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Municipal solid waste management using multiple disposal location-arc routing and waste segregation approach - a real life case study in England

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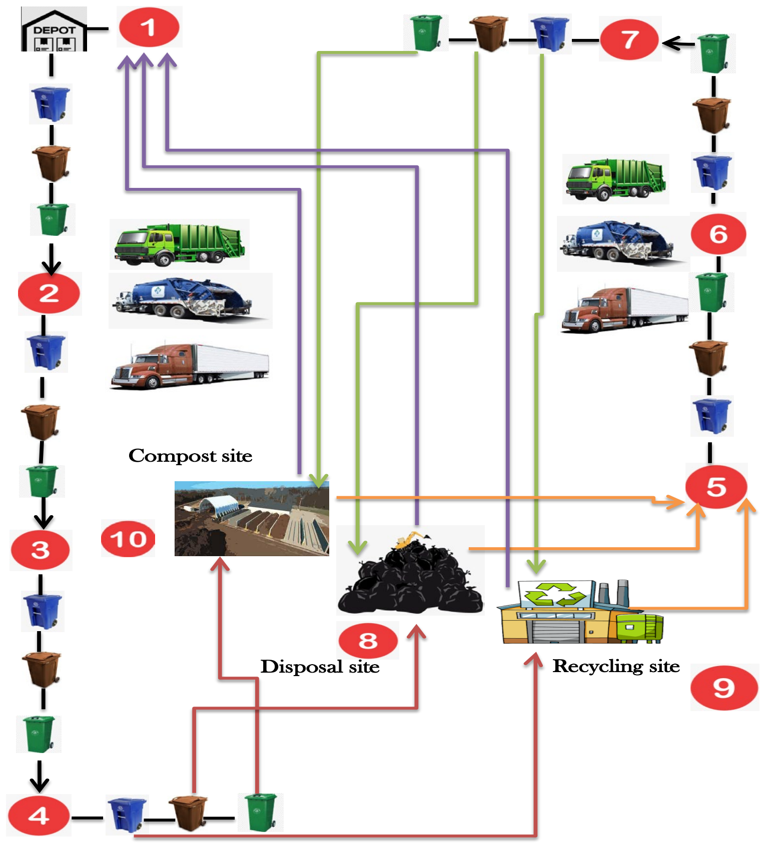
Abstract

In the realm of municipal operations, the effective management of municipal solid waste (MSW) stands out as a pivotal undertaking. It necessitates substantial allocations of fixed and variable resources and financial investments. The bulk of these expenditures are associated with the operational facets encompassing waste collection, transportation, and disposal. This research delves into the examination of multiple Disposal Location Arc Routing Problems (LARP) while considering vehicle capacity limitations and the incorporation of waste segregation. The LARP model is designed to identify the optimal locations for depots and three waste disposal sites. The optimization objectives and constraints applied to the LARP model are geared toward enhancing waste collection efficiency and minimizing costs. Additionally, a triangular fuzzy parameter is introduced to represent the demand. To put this model to the test, a real-world case study in the UK is explored to evaluate its performance and practicality. Finally, a series of sensitivity analyses are conducted, offering valuable managerial insights under varying conditions. The inclusion of waste segregation in this waste management model holds considerable significance for managers. This is particularly relevant because it proposes a more effective strategy for waste management when dealing with diverse types of waste.

Keywords: location arc routing problems, municipal disposal sites, waste collection, waste segregation, mathematical model, fuzzy.



1. Introduction and literature review

Municipal waste management is becoming increasingly important as time passes. The increase in the global population has caused a waste generation to increase. With the growth of population and urbanization, coupled with increased environmental concerns, a critical situation has resulted in the need to look for sustainable means of collecting and disposing of municipal solid waste. A weak policy and ineffective waste management may result in the degradation of valuable land resources, land prices increase, and long-term health and environmental issues [1]. Many researchers have employed mathematical models and different techniques to solve various decision-making problems on waste management system's location-arc routing problem (LARP). Then this study is reviewed the important features of previous studies in some mentioned categories, respectively.

1.1 Municipal Solid Waste Collection model

The actions of gathering, separating, packing, and temporarily storing solid waste from various collection depots to a place or facility approved by a competent state agency are referred to as solid waste collection. Municipal solid waste management (MSWM) poses a significant public health and environmental challenge in urban areas and numerous developing nations. Also, it is a significant issue for densely populated urban regions that face challenges such as limited landfill capacity and ineffective waste management systems. Inadequately handled MSW has substantial negative impacts on both human health and the economy. Furthermore, poorly managed waste contributes to the emission of greenhouse gases, exacerbating the global warming effect. Given these circumstances, it becomes crucial for all public authorities to prioritize the development of an optimal MSW system. In terms of operations (collection, transportation, and disposal), sustainable waste management tries to minimize municipal solid waste (MSW) generated and disposed through a three-pronged approach involving the economy, environment, and social goals [2]. Increasingly, many cities around the world are facing MSW problems because of the lack of adequate infrastructure and serious efforts by responsible authorities and governments [3]. Industrialization [4], urbanization [5], population [6] and economic growth and changes in lifestyle and consumption patterns are all driving massive increases in the generation of MSW [7]. Recently, a few researchers have attempted to address the sustainable collection of MSW. From the perspective of life cycle assessment (LCA), [8] examined the environmental and energy consequences of managing urban municipal solid waste (MSW) collection and transportation systems. [9] analyzed the Shanghai city for MSW management and its current situation to enrich existing MSW management studies. Also, they present two main challenges; inadequate collecting vehicles and limited wet waste treatment capacity. According to the life cycle assessment (LCA), this study seeks to examine the environmental and energy impacts of urban MSW collection and transportation systems.

A mathematical model for the waste collection problem is presented in [10] work, which takes into account the collection of waste from the customers' locations and the disposal of waste in compatible facilities. [11] analyzed a system for sustainable MSWM in Hoi A city (HAC) of Vietnam with proposing a multi-objective optimization model by minimizing cost minimization, landfill and emission minimization. Also, [12] analyzed sustainable municipal solid waste disposal system by a mixed-integer linear programming model and considering fuzzy programming approach to optimize the number and locations of construction sites for recycling centers. [13] proposed a multi-objective fuzzy robust optimization approach for a sustainable MSWM network under uncertainty to minimize the total costs of the network and environmental damages and optimize social impacts by fuzzy goal programming. [14] proposed a MILP model to support MSW as the social side of sustainability in uncertainty by considering waste separating units equipped and utilizing a robust possibility programming approach for three objective functions. The study of [15] will assist municipal officials in determining an appropriate collection and transportation technique for their respective MSW management systems. [16] determined the effects of COVID-19 on the quantity of waste and MSWM. They understood that COVID-19 caused the quantity variation and composition change of MSW.

[17] addressed a new electric waste collection problem with multiple types of wastes. This study aims to introduce the e-waste collection problem, which entails assigning a heterogeneous fleet of electric vehicles to visit a number of locations where waste bins are located. A novel mathematical model for a waste collection problem is presented by [18] considered a new network to collect waste. [19] presented a combination of methodologies for improving e-waste collection efficiency. Providing more efficiency in waste loading and packing, a novel collection vehicle body construction is also proposed. [20] provided a bi-objective MILP sustainable medical waste collection model for pandemics in order to minimize the total costs due to transportation, emissions-related pollution, outsourcing, and use of vehicles. [21] developed a novel multi-stage model for an e-waste management system in three-echelon of vehicle routing, disassembly sequence scheduling, and allocation of vehicles for transporting systems.

While municipal solid waste management studies have provided valuable insights into addressing waste segregation related challenges, there remains a research gap in exploring the integration of municipal solid waste management with waste segregation structure methodologies to further improve efficiency. While some researchers have applied these concepts in practical contexts, further investigations are needed to explore their effectiveness in various settings. This study aims to bridge this research gap by exploring and expanding upon the municipa solid waste management with multiple disposal location-arc routing and waste segregation approach structure methodologies, contributing to the development of more robust and efficient decision-making frameworks.

This study is presented for designing a solid waste management network, and the purpose of this study is to introduce a novel model for addressing the best routes for waste collection, the optimal locations of depots and stations, while considering three types of trash bins (green, brown, and blue), each designated for a specific type of waste. In other words, waste segregation is assumed in this waste management problem. Additionally, three different types of vehicles are considered for collecting different types of waste, with three types of sites for unloading trash, including recycling sites, compost sites, and disposal sites. The depot, disposal site, recycling site, and compost site are located in separate areas. The objective function of the proposed model is to minimize the total waste collection routing cost. Furthermore, the model takes into account the uncertain demand of each region. Therefore, this study aims to present a versatile model capable of accommodating waste segregation in solid waste management as a factor that previous researchers have overlooked in their problem formulations.

1.2 Waste Segregation and food supply chain

The significance of food supply and waste segregation in municipal solid waste management, utilizing multiple disposal locations and arc routing, cannot be emphasized enough. Effectively managing municipal solid waste is vital for maintaining cleanliness, public health, and environmental sustainability in urban areas. By placing emphasis on segregating food waste, which constitutes a significant portion of municipal solid waste, numerous advantages can be realized. Proper segregation enables the diversion of biogas. Moreover, by implementing arc routing techniques, waste collection routes can be optimized, resulting in reduced fuel consumption, lower transportation costs, and improved overall efficiency in waste management operations.

Segregation is an important step that can reduce the risk of environmental pollution and help waste from being recovered. The emergence of a waste management system, for proper waste segregation, exerts a positive impact on the biodegradability scope. Improper waste segregation causes to increase risk of infections, toxic effects, and injuries to care and non-care staff, waste handlers, patients, visitors, and the community. [22] investigates a novel methodology for waste segregation to its effective recycling and disposal thought utilizing a deep learning strategy by the YOLOv3 algorithm. [23] analyzed the performance of CNN-based waste-type classifiers that considered household wastes is separated into four types including general waste, compostable waste, recyclable waste, and hazardous waste by a case study in Thailand.

The goal of [24] is to create a classification of failure modes related to segregation in a health care organization's Medicine Department. This will be accomplished by integrating an intuitionistic fuzzy hybrid weighted Euclidean distance operator with the multicriteria approach Potentially All Pairwise RanKings of all probable Alternatives (PAPRIKA). The subjective and objective weights of risk factors were considered at the same time. [25] developed a queueing-inventory model to manage control patients' congestion in a medical center and manage their waste, considering environmental issues. Also, they considered a queueing system i order to control the patients' congestion in the treatment center, and then another queue is considered for vehicles. Subsequently, an inventory model is employed to prevent waste accumulation. [26] offers a sustainable multi-objective mixed-integer non-linear programming (MINLP) formulation to handle the issues highlighted with vaccine inventory ordering and waste management. Additionally, two test problems that allow for both tiny and medium-sized solutions have been defined. The model is solved using the LP-metric and goal programming techniques.

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Food waste is a severe problem and a major challenge in global food security, so about 20–30% of food waste happens in developing countries' post-harvest stage of the food supply chain [27]. Hence, further controls are needed to reduce food wastages. After lowering the amount of food lost and maximizing the recovery and distribution of edible food, the next phase in the food supply chain is composting the nonedible food to restore soils and grow additional food to put back into the supply chain. In [28] approach, improved composting systems that may be employed as small decentralized units for food and green waste treatment have been created. The inactivation of pathogens in compost piles has been sped up with the developing of a new closed loop heating system. In [29] study, the concept of a circular economy was used to develop a conceptual model for preventing food loss and waste. While agriculture and food production are essentially interdisciplinary, they have shown how to include contributions from different disciplines into their suggested model for total de-pollution of the sector (zero waste supply chain). The aim of [30] paper the primary goal is to investigate and produce a recipe for composting food waste such as peels and pomace from a variety of fruits and vegetables (such as apple, banana and orange), all of which are widespread in household waste (as well as potatoes, cabbage, and carrots).

1.3 Uncertainty

Several studies have been conducted in the area of uncertainty in recent years. [31] developed a mixed-integer linear programming model to formulate the sustainable multi-trip location-routing problem under the pandemic situation in uncertainty with fuzzy chance-constrained programming technique and implementing a weighted goal programming method to minimize the total traveling time, total violation from time service priorities, and total infection risk. [32] presented a framework for identifying the location of sustainable collection centers for e-waste using the fuzzy Best-Worst and fuzzy TOPSIS methods. [33] formulated a fuzzy robust stochastic multi-objective model with a sustainable, resilient disaster waste management network based on the multi-choice goal programming and PSO algorithms. [34] investigated a comprehensive multi-tiered waste supply chain under uncertainty to minimize different types of costs by the chance constraint and Taguchi method. [35] developed a multi-objective mixed-integer linear programming model by considering the reverse flows of expired medicines in competitive market and demand uncertainty situation by LP-metrics method with a heuristic algorithm. Also, [36] used uncertainties in prices and manufacturing costs for maximizing profits and minimizing the amount of carbon emissions. [37] considered two sources of uncertainty for the returned product quality and remanufacturing capacity in sustainable reverse supply chain network.

Uncertainty programming techniques, such as stochastic programming and fuzzy logic, provide valuable tools for modeling and optimizing waste management systems. They can account for uncertain variables like waste composition, generation rates, and disposal costs, leading to more robust decision-making. Some studies integrate environmental and social factors into their uncertainty programming models, helping decision-makers consider the broader impacts of waste management strategies. Uncertainty programming can assist in ensuring waste management strategies remain compliant with evolving regulations and policies [31, 32, 33].

1.4 Location-Arc Routing Problem

There are three key logistical issues that have been examined and solved sequentially, from the strategic to the operational levels, by many researchers: facility location, inventory management, and vehicle routing. An Arc Routing Problem (ARP) is similar to a Vehicle Routing Problem (VRP), with the exception that customer needs are scattered throughout certain edges and arcs of a network, and the goal is to minimize the cost of traversing all such required links. Only a few studies in the literature concentrate on the LARP. LARP occurs when the optimal sites for depots or disposal sites must be picked in addition to the routing, and this is made more complex when the number of depots is a decision variable in and of itself. The cost of distribution could be significantly affected by the number and location of depots and disposal sites. As a result of the complexity of LARP, very little research has been conducted on the development of specific solutions for resolving issues of this kind. Offered valuable insights for tackling challenges associated with location [38]. Location- allocation plays a crucial role in routing problem and [39] focus was on the three primary uses of LARP, including mail delivery and rubbish collection. The study of [40] addressed a location-arc routing problem involving transportation decisions between suppliers and existing depots. It is solved by making a two-goal mathematical model to find the best balance between total costs and make span. [41] developed two mathematical models under two assumptions to address a multi-product location-arc routing problem, namely that all types of products in a necessary arc must be supplied by a tour and each type of product in a required arc must be supplied by a tour. A robust location-arc routing problem with unknown demand and cost factors is addressed in the study of [42]. They utilized a robust optimization strategy to cope with uncertainty in this deterministic mathematical model, which is adapted from existing models in the literature.

According to the above surveys, there are only a few literatures on waste collection LARP. Also, incorporating waste segregation into WMS has not been addressed efficiently. Providing a waste collection and transportation system will require a study of the conflicts and trade-offs between economic, environmental, and social objectives within the main operating constraints. In this study, we look at a more generic situation of LARP that includes vehicle capacity limits and the option of deciding where the depot and various disposal sites should be located. This study will contribute to previous studies in several aspects. Three kinds of vehicles collect special waste, including recycling, general, and plant waste, and they start their trip from depot. When each path's waste has been collected, it is unloaded at a special site designated for that kind of waste. The LARP model will indicate the best locations for the depot and the three waste disposal sites. In order to address these goals, total cost minimization is taken into account. Due to ever-changing market conditions, even if advanced methodologies like time series have been created to improve forecasting accuracy, there are still uncertainties in demand. Therefore, the demand, which in this case is the rate at which trash bins are filled, is deemed as a triangular fuzzy parameter. We use a triangular fuzzy membership function because of its simplicity and high computational efficiency. Consequently, in this study, mixed-integer linear programming is developed for the waste collection location-routing problem with considering waste segregation for MSW collection problem in a real case study by solving several numerical problems with different scales (including small and medium) to examine the performance of the model through an exact method and the result of sensitivity analysis for variables by changing some significant parameters is presented.

The rest of this research is as follows: The definition of the model, assumptions and mathematical model is presented in section 2. Section 3 describes techniques to solve the problem. Computational examples and the results of the numerical experiment are investigated in section 4. Then, the case study is performed in section 5 and the sensitivity analysis is analyzed in section 6. Section 7 explains the discussion and some management insights. Finally, section 8 presents the conclusions and suggestions for future researchers.

2. Problem description

The mathematical model and its specific characteristics are introduced in this section. Operational goals are to calculate the optimal place of the depot and stations and to plan routes optimally. This study develops an effective methodology for determining the best routes for waste collection and the best place of depots and stations. It is assumed that we have three kinds of trash bins: 1) The blue trash bins are for recycling bins such as plastic bottles, paper bags, newspapers, cartons, etc. 2) Green trash bins are for organic waste such as fruits, vegetables, animal waste, house plants including soil, etc. 3) The brown trash bins which are used for garbage bin such as broken mugs and dishes, plastic food wraps, liner bags and, etc. Each trash bin is collected by a vehicle of the same color as the bin. In other words, waste segregation is assumed in this waste management problem. So, we have three kinds of vehicles: blue, brown and green. All of the vehicles start their trip from the depot. Blue, green, and brown vehicles end their trip, at a recycling site, a compost site, and a disposal site. The problem setting alleges us to consider one objective function for mathematical modeling; as cost reduction in waste management has always been a dilemma for decision-makers (DMs), we devote our objective to this. In this regard, we take into account service cost for each kind of vehicle, hiring cost of tours, opening cost of depots, and opening cost of stations (recycle site, compost site, and disposal site).

A LARP with vehicle capacity constraints is defined on a Graph $G' = (V, E \cup A')$ in which V is the set of nodes and $D' \subseteq V, F \subseteq V, F' \subseteq V, F'' \subseteq V$ are the set of potential locations for depot, recycle sites, compost sites and disposal sites, respectively. E is the set of all the edges and A' is the set of all the arcs. Let $A_R \subseteq A'$ and $E_R \subseteq E$ be the sets of arcs and edges on which the service is to be delivered. The problem is to choose the locations of depot, recycle, compost and disposal sites and assign to depot a number of tours, each of which is formed to serve a group of customers in a way that the total cost of transportation, tours hiring and opening of depot and stations is minimized.

Fig1 illustrates the problem schematically. The MSW collection network pictured in Fig1 includes eleven required edges: 1-2, 2-3, 3-4, 4-8, 4-9, 4-10, 5-6, 6-7, 7-8, 7-9, 7-10, one depot, one recycling site, one compost site, and one disposal site. Trash bins indicate required edges, while lines specify traversing edges. All of the vehicles start their trip from the depot. Blue, green, and brown vehicles end their trip, at a recycling site, a compost site, and a disposal site, respectively, which are at separate locations. After finishing their tour, the vehicles return to the depot.

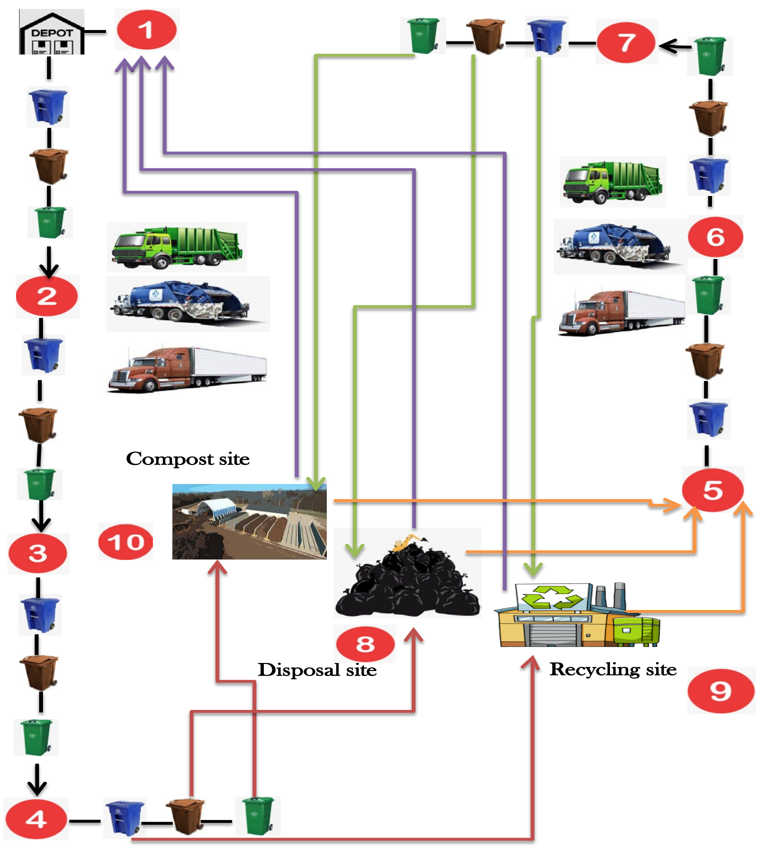

Fig 1.The configuration of the considered problem

2.1. Assumptions

The main assumptions of this model are as follows:

- Three types of trash bins are considered: a green bin for organic wastes, a blue bin for recycling wastes, and a Brown bin for garbage waste.
- Three types of vehicles are analyzed for collecting different types of waste.
- Three types of sites are presented for unloading trash, including recycling site, compost site and disposal site.
- The depot, disposal site, recycling site, and compost site have a separate location in the network.
- Each vehicle does a same number of trips.
- Each vehicle begins and ends its trip from the depot.
- A fleet of homogeneous vehicles for each group (Green vehicle, Blue vehicle, and Brown vehicle) is taken into account.
- Each required arc or edge must be served by exactly one vehicle of each color.The total demand to be served on each tour must not exceed the vehicles capacity (W^b, W^g, W^w).
- The demand for edges is triangular fuzzy parameters, Pishvaee and Torabi method is used for the defuzzification of fuzzy parameters.

2.2. Mathematical model

This study develops a novel single objective Integer Linear Programming Model for the Location Arc Routing Problem in the waste collection system. The notions of this problem including sets, parameters, and decision variables, are presented in Table1. Also, the objective function and constraints are introduced in the following.

Table 1.Problem's notations

Notation	Definition
Sets	

V	Set of nodes; $i, j \in V$
E	Set of edges; $(i, j) \in E$
A	Set of all arcs
A_R	Set of required arcs
S	Set of vehicle trips
$\acute{D}$	The set of potential locations of depots
F	The set of potential locations of recycle sites
$\acute{F}$	The set of potential locations of compost sites
F''	The set of potential locations of disposal sites

Parameter

C_{ij}	Service cost of required arcs; $(i,j) \in A_R$
D_{ij}	Traversing cost for all arcs; $(i,j) \in A_R$
μ^w	Hiring cost for brown car
μ^g	Hiring cost for green car
μ^b	Hiring cost for blue car
G	Opening cost of depot
FF^w	Opening cost of disposal sites
FF^g	Opening cost of compost sites
FF^b	Opening cost recycle sites
$\widetilde{Q}_{ij}$	Demand of edge (i, j)
W^w	Capacity of brown vehicle
W^g	Capacity of green vehicle
W^b	Capacity of blue vehicle
M	Large number

Variable

X_{ijs}^w	Takes 1 if $(i, j) \in V$ is served by tour S for brown vehicle, and 0 otherwise
X_{ijs}^g	Takes 1 if $(i, j) \in V$ is served by tour S for green vehicle, and 0 otherwise
X_{ijp}^b	Takes 1 if $(i, j) \in V$ is served by tour S for Blue vehicle, and 0 otherwise
y_{ijs}^w	The number of times that arc $(i, j) \in A$ is deadheaded in tour S with brown vehicle
y_{ijs}^g	The number of times that arc $(i, j) \in A$ is deadheaded in tour S with green vehicle
y_{ijs}^b	The number of times that arc $(i, j) \in A$ is deadheaded in tour S with blue vehicle
f_{ijs}^w	Total load of brown vehicle after serving the arc $(i, j) \in A$ in tour S
f_{ijs}^g	Total load of green vehicle after serving the arc $(i, j) \in A$ in tour S
f_{ijs}^b	Total load of blue vehicle after serving the arc $(i, j) \in A$ in tour S

$Z_{ḿ}$	Takes 1 if node ḿ∈ Ḿ is selected as a depot, and 0 otherwise
Zz_{n}^{b}	Takes 1 if node n'∈ F́is selected as a recycle site, and 0 otherwise
$Zz_{n'}^{g}$	Takes 1 if node n'∈ F́is selected as a compost site, and 0 otherwise
$Zz_{n''}^{w}$	Takes 1 if node n''∈ F'' is selected as a disposal site, and 0 otherwise
$DC_{ḿ}$	Total hiring cost associated with the tours assigned to node ḿ∈ D́ if ḿ is selected to be a depot and 0 otherwise

2.2.1 Objective function

The objective function minimizes the total waste collection routing cost which is consists of four parts. First part shows the service cost for each kind of vehicle (brown, green, and blue). Second, third and fourth parts presented the deadheading cost, opening cost of depots, and opening cost of stations (recycle site, compost site, and disposal site), respectively by Equation 1. The objective is addressed by economic aspects.

$$MinZ = \sum_{(i,j)\epsilon A}\sum_{S=1}^{S} C_{ij}X_{ijs}^{w} + \sum_{(i,j)\epsilon A}\sum_{S=1}^{S} C_{ij}X_{ijs}^{g} + \sum_{(i,j)\epsilon A}\sum_{S=1}^{S} C_{ij}X_{ijs}^{b} + \sum_{(i,j)\epsilon A_R}\sum_{S=1}^{S} D_{ij}\, y_{ijs}^{g} + \sum_{(i,j)\epsilon A_R}\sum_{S=1}^{S} D_{ij}\, y_{ijs}^{w} + \sum_{(i,j)\epsilon A_R}\sum_{S=1}^{S} D_{ij}\, y_{ijs}^{b} + \sum_{ḿ\epsilon D́} GZ_{ḿ} + \sum_{n\epsilon F} FF^{b}\, Zz_{n}^{b} + \sum_{n'\epsilon F́} FF^{g}\, Zz_{n'}^{g} + \sum_{n''\epsilon F''} FF^{w}\, Zz_{n''}^{w} \quad (1)$$

2.2.2. Constraints

The constraints of the model are described as follows:

$$\sum_{j:(i,j)\epsilon A} X_{ijs}^{w} + \sum_{j:(i,j)\epsilon A_R} y_{ijs}^{w} = \sum_{j:(i,j)\epsilon A} X_{jis}^{w} + \sum_{j:(i,j)\epsilon A_R} y_{jis}^{w} \qquad \forall i\epsilon\, V \cup m' \cup n \cup n' \cup n'',\ \forall S\epsilon\{1,2,\dots,s\} \quad (2)$$

$$\sum_{j:(i,j)\epsilon A} X_{ijs}^{g} + \sum_{j:(i,j)\epsilon A_R} y_{ijs}^{g} = \sum_{j:(i,j)\epsilon A} X_{jis}^{g} + \sum_{j:(i,j)\epsilon A_R} y_{jis}^{g} \qquad \forall i\epsilon\, V \cup m' \cup n \cup n' \cup n'',\ \forall S\epsilon\{1,2,\dots,s\} \quad (3)$$

$$\sum_{j:(i,j)\epsilon A} X_{ijs}^{b} + \sum_{j:(i,j)\epsilon A_R} y_{ijs}^{b} = \sum_{j:(i,j)\epsilon A} X_{jis}^{b} + \sum_{j:(i,j)\epsilon A_R} y_{jis}^{b} \qquad \forall i\epsilon\, V \cup m' \cup n \cup n' \cup n'',\ \forall S\epsilon\{1,2,\dots,s\} \quad (4)$$

The continuity of tours for each color of vehicle is indicated by constraints (2), (3), and (4).

$$\sum_{s=1}^{S} X_{ijs}^{w} = 1 \qquad \forall\ (i,j)\ \epsilon A_R \quad (5)$$

$$\sum_{s=1}^{S} X_{ijs}^{g} = 1 \qquad \forall\ (i,j)\ \epsilon A_R \qquad (6)$$

$$\sum_{s=1}^{S} X_{ijs}^{b} = 1 \qquad \forall\ (i,j)\ \epsilon A_R \qquad (7)$$

Constraints (5), (6), and (7) illustrate that each required arc or edge must be serviced exactly in one tour.

$$X_{m'ms}^{w} \leq Z_{m'} \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (8)$$

$$X_{m'ms}^{g} \leq Z_{m'} \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (9)$$

$$X_{m'ms}^{b} \leq Z_{m'} \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (10)$$

$$X_{n''n_w s}^{w} \leq Z_{n''} \qquad \forall\ n'' \epsilon\ F''\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (11)$$

$$X_{nn_b s}^{b} \leq Z_{n'} \qquad \forall\ n \epsilon\ F\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (12)$$

$$X_{n'n_g s}^{g} \leq Z_{n'} \qquad \forall\ n' \epsilon\ F'\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (13)$$

Constraints (8), (9), and (10) show that for each tour, the auxiliary arc will be chosen at most once to exit from depot, and also for each tour, the auxiliary arc will be chosen at most once to exit from each site (recycle set, compost site, and disposal site) by constraints (11), (12) and (13).

$$\sum_{j:(j,i)\epsilon A} f_{ijs}^{w} - \sum_{j:(i,j)\epsilon A} f_{jis}^{w} = \sum_{j:(j,i)\epsilon A_R} \widetilde{Q}_{ij} X_{ijs}^{w} \qquad \forall i \epsilon\ V, \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (14)$$

$$\sum_{j:(j,i)\epsilon A} f_{ijs}^{g} - \sum_{j:(i,j)\epsilon A} f_{jis}^{g} = \sum_{j:(j,i)\epsilon A_R} \widetilde{Q}_{ij} X_{ijs}^{g} \qquad \forall i \epsilon\ V, \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (15)$$

$$\sum_{j:(j,i)\epsilon A} f_{ijs}^{b} - \sum_{j:(i,j)\epsilon A} f_{jis}^{b} = \sum_{j:(j,i)\epsilon A_R} \widetilde{Q}_{ij} X_{ijs}^{b} \qquad \forall i \epsilon\ V\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (16)$$

As a result of constraints (14), (15), and (16), in each tour, the difference between inflow and outflow at this node must equal to the demand delivered to the entering arcs to node i.

$$f_{m'ms}^{w} \leq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X_{ijs}^{w} + M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (17)$$

$$f_{m'ms}^{g} \leq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X_{ijs}^{g} + M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \qquad \forall S \epsilon \{1,2,\dots,s\} \qquad (18)$$

$$f^{b}_{m'ms} \leq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X^{b}_{ijs} + M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (19)$$

$$f^{w}_{m'ms} \geq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X^{w}_{ijs} - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (20)$$

$$f^{g}_{m'ms} \geq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X^{g}_{ijs} - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (21)$$

$$f^{b}_{m'ms} \geq \sum_{(i,j)\epsilon A_R} \widetilde{Q}_{ij} X^{b}_{ijs} - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (22)$$

According to constraints (17) to (22), in each tour s, the total outgoing flow from depot (m') should not be less than the total demand of all required arcs to be serviced in that tour.

$$f^{w}_{in''s} \leq MZz^{w}_{n''} \qquad \forall\ n'' \epsilon\ F''\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (23)$$

$$f^{g}_{in's} \leq MZz^{g}_{n'} \qquad \forall\ n' \epsilon\ F'\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (24)$$

$$f^{b}_{ins} \leq MZz^{b}_{n} \qquad \forall\ n \epsilon\ F\ , \quad \forall S \epsilon \{1,2,\dots,s\} \qquad (25)$$

Constraints (24), (25), and (26) describe if node n, n', and n'' is not selected as a recycle site, compost site and disposal site, respectively, the outgoing flow from this node will be equal to zero.

$$f^{w}_{im's} = 0 \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (26)$$

$$f^{g}_{im's} = 0 \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (27)$$

$$f^{b}_{im's} = 0 \qquad \forall\ \acute{m} \epsilon\ \acute{D}\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (28)$$

$$f^{w}_{n''m''} = 0 \qquad \forall\ n'' \epsilon\ F''\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (29)$$

$$f^{g}_{n'm'} = 0 \qquad \forall\ n' \epsilon\ \acute{F'}\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (30)$$

$$f^{b}_{nm} = 0 \qquad \forall\ n \epsilon\ F\ , \forall S \epsilon \{1,2,\dots,s\} \qquad (31)$$

Constraints (26), (27) and (28) define in each tour s, the returning flow to depot will be equal to zero since no required arc is connected to this node. Thus, these constraints for different sites including recycle site, compost site and disposal site are display by equation (29), (30) and (31).

$$f^{w}_{ijs} \leq W^{w}(X^{w}_{ijs} + y^{w}_{ijs}) \qquad \forall\ (i,j)\ \epsilon A, \forall S \epsilon \{1,2,\dots,s\} \qquad (32)$$

$$f^{b}_{ijs} \leq W^{b}(X^{b}_{ijs} + y^{b}_{ijs}) \qquad \forall\ (i,j)\ \epsilon A, \forall S \epsilon \{1,2,\dots,s\} \qquad (33)$$

$$f^{g}_{ijs} \leq W^{g}(X^{g}_{ijs} + y^{g}_{ijs}) \qquad \forall\ (i,j) \in A, \forall S \in \{1,2,\dots,s\} \qquad (34)$$

Constraints (32), (33) and (34) ensure an upper bound on the flow variables and then a flow variable can take a positive value only if arc is traversed at least once in tour s.

$$G \geq \mu^{w}\left(\sum_{s=1}^{S} x_{m'ms}\right) - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \in \acute{D} \qquad (35)$$

$$G \geq \mu^{b}\left(\sum_{s=1}^{S} x_{m'ms}\right) - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \in \acute{D} \qquad (36)$$

$$G \geq \mu^{g}\left(\sum_{s=1}^{S} x_{m'ms}\right) - M(1 - Z_{m'}) \qquad \forall\ \acute{m} \in \acute{D} \qquad (37)$$

Constraints (35), (36) and (37) calculates total hiring cost of all tours assigned to depot with deferent types of vehicles.

$$\sum_{m' \in D'} Z_{m'} = 1 \qquad \forall\ \acute{m} \in \acute{D} \qquad (38)$$

$$\sum_{n \in F} Z_{n} = 1 \qquad \forall\ n \in F \qquad (39)$$

$$\sum_{n' \in F} Z_{n'} = 1 \qquad \forall\ n' \in \acute{F} \qquad (40)$$

$$\sum_{n'' \in F''} Z_{n''} = 1 \qquad \forall\ n'' \in F'' \qquad (41)$$

Constraints (38) to (41) display that only one depot, one disposal site, one compost site and one recycle site can be selected in the optimal solution.

$$X^{w}_{ijs}, X^{g}_{ijs}, X^{b}_{ijs} \in \{0,1\} \qquad (i,j) \in A, \forall S \in \{1,2,\dots,s\} \qquad (42)$$

$$Z_{m'}, Z_{n}, Z_{n'}, Z_{n''} \in \{0,1\} \qquad \forall\ \acute{m} \in \acute{D}, \forall\ n' \in F, \forall\ \acute{n}'' \in F'' \qquad (43)$$

$$f^{w}_{ijs}, f^{g}_{ijs}, f^{b}_{ijs} \geq 0 \qquad \forall\ (i,j) \in A_{R}, \ \forall S \in \{1,2,\dots,s\} \qquad (44)$$

$$y^{w}_{ijs}, y^{g}_{ijs}, y^{b}_{ijs} \in \{0,1\}, \text{Integer} \qquad \forall\ (i,j) \in A_{R}, \ \forall S \in \{1,2,\dots,s\} \qquad (45)$$

Constraints on decision variables have been expressed by Equations (42) and (45).

3. Solution methodology

The model is used to solve on both a small-scale and a medium-scale. When solving the small-scale problem, we apply an exact method, and GAMS software is used to achieve the optimal answers. Having said that the demand of each edge is proposed fuzzy. Thus, the defuzzification method is used to solve the problem.

3.1 Defuzzification

In this section we scrutinized our defuzzification method utilized for this problem. [43] methodology is a novel defuzzification method that is used in this article. In this section, we will explain the generalities of this method. This method has five steps that are discussed in the below paragraphs. A brief explanation of the defuzzification method is provided in Fig2.

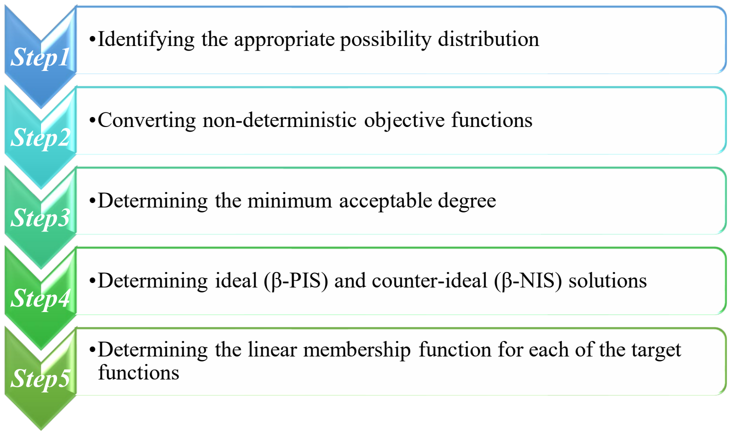

Fig2. Defuzzification method

Step 1: Identify the appropriate possibility distribution. This means that we must specify the probability distribution (triangular or trapezoidal) for the uncertain parameters and its possible multi-objective linear programming modeling.

$$\min Z_1 = f_1(x) \quad (50)$$

$$\max Z_2 = f_2(x) \quad (51)$$

s.t

$$x \in F_x = \{A_i X \leq b_i; \forall i\} \quad (52)$$

Step 2: Convert non-deterministic objective functions using the expected range of relevant parameters [44].

Step 3: Determine the minimum acceptable degree of possible constraints (β), by DM and convert the fuzzy constraints to definite constraints, and rewrite the equivalent definitive model.

Step 4: Determine ideal (β-PIS) and counter-ideal (β-NIS) solutions for each of the target functions at the specified level of the minimum acceptable degree of possible constraints (β).

$$Z_{1\ \beta}^{NIS} = Z_1\left(x_{2\ \beta}^{PIS}\right) \tag{53}$$

$$Z_{2\ \beta}^{NIS} = Z_2\left(x_{1\ \beta}^{PIS}\right) \tag{54}$$

Step 5: Determine the linear membership function for each of the target functions.

$$\mu_{Z_1}(x) = \begin{cases} 1 & \text{if } Z_1(x) \le Z_{1\ \beta}^{PIS} \\ \dfrac{Z_{1\ \beta}^{NIS} - Z_1(x)}{Z_{1\ \beta}^{NIS} - Z_1^{PIS}} & \text{if } Z_{1\ \beta}^{PIS} \le Z_1(x) \le Z_{1\ \beta}^{NIS} \\ 0 & \text{If } Z_{1\ \beta}^{NIS} \le Z_1(x) \end{cases} \tag{55}$$

$$\mu_{Z_2}(x) = \begin{cases} 1 & \text{if } Z_{2\ \beta}^{PIS} \le Z_2(x) \\ \dfrac{Z_2(x) - Z_{2\ \beta}^{PIS}}{Z_{2\ \beta}^{PIS} - Z_{2\ \beta}^{NIS}} & \text{if } Z_{2\ \beta}^{NIS} \le Z_2(x) \le Z_{2\ \beta}^{PIS} \\ 0 & \text{if } Z_2(x) \le Z_{2\ \beta}^{NIS} \end{cases} \tag{56}$$

4. Numerical example

4.1 Computational experiment

This study develops a novel waste collection LARP which is assumed there are three kinds of vehicles that collect special waste, including recycling waste, general waste, and plant waste, allocating the location of depot and different kinds of sites (disposal site, compost site and recycle site). This model can obtain a situation with the lowest total cost (including service, deadheading, hiring, and opening cost of depots and station sites). In order to evaluate the performance of the developed model, two problem scales (such as small and medium) will be presented. An exact method is used for the small-scale problem and this model is solved by GAMS software with CPLEX solver and running on a laptop with a Core i5 CPU and 8 GB of RAM of the operating system Windows 10. The utilization of this software and solver is primarily due to the fact that GAMS serves as an interface for modeling, enabling users to express their optimization models using a high-level language. The integration of CPLEX within GAMS facilitates a smooth workflow that allows for effortless transitioning between different solvers and the ability to evaluate the performance of various solution approaches without the requirement of completely reworking the model.

It is worth mentioning that a real dataset is used in the U.K as a case study and the proposed model's accuracy will be checked. The initial date for this problem to solve in small-scale are shown in Table2 and 3, respectively, and then this information for the medium-scale problem is displayed in Table 4 and 5.

Table 2. Initial information for small-scale problem

Sets	Range Value
Set of all nodes	$\{N_1, N_2, N_3, N_4, N_5, N_6, N_7, N_8, N_9, N_{10}, N_{11}\}$
Subset of required nodes	$\{N_1, N_2, N_3\}$
Subset of recycle sits	$\{N_4, N_5\}$
Subset of compost sits	$\{N_6, N_7\}$
Subset of disposal sits	$\{N_8, N_9\}$
Subset of depots	$\{N_{10}, N_{11}\}$

Table 3. Some of the assumed range value for model's parameters for small-scale problem

Parameters	Range Value	Parameters	Range Value	Parameters	Range Value
μ^w	105	G	152	$D_{2,6}$	9
μ^g	100	$\tilde{Q}_{1,5}$	1	$D_{3,7}$	3
μ^b	110	$\tilde{Q}_{2,7}$	3	$D_{4,9}$	9
M	100000	$C_{1,2}$	22	$D_{5,3}$	10
FF^w	270	$C_{1,3}$	22	$D_{6,1}$	7
FF^g	250	$C_{2,1}$	20	$D_{7,8}$	2
FF^b	300	$C_{2,3}$	21	$D_{8,3}$	4
W^b	18	$C_{3,1}$	23	$D_{9,8}$	4
W^w	18	$C_{3,2}$	20	$D_{10,4}$	5
W^g	18	$D_{1,4}$	14	$D_{11,2}$	11

Table 4. Initial information for medium-scale problem

Sets	Range Value
Set of all nodes	$\{N_1, N_2, N_3, N_4, N_5, N_6, N_7, N_8, N_9, N_{10}, N_{11}, N_{12}, N_{13}$
Subset of required nodes	$\{N_1, N_2, N_3, N_4, N_5\}$
Subset of recycle sits	$\{N_6, N_7\}$
Subset of compost sits	$\{N_8, N_9\}$
Subset of disposal sits	$\{N_{10}, N_{11}\}$
Subset of depots	$\{N_{12}, N_{13}\}$

Table 5. Some of the assumed range value for model's parameters for medium-scale problem

Parameters	Range Value	Parameters	Range Value	Parameters	Range Value
μ^w	130	$\tilde{Q}_{2,3}$	1	$D_{3,7}$	36
μ^g	110	$\tilde{Q}_{3,4}$	1	$D_{4,9}$	7
μ^b	120	$\tilde{Q}_{4,5}$	1	$D_{5,3}$	3
M	100000	$C_{1,2}$	25	$D_{6,1}$	9
FF^w	500	$C_{1,4}$	23	$D_{7,8}$	4

FF^g	450	$C_{2,1}$	20	$D_{8,3}$	6
FF^b	470	$C_{3,5}$	24	$D_{9,8}$	13
G	170	$C_{4,1}$	25	$D_{10,4}$	37
W^w(tone)	20	$C_{5,2}$	25	$D_{11,2}$	7
W^g(tone)	20	$C_{5,4}$	24	$D_{12,10}$	6
W^b(tone)	20	$D_{1,4}$	16	$D_{13,7}$	6
$\tilde{Q}_{1,2}$	3	$D_{2,6}$	11		

4.2 Results

This section analyzes the results of the model, which are solved in small and medium sizes. First, solving the model in small size is presented, and then the results are compared.

4.2.1 Small-scale problem

In this section, the results of small-scale problem solving by GAMS are shown in Table 6.

Table 6. Small-scale's results by Gams

Number of deadheading	**value**	**Flow Traversing in Arc by green vehicle**	**value**
$y^w_{3,5,1}$	1.000	$f^g_{1,2,1}$	3.000
$y^g_{3,7,1}$	1.000	$f^g_{2,3,1}$	4.000
$y^b_{9,11,1}$	1.000	$f^g_{3,7,1}$	4.000
Flow Traversing in Arc by blue vehicle	**value**	**Flow Traversing in Arc by brown vehicle**	**value**
$f^w_{1,2,1}$	3.000	$f^b_{1,2,1}$	3.000
$f^w_{2,3,1}$	4.000	$f^b_{2,3,1}$	4.000
$f^w_{3,5,1}$	4.000	$f^b_{3,9,1}$	4.000
Location of depot	**value**	**Location of recycle site**	**value**
$Z_{\acute{m}}$	11	Zz^b_n	9
Location of compost site	**value**	**Location of disposal site**	**value**
$Zz^g_{n'}$	7	$Zz^w_{n''}$	5
	value	**Computational times (min:s)**	**value**
z^*	1211.000	T	0.091

For the small-size problem, the value of the objective function is 1211. If we look at the value of $Z_{\acute{m}}$, Zz^b_n , $Zz^b_{n'}$ and $Zz^w_{n''}$, it is clear that station 11 is allocating as depot and between station 4-5, 6-7 and 8-9 station 5, 7 and 9 are chosen as disposal site, compost site and recycle site, respectively. Hence, the station which is assigned as depot and different type of sites are given in Fig3 is for the small-scale problem. It is worth mentioning that every edge is served just for one time.

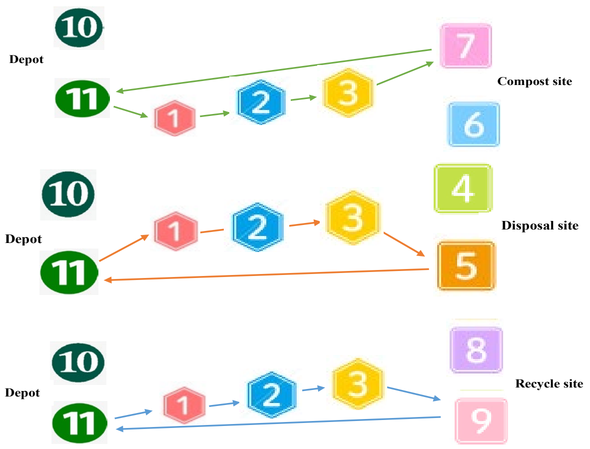

Fig3. The graphical of location-allocation and routing solution for the small-size problem by GAMS software

4.2.2 Medium-scale problem

The results of medium-scale problem solving by GAMS are shown in Table 7.

Table 7. Medium-scale's results by Gams

Number of deadheading	**value**	**Flow Traversing in Arc by green vehicle**	**value**
$y^{w}_{5,7,1}$	1.000	$f^{g}_{1,2,1}$	3.000
$y^{g}_{5,9,1}$	1.000	$f^{g}_{2,3,1}$	4.000
$y^{b}_{11,12,1}$	1.000	$f^{g}_{3,4,1}$	5.000
Flow Traversing in Arc by b blue vehicle	**value**	**Flow Traversing in Arc by brown vehicle**	**value**
$f^{w}_{1,2,1}$	3.000	$f^{b}_{1,2,1}$	3.000
$f^{w}_{2,3,1}$	4.000	$f^{b}_{2,3,1}$	4.000
$f^{w}_{3,4,1}$	5.000	$f^{b}_{3,4,1}$	5.000
$f^{w}_{4,5,1}$	6.000	$f^{b}_{4,5,1}$	6.000
$f^{w}_{5,7,1}$	6.000	$f^{b}_{5,7,1}$	6.000
Location of depot	**value**	**Location of recycle site**	**value**
$Z_{\acute{m}}$	12	Zz^{b}_{n}	11
Location of compost site	**value**	**Location of disposal site**	**value**
$Zz^{g}_{n'}$	7	$Zz^{w}_{n''}$	9

Because the number of nodes and edges in the medium-scale problem increased, the total costs dramatically rise to 2011. The reason is that when the number of edges increases, the total demand for collecting the waste rises and positively impacts the system's total cost. If we look at the result of a medium-scale problem, the opening cost of the depot and different kinds of sites rise, which can also influence the total cost. By this result, station 12 is allocated as depot, and between stations 6-7, 8-9 and 10-11, stations 7, 9 and 11 are chosen as a disposal site, compost site and recycle site, in turn.

5. Case study

The UK government vowed to leave the environment in better shape for the following generation in the 25-Year Environment Plan [45] which is illustrated in Fig4 The Resources and Waste Strategy outlines how they will protect physical resources in England by reducing waste, fostering resource efficiency, and advancing a circular economy. It outlines its plan for decreasing environmental harm through trash reduction, smart waste management, and waste crime enforcement. It provides a clear longer-term policy direction in line with the 25-year environment plan and combines measures they will take now with specific pledges for the next years. It serves as a guide for doubling resource productivity, eliminating avoidable plastic waste throughout the course of the 25-Year Environment Plan, and eliminating avoidable waste by 2050. The Waste (England and Wales) Regulations 20114, which mandate that the waste management plan be reviewed every six years, will be satisfied by this waste management plan for England, or "the Plan." The Plan and the documents that go with it will guarantee that waste management plans are in place for the entire UK and Gibraltar, along with the waste local plans created by local governments, combined with the equivalent plans created by the devolved administrations in Scotland, Wales, Northern Ireland, and Gibraltar. In contrast to the resources and waste strategy, which outlines a vision and a number of policies to move toward a more circular economy, the Waste Management Plan for England focuses on waste arisings and their management. This includes policies to support reuse, repair, and remanufacturing activities. It is a broad document that is not site-specific. It analyses the state of England's waste management at the moment and assesses how the Plan will aid in carrying out the goals and clauses of the waste (England and Wales) Regulations of 2011. A Waste Prevention Program for England will augment it. This will outline our strategies for avoiding the waste of products and materials, including increased reusing, repair, and manufacturing, backed by efforts to guarantee improved design to make this process easier. The following prerequisites apply to both this strategy and the suggested methodology:

• A review of how the Plan would help the implementation of the Waste (England and Wales) Regulations 2011 objectives and provisions;

• An examination of the present waste management scenario within the specified geographical area;

•An analysis of the steps to be taken to improve environmentally sound preparing for reuse, recycling, recovery, and disposal of waste;

• the kind, amount, and source of trash produced on the territory, the waste that will likely be shipped into or out of the national territory, and an assessment of how waste streams will evolve in the future;

• Major disposal and recovery facilities now in operation, including any particular arrangements for waste oils, hazardous waste, trash containing sizable amounts of essential raw materials, or waste streams covered by specialized laws;

• An evaluation of the necessity of expanding waste installation infrastructure and closing existing waste installations in line with the proximity concept. The investments and other financial resources, including those for local governments, that are necessary to achieve such demands are evaluated;

• Information on the methods used to achieve the goal of diverting waste suited for recycling or other recovery (particularly municipal waste) away from landfills;

• An evaluation of existing waste collection schemes, including the scope and territorial coverage of separate collection and steps are taken to improve its operation, any exceptions to the requirement to collect waste separately, and the necessity for new collection schemes;

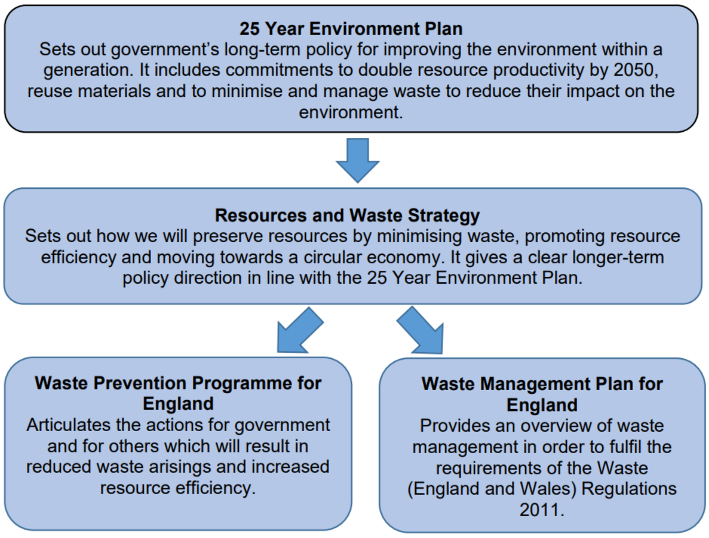

Fig4. Relationship between the Waste Management Plan for England and other policy documents (Source: GOV.UK)

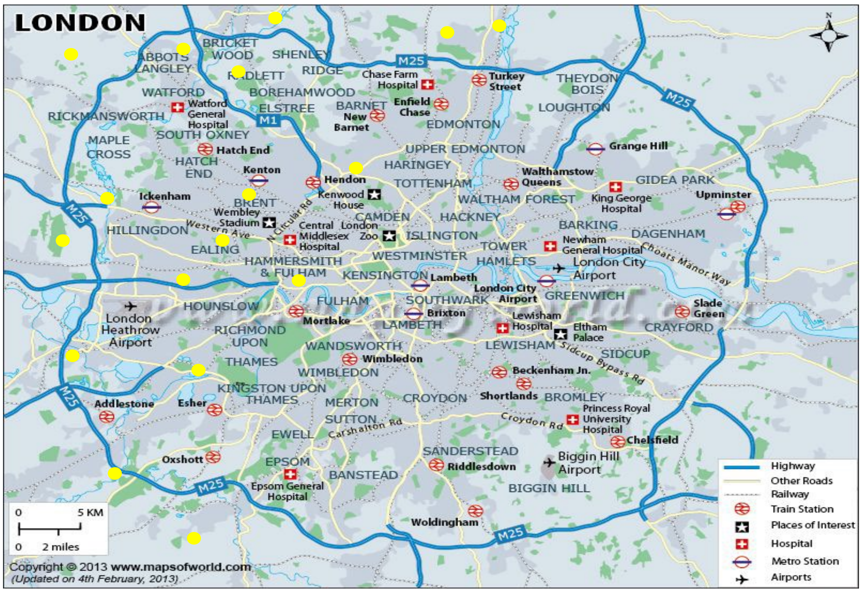

Fig5.Stations in London

We apply our proposed methodology could be applied in one of London's boroughs, designing a waste collection routing system and determining the best locations for the depot and the stations in the procedure. This district has 17 waste generation points, five demand points, and three possible points where the depot and each station could be located. The case is shown schematically in Fig5. Following an investigation and a survey, the case's data were outlined as follows: Opening costs for depot, recycle, compost and disposal site are 168.5, 503, 348 and 421.5 thousand dollars, respectively. The carrying capacity of each vehicle color is 20 tones. Hiring costs for blue, green, and brown trucks are 134.25, 105, 127.5 dollars, respectively. Table 8 shows the results of the model's solution.

Table 8. Case Study's results

Number of deadheading	value	Flow Traversing in Arc by green vehicle	value
$y^{w}_{5,8,1}$	1.000	$f^{g}_{1,2,1}$	3.000
$y^{g}_{5,10,1}$	1.000	$f^{g}_{2,3,1}$	4.000
$y^{b}_{12,15,1}$	1.000	$f^{g}_{3,4,1}$	5.000
Flow Traversing in Arc by blue vehicle	**value**	**Flow Traversing in Arc by brown vehicle**	**value**
$f^{w}_{1,2,1}$	3.000	$f^{b}_{1,2,1}$	3.000
$f^{w}_{2,3,1}$	4.000	$f^{b}_{2,3,1}$	4.000
$f^{w}_{3,4,1}$	5.000	$f^{b}_{3,4,1}$	5.000
$f^{w}_{4,5,1}$	6.000	$f^{b}_{4,5,1}$	6.000

$f^{w}_{5,8,1}$	6.000	$f^{b}_{5,12,1}$	6.000
Location of depot	**value**	**Location of recycle site**	**value**
$Z_{\acute{m}}$	15	Zz^{b}_{n}	12
Location of compost site	**value**	**Location of disposal site**	**value**
$Zz^{g}_{n'}$	10	$Zz^{w}_{n''}$	8

The results show that point 15, 8, 10, 12 are selected as depot, disposal site, compost site and recycle site, respectively. In light of the results, we have some recommendations which are as follows:

- Sanitation companies must work hard, but the government should stop providing relevant policy support if environmental protection and long-term development are to be achieved.
- It's important to keep in mind the social responsibility of environmental protection as well as a healthy work-life balance when planning a waste collection route.
- To support SWC, all sectors of society should speed up their transition to smart cities.

6. Sensitivity analysis

Analyzing model as sensitivity analysis leads to a better understanding of model's behavior. Then, increasing or decreasing some of the parameters changes the final answers. Some of the parameters have more significant influence on the final answers. Hence, in this section, some vital parameters are determined, and we will show their impact on objective function to evaluate the system's behavior in different states. The results of sensitive analyses are given in Figures 6 to 11.

The objective function of the problem, which is to minimize the total cost, consists four parts: a service cost of each kind of vehicle, the deadheading cost, the opening cost of the depot, and the opening cost of stations (recycle site, compost site, and disposal site). It is clear that with increasing every part of these costs, the objective function must increase. Sensitivity analysis is performed for the opening cost of disposal sites in Fig6. Because of increasing the opening cost of disposal sites, the total costs of the system rise. Also, by increasing the opening cost of compost sites, the objective function increases (Fig7). The opening cost of depot and the opening cist of recycle sites are the same as the upward trend by Fig8 and 9.

Also, according to Fig10, comparing between different types of costs are displayed. Clearly, all system costs will increase by increasing the cost variables (the service cost, the deadheading cost, the opening cost of stations). Then the objective function will have ascending behavior.

Fig11 illustrates the sensitive analysis of hiring cost of different types of cars. Hire cost is a recruiting metric that measures the costs associated with hiring new employees. These include expenses such as sourcing and recruitment advertising costs, onboarding, referral bonus program costs, etc. It is used as a constraint and positively influences the objective function. If we look at the hiring cost of the blue car, when it increases then the objective function rises significantly to 1239 (Fig11-a). with regard to green car, at first it remained state at 1211, and then the figure reached its peak at 1229 (Fig11-b). Likewise, the brown car began at 1211 and remained state after which rises to approximately 1234 (Fig11-c). Thus, totally when the hiring cost of different cars rises, the total cost increases.

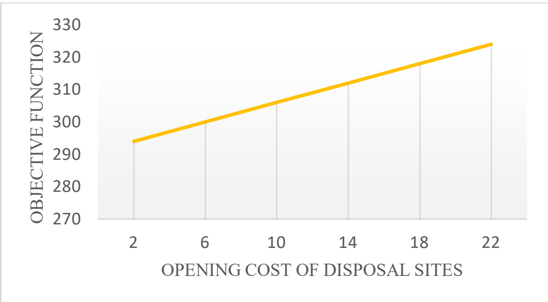

Fig6. Changing the objective function due to increasing the opening cost of disposal sites

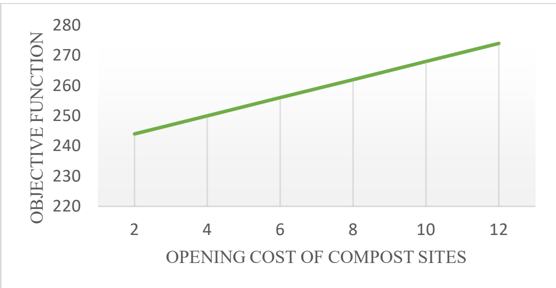

Fig7. Changing the objective function due to increasing the opening cost of compost sites

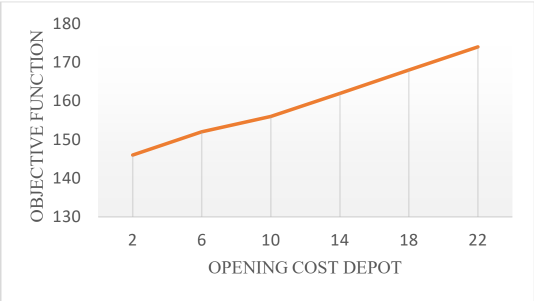

Fig8. Changing the objective function due to increasing the opening cost of depot

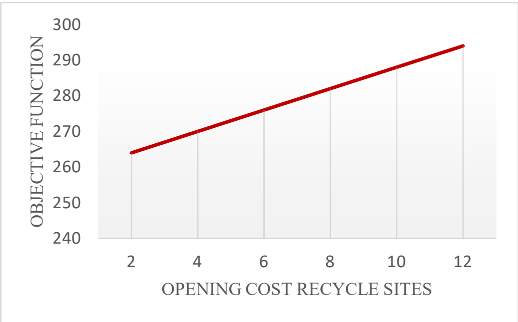

Fig9. Changing the objective function due to increasing the opening cost of recycle sites

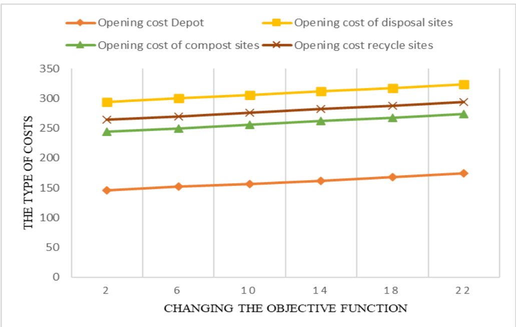

Fig10. Changing the objective function due to increasing four types of costs

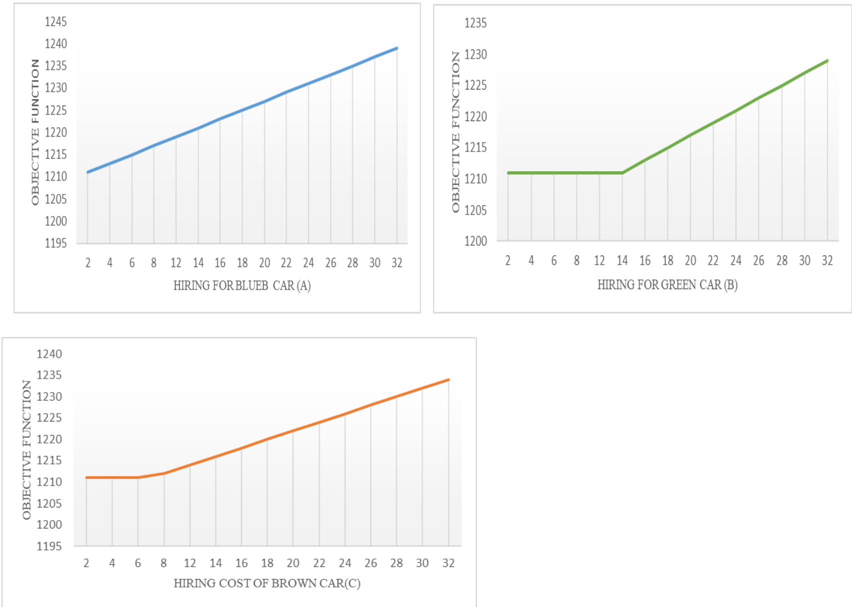

Fig11. Changing the objective function due to increasing hiring costs of different kind of cars

7. Discussion and managerial insight

The proposed model is an optimal solution for waste management with location-allocation and routing problems in the real world. Some of the researchers, such as [40], [44], and [22] and focused on the location-arc routing model. In this study, a new LARP model presented to minimize the system's total cost, the deadheading costs, the opening costs of the depot, and the opening costs of stations by considering different types of waste and bins as waste segregation. Instead of every type of waste, this model has unique bine. And then, the demand of every edge is assumed as a fuzzy parameter that it is certain. Another positive point of this research is that with sensitive analysis, it is clear that changing some parameters plays a crucial role in individual satisfaction and increases the system's total cost. Thus, a real case study is investigated in the UK to test the proposed model's performance. Although researchers and municipalities have made great efforts to develop effective waste management, several key issues need to be efficiently concentrated in the waste management model. Some of the managerial insights are summarized as follows:

- Four different expense forms are shown in Fig10, and their impacts on the objective function are depicted. Managers are advised to dedicate more money to open the disposal site as these expenses rise because the goal function is more sensitive to this parameter.

- According to Fig11, the objective function is more sensitive to the blue vehicles which related to recycling sites. Thus, it is better that managers pay attention to the number of these vehicles. if the number of recycled waste increases, a company ought to pay more and needs more capital.
- This waste management model considering the waste segregation plays a crucial role for the managers. This is the case because when there are numerous kinds of waste, a more efficient strategy is proposed for waste management.
- In urban waste, non-biodegradable materials, such as plastics and glass, impede the treatment processes. As a result, before landfilling, recycling, or using waste-to-energy technology, the labor and operating expenses associated with segregating and sorting these materials are higher. These products have secondary market value for alternative recycling methods such as pyrolysis, liquefaction, or gasification. Even the best waste management systems are made ineffective if municipal solid trash is not separated into several streams, such as organic, plastic, metals, glass, inert materials, textiles, and paper. First and foremost, homes, institutions, and businesses should be responsible for separating municipal solid waste at the source because of the variety of waste streams. This might significantly reduce the prices of solid waste processing in the future. Municipal solid waste collection could be made more efficient and hygienic if waste is separated at the source of generation. The decentralized management system for municipal solid trash is also supported by this approach. Every effort should be made to prevent organics and recyclables from ending up in household garbage. This strategy could be influenced by innovative waste segregation methods and enforcement of disposal restrictions at the source. It's important for citizens to understand the notion of waste classification, which includes recyclable and non-recyclable, flammable and non-flammable, inert and non-inert as well as recyclable and non-recyclable glass, plastics, paper, and food waste. This new innovation, however, is not always understood by the massive municipal solid trash collection vehicles and their built-in collection procedures. In addition to improving their downstream processing technologies, product standards, and customer relationship management, the municipal solid waste recycling businesses should expand alternative markets for end-products and by-products.

- The safety of the staff tasked with waste collection is an essential consideration. As they are constantly exposed to various waste components, the degradation of their health is pretty evident. Due to the absence of effective law enforcement, they confront more difficulties in developing nations. In wealthier nations, a fraction of bulk-produced hazardous trash is managed in an expensive manner, whereas in low-income nations, a big proportion of rubbish is dumped in open spaces, resulting in an unhealthy environment.

8. Conclusion and future research

In this study, a new location-arc routing model for waste collection is analyzed, considering different bins type and situations for unloading the waste. In other words, waste segregation is a crucial point in real life presented in this model as a novelty. The purpose of the model is to minimize total costs, including the service cost, the deadheading costs, the opening costs of the depot, and the opening costs of stations. Another assumption of this model is that the edge demand is considered a fuzzy parameter. Numerical examples in small and medium scales have been presented to demonstrate the model's performance. The problem in these scales has been solved with the exact method by GAMS software. And then, the efficiency of the model was analyzed through a real case study. Also, the presented model and managerial insight can be applied to similar cases. Finally, this model has been performed a sensitivity analysis by changes in some significant parameters to evaluate the performance of the proposed model under different conditions. There are some limitations in this scope; for instance, if this research wants to be continued in other areas, the color of the bins should be changed. In other words, waste segregation is different in every country. Also, the strike plays a crucial role in the world; then it can be as a limitation. Thus, considering the strike can make a problem for this model. In this manner, finding the relative data is one of the important limitations in this scope. In future research, this problem can be considered with multi-depots. In other words, some depots can be considered to start collecting the different types of waste as the same as the different types of stations, which is assumed in this model. Similarly, some different costs can be used in this model, such as fuel costs. Then, assuming industry 4.0 and its modern technics can be useful for future research. Finally, investigating the problem in situations where social sustainability and some environmental problems, such as analyzing emission pollution, are assigned to the model can be considered as future developments for this model.

Declarations

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Consent to Participate: Not applicable.

Consent to Publish: Not applicable.

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