Fuzzy Group Decision Making for the Assessment of Health-Care Waste Disposal Alternatives in Istanbul

Mehtap Dursun, E. Ertugrul Karsak and Melis Almula Karadayi

Abstract—Disposal of health-care waste (HCW) is considered as an important environmental problem especially in large cities. Multiple criteria decision making (MCDM) techniques are apt to deal with quantitative and qualitative considerations of the health-care waste management (HCWM) problems. This research proposes a fuzzy multi-criteria group decision making approach with a multi-level hierarchical structure including qualitative as well as quantitative performance attributes for evaluating HCW disposal alternatives for Istanbul. Using the entropy weighting method, objective weights as well as subjective weights are taken into account to determine the importance weighting of quantitative performance attributes. The results obtained using the proposed methodology are thoroughly analyzed.

Keywords—Entropy weighting method, group decision making, health-care waste management, hierarchical fuzzy multi-criteria decision making

I. INTRODUCTION

RECENTLY, an increasing number of researchers have been focusing on working out realistic solutions to environmental problems. As environmental issues gain higher importance for organizations, the management of environmental decisions becomes critical. Health-care waste (HCW) management is considered as a key part of the environmental management problems. Consequently, constructing an efficient health-care waste management (HCWM) system, which considers environmental, economic, technical and social factors, is of outmost importance.

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 ([1], [2], [3], [4], [5], [6]). Recently, a number of studies have focused on HCWM practices in Istanbul, listed among the world's largest cities with nearly 13 million inhabitants ([7], [8], [9], [10], [11], [12]).

Evaluating HCW disposal 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. In HCWM problems, uncertainty plays an important role. Fuzzy set theory can be used in real-world decision making problems for quantifying the qualitative data.

This paper focuses on the detailed multi-attribute evaluation of a number of HCW disposal alternatives to determine the most suitable one for Istanbul, one of the most crowded cities in Europe. The HCW disposal 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 stream 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 presents a hierarchical distance-based fuzzy multi-criteria group decision making framework for evaluating HCW disposal alternatives for Istanbul enabling both subjective and objective weight assessments of the criteria and related sub-criteria to be taken into consideration. The main contribution of the proposed approach is that it can address decision problems having a multi-level hierarchical structure where qualitative as well as quantitative performance attributes are present. As individuals intuitively attempt to be both as close as possible to the ideal and as distant as possible from the anti-ideal, the ideal and anti-ideal solutions are considered simultaneously in the proposed approach.

The rest of the paper is organized as follows. The following section provides information on the entropy weighting method. Section 3 presents the decision making framework for the evaluation of the HCW disposal alternatives. In section 4, the application of the proposed model to Istanbul's HCWM problem is presented. Finally, concluding remarks are given in section 5.

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II. Entropy WEIGHTING Method

Entropy has become an important concept in the social sciences as well as in the physical sciences. In addition, entropy has a useful meaning in information theory, where it measures the expected information content of a certain message. The entropy idea is particularly useful to investigate contrasts between sets of data. For instance, a criterion does not function much when all the alternatives have the similar outcomes for that criterion. Further, if all the values are the same, we can eliminate the criterion.

Let Ψ be a decision matrix of m alternatives and n criteria where ψ_{ij} represents the rating of alternative i $(i = 1,2,...,m)$ with respect to criterion j $(j = 1,2,...,n)$.

$$\Psi = \begin{bmatrix} \psi_{11} & \psi_{12} & \cdots & \psi_{1n} \\ \psi_{21} & \psi_{22} & \cdots & \psi_{2n} \\ \vdots & \vdots & & \vdots \\ \psi_{m1} & \psi_{m2} & \cdots & \psi_{mn} \end{bmatrix}$$

The entropy Ej of the jth attribute is

$$E_j = -\kappa \sum_i \frac{\psi_{ij}}{\sum\limits_{i=1}^{m} \psi_{ij}} \ln \frac{\psi_{ij}}{\sum\limits_{i=1}^{m} \psi_{ij}}, \ \forall j \tag{1}$$

where κ represents a constant $\kappa = \frac{1}{\ln m}$ which guarantees that $0 \le E_j \le 1$.

The degree of diversification dj of the information provided by the criterion j can be defined as

$$d_j = 1 - E_j, \ \forall j \tag{2}$$

If the decision-maker has no reason to prefer one criterion over another, the principle of insufficient reason suggests that each one should be equally preferred. Then, the best weight set he/she can expect, rather than the equal weight, is

$$\lambda_j = \frac{d_j}{\sum\limits_j d_j}, \ \forall j \tag{3}$$

If the decision-maker has a prior, subjective weight $\widetilde{w}_j$, then by combining $\widetilde{w}_j$ and λ_j the new integrated weight is obtained as

$$\widetilde{w}_j^0 = \frac{\widetilde{w}_j \lambda_j}{\sum\limits_j \widetilde{w}_j \lambda_j}, \ \forall j \tag{4}$$

III. Fuzzy Multi-criteria Decision Making Approach

This paper presents the multi-expert version of the hierarchical distance-based fuzzy MCDM algorithm proposed by Karsak and Ahiska [13] to evaluate the HCW disposal alternatives for Istanbul. The proposed framework can address decision problems possessing a multi-level hierarchical structure with a number of qualitative as well as quantitative performance attributes. The stepwise representation of the proposed fuzzy MCDM algorithm is given below.

Step 1. Construct a decision-makers' committee of z experts $(l = 1,2,...,z)$. Define the alternatives, required selection criteria, and related sub-criteria in a hierarchical structure.

Step 2. Construct the decision matrices that represent the importance weights of criteria and related sub-criteria, and the fuzzy assessments corresponding to qualitative and quantitative sub-criteria for each decision-maker.

Step 3. Define the rating of alternative i with respect to sub-criterion k of criterion j, importance weight of sub-criterion k of criterion j, and importance weight of criterion j for the lth decision-maker as $\widetilde{x}_{ijkl} = (x_{ijkl}^1, x_{ijkl}^2, x_{ijkl}^3)$, $\widetilde{w}_{jkl} = (w_{jkl}^1, w_{jkl}^2, w_{jkl}^3)$ and $\widetilde{w}_{jl} = (w_{jl}^1, w_{jl}^2, w_{jl}^3)$, respectively. Calculate the aggregated ratings of alternatives $(\widetilde{x}_{ijk})$, the aggregated importance weights of sub-criteria $(\widetilde{w}_{jk})$, and the aggregated importance weights of criteria $(\widetilde{w}_j)$ as

$$\widetilde{x}_{ijk} = \sum_l v_l \widetilde{x}_{ijkl} \tag{5}$$

$$\widetilde{w}_{jk} = \sum_l v_l \widetilde{w}_{jkl} \tag{6}$$

$$\widetilde{w}_j = \sum_l v_l \widetilde{w}_{jl} \tag{7}$$

where $v_l \in [0,1]$ and $\sum\limits_l v_l = 1$.

Hence, the aggregated ratings of alternatives with respect to each sub-criterion can be calculated as $\widetilde{x}_{ijk} = (x_{ijk}^1, x_{ijk}^2, x_{ijk}^3)$, the aggregated importance weights of sub-criteria can be computed as $\widetilde{w}_{jk} = (w_{jk}^1, w_{jk}^2, w_{jk}^3)$, and the aggregated importance weights of criteria can be obtained as $\widetilde{w}_j = (w_j^1, w_j^2, w_j^3)$.

Step 4. Normalize the aggregated decision matrix to obtain unit-free and comparable sub-criteria values. The normalized values for the data regarding benefit-related sub-criteria (CB$_j$) as well as cost-related sub-criteria (CC$_j$) are calculated via a linear scale transformation as

$$\tilde{r}_{ijk} = \begin{cases} \left(\dfrac{x_{ijk}^1 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^2 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^3 - x_{jk}^-}{x_{jk}^* - x_{jk}^-} \right), & k \in CB_j \\[3mm] \left(\dfrac{x_{jk}^* - x_{ijk}^3}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^2}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^1}{x_{jk}^* - x_{jk}^-} \right), & k \in CC_j \end{cases} \tag{8}$$

where $\tilde{r}_{ijk}$ denotes the normalized value of $\tilde{x}_{ijk}$, m is the number of alternatives, n is the number of criteria, $x_{jk}^* = \max_i x_{ijk}^3$ and $x_{jk}^- = \min_i x_{ijk}^1$. For benefit-related sub-criteria, the greater the performance value is the more its preference, whereas for cost-related sub-criteria the greater the performance value is the less its preference.

Step 5. Defuzzify the objective ratings as [14]

$$F(\tilde{r}_{ijk}) = \frac{r_{ijk}^1 + 4r_{ijk}^2 + r_{ijk}^3}{6} \tag{9}$$

and construct the decision matrix Ψ.

Step 6. Compute the new integrated weights $\tilde{w}_{jk}^0$ for objective sub-criteria by using Eqs. (1)-(4).

Step 7. Normalize $\tilde{w}_{jk}^0$ by employing Eq. (8). The normalized value of $\tilde{w}_{jk}^0$ are denoted as $\tilde{w}_{jk}'^0$. For subjective sub-criteria, let $\tilde{w}_{jk} = \tilde{w}_{jk}'^0$.

Step 8. Aggregate the performance ratings of alternatives at the sub-criteria level to criteria level as

$$\tilde{y}_{ij} = (y_{ij}^1, y_{ij}^2, y_{ij}^3) = \frac{\sum_k \tilde{w}_{jk}'^0 \otimes \tilde{r}_{ijk}}{\sum_k \tilde{w}_{jk}'^0}, \forall i,j \tag{10}$$

where $\tilde{y}_{ij}$ represents the aggregate performance rating of alternative i with respect to criterion j and $\otimes$ is the fuzzy multiplication operator.

Step 9. Normalize the aggregate performance ratings at criteria level using a linear normalization procedure, which results in the best value to be equal to 1 and the worst one to be equal to 0, as follows:

$$\tilde{y}_{ij}' = \left(\frac{y_{ij}^1 - y_j^-}{y_j^* - y_j^-}, \frac{y_{ij}^2 - y_j^-}{y_j^* - y_j^-}, \frac{y_{ij}^3 - y_j^-}{y_j^* - y_j^-} \right), \forall i,j \tag{11}$$

where $y_j^* = \max_i y_{ij}^3$, $y_j^- = \min_i y_{ij}^1$, and $\tilde{y}_{ij}'$ denotes the normalized aggregate performance rating of alternative i with respect to criterion j.

Step 10. Define the ideal solution $A^* = (r_1^*, r_2^*, \ldots, r_n^*)$ and the anti-ideal solution $A^- = (r_1^-, r_2^-, \ldots, r_n^-)$, where $r_j^* = (1,1,1)$ and $r_j^- = (0,0,0)$ for $j = 1,2,\ldots,n$.

Step 11. Calculate the weighted distances from ideal solution and anti-ideal solution (D_i^* and D_i^-, respectively) for each alternative by employing the distance formula developed by Bojadziev and Bojadziev [15] as

$$D_i^* = \sum_j 1/2 \left\{ \max \left(w_j^1 \left| y_{ij}'^1 - 1 \right|, w_j^3 \left| y_{ij}'^3 - 1 \right| \right) + w_j^2 \left| y_{ij}'^2 - 1 \right| \right\}, \forall i \tag{12}$$

$$D_i^- = \sum_j 1/2 \left\{ \max \left(w_j^1 \left| y_{ij}'^1 - 0 \right|, w_j^3 \left| y_{ij}'^3 - 0 \right| \right) + w_j^2 \left| y_{ij}'^2 - 0 \right| \right\}, \forall i \tag{13}$$

Step 12. Calculate the proximity of the alternatives to the ideal solution, Ω_i^*, by considering the distances from ideal and anti-ideal solutions as

$$\Omega_i^* = \frac{D_i^-}{\left(D_i^* + D_i^- \right)}, \quad \forall i \tag{14}$$

Rank the alternatives according to Ω_i^* values in descending order.

IV. APPLICATION OF THE MCDM FRAMEWORK TO HEALTH-CARE WASTE MANAGEMENT IN 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. Treatment systems for steam sterilization and microwaving are selected with pre-shredding component that exposes a greater surface area for treatment by utilizing a shredder that reduces the waste to a uniform and relatively small size matter. The considered alternatives are incineration (A_1), steam sterilization (A_2), microwave (A_3), and landfill (A_4).

Benefiting from the literature on the assessment of health-care disposal alternatives and discussions with the experts, economic criteria, environmental criteria, technical criteria, and social criteria, and their related sub-criteria are identified as the evaluation attributes in a hierarchical framework as depicted in Fig. 1.

Criteria and related sub-criteria are given in Table I. Capital cost, operating cost, and volume reduction are considered as objective sub-criteria.

In this paper, the importance weights of criteria and related sub-criteria, and the ratings of qualitative criteria are considered as linguistic variables.
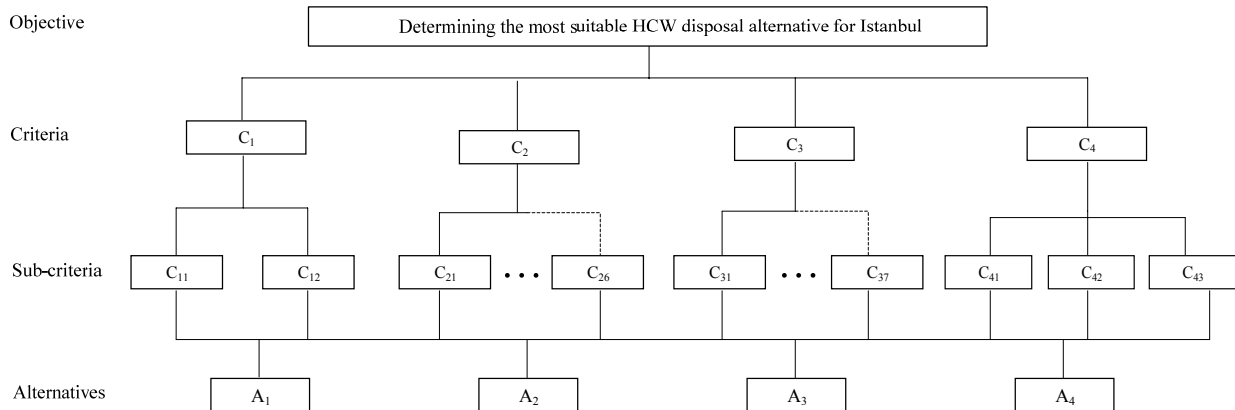
Fig. 1 Hierarchical structure of the problem

TABLE I
CRITERIA AND RELATED SUB-CRITERIA

Economic (C_1)
    Capital cost (C_{11})
    Operating cost (C_{12})
Environmental (C_2)
    Solid residuals and environmental impacts (C_{21})
    Water residuals and environmental impacts (C_{22})
    Air residuals and environmental impacts (C_{23})
    Noise (C_{24})
    Odor(C_{25})
    Release with health effects (C_{26})
Technical (C_3)
    Reliability (C_{31})
    Treatment effectiveness (C_{32})
    Volume reduction (C_{33})
    Level of automation (C_{34})
    Need for skilled operators (C_{35})
    Occupational hazards occurrence frequency (C_{36})
    Occupational hazards occurrence impact (C_{37})
Social (C_4)
    Adaptability to environmental policy (C_{41})
    Public acceptance obstacles (C_{42})
    Land requirement (C_{43})

The decision-makers used the linguistic variables given in Table II to denote the importance of the criteria and sub-criteria, as well as to evaluate the ratings of alternatives with respect to sub-criteria.

TABLE II
LINGUISTIC TERM SET

Very Low (VL)	(0, 0, 0.25)
Low (L)	(0, 0.25, 0.5)
Moderate (M)	(0.25, 0.5, 0.75)
High (H)	(0.5, 0.75, 1)
Very High (VH)	(0.75, 1, 1)

The evaluation is conducted by a committee of five experts, consisting of field experts from ISTAC, a university professor, and a technical advisor specialized in waste management. The computational procedure is as follows:

By using Eqs. (5)-(7), we aggregate the decision-makers' evaluations to obtain the aggregated ratings of alternatives with respect to each sub-criterion, the aggregated importance weights of sub-criteria, and the aggregated importance weights of criteria. One shall note that $v_1 = v_2 = ... = v_5 = \dfrac{1}{5}$ in our case, since equal weights are assigned to decision-makers. Then, the aggregated ratings are normalized by employing Eq. (8). Using Eq. (9) the normalized ratings of the objective sub-criteria are defuzzified, and the Ψ matrix is constructed as

$$\Psi = \begin{bmatrix} 0.075 & 0.370 & 0.857 \\ 0.741 & 0.852 & 0.571 \\ 0.570 & 0.481 & 0.571 \\ 0.985 & 0.932 & 0.167 \end{bmatrix}$$

By employing Eqs. (1)-(3), λ_j are computed as 0.525, 0.172, and 0.304 for capital cost, operating cost, and volume reduction, respectively. After that, the normalized values of the new integrated weights, $\widetilde{w}'^{0}_{jk}$, for the objective sub-criteria are computed by utilizing Eqs. (4) and (8).

Then, sub-criteria values are aggregated to criteria level using Eq. (10). The normalized values of these aggregate performance ratings are computed using Eq. (11). Subsequently, the weighted distances of each HCW disposal alternative from ideal and anti-ideal solutions, D_i^* and D_i^-, are calculated using Eqs. (12) and (13), respectively. Finally, the proximity to the ideal solution for each HCW disposal is computed employing Eq. (14) and the results are presented in Table III.

We observe that that "Steam sterilization", A_2, with the highest Ω_i^* value is the most preferred HCW disposal technology for Istanbul and it is followed by "Microwave" (A_3). "Landfill" is positioned as the third while "Incineration" ranks as the last HCW disposal alternative mainly due to their unfavorable environmental and health impacts.

V. CONCLUDING REMARKS

Recently, due to the rise in the environmental problems caused by the health-care wastes, it is necessary to construct an efficient HCWM system, which considers numerous

factors including environmental, economic, technical, and social aspects.

TABLE III
RANKING OF THE HCW DISPOSAL ALTERNATIVES

A_i	D_i^*	D_i^-	Ω_i^*	Ranking
A_1	2.056	1.678	0.449	4
A_2	1.051	2.802	0.727	1
A_3	1.280	2.573	0.668	2
A_4	1.760	1.929	0.523	3

Some of these factors can be quantified, while others are qualitative at most. Thus, selecting the appropriate HCWM system appears as a multi-criteria decision making problem with a hierarchical structure. In this paper, the multi-expert version of the hierarchical distance-based fuzzy MCDM algorithm initially proposed by Karsak and Ahiska [13] is employed for evaluating the HCW disposal alternatives for Istanbul. In classical MCDM methods, the ratings and the weights of the criteria are assumed to be known precisely. However, in general, crisp data are inadequate to model real-life situations. Besides having the capability of considering numerous attributes that are structured in a multi-level hierarchy, the proposed decision framework enables the decision-makers to use linguistic terms. Since the importance weight of objective criterion is related to both a priori subjective assessment of the criterion's importance, and context-dependency concept of informational importance, the proposed framework employs the entropy weighting method in determining the weights of the objective criteria.

According to the evaluation of four HCW disposal alternatives for Istanbul using the fuzzy multi-criteria decision making technique, non-incineration technologies "steam sterilization" and "microwave" are placed in the first and second ranks since they appear to emit fewer pollutants and generate non-hazardous residues. While "Landfill" is an economic alternative compared with other alternatives, it should only be used in a limited extent considering its several drawbacks for the environment and public health. "Incineration" ranks after non-incineration alternative technologies due to its high costs, and adverse environmental and health impacts.

Future research will focus on applying the decision framework presented in here to real-world group decision making problems in diverse disciplines.

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