the waste collection scenario. All the occupied points considered were within residential areas, making the study specific to housingwaste collection. The results of the study were obtained in five seconds, and to ensurethe validity and reliability of the findings, the analysis was run multiple times for eachzone. For Zone 1, the results were run 21 times, and for Zone 2, the results were run 10 times. The best solution for efficient waste transportation was found by recordingthe shortest distance and the lowest cost, with the eleventh result for Zone 1 yielding a minimum cost of RM29.08 and a shortest distance of 37.69 km, and the third result for Zone 2 yielding a minimum cost of RM16.94 and a shortest distance of 17.22 km.In conclusion, the study effectively addressed the issue of waste collection in

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Marang region and provided a comprehensive solution for efficient waste transportation.

Keywords: Vehicle Routing Problem, Waste Transportation, Household Waste Collection, Ant Colony Algorithm

1. Introduction

The waste management system in residential area is important and has to be treated wisely. Many research projects treat a given area's waste collection problem as a vehicle routing problem (VRP), which results in an efficient collection route [1]. In 2022, the global birth rate is 17.668 births per 1000 people, down 1.15 percent from 2021. According to the most recent United Nations estimatescompiled by World meters, the current global population is 7.9 billion as of March 2022 [2]. Accordingto World meters elaboration of the most recent United Nations data, Malaysia's current population is 33,085,033. The increasing population of people will lead to an increase in high waste disposal rates inMalaysia [3]. Non-domestic and domestic waste generation both grew in 2021, from 4.12 million tonnesand 1.77 million tonnes in 2020 to 5.12 million tonnes and 1.82 million tonnes in 2021, respectively. Thus, a proper waste collection is needed to make a comfortable living life. This situation also happenedin Marang region which is strict at Terengganu. Marang area is chosen to ensure the efficient of garbage collection in the residential area. In Marang, waste collection will only be taken every two days and only one truck is used to collect garbage in each zone. Therefore, the pile of garbage will increase due to the population density in the area. This can cause the pollute in environment like air pollution, smell, visual pollution and soil pollution. Therefore, to preserve a clean environment and a comfortable way of life, an effective garbage collection plan is required in Marang area.

Waste is a problem that poses serious environmental risks [4]. Waste collection and transportation is about 60% to 80% of solid waste management costs, therefore evaluating and optimizing this system will play a significant role in solving and reducing problems in urban service management [5]. Waste transportation is a waste management operational activity that starts at the last point of garbage collection and finishes at the transfer point of acceptance. The low frequency of solid waste transportation, the length of the waste transportation route, the inadequate capacity of the transport vehicle and the length of time for solid waste transportation all contribute to the problem [6].VRP is a logistical challenge that deals with product delivery and pick-up. The location of one depot, the location and demand of customers, and the number and capacity constraints of transportation units(vehicle) are all known in advance in the event of a basic problem [7]. The VRP is a type of optimizationthat involves determining the most cost-effective delivery serving a set of clients [8].

In this study, Ant Colony Optimization (ACO) algorithm is used. The ACO algorithm is used to find the best path, and region partitioning (partition clustering technique) can improve the performance of a large-scale problem. The ACO algorithm is a heuristic algorithm that has been widelyused for various optimization problems and was inspired by real -life ant observations such as how antsfind the shortest path from their nest to a food source [9]. The Global Positioning System (GPS) systemis a satellite- based navigation system consisting of a network of satellites launched into orbit by the United States Department of Defence [10] is used to determine the longitude and latitude for the selectedlocations. Therefore, in this study, the vehicle routing problem for efficient waste transportation is carried out using ant colony optimization algorithm with the assist of Python. The best solution is identified by the minimum total cost and optimal total distance.

2. Methodology

In this study, the mathematical model for solving the vehicle routing problem for efficient waste transportation using ant colony algorithm is described. The Global Positioning system - Vehicle routing problem (GPS-VRP) model is used to determine the shortest path and the most ideal option. It is also essential to consider the ant colony algorithm to achieve the efficient waste transportation in the Marang region. To solve this problem Phyton Programming is considered as a solver. The choice variables that produce the best evaluation of the objective function provide the answer to the problem. The decisions tobe taken in the VRP example specify the order of the sequence of client visits; they are a collection of routes.

2.1 Vehicle Routing Problem for Waste Transportation

VRP is a logistical challenge that deals with product delivery and pick-up. The location of one depot, the location and demand of customers, and the number and capacity constraints of transportationunits (vehicle) are all known in advance in the event of a basic problem [7]. The challenge of planninga set with the lowest cost from a base station to a group of geographically dispersed destinations, subjectto additional constraints, is known as VRP [11]. VRP can be modelled as a directed weighted graph $G(V,E)$ where $V=\{v_0,v_1,\cdots,v_n\}$ be the set of nodes i.e. customers to be visited from the central depot v_0. Also $E=[\{v_i,v_j\},\{i,j)=0,1,2,\cdots,n,i\neq j)]$ is the set of arcs interlinking two locations i,j .

Furthermore, a group of vehicles with the same capacity to service all customers.

Mathematically, VRP can be represented as:

Minimise $F=\sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{K=1}^{V}C_{ij}x_{ij}^{v}$ Eq. 1

Subject to:

$$\sum_{v=1}^{V}\sum_{j=1}^{N}x_{ij}^{v}\leq V \text{ for } i=0 \quad \text{Eq 2}$$

$$\sum_{v=1}^{V}x_{ij}^{v}=\sum_{j=1}^{N}x_{ij}^{v}\leq 1 \text{ for } i=0 \text{ and } v\in\{1,\cdots,V\} \quad \text{Eq 3}$$

$x_{ij}=1$ if customer j is served after serving customer i and 0 , otherwise $(i\neq j:i,j=0,1,\cdots,N)$.

Here:

$K=$ Vehicle
$V=$ Total fleet size
$N=$ Number of locations to be visited
$c_i=$ Node / location i $(i=1,2,\cdots,N)$
$ij=$ Travelling distance between node/location i and node/location j

2.1.1 Objective function

The objective function given by (Eq 1) is to be optimised satisfying constraints (Eq 2) to (Eq 3). Objective function (Eq 1) corresponds to minimisation of total travelled distance. The most common objective is to reduce transportation costs as a function of travel distance or time; fixed costs associated with vehicles and drivers can be taken into account, and thus the number of vehicles can be reduced. The objective function includes both independent variables (decision variables) that are under the planner's control and dependent variables that are a result of the assumed decisions. The choice variables that produce the best evaluation of the objective function provide the answer to the problem. The decisions to be taken in the VRP example specify the order of the sequence of client visits; they are a collection of routes. A route begins at the depot and is an organised series of vehicle trips to clients to fulfil their orders. A feasible solution must be checked to ensure it does not violate any constraints, such as the requirement that the sum of the demands of the visited vertices not exceed the vehicle capacity [11].

2.1.2 Constraints

The first constraint (Eq 2) ensures that all of the tour must be completed with at most V vehicles. Beginning and completion of tour at central depot is ensured by (Eq 3). The basic VRP can be linked to constraints such as the vehicle's maximum capacity, route length, arrival/departure time at each location and service time, and the collection or delivery of items [11].

2.2 Global Positioning System Based Solution

The Global Positioning System (GPS) system is a satellite- based navigation system consisting of a network of satellites launched into orbit by the United States Department of Defence. GPS can assist to arriving at the destination safely and on time by showing the best route or shortcut available going to the destination. This application also can reduce fuel cost by sending the drivers on more efficient routes or making better dispatching decision, GPS tracking devices can help to make cost-saving decisions based on data in real-time [12] which is use for this research to find minimum distance from each node.

2.3 Residential Area in Marang region

There are one disposal site and 18 locations or nodes which are 10 nodes for Zone 1 and 8 nodesfor Zone 2. The garbage station and the 18 locations of node are from the same postcode, which is 21400. The location selected included garbage station in Kampung Sungai Serai, Bukit Payong (disposal site), Taman Mas Padang Leban, PAKR Bukit Payong, Taman Tasek, Taman Koperasi, Taman Putri Bukit Payong 1&2, Taman Sena Rendang, Taman Wakaf Nyior Kembar, Taman Wakaf Jaya Wakaf Dua, Taman Sri Kiambang, Perkedaian Pekan Bukit Payong, Taman Bukit Payong, TamanSafiah Murni, Perkedaian Taman Suaiah Murni, Taman Hassan Husin, PAKR Bukit Sawa, Taman Mewah, Taman Tanah Lot Binjai Rendah and Taman Puteri Indah. Figure 1 shows the Marang region.

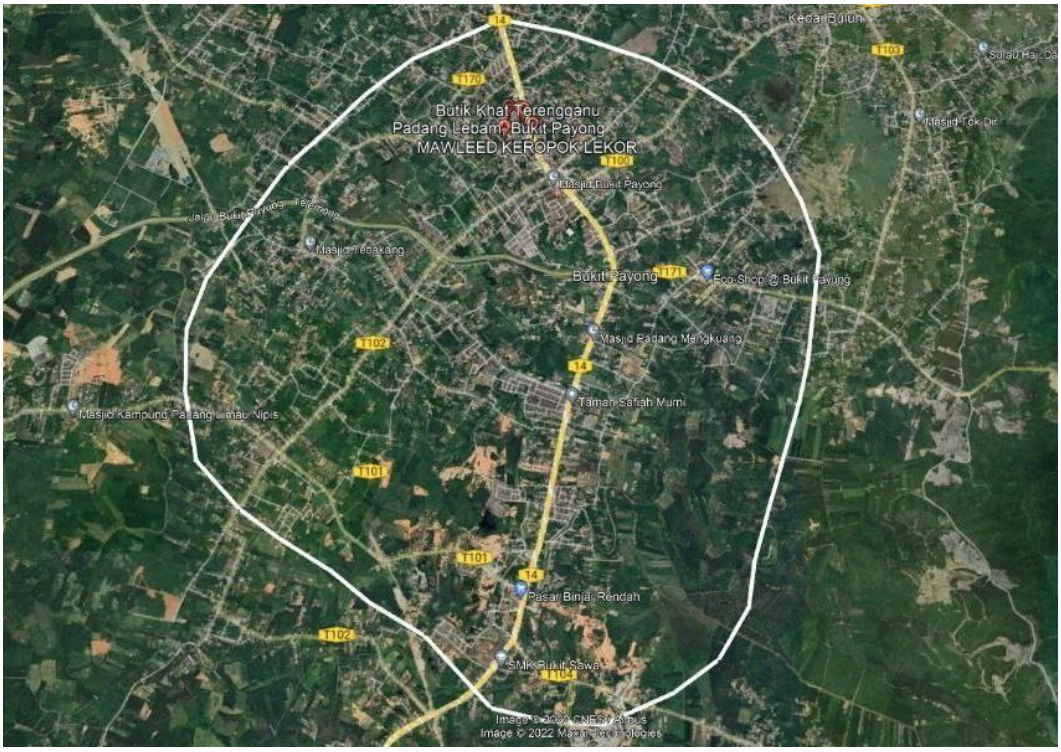

Figure 1: Location in Marang region

Data of latitude and longitude for each node which are determined from GPS Coordinate Malaysia of each node are needed to find the optimum solution for the waste collection problem. Table1 and Table 2 shows the coordinate for each node in Marang region. Node 1 is disposal site, the waste collection and there have 18 nodes which are 10 nodes for Zone 1 and 8 nodes for Zone 2 of demand for waste collection.

Table 1: Details for each node for Zone 1

Node	Location	Latitude	Longitude
1	Pusat Pelupusan Sisa Pepejal, Marang	5.178504	103.149205
2	Taman Mas Padang Leban	5.238783	103.096774
3	Pakr Bukit Payong	5.227517	103.098251
4	Taman Tasek	5.244540	103.095613
5	Taman Koperasi	5.291295	103.167045
6	Taman Putri Payong 1&2	5.227000	103.090400
7	Taman Sena Rendang	5.243936	103.113901
8	Taman Wakaf Nyior Kembar	5.236486	103.107949
9	Taman Wakaf Jaya, Wakaf Dua	5.256600	103.094870
10	Taman Sri Kiambang	5.255230	103.093360
11	Perkedaian Pekan Bukit Payong	5.215940	103.105350

Table 2: Details for each node for Zone 2

Node	Location	Latitude	Longitude
1	Pusat Pelupusan Sisa Pepejal, Marang	5.178504	103.149205
2	Taman Bukit Payong	5.211040	103.102730
3	Taman Safiah Murni	5.212270	103.103530
4	Perkedaian Taman Safiah Murni	5.211530	103.103530
5	Taman Hassan Husin	5.217310	103.096040
6	Pakr Bukit Sawa	5.188810	103.096590
7	Taman Mewah	5.203680	103.103360
8	Taman Tanah Lot Binjai Rendah	5.190340	103.095550
9	Taman Puteri Indah	5.204920	103.105210

Table 1 shows the distance from node to node for Zone 1, meanwhile Table 2 shows the distance from node to node for Zone 2. In additional, this plan just use one garbage truck for each Zone and the waste collection will be collected at intervals of days from Zone 1 to Zone 2.

Table 3: Distance in Matrices Node to Node (in KM) for Zone 1

Node	1	2	3	4	5	6	7	8	9	10	11
1	0	8.87	7.84	9.44	12.70	8.45	8.26	7.90	10.56	10.54	6.40
2	8.87	0	1.26	0.65	9.73	1.49	1.98	1.26	1.99	1.87	2.71
3	7.84	1.26	0	1.92	10.41	0.87	2.52	1.47	3.26	3.13	1.51
4	9.44	0.65	1.92	0	9.46	2.03	2.03	1.63	1.34	1.21	3.36
5	12.70	9.73	10.41	9.46	0	11.10	7.90	8.94	8.87	9.09	10.81
6	8.45	1.49	0.87	2.03	11.10	0	3.21	2.21	3.33	3.16	2.06
7	8.26	1.98	2.52	2.03	7.90	3.21	0	1.06	2.53	2.60	3.25
8	7.90	1.26	1.47	1.63	8.94	2.21	1.06	0	2.66	2.64	2.30
9	10.56	1.99	3.26	1.34	8.87	3.33	2.53	2.66	0	0.23	4.67
10	10.54	1.87	3.13	1.21	9.09	3.16	2.60	2.64	0.23	0	4.57
11	6.40	2.71	1.51	3.36	10.81	2.06	3.25	2.30	4.67	4.57	0

Table 4: Distance in Matrices Node to Node (in KM) for Zone 2

Node	1	2	3	4	5	6	7	8	9
1	0	6.29	6.30	6.25	7.30	5.94	5.80	6.09	5.69
2	6.20	0	0.16	0.10	1.02	2.56	0.82	2.44	0.73
3	6.30	0.16	0	0.08	1.00	2.72	0.96	2.59	0.84
4	6.25	0.10	0.08	0	1.05	2.64	0.87	2.52	0.76
5	7.30	1.02	1.00	1.05	0	3.17	1.72	3.00	1.71
6	5.94	2.56	2.72	2.64	3.17	0	1.82	0.21	2.03
7	5.80	0.82	0.96	0.87	1.72	1.82	0	1.72	0.25
8	6.09	2.44	2.59	2.52	3.00	0.21	1.72	0	1.94
9	5.69	0.73	0.84	0.76	1.71	2.03	0.25	1.94	0

2.4 Ant Colony Optimization Algorithm

The Ant Colony Optimization (ACO) algorithm is used to each cluster once the clusters have been formed to identify the shortest tour. In order to identify the shortest path, the ACO algorithm mimics the behaviour of real ants and the characteristics of their pheromone trails [7].

The ACO algorithm process:

i. Initialized algorithm parameter: k ants, number of cycles $I, q_0, \beta, \rho, \tau_0$, also initialized iteration I and ant k to 1. β determines the importance of the heuristic function related to the pheromonetrail at the instance of decision making, ρ corresponds to the pheromone evaporation coefficient. The $N * N$ is pheromone matrix with each τ_{ij} corresponds to the level of pheromonetrace present on edge (i, j). The initial value of $\tau_{ij} = \tau_0$ also $\eta_{ij} = \frac{1}{d_{ij}}$ corresponds to the desirability level of moving from node i to node j and d_{ij} is the distance from node i to node j.

ii. Locate ant at starting point.

iii. Take new variable q and value for q is taken from a uniform distribution between 0 and 1 if $q \neq q_0$, then select the next stop using (Eq. 4) otherwise select the next move using Eq. 5.

$$p_k^{(i,j)} = \arg\_\max_{\mu \in jk^{(i)}} \{(\tau_{ij}) \cdot (\eta)^{\beta}\} \quad \text{Eq. 4}$$

$$p_k^{(i,j)} = \frac{(\tau^{\alpha}{}_{iz})(\eta^{\beta}{}_{iz})}{\sum_{z \in jk(i)} (\tau^{\alpha}{}_{iz})(\eta^{\beta}{}_{iz})} \quad \text{Eq. 5}$$

iv. If the ant does not visit all of the stops, proceed to next step, otherwise return to the start pointand calculate the total distance travelled. After calculating the travelled distance, use (Eq. 6) toupdate the pheromone level locally.

$$\tau_{ij} = (1-p) * \tau_{ij} + \rho * \tau_0 \quad \text{Eq. 6}$$

v. Determine the optimum cycling route and use (Eq. 7) to update the pheromone level worldwideonce all of the ants have finished the tour of a specific iteration.

$$\tau_{ij} = (1-p) * \tau_{ij} + \rho (l_{mc})^{-1} \quad \text{Eq. 7}$$

vi. When the number of iterations equals the initialization number, the algorithm stops and returns the best or optimum path.
Here:
ij = Travelling distance between node/location i and node/location j
τ = Desirability level of moving
k = Vehicle
η = Heuristic information
ρ = Pheromone

3. Results and Discussion

The results are obtained after running 21 times for Zone 1 and 10 times for Zone 2 in Python and hence the optimum result is determined. The total cost is calculated based on the total distance and theroute.

Table 5 and Table 6 shows the summary of the result for vehicle route calculated using Python.

Table 5: Result for each plan for Zone 1

Solution	Total Cost (RM)	Total distance (KM)	Result (Route)
1	45.45	45.68	Start > 1 > 3 > 8 > 7 > 4 > 2 > 9 >10 > 5 > 11 > 6 > 1 > End
2	34.08	41.95	Start > 1 > 8 > 7 > 10 > 9 > 4 > 2 > 6 > 11 > 3 > 5 > 1 > End
3	37.08	45.55	Start > 1> 3 > 8 > 7 > 11 > 2 > 4> 10 > 9 > 6 > 5 > 1 > End
4	30.08	38.11	Start > 1 > 11 >6 > 3 > 2 > 4 > 9 >10 > 7 > 8 > 5 >1 > End
5	32.08	40.26	Start > 1 >3 > 11 > 6 > 2 > 8 > 7 > 4 > 10 > 9 > 5 > 1 > End
6	31.08	39.40	Start > 1 > 11 > 6 > 2 > 4 > 9 > 10 > 8 > 3 > 7 > 5 > 1 > End
7	33.08	41.04	Start > 1 > 8 > 3 > 11 > 6 > 4 > 2 > 9 > 10 > 7 >5 > 1 > End

8	36.08	46.16	Start > 1 > 3 > 6 > 11 > 4 > 9 > 10 > 8 >7 >2 > 5 > 1 > End
9	35.08	43.26	Start > 1 > 6 >3 > 2 > 4 > 9 > 10 > 8 >7 > 11 > 5 >1 > End
10	32.56	47.47	Start > 1 > 7 > 11 > 6 > 9 > 10 > 2 > 4 > 8 > 5 > 3 > 1 > End
11	29.08	37.69	Start > 1 > 11 > 3 > 6 > 8 >7 > 2 > 4 > 10 > 9 > 5 > 1 > End
12	43.40	43.78	Start > 1 > 4 > 2 > 3 > 6 > 8 > 7 > 5 > 10 > 9 > 11 > 1 > End
13	33.40	43.33	Start > 1 > 6 > 8 > 7 > 2 > 4 > 9 > 10 > 5 > 3 > 11 > 1 > End
14	45.56	46.48	Start > 1 > 7 > 8 > 4 > 2 > 3 > 6 > 11 > 5 > 10 > 9 > 1 > End
15	32.40	42.65	Start > 1 > 7 > 8 > 4 > 2 > 9 > 10 > 5 > 3 > 6 > 11 > 1 > End
16	29.57	45.43	Start > 1 > 11 > 8 > 7 > 10 > 9 > 4 > 6 > 2 > 5 > 3 > 1 > End
17	41.40	42.00	Start > 1 > 6 > 3 > 8 > 7 > 2 > 4 > 10 > 9 > 5 > 11 > 1 > End
18	35.45	45.01	Start > 1 > 2 > 4 > 10 > 9 > 8 > 7 > 5 > 3 > 11 > 6 > 1 > End
19	33.57	49.41	Start > 1 > 10 > 9 > 4 > 2 > 8 > 7 > 6 > 11 > 5 > 3 > 1 > End
20	31.90	42.25	Start > 1 > 11 > 6 > 2 > 4 > 10 > 9 > 7 > 5 > 3 > 8 > 1 > End
21	39.26	39.37	Start > 1 > 11 > 3 > 6 > 8 > 2 > 4 > 10 > 9 > 5 > 7 > 1 > End

Table 6: Result for each plan for Zone 2

Solution	Total Cost (RM)	Total distance (KM)	Result (Route)
1	17.09	17.55	Start > 1 > 2 > 4 > 3 > 5 > 9 > 7 > 6 > 8 >1 > End
2	17.30	17.69	Start > 1 > 8 > 6 > 7 > 9 > 4 > 2 > 3 > 5 >1 > End
3	16.94	17.22	Start > 1 > 7 > 9 > 2 > 3 > 4 > 5 > 8 > 6 > 1 > End
4	19.30	20.18	Start > 1 > 4 > 3 > 2 > 7 > 9 > 8 > 6 > 5 > 1 > End
5	17.69	18.51	Start > 1 > 2 > 4 > 3 > 5 > 6 > 8 > 7 > 9 > 1 > End
6	17.94	18.54	Start > 1 > 2 > 4 > 3 > 7 > 9 > 5 > 8 > 6 > 1 > End
7	18.30	18.44	Start > 1 > 6 > 8 > 5 > 7 > 9 > 4 > 2 > 3 > 1> End
8	18.25	18.80	Start > 1 > 7 > 9 > 6 > 8 > 5 > 2 > 3 > 4 >1 > End
9	18.29	18.41	Start > 1 > 6 > 8 > 5 > 7 > 9 > 4 > 3 > 2 > 1 > End
10	17.80	18.76	Start > 1 > 2 > 4 > 3 > 5 > 8 > 6 > 9 > 7 > 1> End

The optimal solution is Result (11) for Zone 1 with the minimum total cost RM29.08 and the shortestdistance which is 37.69 KM. In addition, the optimal solution is Result (3) for Zone 2 with the minimum total cost RM16.94 and the shortestdistance which is 17.22 KM. Figure 2 and Figure 3 shows the optimum plan of the vehicle route for Zone 1 and Zone 2 calculated by Python.

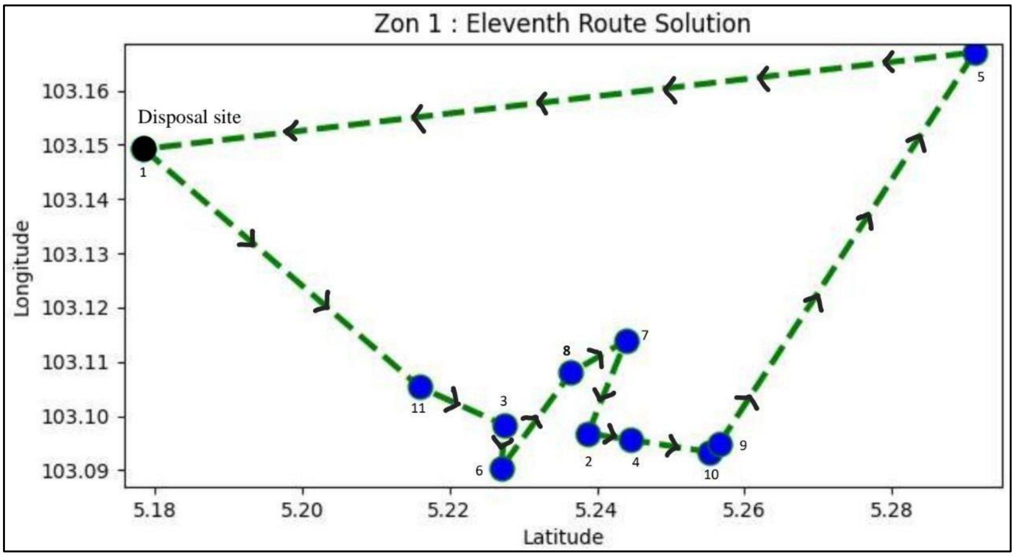

Figure 2: The optimum plan of the vehicle route for Zone 1

From Figure 2, for this trip the vehicle moves from the Garbage station Marang which is the disposal center (Node 1) to Perkedaian Pekan Bukit Payong (Node 11) to Pakr Bukit Payong (Node 3)to Taman Putri Payong 1 &2 (Node 6) to Taman Wakaf Nyior Kembar (Node 8) to Taman Sena Rendang (Node 7) to Taman Mas Padang Leban (Node 2) to Taman Tasek (Node 4) to Taman Sri Kiambang (Node 10) to Taman Wakaf Jaya, Wakaf Dua (Node 9) to Taman Koperasi (Node 5) then back to the Garbage station Marang disposal center (Node 1). The total distance for this plan is 37.69 KM and the total cost for this trip is RM29.08.

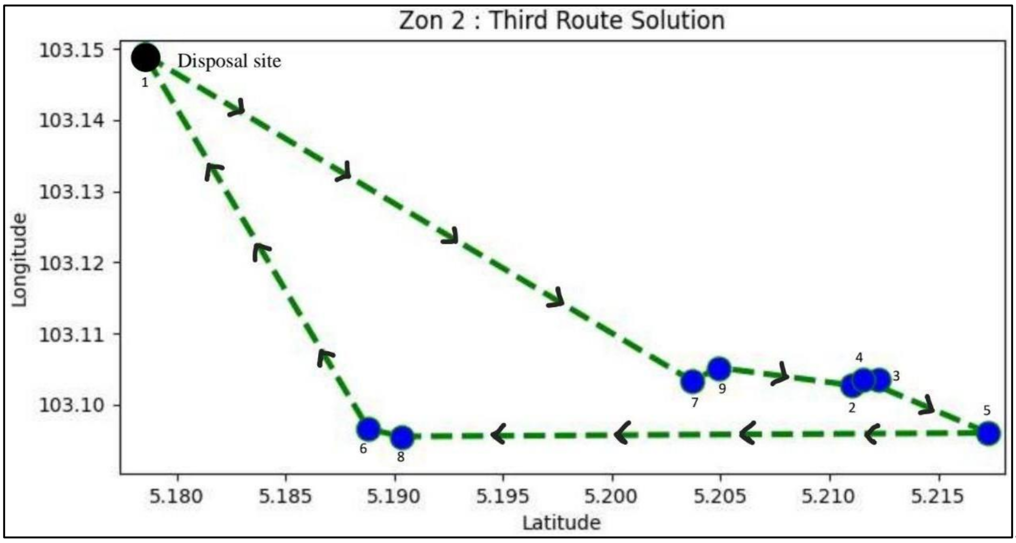

Figure 3: The optimum plan of the vehicle route for Zone 2

From Figure 3, for this trip, the vehicle moves from the Garbage station Marang which is the disposal center (Node 1) to Taman Mewah (Node 7) to Taman Puteri Indah (Node 9) to Taman Bukit Payong (Node 2) to Taman Safiah Murni (Node 3) to Perkedaian Taman Safiah Murni (Node 4) to

Taman Hassan Husin (Node 5) to Taman Tanah Lot Binjai Rendah (Node 8) to Pakr Bukit Sawa (Node 6) then back to the Garbage station Marang disposal center (Node 1). The total distance for this plan is M and the total cost for this trip is RM16.94.

4. Conclusion

Distance and optimum routing are important factors to determine the best solution for waste transportation. This study implemented of Ant Colony Algorithm to solve a vehicle routing problem for efficient waste transportation for housing waste collection in Marang region. The suggested vehicle route for housing waste collection is Result (11) for Zone 1 and Result (3) for Zone 2 as it provides the optimal total cost and the minimum distance without defy the constraints. For future study, it is recommended to add more garbage trucks which can improve the smoothness waste collection in Marang region. In addition, it will be perfect if the real road situation and condition can be predicted, so that the waste transportation will be more efficient.

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