



RESEARCH ARTICLE

Fuzzy vehicle routing problem for a municipal solid waste management system with greenhouse gas emission at various disposal stages

P. Rathinabhagya, J. Merline Vinotha*

Abstract

In developing countries, municipal solid waste management and their authorities face hurdles during the collection, transport, trash segregation process, and disposal of solid waste that will have an environmental impact and affect human health and the economy. This study investigates an existing case study of the waste management system, and the existing case study mainly focuses on determining the routes and clusters within each ward for weekdays and weekends by utilizing the Clarke and Wright algorithm. The availability of daily waste is increasing due to the real-life consequences of dry leaves, household garbage, contaminated material waste, digging waste, etc. Therefore, the availability of daily garbage for each ward is considered fuzzy. This study examines garbage collection from the main region of each ward to the transfer station to the processing plant for weekdays and weekend periods and also addresses greenhouse gas emissions from various disposal stages of the waste management system under an uncertain environment. In this paper, the cluster-first-route-second approach is used to minimize the total travel distance and emission for the fuzzy waste management vehicle routing problem. The Variant Fisher and Jaikumar algorithm and the Sweep algorithm with the Nearest Neighbor algorithm are used to solve this problem. A comparative analysis has been demonstrated between these two algorithms, showing that the Variant Fisher and Jaikumar algorithm with the nearest neighbor algorithm provides the optimal clusters, routes, and minimum distance with the lowest emission value. This approach to urban waste management improves sustainable practices throughout the disposal network.

Keywords: Vehicle routing problem, Sweep algorithm, Variant Fisher and Jaikumar Algorithm, Nearest neighbor algorithm, Pentagonal neutrosophic fuzzy number, Greenhouse gas emission.

Introduction

In a growing nation's emerging cities, handling rising quantities of solid waste is becoming an important issue. Due to rapid growth in urbanization and population explosions, the amount of municipal solid waste (MSW)

is rising throughout the world. The improper management of solid waste causes harmful impacts on the natural environment and the general public's health. For effective management to decrease the production of waste at the level of local government, a standard operating procedure and regulation are needed. A healthy solid waste collection procedure can be attained with appropriate route planning and has positive aspects from both an economic and environmental perspective. In modern society, traditional ways of disposal such as burning, open dumping, and ground disposal are ineffective because they are unable to restrict the rapid growth of environmental pollution due to industrial, radioactive, and agricultural waste. In India, it is not a regular procedure to sort household waste, plastic waste, commercial waste from industry, and electronic waste. According to this consequence, municipal solid waste is not properly handled during the process of gathering, transferring, and disposing of waste materials.

India is third in the global rankings for Solid waste generation. The Transfer Stations are needed for the MSW collection, transfer, and distribution system of waste due to the fact that they serve as a relationship with

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

***Corresponding Author:** J. Merline Vinotha, PG and Research Department of Mathematics, Holy Cross College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli – 620 002, India., E-Mail: merlinevinotha@gmail.com

How to cite this article: Rathinabhagya, P., Vinotha, J.M. (2025). Fuzzy vehicle routing problem for a municipal solid waste management system with greenhouse gas emission at various disposal stages. The Scientific Temper, 16(4):4077-4084.

Doi: 10.58414/SCIENTIFICTEMPER.2025.16.4.09

Source of support: Nil

Conflict of interest: None.

garbage collection and disposal, specifically in situations in which landfills occur far from populated regions. Establishing a transfer station (TS) may decrease the volume of greenhouse gases released as a result of MSW and transfer procedures while also decreasing the cost of trash transport. In order to ensure that the largest amount of waste is gathered at the appropriate time and TS enhances collection frequency. According to the knowledge of some developed nations, waste management is the 2nd-largest research field for reducing emissions during trash handling and waste treatment, as well as after the waste-to-energy process. Hence, one of the most efficient approaches for waste management systems to attain the target of India is decreasing emission levels of greenhouse gases, which involves MSW disposal procedures such as proper landfills, combustion processes, recycling, and composting procedures.

The most important objective of initiatives from the government and the private sector is to build infrastructure that enables the establishment of sufficient and reliable sanitation facilities and water supply systems for urban transformation activities. The government has implemented a number of policies as an element of its national smart city development mission, which has significantly improved waste management in urban areas. The possibility of damage to both the environment and the health condition of the public arises from improperly handling solid waste. The government is especially concerned about renewable energy, organic farming, biological fertiliser products, decreased emissions, and other related problems concerning responsible for consumption as well as production. Currently, India provides a wide variety of processing techniques for waste management. Composting, the production of biogas, the recycling of materials, the manufacturing of fuel, incineration, oxidation, and the conversion of waste into wealth and energy are some of the processing procedures. The majority of the nation's trash is being handled in Chhattisgarh.

Numerous studies have been carried out using mathematical and optimisation techniques to address various issues in the MSWM system, which comprise improving the performance of location facilities and vehicle routing problems, choosing the best technologies for the waste recycling procedure, and exploring various components of the sustainability issue in reverse logistics. (Beltrami and Bodin, 1974) first proposed the waste collection vehicle routing problem (WCVRP) to improve waste collection routes and lower operating expenses.

(Sanchez-Arocha *et al.*, 2018) examined a new technique called Routics that is used to solve the operation system, and routes are generated automatically. (Rekabi *et al.*, 2022) proposed a green vehicle routing problem in the solid waste network issues. This model developed a systematic approach

to recycling municipal solid waste that minimised the cost and maximised the job opportunity. (Rathore and Sarmah, 2019) applied the GIS in conjunction with mathematical optimisation to identify potential TSs for cases involving segregated and unsegregated waste. (Friedrich and Trois, 2016) examined and compared greenhouse gas emissions in three different dumping site scenarios by considering the various methods of treating trash during transport, recycling, composting, and landfill gas recycling. Different route planning methods to reduce the cost of trash and negative miles were discussed by (Sahu *et al.*, 2022). Reducing transportation costs, increasing the recycling revenue system, and applying a chance-constraint programming method to the waste collection vehicle routing model are analysed by (Akbarpour *et al.*, 2021). (Mahdavi *et al.*, 2022) developed intermediate transfer stations and environmental concerns in different areas with multi-trip and multi-period approaches to the study. (Ouertani *et al.*, 2023) proposed a new model for the multi-compartment vehicle routing problem (VRP) for healthcare garbage, and the vehicle separates hazardous and non-hazardous trash during transportation. They proposed the AGATE algorithm to solve this problem. (Rossit and Toncovich, 2024) investigated the route compactness in the waste management VRP. They tested the instances by applying the weighted sum and augmented $\mathcal{E}$ -constraint method.

Clustering algorithms make route planning more effective by categorising customers according to location, consumer demand, or time limitations, which helps solve the VRP. These algorithms assist in lowering travel expenses and enhancing the entire quality of services. (Sultana *et al.*, 2017) proposed a new approach to the Fisher and Jaikumar algorithm, and this new clustering method gives a new method for forming the cone and an efficient result for the capacitated vehicle routing problem. (Chowmali and Sukto, 2021) discussed a new hybrid Fisher and Jaikumar algorithm that examined the multi-compartment VRP for fuel delivery distribution. (Wibowo *et al.*, 2022) analysed the case study of the capacitated vehicle routing problem in the newspaper industry, solving this case study in two phases: first clustering the agents with the help of the sweep algorithm and heuristic algorithm, then finding the route with the help of Google Maps application. (Lestari *et al.*, 2021) examined how the sweep algorithm handled the blood distribution from the blood transfusion unit to the hospital and determined the distribution route for the clusters using the nearest neighbor method.

Fuzzy environment is used in the VRP to handle unpredictability in demand, emission, customer service time, distance, and duration of the trip. This method improves decision-making and adaptability, resulting in logistics solutions that are more effective and flexible. (Aliahmadi *et al.*, 2020) investigate how MSW management deals

with the uncertain situation of the amount of waste and the proposed model. (Sagnak *et al.*, 2021) developed a fuzzy best-worst method and fuzzy TOPSIS approach for determining the location of a sustainable e-waste collection centre. This study discussed the various types of criteria and costs associated with Turkey's e-waste management. (Kuo *et al.*, 2012) created a change-constraint programming model and proposed a HPSOGA to address the capacitated VRP in waste management with variable demand.

In waste management, the VRP has been studied widely, but there are still a number of important unsolved issues. Existing research mostly concentrates on reducing greenhouse gas emissions and fuel consumption but frequently fails to note other important sustainability considerations like waste segregation regulations, alternative fuel transport vehicles, and end-to-end environmental effects. It also accounts for the uncertainties in daily demand for waste, travel time, waiting time, and service time in the real world. Furthermore, the full trip to the final municipal solid waste (MSW) disposal sites is frequently neglected in studies that only take partial routing into account, usually from collection points to collection points within the area or transfer stations. To fill these gaps, this study integrates environmental metrics into the waste collection VRP under vague situation frameworks while providing an effective routing strategy from consumer areas to the final disposal of MSW. The existing case study of Bilaspur's waste management system was concentrated on forming clusters and determining the best routes within 15 subarea wards for weekdays and weekends, ignoring the routing and sustainability practices from the main area of each ward to the end-to-end disposal sites. This work extends and incorporates the environmental concerns and fuzzy availability of daily garbage to address the unpredictable situations that arise while collecting and transporting the Bilaspur city trash on weekdays and weekends from the 15 ward's main area collection points to the TS, recycling centre, and landfill site.

Bilaspur's waste collection points or locations are geographically close together. In this case, clustering algorithms help with the efficient grouping and organisation of nearby locations, and the clustering algorithm's output provides both effective and practical solutions to the problem. Using clustering algorithms in route design helps to create more efficient and environmentally friendly waste management practices by lowering fuel emissions and the total travel distance between collection points, transfer stations, recycling centres, and landfills. In this study, the nearest neighbour algorithm is used to find the optimal routes.

The remaining part of this paper is arranged in the following manner: Section 2 discusses the basics of definitions. Section 3 explains the methodologies of clustering algorithm approaches, route construction,

and calculations for greenhouse gas emissions to tackle the waste collection vehicle routing problem. Section 4 illustrates the case study and discusses the result of this study. Finally, Section 5 presents the conclusion and future directions for this study.

Preliminaries

Neutrosophic set: (Chakraborty, 2020)

A set $\tilde{N}_{euM}$ in the global discourse X , symbolically expressed by x is referred to as a Neutrosophic set if

$$\tilde{N}_{euM} = \left\{ \left\langle X; \left[\tau_{\tilde{N}_{euM}}(x), \rho_{\tilde{N}_{euM}}(x), \varphi_{\tilde{N}_{euM}}(x) \right] \right\rangle; x \in X \right\}$$

where the truthness function is denoted by the expression $\tau_{\tilde{N}_{euM}}(x):X \rightarrow]-0,1+[$ which is stated as the degree of confidence, $\rho_{\tilde{N}_{euM}}(x):X \rightarrow]-0,1+[$ is described as the hesitancy function, which identifies degree of indistinctness and $\varphi_{\tilde{N}_{euM}}(x):X \rightarrow]-0,1+[$ is stated as the falseness function, which assigns the degree of deceptiveness. The $\tau_{\tilde{N}_{euM}}(x), \rho_{\tilde{N}_{euM}}(x) \& \varphi_{\tilde{N}_{euM}}(x)$ shows the following relation:

$$-0 \leq \sup \left\{ \tau_{\tilde{N}_{euM}}(x) \right\} + \sup \left\{ \rho_{\tilde{N}_{euM}}(x) \right\} + \sup \left\{ \varphi_{\tilde{N}_{euM}}(x) \right\} \leq 3 +.$$

Score Function: (Chakraborty, 2020)

The score function actually connects any vague number to the crisp number. A score function is defined and expanded in Pentagonal Neutrosophic Number (PNN) as $\tilde{P}_{pent} = (p_1, p_2, p_3, p_4, p_5; \rho, \tau, \varphi)$. Here, $(1 + \tilde{n})$ is the benefiting portions and $(1 - \tau - \varphi)$ is the hesitancy portions of PNN membership function. The mean of the elements is also given as $\frac{(p_1 + p_2 + p_3 + p_4 + p_5)}{5}$. Thus, Score function is expressed

as $\tilde{S}_{C_{pent}} = \frac{1}{15}((p_1 + p_2 + p_3 + p_4 + p_5) \times (2 + \rho - \tau - \varphi))$ Accuracy function is

expressed as $\tilde{A}_{C_{pent}} = \frac{1}{15}((p_1 + p_2 + p_3 + p_4 + p_5) \times (2 + \rho + \tau + \varphi))$

Methodologies

Sweep Algorithm (SA)

In waste management system, the sweep algorithm is crucial for geographically gathering the collection points as clusters. The algorithm steps as follows:

Step 1

To determine each customer's position by using Cartesian coordinates and the depot's serve as their centre.

Step 2

To figure out each customer's polar coordinates by utilising the equation $\theta = \arctan \tan^{-1} \frac{y}{x}$, where x, y – Cartesian coordinates.

Step 3

Availability of daily waste generation is treated as PNN and convert the fuzzy value into crisp value by using score function.

Step 4

Creating a clustering (grouping), taking into account the vehicle's capacity, from the customer with the smallest polar angle to the customer with the largest.

Step 5

Verify that this cluster includes every customer involved in this group.

Step 6

If one cluster exceeds the capacity of the vehicle, then grouping is stopped. If this occurs, a new cluster is formed, as in the previous step.

Variant Fisher and Jaikumar Algorithm (VFJKA)

The Variant Fisher and Jaikumar algorithm is used in waste management because it is effective in allocating nearby collection points and adapting to variations in the amount of waste produced. The algorithm proceeds with the following steps:

Step 1

Partition the plane into a number of cones equal to the number of vehicles, ensuring that each cone contains an equal number of nodes.

Step 2

Availability of daily amount of garbage is represented as PNN and convert PNN into crisp number using score function.

Step 3

Sort all consumers into their respective cones.

Step 4

Select one consumer from each cone based on either maximum demand or the furthest distance from the origin. Identify the chosen consumer in each cone as the seed for that particular cone.

Step 5

Assign a vehicle to each seed consumer. Each vehicle will be allocated to serve the cone associated with its respective seed consumer.

Step 6

Insertion cost of consumer i and seed consumer k

$$C_{ik} = D_{sdi} + D_{io} - D_{sdo}$$

where D_{sdi} - distance from seed to consumers, D_{io} - distance from consumer to depot, D_{sdo} - distance from seed to depot.

Using the above equations, determine the insertion cost for each consumer in relation to each seed.

Step 7

Based on their insertion costs, consumers are grouped into the vehicles from lowest to highest and do not violate the vehicle's capacity.

Nearest Neighbor Algorithm (NNA)

The NN method is a technique for calculating the shortest path with a closed distance between two consumers.

Step 1

The path can begin at any consumer node in the cluster group.

Step 2

Find the consumer node that is closest to the most recent consumer node added to the path.

Step 3

Repeat step 2 until the path consists of all consumer nodes that have been visited.

Step 4

After visiting all consumer nodes, create a path that return to the depot from the last visited consumer node.

Emission calculation for different scenarios

Emission of Greenhouse gases (GHGs) during Transportation: (Verma and Borongan, 2022)

The (GHGs) emitted by the exhaust from vehicles in the transportation procedure were CO_2 .

$$E_T = F(\text{unit}) / \text{waste}(\text{tons} / \text{day}) \times E(\text{kg} / \text{unit}) \times EF_d(\text{kg } CO_2 / \text{unit})$$

Where, E_T - the amount of Greenhouse gas (GHG) emission in $kg \text{ } CO_2 / \text{tons}$ of waste transported, $F(\text{unit})$ - the total amount of diesel fuel consumed per litres, $\text{waste}(\text{tons})$ - the total amount of garbage transported in the BMC, $E(\text{kg} / \text{unit})$ - the energy content in the diesel fuel and EF_d is the emission factor of diesel fuel for CO_2 .

Estimate the exhaust emissions of greenhouse gases that come from landfills: (Xin et al., 2020)

Compared to CO_2 , CH_4 has a much greater global warming potential. So, in this work only CH_4 emissions were taken into account in the landfill procedure. Therefore, compared to lowering CO_2 emissions, reducing CH_4 emissions may have a more immediate impact on slowing global warming.

$$E_{lf} = E_{CH_4}^{lf} = CH_{4\text{emission}}^{lf} \times GWPW_{CH_4}$$

$$CH_{4\text{emission}}^{lf} = DDOC_m \times F_{CH_4} \times \frac{16}{12} \times (1 - R_{CH_4}) \times (1 - OF)$$

$$DDOC_m = MSW_{lf} \times FDOC \times DOC_d \times MCF_{lf}$$

$$FDOC = \sum DOC_{fi} \times W_{CL}$$

Where W_{CL} - Garbage composition in landfills for daily waste, MSW_{lf} - Mass of garbage in landfill, MCF_{lf} - Methane correction factor based on MSW disposal practises at the landfill, R_{CH_4} - Recovered rate for methane, $GWPW_{CH_4}$ is the effect of global warming potential of CH_4 from garbage, OF - Oxidation factor, DOC_d - Fraction of $FDOC$ that

can decompose, F_{CH_4} - Fraction of generated landfill gas that contains CH_4 , $FDOC$ - Fraction of organic carbon that degrades, DOC_i - Fraction of degradable organic carbon for waste, $DDOC_m$ - mass of the organic carbon that can decompose fractionally, $GWPW_{CH_4}$ is the effect of global warming potential of CH_4 from waste, CH_4^{if} - mass of CH_4 emissions during landfill process, $E_{CH_4}^{if}$ - Methane emissions are equivalent to CO_2 based on the global warming potential, E_{if} - emissions of greenhouse gases from landfills.

Determining the greenhouse gas emissions that come from Waste incineration: (Xin et al., 2020)

Only CO_2 emissions were considered during the combustion process because CH_4 and N_2O were thought to be insignificant.

$$E_{IN} = E_{mci} - E_{eg}$$

$$E_{mci} = MSW_{in} \times \sum (W_c \times dmw \times CFW \times FCFTC \times OF) \times \frac{44}{12}$$

$$E_{eg} = MOG_e \times E_{ef}$$

$$MOG_e = \frac{MSW_{in} \times HV \times HE_{ip}}{3600 \times (1 - ER_{ip})}$$

Where E_{IN} - emission from waste incineration, E_{mci} - emissions from mineral carbon during waste incineration, E_{eg} - emission from electricity generation, HV - Heat value occurs in MSW , W_c - waste consumption during combustion, dmw - The amount of dry matter in the wet weight, $FCFTC$ - fossilized carbon proportion of the total carbon, CFW - $FDOC$ Content of dry weight from garbage, HE_{ip} - Efficiency of heat generation in an incinerator plant, ER_{ip} - Self-used electricity rate for incineration plant, MSW_{in} - Mass of garbage incineration, OF - Oxidation factor, MOG_e - Mass of on-grid energy produced by incineration, E_{ef} - Greenhouse gas emission factor for Electricity.

Greenhouse Gas emissions from the process of Composting: (Verma and Borongan, 2022)

$$E_D = E_{CH_4}^c \times GWPW_{CH_4} + E_{N_2O}^c \times GWPW_{N_2O}$$

where E_D - the emissions from degradation of organic waste $kg CO_2 / tons$, $E_{CH_4}^c$ - the emissions of CH_4 produced by the decomposing process of organic trash, $GWPW_{CH_4}$ is the effect of global warming potential of CH_4 from garbage, $E_{N_2O}^c$ - the N_2O emissions from the decomposition of trash and $GWPW_{N_2O}$ - the effect of global warming potential of N_2O from garbage. E_{op} - the emissions of GHGs from the operational processes.

$$\text{Total GHG}_C = E_{op} + E_D$$

Calculating Kitchen Waste Composting's emissions of greenhouse gases: (Xin et al., 2020)

Comparing CO_2 to CH_4 and N_2O , both of these two have much larger global warming potentials due to the particular aerobic decomposition conditions used in kitchen waste composting. Therefore, Emissions of CH_4 and N_2O were considered during the composting process, but not CO_2 .

$$E_{KW_c} = KW_{qc} \times (E_{CH_4}^{KW_c} \times GWPW_{CH_4} + E_{N_2O}^{KW_c} \times GWPW_{N_2O})$$

Where KW_{qc} - quantity of kitchen waste composted, E_{KW_c} - Kitchen waste composting's emissions of greenhouse gas, $E_{N_2O}^{KW_c}$ - the N_2O emissions from the kitchen waste composting, $E_{CH_4}^{KW_c}$ - the CH_4 emissions from the kitchen waste composting.

Determining the greenhouse gas emissions from recycling renewable resources: (Xin et al., 2020)

The renewable resource of coal consumption, the emission coefficient of standard coal, and the oxidation factor were taken into consideration during the process of renewable resources.

$$E_{rr} = \sum R_{rt} \times RM_{cc} \times EC_c \times OF_{sc} \times \frac{44}{12}$$

Where RM_{cc} - Coal consumption from raw material in trash, OF_{sc} - Waste containing oxidation factor of standard coal, R_{rt} - Recycling the amount of renewable resources in trash, EC_c - coefficient of standard coal's greenhouse gas emissions.

CASE STUDY

In Chhattisgarh state, there is a city called Bilaspur (Latitudes and Longitudes). The Bilaspur Municipal Corporation (BMC) is the only organisation responsible for collecting garbage, transporting it, composting it, and recycling it at the city's MSWM facility. It consists of 55 wards in the residential region. Only 15 wards in Bilaspur city were taken into consideration for this case study. Due to a lack of garbage collection bins, a lack of a regular, ineffective segregation method, inappropriate trash vehicles and their upkeep in Bilaspur city, and other factors, BMC encounters difficulties during the gathering, disposal, and handling of MSW. In Bilaspur city, solid waste is produced at an amount of 2163 metric tons per day. A landfill and processing plant are situated at Kachar. The existing case study of the Bilaspur waste management system (Sarmah, 2019) has concentrated on the precise availability of trash, reducing the clusters and routes within each ward for weekdays and weekend without considering the environmental concerns. The model finds a central point based on geographical location and trash generation at each ward for optimised routes.

A regular mini tipper vehicle does not accommodate all the waste, and it will be scattered on the road, which will create traffic congestion during peak hours from collection

Table 1: Availability of Daily amount of waste for weekdays

S.No.	Ward Name	Availability of Daily Garbage generation in 15 wards
1	Ram Nagar	$\langle\langle 1.15, 1.213, 1.276, 1.339, 1.402; 0.9, 0.1, 0.1 \rangle\rangle$
2	Subhash Nagar	$\langle\langle 0.67, 0.7215, 0.773, 0.8245, 0.876; 0.9, 0.2, 0.1 \rangle\rangle$
3	Shahid Ashafakaula Ward	$\langle\langle 0.61, 0.656, 0.702, 0.748, 0.794; 0.8, 0.1, 0.1 \rangle\rangle$
4	Lajpat Ray Nagar	$\langle\langle 0.72, 0.829, 0.938, 1.047, 1.156; 0.7, 0.2, 0.1 \rangle\rangle$
5	Azad Nagar	$\langle\langle 1.18, 1.34, 1.5192, 1.6792, 1.8392; 0.8, 0.4, 0.07 \rangle\rangle$
6	Nirala Nagar	$\langle\langle 1.31, 1.47, 1.6375, 1.7975, 1.9575; 0.7, 0.2, 0.1 \rangle\rangle$
7	Dr. Ambedkar Nagar	$\langle\langle 1.28, 1.408, 1.536, 1.664, 1.792; 0.9, 0.1, 0.3 \rangle\rangle$
8	Mother Teresa Nagar	$\langle\langle 1.44, 1.56, 1.6875, 1.8075, 1.9275; 0.7, 0.04, 0.1 \rangle\rangle$
9	Rani Luxshmibai Nagar	$\langle\langle 1.89, 2.0148, 2.1396, 2.2644, 2.3892; 0.8, 0.1, 0.05 \rangle\rangle$
10	Shivaji Nagar	$\langle\langle 1.66, 1.988, 2.316, 2.644, 2.972; 0.7, 0.2, 0.35 \rangle\rangle$
11	Vinoba Nagar	$\langle\langle 2.35, 2.585, 2.82, 3.055, 3.29; 0.9, 0.1, 0.3 \rangle\rangle$
12	Krantikumar Bharti Nagar	$\langle\langle 2.46, 2.7361, 3.0122, 3.2883, 3.5644; 0.7, 0.2, 0.05 \rangle\rangle$
13	Priyadarshani Nagar	$\langle\langle 0.93, 0.9894, 1.0488, 1.1082, 1.1676; 0.8, 0.1, 0.04 \rangle\rangle$
14	Gayetri Nagar	$\langle\langle 2.14, 2.319, 2.498, 2.677, 2.856; 0.9, 0.2, 0.23 \rangle\rangle$
15	Sanjay Gandhi Nagar	$\langle\langle 1.97, 2.1, 2.23, 2.36, 2.49; 0.9, 0.2, 0.05 \rangle\rangle$

Table 2: Availability of Daily amount of waste for weekend

S. No.	Ward Name	Availability of Daily Trash generation in 15 wards
1	Ram Nagar	$\langle\langle 1.29, 1.434, 1.578, 1.722, 1.866; 0.7, 0.1, 0.15 \rangle\rangle$
2	Subhash Nagar	$\langle\langle 0.75, 0.799, 0.848, 0.897, 0.946; 0.8, 0.1, 0.05 \rangle\rangle$
3	Shahid Ashafakaula Ward	$\langle\langle 0.67, 0.76, 0.85, 0.94, 1.03; 0.7, 0.2, 0.14 \rangle\rangle$
4	Lajpat Ray Nagar	$\langle\langle 0.82, 0.886, 0.952, 1.018, 1.084; 0.9, 0.2, 0.12 \rangle\rangle$
5	Azad Nagar	$\langle\langle 1.35, 1.599, 1.848, 2.097, 2.346; 0.6, 0.1, 0.31 \rangle\rangle$
6	Nirala Nagar	$\langle\langle 1.48, 1.635, 1.79, 1.945, 2.1; 0.9, 0.2, 0.22 \rangle\rangle$
7	Dr. Ambedkar Nagar	$\langle\langle 1.46, 1.5785, 1.697, 1.8155, 1.934; 0.8, 0.2, 0.02 \rangle\rangle$
8	Mother Teresa Nagar	$\langle\langle 1.61, 1.73, 1.85, 1.97, 2.09; 0.9, 0.1, 0.19 \rangle\rangle$
9	Rani Luxshmibai Nagar	$\langle\langle 2.18, 2.36, 2.54, 2.72, 2.9; 0.8, 0.2, 0.3 \rangle\rangle$
10	Shivaji Nagar	$\langle\langle 1.83, 2.135, 2.44, 2.745, 3.05; 0.6, 0.2, 0.15 \rangle\rangle$
11	Vinoba Nagar	$\langle\langle 2.59, 2.945, 3.3, 3.655, 4.01; 0.8, 0.3, 0.15 \rangle\rangle$
12	Krantikumar Bharti Nagar	$\langle\langle 2.71, 3.245, 3.78, 4.315, 4.85; 0.7, 0.5, 0.05 \rangle\rangle$
13	Priyadarshani Nagar	$\langle\langle 1.26, 1.454, 1.642, 1.833, 2.024; 0.7, 0.2, 0.2 \rangle\rangle$
14	Gayetri Nagar	$\langle\langle 2.38, 2.647, 2.914, 3.181, 3.448; 0.9, 0.3, 0.15 \rangle\rangle$
15	Sanjay Gandhi Nagar	$\langle\langle 2.19, 2.529, 2.868, 3.207, 3.546; 0.5, 0.1, 0.11 \rangle\rangle$

points to transfer stations, landfills, and processing plants. Indian waste management driver's opinions gathered from the organisation suggest that unless the waste transportation process becomes more rapid, it will be difficult to transport all the trash in the allocated time, and this may lead to many trips and some accidents. In India, all the states have small garbage vehicles that are not properly functioning, and frequent accidents have been reported with old compactor vehicles. In this case study, a Refuse garbage compactor truck is considered to improve the effectiveness of the waste management system. It is a type of specialised municipal vehicle used to compact or compress waste, making it easier to handle and more effectively transported. Refuse compactors transporting large amounts of trash in fewer trips, reducing environmental impacts, reducing the risk of disease transmission, and reducing the

time required for collection and transportation. The purpose of using refuse compactor trucks is to maintain hygienic conditions. Additionally, compact waste will emit less odour, which is effective for both waste management workers and neighbours who travel with the trucks.

The availability of the daily amount of waste in MSW is considered in a variety of ways, including food habits, seasons, industrial, agricultural, and commercial activities. Because of this cause, the availability of the daily amount of trash is uncertain. Hence, the availability of the daily amount of waste is taken as a Pentagonal Neutrosophic Fuzzy Number. The existing case study is re-examined, and the problem focuses on extending 15 wards of garbage collection and routes from the main area location to the

Table 3: Parameters of GHG emission

Attribute	Interpretation	Values
W_{CL}	Garbage composition in landfills for daily waste	2.2483 ton/d
MSW_{lf}	Mass of garbage in landfill	10341/ton
DOC_d	Fraction of $FDOC$ that can decompose	0.5
MCF_{lf}	Methane correction factor based on MSW disposal practises at the landfill	1
R_{CH_4}	Recovered rate for methane	0
OF	Oxidation factor	0
MSW_{in}	Mass of garbage incineration	10436/ton
W_c	waste consumption during combustion	1.001
dmw	The amount of dry matter in the wet weight	2.8956
CFW	FDOC Content of dry weight from garbage	0.86
FCFTC	fossilized carbon proportion of the total carbon	2.21
OF_c	Oxidation factor from combustion	0.95
HV	Heat value occurs in MSW	9.427/ ton
HE_{ip}	Efficiency of heat generation in an incinerator plant	0.2
ER_{ip}	Self-used electricity rate for incineration plant	0.2
OF_{sc}	Waste containing oxidation factor of standard coal	0.93/ton
R_{rr}	Recycling the amount of renewable resources in trash	151.4/ton
RM_{cc}	Coal consumption from raw material in trash	0.8445/ ton

Table 4: Comparison between the SA and VFJKA with NNA for weekdays

Algorithm	No. of Cluster groups	Total distance (km)	Co ₂ Emissions during transportation
SA with NNA	2	35.12	11.04
VFJKA with NNA	2	31.41	8.07

Table 5: Comparison between the SA and VFJKA with NNA for weekend

Algorithm	No. of Cluster groups	Total distance (km)	Co ₂ Emissions during transportation
SA with NNA	2	38.12	10.79
VFJKA with NNA	2	31.41	7.69

Table 6: The result of this BMC case study for the emission of GHG from various stages of waste management system

S. No.	Emissions from various stages of solid waste	Total
1	Landfills	781.9348 / t
2	Incineration	34.1597 / t
3	Trash Composting	112.88 / t
4	Kitchen waste Composting	354.619 / t
5	Recycling Renewable Resources	296.421 / t

TS to the final disposal site for weekdays and weekends under vague conditions with GHG emissions at different demolition stages.

Discussion

The objective of this study is to find the optimum route for collecting all the solid waste generated at the collection nodes of each ward location and to also reduce the emission level from the solid waste management (SWM) of BMC. The necessary input data for this study was obtained from Google Maps latitudes and longitudes, and the distance matrix for 15 wards, TS, recycling centres, landfills of Bilaspur city was derived by using the Euclidean distance formula. The availability of crisp daily garbage generation was considered in this study (Sarmah, 2019). The emission values of various dumping stages of GHG in solid waste management systems were taken from studies (Verma and Borongan, 2022) and (Xin *et al.*, 2020). The daily garbage availability for weekdays and weekend is described in Tables 1 and 2. The parameter values for various disposal stages of emission are displayed in Table 3. The comparative analysis of the objective function for this extended study is discussed in Table 4 and Table 5. The results of the different stages of GHG in this study are shown in the Table 6.

Conclusion

This paper investigated a solution for SWM for VRP with various disposal stages of GHG emissions where the availability of the daily amount of garbage is a Pentagonal Neutrosophic fuzzy number. The merit of this study is that reducing the total travel distance, emissions, clusters, number of vehicles, and transfer stations as efficient segregation processes, proper handling processes, and various procedures such as landfill, recycling, composting, and incineration at the trash disposal process in a proper manner decreases the environmental issues in waste management. Comparisons between the outcomes of the VFJKA and the SA with NNA were investigated. The clusters that are formed from the VFJKA with the refuse garbage compactor truck provide the best clusters and reducing the cluster and CO₂ emissions during transportation for the municipal authority in waste management in Bilaspur

Municipal Corporation, Chhattisgarh, and the NNA gives the best total travel distance, route to the waste collection. For weekdays, the VFJKA with NNA reduces the distance by 10.56% and the CO₂ emission by 26.9% when compared to the SA with NNA. For weekend, the VFJKA with NNA reduces the distance by 17.6% and the CO₂ emission by 28.73% when compared with the SA with NNA. The future direction of this study is to develop meta-heuristics for large-scale problems and increase the implementation of new technologies for waste-to-energy conversion, like biogas plants, thermal power plants, modernising the transfer station, and implementing more electric vehicles which will be more comfortable for the garbage picker, garbage vehicle's driver, and the environment.

Acknowledgements

Nil

Conflict of interest

none

References

- Akbarpour, N., Salehi-Amiri, A., Hajiaghaei-Keshteli, M., & Oliva, D. (2021). An innovative waste management system in a smart city under stochastic optimization using vehicle routing problem. *Soft Computing*, 25, 6707-6727.
- Aliahmadi, S. Z., Barzinpour, F., & Pishvaei, M. S. (2020). A fuzzy optimization approach to the capacitated node-routing problem for municipal solid waste collection with multiple tours: A case study. *Waste Management & Research*, 38(3), 279-290.
- Beltrami, E. J., & Bodin, L. D. (1974). Networks and vehicle routing for municipal waste collection. *Networks*, 4(1), 65-94.
- Chakraborty, A. (2020). Application of pentagonal neutrosophic number in shortest path problem. *International Journal of Neutrosophic Science*, 3(1), 21-28.
- Chowmali, W., & Sukto, S. (2021). A hybrid FJA-ALNS algorithm for solving the multi-compartment vehicle routing problem with a heterogeneous fleet of vehicles for the fuel delivery problem. *Decision Science Letters*, 10(4), 497-510.
- Friedrich, E., & Trois, C. (2016). Current and future greenhouse gas (GHG) emissions from the management of municipal solid waste in the eThekweni Municipality-South Africa. *Journal of Cleaner Production*, 112, 4071-4083.
- Kuo, R. J., Zulfia, F. E., & Suryadi, K. (2012). Hybrid particle swarm optimization with genetic algorithm for solving capacitated vehicle routing problem with fuzzy demand-A case study on garbage collection system. *Applied Mathematics and Computation*, 219(5), 2574-2588.
- Lestari, F., Rizky, M., Umam, M. I. H., & Indriyani, F. F. (2021). Vehicle routing problem using sweep algorithm for determining distribution routes on blood transfusion unit. In *Proceedings of the Second Asia Pacific International Conference on Industrial Engineering and Operations Management*, p. 263-73.
- Mahdavi, L., Mansour, S., & Sajadieh, M. S. (2022). Sustainable multi-trip periodic redesign-routing model for municipal solid waste collection network: the case study of Tehran. *Environmental Science and Pollution Research*, 29(24), 35944-35963.
- Quertani, N., Ben-Romdhane, H., Nouaouri, I., Allaoui, H., & Krichen, S. (2023). A multi-compartment VRP model for the health care waste transportation problem. *Journal of Computational Science*, 72, 102104.
- 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.
- Rathore, P., & Sarmah, S. P. (2019). Allocation of bins in urban solid waste logistics system. In *Harmony Search and Nature Inspired Optimization Algorithms: Theory and Applications, ICHSA 2018* (pp. 485-495). Springer Singapore.
- Rekabi, S., Sazvar, Z., & Tavakkoli-Moghaddam, R. (2022). A green vehicle routing problem in the solid waste network design with vehicle and technology compatibility. *Computational Sciences and Engineering*, 2(2), 299-309.
- Rossit, D., & Toncovich, A. (2024). Bi-objective optimization of a VRP problem applied to urban solid waste collection through a model that includes the visual attraction of routes. *arXiv preprint arXiv:2405.00068*.
- Sagnak, M., Berberoglu, Y., Memis, I., & Yazgan, O. (2021). Sustainable collection center location selection in emerging economy for electronic waste with fuzzy Best-Worst and fuzzy TOPSIS. *Waste Management*, 127, 37-47.
- Sahu, M., Sharma, P., Sharma, H. K., Choudhury, T., & Dewangan, B. K. (2022). Route Optimization for Waste Collection. In *Emerging Technologies in Data Mining and Information Security: Proceedings of IEMIS 2022, Volume 1* (pp. 605-613). Singapore: Springer Nature Singapore.
- Sanchez-Arocha, O., Trevino-Garza, G., Cardenas-Barron, L. E., & Meneses-Preciado, C. V. (2018). A framework for solving routing problems for small and medium size companies. *International Journal of Applied and Computational Mathematics*, 4(3), 94.
- Sarmah, S. P., Yadav, R., & Rathore, P. (2019). Development of Vehicle Routing model in urban Solid Waste Management system under periodic variation: A case study. *IFAC-PapersOnLine*, 52(13), 1961-1965.
- Sultana, T., Akhand, M. A. H., & Rahman, M. H. (2017, May). A variant Fisher and Jaikumar algorithm to solve capacitated vehicle routing problem. In *2017 8th International Conference on Information Technology (ICIT)* (pp. 710-716). IEEE.
- Verma, R. L., & Borongan, G. (2022). Emissions of greenhouse gases from municipal solid waste management system in Ho Chi Minh city of Viet Nam. *Urban Science*, 6(4), 78.
- Wang, Z., & Geng, L. (2015). Carbon emissions calculation from municipal solid waste and the influencing factors analysis in China. *Journal of Cleaner Production*, 104, 177-184.
- Wibowo, N. A., Nurbi, R. S., Arza, A., Khofiyah, N. A., & Sutopo, W. (2022). Determining Capacitated Vehicle Routing Problem Model with Comparative Analysis of Sweep Algorithm and Heuristic Algorithm in Newspaper Company: A Case Study. *Proceedings of the International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey*, 2972-2983.
- Xin, C., Zhang, T., Tsai, S. B., Zhai, Y. M., & Wang, J. (2020). An empirical study on greenhouse gas emission calculations under different municipal solid waste management strategies. *Applied Sciences*, 10(5), 1673.