A Fuzzy Multi-Criteria Approach to WEEE Treatment Strategy Selection*

İlke Bereketli[1] Tuncay Gürbüz[2] Müjde Erol Genevois[3]

1, 2, 3 Department of Industrial Engineering, Galatasaray University
İstanbul, Turkey
Email: ibereketli@gsu.edu.tr, tgurbuz@gsu.edu.tr, merol@gsu.edu.tr

Abstract— *Today's one of the biggest environmental problem is the alarming increase of the wastes electrical and electronic equipments (WEEE). This type of waste threats the environment and the human health by contaminating air, soil and water, because of toxic materials including in the electrical and electronic equipments (EEE). That's why we should look for exploring the environmental friendly ways to dispose of these wastes and the producers should select an appropriate strategy. Waste treatment strategies contribute also to either local or global economies by creating a new sector and employment, and by reducing use of scarce resources. In this paper, we use a fuzzy hierarchical TOPSIS method for solving multi attribute group decision making (MAGDM) problems with preference information on alternatives in fuzzy environment. Our aim is to develop a fuzzy hierarchical TOPSIS model to evaluate and to select of a waste treatment strategy for electrical and electronic equipments (EEE). In this direction, three treatment strategies alternatives and six criteria are determined. The best strategy is selected and the key criterion is found.*

Keywords— Fuzzy AHP, Fuzzy Hierarchical TOPSIS, Fuzzy TOPSIS, WEEE treatment strategies.

1 Introduction

Both technological innovation and market expansion continue to accelerate the replacement of equipment leading to a significant increase of waste electric and electronic equipment (WEEE). Hence, electrical and electronic equipments, which are a subset of technological equipments, have already begun to accumulate at the garbage dumps.

Many countries have drafted legislation to improve the reuse, recycling and other forms of recovery of such wastes so as to reduce disposal [1]. The European Commission identified the need for legislation to address the escalating problem of WEEE at the Community level, and this has taken the form of the WEEE Directive. The EU's Directive 2002/96/EC about WEEE has extended producer responsibility as its main principal and aims to increase reuse and recycling ratios [2]. This Directive obligates electronic and electrical equipment producers to take back old equipment from customers free of charge and to dispose of these wastes environmentally [3]. Turkey is also on the way to prepare a new regulation about WEEE.

In this paper, a Fuzzy multi-criteria decision making (MCDM) approach is proposed for multiple attribute group decision making (MAGDM) problems with preference information on alternatives. This approach is used to evaluate and select a waste treatment strategy for electrical and electronic equipments (EEE). In this study, Fuzzy Hierarchical Technique for Order Preference by Similarity to Ideal Solution (FH-TOPSIS) is used to reflect the decision maker's subjective preference information and to determine the weight vector of criteria, and to get the rankings of different alternatives.

In the remaining part of the paper, waste treatment strategies and the case study are mentioned. Section 2 includes some definitions, alternatives and criteria required for the evaluation of the strategies. The proposed methodology is represented in Section 3. Section 4 contains the scope of the application and the results of the study. Finally in Section 5, conclusions driven from the research are provided.

2 Selection of Waste Treatment Strategies and a Case Study

WEEE, or e-waste, can be described in general as all electrical and electronic equipments that have terminated their useful life. Widmer *et al.* defines WEEE as a generic term embracing various forms of electric and electronic equipment that have ceased to be of any value to their owners, or a waste type consisting of any broken or unwanted electrical or electronic appliance [4]. In respect of EU's Directive 2002/96/EC, WEEE's definition is as follows: WEEE means electrical or electronic equipment including all components, subassemblies and consumables which are part of the product at the time of discarding [5]. So many official and non-official foundations give its own definition, therefore there is, as yet, no standard definition.

There are generally three different ways of treating WEEE: reuse, recycling and disposal (such as incineration, landfill). The EEE producers prefer at least one of these treatment strategies in order to discard their e-wastes. In this paper, it is examined that which one should be selected considering related criteria.

A case study was already realized by Bereketli *et al.*, in a telecommunication enterprise which produces and sells cell phones in Turkey [6]. A linear programming technique for multidimensional analysis of preference (LINMAP) method for solving MAGDM problems with preference information on alternatives in fuzzy environment was proposed. The aim was to develop a fuzzy LINMAP model to evaluate and to select of a waste treatment strategy for electrical and electronic equipments (EEE). At the end of the study, The

* This work is financially supported by Galatasaray University Research Fund.

ISBN: 978-989-95079-6-8

Fuzzy LINMAP method gave the ranking of the alternatives under the problems criteria as $A1 \succ A3 \succ A2$.

The objective of this study is to evaluate the alternatives considering all criteria with a different approach, Fuzzy Hierarchical TOPSIS method, and to observe the differences between the results. As we need the independence between the problem's criteria with the proposed method, some of the criteria between which there may be dependences are grouped under one criterion.

There are three alternatives: treating WEEE by reuse and recycling methods (2R), by insourced disposal methods, and by outsourced disposal methods. In the first alternative, the enterprise reuses or recycles its own WEEE within the facility. In the second alternative, the enterprise carries its own WEEE from its own waste collection store to an area which is purchased in order to dispose of the e-wastes by landfill or incineration. In the third and last alternative, the enterprise outsources its disposal process of its own WEEE to a specialized company. This company goes to the waste collection center periodically, gets there e-waste of the telecommunication enterprise, and brings them to its own facility. In its facility, it realizes disassembly of the e-waste and dissects some valuable integrated circuits. The telecommunication enterprise takes back these circuits periodically and reuses them in its assembly line. The outsourced company environment friendly disposes of the other parts of the e-waste.

It has been determined 6 criteria, 3 of them are quantitative (Type-1: T1) and 3 of them are qualitative (Type-2: T2). The criteria based on three alternatives are as follows:

- C1 - Waste release period: It is the period in which e-waste returns to the production line by passing reuse or recycling processes, or ends its life cycle by being disposed of. Small number of periods is preferred. Its unit is period time. (T1)
- C2 - Cost: This criterion includes the first investment, stock and process costs. It is the cost for creating new lines, implementing hardware, buying new machines, and new trucks for transporting e-waste, or purchasing an area where the telecommunication enterprise disposes of its e-waste, or contracting with the outsourced enterprise, stocking e-waste transported from waste collection center, every operation for each process during the period of e-waste treatment. Its unit is thousands of Turkish Liras (TL). (T1)
- C3 - Ratio of resource conservation: It is the ratio of the returned products (e-waste) quantity over total electrical and electronic equipment produced. Its unit is percentage. (T1)
- C4 - Capacity need: It is the need of labor-hour. (T2)
- C5 - Risk of damage for the nature and the human health: It is the potential of damaging the nature and the human health for each alternative when e-wastes are treated by their own way. (T2)
- C6 - Convenience to the possessed technology: It is the criteria about the degree of sufficiency of the technology that the telecommunication enterprise have. (T2)

3 Methodology

3.1 *Basic concepts of Fuzzy Analytic Hierarchy Process (FAHP)*

In this paper the FAHP approach is introduced, with the use of Triangular Fuzzy Numbers for pairwise comparison scale of FAHP according to the method of Chang's [7] fuzzy extent analysis by applying correct normalization formula given later by Wang *et al.* [8].

3.1.1 *The construction of fuzzy judgment*

In the conventional AHP, the pairwise comparisons for each level with respect to the goal are conducted using a nine-point scale proposed by Saaty [9]. According to Zadeh [10], it is very difficult for conventional quantification to define the complex situations, so the notion of a linguistic variable, whose values are words or sentences, is necessary. To assess the relative importance of the criteria and to evaluate the alternatives respecting the problems criteria an assumed weighting set has been developed.

The decision makers can use the linguistic rating set. The triangle fuzzy conversion scale of the linguistic values in the weighting set is shown in Table 1.

Table 1: The triangular fuzzy conversion scale

Very Low (VL)	(0, 3/6,1)
Low (L)	(2/3, 7/6, 5/3)
Medium (M)	(4/3, 11/6, 7/3)
High (H)	(2, 15/6, 3)
Very High (VH)	(8/3, 19/6, 11/3)

3.1.2 *Value of fuzzy synthetic extent*

The steps of Chang's extent analysis can be given as in the following [7]:

- First, by fuzzy arithmetic operations, take the sum of each row of the fuzzy comparison matrix.

$$RS_i = \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij},\ \sum_{j=1}^{n} m_{ij},\ \sum_{j=1}^{n} u_{ij} \right),\quad i = 1,\ldots,n \tag{1}$$

- Using fuzzy synthetic extent analysis, the value of fuzzy synthetic extent with respect to the ith object x_i, $i = 1,2,\ldots,n$ that represents the overall performance of the object across all goals can be determined by the following normalization formula given by Wang et al. [8]:

$$\tilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{\substack{k=1\\ k\neq i}}^{n} \sum_{j=1}^{n} u_{kj}},\ \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{ij}},\ \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{\substack{k=1\\ k\neq i}}^{n} \sum_{j=1}^{n} l_{kj}} \right),\quad i = 1,\ldots,n \tag{2}$$

ISBN: 978-989-95079-6-8

- Compute the degree of possibility of $\tilde{S}_i \geq \tilde{S}_j$ by the following equation where $\tilde{S}_i = (l_i, m_i, u_i)$ and $\tilde{S}_j = (l_j, m_j, u_j)$:

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1, & if \quad m_i \geq m_j, \\ \dfrac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & if \quad l_j \leq u_i, \quad i, j = 1, \ldots, n; i \neq j \\ 0, & otherwise \end{cases} \quad (3)$$

- To compare $\tilde{S}_i = (l_i, m_i, u_i)$ and $\tilde{S}_j = (l_j, m_j, u_j)$, we need both the values of $V(\tilde{S}_i \geq \tilde{S}_j)$ and $V(\tilde{S}_j \geq \tilde{S}_i)$. The degree of possibility for a convex fuzzy number $\tilde{S}$ to be greater than k convex fuzzy numbers $\tilde{S}_i$, i=1,…,k can be defined by:

$$V(M \geq M_1, \ldots, M_k) = V[(M \geq M_1) \wedge \ldots \wedge (M \geq M_k)] = \min V(M \geq M_i) \quad (4)$$
$$\text{for } i = 1,2,\ldots,k$$

- Assume that for the alternative Ai,

$$d'(A_i) = \min V(S_i \geq S_j), \text{ for } j = 1,2,\ldots,n; j \neq i \quad (5)$$

- Then the weight vector is given by,

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (6)$$

- Via normalization, the normalized weight vectors are,

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (7)$$

3.2 *Fuzzy TOPSIS*

3.2.1 *Basic concepts of Fuzzy TOPSIS*

TOPSIS, developed by Yoon [11] and Hwang and Yoon [12] uses the following intuitive principle: The chosen alternative has to be the one having the smallest distance to the ideal solution and the biggest distance to the negative-ideal solution. But, the alternative which has the smallest distance to the ideal solution doesn't have necessarily the biggest distance to the nadir solution and vice versa. Hence, TOPSIS considers both distances to the ideal and nadir solutions simultaneously by measuring the relative closeness, RC, of the alternatives to the alternative called the « ideal solution ».

We can convert the decision matrix into a fuzzy decision matrix and construct a weighted normalized fuzzy decision matrix once the decision makers' fuzzy ratings have been collected. According to the TOPSIS model, we define the fuzzy ideal solution and fuzzy negative-ideal solution. And then a vertex method, proposed by Chen [13] is used in this paper to calculate the distance between two triangular fuzzy ratings.

Finally, the relative closeness of each alternative is defined to determine the final ranking of the alternatives.

3.2.2 *Selection Procedure with Fuzzy TOPSIS*

- Construct the Decision Matrix where all the data for the alternatives according the problems criteria is collected.
- Normalize the DM: To avoid the complicated normalization formula used in classical TOPSIS, the linear scale transformation is used here to transform the various criteria scales into a comparable scale.

$$\tilde{x}_{ij} = \begin{cases} \left(\dfrac{a_{ij} - a_j^-}{c_j^* - a_j^-}, \dfrac{b_{ij} - a_j^-}{c_j^* - a_j^-}, \dfrac{c_{ij} - a_j^-}{c_j^* - a_j^-} \right) & \text{for j of a criteria of output nature} \\ \left(\dfrac{c_j^* - c_{ij}}{c_j^* - a_j^-}, \dfrac{c_j^* - b_{ij}}{c_j^* - a_j^-}, \dfrac{c_j^* - a_{ij}}{c_j^* - a_j^-}, \right) & \text{for j of a criteria of input nature} \end{cases} \quad (8)$$

- Find the weighted DM and define the ideal and the nadir alternatives namely A^+ and A^-. Note that after this normalization, the ideal (resp. nadir) alternative will be found by taking the maximum (resp. minimum) value for each criterion.
- Define distances of A_i from A^+ and A^- as follows:

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{x}_{ij}, \tilde{x}_j^+) \text{ where } i = 1,2,\ldots,M \quad (9)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{x}_{ij}, \tilde{x}_j^-) \text{ where } i = 1,2,\ldots,M \quad (10)$$

with

$$d(\tilde{x}_i, \tilde{x}_j) = \sqrt{\frac{1}{3}\left[(l_i - l_j)^2 + (m_i - m_j)^2 + (u_i - u_j)^2\right]} \quad (11)$$

- Rank the preference order of m alternatives by their relative closeness (RC) to the ideal alternative (the smaller the value of RC for an alternative, the more that alternative is preferred) which is given for the ith alternative as:

$$RC_i = \frac{d_i^+}{(d_i^+ + d_i^-)} \quad (12)$$

3.2.3 *Proposed Method*

In this study, the proposed method works as follows:

- Relative priorities for the criteria and the alternatives for the subjective criteria are obtained from the pairwise comparison matrices of the FAHP method using the extension principle.
- Subjective criteria ratings for the alternatives obtained in the previous step and objective criteria values are collected in a decision matrix.
- Finally Fuzzy TOPSIS is applied in order to find the ranking between the alternatives.

ISBN: 978-989-95079-6-8

4 Application

For the application of the proposed method, we asked their opinions to three decision makers. You can see in Table 2 one of the comparison matrices.

Table 2: Comparison matrices

C6	***A1***	***A2***	***A3***
A1	*	MH, H, H	VH, VH, VH
A2		*	MH, H, MH
A3			*

According to the ratings they have given, the pairwise comparison matrices are formed in order to weigh the problem's criteria and to obtain the relative priorities of the subjective criteria.

From these comparison matrices, using Fuzzy AHP method, the following results presented in Table 3 and Table 4 are obtained:

Table 3: Criteria weights

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Weights	.125	.198	.20	.11	.213	.15

Table 4: Relative priorities of the alternatives for the subjective criteria

	C4	**C5**	**C6**
A1	0.49	0.047	0.273
A2	0.415	0.735	0.281
A3	0.095	0.218	0.446

For the objective criteria, the values obtained by the alternatives are provided by the experts. For C1, the values were given by crisp values. On the other hand, for C2 and C3 they were agreed on giving by using the fuzzy values presented in Table 5.

As we defuzzified the fuzzy linguistic values given by the experts on the subjective criteria using Fuzzy AHP, while we apply Fuzzy TOPSIS in order to rank our alternatives, for these criteria, we will use the relative priorities given in Table 3 as crisp values. For example, the value obtained by A1 for the criteria C4, will be noted as (.49,.49,.49).

Therefore, we constructed the final decision matrix and normalized decision matrix as follows:

Table 5: Final decision matrix

	C1	**C2**	**C3**
A1	(4,4,4)	(887.5, 1095, 1207)	(30, 50, 80)
A2	(1,1,1)	(354.5, 460, 516)	(0,0,0)
A3	(2,2,2)	(174.5, 205, 231)	(3, 6, 10)
	C4	**C5**	**C6**
A1	(.49,.49,.49)	(.087,.087,.087)	(.273,.273,.273)
A2	(.415,.415,.415)	(.689,.689,.689)	(.281,.281,.281)
A3	(.095,.095,.095)	(.224,.224,.224)	(.446,.446,.446)

Table 6: Normalized decision matrix

	C1	**C2**	**C3**
A1	(0,0,0)	(0,.11,.31)	(.38,.63,1)
A2	(1,1,1)	(.67,.72,.83)	(0,0,0)
A3	(.67,.67,.67)	(.95,.97,1)	(.04,.08,.13)
	C4	**C5**	**C6**
A1	(0,0,0)	(1,1,1)	(0,0,0)
A2	(.19,.19,.19)	(0,0,0)	(.05,.05,.05)
A3	(1,1,1)	(.75,.75,.75)	(1,1,1)

From this matrix, using the weights given in Table 3, the weighted normalized decision matrix is calculated and ideal and nadir alternatives are deducted as follows:

$$A^{+} = [(.13,.13,.13)\ \ (.19,.19,.2)\ \ (.08,.,16,.,2)\ \ (.11,.11,.11)\ \ (.21,.21,.21)\ \ (.15,.15,.15)]$$

$$A^{+} = [(0,0,0)\ \ (0,.02,.06)\ \ (0,0,0)\ \ (0,0,0)\ \ (0,0,0)\ \ (0,0,0)]$$

Using the distance calculation formula given in (3.2.2) we calculated the distances of the alternatives from ideal and nadir alternatives and finally found the RC values as shown in the following table:

Table 6: Relative closeness values

	d^{-}	d^{+}	**RC**
A1	0.357	0.553	0.607
A2	0.272	0.639	0.701
A3	0.689	0.221	0.243

Hence the final ranking:

$$A3 \phi\ A1 \phi\ A2$$

5 Conclusions

Nowadays, the depletion of resources and the pollution are two serious problems in the world. WEEE, or e-waste for short, is one of the most influential factors on these problems. This type of waste threats the environment and the human health by contaminating air, soil and water, because of toxic materials including in the EEE. While the hazardous substances in e-waste pollute the environment, their shorter life cycle causes the fast consumption and the continuous overproduction; hence the depletion of resources increases. Therefore, a strong interest is arising in the field improving to recovery of e-waste. To cope with these problems, governments make laws about e-waste treatment and the producers begin to take the responsibility of their e-wastes. There are generally three different ways of treating WEEE: reuse, recycling and disposal.

In this paper, a Fuzzy MCDM approach is proposed for MAGDM problems with preference information on alternatives. This approach is used to evaluate and select a waste treatment strategy for EEE.

In this direction, three treatment alternatives are determined and six criteria based on these alternatives are also stated. The Fuzzy Hierarchical TOPSIS method gives the ranking

ISBN: 978-989-95079-6-8

of the alternatives under the problems criteria as $A3 \succ A1 \succ A2$. So, the best alternative is treating e-wastes by outsourcing its disposal process of its own WEEE to a specialized company. And the worst alternative is to carry its own WEEE from its own waste collection store to an area which is purchased in order to dispose of the e-wastes by landfill or incineration.

The difference of ranking between the LINMAP method and the method used in this paper may be due to the following reasons:

- Major difference between the first and third alternatives' cost. Relatively small difference for C5 and the difference in C3 for the advantage of the first alternative are not enough to compensate this huge difference of cost as well as capacity need and the convenience to the possessed technology.
- Assumption of independence between criteria caused us to unite some of the problem's criteria and as the LINMAP model doesn't require this assumption, this situation possibly caused a different ranking of the alternatives.
- Not enough consistency in expert judgments.

References

[1] J. Cui, and E. Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, *Journal of Hazardous Materials*, B99, 243–263, 2003.

[2] L. Darby, and L. Obara, Household recycling behavior and attitudes towards the disposal of small electrical and electronic equipment, *Resources, Conservation and Recycling*, Vol.No.44, 17–35, 2005.

[3] M. Schmidt, A production-theory-based framework for analyzing recycling systems in the e-waste sector, *Environmental Impact Assessment Review*, Vol. No. 25, 505-524, 2005.

[4] R. Widmer, H. Oswald-Krapf, D. Sinha-Khetriwal, M. Schnellmann, and H. Böni, Global perspectives on e-waste, *Environmental Impact Assessment Review*, 25, 436-458, 2005.

[5] Directive 2002/96/Ec of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE), *Official Journal of the European Union*, L 37/24-38, 13.2.2003.

[6] İ. Bereketli, M. Erol Genevois, Y. E. Albayrak, M. Özyol, WEEE Treatment Strategies' Evaluation Using Fuzzy LINMAP Method, *Proceedings of 8th International FLINS Conference*, 647-652, 2008.

[7] D. Y. Chang, Applications of the extent analysis method on fuzzy AHP, *European Journal of Operational Research* 95, 649–655, 1996.

[8] Y.-M. Wang, Y. Luo, Z. Hua, On the extent analysis method for fuzzy AHP and its applications, *European Journal of Operational Research* 186, 735 – 747, 2008.

[9] T. L. Saaty, *The Analytic hierarchy process*, Mc. Graw-Hill, New York, 1980.

[10] Lotfi A. Zadeh. Fuzzy sets. *Information and Control*, 8:338-353, 1965.

[11] K. Yoon, *Systems selection by multiple attribute decision making*. Ph.D. dissertation. KS: Kansas State University Press, Manhattan, 1980.

[12] CL Hwang, K. Yoon, *Multiple attribute decision making: methods and applications, a state-of-the-art survey*. Berlin: Springer-Verlag, 1981.

[13] C.-T. Chen, Extensions of the TOPSIS for group decision-making under fuzzy environment, *Fuzzy Sets And Systems*, 114, 1-9, 2000.

ISBN: 978-989-95079-6-8