Proceedings of Science and Mathematics
Faculty of Science, Universiti Teknologi Malaysia

Vol. 10, 2022, page 101 - 109

Implementation of Clark and Wright Savings Algorithm in Generating Initial Solution for Solid Waste Collection

Khoo Xu Yi, Farhana Johar*
Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia
*Corresponding author: farhanajohar@utm.my

Abstract
Solid waste collection is an important aspect of waste management since it addresses and solves a variety of issues, including environmental, economic, and social concerns. Vehicle Routing Problem (VRP) is one of the common methods for managing solid waste collection. In general, the Capacitated Vehicle Routing Problem (CVRP) is considered as the classical version of VRP implemented in waste collection. In CVRP, the vehicle with a uniform capacity will serve a product demanded by a number of customers. The aim of this research is to construct an initial solution of CVRP in minimizing the distance of solid waste collection. This research proposes a heuristic approach based on the Clarke and Wright Savings algorithm with the aid of C++ programming in a CVRP model to determine the best initial solution for waste collection. This method can be used to reduce the waste collection budget by minimizing the total collection distance, which helps to reduce the operating costs and time during the collection process. In this research, the Savings algorithm is based on the CVRP model under three categories of data, namely clusters, random, and a mixed random cluster without violating the capacity constraints. The results showed that there is a significant saving in three different datasets which provided the best initial solutions and route optimization in terms of travel distance and the total number of vehicles per route.

Keywords: Solid waste collection; Capacitated Vehicle Routing Problem; Clarke and Wright Savings Algorithm

1. Introduction

Solid wastes are generated due to the result of multiple human activities which are technically referred as all non-valuable materials to be disposed of properly as they might contain certain hazardous contents. The municipal solid waste life cycle can be divided into five stages which are: generation, collection and transportation, transformation, treatment, and final disposal [1]. Waste collection is an important aspect of waste management, as it involves collecting and transporting waste to intermediate or disposal facilities [2]. The typical process of waste collection involves the vehicles departing from the depot and travelling in fixed routes to collect waste by visiting all the required locations which are incurring a gigantic amount of costly and time consuming. If the waste collection plan is properly designed and implemented, it can generate significant savings in all Waste Management Systems.

One of the common methods to manage waste collection is by using the vehicle routing problem or well known as VRP. In mathematical terms, the Vehicle Routing Problem (VRP) is classified as an NP-hard problem and it aims to find a set of the shortest routes to minimize the routing cost [3]. Hence a vehicle routing problem for the solid waste collection is discussed in this research to optimize the waste collection route for cost effectiveness and more eco-friendly purposes.

Vehicle Routing Problem in the solid waste collection is due to the disposal operations. Vehicles must start and end the routes at the depot. Then, the empty vehicles leave the depot and begin collecting waste from a set of pre-defined collection points (customers), and each collection point is visited by one vehicle only with the condition that the location of the depot and each collection point are known. In addition, the total collecting capacity of a vehicle must not exceed its maximum. When the waste collection vehicle is fully loaded or the collection task is completed, it must get back to the disposal facility. The vehicle must make a complete trip every day to carry out disposal operations. In the cases of waste collection, there are numerous customers, which make the VRP even more complicated [4]. Thus, a decision must be made about whether a vehicle should provide collection first between the customers before being emptied at the disposal facility.

The aimed of this research is to construct an initial solution of Capacitated Vehicle Routing Problem (CVRP) by using Clarke and Wright Saving Algorithm with the aid of C++ programming in minimizing the distance of solid waste collection. In short, a well-planned routing of solid waste collection can help the relevant companies to minimize the number of vehicles and the total distance travelled, which in turn reduces logistic costs, capital and the operation time.

2. Literature Review

2.1. Vehicle Routing Problem (VRP)

The Vehicle Routing Problem (VRP) is a combinatorial optimization and integer programming problem that involves finding the optimal route for a group of vehicles to serve a group of customers, without violating any specific constraints, including capacity, time window, vehicle number, and depots. The VRP generalizes the Travelling Salesman Problem (TSP) and was first published by George Dantzig and John Ramser in 1959 [5]. VRP has become one of the most widely studied topics in the Operations Research fields of transportation, logistics, and distribution management [6].

Capacitated Vehicle Routing Problem (CVRP) which is considered to be the classical version of VRP, where each vehicle with the uniform capacity will be serving a product demanded by a number of customers from the depot and eventually returned to the depot [7]. The objectives are to minimize the fleet size and assign a sequence of customers to each truck of the fleet which in turn minimizes the total distance travelled. The Capacitated Vehicle Routing Problem (CVRP) is an NP-optimization problem that plays a major role in common operations research. The objective of CVRP is to determine a set of vehicle routes that can satisfy all the customer demands with minimum overall cost and total distance travelled. The classic CVRP can be described as follows [7]:

Let $G = (V, E)$ be a graph with $V = \{0, \dots, n\}$ being a set of vertices representing n customer locations with the depot located at vertex 0 and E being a set of undirected edges. With every edge $(i, j) \in E, i \neq$ j a non-negative cost C_{ij} is associated. This cost could represent the (geographical) distance between two consumers i and j. Furthermore, assume there are M vehicles stationed at the depot that have the same capacity Q. In addition, every customer $i \in V' = V\backslash\{0\}$ has a demand d_i . The CVRP consists of finding a set of vehicle routes such that

a. Each customer in $V\backslash\{0\}$ is visited exactly once by one vehicle only;
b. All routes start and end at the depot;
c. The total of customer demand within a route does not exceed the vehicles' capacity;
d. The sum of costs of all routes is minimal given the constraints above;

In order to solve the CVRP, many exact and heuristic methods have been researched and proposed. Algorithms such as branch and bound, branch and cut, and branch and price are examples of exact methods, the exact algorithm is only valid for small problem instances whereas Heuristic algorithms are more commonly utilised to save time and complexity in large-scale CVRPs. However, it has precision constraints and takes a long time to execute. As a result, in recent years, the usage of metaheuristic algorithms has grown in popularity, particularly when incomplete data or low computation capability are present [8].

2.2. Waste Collection Studies

In this section, there will be a brief review of the literature on VRP, especially heuristic and metaheuristics methods with waste collection. Constructive and improvement heuristics are two types of classical heuristics. The Clarke and Wright (1962) savings algorithm is the most widely used constructive heuristic due to its relatively high solving speed and simplicity of implementation. Its primary premise is to save money by combining two different routes into one [9]. Given the present prominence of improvement heuristics, a basic scheme like the savings algorithm is sufficient to address the majority of problems [10]. In the year 1974, Beltrami and Bodin [11] use a simple extension of Clarke and Wright's savings heuristic to solve a periodic vehicle routing problem with intermediate facilities (PVRP-IF) that applied to a waste collection problem in New York, so that total vehicle travel time and the number of trucks required per day could be minimized.

While, Markov et al. [12] proposed a mathematical model and a local search heuristic for a complex solid waste collection problem, by adding several new features such as a realistic cost-based objective function, multiple depots, a fixed heterogeneous fleet, site dependencies, a start-of-tour dependent driver break, and a relocation cost, which incentivizes rather than enforcing the vehicle to return to the depot it started from. As a response to real-world situations, the author develops a local search heuristic that currently incorporates most of the capabilities of mathematical models.

Then, a waste collection VRP is including capacity constraints of vehicles with maximum volume or weight for each vehicle at a given time or per day has become a hot topic because of a large and growing body of papers [13–16] which have discussed and included the constraints in their research. Based on these, when a vehicle reaches the maximum weight, it must return to a disposal facility for disposal operations. Hemmelmayr et al. [15] introduced a new hybrid algorithm for the PVRP-IF and offered a formal model for it. A Variable Neighborhood Search (VNS) algorithm with an exact procedure was applied in this paper as a sophisticated insertion technique for intermediate facilities. The solution could be improved if it is combined with a local search algorithm.

A VRP with capacity constraints will be discussed in this research for solid waste collection. By adding constraints to the problem, it is possible to reflect as closely as possible to the real municipal SWM system. However, the time windows will not be included in this research. Although the literature represents these themes in a variety of contexts, this research primarily focuses on the Clarke and Wright savings algorithm in order to address the initial solution for CVRP solid waste collection.

3. Methodology

3.1. Description of CVRP

The static and deterministic basic version of the vehicle routing problem, known as the CVRP was described in this research. In the CVRP all the customers (namely bins) correspond to deliveries, the demands (namely amount of waste) are deterministic and known in advance. Besides, all the vehicles are identical and based at a single central depot. In the meantime, only the vehicle capacity is restricted in our problem. The main objective of this problem is to minimize the cost function, whereby the cost function of this CVRP is the total sum of distance travelled. In addition, the distance between each pair of customers in our problem is the same in both directions, resulting in a symmetric cost matrix [3].

3.2. Problem Formulation

Let $G = (V, E)$ be a graph with $V = \{0, \dots., n\}$ being a set of vertices representing n customer (waste bins) locations with the depot located at vertex 0 and E being a set of undirected edges. With every edge $(i, j) \in E, i \neq$ j is associated a non-negative cost C_{ij}. This cost could represent the (geographical) distance between two consumers i and j. In addition, assume there are M available vehicles based at the depot. Each customer (waste bins) i requires a supply of q_i units from depot 0 (assume q_0). A set of M identical vehicles of capacity Q is stationed at depot 0 and must be used to supply the bin. Let $x_i = (i \neq j)$ be a binary variable equal to 1 if and only if edge (i, j) appears in the optimal solution.

The simplest VRP which only involves a single depot and the distance between the two customers are Euclidean. Euclidean distance is the calculation of the distance of two points in Euclidean space. Euclidean space was introduced about 300 years before the general era by Euclid, a Greek mathematician, to study the relationship between angle and distance [17]. Hence, the distance between two locations can be calculated using the Euclidean distance matrix (d_{ij}) as shown in equation (1) :

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad \text{for } i, j = 0,1,2 \ldots \tag{1}$$

where x_i, y_i and y_j, y_j are the geographical locations of customer i and j.

Below are the parameters involving in CVRP:

N The number of customers
M Total number of vehicles
q_i The volume of waste on vehicle at the point i (demand of customers i)
q_j The volume of waste on vehicle at the point j (demand of customers j)
Q The capacity of vehicle
C_{ij} Travel cost from customer i to customer j by vehicle M
x_{ij} The travel distance from customers i to customer j by vehicle M

The decision variables:

$$x_{ij} = \begin{cases} 1 & \text{if customer } i \text{ and } j \text{ are connected} \\ 0 & \text{otherwise} \end{cases}$$

The integer programming formulation of the CVRP is given below:

Minimize

$$\sum_{M=1}^{M} \sum_{i=0}^{N} \sum_{j=0}^{N} x_{ij} C_{ij} \tag{2}$$

Subject to

$$\sum_{M=1}^{M} \sum_{i=0}^{N} x_{ij} = 1 \qquad j = 1,2, \ldots, N \tag{3}$$

$$\sum_{M=1}^{M} \sum_{j=0}^{N} x_{ij} = 1 \qquad i = 1,2, \ldots, N \tag{4}$$

$$\sum_{i=0}^{N} x_{ij} \leq 1 \tag{5}$$

$$\sum_{j=0}^{N} x_{ij} \leq 1 \tag{6}$$

$$\sum_{j=0}^{N} q_{ij} \left(\sum_{j=0}^{N} x_{ij} \right) \leq Q \tag{7}$$

$$x_{ij} \in \{0,1\} \qquad i = 0,1, \ldots, N; \; i = 0,1, \ldots, N \tag{8}$$

The objective function of equation (2) aims at the shortest distance tours in which all demands of bins are met. In other words, the objective function is to minimize the total collection cost by all vehicles. Equation (3) ensure that a customer (waste bin) is visited exactly once, and equation (4) ensures that each customer departs to only one other customer. Equation (5) and (6) ensure that each customer is served exactly by one vehicle. Equation (7) ensures that the total demand of any route must not exceed the vehicle capacity. Finally, equation (8) is the sign constraint of binary variables.

3.3. Clarke and Wright Savings Algorithm

The Clarke and Wright Savings algorithm is firstly proposed by Clarke and Wright (1964) which is one of the most popular routes building heuristics and it is used to create the initial solution for all models. Clarke and Wright proposed the algorithm to handle the vehicle routing problem, which involves arranging vehicles from a depot to several customers points. The basic savings concept expresses the cost savings obtained by joining two routes in to one route. The Clarke and Wright Savings algorithm calculate all the savings S_{ij} between customers i and j. The classical Savings formula is described as:

$$S_{ij} = C_a - C_b = d(0,i) + d(0,j) - d(i,j) \tag{9}$$

The following are the steps of Clarke and Wright Savings algorithm to solve CVRP which retrieve from [17] and [18] :

Step1:
Make n routes: $v_0 \rightarrow v_i \rightarrow v_0$, $i \geq 1$

Step 2:
Calculate the saving $S_{ij} = d(0,i) + d(0,j) - d(i,j)$ for every pair (i,j) of demand points, all $i,j \geq 1$ and $i \neq j$

Step 3:
Rank the savings in descending order

Step 4:
Starting at the top of the (remaining) list of savings, merge the two routes associated with the largest (remaining) savings, provided that the conditions of merging routes:

a. If neither i nor j have already been assigned to a route, then a new route with both i and j is constructed.
b. If exactly one of the two points (i or j) has already been included in an existing route and that point is not interior to that route (a point is interior to a route if it is not adjacent to the depot in the order of traversal of point), then the link (i, j) is added to that same route. While make a new route with the point (customer) i if it is violating the capacity.
c. If both i and j have already been included in two separate existing routes, and neither point is within the route's interior, then the two routes are merged by connecting i and j. The merge will not be possible if they are on the interior.

Step 5:
Repeat step (4) until no additional savings can be achieved.

3.4. Data Sets and Problem Designed

Throughout this research, 65 VRPTW 100-customer instances of the Solomon benchmark problem were used. These instances have three classes which are C1, R1 and RC1. The problem set of C1 means it has customers located in clusters, customers are randomly placed in the R1 problem set while problem set RC1 contains a mix of both clustered and random positions. Customers, a central depot, customer nodes, customer demand, and the earliest and latest customer time windows are all included in each data instance. The Euclidean distance is used to represent all distances between nodes. In addition, it is assumed that all vehicles have the same constant speed, meaning it takes one unit of time to cover one unit of distance. Therefore, the travel cost, the travel time, and the Euclidean distance between the two customer nodes are the same in terms of numeric. The scatter plot of three different categories of dataset is shown as Figure 1.

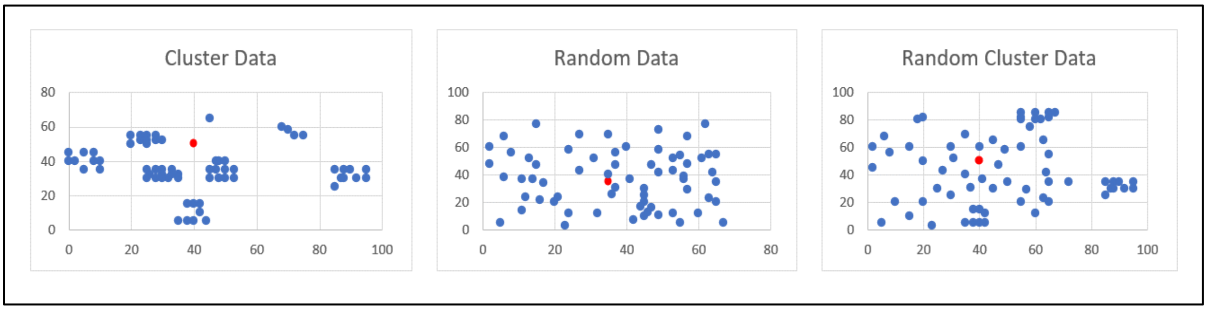

Figure 1 Scatter Plot of Cluster, Random and Random Cluster Data

4. Results and discussion

4.1. Computational Results of Three Different Categories of Data

The research is carried out for three categories of instances which are cluster (C1), random (R1) and a mixed of random cluster (RC1). Assume the maximum vehicle capacity is 200 units.

4.1.1. CVRP in Waste Collection at Clusters Area (C1)

Table 1: Summary of Initial Solution for Cluster Data

Vehicle	Route	Number of Customer	Load (Units)	Distance (Units)
1	0 - 1 - 10 - 22 - 12 - 24 - 13 - 46 - 37 - 47 - 0	9	190	220.253
2	0 - 2 - 5 - 7 - 48 - 65 - 55 - 0	6	130	125.429
3	0 - 3 - 16 - 25 - 28 - 30 - 61 - 31 - 54 - 35 - 45 - 23 - 42 - 0	12	190	319.165
4	0 - 4 - 14 - 39 - 34 - 52 - 64 - 27 - 0	7	120	201.301
5	0 - 6 - 63 - 20 - 8 - 41 - 21 - 49 - 60 - 50 - 53 - 51 - 56 - 58 - 57 - 59 - 0	15	200	322.887
6	0 - 9 - 29 - 62 - 26 - 44 - 17 - 18 - 19 - 0	8	150	251.112
7	0 - 11 - 15 - 32 - 43 - 33 - 36 - 38 - 40 - 0	8	190	173.824
			Total Distance:	**1613.971**

The summary of the initial solution for 65 customers in cluster area (C1) is shown in Table 1. Based on the table above, there are 7 vehicles' routes formed. The results show that the minimum cost function for 65 customers in a cluster area is 1613.971 units. As expected, the total travelling cost can be reduced from 4850.1469 units to 1613.971 units by using Clarke and Wright savings algorithm which save 66.72% (3236.1759 units) in total.

4.1.2. CVRP in waste collection at random area (R1)

Table 2: Summary of Initial Solution for Random Data

Vehicle	Route	Number of Customer	Load (Units)	Distance (Units)
1	0 - 1 - 30 - 2 - 63 - 6 - 40 - 16 - 38 - 19 - 52 - 33 - 0	11	166	325.316
2	0 - 3 - 56 - 7 - 64 - 21 - 62 - 20 - 61 - 13 - 22 - 55 - 47 - 54 - 37 - 0	14	195	422.66
3	0 - 4 - 49 - 8 - 57 - 23 - 48 - 39 - 0	7	110	239.370
4	0 - 5 - 42 - 53 - 12 - 29 - 27 - 28 - 0	7	150	263.223

Vehicle	Route	Number of Customer	Load (Units)	Distance (Units)
5	0 - 9 - 50 - 24 - 18 - 59 - 41 - 60 - 11 - 36 - 26 - 35 - 25 - 34 - 0	13	160	621.504
6	0 - 10 - 43 - 65 - 44 - 58 - 45 - 51 - 46 - 14 - 15 - 32 - 17 - 31 - 0	13	193	416.930
			Total Distance:	**2289.003**

According to Table 2, the results show that the minimum total distance for 65 customers in a cluster area is 2289.003. The minimum travelling cost is computed when the vehicles collect the customers' waste in 6 routes as per shown in table above. By comparing the initial routes of random data (R1), the overall travelling distance has been successfully dropped by 26.78% which is 837.3430 units (from initial 3126.3460 units to 2289.003 units) with the application of Clarke and Wright savings algorithm.

4.1.3. CVRP in Waste Collection at Mix of Random and Clustered Area (RC1)

Table 3: Summary Initial Solution for Random Cluster Data

Vehicle	Route	Number of Customer	Load (Units)	Distance (Units)
1	0 - 1 - 43 - 2 - 36 -3 - 29 - 4 - 22 - 5 - 15 - 17 - 27 - 0	12	195	513.348
2	0 - 6 - 8 - 7 - 9 - 19 - 10 - 12 - 13 - 11 - 20 -16 - 0	11	200	305.887
3	0 - 14 - 23 - 40 - 21 - 54 - 64 - 65 - 58 - 0	10	156	428.218
4	0 - 18 - 37 - 46 - 26 - 45 - 28 - 31 - 30 - 52 - 51 - 42 - 47 - 0	12	188	381.442
5	0 - 24 - 33 - 25 - 50 - 41 - 34 - 48 - 49 - 0	8	121	192.826
6	0 - 32 - 38 - 39 - 44 - 35 - 60 - 59 - 61 - 63 - 55 - 57 - 56 - 0	12	196	410.005
			Total Distance:	**2231.726**

Table 3 show the summary of the initial solution for 65 customers in a mixed random cluster area (RC1). The results show that the minimum cost function the mix random and cluster area is 2231.726. In the meantime, the minimum vehicle transportation cost incurred for all the waste collection in 6 routes. The travelling cost is reduced from 3969.2689 units to 2231.726 units, which is 43.17% (1713.5429 units) savings overall.

4.2. Data Comparison

4.2.1. Comparison of three types of data

Table 4 show the summary result of initial solution of dataset of cluster (C1), random (R1) and a mixed random and cluster (RC1).

Table 4: Comparison of Dataset C1, R1 and RC1

Datasets	Number of Routes	Load (Units)	Total Distances (Units)
Cluster (C1)	7	1170	1613.971
Random (R1)	6	974	2289.003
Random Cluster (RC1)	6	1056	2231.726

Based on Table 4, the total distances of random data are the largest compared to cluster and mixed cluster and random data. Cluster data have the smallest total distance at 1613.971 units, since the customers are located closer to each other. Then followed by a mixed of random and cluster data with total distance of 2231.726 units as it consists of both shorter and longer distances between the customers. Then, random data has the highest total distance, which is 2289.003 units. This is due to the characteristic of random data, as the customers' positions are quite a distance away from each other. Subsequently, different categories of data will influence the total distance travelled.

However, customers in the cluster area require the highest number of routes because the demand is quite high compared to others. The routes cannot be further reduced due to capacity constraints. Although the number of routes through the cluster data is the largest, the total distance is still the smallest. In conclusion, the closer the customer coordinates between each point, the shortest the total distance travelled obtained.

4.2.2. Comparison Data of Different Vehicle Capacity

Table 5: Tabulation of Cluster Data with Different Capacity

Maximum Vehicle Capacity	Average Number of Routes	Load (Units)	Total Distance (Units)
100	13	5	1752.1254
200	7	9	1613.9710
300	5	13	1590.6680

According to Table 5, there are 65 data from cluster customers is study with different vehicle capacities. The results show that the total distance will be affected by the capacity. The vehicle with a capacity of 300 units provides the shortest collection distances which is 1590.668 units with five routes while the vehicle with 100 units capacity requires more routes which is thirteen routes with a total distance of 1752.1253 units to complete the entire collection tour. Hence, it is conclusive that the larger the vehicle capacity, the smaller the number of routes and the shorter the total distance travelled. In short, the garbage truck with a larger capacity could theoretically reduce the total travelling cost incurred.

Conclusion

In a nutshell, the economic viability of any solid waste management system is a fundamental concern for municipalities. To simulate economically viable solid waste collection routes, a mathematical model for CVRP in the solid waste collection by using an efficient heuristic, the Clarke and Wright algorithm was proposed. The Clarke and Wright Saving algorithms can generate good initial solutions for solid waste collection routes and maximize savings in operation cost and time without neglecting the capacity for vehicles. From the results obtained, it is clear to conclude that the vehicle capacity constraint does indeed affect the total distance travelled and the number of routes. Besides, it is conclusive that the larger the vehicle capacity, the smaller the number of routes and the shorter the total distance travelled. The results showed that implementation of Clarke and Wright Savings algorithm in cluster data able save a total distance travelled at 66.72%, random area is 22.78% whereas a mixed random and cluster data show a saving at 43.17%. In conclusion, there is a significant saving in three different datasets which provided the best initial solutions and route optimization in terms of travel distance and total number of vehicles per route. The research has fulfilled all the objectives that have been written in this research which is to construct the initial solution by using Clarke and Wright Saving Algorithm with the aid of C++ programming in minimizing the distance of solid waste collection.

Acknowledgement

The researcher would like to thank all those who supported this research. Special thanks are also dedicated to the Faculty of Science of Universiti Teknologi Malaysia for giving me the opportunity to conduct this research.

References

[1] Wu H, Yang B, Tao F. 2020. Optimization of vehicle routing for waste collection and transportation. *International Journal of Environmental Research and Public Health*, 17(14):1–26.
[2] Idrus Z, Ku-Mahamud KR, Benjamin AM. 2017. Waste collection vehicle routing problem benchmark datasets and case studies: A review. *Journal of Theoretical and Applied Information Technology*, 95(5):1048–57.
[3] Özceylan E, Eligüzel İM, Özkan B. 2020. Vehicle routing for the collection of packaging waste: A case of local municipality. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, (August):375–84.
[4] Hassana SAFB, Nordin SZ. 2015. Tabu search algorithm for solving the vehicle routing problem. *Proceedings - 3rd International Symposium on Information Processing, ISIP 2010*, 11(2):62–6.
[5] Siddharth S, Nandini B. 2020. a Brief Overview of Vehicle Routing Problem and Two-Phase Heuristics. *International Journal of Advanced Research*, 8(5):1239–44.
[6] Korcyl A, Gdowska K, Książek R. 2020. A MILP model for the selective solid waste collection routing problem. *Decision Making in Manufacturing and Services*,13(1):17–35.
[7] Feld S, Roch C, Gabor T, Seidel C, Neukart F, Galter I, et al. 2019. A hybrid solution method for the capacitated vehicle routing problem using a quantum anneale r. *Frontiers in ICT*,6(JUN).
[8] Wongsinlatam W, Thanasate-angkool A. 2021. Optimization of a Capacitated Vehicle Routing Problem for Municipal Solid Waste Collection Using an Intelligence Hybrid Harmony Search Algorithm.
[9] Victorino F, Técnico IS, De U. 2016. Comparing urban solid waste collection routes obtained through the application of heuristics and GIS, (2006):1–10.
[10] Laporte G. 2007. What you should know about the vehicle routing problem. *Naval Research Logistics*, 54(8):811–9.
[11] Beltrami EJ, Bodin LD. 1974. Networks and vehicle routing for municipal waste collection. *Networks*, 4(1):65–94.
[12] Markov I, Varone S, Bierlaire M. 2014. Vehicle Routing for a Complex Waste Collection Problem. *14th Swiss Transport Research Conference* [Internet], (April):1–25.
[13] Kim BI, Kim S, Sahoo S. 2006. Waste collection vehicle routing problem with time windows. *Computers and Operations Research*, 33(12):3624–42.
[14] Markov I, Varone S, Bierlaire M. 2015. The waste collection VRP with intermediate facilities , a heterogeneous fixed flee and a fexible assignment of origin and destination depot. *Report TRANSP-OR*, 1–25.
[15] Hemmelmayr V, Doerner KF, Hartl RF, Rath S. 2013. A heuristic solution method for node routing based solid waste collection problems. *Journal of Heuristics*, 19(2):129–56.
[16] M. G, A. H, G. L. 1994. A Tabu Search Heuristic for the Vehicle Routing Problem. *Management Science*, 40(10):1276–90.
[17] Morihito R, Montolalu C, Pinontoan B. 2018. Application Of Vehicle Routing Problem Using Clarke And Wright Algorithm For Distribution Of White Sugar By “Toko Bersama Trader.” *d’CARTESIAN*, 7(2):68.
[18] Pichpibul T, Kawtummachai R. 2013. A heuristic approach based on Clarke-Wright algorithm for open vehicle routing problem. *The Scientific World Journal*, 2013:1–11.