A Comparative Assessment of GIS Integrated ILP and MILP Techniques for Solid Waste Routing

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doi: https://doi.org/10.21467/proceedings.156.6

ABSTRACT

Municipal solid waste management is a growing issue all around the world. The transport of the solid waste is the major cost component in middle- and low-income group countries. Hence, optimizing the solid waste collection route is important. In this paper, optimizing the solid waste transport route was carried out using different algorithms (integer linear programming, and mixed integer linear programming considering the capacity of vehicle) and a comparative assessment of the results were carried out. The optimum route depends on the constraints induced and will vary according to capacity to be transported. The shortest route was 31.85 Km for Eicher pro-1080 and 41.77 Km for Tata Ace Mega.

Keywords: Solid waste routing, Integer linear programming, QGIS

1 Introduction

Solid waste pollution has reached the level of being a real threat to human life. Fast paced urbanization, population growth, and economic expansion have all contributed to a sharp rise in the production of municipal solid waste. The world produces 2.01 billion tonnes of municipal solid garbage yearly, and around 33% of it not being managed in a way that is safe for the environment according to the World Bank's What a Waste 2.0 study (2018) [1]. It is anticipated that by 2050, because of fast urbanisation, population growth, and economic development, it will increase by 70% (3.4 billion tonnes). Currently, India is the largest producer of waste, owing largely to the size of its population [2]. According to the Central Pollution Control Board, even though just 31% of India's 377 million people live in cities, they produce an enormous 1,43,449 metric tonnes of municipal solid trash daily [3].

One of the important issues faced in the management of solid waste generally is solid waste collection and transportation. Transport cost comes to more than 50% of the total cost in developed, 50-80% in middle income and 80-90% in low-income countries [2], [4]. Because transportation involves getting from one point to another, geospatial technology and applications are well suited to the industry. These applications can include route planning, position location, navigation, asset management, and surveillance. Various studies have therefore investigated the solid waste collection problem from an optimization point of view using mathematical programming and GIS based approaches to ensure resource conservation and environmental protection [2], [5]–[7]. The orienteering vehicle routing problem can be solved using an integer programming (ILP) formulation, which maximises the total collected profit while satisfying a maximum time requirement for the route. ILP solutions are produced using the branch-and-cut procedure. Additionally, ILP is excellent for use if a user only has some preliminary data that are limited to numbers. If other specific data are available, which includes both integers and non-integers, the user can use mixed integer programming approach (MILP) that is expected to give a more accurate solution [8]–[11].

The objective of the present study is the route optimization for the collection and transportation of solid waste in a locality from collection points to the disposal site with vehicles of varying capacity using the GIS

Proceedings DOI: 10.21467/proceedings.156; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-961472-7-3

using ILP and MILP algorithms. A comparative assessment of the performance of the different algorithms is provided.

2 Methodology

2.1 Study area

Malayinkeezhu grama panchayath in Thiruvananthapuram district of Kerala, India was chosen as the study area for the route optimization study. The panchayath has 20 wards. In the solid waste collection system, the waste is collected at one point in each ward and is then transported to the disposal site using a Tata Ace Mega truck. The collection frequency is single trip, once a month with a distance travelled around 50 KM. Currently, the municipal solid waste management system of Malayinkeezhu panchayath is not having any specific route for waste collection.

2.2 Data collection and digitization

The data collected for the present study includes map of Malayinkeezhu panchayath including the ward boundaries, the GPS co-ordinates of the collection points within the wards and the disposal site. Road network map of the locality, current waste collection methods and details of number of households in each ward. Digitized map of the panchayath was developed using QGIS by heads up digitization by adding the map as a georeferenced raster layer in the backdrop. Different vector data like road, collection points locations, disposal site location and other features were added to the shape file of the panchayath as separate shape layers.

2.3 Route optimization

Route optimization is carried out as five different cases. The first case considers route optimization as a simple vehicle routing problem or ILP with the objective function as minimizing the distance travelled. Case 2 is a MILP with objective function as minimizing the travel time considering the conditions of the road along with other conditions depicted in case 1. Both these cases are solved in QGIS using ORS TOOL plugin, which provides access to most of the functions of openrouteservice.org based on OpenStreetMap. For case 2, the ORS plugin takes inputs like travel time, number of traffic lanes, traffic restrictions etc. from the open street map. For both the cases the total cost of operation was calculated considering tata ace mega as the transport vehicle.

Case 3 was formulated as a capacitated vehicle routing problem. A python program was developed with objective of minimizing the travel distance. An additional constraint is included in the optimization as the total quantity of waste collected should be less than or equal to the capacity of the vehicle as shown in the problem formulation section. The volume of waste generated was calculated based on the number of households in each ward and as per assumptions based on manual on municipal solid waste management [3]. The assumptions include the following.

a) There are 4 members in every household.
b) 0.4 kg per day waste is generated per head.
c) Collection efficiency is 0.5
d) Density of Municipal solid waste in India is 300 kg/m^3

The volume and weight data were stored in an excel sheet and was given as an input to the python program. The distance travelled and time required for the operation of different capacities of vehicles were obtained from QGIS. Flowchart showing the different work elements are depicted in Figure 1.

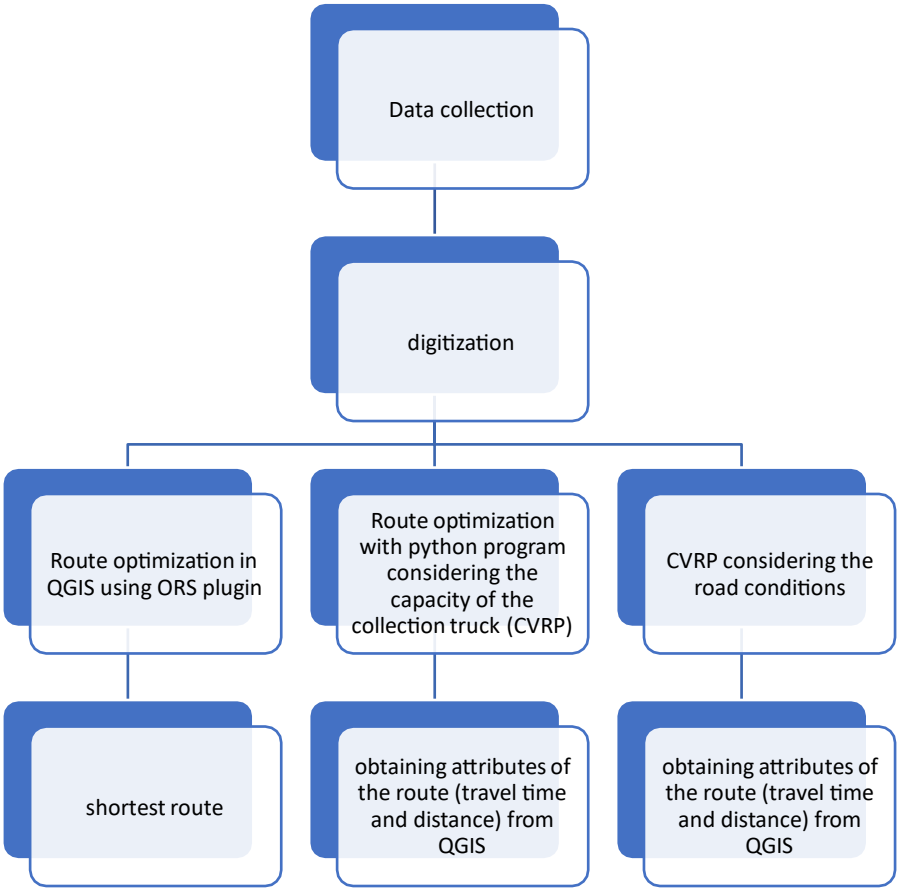

Figure 1: *Flowchart indicating the work elements*

3 Results and Discussions

Digitized map of the panchayath showing the different layers with road network within the panchayath and the collection is provided in Figure 2. The weight and volume of thewaste calculated for each ward under consideration is provided in Table 1.

The shortest and fastest route obtained from QGIS is depicted in Figure 3a and b respectively. The cost of travel was calculated considering the mileage of tata ace mega. (which is currently used for the collection and petrol cost at Rs. 92.70). The total labour cost for a day was taken as Rs. 3000. The distance, time and cost of travel for the shortest and fastest route is given in Table 2. The table indicates that every route conditions are having cost amount in almost similar range, with shortest route slightly less costly than fastest route. Since the total cost is calculated assuming the average milage of the vehicle without considering the road and traffic conditions, the actual scenario may vary in the field as the difference is very less.

Proceedings DOI: 10.21467/proceedings.156
ISBN: 978-81-961472-7-3

Series: AIJR Proceedings
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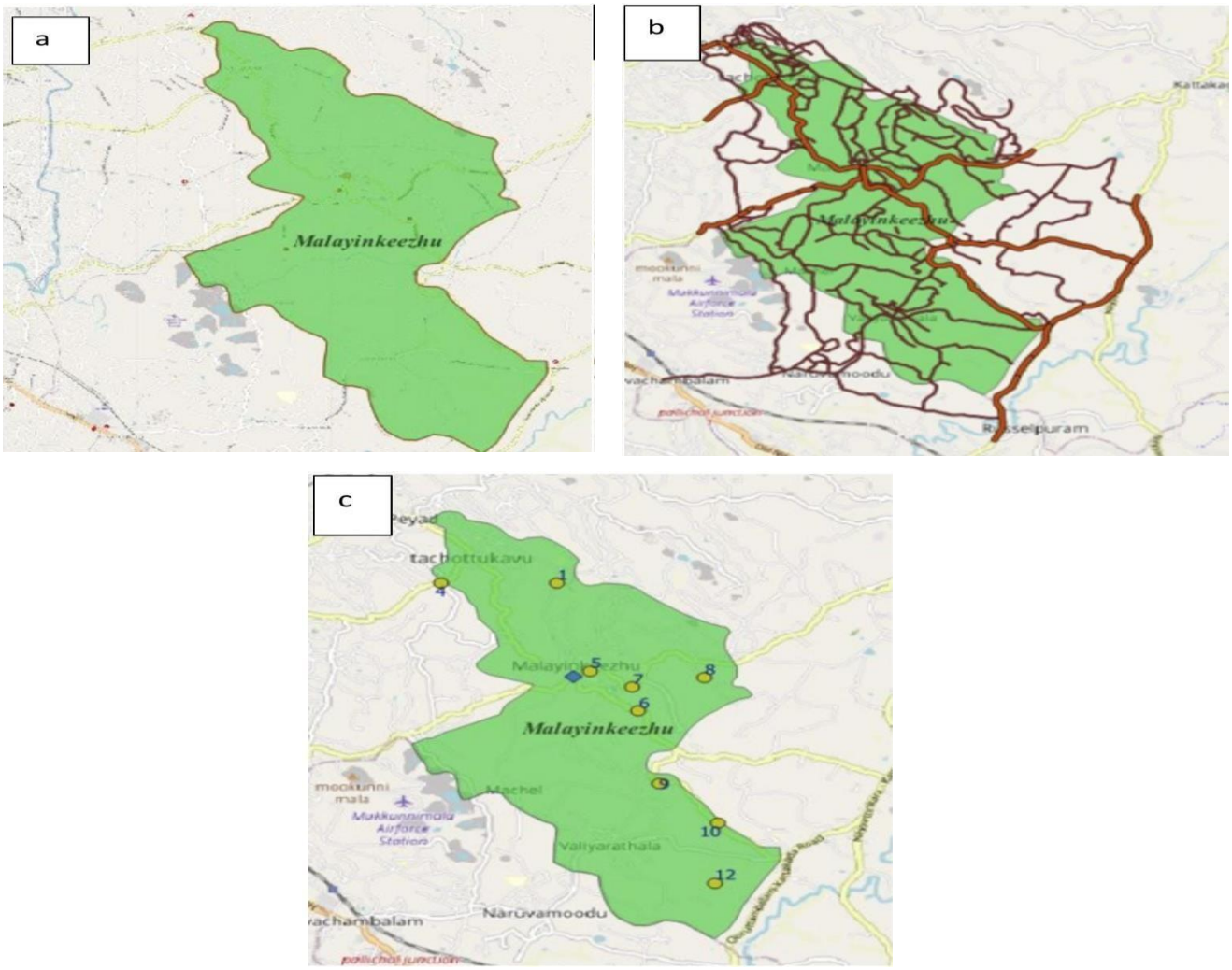

Figure 2: *Digitized map of Malayinkeezhu panchayath showing (a) Panchayathboundary (b) road network and (c) collection points*

Table 1: *Volume of waste generated at each collection point.*

Ward No.	Total No. of houses	Total population	Weight ofwaste generated (kg)	Volume ofwaste generated (m^3)
1	1300	5200	1040	3.46
4	630	2520	504	1.68
5	640	2560	512	1.70
6	825	3300	660	2.20
7	521	2084	568	1.89
8	530	2120	424	1.41
9	470	1880	376	1.25
10	570	2280	456	1.52
12	632	2528	505.6	1.68

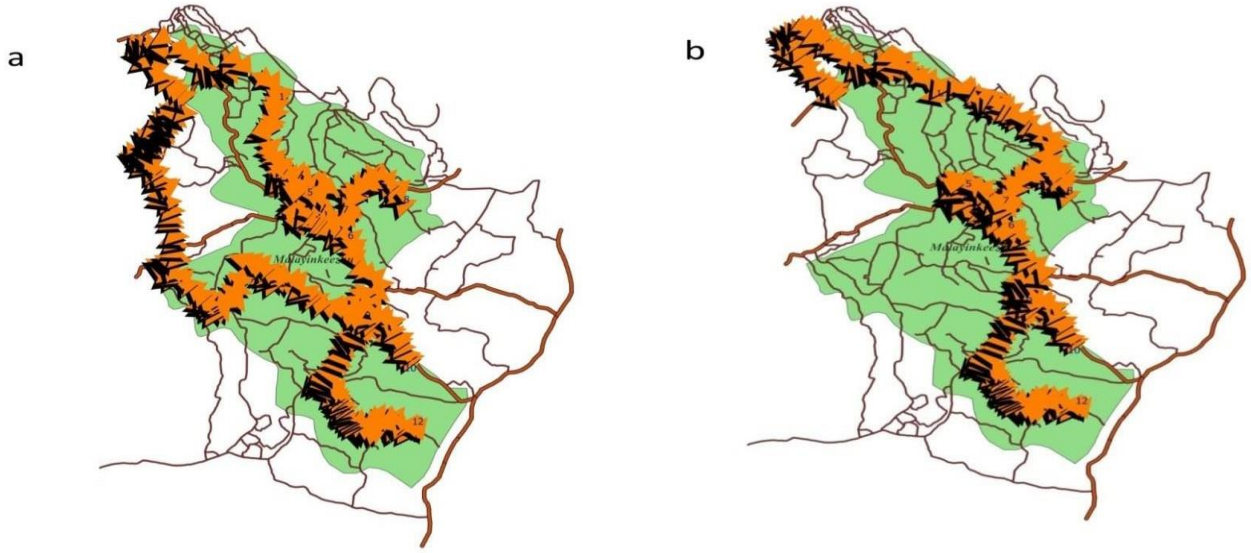

Figure 3: *Output from QGIS using ORS plugin (a) shortest route (b) fastest route*

Table 2: *Results from different route optimization conditions in QGIS*

SL No.	Condition	Distance (km)	Time (hour)	Cost (Rs.)
1	Fastest	37.613	0.769	3179.34
2	Shortest	31.849	0.915	3151.86

Using the python program developed optimized route with vehicles of different capacity were found out. Tata ace mega truck (3.5 m^3), Mahindra bolero pickup (5.67 m^3) and Eicher pro 1080 truck (17.1 m^3) were considered as the collection vehicles. In this analysis, optimized route is selected based on the total cost of the travel. An assumption is made that all vehicles are comfortably able to travel through road networks of the Malayinkeezhu panchayath i.e., width of road is not considered as a variable. Graphical output while using vehicle capacity of 3.5 m^3, 5.67m^3 and 17.1m^3 are converted into digitized map in QGIS (fig. 4a, 4b and 4c). From the digitized map in QGIS attribute data options used to extract the data like time taken and distance travelled in each cycle. The data is shown in Table 3. From the table it could be observed that the Tata ace mega and Mahindra bolero pickup requires more than one cycle of operation to collect the total quantity of waste generated in the locality. This indicates that the shortest or fastest route condition with the current collection vehicle would fail, as the capacity of the vehicle is not sufficient to complete the collection in a single cycle. The travel distance and travel time for the different capacity of vehicles follows the order, Tata ace mega > Mahindra bolero pickup >Eicher pro 1080 truck. The total travel distance for Tata ace mega (which is used by the panchayath for solid waste collection) after the optimization cycle is approximately 42 Km. This is lesser than the distance travelled at present for the collection (approximately 50 Km, as reported by the panchayath) and substantially higher than the distance to be travelled if higher capacity vehicles were used. Hence, based on the shortest distance and fastest route criteria Eicher pro 1080 truck seems to be the optimal solution.

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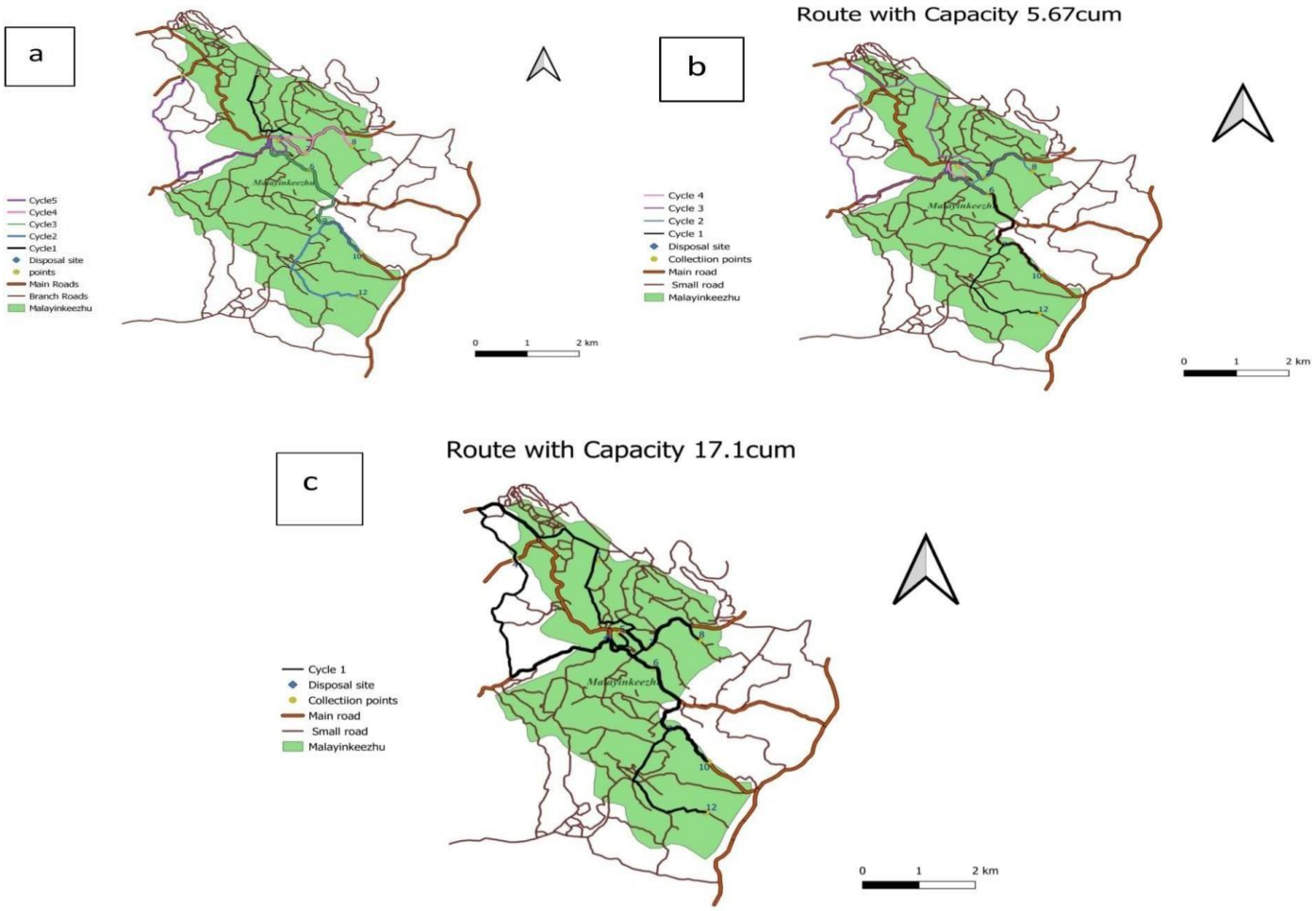

Figure 4: *Digitized map of all trips for different vehicle capacities(a) 3.5m³(b) 5.67 m³(c) 17.1 m³*

Table 3*: Travel distance and travel time comparison of different vehicles*

Vehicle name	**Tata ace mega**		**Mahindra boleropickup**		**Eicher pro 1080truck**	
	Travel distance	**Travel time**	**Travel distance**	**Traveltime**	**Travel distance**	**Travel time**
Cycle 1	2.89 km	0.11 hr	15.08 km	0.35 hr	31.849 km	0.915hr
Cycle2	15.07 km	0.35 hr	6.43 km	0.12 hr	-	-
Cycle3	6.51 km	0.11 hr	12.08 km	0.36 hr	-	-
Cycle4	4.77 km	0.11 hr	2.1 km	0.1 hr	-	-
Cycle5	12.52 km	0.33 hr	-	-	-	-

For further consideration, the total cost of collection with different capacities of vehicles were calculated considering the average mileage of the vehicles. The results of the analysis are provided in Table 4. From the table, it is understood that Tata ace mega truck is having the minimum cost of transportation, even though the route distance and time required was higher. This was due to the higher milage of the vehicle in comparison to other vehicles under consideration. If the cost of collection is considered as the parameter

to be optimized Tata ace mega truck, which had the highest route distance and travel time is the best solution.

Table 4: *Comparison of cost of collection for different capacities of vehicles*

Collection vehicle	Tata acemega	Mahindra boleropickup	Eicherpro-1080 truck
Payload capacity (kg)	1000	1700	5130
Volume capacity (m^3)	3.5	5.67	17.1
Mileage (Km/L)	19	13	9
Number of trips	5	4	1
Total travel distance (km)	41.769	35.703	31.849
Total travel time (hours)	1.042	0.954	0.915
Total cost of collection	3220	3280	3330

Comparing all the situations, it can be noted that shortest route and fastest route conditions are unrealistic in case of solid waste collection as the capacity of the collection vehicle and quantity of waste generated at each node is critical. Hence, solid waste routing can be modelled better as a capacitated vehicle routing problem. In the present work, it was assumed that all vehicles are comfortably able to travel through all the roads, which may not be the case in the field. Hence the problem will become more complex. Also, with change in the objective of the capacitated VRH from minimizing the travel distance to minimizing the travel cost, the solution varied drastically.

4 Conclusions

In the present study, three scenarios for optimizing the solid waste collection route in Malayinkeezhu panchayath were tested. The shortest route of travel was obtained as 31.85 Km with a travel time of 0.769 hour and the fastest route was having a travel distance of 37.61 Km with travel time of 0.915 hour. In both these conditions the volume of waste generated, and the capacity of the vehicle was not considered. The shortest route while considering the capacity of the vehicle was 31.85 Km for Eicher pro-1080, whereas for Tata ace mega which is currently used in the panchayath had to travel 41.77 Km to complete the collection process. However, when the cost of collection was calculated considering the milage of the vehicles, tata ace mega was the most economical option.

5 Publisher's Note

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Jose *et al.* (2023). A Comparative Assessment of GIS Integrated ILP and MILP Techniques for Solid Waste Routing. *AIJR Proceedings*, 46-53. https://doi.org/10.21467/proceedings.156.6

References

[1] S. Kaza, L. Yao, P. Bhada-Tata, and F. Van Woerden, *WHAT A WASTE 2.0 A Global Snapshot of Solid Waste Management to 2050 OVERVIEW Tokyo Development Learning Center*. 2018. Accessed: Mar. 21, 2023. [Online]. Available: https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/211329ov.pdf

[2] S. Das and B. K. Bhattacharyya, "Optimization of municipal solid waste collection and transportation routes," *Waste Management*, vol. 43, pp. 9–18, Sep. 2015, doi: 10.1016/J.WASMAN.2015.06.033.

[3] CPHEEO, "Manual on Municipal Solid Waste Management - 2016," *Central Public Health & Environmental Engineering Organisation (CPHEEO)*, 2016. https://cpheeo.gov.in//cms/manual-on-municipal-solid-waste-management-2016.php (accessed Mar. 21, 2023).

[4] V. Sanjeevi and P. Shahabudeen, "Optimal routing for efficient municipal solid waste transportation by using ArcGIS application in Chennai, India," *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 34, no. 1, pp. 11–21, Oct. 2015, doi: 10.1177/0734242X15607430.

[5] H. Han and E. Ponce-Cueto, "Waste Collection Vehicle Routing Problem: Literature Review," *Promet - Traffic&Transportation*, vol. 27, no. 4, pp. 345–358, Aug. 2015, doi: 10.7307/PTT.V27I4.1616.

[6] S. R. Agha, "OPTIMIZING ROUTING OF MUNICIPAL SOLID WASTE COLLECTION VEHICLES IN DEIR EL-BALAH – GAZA STRIP," *IUG Journal of Natural Studies*, vol. 14, no. 2, pp. 1726–6807, Feb. 2016, Accessed: Mar. 21, 2023. [Online]. Available: https://journals.iugaza.edu.ps/index.php/IUGNS/article/view/1602

[7] U. Sonesson, "Modelling of waste collection - a general approach to calculate fuel consumption and time," *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 18, no. 2, pp. 115–123, Apr. 2000, doi: 10.1177/0734242X0001800203.

[8] A. Dao-Tuan, A. Nguyen-Thi-Ngoc, K. Nguyen-Trong, A. Bui-Tuan, and V. Dinh-Thi-Hai, "Optimizing vehicle routing with path and carbon dioxide emission for municipal solid waste collection in Ha Giang, Vietnam," *Industrial Networks and Intelligent Systems*, vol. 221, pp. 212–227, 2018, doi: 10.1007/978-3-319-74176-5_19.

[9] T. Bányai, P. Tamás, B. Illés, Ž. Stankevičiūtė, and Á. Bányai, "Optimization of Municipal Waste Collection Routing: Impact of Industry 4.0 Technologies on Environmental Awareness and Sustainability," *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 634*, vol. 16, no. 4, p. 634, Feb. 2019, doi: 10.3390/IJERPH16040634.

[10] M. Akhtar, M. A. Hannan, R. A. Begum, H. Basri, and E. Scavino, "Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization," *Waste Management*, vol. 61, pp. 117–128, Mar. 2017, doi: 10.1016/J.WASMAN.2017.01.022.

[11] M. A. Hannan *et al.*, "Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goals," *Sustain Cities Soc*, vol. 62, p. 102393, Nov. 2020, doi: 10.1016/J.SCS.2020.102393.