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RESEARCH ARTICLE

Fuzzy AHP approach for prioritizing electronic waste management options: a case study of Tehran, Iran

Afshin Khoshand[1] · Kian Rahimi[1] · Majid Ehteshami[1] · Shayan Gharaei[2]

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Abstract
Electronic waste (E-waste) can be considered as challenging solid waste streams especially in some developing countries, including Iran. Several alternatives for collecting and processing E-waste have been developed and applied throughout the world. In this research, a model was developed according to fuzzy-AHP approach for the evaluation of different alternatives for E-waste's collection and processing in Tehran, Iran. Three alternatives for processing section (including recycling, exporting, landfilling) and three alternatives for collection section (door-to-door, special event, permanent drop-off) were studied in terms of different economic, social, technical, and environmental criteria. To establish a database in the current research, a questionnaire survey was performed and then the relative importance of each alternative in terms of each criterion was evaluated. The obtained results indicated that in the section of collection and processing of E-waste, permanent drop-off and recycling have the highest priorities among studied alternatives, respectively. Also, economic and environmental criteria were determined as the most significant ones in collection and processing sections, respectively. Furthermore, the developed model can be considered as a practical tool that will help the decision makers to determine the most appropriate E-waste management alternatives when diverse criteria are partially or completely in conflict.

Keywords E-waste management · Decision making · FAHP · Iran · Tehran

Introduction

All Electrical and Electronic Equipment (EEE) and their components that are not being used anymore and discarded are considered as electronic and electric waste (or E-waste) (Gregory et al. 2009). E-waste management is a significant issue in several developing countries (including Iran) mostly because of increasing rate of E-waste generation. The high growth in the rate of E-waste generation generally occurred due to fast advances in the EEE industries, population growth, and urbanization (Balabanic et al. 2011), as well as changes in consumption patterns and lifestyle (Babu et al. 2007). However, E-waste management has been enhanced recently through setting up several plans in developed countries but governments in various low-income and middle-income countries are still encumbered by management of E-waste in efficacious ways (Manhart 2011).

Undesirable impacts of E-wastes on the environment (including air, soil, and water pollution) besides substandard E-waste management impose serious risks to the public health and the environment (Kiddee et al. 2013).

There are several options for collecting, processing, disposing, and in general E-waste management. Collecting E-waste can be conducted in different ways (as presented in Table 1) such as establishing permanent drop-off location, planning special drop-off event, and also door-to-door pickup plans, which can be performed by owners of EEEs, Original Equipment Manufacturers (OEMs), and also local governments (Gregory et al. 2009). As tabulated in Table 1, each of responsible individuals has a different role in mentioned systems for collecting E-waste. E-waste processing mainly includes exporting, reusing, refurbishing, and recycling (since E-wastes consist of valuable and precious materials such as platinum, copper, silver, and gold) (Puckett 2002) by various

Responsible editor: Philippe Garrigues

✉ Afshin Khoshand
khoshand@kntu.ac.ir

[1] Faculty of Civil Engineering, K.N. Toosi University of Technology, No. 1346, Vali Asr Str, Tehran, Iran

[2] Faculty of Civil Engineering, Iran University of Science and Technology, Tehran, Iran

Table 1 Common E-waste collection systems

System of E-waste collection	Role of			
	Government	Retail	Commercial	OEM
Permanent drop-off location	Offices as drop-off locations	Located at retail stores	Located at entity	Location created in partnership with stakeholders
Special drop-off event	A short time (1 to 2 days) event devoted for dropping off E-waste at special location			
Door-to-door pickup	Curbside pick up	NA	Direct pick up mainly from commercial individuals	Pick up by logistics companies or mail

methods (such as manual dismantling, mechanical treatment, and chemical treatment) at different levels (Chagnes et al. 2016). The disposal options of E-waste are mainly sanitary landfilling and incineration (Kiddee et al. 2013). Each of the mentioned options for E-waste management has different environmental, economic, social, and technical aspects.

For selecting the most appropriate alternative in the E-waste management, different aspects of each alternative as well as all associated disadvantages and advantages in terms of social, environmental, economic, and technical issues should be precisely evaluated (De Souza et al. 2016). It should be noted that the most appropriate alternative for E-waste management is an economically affordable, environmentally effective, socially acceptable, and technically feasible option (Kiddee et al. 2013; De Souza et al. 2016).

As the options for E-waste management grow in complexity and number, the need for one effective strategy regarding the evaluation of different options is more highlighted. Several strategies including Extended Producer Responsibility (EPR), Life Cycle Assessment (LCA), Material Flow Analysis (MFA), and Multi-Criteria Decision Making (MCDM) have been established and applied in order to deal with the selection of the most appropriate options for E-waste management (Kiddee et al. 2013). It should be noted that LCA (Ahluwalia and Nema 2007; Barba-Gutiérrez et al. 2008; Duan et al. 2009), MFA (Shinkuma and Nguyen Thi Minh 2009; Yoshida et al. 2009; Wäger et al. 2011), and EPR (Khetriwal et al. 2009; Manomaivibool 2009; Manomaivibool and Vassanadumrongdee 2011) have been widely used for E-waste management and only limited studies applied MCDM in this field.

Queiruga et al. (2008) combined PROMETHEE (which is one of the practical and outranking models of MCDM) with a survey of experts for selecting the most appropriate location for an E-waste recycling plant in Spain. Rousis et al. in 2008 compared and ranked different 12 alternatives for E-waste management systems based on 17 individual sub-criteria, which were categorized in four groups (including social, environmental, economic, and technical criteria) through applying the Multi-Criteria Decision Making (MCDM) method of PROMETHEE in Cyprus. The partial disassembly and forwarding of recyclable materials to the native existing market (Management System 7) was identified as the optimum alternative. Furthermore, Kim et al. in 2013 studied the application of Delphi-AHP technique for determining the E-waste management priority to be included in the extended producer responsibility (EPR) system in South Korea. For this purpose, four criteria were defined, including emission rate, recycling benefit, similarity to current EPR items, and similar products in the current plastic disposal fee charging system. In addition, three sub-criteria were defined under the recycling benefit, including availability of recycling technology, higher valuable metal recovery, and establishment of a feasible collection system. The results indicated that the top 10 target recycling products for the expansion of the E-waste list were vacuum cleaners, electric fans, electric rice cookers, large freezers, microwave ovens, water purifiers, air purifiers, humidifiers, kitchen dryers, and standard telephones in order from first to last. Moreover, Shumon et al. (2016) applied Fuzzy Analytical Hierarchy Process (FAHP) to choose the best beneficial E-waste collection system in a reverse supply chain (in Malaysia) based on different criteria including economic, operational, strategic, and social ones. The derived results demonstrated that system A (company/authority D2D collection-recovery facility) has the highest priority with respect to the main goal.

In the E-waste management, diverse criteria are partially or completely in conflict and thereby models based on the use of MCDM techniques could be considered as beneficial methods (Queiruga et al. 2008; Rousis et al. 2008; Kim et al. 2013; Shumon et al. 2016). The Analytic Hierarchy Process (AHP) is one of the most convenient methods for dealing with complicated decision-making problems where qualitative and quantitative aspects should be considered. Additionally, the AHP cannot consider the ambiguity associated with the judgment of decision makers regarding numeric values. Since fuzziness is a common characteristic of decision-making problems, the FAHP technique has been developed to address this issue, allowing decision makers to express approximate preferences through fuzzy numbers, where adding fuzziness to the input implies adding fuzziness to the judgment.

Therefore, FAHP can be considered as one of the best MCDM techniques, which can be widely used to analyze a variety of decision problems in different categories including E-waste management (Kahraman 2008).

The main goal of the current research is to integrate the preferences of diverse criteria and develop a model in order to evaluate and compare several diverse alternatives for E-waste management in collection and processing section. This model was established according to a multi-criteria analysis of AHP structure, applied for the case study of Tehran, Iran. Therefore, decision-makers are able to select and evaluate the most appropriate options for E-waste management. It should be noted that studied collecting and processing options for E-waste management were selected according to a comprehensive literature review and also the applicably of all investigated options in the studied area were deeply considered. Moreover, it was supposed that design, construction, implementation, and operation of all studied options for E-waste management are correct, as well as it was assumed that any byproduct of all studied options was treated appropriately.

Study area

Tehran is placed approximately at the center of northern Iran, with a land area of 664 km^2 and population of about 8.2 million, which make it the largest and the most civilized metropolis in the country. The mean population density in the metropolis of Tehran is currently near to 12,350 inhabitants/km^2 and is expected to be 14,910 inhabitants/km^2 by 2030 (United Nations 2014).

The general legislation related to waste management is in place in Iran (since 2004), which applies to E-waste management (clause 12 of the executive instruction) as well. Unfortunately, this general regulation did not offer a clear explanation for practical details (even the different categories of E-wastes were not defined). Moreover, statistical data of E-waste was not released officially by the national government (Taghipour et al. 2012).

According to the research by Taghipour et al. (2012), amount of generated E-waste in Iran for eight selected electronic items (including laptops or notebooks, photocopiers, radio and tape recorders, televisions, mobile telephones, personal computers, printers, and video projectors) was 115,286, 112,914, and 115,151 t from 2008 to 2010, respectively. In addition, according to Baldé et al. (2014), the annual per capita production of E-waste in Iran is estimated 7.4 kg, which is nearly double of the Asian average. On the other hand, there is an unclear procedure for E-waste management in Tehran, and generally, E-wastes are collected, processed, and disposed under very poor management conditions (Taghipour et al. 2012).

Material and methods

Methodology

In the current study, the developed model is according to AHP method proposed by Saaty (1990), as a practical method that assists decision makers to handle complicated problems which includes multiple subjective and conflicting criteria through a simple technique. The main disadvantage of AHP is the application of constant judgmental scale that is unable to solve the roughness and uncertainty in administering pairwise comparison among different attributes (Karapetrovic and Rosenbloom 1999; Kahraman 2008). The inability of AHP in dealing with the uncertainty and imprecision has been improved in FAHP. The FAHP can be considered as a comprehensive approach in alternative selection problems through applying the concepts of fuzzy set theory, which is combined with hierarchical structure analysis (Kahraman 2008). Fuzzy sets were first introduced by Zade (1965) to assign a partial membership for a specific value rather than a crisp one. In the FAHP, linguistic variables are converted to fuzzy numbers in order to determine the priority of specific decision variable over another. In this study, the developed model based on FAHP technique includes the following steps.

1) Identification and selection of criteria and alternatives

Most of the criteria and alternatives selected in the current research are derived from previous studies (Patterson-Moulton et al. 2004; Kang and Schoenung 2005; Rousis et al. 2008; Kim et al. 2013; Baldé et al. 2014; Shumon et al. 2016) and the rest were defined through discussions and interactions in meetings with professionals. The selected ones were classified in to economic (including economic aspect), technical (including time, adaption to local conditions, and existing capability/experience), social (including new job creation, motivation potential, and accessibility), and environmental (environmental aspects) categories. Also, the alternatives were divided into the collection (including permanent drop-off location, special drop-off event, and also door-to-door pickup) and processing (including recycling, exporting, and landfilling) of E-wastes.

2) Developing the hierarchy structure

Hierarchy is a system that provides an interaction between the alternatives and the main goal through a loop in which priorities of alternatives and main goal are determined with regard to another one (Teknomo 2006). Figures 1 and 2 present the hierarchy structure and illustrate key elements and their relationships for the decision problem in processing and collection section, respectively. The main goal is the first cluster on the top is decomposed into criteria and sub-criteria in a

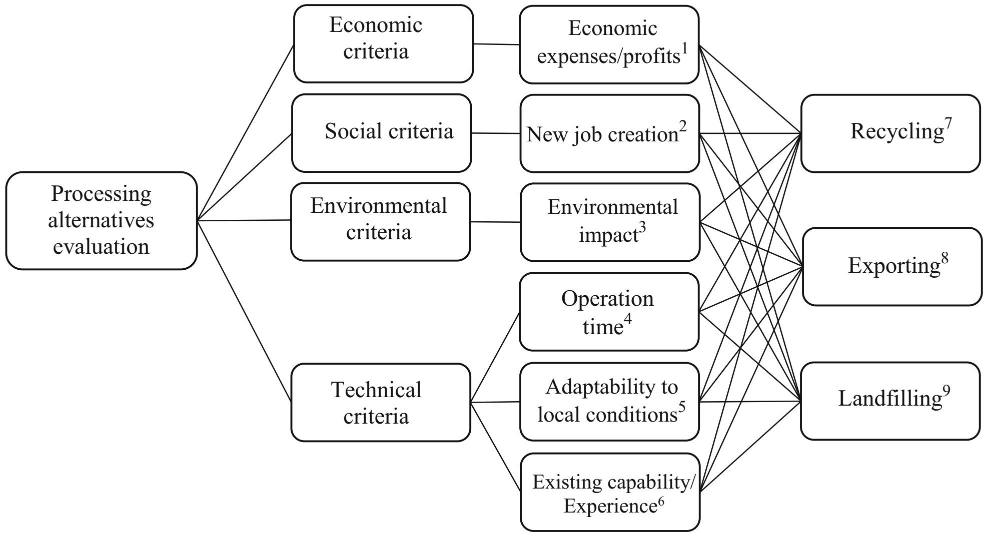

Fig. 1 Hierarchy structure of E-waste processing alternatives and related criteria and sub-criteria. [1]Economic expenses/profits refer to all expenses and earnings in the process of alternative execution which includes all fixed and operating costs. [2]New job creation refers to the potential of an alternative for new job generation. [3]Environmental impacts refer to any environmental pollution which an alternative would impose into the air, water, and soil. [4]Operation time refers to the needed period of time for an alternative execution. [5]Adapting to local conditions is a technical criterion that refers to the necessity/priority of an alternative execution for the studying region. [6]Existing capability/experience refers to the capability and experience of an entity relating to technical issues. [7]Recycling refers to any process including treatments to recycle valuable materials in an E-waste. [8]Exporting refers to selling E-wastes (after collection) without any recycling. [9]Landfilling refers to dumping collected E-wastes in landfills without any treatment or recycling

hierarchy structure with different alternatives at the bottom of the hierarchy. It should be mentioned that in both Figs. 1 and 2, apart from the goal, three layers are presented as criteria, sub-criteria, and alternatives.

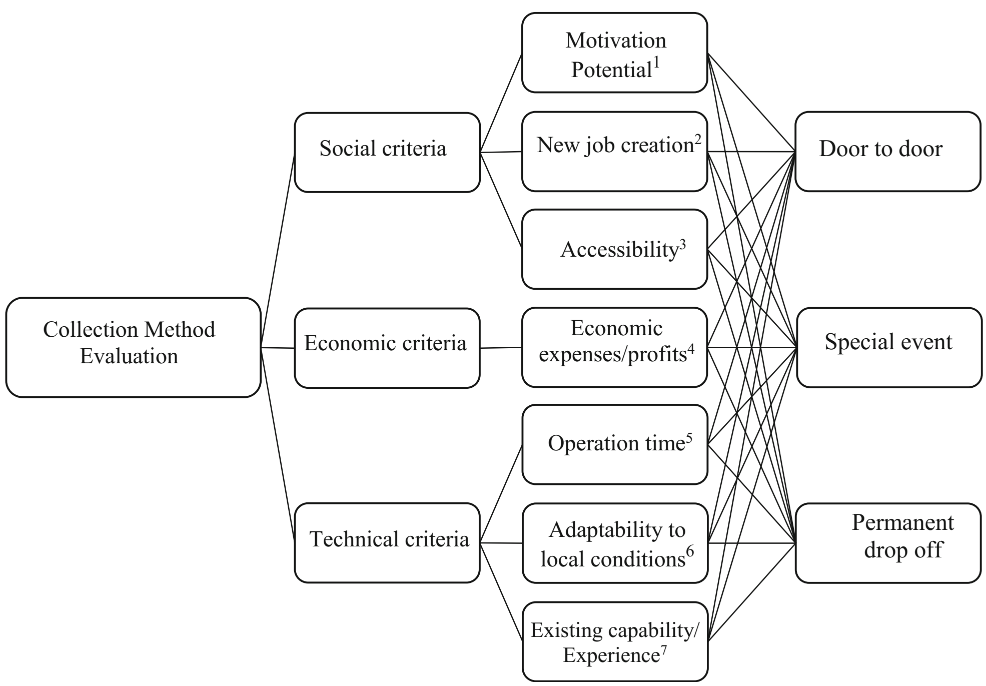

Fig. 2 Hierarchy structure of E-waste collection alternatives and related criteria and sub-criteria. [1]Motivation potential refers to the motivation creation of a collection system to provoke public participation in order to deliver their E-waste. [2]New job creation refers to the potential of an alternative for new job generation. [3]Accessibility refers to the reachability of a collection system for end user whom to dispose the E-waste. [4]Economic expenses/profits refer to all expenses and earnings in the process of alternative execution which includes all fixed and operating costs. [5]Operation time refers to the needed period of time for an alternative execution. [6]Adapting to local conditions is a technical criterion refers to the necessity/priority of an alternative execution for the studying region. [7]Existing capability/experience refers to the capability and experience of an entity relating to technical issues

3) Database establishment and judgments

The database for the current study was established through a questionnaire survey. Numerous meetings were held with professional respondents for interacting with respondents and administering questionnaire surveys. Alternatives and criteria and their related advantages and disadvantages were described in detailed in meetings in order to enable respondents to have a better understanding of alternatives and criteria, as well as assisting their awareness of the decision problem as much as possible.

Generally, a questionnaire survey in this research was performed for deriving some compromise judgment on alternatives and criteria. Several studies revealed that the use of questionnaire survey besides holding group meetings is a helpful technique in judgment and consequently deriving consensus weighting (Kahraman et al. 2004; Rousis et al. 2008; Kim et al. 2013).

4) Quantification of judgments and creation of pairwise comparison matrix

Questionnaire's respondents were introduced to the fundamentals of the applied method (FAHP) in meetings. It should be noted that the FAHP was defined as a beneficial technique capable of integrating the main decision problem while dealing with smaller decision problems at the same time. In a pairwise comparison, the judgments are expressed by linguistic variables; each of them refers to a specific fuzzy number to calculate the weights. Table 2 represents each linguistic variable and their related Triangular Fuzzy Numbers (TFNs). The TFN can be simply represented as (l, m, u), in which "l" represents smallest likely value, "m" the most probable value, and "u" the largest possible value of any fuzzy event (Chang 1996).

Note that these values are L_1, L_2, L_4, L_6, and L_8 and values of L_3, L_5, L_7, and L_9 are taken as intermediate values for describing the comparisons.

A fuzzy number N on R is defined as a triangular fuzzy number if its membership function $\mu_N(x): R \rightarrow [0.1]$ is equal to

Table 2 Conversion scale of triangular fuzzy

Variable	Linguistic variable	TFN
L_1	Preferred equally	(1,1,2)
L_2	Preferred moderately	(1,2,3)
L_4	Preferred strongly	(3,4,5)
L_6	Preferred very strongly	(5,6,7)
L_8	Preferred absolutely	(7,8,9)

$$\mu_N(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l} & x\epsilon[l.m] \\ \frac{x}{m-u} - \frac{u}{m-n} & x\epsilon[m.u] \\ 0 & \text{Otherwise} \end{cases} \quad (1)$$

Then, the fuzzy evaluation matrix ($M_{n\times n} = (N_{ij})_{n\times n}$) can be calculated through pairwise comparision as follow:

$$M = \begin{bmatrix} (1.1.1) & (l_{12}.m_{12}.u_{12}) & \dots & (l_{1n}.m_{1n}.u_{1n}) \\ (l_{21}.m_{21}.u_{21}) & (1.1.1) & \dots & (l_{2n}.m_{2n}.u_{2n}) \\ \dots & \dots & \dots & \dots \\ (l_{n1}.m_{n1}.u_{n1}) & (l_{n2}.m_{n2}.u_{n2}) & \dots & (1.1.1) \end{bmatrix}$$

where $N_{ij} = (l_{ij}, m_{ij}, u_{ij})$ describes the relative importance of the x_i object in comparison to the u_j goal and $N_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$, $N_{ii} = (1,1,1)$ for all i and j.

It should be noted that for two given TFNs, like $N_1 = (l_1, m_1, u_1)$ and $N_2 = (l_2, m_2, u_2)$, basic operation laws are as follows:

$$N_1 \oplus N_2 = (l_1 + l_2.m_1 + m_2.u_1 + u_2)$$
$$N_1 \otimes N_2 = (l_1 l_2.m_1 m_2.u_1 u_2)$$

5) Analytical evaluation

This research has used the extent analysis proposed by Chang (1996) that is a practical method of FAHP solutions.

In case of being components of alternatives, they are compared with each other according to each criterion or sub-criterion. Moreover, in case of being components of criteria or sub-criteria, they are compared together with respect to the main goal. The X and U are components of each tier (criteria, sub-criteria, and alternatives). In this method, $X = \{x_1, x_2, \dots, x_n\}$ and $U = \{u_1, u_2, \dots, u_m\}$ represent object and goal sets, respectively. Based on the principles of Chang's extent analysis, each object is considered, and then for each specific goal (g_i), extent analysis is conducted (Chang 1996). In other words, objects and goals are two sides of each single pairwise comparison matrix (M). Therefore, m extent analysis value for each specific object is defined as

$$N_{g_i}^1.N_{g_i}^2.N_{g_i}^m i = 1.2.n \quad (2)$$

where $N_{g_i}^j$ ($j = 1, 2, \dots, m$) are TFNs that are consisting ith row of M and must be selected according to Table 2 values.

For determining the weight vector of a comparison matrix based on Chang's extent analysis method (Chang 1996), the following steps are followed.

(a) The value of fuzzy synthetic in terms of ith object can be introduced as follows:

$$S_i = \sum_{j=1}^{m} N_{g_i}^{j} \otimes \sum_{i=1}^{n}\sum_{j=1}^{m}\left[N_{g_i}^{j}\right]^{-1} = \left(\sum_{j=1}^{m} l_j.\ \sum_{j=1}^{m} m_j.\ \sum_{j=1}^{m} u_j\right) \otimes \left(\frac{1}{\sum_{i=1}^{n} u_i}.\frac{1}{\sum_{i=1}^{n} m_i}.\frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (3)$$

(b) The degree of possibility of any two given TFNs like $N_2 = (l_2, m_2, u_2) \geq N_1 = (l_1, m_1, u_1)$ is defined as

$$V(N_2 \geq N_1) = \mathrm{Sup}_{y \geq x}\left[\min\left(\mu_{N_1}(x).\mu_{N_2}\left(y\right)\right)\right] \quad (4)$$

which is able to be expressed as

$$V(N_2 \geq N_1) = \mathrm{hgt}(N_1 \cap N_2) = \mu_{N_2}(x_d) \quad (5)$$

or

$$V(N_2 \geq N_1) = \begin{cases} 1 & \text{if and only if } m_2 \geq m_1 \\ 0 & \text{if and only if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (6)$$

where d is defined as the ordinate of the highest intersection point between μ_{N_1} and μ_{N_2} (as illustrated in Fig. 3) and where the ordinate d is found (in the domain of μ_{N1} and μ_{N2}) is x_d.

(c) The degree of possibility in case of a convex fuzzy number to be more than *k* convex fuzzy numbers N_i (i = 1,2, …, k) can be presented by

$$V(N \geq N_1.N_2.\ldots.N_k) = V[(N \geq N_1)\text{and } (N \geq N_2)\text{and}\ldots\text{and}(N \geq N_k)] = \min V(N \geq N_i).i = 1.2.3.\ldots.k \quad (7)$$

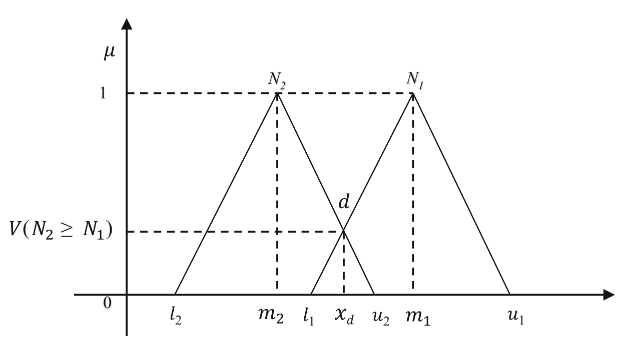

Fig. 3 The intersection between TFNs (N_1 and N_2)

By applying the principles of comparing fuzzy numbers described in step (b), for each obtained S_i (calculated in step (a)), the weight of each element with respect to other elements in the comparison matrix under a certain criterion can be defined based on the following equation:

$$d'(A_i) = \min V(S_i \geq S_k) \qquad \text{for } k = 1.2.\ldots.n; k \neq i \quad (8)$$

So, the weight vector can be presented as

$$W' = \left(d'(A_1), d'(A_2), \ldots.d'(A_n)\right)^T \quad (9)$$

where A_i (i = 1,2, …, n) is *n* elements.

(d) The normalized weight vectors can be obtained through normalization as

$$W = (d(A_1).d(A_2).\ldots.d(A_n))^T \quad (10)$$

In this equation, W is a non-fuzzy number presenting the priority weights of each specific element.

6) Interpreting the results for deriving the overall priorities of elements

The overall priorities of the alternatives in terms of the main goal can be calculated through normalized additive aggregation technique.

In the current study, respondents were chosen in different categories ranging from academic to executive experts with experiences in waste management area in order to cover different interests and points of views. Each of respondents participated in the questionnaire survey based on personal experience and knowledge in the field of E-waste management and also their understanding about conditions of current practice of E-waste management (including all economic, technical, social, and environmental concerns) in the study area. The conflict of interests was observed (for example, some of experts considered economic criteria more important than environmental conservation issues and some of them vice versa). Similarly, the literatures do not ubiquitously agree on the preference of specific alternative with respect to the environmental, economic, technical, and social aspects (for example, although many studies suggest that E-waste recycling is the most suitable alternative, but some of them do not consider this alternative as the best possible solution mainly because of the adverse environmental impact of a recycling plant (Kiddee et al. 2013)).

It should be noted that one of the main advantages of FAHP method is providing the benefits of a broader spectrum of information, much more experience and fewer evaluation mistakes, and also an increased acceptance of the solution (Sims 2002; Cassidy and Kreitner 2011). For reaching consensus in case of conflict of interests, after each respondent (expert person) comes to the specific independent FAHP results, the results of each individual priority values were aggregated to the final group priorities through weighted arithmetic mean as proposed by Chagnes et al. (2016).

Similar to all MCDM methods, the use of FAHP has also some limitations. The most important one is that the respondents should pay their complete attentions for answering the questions in the questionnaire in order to have the most reliable answers as possible. For overcoming this problem, some questions were asked in different ways in the questionnaire to make sure that answers are reliable. In addition, the uncertainty would also occur in case of having a large number of alternatives. The adopted solution to deal with this issue was prescreening the alternatives (through holding meetings with the group of experts) in order to have a reasonable number of alternatives.

Results and discussion

The local and overall weights of studied criteria and sub-criteria, which were derived through applying the mentioned technique, are presented in Tables 3 and 4. It is clear that each criterion with higher weight is more effective in the decision-making process. Out of study criteria in the processing section, it can be seen that the environmental criterion was the most influential criterion (with the global weight of 0.61), whereas the technical criterion had the least effect (with the global weight of 0.09). This implies that the major concern of respondents to select the most beneficial alternative for processing E-waste is the environmental issues. Because Tehran is facing serious environmental problems that make this city as one of the world's most polluted cities (Taghipour et al. 2012; Tahbaz 2016). Also, as for waste management crisis, according to Qarehgozlou (2017), 77.5% of the wastes are burnt or buried in informal landfills located in the countryside or deserts near cities.

Moreover, social criterion was recognized as the most influential one (with the global weight of 0.4) in the collection section, which is followed by economic criterion (with the global weight of 0.36). The high priority of social criteria is mainly due to the necessity for raising awareness concerning E-waste pollution and role of citizens in successful management; this factor has a substantial role in the road to proper E-waste management. According to Kiddee et al. (2013), this issue has been also highlighted in different sectors of waste management. Hasan (2004) investigated a case study of remediation of a contaminated site by hazardous waste in the USA that required public participation largely. It was concluded without considering public awareness; the success of even the best-conceived waste management plan becomes questionable.

The priority weights for alternatives concerning the weights of each specific criterion for both processing and collection sections presented in Tables 5 and 6. It can be seen that, in the processing section, the recycling has the highest priority in terms of economic, social, and technical (adapting to local conditions) criteria with priority weights of 0.82, 1.00, and 0.68, respectively. Additionally, exporting as a processing alternative has the highest priority in terms of environmental and technical (operation time), criteria with priority weights of 0.59 and 0.95, respectively. It should be noticed that landfilling has the lowest priority with respect to all criteria and sub-criteria, except for technical dimension (existing capability/experience), which has the priority weight of 0.56. This can be attributed to the fact that the most practiced disposal method for various kinds of wastes in the studied area is landfilling currently (Damghani et al. 2008); thereby, several negative impacts of this method have been identified.

In collection section, the door-to-door method has the highest priority in terms of all social criteria (motivation potential, accessibility, and new job creation with priority weights of 0.36, 0.45, and 0.54, respectively). The permanent drop-off alternative has the highest priority with respect to economic, technical (adapting to local conditions), and technical (existing capability/experience) views.

It is noticeable that special event as a collection alternative has the highest priority only with respect to technical (operational time) dimension. The advantage of short-term performance of special event method (Patterson-Moulton et al. 2004) notwithstanding, generally, a set of obstacles, namely, setup, breakdown, and planning encumbrance, make this method of collection unfavorable for the studying area.

Table 3 Local and global weights for processing section

Criteria	Weight	Sub-criteria	Local weight	Global weight
Economic	0.18	Economic aspects	1.00	0.18
Social	0.12	New job creation	1.00	0.12
Environmental	0.61	Environmental issues	1.00	0.60
Technical	0.09	Operation time	0.25	0.02
		Adapting to local conditions	0.17	0.03
		Existing capability/experience	0.58	0.05

Table 4 Local and global weights for collection section

Criteria	Weight	Sub-criteria	Local weight	Global weight
Economic	0.36	Economic aspects	1.00	0.36
Social	0.4	New job creation	0.26	0.11
		Accessibility	0.26	0.1
		Motivation potential	0.48	0.2
Technical	0.24	Operation time	0.19	0.04
		Adapting to local conditions	0.26	0.06
		Existing capability/experience	0.55	0.13

Moreover, processing alternative priorities in terms of individual criteria are shown in Fig. 4. Evaluating processing alternatives with respect to environmental criteria (which is the most influential criterion in processing section) reveals that recycling and exporting have a comparable priority while landfilling has negligible priority comparing to those. This can be attributed to the negative environmental impacts of landfilling in comparison to the proper recycling and exporting of E-waste for studying area (Robinson 1991). Most of previous studies also determined the landfilling as a least favorable option in E-waste processing because of related environmental disadvantages (Choi et al. 2006; Apisitpuvakul et al. 2008; Wäger et al. 2011; Kim et al. 2004).

The results also show that in term of E-waste processing economic aspects (which are recognized as another substantial criterion), the recycling is highly preferred. This can be resulted in several beneficial economic effects of E-waste recycling such as recovering valuable and precious materials, conserving natural resources, saving energy, creating new jobs, and saving landfills (Chagnes et al. 2016). On the other side, the recycling has negligible priority in terms of existing capability preferences. A wide variety of materials contained in E-waste requires varied, separate, and advanced treatment processes as well as state-of-the-art technologies to reach appropriate recovery rates (Wang et al. 2012), whereas accessing to mentioned innovative technologies is so limited in the studied area (Taghipour et al. 2012).

Figure 5 represents the priorities of collection alternatives in terms of individual criteria. Based on the obtained results, the economic criteria have the highest priority (global weight) in collection section and permanent drop-off as a collection alternative is preferred economically (according to Fig. 3). This preference is both related to nature of drop-off method, which can be more economically implemented compared to the other alternatives, and also existing presence of drop-off system infrastructure in Tehran City which accepts various

Table 5 Evaluation of processing alternatives in terms of criteria and sub-criteria

Criteria	Priority weight	Sub-criteria	Priority weight	Alternatives	Priority weight
Economic	0.18	Economic aspect	1	Recycling	0.82
				Exporting	0.18
				Landfilling	0
Social	0.12	New job creation	1	Recycling	1
				Exporting	0
				Landfilling	0
Environmental	0.61	Environmental issues	1	Recycling	0.41
				Exporting	0.59
				Landfilling	0
Technical	0.09	Operation time	0.17	Recycling	0
				Exporting	0.95
				Landfilling	0.05
		Adapting to local conditions	0.25	Recycling	0.68
				Exporting	0.32
				Landfilling	0
		Existing capability/experience	0.58	Recycling	0
				Exporting	0.44
				Landfilling	0.56

Table 6 Evaluation of collection alternatives in terms of criteria and sub-criteria

Criteria	Priority weight	Sub-criteria	Priority weight	Alternatives	Priority weight
Economic	0.36	Economic aspects	0.36	Door to door	0.23
				Special event	0.23
				Permanent drop off	0.54
Social	0.41	Motivation potential	0.2	Door to door	0.36
				Special event	0.32
				Permanent drop off	0.32
		Accessibility	0.1	Door to door	0.45
				Special event	0.05
				Permanent drop off	0.5
		New job creation	0.11	Door to door	0.54
				Special event	0.06
				Permanent drop off	0.39
Technical	0.24	Operation time	0.04	Door to door	0.29
				Special event	0.44
				Permanent drop off	0.27
		Adapting to local conditions	0.06	Door to door	0.25
				Special event	0.16
				Permanent drop off	0.59
		Existing capability/experience	0.13	Door to door	0.3
				Special event	0.14
				Permanent drop off	0.56

kinds of wastes (for recycling purposes) and can accept E-wastes as well.

As shown in Fig. 5, all collection alternatives have a similar and comparable priority in terms of motivation potential, highlighting that each of proposed collection alternatives has no significant motivational potential in comparison to the other proposed collection alternatives from respondents' point of view. This can be related to the lack of public awareness of E-waste collection in the studied area (Taghipour et al. 2012). Therefore, public awareness in this area through the public educational programs (such as holding public educational meeting, broadcasting educational programs through media) should be increased (Patterson-Moulton et al. 2004). Simply put, improving awareness of a society on E-waste collection alternatives causes individuals to get familiar with advantages and disadvantages and finally motivational potential of each alternative (Patterson-Moulton et al. 2004; Kiddee et al. 2013).

Furthermore, the priority weights of each alternative regarding all criteria and sub-criteria are calculated individually through global and local weights of criteria and priority weights of alternatives in terms of each criterion. The results

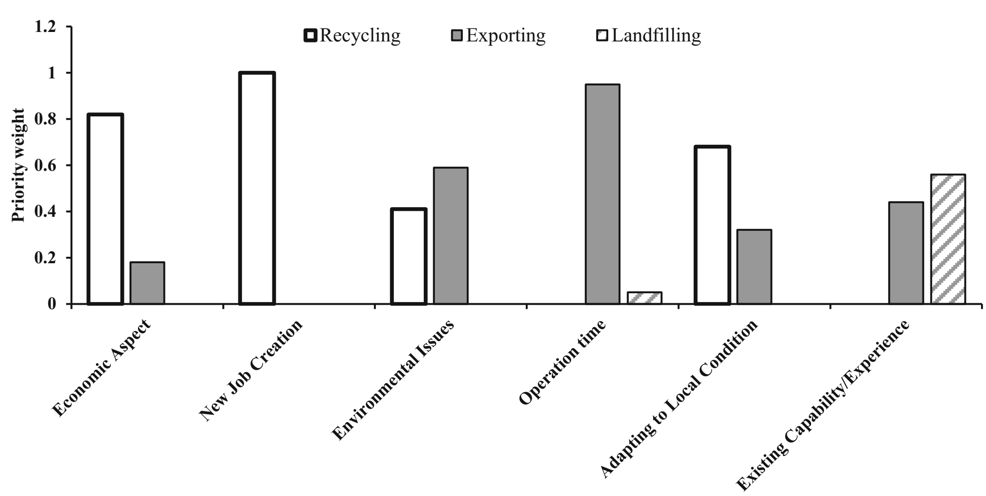

Fig. 4 The priority of processing alternatives in terms of individual criteria

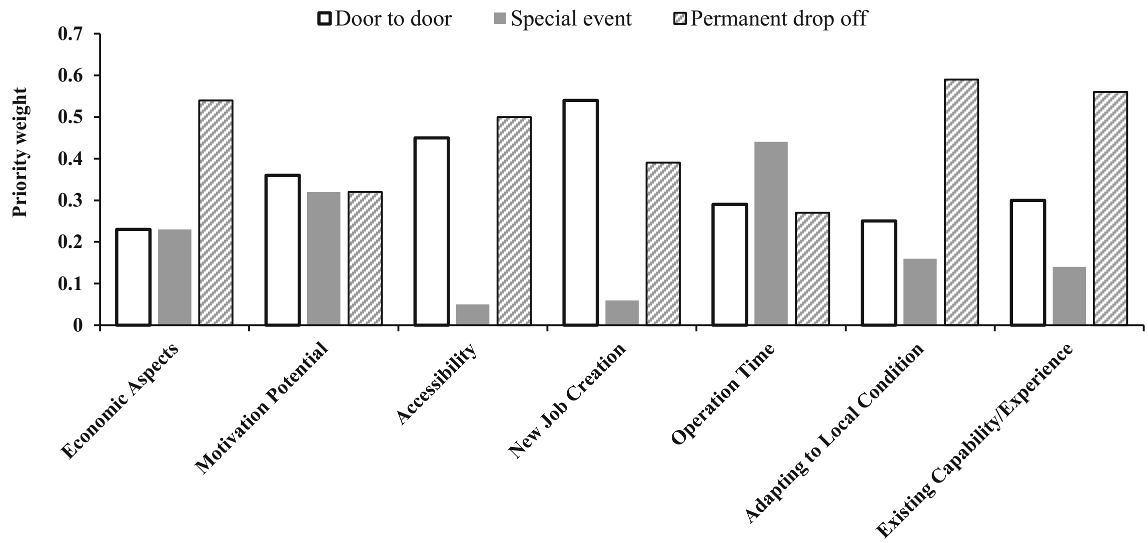

Fig. 5 The priority of collection alternatives in terms of individual criteria

of evaluating alternatives are determined for both processing and collection sections as shown in Fig. 4. The results indicated that recycling has the highest priority in the processing section while landfilling has the lowest one. This can be related to the fact that the recycling of E-waste conserves natural resources, protects the environment, contributes to economic growth, and also saves landfills (Kiddee et al. 2013; Chagnes et al. 2016). It should be noted that landfilling is the most conventional disposal technique for all variety of waste streams, including E-waste in Tehran. Most of these sites in the studied area are unregulated or open dumps, which host to invisible informal recyclers (Taghipour et al. 2012). Therefore, landfilling is ranked as the least favorable alternative in the processing section according to the respondents' point of view. Additionally, the E-waste exporting achieved a noticeable priority. On one hand, exporting does not induce the encumbrance of dealing with recycling processes and its associated problems, and on the other hand, it has economic merits for the exporter. The E-wastes importers, which are usually among developing countries, recycle the imported E-wastes under uncontrolled recycling conditions, which can be potentially hazardous for the environment (Breivik et al. 2014).

As shown in Fig. 6, permanent drop-off alternative has the highest priority in comparison to other studied alternatives. Permanent drop-off alternative is the most practiced method in Tehran City. Several permanent drop-off locations in Tehran are open for residents and businesses to drop off their waste, except for municipal solid waste. There are no quantity limitations and all types of E-waste are accepted. The next collection alternative, which has the high priority, is door-to-door pickup that is slightly practiced in the study area for E-waste. It should be noted that door-to-door pickup is a practiced method in the study area but this alternative is generally more expensive than other alternatives (Patterson-Moulton et al. 2004); this can be the main reason for not extensively execution for E-waste collection.

The E-waste management is studied in a multitude of literatures through different tools including LCA, MFA, and EPR (Kiddee et al. 2013). Generally, application of MCDM methods and specially FAHP in E-waste management area is limited but application of this method can be recommended as

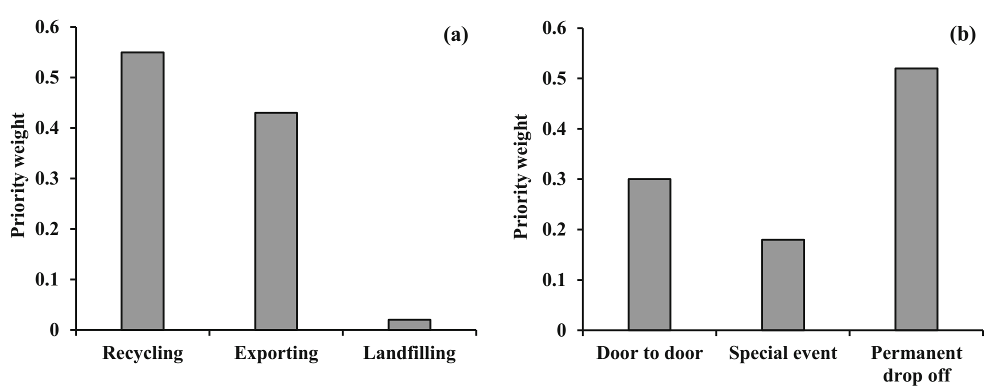

Fig. 6 The priority of E-waste management alternatives in terms of all sub-criteria and criteria. **a** Processing alternatives. **b** Collection alternatives

a conducive way for the legislators and authorities to reach the most effective and comprehensive strategy.

To compare the results of this study holistically with similar investigations in this area, several studies consider recycling as the most effective strategy comparing to other methods including exporting, landfilling, and incineration (Apisitpuvakul et al. 2008; Wäger et al. 2011). Likewise, in the current study, using FAHP method, recycling also gained the highest priority among the other alternatives and landfilling was the least favorable one. Moreover, permanent drop-off system has the highest priority in comparison with the other collection alternatives in this study. Similar studies did not agree on a certain collection alternative and suggested different collection options (such as door-to-door or special event, or combination of them) (Patterson-Moulton et al. 2004; Shumon et al. 2016). This can be attributed to the fact found by Gregory et al. (2009), which implies that collection method is significantly influenced by social, economic, technical, and environmental condition of each specific case study.

Conclusion

In this research, a well-known decision-making method was employed to select the best E-waste management system. Six management scenarios in E-waste collection and processing as alternatives and various influencing criteria were chosen according to the comprehensive literature review and consulting with experts. Chang's fuzzy-AHP method was selected for decision making as a powerful tool, which has the advantages of classic AHP process and in addition improved in terms of imprecision and subjectiveness. Operating the decision-making, a group of experts was selected to participate in this survey. The overall results showed the top priority of E-waste collection by means of permanent drop-off systems, followed by recycling in a proper manner. Apparently, permanent drop-off systems are currently existed and practiced throughout the city, whereas the E-waste recycling is still inchoate. Priority of each alternative in term of each criterion was evaluated for further analysis. The results indicated that the economic and the environmental dimensions are the most influential criteria in E-waste collection and processing, respectively. The high weight of social factor (e.g., motivation potential) for E-waste collection systems emphasizes the essence of citizens' role in a successful E-waste management system. Raising public awareness of E-waste environmental and health issues are considered to be one of the most effective methods to fulfill the highest participation. As a concluding remark, E-waste management systems consisted of many complex and various parts and factors, and the use of techniques like multi-criteria decision analysis would be helpful and invaluable to achieve successful E-waste management.

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