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Evaluation of outsourcing companies of waste electrical and electronic equipment recycling

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ABSTRACT: An increasing number of companies have focused on reducing the amount of waste properly or gaining value from used products. Facilitating the reverse flow of used products from consumers to manufacturers is a difficult and expensive process depending on the product and transportation type and distance. Another alternative is to outsource these activities. Outsourcing management helps companies for better using of time, energy, labor, technology, capital, resources etc. Moreover, working with wrong partners effects manufacturers' financial and operational situations. In order to get the best services, manufacturers usually invite several outsourcing companies for providing their tenders and then select the best offer. In this stage, using mathematical decision making techniques may help decision makers to get realistic results. In this paper the proposed methodology integrates two multi-criteria decision methods for ranking alternatives. This methodology is applied to a mid-sized firm operating in the field of electrical and electronic equipment. The results indicate that the most important criterion is cost for determining the best alternative. Besides, as it can be seen from the results, the best alternative for the manufacturer is the second alternative. These results propose a guideline for manufacturers for selecting the best alternative. From the results it can easily be seen that this approach shows its potential advantage in selecting suitable alternative due to its sound logic and easily programmable computation procedure.

Keywords*:* *Electronic recycling; Fuzzy analytical hierarchy process; Outsourcing management*

INTRODUCTION

There is an increased interest in the products which are at the end of their life phase (EOL). The amount of products that reaches their end of life is growing due to changes in consumer attitude. Waste electrical and electronic equipment recycling market is growing 8.1 % every year in Turkey. The current threatening level of environmental problems, along with related customer pressure and governmental regulations, motivates corporations to undertake environmentally conscious initiatives (Tuzkaya and Gülsün, 2008). Electrical equipments contain hazardous materials: lead, mercury, cadmium, chromium, phosphorus, barium, beryllium, etc (Bicheldey and Latushkina, 2010; Karapidakis *et al*., 2010). One way of preventing hazardous effects of electrical equipments is to treat them in a proper way and to recycle valuable parts and materials (Lin *et al*., 2010). This also prevents depletion of resources. Such an approach results in cost and waste reduction.The increasing global competition for primary raw materials and the increasing price volatility will enforce companies to pay more attention to recycling activities. The manufacturers can benefit from waste electrical and electronic equipment (WEEE) recycling activities by using cheaper secondary materials instead of using expensive primary raw materials in their production (Liu *et al*., 2010). However, some obstacles make recycling challenging for today's manufactured products. First, it is difficult to gain all the information necessary to plan for the recycling evaluation. Another problem in recycling EOL products is lack of technologies to handle the very complex products that are being discarded today, because the knowledge of how to do so is owned by the recycler (Kuo, 2010). Outsourcing has become an important business approach and a competitive advantage may be gained as products or services are produced more effectively and efficiently by outside providers (Yang *et al*., 2007). The purpose of outsourcing is helping firms to reduce costs and concentrate on their core competency (Gottfredson

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et al., 2005). Outsourcing also plays a strategic role by helping firms to acquire new capabilities, to bring about fundamental changes to managerial strategy and organizational structure and to facilitate the transformation of business models (Linder, 2004; Cao and Wang, 2007;).

Manufacturers can make contract with WEEE outsourcing companies in order to take advantages of outsourcing. The contract can cover different process such as collection, inspection, testing and disassembling of used products and gaining raw materials. The quality of gained raw materials is related to manufacturer's WEEE outsourcing company. Prior to making contracts with outsourcing companies, a detailed survey has to be done during the evaluation process.

Many criteria must be considered in the selection procedure. Thus, this problem can be viewed as a multiple criteria decision making (MCDM) problem in the presence of many quantitative and qualitative criteria (Tuzkaya *et al*., 2009). Many researchers have attempted to use PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations), in waste management. Mergias *et al*. (2007) used PROMETHEE in selecting the best compromise scheme for the management of End-of-Life Vehicles (ELVs). Kapepula *et al.* (2007) utilized PROMETHEE II in ranking nine areas of the city for household solid waste management in the urban community of Dakar with respect to multiple criteria of nuisance. Vego *et al.* (2008) provided new insights to waste management planning at strategic level. Two multi-criteria decision-making (MCDM) methods, PROMETHEE and GAIA (Geometrical Analysis for Interactive Assistance) were applied to assist with the systematic analysis and evaluation of the alternatives.

Although, there were a number of publications in these subjects, few of them have been interested in WEEE recycling. Queiruga *et al.* (2008) described a method for ranking Spanish municipalities according to their appropriateness for the installation of WEEE recycling plants. In order to rank the alternatives, the discrete multi-criteria decision method PROMETHEE, combined with a survey of experts, was applied. Rousis *et al.* (2008) examined alternative systems for the WEEE management in Cyprus. These systems are evaluated by developing and applying the MCDM method PROMETHEE. Moreover, some researchers have used PROMETHEE while concentrating in outsourcing management. Dulmin and Mininno (2007) proposed a PROMETHEE based approach which is applied to a mid-sized Italian firm operating in the field of public road and rail transportation for supplier selection. Araz *et al.* (2007) developed an outsourcer evaluation and management system for a textile company using fuzzy goal programming. The existing outsourcers of the company are evaluated by PROMETHEE. Araz and Ozkarahan (2007) described a supplier evaluation and management methodology, based on PROMETHEE methodology, for strategic sourcing. In their work, the suppliers are assessed considering to the supplier's co-design capabilities and categorized based on overall performances. Additionally, the potential reasons for differences in performance of supplier groups are identified and performances of the suppliers are improved by applying supplier development programs. Wang and Yang (2007) proposed the use of analytic hierarchy process and preference ranking organization method for enrichment evaluations PROMETHEE as aids in making IS (Information System) outsourcing decisions. The AHP is used to analyze the structure of the outsourcing problem and determine weights of the criteria and PROMETHEE method is used for final ranking, together with changing weights for a sensitivity analysis. Tuzkaya (2009) applied PROMETHEE to choose the environmentally convenient transportation mode with respect to the determined evaluation criteria in Marmara Region of Turkey. In addition, other multi criteria techniques are used for waste management. Karamouz *et al.* (2006) introduced a framework in which to develop a master plan for industrial solid waste management. Salman Mahini and Gholamalifard (2006) described a type of multi-criteria evaluation (MCE) method called weighted linear combination (WLC) in a GIS environment to evaluate the suitability of the study region for landfill. Hsu and Hu (2008) examined the consistency approaches by factor analysis that determines the adoption and implementation of green supply chain management in Taiwanese electronic industry.

There are many weight calculation procedures, but the AHP has some advantages. One of the most important advantages of the AHP attributes to its pair-wise comparison. Also PROMETHEE is a widely accepted multi-criteria decision-making technique due to its sound logic and easily programmable computation procedure. Besides, there is no evidence in the literature that any of the work were prepared with the aim of selecting the suitable outsourcing companies for WEEE recycling using Fuzzy AHP and PROMETHEE. This study proposes a combined Fuzzy AHP and PROMETHEE methodology for evaluating and selecting the most suitable company which offers WEEE recycling outsourcing service for Electrical and Electronic Equipment Manufacturers.

The manufacturer in this study aims to evaluate the various companies' offers that operate in WEEE recycling in Istanbul. Compared to the previous evaluation researches, the proposed method makes following contributions. Firstly, there is not any evaluation research about companies which offer WEEE recycling outsourcing service for Electrical and Electronic Equipment Manufacturers. Secondly, a new integrated methodology, Fuzzy AHP-PROMETHEE, is developed for evaluation process. For this reason, this integrated methodology is applied to this problem. The integrated methodology is based on Fuzzy AHP and PROMETHEE. Fuzzy sets are used in describing uncertainties in the pairwise comparison of criteria in the proposed method.

The rest of the paper is organized as follows: The contents of the fuzzy AHP process and PROMETHEE methodology are described in Section 2. Application of the integrated model to the outsourcing companies' evaluation problem as a real world case study is presented in Section 3. The results of the application and sensitivity analysis are discussed in this section. In section 4, conclusions, main findings and contributions are drawn and future developments are suggested.

MATERIALS AND METHODS

Fuzzy AHP Procedure

In the proposed methodology, AHP with its fuzzy extension, namely fuzzy AHP, is applied to obtain more decisive judgments by prioritizing the evaluation criteria and weighting them in the presence of vagueness. There are various fuzzy AHP applications in the literature that propose systematic approaches for evaluation of alternatives and justification of problem by using fuzzy set theory and hierarchical structure analysis. Decision makers usually find it more convenient to express interval judgments than fixed value judgments due to the fuzzy nature of the comparison process (Bozdag *et al.*, 2003). This study concentrates on a fuzzy AHP approach introduced by Chang (1992), in which triangular fuzzy numbers are preferred for pairwise comparison scale. Extent analysis method is selected for the synthetic extent values of the pairwise comparisons. The outlines of the extent analysis method for fuzzy AHP are given in the following. A linguistic variable is a variable whose values are expressed in linguistic terms. The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Kaufmann and Gupta, 1991; Zadeh, 1965; Zimmermann, 1991).

In this study, the linguistic variables that are utilized in the model can be expressed in positive TFNs (Triangular fuzzy numbers) for each criterion as in Fig. 1. The linguistic variables matching TFNs and the corresponding membership functions are

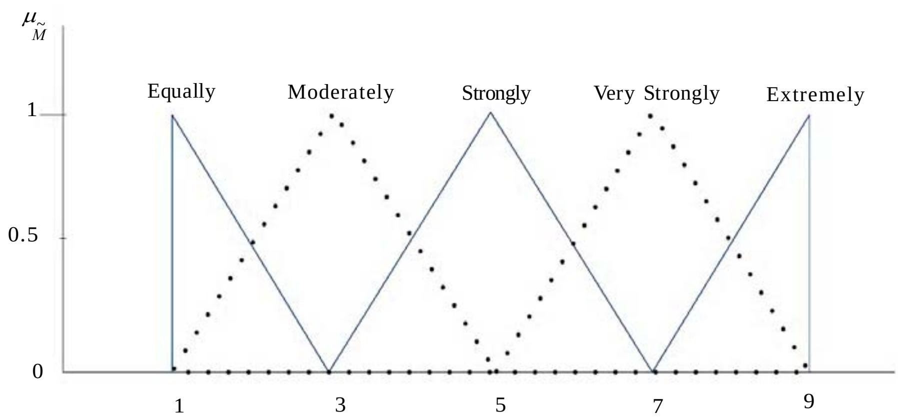


Fig. 1: Linguistic variables for the importance weight of each criterion

provided in Table 1. Proposed methodology employs a Likert scale of fuzzy numbers starting from $\tilde{1}$ to $\tilde{9}$ symbolized with tilde (~) for the fuzzy AHP approach. Table 1 depicts AHP and fuzzy AHP comparison scale considering the linguistic variables that describes the importance of attributes and alternatives to improve the scaling scheme for the judgment matrices.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, whereas $U = \{u_1, u_2, \ldots, u_m\}$ is a goal set. According to fuzzy extent analysis, the method can be performed with respect to each object for each corresponding goal, resulting in m extent analysis values for each object, given as $M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m, i = 1, 2, \ldots, n$, where all the M_{gi}^j ($j = 1, 2, \ldots, m$) are triangular fuzzy numbers representing the performance of the object x_i with regard to each goal u_j. The value of fuzzy synthetic extent with respect to the ith object is defined as (Chang, 1992).

where the degree of possibility of $M_1 \geq M_2$ is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \quad (1)$$

$$V(M_1 \geq M_2) = \sup_{x \geq y} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad (2)$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y)$, the equality equation $V(M_1 \geq M_2) = 1$ holds. Since M_1 and M_2 are convex fuzzy numbers and can be expressed as in Eqs. (3) and (4):

$$V(M_1 \geq M_2) = 1 \text{ iff } m_1 \geq m_2, \quad (3)$$

$$V(M_1 \geq M_2) = \text{hgt}(M_1 \cap M_2) = \mu_{M_1}(d) \quad (4)$$

where, d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (Fig. 2). When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by the following equation:

To compare M_1 and M_2 both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are required. The degree

Table 1: Linguistic variables describing weights of attributes and values of ratings

Linguistic scale for importance	Fuzzy numbers for fuzzy AHP	Membership function	Domain	Triangular fuzzy scale (l, m, u)
Just equal				(1.0, 1.0, 1.0)
Equal importance	$\tilde{1}$	$\mu_M(x) = (3-x)/(3-1)$	$1 \leq x \leq 3$	(1.0, 1.0, 3.0)
Weak importance of one over another	$\tilde{3}$	$\mu_M(x) = (x-1)/(3-1)$	$1 \leq x \leq 3$	(1.0, 3.0, 5.0)
		$\mu_M(x) = (5-x)/(5-3)$	$3 \leq x \leq 5$	
Essential or strong importance	$\tilde{5}$	$\mu_M(x) = (x-3)/(5-3)$	$3 \leq x \leq 5$	(3.0, 5.0, 7.0)
		$\mu_M(x) = (7-x)/(7-5)$	$5 \leq x \leq 7$	
Very strong importance	$\tilde{7}$	$\mu_M(x) = (x-5)/(7-5)$	$5 \leq x \leq 7$	(5.0, 7.0, 9.0)
		$\mu_M(x) = (9-x)/(9-7)$	$7 \leq x \leq 9$	
Extremely preferred	$\tilde{9}$	$\mu_M(x) = (x-7)/(9-7)$	$7 \leq x \leq 9$	(7.0, 9.0, 9.0)
Intermediate values between the two adjacent judgments				
If factor i has one of the above numbers assigned to it when compared to factor j, then j has the reciprocal value when compared with I				Reciprocals of above $M_1^{-1} \approx (1/u_1, 1/m_1, 1/l_1)$

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \quad (5)$$

possibility of a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i= 1, 2, … , k) can be defined by Eq. (6).

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), \quad (6)$$

i = 1, 2, 3, … , k.

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k) \quad (7)$$

For k = 1, 2, … , n; $k \neq i$. Then, the weight vector is given by as in Eq. (8):

where A_i (i = 1, 2, … , n) has n elements. The normalized weight vectors are defined as:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (8)$$

where W is a nonfuzzy number.

$$W = ((d(A_1), d(A_2), \ldots, d(A_n))^T \quad (9)$$

PROMETHEE Methodology

In the following section, some basic important definitions of PROMETHEE from Araz *et al.* (2007), Mergias *et al.* (2007); Vego *et al.* (2008) are reviewed and summarized. PROMETHEE, which is developed by Brans *et al.* (1986), is a non-parametric outranking method for a finite set of alternatives. It is based on positive and negative preference flows for each alternative in the valued outranking relation to rank the alternatives according to the selected preferences (weights). Positive flow expresses how much the specific alternative is dominating other alternatives and negative flow expresses how much that alternative is dominated by the others. Like all outranking methods, PROMETHEE proceeds to a pair of wise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative *a* over alternative b. Preference function $P_j(a,b)$ is calculated after evaluation matrix is formed. It is applied to decide how much the outcome *a* is preferred to b. It translates the difference between the evaluations obtained by two alternatives (a and b) in terms of a particular criterion, into a preference degree ranging from 0 to 1. $d_{a,b}$ is the difference of the value of criterion between a and b. In order to facilitate the evaluation of a specific preference function, six basic types have been proposed. Table 2 summarizes various preference functions.

If a is better than b according to jth criterion, $P_j(a,b) > 0$ otherwise $P_j(a,b) = 0$. Using the weights w_j assigned to each criterion (where $\sum w_j$ =1), one can determine the aggregated preference indicator as follows:

$$\Pi(a,b) = \sum w_j P_j(a,b) \quad (10)$$

Overall ranking is done by aggregating the measures of pair wise comparisons. For each alternative $a \in A$, the following two outranking dominance flows can be obtained with respect to all other alternatives $x \in A$:

The leaving flow is the sum of the values of the arcs leaving node a and therefore provide a measure of the outranking character of *a*. The higher the $\phi^+(a)$, the better the alternative *a*.

$$\phi^+(a) = \frac{1}{n-1}\sum_{x \in A} \Pi(a,x) \quad (11)$$

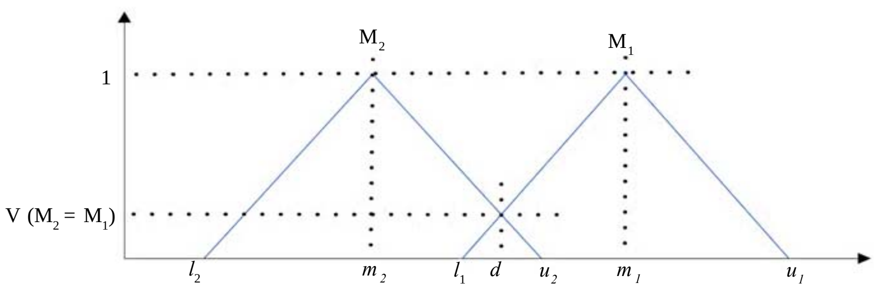
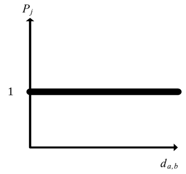
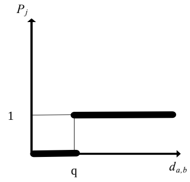
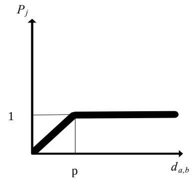
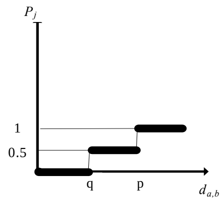
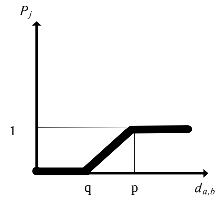
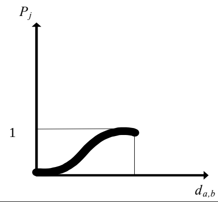


Fig. 2: Intersection point “d” between two fuzzy numbers M_1 and M_2

Table 2: Different Preference Functions in PROMETHEE (Vego *et al*,. 2008)

Function	Shape	Mathematical justification
Type 1 Usual criterion		$P_j(a,b)=\begin{cases}0 \text{ if } d_{a,b} \le 0\\ 1 \text{ if } d_{a,b} > 0\end{cases}$
Type 2 Quasi-criterion (U-Shape)		$P_j(a,b)=\begin{cases}0 \text{ if } d_{a,b} \le q\\ 1 \text{ if } d_{a,b} > q\end{cases}$
Type 3 Criterion with linear preference (V-Shape)		$P_j(a,b)=\begin{cases}\dfrac{d_{a,b}}{p} \text{ if } 0 < d_{a,b} \le p\\ 1 \text{ if } d_{a,b} > p\end{cases}$
Type 4 Level criterion		$P_j(a,b)=\begin{cases}0 \text{ if } 0 < d_{a,b} \le q\\ 0.5 \text{ if } q < d_{a,b} \le p\\ 1 \text{ if } d_{a,b} > p\end{cases}$
Type 5 Criterion with linear preference and indifference area		$P_j(a,b)=\begin{cases}0 \text{ if } d_{a,b} \le q\\ \dfrac{d_{a,b}-q}{p-q} \text{ if } q < d_{a,b} \le p\\ 1 \text{ if } d_{a,b} > p\end{cases}$
Type 6 Gaussian criterion $d_{a,b}$ is the difference value of alternative *a* and *b* in each criterion		$P_j(a,b)=\left\{\dfrac{e^x}{1+e^x}\right.$

The entering flow measures the outranked character. The smaller $\phi^-(a)$, the better the alternative *a*.

The two main PROMETHEE tools can be used to analyse the evaluation problem:

- the PROMETHEE I partial ranking,
- the PROMETHEE II complete ranking.

The PROMETHEE I partial ranking provides a ranking of alternatives. In some cases, this ranking may be incomplete. This means that some alternatives cannot be compared and, therefore, cannot be included in a complete ranking. This occurs when the first alternative obtains high scores on particular criteria for which the second alternative obtains low scores and the opposite occurs for other criteria. The use of PROMETHEE I, then, suggests that the decision-maker should engage in additional evaluation efforts. PROMETHEE II provides a complete ranking of the alternatives from the best to the worst one. Here, the net flow is used to rank the alternatives. Leaving flow and entering flow are used in PROMETHEE I.

There are two basic rules for outranking in PROMETHEE I.

$$\phi^-(a)=\frac{1}{n-1}\sum_{x\in A}\Pi(x,a) \quad (12)$$

a outranks *b* (*aPb*) if:

$$\phi^+(a)\geq\phi^+(b) \text{ and } \phi^-(a)\leq\phi^-(b) \quad \text{or} \quad (13)$$

$$\phi^+(a)>\phi^+(b) \text{ and } \phi^-(a)=\phi^-(b) \quad \text{or} \quad (14)$$

$$\phi^+(a)=\phi^+(b) \text{ and } \phi^-(a)<\phi^-(b) \quad (15)$$

a and *b* (*aRb)* are incomparable if:

$$\begin{array}{l}\phi^+(a)>\phi^+(b) \text{ and } \phi^-(a)>\phi^-(b) \text{ or} \\ \phi^+(a)<\phi^+(b) \text{ and } \phi^-(a)<\phi^-(b)\end{array} \quad (16)$$

a and *b* (*aIb)* are indifference if:

$$\phi^+(a)=\phi^+(b) \text{ and } \phi^-(a)=\phi^-(b) \quad (17)$$

$$\phi(a)=\frac{1}{n-1}\sum_{x\in A}\left(P_j(a,x)-P_j(x,a)\right) \quad (18)$$

One other parameter, net flow, is used for resulting PROMETHEE II.
$\phi(a)$ quantifies the position of alternative *a* according to criterion *j* with respect to all the other alternatives in the set *A*. The larger the single criterion net flow the better alternative ***a*** on criterion *j*.

RESULTS AND DISCUSSION

Application of the integrated Fuzzy AHP-PROMETHEE methodology to a case study

The technologic industry in Turkey has gone through a number of significant changes in the last years. Technological advances and customer demand are the main reasons of this development. In order to get sustainable competitiveness in the sector, manufacturers need to take strategic decisions. One of the most important decisions is recycling activities to gain value from reused products. Since this decision requires a long term investment, to outsource these activities make manufacturers more compatible.

As a real world case study, WEEE recycling provider evaluation problem is proposed to verify our methodology. The company in the case study is operating in the Electrical and Electronic Equipment industry in Turkey. Its application area is in home appliances sector and international electronic manufacturers. Its products are televisions, DVD players, digital satellite receivers, air-conditioning products, air conditioners, white goods and washing machines. This case study is a proposal for an Electrical and Electronic Equipment manufacturer which has an objective to gain 300,000 ton of recycled WEEE. The manufacturer decides to outsource its WEEE recycling activities and wanted to contract with the optimal recycler to get the best service. The manufacturer wants to evaluate various companies' offers that operate in WEEE recycling. For this reason, this integrated methodology is applied to this problem. The integrated methodology is based on Fuzzy AHP and PROMETHEE. Fuzzy sets are used in describing uncertainties in the pairwise comparison of criteria.

A detailed survey is conducted through the distribution of a comprehensive questionnaire to the managers and the related authorities in the manufacturing company. The questionnaire related with the data regarding the qualitative and quantitative criteria is formed for the evaluation model. Furthermore a lot of face-to-face interviews are held to develop solid information on the selected criteria and alternatives. After determining all selected criteria and alternative companies, the paired comparisons in the questionnaire are made by using the triangular fuzzy numbers to tackle the ambiguities involved in the process of the linguistic assessment of the data. Fig. 3 summarizes the integrated methodology. The stepwise procedure of the methodology contains three phases:

Step 1. Pre-research phase
Step 2. Fuzzy AHP phase
Step 3. PROMETHEE phase

Pre-research phase

In the pre-research phase the WEEE recyclers in the market are investigated. Then the related criteria are determined with related authorities. In this study six criteria are determined by the company and five WEEE recycling companies (A_1, A_2,…, A_5) are taken into consideration for evaluation. It is essential to identify a set of evaluation criteria that evaluate all of the proposed alternatives. The following criteria are selected in this particular case:

1. *Cost:* The fee of one year contract with each company.

2.*Capacity utilization:* The percentage of the capacity that can be assigned for the manufacturer's products.
3. *Existing collection networks*: The number of existing collection networks of each company in Turkey.
4. *Capability of disassembly infrastructure*: To measure if each company's disassembly infrastructure is adequate or not. Five points scale is used to express each company's capability.
5. *Availability of new waste processing programs:* Waste Processing Programs related with environmental legislation help these kinds of companies in recycling process. To measure the existence of these programs, a value of one was given to a company with a waste processing program and zero to a company with no such a program.
6. *Land requirement:* To measure if each company needs area for the installation of the mechanical equipment as well as the auxiliary infrastructures. A value of 1 was given to a company which needs area and 0 to a company with no requirement.

Fuzzy AHP phase

In the second phase, decision-makers do pairwise comparison in linguistic form in the questionnaire for obtaining criteria weights. The linguistic forms are converted into triangular fuzzy numbers for Fuzzy AHP evaluations. Fuzzy comparisons are defuzified with Chang's extent analysis and the criteria weights are obtained in Fuzzy AHP phase. Criteria weights are calculated by using Fuzzy AHP. Table 1 is used for pairwise comparison. Table 3 depicts the pairwise comparison matrix set by TFNs (Triangular Fuzzy Numbers) that matches linguistic statements of data. The fuzzy values of paired comparison are converted to crisp values via the Chang's extent analysis (1992) mentioned as before. The obtained priority weight vector of criteria is figured out in the last column of Table 3.

PROMETHEE Phase

In the last phase the data related with alternatives' decision matrix is obtained from related authorities. PROMETHEE is used to rank potential companies which offer WEEE recycling outsourcing service for Electrical and Electronic Equipment Manufacturers. The last phase of the study starts establishing evaluations of the alternative companies with respect to the individual criteria. This is a decision matrix for ranking alternatives and indicates the performance

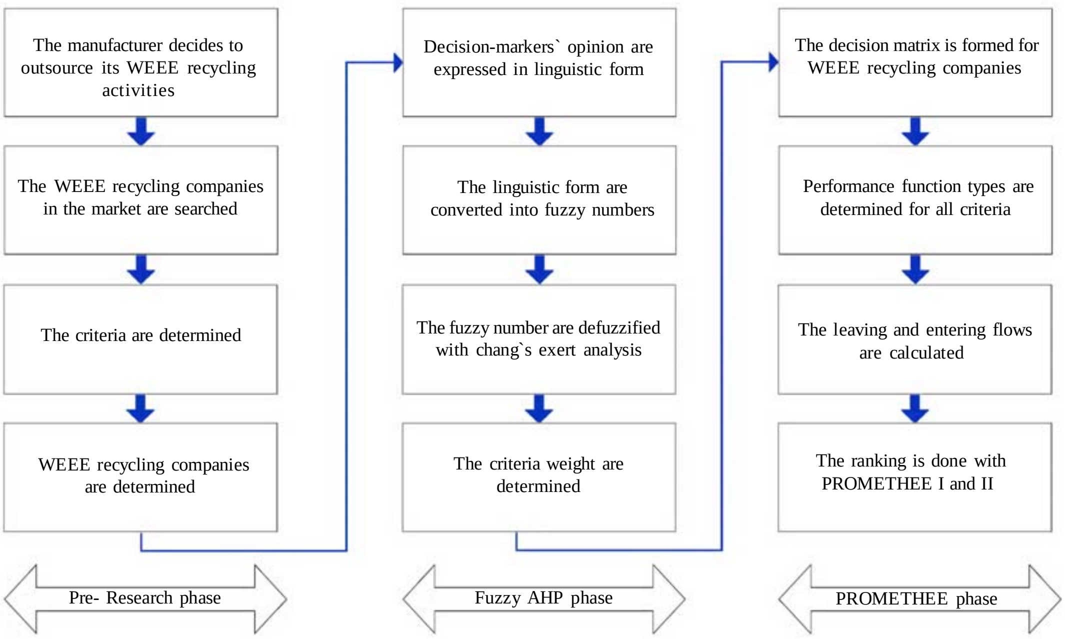


Fig. 3: Proposed approach

ratings of the alternatives according to the criteria. Before constituting decision matrix, preference function types are determined. Vego *et al.* (2008) chose linear preference for cost (C_1) or criteria that are expressed with real numbers (C_3). Araz *et al.* (2007) used linear preference function for "Capacity utilization (C_2)". Also they chose level preference function for 5-point scale expressions (C_4). The criteria: "Availability of new waste processing programs (C_5)" and "Land requirement (C_6)", were measured with "yes" (1) or "no" (0). For that reason a usual preference function, which expresses only indifference or strict preference, was applied (Queiruga *et al.* (2008). (C_1) and (C_6) should be minimized and (C_2), (C_3), (C_4) and (C_5) should be maximized. Threshold values for preference functions depend on decision-makers opinions and expertise. In this study these threshold values are determined with company managers. Decision matrix and criteria characteristics are shown in Table 4. Decision LAB. 2000 commercial software is used for PROMETHEE calculations.

Indifference threshold is the maximum value that represents two alternatives' indifference. Preference threshold is the maximum value that represents one alternative's preference to another. If the difference of two alternatives ($d_{a,b}$) is greater than preference threshold so alternative *a* is strictly preferred to b. To explane the calculations, Table 5 is presented for the comparison of A_1 with A_2.

C_1's preference is minimization so the smallest value is the best. A_1's value is greater than A_2's value in C_1, so $P_1(1,2) = 0$. C_2's, C_3's, C_4's and C_5's preferences are maximization and A_1's value is smaller than A_2's value in C_2, so $P_2(1,2) = 0$. In C_3 $d_{1,2} = 15 - 8 = 7$ and $P_3(1,2) = (7-2)/(10-2) =$ 0.625 (In Table 2 Type 5). A_1's value is smaller than A_2's value in C_4, so $P_4(1,2) = 0$. A_1's value is equal to A_2's value in C_5, so $P_5(1,2) = 0$. At last, A_1's value is greater than A_2's value in C_6, so $P_6(1,2) = 0$ because of minimization preference. $\Pi(1,2) = 0.625 * 0.049 = 0.03$ (Eq.(10)). This comparison is done with all other alternatives and by using Eq. (11), Eq. (12) and Eq. (18). The leaving flows, the entering flows and the net flow of each alternative are calculated.

Results and sensitivity analysis

The results of the leaving flows $\phi^+(a)$, entering flows $\phi^-(a)$ and net flow $\phi\ (a)$ for PROMETHEE I and II are presented in Table 6. Also the partial ranking in PROMETHEE I is presented in Fig. 4, while the complete ranking of alternatives in PROMETHEE II from best to worst in terms of comparison with respect to Eqs. (13 - 17) is presented in Fig. 5.

In the PROMETHEE representation, if *a* outranks *b*,

Table 3: Pairwise comparisons of criteria

	Cost (C_1)	Capacity utilization (C_2)	Existing collection networks (C_3)	Capability of disassembly infrastructure (C_4)	Availability of new waste processing programs (C_5)	Land requirement (C_6)	Weights
Cost (C_1)	(1,1,1)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	0.523
Capacity utilization (C_2)	(0.11,0.14,0.2)	(1,1,1,)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	0.304
Existing collection networks (C_3)	(0.14,0.2,0.33)	(0.2,0.33,1)	(1,1,1)	(1,3,5)	(1,1,3)	(0.14,0.2,0.33)	0.409
Capability of disassembly infrastructure (C_4)	(0.11,0.14,0.2)	(0.2,0.33,1)	(0.2,0.33,1)	(1,1,1)	(1,3,5)	(1,1,3)	0.064
Availability of new waste processing programs (C_5)	(0.14,0.2,0.33)	(0.2,0.33,1)	(0.33,1,1)	(0.2,0.33,1)	(1,1,1)	(1,3,5)	0.011
Land requirement (C_6)	(0.11,0.14,0.2)	).14,0.2,0.33)	(3,5,7)	(0.33,1,1)	(0.2,0.33,1)	(1,1,1)	0.049

$V(S_{c1} >= S_{c2}, S_{c3}, S_{c4}, S_{c5}, S_{c6}) = 1.00$; $V(S_{c2} >= S_{c1}, S_{c3}, S_{c4}, S_{c5}, S_{c6}) = 0.59$;
$V(S_{c3} >= S_{c1}, S_{c2}, S_{c4}, S_{c5}, S_{c6}) = 0.09$; $V(S_{c4} >= S_{c1}, S_{c2}, S_{c3}, S_{c5}, S_{c6}) = 0.12$;
$V(S_{c4} >= S_{c1}, S_{c2}, S_{c3}, S_{c4}, S_{c6}) = 0.02$; $V(S_{c5} >= S_{c1}, S_{c2}, S_{c3}, S_{c4}, S_{c5}) = 0.09$;

Table 4: Decision matrix for PROMETHEE

	C_1	C_2	C_3	C_4	C_5	C_6
Min/Max	Min	Max	Max	Max	Max	Min
Preference Function	Linear	Linear	Linear	Level	Usual	Usual
Indifference Threshold (q)	5,000	0.03	2	0.5	-	-
Preference Threshold((p)	70,000	0.2	10	1.5	-	-
Unit	TL/year	%	No. Networks	5-point scale	Yes/No	Yes/No
A_1	250,000	0.6	15	1	1	1
A_2	225,000	0.75	8	3	1	0
A_3	240,000	0.45	5	4	0	0
A_4	195,000	0.55	20	2	1	1
A_5	320,000	0.7	14	3	0	1

Table 5: The explanation of the comparison of A_1 to A_2

	C_1	C_2	C_3	C_4	C_5	C_6
	Min The smallest is the best	Max The largest is the best	Max The largest is the best	Max The largest is the best	Max The largest is the best	Min The smallest is the best
A_1	250,000	0.6	15	1	1	1
A_2	225,000	0.75	8	3	1	0
$d_{1,2}$	-	-	15-8=7	-	-	-
$P(1,2)$	0	0	0.625	0	0	0

Table 6: Leaving, entering and net flows

	Φ^+(a)	Φ^-(a)	Φ (a)
A_1	0.218	0.320	-0.102
A_2	0.473	0.084	0.389
A_3	0.226	0.382	-0.157
A_4	0.442	0.195	0.247
A_5	0.202	0.578	-0.377

the representation is as $a \rightarrow b$. As it can be seen in Figs. 4 and 5, the best alternative for the manufacturer is the second alternative. A_4 is the second best alternative. However, A_1 and A_3 are incomparable (A_1 R A_3) because $\phi^+(A_3) > \phi^+(A_1)$ and $\phi^-(A_3) > \phi^-(A_1)$. As it can be seen in Fig. 5, in net flow $\phi\ (A_1) > \phi\ (A_3)$ so A_1 is better than A_3. Lastly A_5 is the worst alternative with respect to both PROMETHEE I and PROMETHEE II.

Another analysis is represented in Fig. 6. It presents the criteria's effects on the alternatives. The x-axis is criteria. The scores are between +1 (being the best) and "1 (being the worst). The strong and the weak sides of each alternative can be seen in this figure. The second, the third and the fourth alternatives are positively impacted from C_1 whereas the fifth alternative is negatively impacted. The second and the fifth alternatives are positively impacted from C_2 whereas the first, the third and the fourth alternatives are negatively impacted. The first, the fourth and the fifth alternatives are positively impacted from C_3 whereas the second and the third alternatives are negatively impacted. The second, the third and the fifth alternatives are positively impacted from C_4 whereas it has negative impact on the first and the forth alternatives. The first, the second and the forth alternatives are positively impacted from C_5 whereas the third and the fifth alternatives are negatively impacted.

The second and the third alternatives are positively impacted from C_6 whereas the first, the forth and the fifth alternatives are negatively impacted. Besides A_2

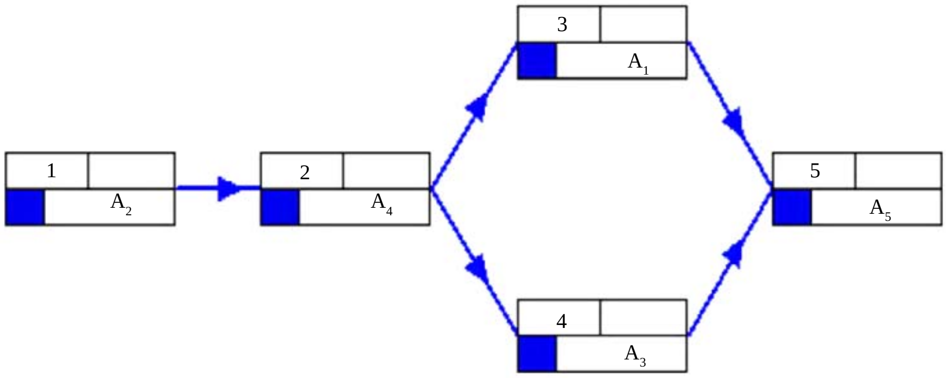


Fig.4: The partial ranking in PROMETHEE I

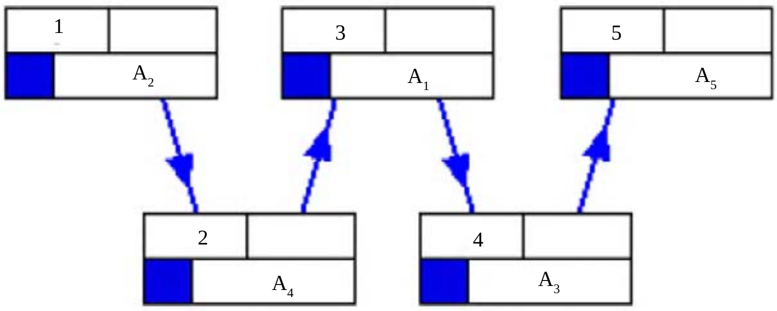


Fig. 5: The complete ranking in PROMETHEE II

Table 7: Sensitivity analysis results

Creiteria exchange	New criteria wieghts	Results of PROMETHEE II
Base	0.523, 0.304, 0.049, 0.064, 0.011, 0.049	2 → 4 → 1 → 3 → 5
1 ↔ 2	0.304, 0.523, 0.049, 0.064, 0.011, 0.049	2 → 4 → 5 → 1 → 3
1 ↔ 3	0.049, 0.304, 0.523, 0.064, 0.011, 0.049	2 → 5 → 4 → 1 → 3
1 ↔ 4	0.064, 0.304, 0.049, 0.523, 0.011, 0.049	4 → 5 → 1 → 2 → 3
1 ↔ 5	0.011, 0.304, 0.049, 0.064, 0.523, 0.049	2 → 1 → 4 → 5 → 3
1 ↔ 6	0.049, 0.304, 0.049, 0.064, 0.011, 0.523	2 → 5 → 4 → 1 → 3
2 ↔ 3	0.523, 0.049, 0.304, 0.064, 0.011, 0.049	4 → 2 → 1 → 3 → 5
2 ↔ 4	0.523, 0.064, 0.049, 0.304, 0.011, 0.049	2 → 4 → 3 → 1 → 5
2 ↔ 5	0.523, 0.011, 0.049, 0.064, 0.304, 0.049	4 → 2 → 1 → 3 → 5
2 ↔ 6	0.523, 0.049, 0.049, 0.064, 0.011, 0.304	4 → 2 → 3 → 1 → 5
3 ↔ 4	0.523, 0.304, 0.064, 0.049, 0.011, 0.049	2 → 4 → 1 → 3 → 5
3 ↔ 5	0.523, 0.304, 0.011, 0.064, 0.049, 0.049	2 → 4 → 1 → 3 → 5
3 ↔ 6	0.523, 0.304, 0.049, 0.064, 0.011, 0.049	2 → 4 → 1 → 3 → 5
4 ↔ 5	0.523, 0.304, 0.049, 0.011, 0.064, 0.049	2 → 4 → 1 → 3 → 5
4 ↔ 6	0.523, 0.304, 0.049, 0.049, 0.011, 0.064	2 → 4 → 1 → 3 → 5
5 ↔ 6	0.523, 0.304, 0.049, 0.064, 0.049, 0.011	2 → 4 → 1 → 3 → 5

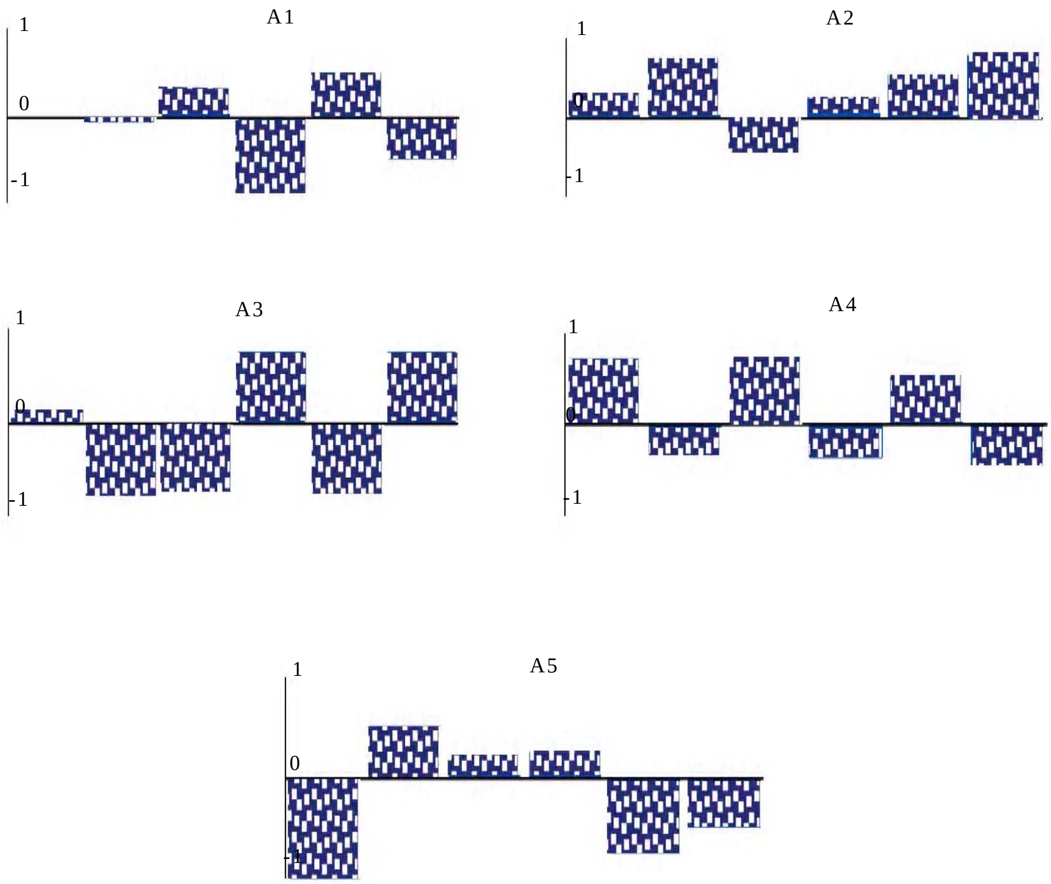


Fig. 6: The criteria's effects on the alternatives y-axis the scores x-axis the criteria

is the best alternative according to all criteria, it is quite low in C_4 and C_6. The second alternative A_4 is quite low in C_3. The third alternative A_1 is quite low in C_3 and C_5. The forth alternative A_3 is quite low in C_2, C_4 and C_6. The last alternative A_5 is quite low in C_1, C_5 and C_6.

Besides, sensitivity analysis is done for getting accurate results. The idea of sensitivity analysis is to exchange each criterion's weight with another criterion weight. Thus, 15 different calculations are formed. Table 7 summarizes sensitivity analysis results. As it can be seen from Table 7, 40 % of the calculations give the exactly same ranking of our result. 73% of the calculations choose the second alternative as the best alternative. However, 27 % of the calculations choose the forth alternative as the best alternative. However, decision maker can decide on the importance of criteria and can choose any weight ranking.

CONCLUSION

The objective of this study is to analyze the potential alternatives and to choose the best alternative by using a multi-criteria approach. In this paper a Fuzzy-AHP and PROMETHEE based method for ranking potential companies which offer WEEE recycling outsourcing service for Electrical and Electronic Equipment Manufacturers is proposed. This evaluation is based on the comparisons of alternatives according to their performances with respect to relevant criteria. The ranking of the approach has the purpose of discovering the worst and best alternatives. Fuzzy method is used for dealing uncertainty and improving lack of precision in evaluating criteria. Using fuzzy numbers enables decision makers to get better results in the overall importance of criteria. In other words, using linguistic preferences can be very useful for uncertain situations.

Triangular numbers are applied into traditional AHP method in this study. PROMETHEE calculations and analyses are done by Decision Lab 2000 software. The results indicate that the second alternative has significant advantages over all alternatives. As a result of the study, it is found that the proposed method is practical in ranking alternatives with respect to multiple conflicting criteria. Compared with the previous evaluation researches, following contributions are made with the proposed method. Firstly, there is not any evaluation research about companies which offer WEEE recycling outsourcing service for Electrical and Electronic Equipment Manufacturers. Secondly; a new integrated methodology, Fuzzy AHP-PROMETHEE, is developed for evaluation process. Such a framework has never being found before in the literature. From the case study, it can be seen that this approach shows its potential advantage in selecting suitable alternative due to its sound logic and easily programmable computation procedure. For further research, developing a group decision making system can be very useful. In this way different authorities' opinions can be taken into account. Also, different hierarchical and detailed objectives can be incorporated into the study. Lastly, mathematical models or metaheuristics can be combined with the existing method.

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