A Two Step Solution Procedure to a Fuzzy Medical Waste Disposal Facility Location Problem

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Abstract— *This paper handles the medical waste disposal facility location problem in Istanbul by using fuzzy TOPSIS (FETOPSIS) to select the adequate place between some candidate points that are obtained from the Ishii's undesirable facility location algorithm. Medical waste must be disposed without damaging environment and human health, complying with new regulations. The aim is to provide an alternative method to the medical waste disposal facility location problem in Istanbul, able to handle the fuzziness of the real world. People attempt to minimize the undesirable effects introduced by the new facility by maximizing its minimum Euclidean distance with respect to all demand points and also to minimize the total transportation costs. This study proposes a modified model of Ishii's algorithm to obtain a list of candidate points. Then a selection is made between these candidate points considering other criteria as earthquake risk, distance to natural water sources and level of air pollution.*

Keywords— Undesirable Facility Location, Maximin, FETOPSIS, Medical Waste, Euclidean Distances.

1 Introduction

The infectious, pathological, cutter-driller wastes emanating from medical institutions are known as medical wastes. Recently, the controlled collection and safe disposal of medical waste has become an important field of environment protection in Turkey as in whole world. The 50% of environmental pollution has occurred in the last 35 years. As a result, the scientists work on eliminating all harmful factors on air, earth, water and human life. The safe disposal and the regain of waste are some of the important fields that they work on. Even if the medical waste consist a small part of waste amount, when we consider the threat they constitute on human life, their safe disposal is vital.

The present position is that medical wastes are stored at special hazardous waste storage areas or medical waste disposal areas if they cannot be disposed by incineration. The technical criteria concerning storage are included in the By-Law on the Control of Medical Wastes (2005).

Throwing away without control or common disposal with household waste poses a serious threat for all livings. That is why medical waste must be disposed without damaging the human mental and physical health, the animal health, the flora, the water and the welfare of the society, complying with new regulations.

The aim of this study is to provide an alternative method to solve the medical facility location problem in Istanbul, able to handle the fuzziness of transportation costs and people preferences. Nuclear plant, oil refining plant, waste disposal plant must not be close to residential area. People attempt to minimize the undesirable effects introduced by the new facility by maximizing its minimum Euclidean distance with respect to all demand points and also to minimize the total transportation costs. These are semi-obnoxious facilities and to locate them, facility planners determined two objectives [1]. The first objective aims to maximize the minimum distance from the new facility to the demand points; this is the maximin problem. The second aim is to minimize the total distance from the facility to the demand points in order to minimize the transportation costs. In this study, we propose the following two-step solution procedure where we obtain all efficient solutions at the first step and then we choose the best solution at the second step. Considering the fuzzy nature of the people attitude towards the location of this kind of facilities we will try to find the site of the facility which maximizes the minimal satisfaction degree among all demand points and maximizes the preference of the site by using a method based on the Ishii's where the attitudes of people are expressed by a trapezoidal membership function [2]. The function represents the satisfaction degree of demand points with respect to the distance from these points to the facility site. We reformulate the Ishii's model to obtain a list of candidate points. Then, we make a selection between these candidate points by solving a fuzzy TOPSIS (FETOPSIS). The use of this method allows us to consider other criteria as earthquake risk, distance to natural water sources and level of air pollution. These criteria will be evaluated by experts with the first two criteria: distance to districts and transportation costs.

2 Disposal of medical waste

There are many proven techniques for the safe disposal of medical waste all around the world. Nowadays, new contagious diseases that appeared in diverse countries induced all medical authorities to take severe precautions. In 2003, with the outbreak of severe acute respiratory syndrome (SARS) the authorities take more serious steps in managing medical waste. The procedures for handling, treatment and disposal of this waste were required to comply with the most stringent standards [3, 4]. The health authority in Taiwan had to handle the current status of waste

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production for further management planning. The quantity of waste generated by hospitals varies by changes in local legislation according to the studies [5, 6, 7, 8].

In Turkey, the medical waste production increases due to the economic and social changes and the population increase. The amount of waste is too huge to dispose in the dumping ground and requires an integrated management concept involving collection, transportation and disposal. By 2005 the number of hospital in Turkey has become 1198 and due to development of medical technologies and hygienic precautions, total waste amount has been increasing. According to MEF's researches, total waste amount in Turkey is 238.26 tons per day and 86 968 tons per year. 23 000 tons of this amount is collected in Istanbul by ISTAC (sub institution of Istanbul Metropolitan Municipality) and district municipalities.

The mortal contagious diseases that appeared recently in Turkey as Avian Influenza, as well-known name bird flu, Crimean-Congo hemorrhagic fever (CCHF) and the holocausts related to these diseases, furthermore the increase of other contagious diseases as aids, hepatitis and tuberculosis accentuate the vitality of the collection and the safe disposal of medical waste.

The regulations of medical waste control inure on 20.07.2005 in Turkey. The regulations are based on the 8th article of the environment code where it is denoted that inappropriate collection, transportation and disposal are forbidden. In the 35th article of regulations there is a legal decision on the medical waste disposal facility location: The distance of disposal facility can't be closer than 1000 meters to the residential area. As it is mentioned clearly in the regulations these following criteria must be considered in the decision making process:

1. Distance between disposal facility and districts. (C_1)
2. Transportation costs. (C_2)
3. Earthquake risk. (C_3)
4. Distance to the water sources. (C_4)
5. Existing air quality. (C_5)

The first two quantitative criteria will be handled by using a fuzzy facility location method so as to obtain worthwhile candidate points. Then these points will be handled by a fuzzy TOPSIS method considering the five criteria above all together to select a single point.

3 Methodology

3.1 Fuzzy Facility Location with Preference of Candidate Sites

Facilities as power plants, chemical plants, dumping grounds, airports are undesired close to residential area but they must also be at a reasonable distance easy to reach in order to minimize transportation costs. By using different decision making methods one must compromise two objectives. People don't want to live near a dumping ground but want also to get rid of the waste they produce as fast as possible. So the facility can not be placed to an inaccessible distance.

The first step of this study is based on the [2]'s fuzzy facility location problem, where the attitudes of the demand points (people, clients) towards the location of new facility are expressed by a trapezoidal membership function. Ishii's problem is reformulated to obtain a list of candidate points. Reference 2 categorizes people attitudes in three categories. In this study we have two categories of attitude: 1. People don't want the facility near. 2. People don't want high costs of transportation. As it is mentioned in the medical waste regulations, the burning and storage facility can not be close more than 1000 meters. Anyway people prefer the facility to be more than 5000 meters far from their residential area.

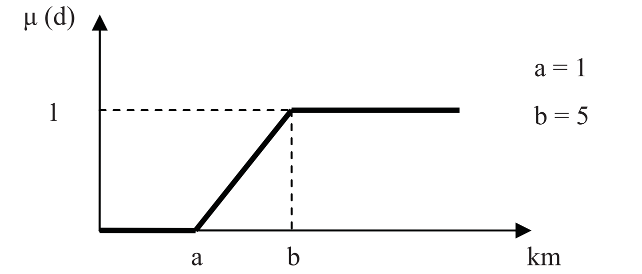

Figure 1: Membership function related to distances.

$$d_i(X)=\begin{cases}E(x-p_i)+N(y-q_i) & (x\ge p_i, y\ge q_i)\\ W(x-p_i)+N(y-q_i) & (x\le p_i, y\ge q_i)\\ E(x-p_i)+S(y-q_i) & (x\ge p_i, y\le q_i)\\ W(x-p_i)+S(y-q_i) & (x\le p_i, y\le q_i)\end{cases} \quad (1)$$

$$\mu(d_i)=\begin{cases}0 & (d_i\le a)\\ \dfrac{d_i-a}{b-a} & (a\le d_i\le b)\\ 1 & (b\le d_i)\end{cases} \quad (2)$$

N: North = 1; *S*: South = –1; *E*: East = 1; *W*: West = –1 are constants used to provide nonnegative differences between coordinates. Let be n demand points in the rectangular area. These points are represented as $(p_i, q_i),\ \ i=1,2,\ldots,n$. The facility that we will build is represented as $\chi=(x,y)$ and $X=\{(x,y)|p_L\le x\le p_U,\ \ q_L\le y\le q_U\}$ [2]. Site $\chi\in X$.

Define α: α = $\mu(d_i)$. Then, we model the problem as [2]:

Maximize α

such that

$$\alpha\le\frac{d_i(x)-a}{b-a}$$
$$0<\alpha\le 1$$
$$p_L\le x\le p_U$$
$$q_L\le y\le q_U \quad (3)$$

But the way that we will pursue to solve this problem is to partition the rectangular area to small rectangles by tracing the horizontal and vertical lines passing by each demand

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points. For each line intersection point called x_{jm} we will solve the sub-problem (4). The optimums of each sub problem can be handled by another decision making tool in order to select the best location for the facility.

Q: Maximize α

$$\begin{aligned} \text{such that}\quad & \alpha(b-a)+a \le E(x-p_i)+N(y-q_i) \\ & \alpha(b-a)+a \le W(x-p_i)+N(y-q_i) \\ & \alpha(b-a)+a \le E(x-p_i)+S(y-q_i) \\ & \alpha(b-a)+a \le W(x-p_i)+S(y-q_i) \\ & 0<\alpha\le 1 \qquad x\in X \qquad i=1,2,\dots,n \end{aligned} \tag{4}$$

3.2 Selection of the Best Candidate Site with Fuzzy TOPSIS

Method TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Hwang and Yoon (1981) as an alternative to the ELECTRE method. The basic concept of the method is that the selected alternative should have the shortest distance to the ideal solution and the farthest distance to the negative-ideal solution. The Euclidian distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution [4]. It solves the dilemma of the choice between ideal and anti-ideal by using an idea that Dasarathy (1976) applies to the data analysis. The TOPSIS method evaluates the decision matrix which refers to m alternatives which are evaluated in terms of n criteria [9].

In real-world situation, because of incomplete or non-obtainable information, (for example, human judgments including preferences are often vague and cannot estimate his preference with an exact numerical data), the data are not deterministic; therefore they usually are fuzzy / imprecise, so, TOPSIS for fuzzy data is used [10]. The main advantage of fuzzy formulation compared to the crisp formulation is that the decision maker is not obligated to give a precise formulation, for the sake of mathematical reasons, even though he or she might be able or willing to describe the problem in fuzzy terms [11].

The extension of TOPSIS to fuzzy TOPSIS provides a new multi-criteria decision making method compatible with the real world decisions. There are diverse applications of this method in the literature as the evaluation of airline service quality of [12], selection of expatriate host country of [13], bridge risk assessment of [14], new product introduction of [15], industrial robotic system selection of [16] etc.

Let $A_1, A_2,\dots, A_m$ be m alternatives among which we will make the selection, $C_1, C_2,\dots, C_n$ be n the criteria that are under consideration during the decision making process. $\tilde{x}_{ij}$ is the fuzzy rating of alternative A_i according to the criterion C_j. Fuzzy data used here is triangular fuzzy number. We can express this fuzzy multi criteria decision making problem in matrix format [10]:

$$\begin{array}{cccccc} & C_1 & C_2 & \cdots & C_n \\ A_1 & \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ A_2 & \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_m & \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{array} \tag{5}$$

The purpose of linear scales transformed with normalization function used in this study is to preserve the property that the ranges of normalized triangular fuzzy numbers to be included in (0,1). [17]:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}; \frac{b_{ij}}{c_j^*}; \frac{c_{ij}}{c_j^*} \right) \tag{6}$$

Here, $c_j^* = \max_i c_{ij}$

Thereby, the normalized fuzzy decision matrix $\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n}$ is generated. In decision making process each criterion can have a different importance for the decision maker who will assign different weights to each criterion. But in our study we assume that all criteria are equally important.

We define the positive ideal solution A^* and the negative ideal solution A^- [17]:

$$A^* = \left(\tilde{r}_1^*, \tilde{r}_2^*, \dots, \tilde{r}_n^*\right) \tag{7}$$

$$A^- = \left(\tilde{r}_1^-, \tilde{r}_2^-, \dots, \tilde{r}_n^-\right) \tag{8}$$

Then, we have to calculate the distance of each alternative to A^* and A^-, by using the formula of distance between two fuzzy numbers.

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{r}_{ij}, \tilde{r}_j^*\right), i = 1,\dots,m \tag{9}$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{r}_{ij}, \tilde{r}_j^-\right), i = 1,\dots,m \tag{10}$$

The distance between two fuzzy numbers is calculated as:

$$\tilde{x} = \left(a_1, b_1, c_1\right),\quad \tilde{y} = \left(a_2, b_2, c_2\right) \tag{11}$$

$$d(\tilde{x},\tilde{y}) = \sqrt{\frac{1}{3}\left[\left(a_1-a_2\right)^2 + \left(b_1-b_2\right)^2 + \left(c_1-c_2\right)^2\right]} \tag{12}$$

A relative closeness index between d_i^* and d_i^- is calculated to determine the ranking order of alternatives [17,10]:

$$R_i = \frac{d_i^-}{d_i^* + d_i^-},\quad i = 1,\dots,m \tag{13}$$

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4 Application

This two-step model is applied to the medical waste facility selection for the most populated region of Istanbul including the districts Şişli, Kağıthane, Beşiktaş and Sarıyer. The figure 2 is the Google Earth map showing the application region. The distances and coordinates are provided by Google Earth.

Figure 2: Selection of a medical waste disposal facility in Istanbul.

In rectangular area there are four demand points and all lines passing through form 25 points which means that we will solve the sub problem (4) 25 times by using LINDO software. The optimum membership values and optimum candidate facility sites are in the Table 1. As our aim is to maximize membership value α, we can select the biggest α value as new facility site but there are many α values closer to each other. So, the most reasonable attitude is to handle some candidate points having big α value, considering other criteria. In this study, we handle seven points as alternatives having α value bigger than 0.600 in terms of an observation made on the map.

Table 1: Optimum α values and optimum candidate facility sites

SUB PROBLEMS	OPTIMUM POINT	OPTIMUM α VALUE
1	-	-
2	(1.790; 3.450)	0.110
3	(6.350; 0.000)	0.140
4	(5.330; 7.110)	0.167
5	(5.080; 2.160)	0.217
6	(5.080; 3.645)	0.261
7	(5.330; 3.645)	0.324
8	(4.445; 2.160)	0.376
9	(5.080; 2.795)	0.376
10	(5.080; 2.795)	0.376
11	(3.230; 0.000)	0.410
12	(6.350; 2.160)	0.410
13	(2.675; 0.540)	0.413
14	(6.350; 7.110)	0.422
15	(2.675; 0.000)	0.549
16	(0.000; 0.565)	0.565
17	(3.230; 7.110)	0.567
18	(6.350; 3.645)	0.579
19	(1.640; 5.645)	0.621
20	(6.350; 3.045)	0.631
21	(0.000; 3.100)	0.645
22	(0.000; 0.000)	0,700
23	(1.640; 7.110)	0.965
24	(0.000; 5.520)	1.000
25	(0.080; 5.690)	1.000

Seven candidate waste disposal facilities are highlighted in the Table 1. As there are several candidate points, we need a second decision process where we will introduce new decision criteria that are mentioned in the regulations to find out the best place for a medical waste disposal facility. The five criteria mentioned in the second section are evaluated for each candidate site by experts. The fuzzy TOPSIS method of [17] was used to handle these evaluations.

For the evaluation of the first criterion, the distance between the facility and the districts, experts used the α values of seven candidate points. Bigger α values improve our model.

To figure out the transportation costs, the distances between districts and candidate points are measured and given in the Table 2. The waste amount generated by each district is in the Table 3. These amounts help us to determine the weights of each district that are used in the calculation of transportation costs.

Table 2: Distances of candidate sites to each demand point

SITE	SISLI	BESIKTAS	KAGITHANE	SARIYER
1	6.680	5.870	3.800	10.770
2	3.580	7.890	2.580	7.670
3	3.525	3.525	5.595	3.915
4	5.300	10.310	5.000	5.250
5	3.785	8.795	3.485	3.485
6	5.390	10.400	5.090	5.000
7	5.250	10.260	4.950	4.860

Table 3: Waste amounts of each district and weights (Istanbul Metropolitan Municipality).

DISTRICTS	MEDİCAL WASTE AMOUNT (KG/YEAR)	WEIGHT
SISLI	87 600	0.362
BESİKTAS	64 800	0.268
KAGITHANE	64 800	0.268
SARIYER	24 600	0.102

To evaluate the earthquake risk criteria, the experts used the earthquake map of Istanbul published by earthquake observatory of Istanbul. There are five different risk levels in the map. They evaluated each candidate point according to their location on the map.

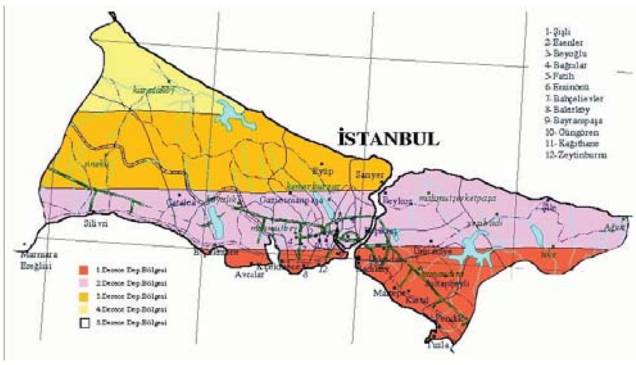

Figure 3: Earthquake Risk Map of Istanbul.

Distances of each candidate point to the water sources were measured using Google Earth. The results were evaluated by experts.

For the evaluation of air quality criterion, the experts used the data of Istanbul Technical University pollution reports.

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The figure 4 is the regional pollution map. The amount of SO_2 differs for each color in the map. It is denoted in the regulations that the waste disposal facility must be located in a region where it will not increase the pollution to high levels. So it is convenient to locate the facility in a less polluted area.

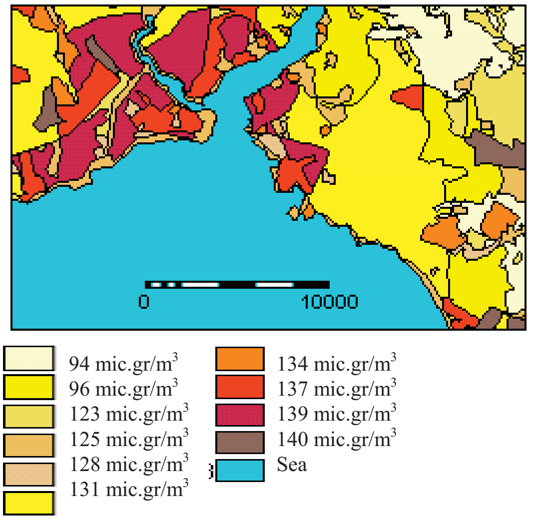

Figure 4: SO_2 amount for different places in Istanbul

The linguistic variables used by experts are in the Table 4. In our study we used a scale of [17]. The evaluation matrix and the normalized decision matrix of fuzzy TOPSIS decision process of this study are given in the Table 5 and Table 6.

Table 4: Linguistic Variables

Very poor (VP)	(0; 1; 3)
Poor (P)	(1; 3; 5)
Fair (F)	(3; 5; 7)
Good (G)	(5; 7; 9)
Very Good (VG)	(7; 9; 10)

Table 5: Expert Evaluation

	C1	C2	C3	C4	C5
A1	VP	G	F	VP	VG
A2	VP	VG	P	F	VP
A3	P	G	P	G	F
A4	F	P	VP	VG	P
A5	VG	VP	F	P	VG
A6	VG	VP	F	P	VG
A7	VG	VP	F	P	VG

Table 6: Normalized Decision Matrix

	C_1	C_2	C_3	C_4	C_5
	0.00	0.50	0.43	0.00	0.70
A_1	0.10	0.70	0.71	0.10	0.90
	0.30	0.90	1.00	0.30	1.00
	0.00	0.70	0.14	0.30	0.00
A_2	0.10	0.90	0.43	0.50	0.10
	0.30	1.00	0.71	0.70	0.30
	0.10	0.50	0.14	0.50	0.30
A_3	0.30	0.70	0.43	0.70	0.50
	0.50	0.90	0.71	0.90	0.70
	0.30	0.10	0.00	0.70	0.10
A_4	0.50	0.30	0.14	0.90	0.30
	0.70	0.50	0.43	1.00	0.50
	0.70	0.00	0.43	0.10	0.70
A_5	0.90	0.10	0.71	0.30	0.90
	1.00	0.30	1.00	0.50	1.00
	0.70	0.00	0.43	0.10	0.70
A_6	0.90	0.10	0.71	0.30	0.90
	1.00	0.30	1.00	0.50	1.00
	0.70	0.00	0.43	0.10	0.70
A_7	0.90	0.10	0.71	0.30	0.90
	1.00	0.30	1.00	0.50	1.00

The results are given in the Table 7. According to these results, three areas, A_5, A_6, and A_7 are equally adequate for the medical waste disposal facility. Selected point is sufficiently far from residential area and not too far to increase the transportation costs. So one can conclude that this study is meaningful for this kind of problems. But this model does not take into account other logistical constraints.

Table 7: Range of alternatives

	d_i^*	Range	d_i^-	Range	R_i	Range
A_1	1.64	3	1.83	3	0.53	3
A_2	2.13	5	1.35	5	0.39	5
A_3	1.57	2	1.93	2	0.55	2
A_4	2.04	4	1.45	4	0.42	4
A_5	1.30	1	2.17	1	0.62	1
A_6	1.30	1	2.17	1	0.62	1
A_7	1.30	1	2.17	1	0.62	1

5 Conclusions

This paper deals with the problem of determining the undesirable facility location site in Istanbul. We tried first to find the site of the facility which maximizes the minimal satisfaction degree among all demand points and maximizes the preference of the site by using a method based on the Ishii's.

There are four drawbacks in this kind of solution procedure. The first is that this solution procedure suggests that residential areas are discrete points. This problem can be handled by revising the intervals of membership function as in this study. Second is that more than one sub-problem can have the same optimum solution. To handle this problem we use the optimum of each sub-problem having nearly same α values, bigger than a fixed value, in a new decision making process. The inaptitude to introduce qualitative criteria to the decision process is another drawback. A fuzzy TOPSIS

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method is introduced to the decision making process as a second step to improve the model. The last drawback is not handled in this study but can be subject to a further study. When the number of districts increases, the number of sub problems increases hugely and it complicates the decision making process. For a limited number of districts, the apparent advantage of our solution procedure is that all problems are converted to linear problems and we solve them easily using LINDO software.

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References

[1] E. Melachrinoudis, Z. Xanthopulos, A Semi-obnoxious single location in Euclidean space, *Computers&Operations Research*, 30, 2191-2209, 2002.

[2] H. Ishii, Y.L. Lee, K.Y. Yeh, Fuzzy facility location problem with preference of candidate sites, *Fuzzy Sets and Systems*, 158, 1922-1930, 2007.

[3] C.F. Chiang, F.C. Sung, F.H. Chang, C.T. Tsai, Hospital waste generation during the SARS outbreak in Taiwan, *Infection Control and Hospital Epidemiology*, 27, 519-522,2006.

[4] Y.W. Cheng, F.C. Sung, Y. Yang, Y.H. Lo, Y.T. Chung, K.-C. Li, Medical waste production at hospitals and associated factors, *Waste Management*, 29, 440-444, 2009.

[5] M. Askarian, M. Vakili, G. Kabir, Results of a hospital waste survey in private hospitals in Fars Province, Iran, *Waste Management*, 24, 347-352, 2004.

[6] S. Fisher, Healthcare waste management in the UK: the challenges facing healthcare waste producers in light of changes in legislation and increased pressures to manage waste more efficiently, *Waste Management*, 25, 572-574, 2005.

[7] R. Mohee, Medical wastes characterization in healthcare institutions in Mauritius, *Waste Management*, 25, 575-581, 2005.

[8] A. Bdour, B. Altrabsheh, N. Hadadin, M. Al-Shareif, Assessment of medical wastes management practice: a case study of Northern Part of Jordan, *Waste Management*, 27, 746-759, 2007.

[9] J-C. Pomero, S. Barba-Romero, *Choix multicritère dans l'entreprise, principe et pratique*, Editions Hermes, Paris, (1993).

[10] G.R. Jhanshahloo, F. H. Lotfi, M. Izadikhah, Extension of the TOPSIS metod for decision-making problems with fuzzy data, *Applied Mathematics and Computation*, 181(2), 1544-1551, 2006.

[11] H.-J. Zimmermann, Fuzzy set theory and mathematical programming in: A. Jones et al., *Fuzzy Set Theory and Applications*, 99-114, Reidel, Dordrecht, 1986.

[12] S-H. Tsaur, T-Y. Chang and C-H. Yen, The evaluation of airline service quality by fuzzy MCDM, *Tourism Management*, 23(2), 107-115, 2002.

[13] M-F. Chen and G-H. Tzeng, Combining grey relation and TOPSIS concepts for selecting an expatriate host country, *Mathematical and Computer Modelling*, 40(13), 1473-1490, 2004.

[14] Y-M. Wang and T. M.S. Elhag, Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment, *Expert Systems with Applications*, 31(2), 309-319, 2006.

[15] C. Kahraman, G. Büyüközkan and N. Y. Ates, A two phase multi-attribute decision-making approach for new product introduction, *Information Sciences*, 177(7), 1567-1582, 2007.

[16] C. Kahraman, S. Çevik, N. Y. Ates and M. Gülbay, Fuzzy multi-criteria evaluation of industrial robotic systems, *Computers & Industrial Engineering*, 52(4), 414-433, 2007.

[17] T-C. Wang, T-H. Chang, Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment, *Expert Systems with Applications*, 33, 870-880, 2007.