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Research Article

Application of Robust Approach to Capacitated Location of Collection Sites and Capacitated Vehicle-routing Problem Model in an Urban Waste Management System

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Abstract
In the present study, a model including two robust objective functions to reduce costs related to the location of waste transfer facilities in Bushehr. Using the first objective function not only reduces the selection of collection sites but also ensures the overall cost associated with the collection phase. In addition, the first objective function of this research seeks to optimally allocate citizens to collection sites. Also, this model includes the types of bins required for allocation to collection sites so that the total demand of the area is met. Another result of this objective function is that the landfills allocated to these sites may be of different types, with different distances from citizens' homes and even different capacities. Finally, each citizen receives service through a waste collection site with the shortest distance from home to the collection point. The second robust objective function to minimize total collection distance has been discussed. Waste collection widely depends on the route optimization problem that involves a large amount of expenditure in terms of capital, labor, and variable operational costs. Thus, the more waste collection route is optimized, the more reduction in different costs and environmental effect will be. This study proposes a modified robust optimization in a capacitated vehicle routing problem (CVRP) model to determine the best waste collection and route optimization solutions. Other results of this research show that the value of the objective functions determined in the robust method is less than the definite method.
Keywords: Waste management, collection sites, vehicle-routing problem, robust planning, uncertainty.

Introduction

Urban development, population growth, lifestyle changes, changing consumption patterns have caused many problems for urban communities. Nowadays, increasing waste production in urban communities has led to waste management as one of the most basic parts of control, because it can have social, political, and even economic effects. From a social point of view, we can point to the increase in population as well as concerns about environmental protection. The political significance of this issue can not only be from the citizens, because they can choose alternative ways for this issue by being aware of municipal waste management; This

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can also be a concern for many organizations. The economic importance of this issue can also be due to the many resources behind municipal waste management and also the large number of actors involved in the process. Therefore, in order to manage municipal waste, a large part of the available budget should be spent on serving the citizens, who contribute to this issue by paying taxes. On the other hand, some private organizations tend to be directly involved in the municipal waste management process and receive many benefits such as waste recycling and sales, as well as energy production from waste.

One of the major problems of urban communities is the growing population and the consequent production of waste. Increasing the volume of waste on the one hand and their diversity on the other hand, adds to the complexity of how to separate and dispose of them. Waste disposal issues have always been of particular importance, because if waste disposal is not done properly, there will be many environmental hazards. Managers and officials in industrialized countries have gained enough information about the consequences of improper waste disposal and in this regard, are trying to implement environmentally and economically acceptable methods. Waste disposal methods include recycling, incineration, sanitary landfilling and composting using traditional, semi-traditional systems. In the following, we will explain the efficiency of each of these facilities.

Compost (preparation of fertilizer from waste) is the decomposition of organic matter in waste under special and controlled conditions and at the appropriate temperature and humidity, by fungi, bacteria, molds and aerobic and anaerobic microorganisms. Compost itself is a type of recycling of organic matter from waste and the fertilizer obtained in this way is used to improve the fertility of agricultural lands and is a good alternative to chemical fertilizers. Recycling means preparing the materials used for reuse. Recyclable materials include scrap iron, hardware, glass, paper, cardboard, plastic and some chemicals. Recycling prevents the waste of useful national resources and reduces the consumption of raw materials and energy.

There are many benefits to using waste incineration technology to dispose of waste, but if waste incinerators are not designed properly, many pollutants can enter the environment due to incomplete combustion. Incineration of waste destroys toxic and pathogenic compounds in them and reduces the volume and mass of waste for final disposal. Sanitary landfilling is the transfer of solid waste to a special landfill, so that it has the least risk to the environment. Sanitary landfilling is the most common method of waste disposal.

Supply chain design for municipal solid waste management can be divided into two main categories: direct supply chain and reverse supply chain. In the direct supply chain, the work process to This is so that the waste enters the landfill directly without going to recycling centers, compost, incinerators or other waste disposal facilities. But in the case of the reverse supply chain, the waste goes to the recycling center, compost and energy production centers after separation, which means that the waste is turned into a product again and is reused. A closed-loop supply chain is a combination of direct and reverse supply chains in which waste recycling products are returned to the primary consumers of these products.

In general, the municipal waste management process consists of four activities: waste generation, collection, transfer, and landfill. Also, waste collection and transfer activities have the largest share in the total cost of waste management in most countries. More than sixty percent of the costs related to the waste management system are related to the collection and transfer activities and manpower costs, high fuel costs, and maintenance and equipment repairs. Efficient and efficient implementation of each of these steps requires making the right decisions in the field of strategy and is operational. For example, these decisions include: choosing the right recycling technology, choosing the right place for landfilling, forecasting the capacity of landfills, allocating the equipment needed for waste collection, choosing the day of collection for each type of bin according to the type of waste Produced and decide on the scheduling and routing of waste trucks.

Problem Identification

Today, waste management process optimization has become one of the most interesting topics in the field of urban management. One of the sciences that plays an important role in optimizing decisions in the field is operation research. One of the main applications of operations research in the field of urban management is the design of a waste collection networks, which includes determining waste collection sites and allocating demand in different parts of the city using mathematical models, optimization algorithms, and multi-criteria decision-making techniques. This research pursues two main goals. The first goal is to determine the minimum sites required for the allocation of waste bins in the city and the optimal allocation of citizens to these sites. To achieve this goal, by studying the theoretical literature, the amount of waste production per citizen was determined. Also, according to the types of waste (such as: glass, plastic, iron, etc.) that are produced in the city, several types of waste bins have been defined. In general, in the issue of locating waste collection sites, the most basic question is where the facilities will be located, how many, and what kind of facilities are needed.

The second purpose of this research is the problem of routing a capacity vehicle. By solving this problem, the minimum number of vehicles required for waste collection can be determined. Also, finding the minimum time required for waste transfer is another result of this objective function. It should also be noted that in the issue of waste management planning at the city level, it is very difficult to accurately identify the distribution of parameters, and most of the required data are uncertain. Of course, the uncertainty of this data cannot be considered due to the random aspect of events. For such situations where we face epistemological uncertainty and lack of knowledge, using a robust optimization approach is a suitable computational approach for managing uncertainty. Our approach is tested on real data related to the city of Bushehr, in the south of Iran, which represents a good sample of the medium sized urban areas, with its 300000 inhabitants.

Literature Review

In this section, studies conducted in the field of waste management process optimization, which includes waste collection, transfer, and vehicle routing issues, will be discussed. According to the World Bank, more than 2.01 billion tons of waste is generated annually worldwide. Hence, the global outlook is to increase waste production by 3.40 billion tons by 2050, given the growing population (Showket Mir et al., 2021).

Today, waste management has become one of the most complex issues facing countries. In other words, in developed countries, if the rate of waste generated is between 0.8 and 1.4 kg/person/day is appropriate (Kumar Das et al., 2021). Compared to developed countries, the average generation rate of municipal solid waste in developing countries is 0.3–0.5 kg/person/day, but the management is inadequate and improper. So, SWM in various cities developing countries is becoming a complicated challenge (Hantoko et al., 2021). Instinctively, urbanization itself is not a root of the problems associated with sustainability; however, unplanned and haphazard urbanization growth leads to many economic, social, and environmental challenges. Municipal solid waste (MSW) management is an example of one such challenge, which has a direct association with rapid urbanization (Goel et al., 2017; Mostafayi Darmian et al., 2020).

The increase in waste production is due to the increase in population and the exponential growth of urbanization. Most countries face many problems in the field of waste management because their subsets do not have sufficient funding for waste management activities. Therefore, they need to develop a regular policy plan for waste management to minimize costs as well as overcome the challenges that arise (Lin et al., 2020). Therefore, in most countries, waste disposal methods are used to overcome its accumulation in the community. Currently, CO_2 in the atmosphere is reaching approximately 390 ppm, which leads to global warming. The rapid growth of urbanization and population along with the environmental concern have created a critical situation for waste management (Pérez-López et al, 2019).

Recycling waste can be a less costly method than recycling options, which is why it attracts the attention of most city managers. Also, with the advancement of technology, landfilling does not seem to be a sustainable solution to the problem of waste accumulation. Landfills come with a lot of concerns, such as polluting effects, landfill space shortage which is scarce (Schoeman et al., 2021).

Different cities face different problems with waste managers. In most cities, the executive does not have a coherent waste collection policy. Most researchers have found that these problems occur in communities facing increasing populations, and local governments often do not have enough data. On the other hand, waste collection creates high costs for these communities, so that waste collection and transportation are the most costly (Monzambe et al., 2021).

Due to the lack of required infrastructure and little attention from city officials, it has caused many problems in the field of municipal solid waste ((Mamashli and Javadian, 2020). Waste management is extremely important because of the potential threats it poses to the environment and local residents. The design of the municipal waste management system consists of several parts, for example, determining the locations and size of recycling facilities, disposal and organizing the transportation of hazardous waste between different facilities (Yu et al., 2020). Selecting suitable locations for municipal waste management facilities such as collection and transfer stations is a matter of great importance. Many criteria and features need to be analyzed to finalize the location of these facilities. Using multi-criteria decision approaches to rank several potential locations and select the best option is very effective (Yadav et al., 2020).

Studies can also be divided into several main categories based on the type of waste disposal facility. The first category is articles that consider both recycling centers and sanitary landfills for waste disposal. In this regard, Yu and Solvang (2017) presented a multi-objective model with the aim of minimizing the total cost of waste management and minimizing greenhouse gas emissions and environmental impacts, and in their model also considered the transfer stations and the final landfill. Also, Habibi (2018) proposed a model for locating waste disposal facilities, including a recycling plant and a landfill, with the aim of minimizing costs, emitting greenhouse gases, and minimizing environmental pollution. They also considered transmission stations at their network levels. Asefi et al. (2019) proposed a location-routing model considering transfer stations with the aim of minimizing costs. They categorized waste into two general categories, hazardous and non-hazardous, and considered a separate landfill for each.

The second category is articles that used compost and landfills at the same time. For example, Yadav et al. (2017) presented a linear model under fuzzy uncertainty for locating waste disposal facilities with transfer stations in mind and the purpose of their model, was the minimization of waste management costs. The third category is articles that consider both sanitary landfills and incinerators for waste disposal. In this regard, Wu et al. (2018) proposed a stochastic mathematical programming model considering the limitations of greenhouse gas emissions and the capacity constraints for waste disposal facilities.

The fourth category is articles on waste disposal, which consider all four facilities of recycling centers, composting centers, incinerators and landfills. In this regard, Gaska et al. Presented. The purpose of their model was to minimize the costs of waste management (Gaska et al., 2021). Rabbani et al. (2020) proposed a multi-objective nonlinear model for the location of waste disposal facilities that Their goal was to minimize costs and emit greenhouse gases. Anwar (2018) proposed a mathematical model for allocating waste to waste recycling facilities. The purpose of this multi-cycle model, Maximizing the benefits of recycling. Mohammadi et al. (2019) presented a single-objective model with the aim of minimizing deployment and transportation costs. Heidari et al. (2019) proposed a model for facility location. They have proposed waste disposal and have considered alternative trucks in their model for transporting waste. Nobil et al. (2018) proposed a multi-objective linear model for the location of waste disposal facilities, taking into account the objectives of minimizing annual waste management costs and negative environmental impacts.

Habib et al. (2019) designed a large-scale sustainable waste management system in times of crisis. They used fuzzy multi-objective mathematical modeling to design a waste management supply chain. Their proposed model was validated using real data in crisis situations in Pakistan. Rathore and Sarmah (2019) proposed a mixed integer modeling for the problem of locating waste transfer stations at the time of separation from the waste generation source. They could validate their model using a real case study problem which was implemented by CPLEX solver and Arc- GIS.

Gambella et al. (2019) proposed a stochastic integer modeling for waste flow allocation for the solid waste management problem. They examined the real limitations raised by waste experts. They also examined different scenarios to validate their model. Yadav et al. (2017) used mathematical modeling to locate waste collection facilities in conditions of uncertainty. They considered parameters such as waste generation, operating costs of facilities, transportation costs as the most important part of their model. Yadav et al. (2018), based on their previous research, used multi-period fuzzy linear modeling to evaluate the waste management system. They also used fuzzy two-level modeling to evaluate the waste management system of Muneeb et al. (2018). This model was designed for waste collection systems according to reliability capabilities. They addressed the allocation and inventory planning of the collection, distribution, treatment, and disposal centers. Finally, a numerical example was designed to evaluate the performance of their proposed model using the fuzzy goal programming (GP) method (Hannan et al., 2018)

The typical process of waste collection involves vehicles starting from the depot and traveling in fixed routes to collect waste by visiting all locations, which costs a large amount of budget. This process causes wastage of resources because of traveling to empty a bin that is not full yet (Gilardino et al., 2017). This route optimization method can save travel distance and minimize the number of vehicles, which in turn reduce labor cost, fuel cost, operation time, and GHG emission (Mahmuda et al., 2017). The route optimization cannot be effective with the conventional waste collection process given no real time information about bin status. A waste collection route needs to be designed on the basis of the waste status of smart bin data to ensure the efficiency of waste collection (Nowakowski, 2017).

Model Development

The proposed problem is a robust planning model for locating facilities in the field of municipal waste management. In general, a municipal waste management collection network has different limitations such as capacity constraints as well as constraints on the allocation of various facilities. In this study, a network of diagrams to show urban areas called G (N, A), so that N indicates the number of nodes and A is a set of arcs whose connections between nodes in networks. In general, there are several areas in each urban network; Such as demand nodes and local candidate nodes and the establishment of waste collection facilities. Also, the facilities should be located in such a way that the highest level of service to these demand nodes is achieved in different regions.

In addition, some potential sites are considered for processing or disposal sites in the vicinity of the network. To develop the mathematical model, some practical assumptions have been taken from the theoretical literature of the research and some of them have been proposed based on our research participation.

The basic concept of VRP is to serve a set of customers to find the least total travel distant routes from starting to returning at the depot. When vehicle capacity is considered, it becomes CVRP. CVRP in the solid waste collection is defined as informing a set of collection nodes (bins) by a fleet of vehicles, and the vehicles start and return constraints at the depot.

Therefore, the main assumptions that distinguish this model from other existing models are as follows:

- A metropolis is divided into different regions. These areas should be such that the total waste collected in each of them exceeds the capacity of the relevant equipment at the point of operation; Does not exceed.
- A planning horizon must be considered.
- Each region includes predefined demand nodes, so that the value of demand varies in each period.
- Reduce the total distance traveled in the whole area, which can eventually lead to reduced fuel consumption, car depreciation as well as waste collection time.
- Each vehicle collects the maximum amount of waste along the route according to its capacity and then enters the depot station.

Deterministic mathematical model

This section describes the proposed mathematical model step by step. First, the indexes, parameters, and variables are given by tables 1 and 2. The two objective functions is addressed towards the total cost minimization of the waste management network, which is represented by equations (1)–(2). Finally, the constraints of the system are described by equations (3)–(18).

Table 1. Indexes of the mathematical model

Index	Description
i	Indexes of waste generation sources (i.e., the citizens)
j	Index of potential sites where to collect the urban waste
k	set of different bin types available for allocation to collection sites
V	A set of homogenous vehicles V = {1, 2 . . .m} is available at the depot to collect waste, where the maximum capacity of each vehicle is C.

Table 2. Parameters of the mathematical model

Parameters	Description
Q_k	capacity of a bin of type $k \in K$
l_k	linear length of a bin of type $k \in K$
b_k	total number of bins of type k ∈ K available for allocation
q_i	daily generation of wastes related to centroid $i \in V_1$
L_{ij}	linear length associated with potential collection site $j \in V_2$
Q_V	maximum capacity of a truck
$Q_{k\,max}$	maximum capacity of a bin of type $k \in K$

Table 3. Variables of the mathematical model

Variables	Description
Z_j	binary variable that takes value 1 if the potential collection site $j \in V_2$ is activated, 0 otherwise
X_{ij}	binary variable that takes value 1 if centroid $i \in V_1$ is allocated to collection site $j \in V_2$, 0 otherwise
y_{kj}	integer variable that represents the number of bins of type $k \in K$ to be allocated to collection site $j \in V_2$
X_{ijm}	1 if vehicle m can travel from waste generation sources i to potential sites j, 0 otherwise
y_{km}	1 if bin k is visited by vehicle m , 0 otherwise

Thus, a mathematical formulation, that minimization of the waste management network, is:

$$Min\, w1 = \sum_{j \in V_2} Z_j \tag{1}$$

$$Min\, w2 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{V=1}^{m} L_{ij}\, X_{ijm} \tag{2}$$

st:

$$\sum_{i \in V_1} q_i X_{ij} \leq \sum_{j \in V_2} Q_k y_{kj} \qquad \forall j \in V_2 \tag{3}$$

$$\sum_{k \in K} l_k y_{kj} \leq L_j Z_j \qquad \forall j \in V_2 \tag{4}$$

$$\sum_{j \in U_i} X_{ij} = 1 \qquad \forall\, i \in V_1 \tag{5}$$

$$\sum_{j \in V_2} y_{kj} \leq b_k \qquad \forall k \in K \tag{6}$$

$$\sum_{i=0}^{n} \sum_{V=1}^{m} X_{ijV} = 1 \qquad \forall j = 1,2,\dots,m \tag{7}$$

$$\sum_{j=1}^{n} \sum_{V=1}^{m} X_{0jV} = 1 \tag{8}$$

$$\sum_{j=1}^{n} q_{0jV} = 1 \qquad \forall\, V = 1,2,\dots,m \tag{9}$$

$$\sum_{i=1}^{n} \sum_{V=1}^{m} X_{i0V} = 1 \tag{10}$$

$$\sum_{k=1}^{n} Q_k X_{ijV} \leq Q_{k\,max} \qquad \forall k = 1,2,\dots,n;\ V = 1,2,\dots,m \tag{11}$$

$$\sum_{i=0}^{n} \sum_{V=1}^{m} q_{jiV} - \sum_{i=0}^{n} \sum_{V=1}^{m} q_{ijV} = Q_V \qquad \forall\, V = 1,2,\dots,m \tag{12}$$

$$\sum_{j=1}^{n} X_{ijV} = \sum_{j=1}^{n} X_{jiV} = y_{km} \qquad \forall i = 1,2,\dots,n\,;\ V = 1,2,\dots,m \tag{13}$$

$$\in \{0,1\} X_{ijm} \tag{14}$$

$y_{km} \in \{0,1\}$ (15)
$Z_j \in \{0,1\}, \quad \forall j \in V_2$ (16)
$X_{ij} \in \{0,1\}, \quad \forall\, i \in V_1 \;, \forall j \in V_2$ (17)
$y_{kj} \geq 0\,, integer \quad \forall j \in V_2 \;, \quad \forall k \in K$ (18)

Formulation of the objective function

This model is used to determine the appropriate location to create the required facilities in the field of waste management. This model includes two objective functions. The first objective function (Equation 1) minimizes the total number of activated collection sites. The second objective function (Equation 2) minimizes total collection distance.

Formulation of the constraints

While the meaning of the elements in V_2 is obvious, the elements in V_1 deserve some explanation. Indeed, each element in V_1 represents a cluster of citizens, grouped according to their position. A cluster may include all the citizens residing in the street, or in a portion of it, considering them as point sources. We note that, in zones which are not densely populated, a source may coincide even with a single home. We call each element in V_1 as a centroid. By using this assumption, the set of arcs $A = V_1 \times V_2$ represents the waste flow between the centroids and the potential sites. To each arc is associated an attribute d_{ij} representing the distance between the centroid $i \in V_1$ and the potential site $j \in V_2$.

Inequalities (equations 3 and 4) are capacity constraints and, at the same time, express obvious logical relations between the problem's variables. In particular, constraints (equation 3) impose that the total waste to be directed to collection site $j \in V_2$ is at most equal to the total capacity of the bins allocated to it. Constraints (equation 4) prevent that each potential collection site $j \in V_2$hosts more bins than its capacity, in terms of length. Constraints (Equation 5) allocate each centroid $i \in V_1$ to exactly one activated collection site within the threshold distance Di. Constraints (equation 6) ensure that the number of bins of each type allocated to the activated collection sites is less than or equal to the maximum available quantity.

Equation 7 specifies that bin k is visited by not more than one vehicle m, whereas Equation 8 and (9) ensure that a truck starts from the depot and it does not carry any waste. Constraint (equation 10) guarantees that, after visiting the last waste bin, a vehicle will reach the depot. Equation 11 shows the collected bin that exceeds the TWL, in which capacity constraint is an important issue. Equation 12 presents that the total amount of waste in a truck cannot exceed its maximum capacity. Constraint (equation 13) indicates that a vehicle must fully empty all bins it visits. Therefore, the filled capacity of the vehicle will be equal to the summation of the waste amount of the visited bins. Finally, constraints (14) to (18) define the domain of the decision variable.

Material and Methods: Bertsimas and Sim's Robust optimization

The robust optimization approach seeks near-optimal solutions to be feasible with a high probability (Wang et al. 2018). Bertsimas and Sim (2004) suggested an optimization approach based on multi-dimensional uncertain sets. They claimed that it is very rare that at all the uncertain parameters of a constraint take different values far from their nominal and at their limit values simultaneously for a parameter of z_{ij}.

$$z_{ij} = \frac{a_{ij} - \tilde{a}_{ij}}{\hat{a}_{ij}} \quad \in [-1.1]$$
$$\sum_j |z_{ij}| \le \Gamma_i \quad \forall i, \Gamma_i\ [0, |J_i|] \tag{19}$$

where J_i denotes the set of uncertain parameters in the i[th] row of the coefficient matrix of constraints. The constraints' coefficients are uncertain values that take value in an interval with the center of $\tilde{a}_{ij}$ and the radius of $\hat{a}_{ij}$. Here, Γ_i represents the conservatism level and is known as the budget on uncertainty. When $\Gamma_i = 0$, all the uncertain parameters of the problem take the center value of the interval and the robust model turns into a deterministic model. In contrast, the robust model will be equal to the model proposed by Soyster (1973) for $\Gamma_i = |J_i|$ such that all the uncertain coefficients take their worst possible values at the upper bound of the interval.

Now, by assigning each value from the middle of the interval to Γ_i , a trade-off occurs between the robustness and optimality of the problem. In fact, Γ_i is determined by a decision-maker and its value is dependent on the risk aversion and the importance of the constraint for the decision maker. The proposed optimization model by Bertsimas and Sim (2004) is as follows:

$$Max\ Z = \sum_{j=1}^{n} c_j x_j \tag{20}$$

$$st: \sum_{j=1}^{n} a_{ij} x_j + z_i \Gamma_i + \sum_{j=1}^{n} p_{ij} \le b_i \qquad \forall i = 1, \dots, m \tag{21}$$

$$z_i + p_{ij} \ge \hat{a}_{ij} y_i \qquad \forall i = 1, \dots, m\ , j = 1, \dots, n \tag{22}$$

$$-y_j \le x_j \le y_j \qquad \forall j = 1, \dots, n \tag{23}$$

$$x_j, y_j \ge 0 \qquad \forall j = 1, \dots, n \tag{24}$$

$$z_i \ge 0 \qquad \forall i = 1, \dots, m \tag{25}$$

$$p_{ij} \ge 0 \qquad \forall i = 1, \dots, m\ , j = 1, \dots, n \tag{26}$$

Where, p_{ij}, z_i and y_j are the auxiliary dual variables that are used to prevent non-linearization of the problem (Bertsimas and Sim, 2004).

Application of robust model

In this section, we use the proposed model to locate the facilities needed to collect production waste in Bushehr. A city has different wastes such as household waste, industrial waste, construction waste, etc. that must be collected. Therefore, the following robust model is used for this research problem.

$$Min\ w1 = \sum_{j \in V_2} Z_j \tag{27}$$

$$Min\ w2 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{V=1}^{m} L_{ij} X_{ijm} \tag{28}$$

st:

$$\sum_{i\in V_1} q_i X_{ij} + z_i \Gamma_i + \sum_{j=1}^{n} p_{ij} \leq \sum_{j\in V_2} Q_k y_{kj} \qquad \forall j \in V_2 \tag{29}$$

$$\sum_{k\in K} l_k y_{kj} \leq L_j Z_j \qquad \forall j \in V_2 \tag{30}$$

$$\sum_{j\in U_i} X_{ij} = 1 \qquad \forall\, i \in V_1 \tag{31}$$

$$\sum_{j\in V_2} y_{kj} \leq b_k \qquad \forall k \in K \tag{32}$$

$$\sum_{i=0}^{n}\sum_{V=1}^{m} X_{ijV} = 1 \qquad \forall j = 1,2,\dots,m \tag{33}$$

$$\sum_{j=1}^{n}\sum_{V=1}^{m} X_{0jV} = 1 \tag{34}$$

$$\sum_{j=1}^{n} q_{0jV} = 1 \qquad \forall\, V = 1,2,\dots,m \tag{35}$$

$$\sum_{i=1}^{n}\sum_{V=1}^{m} X_{i0V} = 1 \tag{36}$$

$$\sum_{k=1}^{n} Q_k X_{ijV} \leq Q_{k\,max} \qquad \forall k = 1,2,\dots,n;\ V = 1,2,\dots,m \tag{37}$$

$$\sum_{i=0}^{n}\sum_{V=1}^{m} q_{jiV} - \sum_{i=0}^{n}\sum_{V=1}^{m} q_{ijV} = Q_V \qquad \forall\, V = 1,2,\dots,m \tag{38}$$

$$\sum_{j=1}^{n} X_{ijV} = \sum_{j=1}^{n} X_{jiV} = y_{km} \qquad \forall i = 1,2,\dots,n\,;\ V = 1,2,\dots,m \tag{39}$$

$$\in \{0,1\} X_{ijm} \tag{40}$$

$$y_{km} \in \{0,1\} \tag{41}$$

$$z_i + p_{ij} \geq \widehat{q_\iota} y_i \qquad \forall i = 1,\dots,m\ , z\, j = 1,\dots,n \tag{42}$$

$$-y_j \leq X_{ij} \leq y_j \qquad \forall j = 1,\dots,n \tag{43}$$

$$y_j \geq 0 \qquad \forall j = 1,\dots,n \tag{44}$$

$$z_i \geq 0 \qquad \forall i = 1,\dots,m \tag{45}$$

$$p_{ij} \geq 0 \qquad \forall i = 1,\dots,m\ , j = 1,\dots,n \tag{46}$$

$$Z_j \in \{0,1\}, \qquad \forall j \in V_2 \tag{47}$$

$$X_{ij} \in \{0,1\}, \qquad \forall\, i \in V_1\ ,\ \forall j \in V_2 \tag{48}$$

$$y_{kj} \geq 0\,, integer \qquad \forall j \in V_2\ ,\qquad \forall k \in K \tag{49}$$

A very important point to note is that the transfer of municipal waste to recycling and landfills, or even during collection by waste trucks, consumes fuel. Therefore, it is necessary to define the second objective function to minimize total collection distance according to the existing conditions and facilities required.

Result and Discussion

To evaluate the proposed model, first the definite model and the robust model are solved separately using different levels of uncertainty. GAMS software was used to solve the model. For this purpose, we first generate the parameters that are uncertain at random in the relevant interval. Due to the unavailability of some exact information, the numbers related to them were estimated and placed in the model. It is worth noting that these numbers are randomly generated due to their range of change. Also, all information related to the problem has been collected using the team of experts of Bushehr Port Municipal Waste Organization (table 5).

Table 4. Generated problems based on real-life data

Types of waste bins	Capacity of each bins (kg)	Distance of each bins (meters)	Number of types of bins
K=1	15		200
K=2	50	Uniform (100,700)	300
K=3	100		400

According to the table 4, three different types of bins with different capacities can be installed in any potential location. Also, the distance between the types of collection bins in potential locations is estimated using the uniform function.

Table 5. Allocation of waste collection bins at different levels of uncertainty

Level of uncertainty	Daily waste production per person (kg)	Deterministic Model			Robust Model			The percentage of reduction
		K=1	K=2	K=3	K=1	K=2	K=3	
0/1	2	151	262	323	121	233	265	٪15
	3	151	262	323	136	245	274	٪11
	5	151	262	323	148	257	284	٪6
0/2	2	151	262	323	135	237	266	٪13
	3	151	262	323	141	248	279	٪9
	5	151	262	323	147	256	286	٪6
0/5	2	151	262	323	137	239	277	٪11
	3	151	262	323	144	250	291	٪6
	5	151	262	323	147	257	302	٪4
The average reduction in the allocation of waste collection bins								٪9

As can be seen in table 5, the dimensions of the problem of this research have been solved at different levels of uncertainty of 0.1, 0.2 and 0.5. The output results of the objective functions show a significant difference in both cases. The results of solving the above model show that the problem in the robust state allocates a smaller number of types of reservoirs to potential locations. The difference between the objective functions in the deterministic and robust states shows that the model in the robust state can generate more reliable answers in the uncertain state.

Table 6. Determining the number of active sites for waste collection from potential sites

Level of uncertainty	Number of potential locations	Number of active locations	The percentage of reduction
0/1	290	157	٪45
0/2	290	136	٪53
0/5	290	121	٪58
Average percentage reduction of active places for waste collection			٪52

As can be seen in table 6, the number of potential locations and the number of active locations at different levels of uncertainty is estimated using the proposed model in the problem. The results of the above table show that using the proposed research model can reduce the number of sites required for waste collection in Bushehr, which reduces a variety of costs.

The second objective of this study is to optimize a waste collection route by implementing smart bin. This section deals with the improvement in waste collection and route optimization by applying the TWL concept in robust model. This study focuses on the optimization of bin number and bin size and on route to collect waste from a bin. Thus, a variable number of bins in every location are considered on the basis of the demand of that node. Demand in the dataset is considered the percentage of bin waste level. The maximum capacity of each bin is taken to be 15 units, and node demand is considered uniformly distributed in all bins. We consider five threshold waste levels (TWL), namely, 60%, 70%, 75%, 80%, and 90%, in computing an efficient waste collection route. Waste bin exceeding a certain TWL needs to be collected immediately. Table 7 shows the obtained results, such as distance, improvement, total collected waste and its collection percentage, and the tightness of the system under different datasets, TWLs, nodes, vehicle capacities, and bins.

Table 7. Obtained results by applying the TWL concept in robust algorithm under different scenario

scenario	Capacity of vehicle (unit)	Capacity of bin (unit)	TWL (%)	N	V	Distance (unit)	Improvement (%)	Total collected waste	Collected waste (%)	Tightness (waste/capacity)
1	110	15	0	32	5	661	0.00	446	100	0.89
			60	28	5	629	4.84	431	96.64	0.86
			70	25	4	585	11.50	392	87.89	0.98
			75	21	4	533	19.36	336	75.34	0.84
			80	17	3	457	30.86	252	56.50	0.84
			90	12	2	374	43.42	180	40.39	0.90
2	110	15	0	45	7	914	0.00	603	100	0.86
			60	38	7	895	2.08	496	82.26	0.71
			70	28	5	750	17.94	475	78.77	0.95
			75	22	4	634	30.63	389	64.51	0.97
			80	18	4	548	40.04	313	51.91	0.78
			90	14	3	449	50.86	222	36.82	0.74
3	110	15	0	59	9	1371	0.00	829	100	0.92
			60	41	8	1258	8.24	738	89.02	0.92
			70	38	8	1223	10.80	713	86.00	0.89
			75	31	6	1048	23.56	586	70.69	0.98
			80	29	6	979	28.59	517	62.36	0.86
			90	19	4	693	49.45	319	38.48	0.80

Conclusions and Recommendations

Locating the required facilities in the field of waste systems is one of the most important issues that can significantly reduce the costs of the waste management unit in municipalities.
Currently, most of the financial and human resources for municipal solid waste management are spent on collection and transportation, and not much work is done in the fields of production, on-site storage, recycling and disposal. The issue of location of facilities and related financial issues have a significant impact on the structure of the supply chain. Most location issues have been with the assumption that only One type of facility is to be located,

while in most cases managers intend to locate different facilities that are related in one or more ways.

In many facility location models, the assumption of uncertainty of some parameters seems an inevitable assumption. The model presented here is a complex integer programming model that includes two objective functions that are used to locate and allocate waste facilities optimally as well as control the amount of fuel. In this paper we have faced the problem of locating collection sites in an urban waste management system. We have proposed an optimization model which helps in deciding the sites where to locate the garbage collection bins, as well as the number and the characteristics of the bins to be positioned at the different collection sites. This model introduces constraints that, from one side, ensure the Quality of Service from the citizens' point of view, and, from the other side, allocate bins to collection sites, so to provide the least necessary capacity to fit the expected waste to be directed to the sites. Then, to validate the model and compare the definite and uncertainty conditions, several scenarios were solved using GAMS software, using real data collected by experts in the field of waste in Bushehr Port Municipality.

According to the review of the theoretical literature of the research, the amount of waste production per person in the city was determined. Therefore, three types of waste bins with specific capacity were considered. Also, a uniform function was used to determine the distance between waste bins in the city. The first objective function of this study shows the number of required bins of each type in different areas of the city. Therefore, the first objective function was solved definitively and also by robust modeling and the required number of each type of waste bin was determined in both methods. The results of solving this objective function showed that using the proposed method can significantly reduce the number of bins used in the city, which reduces costs. Also, another result of solving this function is to determine the number of potential and active sites for the establishment of waste bins. The results of solving this model in different levels of uncertainty showed that according to the proposed model, the number of active sites has decreased by an average of about 52%. Therefore, to validate the proposed model, the results of this study were compared with other related studies, which are shown in the table 8.

Table 8. Comparison table of this study with relevant research

Reference	Problem			Condition		Objective/Criterion			Case study	Solution technique
	Location	Allocation	CVRP	Deterministic	Uncertain	Economic	Social	Environmental		
Current study	✓	✓	✓		✓	✓	✓		✓	MILP and CPLEX solver
Gambella et al. (2019)	✓	✓			✓				✓	MILP and CPLEX solver
Rathore and Sarmah (2019)	✓	✓		✓		✓			✓	MILP, ArcGIS and CPLEX solver
Muneeb et al. (2018)	✓	✓			✓	✓				Fuzzy GP and AMPL software
Yadav et al. (2018)	✓				✓	✓			✓	Interval optimization algorithm

Also, this study proposes CVRP model to check the feasibility of smart bin in solid waste collection and route optimization. The developed CVRP model determines the optimized route for solid waste collection by minimizing travel distance and total cost on the basis of specific constraints and objective function. The results of solving the second objective function show how many vehicles are needed to collect all the generated waste to solve each type of scenario proposed in the research. To solve this function, the target threshold level for waste bins is also considered. To solve the second objective function, six threshold limits of 0, 60, 75, 75, 80 and 90 were identified, which indicate the status of the waste in each bin. According to each threshold level, the number of vehicles to collect the total waste was determined. Also, from the other results of this objective function, the amount of route traveled for all vehicles has been determined. Also, determining the percentage of waste collection produced according to the capacity of vehicles is another result of solving the second objective function of this research. By finding the shortest paths, this objective function can significantly help reduce fuel consumption as well as air pollution, depreciation of waste collection machines and manpower costs. At the same time, defining the dimensions of the problem interactively with the participation of experts leads to the use of real hypotheses and also trust in the proposed solution.

Also, based on the limitations of this research, it can be suggested for future studies and research in this field that the use of innovative and meta-innovative methods to solve larger models will be more efficient. Other uncertain approaches such as gray systems and stochastic optimal control systems and its comparison with the fuzzy-robust approach can be used to develop the model of this research. In addition, in order to be close to real-world conditions, new goal functions can be defined, such as maximizing citizens' satisfaction with the waste collection system, which is one of the aspects of human social life.

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