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# A Multi-Trip Vehicle Routing Problem with Time Windows for Waste Collection in Bidor Region

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**Abstract**: The household waste collection would be a huge problem if it is not handled properly, thus an efficient plan for waste collection is needed to maintain a clean environment and comfortable living life. This research aims to study a multi-trip vehicle routing problem with time windows (MTVRP) specifically related to household waste collection in Bidor region. In the raised problem, our objective is to minimize the traversing cost, vehicle cost, and penalty from violating time windows and capacity of the vehicle. Since the vehicle routing problem belongs to the NP-hard problem, efficient simulated annealing (SA) is used to solve the problem with the assist of MATLAB software. The latitude and longitude for the disposal center from Tapah and 15 locations in Bidor region were directly taken from the Global Positioning System (GPS). The total distance of the route obtained was recorded in Euclidean distance. The result was run ten times to determine the best solution for the vehicle routing which used the least total distance with zero violate condition in the solution. The seventh result with the minimum cost RM475.988 is the optimum route solution. The cooling process to obtain the best cost for the vehicle route was followed the property of SA algorithm.

**Keywords**: Multi-Trip Vehicle Routing Problem, Time Windows, Household Waste Collection, Simulated Annealing Algorithm

## 1. Introduction

In the past few decades, optimizing waste collection service has been carried out extensive research since it is the most common research method in the field of waste management [1]. In 2021, the current world population has increased rapidly to 7.9 billion [2] compared with the world population in 2011 which was 7.1 billion. Malaysia's population in 2021 has raised from 28,650,959 people to 32,776,194 people (14.39%) in the past 10 years [3]. The increase in population comes with the increase of waste products which in turn lead to high toxic production. Thus, waste collection is needed to create a comfortable living life.

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Vehicle Routing Problem (VRP) is the operational level of the transportation plans [4]. Non-deterministic problem, NP is a solution can be guessed and verified in polynomial time. VRP is a typical non-deterministic polynomial-time hardness, NP-hard problem in combinatorial optimization [5] which means the property of this problem is informally "at least as hard as the hardest problem in NP problem. The activity of VRP is to plan a desirable assemblage or delivery routes for a set of vehicles from a depot to a set of geographically scattered consumer, subject to several restrictions like vehicle capacity, route length, and time windows. There are many types of VRP. The scope of this study is multi-trip vehicle routing problem (MTVRP) and vehicle routing problem with time windows (VRPTW). The characteristic for MTVRP is each vehicle can conduct a subset of routes, called a vehicle schedule, subject to maximum driving time constraints with minimum total cost [6]. For VRPTW, the service must be provided to each consumer at a specific time interval [7] and there is a priority of service which concerning the harmfulness level of the waste and determine whether use hard or soft time windows [8]. The hard time window shows the length of time the delivery needs to be done while the soft time window presents the customer's preferences [9].

The intricacy of the MTVRP makes it cannot be solved efficiently by the accurate method [10]. In this study, simulated annealing (SA) which is one of the preferred hybrid heuristic methods is used to solve the larger instance of VRP problem in improving the algorithm [11]. Its feature is using less memory, thus does not use any information gathered during the search. Meanwhile, the Global Positioning System (GPS) as a gold standard for mobility research [12] is applied to find the latitude and longitude for the selected location. Then, the latitude and longitude are used to determine the Euclidean distance between two locations. Therefore, in this study, the optimization of MTVRP with time windows is carried out using SA algorithm with the assist of MATLAB software. The best solution is identified by taking into account the use of vehicles, total distance travelled, overtime and overloading penalties.

## 2. Methodology

In this phase, the mathematical model for solving the multi-trip vehicle routing problem (MTVRP) with a time window is described. Since vehicle routing problems (VRP) belong to NP-hard problems, the efficient method which is simulated annealing (SA) is used to solve the problem. It is also essential to consider the time window to achieve the best waste collection in the Bidor region. To validate the eligibility of the model, MATLAB software is implemented.

### 2.1 Objective function

This problem involves looking for the optimal path to each vehicle to minimize total cost, embrace vehicle usage cost, transportation costs through the network edge, and the allowable time window from the service violates penalties. The vehicle is located (Node number 0) and begins to go to the demand node (Node with waste). A new trip begins by moving the disposal field to the remaining requirements node when required. Finally, they will return to the disposal site and complete the service trip. Besides, for the size limit, the maximum allowable usage time of each vehicle is also important. The assumptions for this study are as follows:

- Each requirement node has only one vehicle service.
- Vehicles are heterogeneous since they have different capacities, variable costs, and the latest returning times to the disposal sites.
- The grid is asymmetrical since the spacing of latitude and longitude is different when drawing the vehicle path.
- The vehicle will go back to the disposal site after the end of the trip.
- Each vehicle has the maximum service time.
- Multiple trips are allowed for each vehicle, the first from the depot to the disposal site, other trips will start at the disposal site and then again, end at the disposal site.
- Unbiased time and cost of a route for all vehicles.
- Each demand node has a hard time window and a soft time window for the service. Violation of

hard time windows are completely prohibited while violation of soft time windows will result in penalty.

Thus, the objective function is defined as

Minimize

$$Z = \sum_{i=1}^{NT}\sum_{j=1}^{NT}\sum_{k=1}^{K}\sum_{r=1}^{R} c_{ij} x_{ijk}^{r} + \sum_{k=1}^{K}\sum_{i=1}^{NC}(PtYt_{ki} + PlYl_{ki}) \qquad Eq.1$$

The objective function of the problem is to minimize the total cost, involving vehicles usage, traversing costs, and the fine for disobey from permissible time windows (soft time window). The description for all the symbol is as the following: $NC$ represents set of nodes with demand (demand node), $NT$ represents set of total nodes, $K$ represents set of vehicles, $R$ represents set of vehicle trips, $i, j$ represents demand node index, $k$ represents vehicle index, and $r$ represents trip index. While for the parameter $c_{i,j}$ represents cost of the total distance, $Pt$ represents overtime cost, $Pl$ represents overload cost. Besides, for the variables $Yt_{ki}$, represents amount of violate time windows of the demand node $i$ by vehicle $k$, and $Yl_{ki}$ represents amount violate capacity of the demand node $i$ by vehicle $k$.

2.2 Qualification of the objectives

There are 19 constraints and 5 linearization constraints for the MTVRP with time windows model. The constraints for the problem are formulated as

Constraint (2) shows the denote of the stability of flow for each vehicle. The vehicle should leave the certain node once it arrives there.

$$\sum_{j \in NT} x_{ijk}^{r} = \sum_{j \in NT} x_{jik}^{r} \qquad \forall i \in NT \setminus \{1, n\}, \forall k \in K, \forall r \in R \qquad Eq.2$$

Constraint (3) ensure that only one vehicle is serviced in each demand node.

$$\sum_{i=1}^{NT}\sum_{k=1}^{K}\sum_{r=1}^{R} y_{ijk}^{r} = 1 \quad \forall j \in NC \qquad Eq.3$$

Constraint (4) indicates vehicle capacity constraints.

$$\sum_{j=1}^{NT}\sum_{i=1}^{NT} d_j y_{ijk}^{r} \le W_k \qquad \forall k \in K, \forall r \in R \qquad Eq.4$$

Constraint (5) indicates that the service will only conduct by the vehicle which has already arrived at the demand node. Thus, a vehicle may pass through a node without serving it.

$$y_{ijk}^{r} \le x_{ijk}^{r} \qquad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.5$$

Constraint (6) specifies the vehicle is used upon payment.

$$\sum_{i=1}^{NT}\sum_{j=1}^{NT}\sum_{r=1}^{R} x_{ijk}^{r} \le Mu_k \qquad \forall k \in K \qquad Eq.6$$

Constraint (7) and (8) express the whole loading and unloading time for each vehicle per trip respectively.

$$LT_k^r = ul\sum_{j=1}^{NT}\sum_{i=1}^{NT} d_j y_{ijk}^r \quad \forall k \in K, \forall r \in R \qquad Eq.7$$

$$UT_k^r = uu\sum_{j=1}^{NT}\sum_{i=1}^{NT} d_j y_{ijk}^r \quad \forall k \in K, \forall r \in R \qquad Eq.8$$

Constraint (9) shows the usage time limitation for each vehicle.

$$\sum_{r=1}^{R} LT_k^r + \sum_{r=1}^{R} UT_k^r + \sum_{i=1}^{NT}\sum_{j=1}^{NT}\sum_{r=1}^{R} t_{ij} x_{ijk}^r \le T_{\max} \qquad Eq.9$$

Constraint (10) eliminates sub-tours.

$$\sum_{i \in S}\sum_{\substack{j \in S \\ i \ne j}}\sum_{k=1}^{K} x_{ijk}^1 \le |S| - 1 \quad \forall S \in NT \setminus \{1, n\}, S \ne \varnothing, \qquad Eq.10$$

Constraint (11) and (12) make certain that the order of vehicle trips' number is from $r$ to $r+1$ in succession respectively.

$$\sum_{j \in NT} x_{1jk}^1 \ge \sum_{j \in NT} x_{njk}^2 \quad \forall k \in K \qquad Eq.11$$

$$\sum_{j \in NT} x_{njk}^r \ge \sum_{j \in NT} x_{njk}^{r+1} \quad \forall r \in \{2, 3, ..., R-1\}, \forall k \in K \qquad Eq.12$$

Constraint (13) and (14) make a calculation for the entrance time of vehicles at the demand node.

$$tt_j = \sum_{i=1}^{NT}\sum_{k=1}^{K}\sum_{r=1}^{R} (tt_i + t_{ij}) y_{ijk}^r \quad \forall j \in NC \qquad Eq.13$$

$$tt_i = 0 \quad \forall i \in 1 \qquad Eq.14$$

For the linearization of constraint (13)

$$f_{ijk}^r \le tt_i \quad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.15$$

$$f_{ijk}^r \le M y_{ijk}^r \quad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.16$$

$$f_{ijk}^r \ge tt_i - M(1 - y_{ijk}^r) \quad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.17$$

$$tt_j = \sum_{i=1}^{NT}\sum_{k=1}^{K}\sum_{r=1}^{R} f_{ijk}^r + t_{ij} y_{ijk}^r \quad \forall j \in NC \qquad Eq.18$$

$$f_{ijk}^r \ge 0 \quad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.19$$

Constraint (20) delineate the hard time window of service for each demand node.

$$e_i \le tt_i \le l_i \quad \forall i \in NC \qquad Eq.20$$

Constraint (21) and (22) make a calculation for the amount of violate at the demand node.

$$Yt_{ki} \ge ee_i - tt_i \quad \forall k \in K, \forall i \in NC \qquad Eq.21$$

$$Yl_{ki} \geq tt_i - ll_i \qquad \forall k \in K, \forall i \in NC \qquad Eq.22$$

Constraints (23) and (24) indicate that the vehicle will depart from the disposal site and return to the disposal site on the second, third, and subsequent trips, while other trips will depart from the disposal site.

$$\sum_{i \in NC} x_{ink}^{r} \leq M(1-u_k)+1 \qquad \forall r \in (2,3,...,R\}, \forall k \in K \qquad Eq.23$$

$$\sum_{j \in NC} x_{njk}^{r} \leq M(1-u_k)+1 \qquad \forall r \in (2,3,...,R\}, \forall k \in K \qquad Eq.24$$

Constraint (25) shows the types of the variables.

$$x_{ijk}^{r}, y_{ijk}^{r}, u_k \in (0,1), Yt_{ki}, Yl_{ki}, tt_i, LT_k^r, UT_k^r \geq 0 \qquad \forall i, j \in NT, \forall k \in K, \forall r \in R \qquad Eq.25$$

2.3 Determine the residential house in Bidor region

There are one deposal site and 15 locations for managing this waste collection problem for this research which correspond to the garbage station and the location with the same postcode, 35500. The location selected included garbage station in Tapah, Bedrock Estate, Kampung Baru, Kampung Baru Bidor Stesyen, Kampung Baharu Pekan Pasir, Kampung Baharu Kuala Bikam, Kampung Baru Kuala Gepai, Kampung Baru Tanah Mas, Kampung Baru Timur, Kampung Bertuah, Kampung Chang, Kampung Baharu Cold Stream, Kampung Dato Sri Kamaruddin, Kampung Jalan Bruseh, Kampung Jeram Mengkuang, and Kampung Kuala Gepai. Figure 1 shows the Bidor region using GPS.

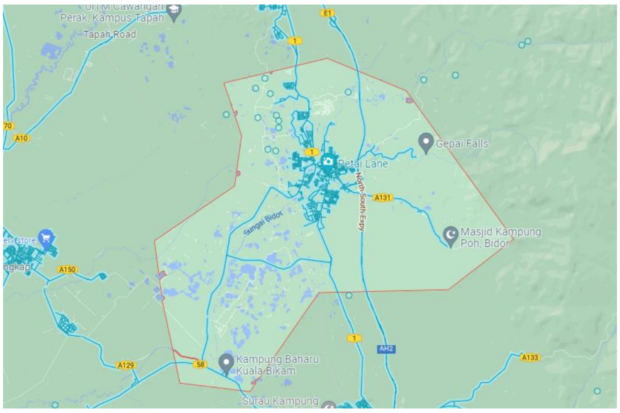


**Figure 1: GPS to located Bidor region**

Data of longitude and latitude 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. Table 1 shows the coordinates, service time, capacity of load, start time and end time for the disposal site and 15 nodes of demand for waste collection. The location for a bigger area is set for a longer time and bigger capacity than those in a smaller area. The worker's working hour is set from 6:00 a.m. to 2:00 p.m. Table 1 shows the service time and capacity in each node. Since it needs an average of 2 hours from the depot center to Bidor, the time window set 8:00 a.m.-12:00 p.m. as the available time window for each node. In additional, the maximum capacity of the vehicle is set as 200 tons while the maximum number of vehicles used for waste collection is 3.

**Table 1: Details for each node**

| Node | Location | Latitude | Longitude | Service time | Capacity | Start time | End time |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | Garbage Station Tapah | 4.55271 | 101.01057 | 0 | 0 | 6:00 a.m. | 2:00 p.m. |
| 1 | Bedrock Estate | 4.10856 | 101.27800 | 35 | 3.5 | 8:00 a.m. | 12:00 p.m. |
| 2 | Kampung Baru Bidor | 4.11694 | 101.28876 | 35 | 3.5 | 8:00 a.m. | 12:00 p.m. |
| 3 | Kampung Baru Bidor Stesyen | 4.10471 | 101.26599 | 35 | 3.5 | 8:00 a.m. | 12:00 p.m. |
| 4 | Kampung Baharu Pekan Pasir | 4.07056 | 101.28742 | 50 | 5 | 8:00 a.m. | 12:00 p.m. |
| 5 | Kampung Baharu Kuala Bikam | 4.02326 | 101.24382 | 40 | 4 | 8:00 a.m. | 12:00 p.m. |
| 6 | Kampung Baru Kuala Gepai | 4.10175 | 101.30996 | 60 | 6 | 8:00 a.m. | 12:00 p.m. |
| 7 | Kampung Baru Tanah Mas | 4.14861 | 101.26638 | 35 | 3.5 | 8:00 a.m. | 12:00 p.m. |
| 8 | Kampung Baru Timur | 4.11517 | 101.28313 | 30 | 3 | 8:00 a.m. | 12:00 p.m. |
| 9 | Kampung Bertuah | 4.10100 | 101.28239 | 35 | 3.5 | 8:00 a.m. | 12:00 p.m. |
| 10 | Kampung Chang | 4.12083 | 101.31917 | 40 | 4 | 8:00 a.m. | 12:00 p.m. |
| 11 | Kampung Baharu Cold Stream | 4.04666 | 101.23954 | 60 | 6 | 8:00 a.m. | 12:00 p.m. |
| 12 | Kampung Dato Sri Kamaruddin | 4.11182 | 101.27895 | 40 | 4 | 8:00 a.m. | 12:00 p.m. |
| 13 | Kampung Jalan Bruseh | 4.10527 | 101.29599 | 40 | 4 | 8:00 a.m. | 12:00 p.m. |
| 14 | Kampung Jeram Mengkuang | 4.06406 | 101.23976 | 40 | 4 | 8:00 a.m. | 12:00 p.m. |
| 15 | Kampung Kuala Gepai | 4.10243 | 101.31297 | 60 | 6 | 8:00 a.m. | 12:00 p.m. |

### 2.4 Primary solutions

Primary solution is required before applied the SA algorithm. The steps are as follows:

Step 1: Randomly select a vehicle. The first trip starts from the vehicle segment.

Step 2: In the remaining demand, randomly choose nodes according to the time window, priority, and the shortest distance to the depot among the remaining demand nodes, then enter Step 3.

Step 3: If there is any remaining demand node that meets the service conditions, adds it to the vehicle's trip then go to Step 4, else, move to Step 5.

Step 4: Allows the capacity and use of the selected vehicle, enter Step 3 after a randomly is done. If there is no qualified demand node, move to Step 5.

Step 5: Update the record as a violate time window if exceeds the service time provided or record it as a violate capacity if the trip carry exceeds capacity, after that go to Step 6.

Step 6: Move to Step 7 if all demand nodes are settled, else update the vehicle's capacity constraints. If the vehicle's time limit allows at least a trip from the disposal site to the demand node, move to Step 3. Else, select the next vehicle and move to Step 2.

Step 7: Stop the algorithm.

### 2.5 Create a Neighbourhood

This step is involved in Step 2 from the primary solution. The methods for constructing the neighborhoods in the algorithm are as follows:

(a) Insertion: Randomly select two locations, and then insert the element at the first location after the second element.

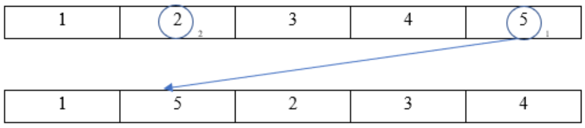


**Figure 2: Insertion**

(b) Reversion: Randomly select two locations, and then arrange the elements between these two positions in reverse order.

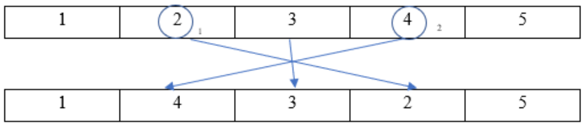


**Figure 3: Reversion**

(c) Swap: Randomly select two positions, and then swap the elements in these two positions.

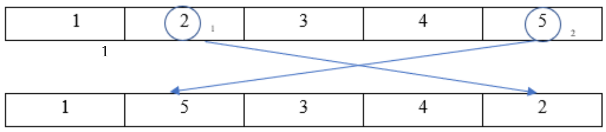


**Figure 4: Swap**

### 2.6 SA algorithm

To solve the problem, a computer with a Core i5-6200U @ 2.88Hz processor and 8.00GB of RAM is used. The proposed algorithm is coded in MATLAB R2021b software. The result was running ten times to obtain the greatest result by setting the parameter algorithm iteration for each temperature $M = 200$, initial temperature $T_0 = 200$, cooling rate $\alpha = 0.98$, the final temperature $T_{end} = 1$, and Boltzmann's constant $K = 0.8$. The total distance along the path is calculated using the Euclidean distance. The cost is calculated by RM100 per vehicle used plus RM50 per unit distance plus the penalty for the violate capacity and the penalty for violating time windows. Both the penalty is set as 100 times the violated conditions. Furthermore, the soft window allowed is given as 120 minutes. The pseudo-code for SA algorithm used in this paper [8] is as below

**Begin**
Choose The best initial solution ($S_1$)
Choose an initial temperature ($T_0$)
Repeat
    While (M<m)
        $S_2$ =Generate a neighbor of the solution $S_1$
        Delta=Objective ($S_1$)- Objective ($S_2$)
        If Delta<0 Then
        $S_1 := S_2$
        Else if exp(Delta/(-k*T)>Random (0-1) Then
        $S_1 := S_2$
    End if
        M=M+1

```
    End while
            T=T*alpha
Until       T < T_end
End
```

## 3. Results and Discussion

The result is obtained after running 10 times in MATLAB then the optimum result is determined. Table 2 shows the summary of the result for vehicle route calculated using MATLAB.

**Table 2: Details for each node**

| Sol | No. of vehicle used | Total distance (unit) | Best cost (RM) | Time exceeds (minutes) | Result |
|---|---|---|---|---|---|
| 1 | 3 | 3.6315 | 480.9278 | Route 2: 225 | Route 1: 0->6->0<br>Route 2: 0->3->8->12->13->9->4->2->11->5->15->10->7->0<br>Route 3: 0->1->14->0 |
| 2 | 2 | 2.6502 | 479.167 | Route 2: 110 | Route 1: 0->9->13->3->5->7->12->0<br>Route 2: 0->8->1->2->4->15->6->10->14->11->0 |
| 3 | 3 | 3.7509 | 480.2114 | Route 1: 85 | Route 1: 0->7->11->2->1->12->15->6->13->0<br>Route 2: 0->4->10->0<br>Route 3: 0->3->9->5->8->14->0 |
| 4 | 2 | 2.7955 | 476.1584 | Route 1: 10,<br>Route 2: 70 | Route 1: 0->8->4->11->12->2->9->3->0<br>Route 2: 0->1->15->13->5->6->7->14->10->0 |
| 5 | 3 | 3.956 | 478.3895 | Route 1: 5,<br>Route 2: 35 | Route 1: 0->3->1->10->11->2->14->8->0<br>Route 2: 0->15->5->13->12->6->7->4->0<br>Route 3: 0->9->0 |
| 6 | 2 | 2.8523 | 483.5212 | Route 1: 155 | Route 1: 0->10->11->9->14->1->12->4->6->7->13->0<br>Route 2: 0->5->2->8->15->3->0 |
| 7 | 3 | 3.9025 | 475.988 | Route 1: 60 | Route 1: 0->9->12->3->15->1->2->11->13->0<br>Route 2: 0->4->0<br>Route 3: 0->5->10->6->7->14->8->0 |
| 8 | 3 | 3,7605 | 480.3391 | Route 2: 5 | Route 1: 0->10->2->0<br>Route 2: 0->11->12->3->6->4->15->0<br>Route 3: 0->7->14->8->13->9->5->1->0 |
| 9 | 3 | 3.7962 | 477.3344 | 0 | Route 1: 0->8->10->7->9->14->0<br>Route 2: 0->6->13->11->12->0<br>Route 3: 0->1->3->15->5->4->2->0 |
| 10 | 3 | 3.7208 | 482.8239 | 0 | Route 1: 0->5->12->8->11->14->3->0<br>Route 2: 0->13->9->1->15->7->10->0<br>Route 3: 0->4->6->2->0 |

The optimum solution is Result (7) since it obtains the minimum cost with no violation capacity and is within the soft time window given which the time for violation is less than 120 minutes. The best cost obtained for the vehicle route is RM475.988 with a total distance of 3.9025 units. The elapsed time for MATLAB to run this result is 1.543384 seconds. Figure 5 shows the optimum plan of the vehicle route calculated by MATLAB.

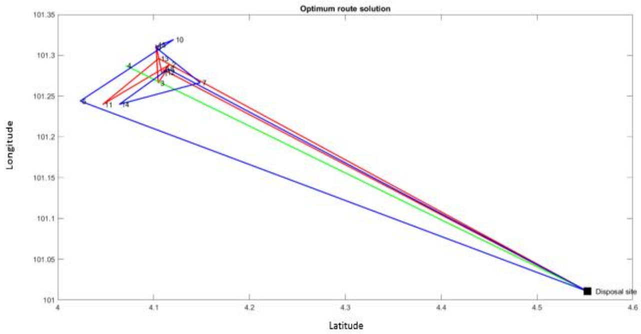


**Figure 5: The optimum plan of the vehicle route calculated by MATLAB**

From Figure 5, three vehicles are used. For Route 1 (red colour), the vehicle moves from Garbage Station Tapah (Disposal site) to Kampung Bertuah (Node 9) to Kampung Dato Sri Kamaruddin (Node 12) to Kampung Baru Bidor Stesyen (Node 3) to Kampung Kuala Gepai (Nsode 15) to Bedrock Estate (Node 1) to Kampung Baru (Node 2) to Kampung Baharu Cold Stream (Node 11) to Kampung Jalan Bruseh (Node 13) then return to Garbage Station Tapah (Disposal site). For Route 2 (green colour), the vehicle moves from Garbage Station Tapah (Disposal site) to Kampung Baharu Pekan Pasir (Node 4) only then back to Garbage Station Tapah (Disposal site). For Route 3(blue colour), the vehicle moves from Garbage Station Tapah (Disposal site) to Kampung Baharu Kuala Bikam (Node 5) to Kampung Chang (Node 10) to Kampung Baru Kuala Gepai (Node 6) to Kampung Baru Tanah Mas (Node 7) to Kampung Jeram Mengkuang (Node 14) to Kampung Baru Timur (Node 8) then return to Garbage Station Tapah (Disposal site). Moreover, the trend chart of the total cost for Result (7) for its overall progress is shown in Figure 6.

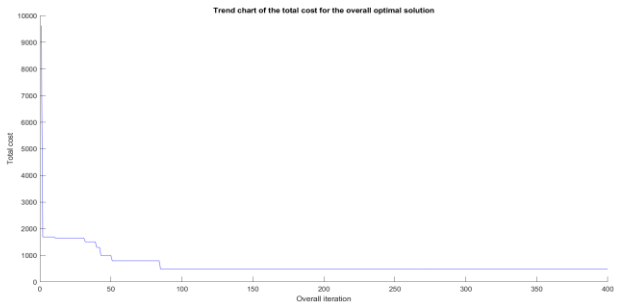


**Figure 6: Trend chart for the total cost for Result (7)'s overall optimal solution**

Figure 6 shows that the flow of the total cost follows the characteristics of the SA algorithm. The algorithm simulates the cooling process by gradually reducing the temperature of the system until it converges to a stable freezing state. Here, cost corresponds to temperature, and overall iteration corresponds to time. At the starting temperature, there must be hot enough temperature to allow movement to an adjacent state. At high temperatures, worse actions are acceptable. As the temperature decreases, the calculated required cost gradually decreases and stabilizes because it reduces the effort to move to the neighboring state. When the stop criterion is reached, that is, when the temperature reaches zero or moves closer to zero, no better or worse movement is accepted.

## 4. Conclusion

Optimum routing and vehicle allocating are important factors to determine the best solution for waste collection. This paper discusses the implementation of SA algorithm to solve MTVRP with time windows for waste collection based on the considered assumptions in the problem. The trend chart for the total cost along the iteration shows the result had followed the properties of SA algorithm. The suggested vehicle route for the household waste collection is Result (7) as it provided the best cost without violating the constraints. In the future study, it is recommended to consider taking the unit of the distance in kilometers. Besides, it will be perfect if the real road condition can be predicted then do the algorithm although it might not be possible.

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