PROPOSING A ROBUST OPTIMIZATION MATHEMATICAL MODEL FOR SITE SELECTION- HOSPITAL WASTE DISTRIBUTION

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ABSTRACT

The environmental, social and economic effects of hospital waste are the vital issue for managers. In this paper a mathematical model is provided for hospital waste management with the site selection of disposal, recycling and treatment of hospital waste taken into consideration. The strength of the proposed model is to reduce the cost of transporting waste materials between the disposal, treatment and recycling centers.

An application of the proposed model for waste management of a hospital in Iran is provided. Some of the model parameters are considered uncertain parameters and we use a robust optimization approach to solve it. The reason of using robust optimization is the ability of this method to find the optimal solution under varying degrees of uncertainty.

INTRODUCTION

Determining the location of incinerating centers for the hazardous materials is an important issue due to the environmental, social, and economic effects. Costs associated with these facilities and risks against the population that are near these materials are important challenges. Medical waste disposal site selection is a complex and important social problem because decisions related to site selection impose costs and high risks on those who use these facilities. Due to the fact that the costs and risks are too great, such facilities are often established by the government centers. In the event that such decisions are not directly made by a government entity, they are strictly monitored by the government (Almeida et al., 2009).

Pollutants in the air are among the major concerns to determine the location of hospital wastes especially issues involved with incinerating the materials. Emissions of atmospheric pollutants impose risks to different people both continuously and randomly. Mathematical programming is applied to the problems of air quality control. The severity of the risk depends on several factors such as the location of emissions sources, weather conditions (eg, wind direction), and the persons who may be affected. The potential for random emission with large negative effects on different subsets of the population generally leads to real inequality in the distribution of risks. As a result, in recent years issues related to environmental justice have received considerable attention on the part of news media, policy makers, environmentalists, and academic researchers (Chakraborty and Armstrong, 1995).

Moreover, benefits, costs, and risks associated with the hospital waste facilities are scattered among different people. As a result, considerable studies have analyzed these problems. The use of mathematical programming techniques in site selection of the hospital waste goes back to the late 1970s. This special issue is first appeared in 1995 (Brimberg and Weselowsky, 2000). Multidimensional methods for determining the location of public facilities and hospital waste sites are among the first applications. Total risk, the share of imposed risk and dollar costs associated with the site selection projects are the three important purposes discussed in the literature. Several methods have been adopted to address the share of risk. Minimizing the risk imposed on any person or in any area has been an important approach for risk modeling (Current et al., 1995). In this paper, robust modeling is utilized to select the site location of hospital waste disposal.

REVIEW OF LITERATURE

ReVelle et al. (1991) made the first attempt to model the routing problem, utilizing a system that includes HAZMAT. They developed a model to routing model to minimize both the cost and the risk of transportation. They used 0 and 1 mathematical programming for the shortest route and method of multi-function weighting programming to solve the problem. Cappanera et al. (2003) presented a central site selection and method of routing the discrete harmful activities.

Since the proposed NP model was difficult, they proposed a Lagrangian method to decompose the problem into two different site-selection and routing problems, and used the branch-and-bound approach to solve the problems. Alumur & Kara (2007) modeled the location- and routing problem, in which the location of the disposal center and health centers, and the type of technology used by the centers should be defined. They presented the use of the model by implementing it in Central Anatolia in Turkey utilizing CPLEX software. They solved the multi objective routing problem by a meta-heuristic method based on taboo search to study the site of two plants for solid animal waste disposal. Their objective function included: 1) minimizing the fixed costs 2) minimizing the transportation costs 3) minimizing rejection by the cities through which the trucks pass 4) minimizing losses of between involved cities and 5) minimizing rejection by the cities close to the factory. This model was used by some other researchers too (Samanlioglu, 2013; Dai et al., 2011; Cabalro et al., 2011; Cabalro et al., 2007).

Zhao& Zhao (2010) used a multi-purpose mixed integer programming model for simultaneous location- routing HAZMAT and used a technique for overcoming the cost and risk symmetry normal percentage. They developed a target based programming technique to solve the problem. Zee et al. (2010) solved the location- routing. Zee et al. (2010) solved the location- routing problem by allowing various modes for transportation that can be changed when necessitated. In the heuristic method they consider a set of M cases of the best candidate solutions that is upgraded whenever a new solution with higher quality is found. Thus by the termination of the heuristic solution the result includes M cases of the best solutions that are close to optimal results.

In general there are four types of problems in case of HAZMATs. These problems include: routing/scheduling, risk analysis, location analysis, and waste management (Moungla and Jost, 2010). Samanlioglu (2013) mentioned that industrial hazardous waste management includes collection, transportation, recycling, and disposal of industrial hazardous substances that cause damage to the environment (Samanlioglu, 2013). He proposed a new multi-dimensional location – routing model developed and implemented in Turkey's Marmara region. The model can help the decision makers to determine the location of treatment plants using different technologies, different types of industrial hazardous waste routing to the adapted treatment plants, site selection of the recycling centers and routing of hazardous residual waste to these centers, and site selection of waste disposal sites and routing the waste residuals.

In the mathematical model, three criteria have been considered: (1) minimizing the total costs that include the total cost of transporting the hazardous materials and waste residuals, (2) the fixed cost of creating the treatment, disposal and recycling centers, and (3) minimizing the risk and potential cost to both the population living along the hazardous material transportation routes and to those who live around the treatment and disposal center sites.

The weighted Tchebycheff Samanlioglu formula has been developed and calculated using CPLEX software to determine the efficient solutions of the problem. The data on the Marmara region was obtained by Arcview GIS 9.3 and the geographical database software in Marmara region. Kang et al (2014) proposed a model to determine the routing for HAZMAT transport based on the confidence level for the specified risk called VAR. VAR is a threshold value so that the probability of loss greater than the VAR value is less than the probability level. The purpose of their model is to determine a path that minimizes the risk that exceed the thresholds.

Multiple properties have been established for the VAR model. An exact solution has been proposed and tested for solving a single trip. To test the application of this approach, the paths obtained by the VAR model were compared with the paths obtained by other HAZMAT goals in a numerical example. Also a HAZMAT routing scenario was extracted from the Albany area of New York State. Depending on the confidence level, the VAR model presents different routes and it is concluded that routing is a function of the decision-maker's level of risk tolerance. Higher modifications of the VAR model have been also discussed.

Today, especially in the systems that deal with HAZMAT, in addition to minimizing the cost of operations in the facilities and routing, assessing the risk of this operation is an important consideration. Arjmand et al (2015) proposed a new mathematical model for site selection and routing in the disposal centers and sites. In their research, the risk and cost of transportation from the center to clients was considered.

The mathematical model presented the total weight of the cost and risk by identifying the following: (1) the central site (facility) that produces the HAZMAT (2) the location of disposal sites; (3) which customer should be allocated to which facility 4) which facility should be allocated to which disposal center (5) which route should be selected to provide services to the customers., and (6) which route should be selected to reach the disposal sites. A new genetic algorithm (GA) was used to solve the model.

The GA results presented the optimized solutions with high quality and suitable execution times. Generally the studies in this area could be divided into site selection, routing, risk consideration, and providing the mathematical models. In this regard, Table 1 shows a summary of these studies.

TABLE 1. ANALYSIS OF PREVIOUS STUDIES ON WASTE MANAGEMENT

Author	Year	Main features				
		Site selection	Routing	Risk consideration	Mathematical modeling (Operations Research)	Robust optimization approach
Cohon, and Shobrys	1991	✓	✓	✓	✓	
Stowers and Palekar	1993	✓	✓	✓	✓	
Jacobs and Warmerdam	1994	✓	✓	✓	✓	
Caballero et al.	2007		✓		✓	
Alumour & Kara	2007	✓	✓		✓	
Bafi et al.	2008	✓			✓	
Zhao and Zhao	2010	✓	✓	✓	✓	
Xie et al.	2012	✓	✓		✓	
Zee et al.	2012	✓	✓		✓	
Samanlioglu	2013	✓	✓	✓	✓	
Kang et al.	2014		✓	✓	✓	
Arjmand et al	2015	✓	✓	✓	✓	

A review of past studies indicates that the uncertainty factor has not been seriously studied. However, not much research has been done on site selection and routing the HAZMAT with uncertainty factors. Based on the lack of research in this area and the increased demand for it, this study attempts to present and analyze a robust optimization model for site selection and transporting hospital waste. The developed model of this study has been applied to two cases using different networks to demonstrate its application.

MATERIALS AND METHODS

Indices Used in the Model

Medical waste generation centers:	G = {1, … , g}
Potential centers for the treatment of hospital waste:	T = { 1, … , t}
Available centers for the treatment of hospital waste:	T′ = {1, … , t′}
Potential centers for disposal of hospital waste:	D = {1 , … , d}
Available canters for disposal of hospital waste:	D′ = { 1 , … , d′}
Potential centers for recycling of hospital waste:	H = { 1 , … , h}
Available centers for recycling of hospital waste:	H = { 1 , … , h}
Available centers for recycling of hospital waste:	H′ = { 1, … , h′}
Type of hospital waste:	W= { 1, … , w}
Potential technologies for dealing with hospital waste:	Q = {1, … , q}
Available technologies for dealing with hospital waste:	Q′ = { 1, … , q′}

Parameters Used in the Model

The cost of transporting a unit of waste between the waste generation and its treatment centers: $C_{i,j}$

The cost of transporting a unit of waste residual between the treatment and disposal of it: $cz_{i,j}$

The cost of transporting a unit of waste residual between the recycling and disposal of it: $cv_{i,j}$

The cost of transporting a unit of residual waste between the generation and recycling of it: $cr_{i,j}$

The cost of transporting a unit of treated recyclable waste between the recycling and recycling of it: $crr_{i,j}$

Fixed cost of establishing a treatment technology in a treatment center: $fc_{q,i}$

Fixed cost of establishing a waste disposal center: fd_i

Fixed cost of establishing a waste recycling center: fh_i

The number of people existing in the distance between waste generation and treatment centers: $POPgt_{i,j}$

The number of people existing in the distance between waste treatment and disposal centers: $POPtd_{i,j}$

The number of people existing in the treatment center with Q technology: $POPA_{q,i}$

The number of people existing within the area of a center: $POPB_i$

The amount of w waste generated in the generation center i: $gen_{w,i}$

Recycling percentage of waste w generated in the generation center i: $a_{w,i}$

Recycling percentage of waste w recycled by technology Q: $\beta_{w,q}$ $r_{w,q}$

Percentage of total waste recycled at the recycling center i: γ_i

Q technology capacity to recycle the waste in the center i: $TC_{q,i}$

The minimum level of waste that can be treated by Q technology: $tc_{q,i}^{m}$

Waste disposal capacity in the waste disposal center i: dc_i
Minimum required waste to create a waste disposal center: dc_i^m
The capacity to recycle the waste in the recycling center i: rc_i
The minimum required waste to establish a recycling center in node i: rc_i^m
0 and 1 parameter: it takes the value 1 is the type of the waste i is compatible with Q technology: $com_{w,q}$

Decision Variables

The amount of waste w transferred between the waste generation and treatment centers: $X_{w,i,j}$
The amount of residual waste transported between the waste treatment and disposal centers: $Z_{i,j}$
The amount of recyclable waste transported from the waste generation and recycling centers: $L_{i,j}$
The amount of recyclable waste transported from the waste treatment i to the waste recycling j centers: $K_{i,j}$
The amount of final waste transported from the waste recycling 1 to the waste disposal j centers: $V_{i,j}$
The amount of waste w that will be treated in the treatment center i using the technology q: $Y_{w,q,i}$, $y_{w,q,j}$
The amount of waste that is lost in the waste disposal center j: dis_i , dis_j
The amount of waste that is lost in the waste recycling center i: hr_i,hr_j
If the q technology is established in the waste recycling center i: $F_{q,i}$
If the waste disposal center is established in the center i: dz_i
If the waste recycling center is established in the center i: b_i

Linear Mathematical Model

$$\min f_1(x) = w1\left(\sum_{i\in G}\sum_{j\in T}\sum_{w\in W} c_{i,j} \times x_{w,i,j} + \sum_{i\in T}\sum_{j\in D} cz_{i,j} \times z_{i,j} + \sum_{i\in H}\sum_{j\in D} cv_{i,j} \times v_{i,j} + \sum_{i\in G}\sum_{j\in H} cr_{i,j} \times l_{i,j} + \sum_{i\in T}\sum_{j\in H} crr_{i,j} \times k_{i,j} + \sum_{i\in T}\sum_{q\in Q} fc_{q,i} \times f_{q,i} + \sum_{i\in D} fd_i \times dz_i + \sum_{i\in H} fh_i \times b_i\right) \quad (1)$$

$$\min f_2(x) = w2\left(\sum_{i\in G}\sum_{j\in T}\sum_{w\in W} POPgt_{i,j} \times x_{w,i,j} + \sum_{i\in T}\sum_{j\in D} POPtd_{i,j} \times z_{i,j}\right) \quad (2)$$

$$\min f_3(x) = w3\left(\sum_{w\in W}\sum_{q\in Q}\sum_{i\in T} POPA_{q,i} \times y_{w,q,i} + \sum_{i\in D} POPB_i \times dis_i\right) \quad (3)$$

$$gen_{w,i} = \alpha_{w,i} \times gen_{w,i} + \sum_{j\in T} x_{w,i,j} \qquad \forall i \in G \quad (4)$$

$$\sum_{w\in W} \alpha_{w,i} \times gen_{w,i} = \sum_{j\in H} l_{i,j} \qquad \forall i \in G \quad (5)$$

$$\sum_{i\in G} x_{w,i,j} = \sum_{q\in Q} y_{w,q,j} \qquad \forall w \in W, \forall j \in T \quad (6)$$

$$\sum_{w\in W}\sum_{q\in Q} y_{w,q,i}\left(1-r_{w,q}\right)\left(1-\beta_{w,q}\right)=\sum_{j\in D} z_{i,j} \qquad \forall i\in T \tag{7}$$

$$\sum_{w\in W}\sum_{q\in Q} y_{w,q,i}\left(1-r_{w,q}\right)\left(\beta_{w,q}\right)=\sum_{j\in H} k_{i,j} \qquad \forall i\in T \tag{8}$$

$$f_{q,i}=1 \qquad \forall q\in Q^{\prime}, \forall i\in T^{\prime}$$

$$(\sum_{i=T} k_{i,j}+\sum_{i=G} l_{i,j}=hr_j \qquad \forall j\in H \tag{9}$$

$$hr_j(1-y_i)=\sum_{j\in D} v_{i,j} \qquad \forall j\in H \tag{10}$$

$$b_i=1 \qquad \forall i\in H^{\prime}$$

$$\sum_{i\in H} v_{i,j}+\sum_{i\in T} z_{i,j}=dis_j \qquad \forall j\in D \tag{11}$$

$$dz_i=1 \qquad \forall i\in D^{\prime}$$

$$\sum_{q\in Q} y_{w,q,i}\leq tc_{q,i}\times f_{q,i} \qquad \forall q\in Q\ ,\forall i\in T \tag{12}$$

$$\sum_{q\in Q} y_{w,q,i}\geq tc^{m}_{q,i}\times f_{q,i} \qquad \forall q\in Q\ ,\forall i\in T \tag{13}$$

$$tc^{m}_{q,i}\times f_{q,i}+\Gamma_3\times\tau_3+\varphi_3\times\sigma_{3,q,i}\leq\sum_{q\in Q} y_{w,q,i} \qquad \forall q\in Q\ ,\forall i\in T \tag{14}$$

$$\tau_3+\sigma_{3,q,i}\geq t\hat{c}^{m}_{q,i}\left|f_{q,i}\right| \qquad \forall q\in Q\ ,\forall i\in T \tag{15}$$

$$\tau_3\ ,\sigma_{3,q,i}\geq 0 \qquad \forall q\in Q\ ,\ \forall i\in T$$

$$y_{w,q,i}\leq tc_{q,i}\times com_{w,q} \qquad \forall w\in W, \forall q\in Q, \forall i\in \mathrm{T} \tag{16}$$

$$dis_i\leq dc_i\times dz_i \qquad \forall i\in D \tag{17}$$

$$dis_i+\Gamma_1\times\tau_1+\varphi_1\times\sigma_{1,i}\leq dc_i\times dz_i \qquad \forall i\in D \tag{18}$$

$$\tau_1+\sigma_1\ ,i\geq dc\hat{}\_i \qquad \forall i\in D \tag{19}$$

$$\tau_1\ ,\sigma_{1,i}\geq 0$$

$$dis_i\geq dc^{m}_{i}\times dz_i \qquad \forall i\in D \tag{20}$$

$$hr_i\leq rc_i\times b_i \qquad \forall i\in H \tag{21}$$

$$hr_i+\Gamma_2\times\tau_2+\varphi_2\times\sigma_{2,i}\leq rc_i\times b_i \qquad \forall i\in H \tag{22}$$

$$\tau_2+\sigma_{2,i}\geq rc_i \qquad \forall i\in H \tag{23}$$

$$\tau_2\ ,\ \ \sigma_{2,i}\geq 0 \qquad \forall i\in H$$

$$hr_i \geq rc_i^m \times b_i \quad \forall i \in H \tag{24}$$

$$x_{w,i,j}, z_{i,j}, l_{i,j}, k_{i,j}, v_{i,j}, y_{w,q,i}, y_{w,q,j}, dis_i, dis_j, hr_i, hr_j \geq 0$$

$$f_{q,i}, dz_i, b_i \in \{0\,\text{و}1\}$$

Objective Function and Constraints Description

First Objective Function

The first objective function is cost minimization to reduce the following costs respectively:

A. Total cost of waste transfer between the waste generation and treatment centers
B. Total cost of waste transfer between the waste treatment and disposal centers
C. Total cost of waste transfer between the waste recycling and disposal centers
D. Total cost of recyclable waste transfer between the waste generation and recycling centers
E. Total cost of recyclable residual treated waste transfer between the waste treatment and recycling centers
F. Total fixed cost of establishing treatment technologies in the treatment centers
G. Total fixed cost of establishing waste disposal centers
H. Total fixed cost of establishing waste recycling centers

Second and Third Objective Function

The second objective function is aimed at reducing individuals' risk of contamination due to potential exposure to hazardous materials at the point of waste generation and during transport to the treatment centers. The third objective function is aimed at reducing individuals' risk of contamination due to potential exposure to hazardous materials at the point of waste treatment and during transport to the waste disposal centers.

Constraints

Equations 3, 5 and 6 are associated with the flow balance between the source and destination centers.
Equations 7 and 8 control the flow level from the treatment center to disposal center. These two constraints also consider the use of various treatment technologies.
Equation 9 sorts and lists available centers with total existing technologies.
Equation 10 defines the flow rate between waste generation and treatment centers and the waste recycling center.
Equation 11 defines the flow rate between waste recycling and waste disposal centers.
Equation 12 defines the existing waste recycling centers.

Equation 13 specifies and estimates the waste flow from the treatment and recycling centers to the waste disposal center.
Equation 14 determines the available waste disposal centers.
Equations 16, 17 and 18 are capacity constraints for treatment, disposal and recycling centers.

As it is clear the uncertainty is considered in equations 15, 17 and 19. It means that it is assumed that the following parameters are uncertain and their exact amount is not available:

"The minimum level of waste that can be treated by Q technology"
"The capacity of waste disposal in waste disposal center"
"The capacity of waste recycling in the waste disposal center"

It should be noted that these parameters are selected among all parameters with the capability to consider uncertainty. In other words, all expressed parameters in the proposed mathematical model can be considered as an uncertain parameter but this is due to the complexity of the model. Thus the mentioned parameters are extracted as important and sample uncertain parameters.

Numerical example

In order to evaluate the performance of the proposed model a numerical example is coded by GAMS software and run. The numerical example relates to a hospital and real data are used to run the model.

The initial information is based on the following descriptions:

The number of waste generation centers of Hospital:	1
The number of potential centers for the waste treatment of hospital:	2
The number of available centers for the treatment of hospital waste:	0
The number of potential sites for the disposal of hospital:	2
The number of available centers for hospital waste disposal:	0
The number of potential centers for recycling hospital waste:	2
The number of available centers for recycling hospital waste:	0
The number of hospital waste types:	1
The number of potential technologies dealing with hospital waste:	2
The number of existing technologies dealing with hospital waste:	0
The cost of transporting a unit of waste between the waste generation and its treatment centers:	10
The cost of transporting a unit of waste residual between the treatment and disposal of it:	15
The cost of transporting a unit of waste residual between the recycling and disposal of it:	8
The cost of transporting a unit of residual waste between the generation and recycling of it:	10
The cost of transporting a unit of treated recyclable residual waste between the treatment and recycling of it:	11
The fixed cost of establishing a treatment technology in a treatment center:	9
The fixed cost of establishing a waste disposal center:	200
The fixed cost of establishing a waste recycling center:	200

The number of people existing in the distance between waste generation and treatment centers:	150
The number of people existing in the distance between waste treatment and disposal centers:	200
The number of people existing in the treatment center with Q technology:	250
The number of people existing within the area of a center:	200
The amount of w waste generated in the waste generation center i:	500
Recycling percentage of w waste generated in the waste generation center i:	0.8
Recycling percentage of waste w recycles by technology q:	0.8
Percentage of total wastes recycled at the recycling center i:	0.5
Q technology capacity to treatment the waste in the center i:	1000
The minimum level of waste that can be treated by Q technology:	60
Waste disposal capacity in the waste disposal center i:	2000
Minimum required waste to create a waste disposal center:	10
The capacity to recycle the waste in the disposal center i:	2000
The minimum required waste to establish a recycling center in node i:	30
0 and 1 parameter: the value is 1 if the type of the waste i be compatible with Q technology:	1

In the numerical example a fixed value is considered for all parameters. As stated previously, some of the essential parameters of the model are identified and (these parameters are intended for uncertainty) the uncertainties are taken into account. These parameters include:

1. The minimum level of waste that can be treated by Q technology
2. Waste disposal capacity in the waste disposal center
3. The capacity to recycle the waste in the disposal center

RESULTS AND DISCUSSION

The results of the numerical example have shown below:

The amount of waste w transferred between the waste generation and treatment centers:
$X_{1,1,1} = 350$, $X_{1,1,2}=150$
The amount of residual waste transported between the waste treatment and disposal centers:
$Z_{1,1}=40$, $Z_{1,2}=5$, $Z_{2,1}=80$, $Z_{1,1}=0$
The amount of recyclable waste transported from the waste generation and recycling centers: 0
The amount of recyclable waste transported from the waste treatment center i to the waste recycling center j: k1,1=60 , k1,2=30 , k2,1=0 , k2,2=0
The amount of final waste transported from the waste recycling center i to the waste disposal center j: 0
The amount of waste w that will be treated in the treatment center i using the technology q:
$y_{1,1,1}=230$, $y_{1,1,2}=70$

To better assessment of the proposed model, three other numerical examples are randomly generated and studied. Table 2 shows the overall results:

TABLE 2. THE RESULTS OF THE SOLUTION OF NUMERICAL EXAMPLES

No	Number of hospitals	Number of recycling centers	Number of disposal centers	Number of treatment centers	Value of the objective function in uncertainty level 0	Value of the objective function in uncertainty level 0.5	Value of the objective function in uncertainty level 1
1	1	2	3	3	45852	45852	45852
2	1	3	3	5	2546	2548	3500
3	1	5	6	6	685412	685412	685412

The above table is interpreted as follows:

A. Other-parameters data are generated randomly using MATLAB software and presented to GAMS randomly.

B. In this table, only the uncertainty of the waste disposal center capacity is investigated. Other-parameters uncertainty are expected to show similar behavior.

C. The problem of the case study is solved in certain mode. This is due to the lack of uncertainty in the data obtained from the case study (Hospital).

D. According to the above table for problems 1 and 3 the uncertainty had no effect on the optimal solution of the problem. This is because this center had the ability to respond to all disposed waste even in the worst cases. However, in problem 2, by increasing the uncertainty level, the amount of the objective function is worsened; this means the wastes that could have been disposed are transferred to another center for strict considerations or they are removed from the cycle that has increased the costs, thus worsening the objective function.

CONCLUSION

In this paper, a mathematical model is proposed for hospital waste management. Taken into consideration are site selection of disposal, recycling, and treatment centers of hospital waste Based on the numerical results obtained in this paper, it is possible to obtain the optimal location for the recycling, treatment and disposal of hospital waste.

The most important function of this model is to reduce the cost of transporting the waste materials among disposal, treatment and recycling centers. To evaluate the performance of the proposed model, a real case study utilizing actual hospital data to obtain optimal locations for site selection of disposal, recycling, and treatment centers of hospital waste. Based on the obtained results, the proposed model is capable of providing optimal solutions to small and medium-sized problems.

Also another innovation of the proposed model is considering uncertainty factors. The robust optimization approach is used to solve parameters that are considered as uncertain parameters. It is also possible to change the parameters of the model to analyze the effect of them on the system and to identify the critical parameters as well.

According to the research gaps identified during the study, the authors propose future studies be conducted on providing an optimal solution method for large-size problems utilizing the method discussed. Although this study did not focus on reducing hospital waste generation, future research could lead to the reduction of hospital pollution through effective hospital management.

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