A SOLID WASTE MANAGEMENT FOR VEHICLE ROUTING PROBLEM WITH SPLIT DELIVERY UNDER UNCERTAINTY

P. Rathinabhagya[1], J. Merline Vinotha[2]

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Abstract

The waste collection vehicle routing problem is an evolving variant of the vehicle routing problem that could be used to resolve issues that occur while transporting waste to their disposal facilities. Municipal solid waste management is a complex task for municipal authorization owing to a lack of infrastructure, rapid population growth, high levels of urbanisation, an improper segregation system, and inadequate waste vehicles. Furthermore, the problem becomes more complicated and challenging due to the increase in availability and quantity, which has attracted many researchers to do the research work in recent years. In natural world issues, the availability of daily waste in any urban city is determined by a variety of factors, including eating habits, living cultures, and seasonal timing. Due to this reason, the availability of daily waste is considered an uncertainty. In this paper, waste management for fuzzy vehicle routing problems with split delivery and multi-compartment vehicles is considered. The objective of this study is to minimise the distance and find the best route. The Branch and Bound algorithm will be used to investigate this issue, and the outcomes are to be compared to those of the Clarke and Wright algorithm.

Keywords: Vehicle Routing Problem, Interval Type-2 Trapezoidal Fuzzy Number, Multi-Compartment Vehicles, Branch and Bound Algorithm, Clarke and Wright Algorithm.

[1,2]PG and Research Department of Mathematics, Holy Cross College (Autonomous) (Affiliated to Bharathidasan University), Tiruchirappalli – 620 002, India.

Email: [1]rathinabhagya20@gmail.com, [2]merlinevinotha@gmail.com

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1. Introduction

The objective of the vehicle routing problem (VRP) is to compute the optimum number of routes for a series of vehicles that must travel in order to deliver an identified number of consumers. The extended form of the travelling salesman problem is called VRP, and it was first introduced by Dantzig and Ramser in 1959. There are many variant in the VRP. The problem which satisfying the demand of each consumer is within the vehicle's capacity called Capacitated *VRP* (CVRP). The relaxation model from the classical *VRP* allows for the splitting of a customer's demand and the delivery of multiple vehicles in the goods distribution. This type of problem is called *VRP* with split delivery. The goods are delivered for a certain period of time or a seasonal period. This type of distribution problem is called periodic *VRP*. The Waste Collection Vehicle Routing Problem (*WCVRP*) is a developing model that is different from the classical *VRP*. In general, *VRP* involves vehicles delivering their goods to all customers and then returning them to their corresponding depot. In a *WCVRP*, the vehicles collect the garbage from the collection points to deposit at the landfill or disposal facility, and then the unloaded vehicles come back to the depot. The rising problem of transporting waste to more than one transfer station is considered. This type of problem can be solved by increasing the proper and systematic approach to waste management services.

Municipal solid waste management (*MSWM*) entails the collection, storage facilities, production, transport, handling, and dumping of waste. In India, 85% of total expenses are spent on the cost of trash collection and transport. This issue can be solved by developing the collection bins, collection vehicles, transfer stations, treating plant, and landfills of the waste management system. Municipal Solid Waste (*MSW*) is produced by many sources like residential, market, hospital, hotel, industry, etc. *MSW* is classified into two types: organic and inorganic wastes. The collected *MSW* is segregated and sent to its corresponding processing plant for recycling. Due to these procedures, less waste ends up in landfills, and the sale of products made from recycled materials yields income for the sovereign state. In the waste collection system for urban cities, a lesser amount of trash is recycled, and the remaining trash is not properly segregated and transported for recycling, composting, or incineration processes. A transfer station connects a collection point to a landfill or disposal site in the collection system. This is escalating the effectiveness of MSWM and lowering the cost of transportation, operating, and pollution during the process of the system. Due to this reason, many researchers are attracted to and motivated to do research in the waste management system.

Dror et al. [5] introduced exact algorithm to solve the VRP with split delivery. Archetti et al. [1] proposed the branch and price technique used to deal with split delivery vehicle routing problem with time windows. Yuliza [20] investigated the issue of waste collection vehicle routing in big cities and time windows. Malakahmad [12] suggests using Geographical Information System to optimize solid waste collection routes. Kim et al.,[11] approach a real-world *WCVRP* with time windows and discuss multiple trips for disposal. Chang and Hossain [3] investigated the significance of MSW recycling in reducing carbon emissions. Ghiani et al. [7] proposed an integer programming method for assigning the best location for bins to reduce the entire number of collection sites. Filscha and Lestari [6] developed a model for resolving garbage routing with the following features, such as several trips, time windows, and split deliveries. Semiao [19] discovered that gradient is an important factor in fuel consumption, and GIS software is used to optimise routes for solid waste collection and transportation. Khan [10] discussed the optimised collection bins and route using GIS. Minoglou [13] suggested mathematical programming for treatment and disposal of municipal wastes. Reed et al. [18] suggested solving the two-compartment vehicle routing problem of waste collection with the help of the ant colony algorithm. Pang [14] analysed the multi-compartment vehicle's advantage for waste management. Oliveira et al. [15] proposed heuristic method to handle the multi-compartment *VRP* for trash material recycling. Hazra [8] established the challenges of collecting waste to the disposal facility. Rathore [16] developed a model for location bins and separation of solid waste.

In this paper, a study of the Bilaspur Municipal Corporation was carried out to ascertain the collection and dumping of solid waste for each ward in the city as well as the improper transportation of waste in the city. The main objective of this paper is to minimise the total distance and identify the best route. The remaining part of this paper is organised by its characters in the following way: Section 2 studies the basics of definitions and notations. Section 3 discusses the assumptions and algorithm approach in order to address the *WCVRP*. Section 4 illustrates

calculations for travel distance and route construction for a case study. Finally, Section 5 concludes the full discussion.

Basic Definitions

Robust ranking index

The robust's ranking index can be referred to as follows, where R_0 is a convex fuzzy number:

$$R(\tilde{R}_0)=\frac{1}{2}\int_0^1 [\tilde{R}_\delta^{l_1}, \tilde{R}_\delta^{u_1}]\,d\delta, \text{ where } [\tilde{R}_\delta^{l_1}, \tilde{R}_\delta^{u_1}]$$

is the δ-level cut of the fuzzy number $\tilde{R}_0$.

In this study, a robust ranking technique is used to defuzzy the interval type-2 trapezoidal fuzzy number. This ranking method is effective and easy to convert from a fuzzy to a defuzzy number.

Notations:

i - Set of Collection points

j - Set of Collection points

d_{ij} - Distance between the depot to collection points and collection point i to collection point j

Transfer Station - TS

Municipal Solid Waste Management - MSWM

Municipal Solid Waste Management System - MSWMS

Municipal Solid Waste - MSW

Bilaspur Municipal Corporartion - BMC

Branch and Bound Algorithm - BBA

Clarke and Wright Algorithm - CWA

Assumptions

1. In this model, the fixed cost for transportation has been calculated on a daily basis.
2. The municipal solid waste management system of Bilaspur city has landfills and processing plants at the same location.
3. All the collected segregated recycle waste is going to the processing plants to be completely converted into reusable products, and idle waste is going directly to the landfill from TS.
4. Collecting the garbage from collection points to TS is convenient to handle for the segregation process by using multi-compartment vehicles.
5. A twin-bin garbage tripper vehicle is considered a multi-compartment vehicle for the collection system.
6. In some cases, the total amount of collected waste does not go directly to the landfill. First, the collected waste goes to the TS, and then the garbage is transferred to the landfill with multiple trips.
7. Based on the above assumption, the waste collection vehicle routing problem is incorporated with split delivery.

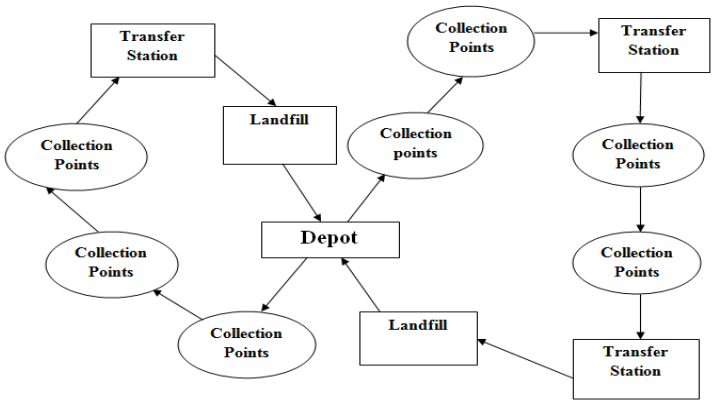

Fig. 1 shows the waste collection methodology.

Algorithms for the Case Study

Clarke and Wright algorithm:

Step1: Determine the distance data, cost data, service time data, and vehicle capacity as inputs.

Step 2: Make a distance matrix between the depot and the customer, as well as between the depot and the customer.

Step 3: Evaluate the saving matrix by using the following equation:

$$S_{ij} = d_{0i} + d_{0j} - d_{ij}$$

Step 4: Sort the saving values from greatest to lowest.

Step 5: Form a route by associating the consumers according to their savings. The following cases need to be considered:

1. Do not disrupt any links that were established prior to the route.

2. If the vehicle's capacity is not violated, then customers will be noted as being visited.
3. The process will come to an end when all customers are on the route.

Branch and bound algorithm:

Step 1: Create a distance matrix involving the depot's distance from every city excluding x_{ii}.

Step 2: Minimum entry in a row is obtained first, and it is then subtracted from all the other entries in the row, giving a zero to the row.

Step 3: Similarly, the minimum entry in a column is found, and then they subtract from all the other entries in the column, bringing a zero to the column.

Step 4: From the reduce matrix, the total minimum row entry value and the total minimum column entry value are added, and it will give the value of the lower bound.

Step 5: Branching begins from the lower bound value, and for each branch showing the travelled path, we construct $n-1$ branches.

Step 6: Likewise, compute the lower bound for the next level of branch and continue this process.

Step 7: The process will be stopped while a reduced matrix is attained with a minimum lower bound value and all the cities are covered by the branching that gives the optimum route.

Case Study

The city of Bilaspur is situated in the Indian state of Chhattisgarh $\left(\text{Latitudes } 21^{\circ}.37^{''} \text{ to N } 23^{\circ}.07'' \text{ Longitudes } 81^{\circ}.12'' \text{ to } 83^{\circ}.40^{''} \text{ E}\right)$. The only organisation incharge of gathering garbage and delivering it to the city's $MSWM$ facility is the Bilaspur Municipal Corporation (BMC). It covers a residential area of 55 wards. In this case study, only 15 wards of Bilaspur city have been considered. $BMC$is facing problems during the collection, disposal, and processing of MSW due to the unavailability of trash collection bins, the insufficiency of a regular, proper segregation process, and the inadequacy of garbage vehicles and their maintenance in Bilaspur city.

Municipal Solid Waste Management System for BMC

The $MSWMS$ in India is generally composed of waste from residential, market, street wiping, hospital, commercial, industrial, and construction activities. The daily generation of solid waste in Bilaspur City is 2163 metric tonnes per day. Kachar is home to a landfill and a processing plant. Bilaspur's waste collection system is split into two categories: primary and secondary. The original system consists of going door to door and collecting solid waste from households, hospitals, markets, industries, and commercial sources using multi-compartment trash vehicles, transporting these wastes to a transfer station, and then disposing of them in a landfill. The secondary system is the process of collecting the solid waste from open dumping places and waste bins and transferring this waste to landfills by using twin-bin garbage vehicles or trucks, depending on the garbage collection and segregation process. The availability of MSW generation for each ward is determined by a variety of factors, including eating habits, living cultures, season, and improper disposal. The gathering and dumping of solid garbage for each ward, and furthermore, the lack of proper waste transportation and maintenance in Bilaspur city causing an uncertain situation. Due to this reason, the availability of this case study is taken to be a fuzzy number. Transfer stations and multi-compartment vehicles aid the segregation process, provide proper transportation, and reduce the cost, odour, and time of waste management system services. Fixed costs include vehicle damage and condition costs, labour wages, etc. The total transportation cost is determined by total travel distance and the fixed cost for each trip.

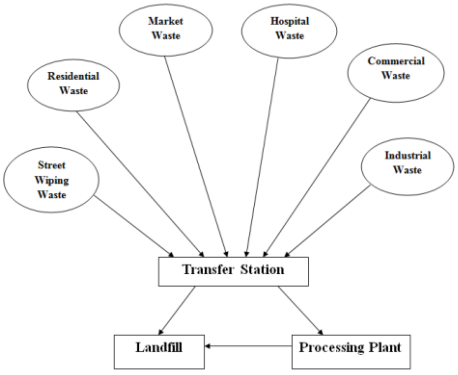

Fig. 2 Flow chart of trash collection system

The intention of this study is to find out the best route for collecting all the solid-produced garbage at the collection points of each ward at the lowest possible expense to BMC. The required input data for this case study was obtained from Google Maps latitudes and longitudes, and the distance matrix was calculated using the Euclidean distance formula for 15 wards of Bilaspur city. The availability of waste generation was also taken into account in the study [15].The proposed algorithm in this section is used to resolve this issue. The routes shown in the table 2 are obtained by using the branch and bound algorithm. The result of this study is compared in the table 3 and 4.

Table 1: Availability of Daily Solid Waste in Urban city wards

S.No.	Ward Name	Availability of Daily Waste generation in 15 wards
1	Ram Nagar	[(8.30,8.31,8.33,8.36), (8.32,8.33,8.35,8.38)]
2	Subhash Nagar	[(4.80,4.83,4.85,4.87), (4.83,4385,4.87,4.90)]
3	Shahid Ashafakaulla Ward	[(4.35,4.37,4.39,4.40), (4.35,4.39,4.41,4.42)]
4	Lajpat Ray Nagar	[(5.21,5.22,5.24,5.26), (5.22,5.24,5.26,5.29)]
5	Azad Nagar	[(8.1,8.3,8.7,8.8), (8.3,8.6,8.8,8.9)]
6	Nirala Nagar	[(9.47,9.49,9.52,9.53), (9.50,9.51,9.53,9.55)]
7	Dr. Ambedkar Nagar	[(9.28,9.30,9.32,9.33), (9.30,9.32,9.34,9.35)]
8	Mother Teresa Nagar	[(10.38,10.40,10.42,10.45), (10.41,10.42,10.44,10.46)]
9	Rani Luxshmibai Nagar	[(13.75,13.78,13.82,13.86), (13.80,13.81,13.83,13.85)]
10	Shivaji Nagar	[(11.90,11.94,11.96,11.99), (11.93,11.96,11.98,11.99)]
11	Vinoba Nagar	[(16.87,16.91,16.93,16.95), (16.90,16.93,16.95,16.99)]
12	Krantikumar Bharti Nagar	[(17.65,17.70,17.72,17.74), (17.70,17.72,17.74,17.77)]
13	Priyadarshani Nagar	[(7.10,7.14,7.16,7.19), (7.15,7.18,7.21,7.25)]
14	Gayetri Nagar	[(15.40,15.42,15.46,15.49), (15.43,15.46,15.50,15.54)]
15	Sanjay Gandhi Nagar	[(14.12,14.15,14.26,14.27), (14.20,14.24,14.28,14.31)]

Table 2: Result of this case study

Total Distance (km)	Best route
19.8392	0-1-12-11-9-14-5-15-6-10-2-13-3-7-8-4-0

Table 3: Cost Comparison for Total Transportation Cost

S.No.	Algorithm	Fixed Cost	Total cost
1	Branch and bound	200	3967.84
2	Clarke and Wright	200	5149.44

Table 4: Comparison between the outcomes of the Savings and Branch & Bound algorithm

S. No.	Algorithm	Total Distance (km)
1	Branch and bound	19.8392
2	Clarke and Wright	25.7472

2. Conclusion

This paper examined a solution to the waste collection vehicle routing problem with split delivery where the availability of daily wastes is fuzzy numbers. In this paper, Transfer stations and twin-bin garbage vehicles have been included to the Municipal Solid Waste collection system are considered. The case study that is expressed in this paper determined how to find best route and transfer station needed and the necessity of twin-bin garbage vehicles in the waste management system. The results obtained by BBA were compared to those attained by CWA . The branch and bound algorithm gives minimum transportation cost, distance and best route. This study can be enlarged in many directions. It is possible to include the vehicle routing problem to further minimise collection costs, carbon emissions, the number of location bins, and the proper segregation process.

3. References

1. Archetti C, Bianchessi N, Speranza MG (2014) Branch-and-cut algorithms for the split delivery vehicle routing problem. Eur J Oper Res 238(3):685–698.
2. Archetti C, Bianchessi N, Speranza MG (2011) A column generation approach for the split delivery vehicle routing problem. Networks 58(4):241–254.
3. Chang, Ni-Bin; Qi, Cheng; Islam, Kamrul; & Hossain, Fahim (2012), "Comparisons

between global warming potential and cost-benefit criteria for optimal planning of a municipal solid waste management system", Journal of Cleaner Production, 20, 1-13.

4. Dantzig, G.B., Ramser, J.H., 1959. The truck dispatching problems. Management Science 6, 1, 80-91.
5. Dror M, Laporte G, Trudeau P (1994) Vehicle routing with split deliveries. Discrete Appl Math 50(3):239–254.
6. Filscha Nurprihatin, Anggun Lestari (2020), "Waste Collection Vehicle Routing Problem Model with Multiple Trips, Time Windows, Split Delivery, Heterogeneous Fleet and Intermediate Facility" Engineering Journal, Volume 24, Issue 5. ISSN 0125-8281.
7. Ghiani, G., Lagana, D., Manni, E., & Triki, C. (2012), "Capacitated location of collection sites in an urban waste management system", Waste Management, 32(7), 1291-1296.
8. Hazra, T., & Goel, S., (2009). Solid waste management in Kolkata, India: Practices and challenges. Waste Management, 29(1), 470-478.
9. Jin M, Liu K, Eksioglu B (2008) A column generation approach for the split delivery vehicle routing problem. Oper Res Lett 36(2):265–270.
10. Khan D and Samadder SR., (2016), Allocation of solid waste collection bins and route optimisation using geographical information system: A case study of Dhanbad City, India. Waste Management & Research, 34(7), 666-676.
11. Kim, B., Kim, S., & Sahoo, S., (2006), "Waste collection vehicle routing problem with time windows", Computers & Operations Research, 33, 3624-3642.
12. Malakahmad A., Bakri P., Mokhtar M. R., & Khalil N., (2014), "Solid waste collection routes optimization via GIS techniques in Ipoh city, Malaysia", Procedia Engineering, 77, 20-27.
13. Minoglou, M., & Komilis, D., (2013). Optimizing the treatment and disposal of municipal solid wastes using mathematical programming – A case study in a Greek region. Resources, Conservation & Recycling, 80, 46-57.
14. Muyldermans, L., Pang, G., (2010), "On the Benefits of Co-collection: Experiments with a Multi-compartment Vehicle Routing Algorithm", European Journal of Operational Research, 206, 93–103.
15. Oliveira, A.D., Ramos, T.R.P., Martins, A.L., (2015). "Planning Collection Routes with Multi-compartment Vehicles". Oper. Res. Big Data, 15, 131–138.
16. Rathore, P., Sarmah, S. P., (2019). Modeling transfer station locations considering source separation of solid waste in urban centers: A case study of Bilaspur city, India. Journal of Cleaner Production, 211, 44-60.
17. Rathore P., Sarmah S. P., Yadav R., (2019). Development of Vehicle routing model in urban solid waste management system under periodic variation: A case Study. IFAC Papers Online 52-1: 1961-1965.
18. Reed, M.; Yiannakou, A., Evering, R., (2014), "An ant colony algorithm for the multi-compartment vehicle routing problem", Applied Soft Computing Journal, 15, 169–176.
19. Tavares, G., Zsigraiova, Z., Semiao, V., (2011), "Multi-criteria GIS-based siting of an incineration plant for municipal solid waste", Waste Management, 31(9-10), 1960-1972.
20. Yuliza E, F M Puspita, S S Supadi and S Octarina (2020), "The Robust counterpart open capacitated vehicle routing problem with time windows", Journal of Physics: Conference Series, Volume 1663(2020)012030, doi: 10.1088/1742-6596/1663/1/012030.