

A Fuzzy MCDM Approach for Health-Care Waste Management

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Abstract—The management of the health-care wastes is one of the most important problems in Istanbul, a city with more than 12 million inhabitants, as it is in most of the developing countries. Negligence in appropriate treatment and final disposal of the health-care wastes can lead to adverse impacts to public health and to the environment. This paper employs a fuzzy multi-criteria group decision making approach, which is based on the principles of fusion of fuzzy information, 2-tuple linguistic representation model, and technique for order preference by similarity to ideal solution (TOPSIS), to evaluate health-care waste (HCW) treatment alternatives for Istanbul. The evaluation criteria are determined employing nominal group technique (NGT), which is a method of systematically developing a consensus of group opinion. The employed method is apt to manage information assessed using multi-granularity linguistic information in a decision making problem with multiple information sources. The decision making framework employs ordered weighted averaging (OWA) operator that encompasses several operators as the aggregation operator since it can implement different aggregation rules by changing the order weights. The aggregation process is based on the unification of information by means of fuzzy sets on a basic linguistic term set (BLTS). Then, the unified information is transformed into linguistic 2-tuples in a way to rectify the problem of loss information of other fuzzy linguistic approaches.

Keywords—Group decision making, health care waste management, multi-criteria decision making, OWA, TOPSIS, 2-tuple linguistic representation

I. INTRODUCTION

HEALTH-CARE waste is defined as any type of waste generated by biomedical institutions, including hospitals, medical laboratories, animal experimentation units, and clinics [1]. Over the past two decades, health-care waste has been identified as one of the major problems that negatively impact both human health and the environment when improperly stored, transported and disposed. For many years, the World Health Organization has advocated that medical waste be regarded as special waste [2], and it is now commonly acknowledged that certain categories of health-care waste are among the most hazardous and potentially dangerous of all waste arising in communities [3].

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In the literature, there are only a few analytical studies about health-care waste management (HCWM). Mostly, health-care institutions generating the wastes are surveyed through the prepared questionnaires, field research and personnel interviews ([4], [5], [6], [7], [8], [9], [10], [11]).

The abovementioned studies are useful in analyzing the current situation in developing countries. Apart from these studies, there are a few studies that use decision making tools to implement a comprehensive health-care waste management strategy ([12], [13], [14], [15], [16], [17]).

Recently, a number of studies have focused on HCWM practices in Istanbul, a metropolis with over 12 million inhabitants ([18], [19], [20], [21], [22], [23]).

Evaluating HCW treatment alternatives, which considers the need to trade-off multiple conflicting criteria with the involvement of a group of experts, is a highly important multi-criteria group decision making problem. The objective of this study is to evaluate HCW treatment alternatives to determine the most suitable one for Istanbul, the largest city of Turkey. The importance of forming a group in every decision-making activity has increased in our day-to-day life in order to come across a satisfactory decision. In this view, several group decision-making schemes have been developed by the researchers to provide better decisions to deal with the real world decision problems [24].

The HCW treatment alternatives considered in this study include "incineration", "steam sterilization", "microwave", and "landfill". Incineration is the controlled-flame combustion to decline waste materials to noncombustible residue or ash and exhaust gases; it is a remedial technology that destroys contaminants at high temperatures. Incineration is being used as the existing method to dispose HCW generated by health-care institutions in Istanbul. Steam sterilization, or autoclaving, is a process to sterilize medical wastes prior to disposal in a landfill. Microwave disinfection is essentially a steam-based process, since disinfection occurs through the action of moist heat and steam generated by microwave energy. Sanitary landfilling is the preferred method of solid waste disposal in certain cases due to its low cost, minimal environmental impacts when designed and operated correctly, and effectiveness in controlling health risks.

This paper employs the fuzzy multi-criteria decision making (MCDM) approach proposed by Dursun and Karsak [25], which is based on fusion of fuzzy information, 2-tuple linguistic representation model, and TOPSIS. This method ensures to incorporate both crisp data and fuzzy data

represented as linguistic variables or triangular fuzzy numbers into the analysis, and disregards troublesome fuzzy number ranking process that may yield inconsistent results when different ranking methods are used. The method enables managers to deal with heterogeneous information, and thus, allows for the use of different semantic types by decision-makers. Furthermore, HCWM problem involves the consideration of numerous performance attributes, yielding in general a multi-level hierarchical structure. However, many decision-making problems cannot be structured hierarchically because they involve interaction of various factors, with high-level factors occasionally depending on low-level factors. The possible dependency among factors can be determined as a result of internal and external environmental analyses. For this reason, this paper employs the nominal group technique (NGT), which is a method of systematically developing a consensus of group opinion, to reduce the number of performance attributes.

In group decision making problems, aggregation of expert opinions is essential for properly conducting the evaluation process. The employed decision-making approach uses the ordered weighted averaging (OWA) operator to aggregate decision makers' opinions. The OWA operator is a common generalization of the three basic aggregation operators, i.e. max, min, and the arithmetic mean. This operator differs from the classical weighted mean in that coefficients are not associated directly with a particular attribute but rather to an ordered position. It encompasses several operators since it can implement different aggregation rules by changing the order weights.

The rest of the paper is structured as follows: Section 2 and Section 3 delineate the fusion of fuzzy information approach and 2-tuple fuzzy linguistic representation model, respectively. In Section 4, the fuzzy decision making framework is presented. The application of the fuzzy decision making framework to evaluate HCW treatment alternatives for Istanbul is set forth in Section 5. Finally, conclusions and directions for future research are provided in Section 6.

II. FUSION OF FUZZY INFORMATION

Fusion approach of fuzzy information, which was proposed by Herrera, Herrera-Viedma, and Martínez [26] is used to manage information assessed using both linguistic and numerical scales in a decision making problem with multiple information sources. This approach is carried out in two phases:

1. Making the information uniform: The performance values expressed using multi-granularity linguistic term sets are converted (under a transformation function) into a specific linguistic domain, which is a basic linguistic term set (BLTS), chosen so as not to impose useless precision to the original evaluations and to allow an appropriate discrimination of the initial performance values [26]. The transformation function is defined as follows [26]:

Let $A = \{l_0, l_1, \dots, l_p\}$ and $S_T = \{s_0, s_1, \dots, s_g\}$ be two linguistic term sets, such that $g \geq p$. Then, the transformation function, τ_{AS_T} , is defined as

$$\begin{aligned} \tau_{AS_T} : A &\rightarrow F(S_T), \\ \tau_{AS_T}(l_i) &= \left\{ \left(s_k, \gamma_k^i \right) / k \in \{0, 1, \dots, g\} \right\}, \quad \forall l_i \in A, \\ \gamma_k^i &= \max_y \min \left\{ \mu_{l_i}(y), \mu_{s_k}(y) \right\}, \end{aligned} \quad (1)$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T , and $\mu_{l_i}(y)$ and $\mu_{s_k}(y)$ are the membership functions of the fuzzy sets associated with the terms l_i and s_k , respectively.

The max-min operation has been chosen in the definition of the transformation function since it is a classical tool to set the matching degree between fuzzy sets [26].

2. Computing the collective performance values: For each alternative, a collective performance value is obtained by means of the aggregation of the aforementioned fuzzy sets on the BLTS that represents the individual performance values assigned to the alternative according to each information source [26]. Therefore, each collective performance value is a new fuzzy set defined on a BLTS. This paper employs the OWA operator, initially proposed by Yager [27], as the aggregation operator. This operator provides an aggregation which lies in between the "and" requiring all the criteria to be satisfied, and the "or" requiring at least one of the criteria to be satisfied. Indeed, the OWA category of operators enables trivial adjustment of the ANDness and ORness degrees embedded in the aggregation [28].

Let $A = \{a_1, a_2, \dots, a_n\}$ be a set of values to be aggregated. The OWA operator F is defined as

$$F(a_1, a_2, \dots, a_n) = \mathbf{w}\mathbf{b}^T = \sum_{j=1}^n w_j b_j, \quad (2)$$

where $\mathbf{w} = (w_1, w_2, \dots, w_n)$ is a weighting vector, such that

$w_i \in [0, 1]$ and $\sum_{i=1}^n w_i = 1$ and \mathbf{b} is the associated ordered value vector, where $b_j \in \mathbf{b}$ is the j th largest value in A .

A key characteristic of the OWA operator is the reordering of the arguments based upon their values, in particular an argument a_i is not associated with a specific weight w_i but rather a weight w_i is associated with a specific ordered position i of the arguments [29].

To apply the OWA operator for decision making, a crucial issue is to determine its weights. The weights of the OWA operator are calculated using fuzzy linguistic quantifiers, which for a non-decreasing relative quantifier Q , are given by

$$w_i = Q(i/n) - Q((i-1)/n), \quad i = 1, \dots, n. \quad (3)$$

The non-decreasing relative quantifier, Q , is defined as [26]

$$Q(y) = \begin{cases} 0 & , y < a, \\ \frac{y-a}{b-a} & , a \leq y \leq b, \\ 1 & , y > b, \end{cases} \quad (4)$$

with $a, b, y \in [0, 1]$, and $Q(y)$ indicating the degree to which the proportion y is compatible with the meaning of the quantifier it represents. Some non-decreasing relative quantifiers are identified by terms 'most', 'at least half', and 'as many as possible', with parameters (a, b) given as $(0.3, 0.8)$, $(0, 0.5)$, and $(0.5, 1)$, respectively.

III. 2-TUPLE FUZZY LINGUISTIC REPRESENTATION MODEL

The 2-tuple linguistic model that was presented by Herrera and Martínez [30] is based on the concept of symbolic translation. It is used for representing the linguistic assessment information by means of a 2-tuple that is composed of a linguistic term and a number. It can be denoted as (s_i, α) where s_i represents the linguistic label of the predefined linguistic term set S_T , and α is a numerical value representing the symbolic translation [31].

Let $r_1 = (s_1, \alpha_1)$ and $r_2 = (s_2, \alpha_2)$ be two linguistic variables represented by 2-tuples. The main algebraic operations can be expressed as follows [32]:

$$r_1 \oplus r_2 = (s_1, \alpha_1) \oplus (s_2, \alpha_2) = (s_1 + s_2, \alpha_1 + \alpha_2), \quad (5)$$

$$r_1 \otimes r_2 = (s_1, \alpha_1) \otimes (s_2, \alpha_2) = (s_1 s_2, \alpha_1 \alpha_2), \quad (6)$$

where \oplus and \otimes represent the addition and multiplication operators, respectively.

In the following, we define a set of transformation functions between fuzzy sets defined on the BLTS and numerical value, and between numerical value and 2-tuples:

Definition 1 [32]: Let $L = (\gamma_0, \gamma_1, \dots, \gamma_g)$ be a fuzzy set defined in S_T . A transformation function χ that transforms L into a numerical value in the interval of granularity of S_T , $[0, g]$ is defined as

$$\chi : F(S_T) \rightarrow [0, g],$$

$$\chi(F(S_T)) = \chi(\{(s_j, \gamma_j), j = 0, 1, \dots, g\}) = \frac{\sum_{j=0}^g j \gamma_j}{\sum_{j=0}^g \gamma_j} = \beta. \quad (7)$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T .

Definition 2 [30]: Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5],$$

$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5], \end{cases} \quad (8)$$

where 'round' is the usual round operation, s_i has the closest index label to ' β ' and ' α ' is the value of the symbolic translation.

Proposition 1 [30]: Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function, such that, from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \mathfrak{R}$. This function is defined as

$$\Delta^{-1} : S \times [-0.5, 0.5] \rightarrow [0, g],$$

$$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta. \quad (9)$$

IV. FUZZY DECISION MAKING FRAMEWORK

Evaluation of HCW treatment alternatives requires the consideration of multiple conflicting criteria with the involvement of a group of experts. Since human judgments regarding preferences are often vague, it is difficult to indicate preference with an exact numerical value. A more realistic approach may be to use linguistic assessments rather than numerical values, i.e., to assume that the ratings and weights of the criteria in the problem are assessed by means of linguistic variables [33]. This section outlines the fuzzy MCDM approach proposed by Dursun and Karsak [25], which is based on fusion of fuzzy information, 2-tuple linguistic representation model, and TOPSIS. The stepwise representation of the fuzzy MCDM algorithm is given below.

Step 1. Construct a decision-makers' committee of l experts, and identify the alternatives.

Step 2. Define the required selection criteria employing NGT.

The NGT originated by Delbecq and Van de Ven [34] is a structured group decision-making process for generating ideas, identifying problems, and providing a prioritized list of ideas through voting by group members [35]. It yields a list of ideas pertaining to the topic or issue at hand, and individual and aggregate measures of the desirability of these ideas. The NGT's principal strengths lie in providing an equal voice for all participants, mitigating the stifling effects of perceived status differences among group members, and preventing meetings from descending into incivility or inconclusiveness [36].

Step 3. Construct the decision matrices for each decision-maker that denote the importance weight of criteria, and the fuzzy assessments corresponding to qualitative criteria.

Step 4. Normalize data to obtain unit-free and comparable criteria values. The normalized values for the data regarding benefit-related as well as cost-related sub-criteria are calculated via a linear scale transformation as

$$\tilde{r}_{ijk} = (r_{ijk}^1, r_{ijk}^2, r_{ijk}^3) = \begin{cases} \left(\frac{x_{ijk}^1 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \frac{x_{ijk}^2 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \frac{x_{ijk}^3 - x_{jk}^-}{x_{jk}^* - x_{jk}^-} \right), & k \in CB_j \\ \left(\frac{x_{jk}^* - x_{ijk}^3}{x_{jk}^* - x_{jk}^-}, \frac{x_{jk}^* - x_{ijk}^2}{x_{jk}^* - x_{jk}^-}, \frac{x_{jk}^* - x_{ijk}^1}{x_{jk}^* - x_{jk}^-} \right), & k \in CC_j \end{cases} \quad (10)$$

where \tilde{r}_{ijk} denotes the normalized value of \tilde{x}_{ijk} , which is the linguistic value assigned to alternative i with respect to the criterion j by decision-maker k , m is the number of alternatives, n is the number of criteria, CB_j is the j th benefit-related criterion for which the greater the performance value the more its preference, CC_j is the j th cost-related criterion for which the greater the performance value the less its preference, $x_{jk}^* = \max_i x_{ijk}^3$ and $x_{jk}^- = \min_i x_{ijk}^1$.

Step 5. Considering the importance weights of each criterion, calculate the weighted ratings of each alternative as

$$\tilde{P}_{ijk} = \tilde{w}_{jk} \otimes \tilde{r}_{ijk}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n; k = 1, 2, \dots, l \quad (11)$$

where \tilde{P}_{ijk} is the weighted rating of alternative i with respect to criterion j and decision-maker k , and \otimes denotes the fuzzy multiplication operator.

Step 6. Convert the weighted ratings \tilde{P}_{ijk} into the basic linguistic scale S_T by using Eq. (1). The fuzzy assessment vector on S_T , $F(\tilde{P}_{ijk})$, can be represented as

$$F(\tilde{P}_{ijk}) = (\gamma(\tilde{P}_{ijk}, s_0), \gamma(\tilde{P}_{ijk}, s_1), \dots, \gamma(\tilde{P}_{ijk}, s_8)), \quad \forall i, j, k \quad (12)$$

In this study, the label set given in Table 1 is used as the BLTS [26].

TABLE I
 LABEL SET

Label set	Fuzzy number
s_0 :	(0,0,0.12)
s_1 :	(0,0.12,0.25)
s_2 :	(0.12,0.25,0.37)
s_3 :	(0.25,0.37,0.50)
s_4 :	(0.37,0.50,0.62)
s_5 :	(0.50,0.62,0.75)
s_6 :	(0.62,0.75,0.87)
s_7 :	(0.75,0.87,1)
s_8 :	(0.87,1,1)

Step 7. Aggregate $F(\tilde{P}_{ijk})$ to yield the fuzzy assessment vector $F(\tilde{P}_{ij})$. The aggregated parameters obtained from the assessment data of l experts can be calculated using Eq. (2) as

$$\tilde{P}_{ij}(s_z) = \phi_Q(\gamma(\tilde{P}_{ij1}, s_z), \gamma(\tilde{P}_{ij2}, s_z), \dots, \gamma(\tilde{P}_{ijl}, s_z)), \quad \forall i, j, z \quad (13)$$

where ϕ_Q denotes the OWA operator whose weights are computed using the linguistic quantifier, Q . Then, the fuzzy assessment vector on S_T with respect to criterion C_j , $F(\tilde{P}_{ij})$, is defined as

$$F(\tilde{P}_{ij}) = (\gamma(\tilde{P}_{ij}, s_0), \gamma(\tilde{P}_{ij}, s_1), \dots, \gamma(\tilde{P}_{ij}, s_8)), \quad \forall i, j \quad (14)$$

Step 8. Compute the β values of alternatives with respect to criteria and transform these values into a linguistic 2-tuple, $r_{ij} = (s_{ij}, \alpha_{ij})$, by using Eqs. (7) and (8), respectively.

Step 9. Define the ideal fuzzy linguistic rating value $A^* = (r_1^*, r_2^*, \dots, r_n^*)$ and the anti-ideal fuzzy linguistic rating value $A^- = (r_1^-, r_2^-, \dots, r_n^-)$, where $r_j^* = \max_i \{(s_{ij}, \alpha_{ij})\}$ and $r_j^- = \min_i \{(s_{ij}, \alpha_{ij})\}$ for $j = 1, 2, \dots, n$.

Step 10. Calculate the distances from the ideal and the anti-ideal fuzzy linguistic rating values (d_i^* and d_i^- , respectively) for each alternative A_i as

$$d_i^* = d(A_i, A^*) = \sum_{j=1}^n d(r_{ij}, r_j^*) \quad (15)$$

where

$$d(r_{ij}, r_j^*) = \Delta^{-1}(\max_i \{(s_{ij}, \alpha_{ij})\}) - \Delta^{-1}(s_{ij}, \alpha_{ij}) \quad (16)$$

and

$$d_i^- = d(A_i, A^-) = \sum_{j=1}^n d(r_{ij}, r_j^-) \quad (17)$$

where

$$d(r_{ij}, r_j^-) = \Delta^{-1}(s_{ij}, \alpha_{ij}) - \Delta^{-1}(\min_i \{(s_{ij}, \alpha_{ij})\}) \quad (18)$$

Step 11. Calculate the ranking index (RI) of alternative i as follows:

$$RI_i = \frac{d_i^-}{d_i^- + d_i^*}, \quad i = 1, 2, \dots, m \quad (19)$$

Step 12. Rank the alternatives according to RI_i values in descending order. Identify the alternative with the highest RI_i as the best alternative.

V. EVALUATING HCW TREATMENT ALTERNATIVES USING FUZZY MCDM APPROACH

The amount of wastes collected and processed at the incineration plant in Istanbul has steadily increased as a result of the training effort and the consequence of the regulation [23]. The capacity of the existing incineration plant at Kemberburgaz-Odayeri is not sufficient to incinerate all the health-care wastes generated from both sides of Istanbul.

As a result of discussions with experts from Istanbul Metropolitan Municipality Environmental Protection and Waste Materials Valuation Industry and Trade Co. (ISTAC), capacity of alternative treatment technology is determined as 24 tons/day. We have defined four possible treatment technologies for the disposal of health-care wastes in Istanbul. The considered alternatives are incineration (A_1), steam sterilization (A_2), microwave (A_3), and landfill (A_4).

Employing the NGT, we have defined 12 evaluation criteria as

- i. Cost (C_1),
- ii. Solid residuals and environmental impacts (C_2),
- iii. Water residuals and environmental impacts (C_3),
- iv. Air residuals and environmental impacts (C_4),
- v. Odor (C_5),
- vi. Release with health effects (C_6),
- vii. Reliability (C_7),
- viii. Treatment effectiveness (C_8),
- ix. Level of automation (C_9),
- x. Occupational hazards occurrence frequency (C_{10}),
- xi. Public acceptance obstacles (C_{11}),
- xii. Land requirement (C_{12}).

C_7 , C_8 , and C_9 are classified as benefit-related criteria for which the greater the performance value the more its preference, and the rest are considered as cost-related criteria

for which the greater the performance value the less its preference.

In this paper, the evaluation is conducted by a committee of four decision-makers (DM_1 , DM_2 , DM_3 , and DM_4), which are field experts from ISTAC. DM_1 and DM_2 used the linguistic term set shown in Figure 1, and DM_3 and DM_4 used the linguistic term set depicted in Figure 2 to evaluate the alternatives with respect to each criterion, and to assess the importance of the criteria.

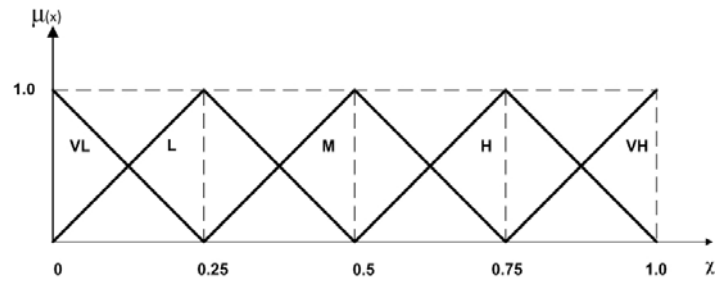


Fig. 1 A linguistic term set where VL : (0, 0, 0.25), L : (0, 0.25, 0.5), M : (0.25, 0.5, 0.75), H : (0.5, 0.75, 1), VH : (0.75, 1, 1).

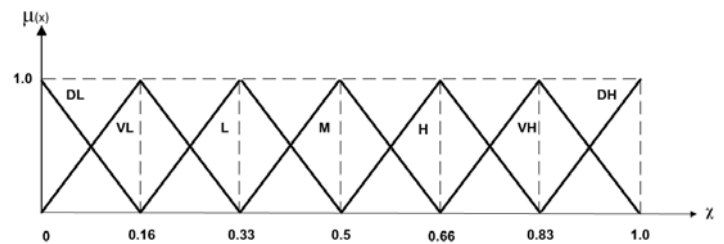


Fig. 2 A linguistic term set where DL : (0, 0, 0.16), VL : (0, 0.16, 0.33), L : (0.16, 0.33, 0.50), M : (0.33, 0.50, 0.66), H : (0.50, 0.66, 0.83), VH : (0.66, 0.83, 1), DH : (0.83, 1, 1).

The computational procedure is summarized as follows:

First, the data is normalized using Eq. (10). Next, the weighted ratings of each alternative are calculated using Eq. (11). These fuzzy numbers are then converted into the BLTS employing Eq. (12). By using the linguistic quantifier 'most' and Eqs. (3) and (4), the OWA weights for four decision-makers are computed as $w = (0, 0.4, 0.5, 0.1)$. Then, we aggregate the weighted ratings converted into BLTS to obtain the aggregated ratings of each alternative with respect to each criteria using Eqs. (13) and (14). The β value of these ratings are computed and transformed into a linguistic 2-tuple using Eqs. (7) and (8), respectively. The distances from the ideal and the anti-ideal fuzzy linguistic rating values for each alternative are computed using Eqs. (15)-(18). Finally, the ranking index for each alternative is computed using Eq. (19) as $RI_1 = 0.543$, $RI_2 = 0.742$, $RI_3 = 0.717$, and $RI_4 = 0.278$. The ranking order of the four alternatives is

$A_2 \succ A_3 \succ A_1 \succ A_4$. Table II summarizes the results obtained using the fuzzy decision framework.

TABLE II
RANKING OF THE ALTERNATIVES USING THE FUZZY DECISION FRAMEWORK

A_i	RI values	Rank
A_1	0.543	3
A_2	0.742	1
A_3	0.717	2
A_4	0.278	4

We observe that "steam sterilization", A_2 , is determined as the most suitable HCW treatment technology and "microwave", A_3 , is ranked as the second alternative treatment technology. "Incineration" ranks as the third while "Landfill" ranks as the last alternative mainly due to their adverse environmental and health impacts.

VI. CONCLUDING REMARKS

Management of the HCW produced in hospitals or health-care facilities has raised concerns relating to public health, occupational safety, and the environment. Therefore, in developing countries there is growing awareness of the need to impose stricter controls on the handling and disposal of HCW. The HCWM problem, which considers several individual attributes exhibiting vagueness and imprecision, may be regarded as a highly important group decision-making problem. The classical MCDM methods that consider deterministic or random processes cannot effectively handle group decision-making problems including imprecise and linguistic information. In this paper, the fuzzy multi-criteria decision making algorithm proposed by Dursun and Karsak [25] is employed to rectify the problems encountered when using classical decision making methods in group decision making problems. The decision making approach set forth in this paper disregards the troublesome fuzzy number ranking process, which may yield inconsistent results for different ranking methods, and as a result improves the quality of decision. Furthermore, the algorithm enables managers to deal with heterogeneous information, and thus, allows for the use of different semantic types by decision-makers.

The evaluation of four HCW treatment alternatives for Istanbul using the fuzzy multi-criteria decision making technique yields "Steam sterilization" as the most suitable alternative, which is followed by "Microwave". "Steam sterilization" is the preferred alternative treatment method for Istanbul since it minimizes the impact on the environment and demonstrates a commitment to public health. "Incineration" ranks after "Microwave" due to its high costs, and adverse environmental and health impacts. Although "Landfill" is an economic alternative compared with other alternatives, it should only be used in a limited extent because of its significant drawbacks related to environment and public health. Future research will focus on taking financial

limitations of Istanbul Metropolitan Municipality explicitly into consideration.

ACKNOWLEDGMENT

This research has been financially supported by Galatasaray University Research Fund Project 09.402.019.

REFERENCES

- [1] V.J. Landrum, R.G. Barton, R. Neulicht, M. Turner, D. Wallace, and S. Stacy, "Medical waste management and disposal," U.S. Environmental Protection Agency, Office of Solid Waste, New Jersey, 1991.
- [2] A. Prüss, E. Giroult, and P. Rushbook, "Safe management of wastes from health-care activities," World Health Organization, Geneva, Switzerland, 1999.
- [3] M. Sawalem, E. Selic, and J.D. Herbell, "Hospital waste management in Libya: A case study," *Waste Management*, vol. 29, pp.1370-1375, 2009.
- [4] B.K. Lee, M.J. Ellenbecker, and R. Moure-Ersaso, "Alternatives for treatment and disposal cost reduction of regulated medical wastes," *Waste Management*, vol. 24, pp. 143-151, 2004.
- [5] L.F. Diaz, G.M. Savage, and L.L. Eggerth, "Alternatives for the treatment and disposal of healthcare wastes in developing countries," *Waste Management*, vol. 25, pp. 626-637, 2005.
- [6] T.L. Tudor, C.L. Noonan, and L.E.T. Jenkin, "Healthcare waste management: a case study from the National Health Service in Cornwall, United Kingdom," *Waste Management*, vol. 25, pp. 606-615, 2005.
- [7] L.F. Diaz, L.L. Eggerth, Sh. Enkhtsetseg, and G.M. Savage, "Characteristics of healthcare wastes," *Waste Management*, vol. 28, pp. 1219-1226, 2008.
- [8] E. Shinee, E. Gombojav, A. Nishimura, N. Hamajima, and K. Ito, "Healthcare waste management in the capital city of Mongolia," *Waste Management*, vol. 28, pp. 435-441, 2008.
- [9] I.A. Al-Khatib, and C. Sato, "Solid health care waste management status at health care centers in the West Bank – Palestinian Territory," *Waste Management*, vol. 29, pp. 2398-2403, 2009.
- [10] L.F. Mohamed, S.A. Ebrahim, and A.A. Al-Thukair, "Hazardous healthcare waste management in the Kingdom of Bahrain," *Waste Management*, vol. 29, pp. 2404-2409, 2009.
- [11] M.M.A. El-Salam, "Hospital waste management in El-Beheira Governorate, Egypt," *Journal of Environmental Management*, vol. 91, pp. 618-629, 2010.
- [12] A.C. Brent, D.E.C. Rogers, T.S.M. Ramabitsa-Siimane, and M.B. Rohwer, "Application of the analytical hierarchy process to establish health care waste management systems that minimize infection risks in developing countries," *European Journal of Operational Research*, vol. 181, pp. 403-424, 2007.
- [13] M. Chaerul, M. Tanaka, and A.V. Shekdar, "A system dynamics approach for hospital waste management," *Waste Management*, vol. 28, pp. 442-449, 2008.
- [14] P.F. Hsu, C.R. Wu, and Y.T. Li, "Selection of infectious medical waste disposal firms by using the analytic hierarchy process and sensitivity analysis," *Waste Management*, vol. 28, pp. 1386-1394, 2008.
- [15] M. Tanaka, and A.V. Shekdar, "Resolving complexities in healthcare waste management: a goal programming approach," *Waste Management & Research*, vol. 26 (3), pp. 217-232, 2008.
- [16] W. Zhao, E. van der Voet, G. Huppel, and Y. Zhang, "Comparative life cycle assessments of incineration and non-incineration treatments for medical waste," *Int J. Life Cycle Assess.*, Vol. 14, pp. 114-121, 2009.
- [17] A. Karagiannidis, A. Papageorgiou, G. Perkoulidis, G. Sanida, and P. Samaras, "A multi-criteria assessment of scenarios on thermal processing of infectious hospital wastes: A case study for Central Macedonia," *Waste Management*, vol. 30, pp. 251-262, 2010.
- [18] M. Kilic, "Optimization of the health-care waste handling and final disposal of the infectious wastes of the hospital-medical centers in the Anatolian Side of Istanbul," M.S. Thesis, Bogazici University, Istanbul, 2004.
- [19] B.A. Zeren, "Health-care waste management of the hospitals in the European Side of Istanbul," M.S. Thesis, Bogazici University, Istanbul, 2004.

- [20] A.Z. Alagoz, and G. Kocasoy, "Treatment and disposal alternatives for health-care waste in developing countries-A case study in Istanbul, Turkey," *Waste Management & Research*, vol. 25, pp. 83-89, 2007.
- [21] A.Z. Alagoz, and G. Kocasoy, "Determination of the best appropriate management methods for the health-care wastes in Istanbul," *Waste Management*, vol. 28, pp. 1227-1235, 2008a.
- [22] A.Z. Alagoz, and G. Kocasoy, "Improvement and modification of the routing system for the health-care waste collection and transportation in Istanbul," *Waste Management*, vol. 28, pp. 1461-1471, 2008b.
- [23] M.E. Birpinar, M.S. Bilgili, and T. Erdogan, "Medical waste management in Turkey: A case study of Istanbul, *Waste Management*" vol. 29, pp. 445-448, 2009.
- [24] C. Chakraborty, and D. Chakraborty, "A fuzzy clustering methodology for linguistic opinions in group decision making," *Applied Soft Computing*, vol. 7, pp. 858-869, 2007.
- [25] M. Dursun, and E.E. Karsak, "A fuzzy MCDM approach for personnel selection," *Expert Systems with Applications*, vol. 37(6), pp. 4324-4330, 2010.
- [26] F. Herrera, E. Herrera-Viedma, and L. Martínez, "A fusion approach for managing multi-granularity linguistic term sets in decision making," *Fuzzy Sets and Systems*, vol. 114(1), pp. 43-58, 2000.
- [27] R.R. Yager, "On ordered weighted averaging aggregation operators in multi-criteria decision making," *IEEE Transactions on Systems Man and Cybernetics*, vol. 18(1), pp. 183-190, 1988.
- [28] M. Zarghami, and F. Szidarovszky, "Fuzzy quantifiers in sensitivity analysis of OWA operator," *Computers & Industrial Engineering*, vol. 54(4), pp. 1006-1018, 2008.
- [29] D.P. Filev, and R.R. Yager, "On the issue of obtaining OWA operator weights," *Fuzzy Sets and Systems*, vol. 94, pp. 157-169, 1998.
- [30] F. Herrera, and L. Martínez, "A 2-tuple fuzzy linguistic representation model for computing with words," *IEEE Transactions on Fuzzy Systems*, vol. 8(6), pp. 746-752, 2000b.
- [31] Z.P. Fan, B. Feng, Y.H. Sun, and W. Ou, "Evaluating knowledge management capability of organizations: a fuzzy linguistic method," *Expert Systems with Applications*, vol. 36(2), pp. 3346-3354, 2009.
- [32] F. Herrera, and L. Martínez, "An approach for combining linguistic and numerical information based on 2-tuple fuzzy representation model in decision-making," *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, vol. 8(5), pp. 539-562, 2000a.
- [33] C.T. Chen, "Extension of the TOPSIS for group decision-making under fuzzy environment," *Fuzzy Sets and Systems*, vol. 114, pp. 1-9, 2000.
- [34] A.L. Delbecq, and A.H. Van de Ven, "Nominal versus interacting group processes for committee decision-making effectiveness," *Acad. Manage. J.*, vol. 14, pp. 203-212, 1971.
- [35] C. Moon, J. Lee, and S. Lim, "A performance appraisal and promotion ranking system based on fuzzy logic: An implementation case in military organizations," *Applied Soft Computing*, vol. 10, pp. 512-519, 2010.
- [36] D.M. Spencer, "Facilitating public participation in tourism planning on American Indian reservations: A case study involving the Nominal Group Technique," *Tourism Management*, vol. 31, pp. 684-690, 2010.

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