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A three-stage methodology for initiating an effective management system for electronic waste in Turkey

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ABSTRACT

Due to both consumption and obsolescence rates of new technology and shorter life cycles of electronic products, the volume of electronic waste (e-waste) is significantly increasing. While managing a great amount of e-waste, government institutions face compelling problems because of the economic and environmental concerns. This study uses a three-stage methodology to initiate the e-waste management activities in context of a collection campaign in Istanbul, explaining the potential benefits and underlying reasons. The problem includes selecting a superior set among a large but finite number of alternatives. Since it is hard to utilize advanced compensatory methods to solve these problems, a three-stage methodology is proposed for systematically reducing the number of alternatives. In this study, we employ the methodology to determine the locations of collection nodes in Istanbul. The main reason that we select Istanbul, is the requirement of an urgent intervention to deal with the large quantities of e-wastes. The result of this study will strongly assist the authorities to configure well-structured strategies for future e-waste management system.

1. Introduction

The global consumer electronics market is the fastest growing market around the world. Some electronic products, such as mobile phones and laptops, become outdated before its expected life ends. Any innovative challenge expedites the consumption of these products and causes an exponentially increasing electronic waste problem. Since an electronic waste includes both precious and toxic materials, it is economically and environmentally important to minimize the negative environmental effects and to maximize the positive outcome by recycling valuable ingredients, simultaneously.

This study proposes an e-waste collection campaign for Istanbul by explaining the potential benefits and underlying reasons. The main reason for selecting Istanbul depends on requirement of recovery processes regarding its demographics and infrastructural systems. Demographics are concerned with the great amount of population, high penetration rate, higher education level and high-income level of its residents. Young and rapidly growing population have a great demand for new technologies causing the higher utilization rate of the technological devices and a huge quantity of e-waste, which is generated at the end of use. Hence, city planners should build an integrated system including proper collecting, recycling and discard/reuse processes as stated in EU Directives.

Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) emphasize the necessities for a separate e-waste collection system. Directive defines "separate collection" as a precondition for ensuring specific treatment and recycling of WEEE and is necessary to achieve the chosen level of protection of human health and the environment. For this purpose, it states that convenient facilities should be set up for the return of WEEE, including public collection nodes, where private households should be able to return their waste at least free of charge. Distributors have an important role in contributing to the success of WEEE collection. In this context, collection nodes could be set up at retail shops for very small WEEE, which should not be subject to the registration or permit requirements of Directive 2008/98/EC. City planners/directors should settle systems in order to minimize the disposal of WEEE as unsorted municipal waste. They should inform their residents to achieve a high level of separate collection of WEEE by adopting appropriate training programs and legislations.

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As referred by WEEE Directive 2012/19/EU, we propose a separate collection system for EOU/EOL mobile phones for Istanbul city. A separate and specialized collection system should be considered by local authorities regarding the small product size, the specified handling/storage requirements, the economic and security features of the products. This study emphasizes the importance and the need of location determining of e-waste collection nodes for an urban planning system. Hence, a methodology is formed to determine the proper locations for collecting of e-waste products in an economical and accessible manner. The rest of the paper is organized as follows. Section 2 presents the statement of e-waste problem in Istanbul; Section 3 represents the new methodology in taking account of the use of city's resources for setting up collection nodes. In Section 4, a case study is presented a separate collection system for Istanbul. Section 5 concludes some suggestions and recommendations for a separate e-waste collection system.

2. Problem statement

Istanbul is the economic, cultural, and historical metropolitan in Turkey, with the population of 13.9 million. The average age of Istanbul's population is younger (at 23) than Turkey"s average (at 29) because of it is a university city, with over 150,000 students attending the three big universities and dozens of colleges. The city boasts with many of its qualified historical and modern malls which house an astonishing ranges of cafes, restaurants, entertainment options and, shops. These shopping malls have a great potential considering their annual and daily number of visitors. We collect the annual and daily number of visitors from different sources including mall owners/managers and other alternative sources including chambers of commerce, newspapers, and websites. The average number of visitors for the shopping malls of Istanbul varies between 2 and 29 million annually and 30,000–150,000 daily. Considering this popularity of shopping malls in Istanbul, we propose to set up collection nodes in shopping malls. Thus, to bring an EOU/EOL mobile phone to a collection point becomes effortless and less time consuming. There are many advantages of setting up a collection point in a shopping mall: first, shopping malls are safe public places for both people and collection nodes of EOL/EOU mobile phones; second, in shopping malls service providers/electronic retailers mount several marketing campaigns to sell mobile phones, and lastly; shopping malls have a great potential of electronic buyers. In 2012, Council of the Shopping Centers-Turkey (AYD), in cooperation with GfK, has conducted a survey with 1592 respondents, and determined that %57 of electronic buyers prefer shopping malls for buying electronic products.

Information and Communication Technologies Authority (ICTA), which is a Turkish national telecommunications regulatory authority, releases several research reports and periodic bulletins by tracking the developments of the electronic communications sector. In the Bulletin of the Yearly Statistics at Provincial Level for Turkish Electronic Communications Market (2007–2012) of ICTA [1], 24.55% of Turkey's mobile phone subscribers is constituted by Istanbul with 15.7 million. Additionally, the mobile phone penetration rate should be considered as a decisive parameter designating the number of active mobile phone numbers. Regarding the bulletin, Istanbul's mobile penetration rate ranges from 118% to 122% between 2007 and 2012 while it has been about only 0.9% in 1994.

Upon the developments in new technology and innovative designs, mobile phones–smart phones are becoming fancier and more popular. Creative applications for facilitating daily life, favored use of social media applications and convenient educational/business applications increased the rate of mobile phone replacement. The high replacement rate of mobile phones results in a huge quantity of EOL/EOU products. Geyer and Blass (2010) imply that direct landfill option for WEEE is not an acceptable end-of-use management option. Diversion from landfill, either through voluntary take-back and collection programs, mostly leads to the recycling of e-waste, which typically comprise of the recovery of a limited number of metals. Mobile phones are currently one of the few electronic products, if not the only one, that also have a useable reuse market. Regarding the rising demand for new technology, the continuous increase in the population and upward trend in mobile phone penetration rates, Istanbul stands for a promising mobile phone market. Therefore, it is essential to settle a regulatory system both for secondary markets and EOL/EOU products.

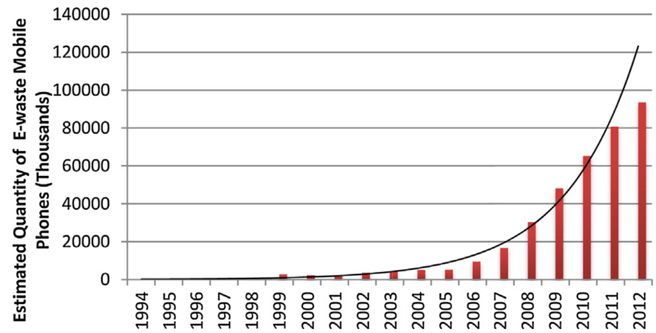

Fig. 1. The cumulative number of mobile phone e-wastes in Turkey

In Istanbul, the efforts for a separate collection of WEEE are still not sufficient. In 2006, Life SMILE Project (LIFE06TCY/TR/000282) was started by Istanbul Metropolitan Municipality as the first effort to manage local e-waste in Istanbul. The project aimed to implement a sustainable management system for WEEE in Istanbul, in line with EU objectives. The project established the plans and proposals for implementing WEEE management regulations and introduced voluntary agreements, administrative and financial tools, and training of staff for the reduction of WEEE. The project runs a public awareness campaign but until now it could not reconstruct residents' behaviors and establish a widely known collection system.

Regarding all these data and evaluations, lifecycle of mobile phones has shortened and a very large scale of mobile phone waste has been accumulated. According to the ICTA data for Turkey, the imported amount of mobile phone between 1994 and 2012 is about 160.67 million and active mobile phone user number is 67.68 million in 2012. With a rough computation, the severity of the problem should be better recognized that there is no track related to 93 million of EOU/EOL mobile phones. Fig. 1 reveals the exponentially increasing characteristic for the cumulative quantity of EOL/EOU mobile phones.

3. Literature review

We reviewed many e-waste papers that have been published in recent years and classified them according to types of wastes as; solid waste, e-waste, hazardous waste and recyclable waste (glass, plastics and etc.). We observed the recycling and disposal strategies with the methods, such as multi criteria decision making methods and their fuzzy extensions, clustering and set covering methods, mixed integer models and meta-heuristic algorithms through this analysis. The recent literature is summarized in Table 1. For an extensive literature review, we refer the detailed study of Qu et al. (2013).

Moreover, we reveal the main waste management issues considered in the literature under the subtitles of site selection, vehicle routing and clustering problems. Here, we understand that the literature is still insufficient. Numerious types of e-wastes in large

Table 1
A comprehensive summary of relevant literature.

Author (Year)	Method	Solid waste	e-Waste	Hazardous waste	Recyclable waste	Set partitioning	Location	Routing	Collection
Achillas et al. (2010)	Decision Support System (ELECTRE III)		x				x		
Aragonés-Beltrán et al. (2010)	Analytic Hierarchy Process And Analytic Network Process	x					x		x
Bereketli et al. (2011)	Decision Support Model (LINMAP)		x						
Bing et al. (2014)	Tabu Search Heuristic				x			x	x
Chang et al. (2008)	GIS Based MCDA With Fuzzy Operators	x					x		
Gbanie et al. (2013)	GIS Based AHP And Ordered Weighted Averaging Method	x					x		
Ghiani et al. (2012)	Integer Programming And Constructive Heuristic				x		x		x
Ghiani et al. (2014)	Integer Programming And Constructive Heuristic				x				
Gorsevski et al. (2012)	GIS Based AHP And Ordered Weighted Averaging Method	x					x		
Groot et al. (2014)	Cost Based Decision Support Model				x				x
Hatami-Marbini et al. (2013)	Fuzzy ELECTRE Method			x					
Hauge et al. (2014)	Hybrid Column Generation-Tabu Search Algorithm				x	x		x	x
Khadivi and Fatemi Ghomi (2012)	Analytical Network Process And Data Envelopment Analysis	x					x		
Kurka et al. (2012)	GIS				x		x		
Liu et al. (2011)	Cluster Analysis			x				x	x
Othman et al. (2012)	GIS And Analytic Hierarchy Process			x			x		
Queiruga et al. (2008)	PROMETHEE		x				x		
Ramos et al. (2013)	Mixed Integer Linear Programming				x			x	x
Ramos et al. (2014)	Unified Multi-Modular Solution Methodology				x			x	x
Rogge and De Jaeger (2013)	Non-Parametric Data Envelopment Analysis	x							
Samanlioglu (2013)	Multi Objective Mathematical Model			x			x	x	
Sharifi et al. (2009)	GIS and Analytic Hierarchy Process			x			x		
Şener et al. (2010)	GIS and Analytic Hierarchy Process	x					x		
Tavares et al. (1972)	GIS and Analytic Hierarchy Process	x					x		
Toso and Alem (2014)	Two-Stage Stochastic Programming Model				x		x		x
Wy et al. (2013)	Neighborhood Search Based Iterative Heuristic				x			x	x

quantities, which require different processes, create the complex structure of e-waste management problem for local authorities. As seen in the literature review, this era is still demanding for the guidance of scientific studies. Therefore, we develop a new approach to plan a roadmap for initiating e-waste management processes in Section 4.

4. A methodology for the process of initiating e-waste management

This study aims encouraging academicians to propose effective approaches for e-waste management and imposing city planners/managers to build integrated systems for different types of e-wastes. In this respect, we propose an integrated methodology to determine locations for collection nodes over a large number of possible locations.

The presence of numerous alternatives does not allow a comprehensive evaluation of each candidate. Thus, we introduce a three stage methodology to simplify this comprehensive evaluation without losing any intellectual ability and interaction between the criteria. The proposed methodology contains three stages as follows: (i) eliminating strictly dominated candidates by means of specific criteria, Elimination by Aspects (EBA) is utilized, (ii) decreasing the number of alternatives for a classification by means of geographical information data, Geographical Information System (GIS) is employed and, (iii) the ranking of most performing alternatives is obtained by using a MCDA method. Shortly, the first and second stages decrease the number of alternatives to satisfy the minimum requirements, while the third stage considers the interaction between criteria to select the proper collection points. Fig. 2 illustrates the proposed three-stage methodology. The stages of the methodology are explained in detail as follows.

4.1. Stage 1: Elimination by aspects as a non-compensatory method

In complex situations, individuals frequently attempt to simplify decision-making process by use straightforward heuristics. One of these attempts, Tversky (1972) proposed the Elimination

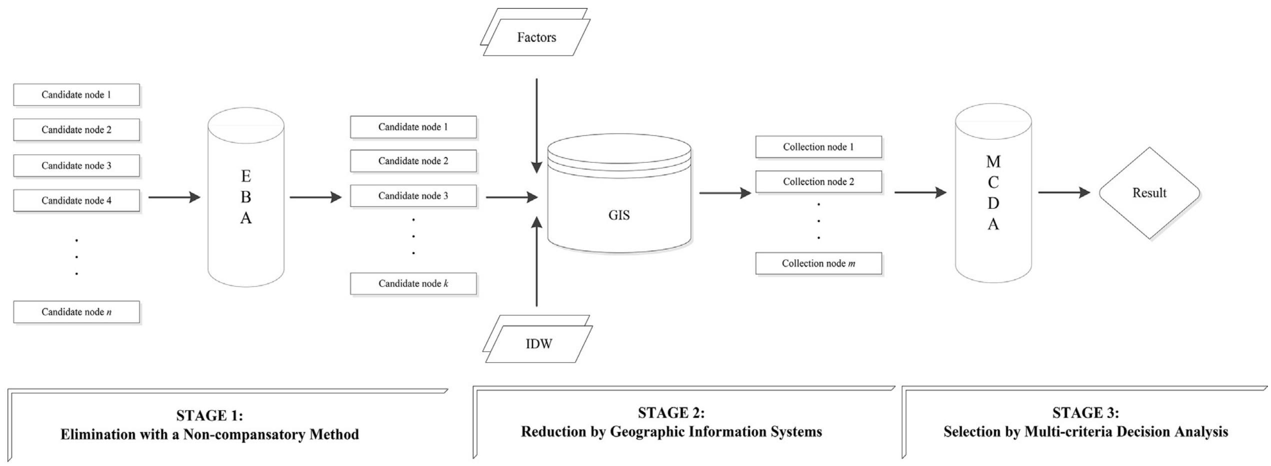

Fig. 2. Proposed three-stage methodology to determine the locations for e-waste collection campaign

by Aspects (EBA) to allow any reduction in the complexity by simple reasoning and scalability principles. A general theory of choice based on a covert elimination process is developed in which each alternative is viewed as a set of aspects. At each stage in the process, an aspect is selected (with probability proportional to its weight), and all the alternatives that do not include the selected aspect are eliminated (Tversky, 1972).

We retain EBA with the intention of eliminating strictly dominated alternatives by means of some relevant criteria. Therefore, we effortlessly decrease the number of alternatives from $\boldsymbol{n}$ to $\boldsymbol{k}$ where $\boldsymbol{k} \ll \boldsymbol{n}$ holds.

4.2. Stage 2: GIS

The GIS technology is appropriate for a variety of use including environmental management, industry and trade, tourism, health management, security and defense, transport planning. GIS possesses unique capabilities for automating geospatial analysis.

One of the most commonly used deterministic models in spatial interpolation is the inverse-distance weighting (IDW) method. IDW methods are based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. It is relatively fast and easy to compute, and straightforward to interpret. IDW method is one of the more popular methods adopted by geoscientists and geographers partly because it has been implemented in many GIS packages. The general premise of this method is that the attribute values of any given pair of points are related to each other, but their similarity is inversely related to the distance between the two locations Its general idea is based on the assumption that the attribute value of an unsampled point is the weighted average of known data within the neighborhood, and the weights are inversely related to the distances between the prediction location and the sampled locations (Lu and Wong, 2008). Several options are available for inverse distance weighted interpolation. The simplest form of inverse distance weighted interpolation is sometimes called “Shepard’s method” (Shepard, 1968).

Inverse distance weighted interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted (ESRI-Johnston et al., 2001). The equation is as follows.

$$K(a,b) = \sum_{i=1}^{n} w_i s_i \tag{1}$$

where n is the number of scatter points in the set, s_i are the prescribed function values at the scatter points (e.g. the dataset values), and w_i are the weight functions assigned to each scatter point. The classical form of the weight function is:

$$w_i = \frac{d_i^{-m}}{\sum_{j=1}^{n} d_j^{-m}} \tag{2}$$

where m is an arbitrary positive real number called the power parameter (typically, $m=2$) and d_i is the distance from the scatter point to the interpolation point or:

$$m_i = \sqrt{(a-a_i)^2 + (b-b_i)^2} \tag{3}$$

where (a,b) are the coordinates of the interpolation point and (a_i, b_i) are the coordinates of each scatter point. The weight function varies from a value of unity at the scatter point to a value-approaching zero as the distance from the scatter point increases. The weight functions are normalized so that the weights sum to unity.

We prefer to employ GIS with the intention of classifying some alternatives by means of geographical information data and some relevant criteria. This stage of the methodology aims to decrease the number of alternatives to a reasonable number regarding the predetermined factors by utilizing GIS software. The factors allows us to decrease the number alternatives from $\boldsymbol{k}$ to $\boldsymbol{m}$ where $\boldsymbol{m} < \boldsymbol{k}$ holds.

4.3. Stage 3: Choquet integral as MCDA method

MCDA present a set of modern methods to structure and appraise complex decision-making problems. Choquet integral technique has recently been introduced as a MCDA method. A fuzzy integral is a sort of general averaging operator that can represent the notions of importance of a criterion and interactions among criteria. To define fuzzy integrals, a set of values of importance is needed. This set is composed of the values of a fuzzy measure. So, a value of importance for each subset of attributes is needed.

The success of a Choquet integral depends on an appropriate representation of fuzzy measures, which captures the importance of individual criterion or their combination. In this paper, the generalized Choquet integral proposed by Auephanwiriyahul et al. (2002) will be used, in which measurable evidence is represented in terms of intervals, whereas fuzzy measures are real numbers, is an extension of the standard Choquet integral. In contrast to Auephanwiriyahul et al. (2002), Tsai and Lu (2006) propose a generalization that involves linguistic expressions as well as information fusion between criteria to overcome vagueness and imprecision of linguistic terms in questionnaires. Our methodology follows Tsai and Lu's (2006) approach to Auephanwiriyahul et al. (2002). In the following, some definitions are given to explain the basics of Choquet integral (Modave and Grabisch, 1998):

Let I be the set of attributes. A set function $\mu: P(I) \to [0,1]$ is called a fuzzy measure if it satisfies three following axioms:

(1) $\mu(\emptyset)=0$: an empty set has no importance,
(2) $\mu(I)=1$: the maximal set has a maximal importance,
(3) $\mu(B) \le \mu(C)$ if $B,C \subset I$ and $B \subset C$: a new added criterion cannot make the importance of a coalition (a set of criteria) diminish.

The methodology is composed of eight steps (Tsai and Lu, 2006; Demirel et al., 2010):

Step 1. Given criterion i, respondents' linguistic preferences for the degree of importance, perceived performance levels of alternatives and tolerance zone are surveyed.

Step 2. In view of the compatibility between perceived performance levels and the tolerance zone, trapezoidal fuzzy numbers are used to quantify all linguistic terms.

Given respondent t and criteria i, linguistic terms for the degree of importance is parameterized by $\tilde{A}_i^t = \left(a_{i1}^t, a_{i2}^t, a_{i3}^t, a_{i4}^t\right)$ perceived performance levels by $\tilde{p}_i^t = \left(p_{i1}^t, p_{i2}^t, p_{i3}^t, p_{i4}^t\right)$, and the tolerance zone by $\tilde{e}_i^t = \left(e_{i1L}^t, e_{i2L}^t, e_{i3L}^t, e_{i4L}^t\right)$.

In this case study, $t=1, 2, 3$; $i=1, \ldots, n_j$; $j=1, 2, 3, 4$; $n_1=2$, $n_2=2$, $n_3=2$, $n_4=2$; where n_j represents the number of criteria in dimension j.

Step 3. Average $\tilde{A}_i^t$, $\tilde{p}_i^t$ and $\tilde{e}_i^t$ into $\tilde{A}_i$, $\tilde{p}_i$ and $\tilde{e}_i$, respectively, using the following equation:

$$\tilde{A}_i = \frac{\sum_{t=1}^{k}\tilde{A}_i^t}{k} = \left(\frac{\sum_{t=1}^{k}a_{i1}}{k}, \frac{\sum_{t=1}^{k}a_{i2}}{k}, \frac{\sum_{t=1}^{k}a_{i3}}{k}, \frac{\sum_{t=1}^{k}a_{i4}}{k}\right) \quad (4)$$

Step 4. Normalize the location value of each criterion using Eqs. (5)–(6).

$$\tilde{f}_i = ||\tilde{f}_i^\alpha = || \left[f_{i,\alpha}^-, f_{i,\alpha}^+\right] \qquad \forall\alpha \in [0,1] \quad (5)$$

where $f_i \in F(S)$ is a fuzzy-valued function. $\tilde{F}(S)$ is the set of all fuzzy-valued functions f,

$$f_i^\alpha = \left[f_{i,\alpha}^-, f_{i,\alpha}^+\right] = \frac{\bar{p}_i^\alpha - \bar{e}_i^\alpha + [1,1]}{2} \qquad \forall\alpha \in [0,1] \quad (6)$$

$\bar{p}_i^\alpha$ and $\bar{e}_i^\alpha$ are α-level cuts of $\tilde{p}_i$ and $\tilde{e}_i$.

Step 5. Find the location value of dimension j using Eq. (7).

$$(C)\int \tilde{f}\, d\tilde{g} = || \left[(C)\int f_\alpha^-\, dg_\alpha^-, (C)\int f_\alpha^+\, dg_\alpha^+\right] \qquad \forall\alpha \in [0,1] \quad (7)$$

where $\bar{g}_i : P(S) \to I(R^+)$, $\bar{g}_i = \left[g_i^-, g_i^+\right]$ and $\bar{f}_i : S \to I(R^+)$, $\bar{f}_i = \left[f_i^-, f_i^+\right] \forall i \in \left\{1, 2, \ldots, n_j\right\}$

The λ value and n fuzzy measures $g(A(i))$ for all $i \in \left\{1, 2, \ldots, n\right\}$ are required to be able to calculate this location value, These are obtained from the following Eqs. (8)–(10) (Sugeno, 1974; Ishii and Sugeno, 1985):

$$g\left(A_{(n)}\right) = g\left(\left\{s_{(n)}\right\}\right) = g_n \quad (8)$$

$$g\left(A_{(i)}\right) = g_i + g\left(A_{(i+1)}\right) + \lambda g_i g\left(A_{(i+1)}\right) \quad \text{where} \quad 1 \le i \le n \quad (9)$$

$$1 = g(S) = \begin{cases} \frac{1}{\lambda}\left\{\prod_{i=1}^{n}\left[1 + \lambda g(A_i) - 1\right]\right\} & \text{if} \quad \lambda \neq 0 \\ \sum_{i=1}^{n} g(A_i) & \text{if} \quad \lambda \neq 0 \end{cases} \quad (10)$$

where $A_i \cap A_j = \emptyset$ for all $i, j \in \left\{1, 2, 3, \ldots, n\right\}$ and $i \neq j$, and $\lambda \in (-1, \infty)$.

Let μ be a fuzzy measure on $(I, P(I))$ and an application: $I \to \Re^+$. The Choquet integral of f with respect to μ is defined as

$$(C)\int_I f d\mu = \sum_{i=1}^{n}\left[f(\sigma(i)) - f(\sigma(i-1))\right]\mu\left(A_{(i)}\right) \quad (11)$$

where σ is a permutation of the indices in order to have

$$f(\sigma(1) \le \cdots \le f(\sigma(n)))\, \Lambda f(\sigma(0)) = 0, \quad (12)$$

by convention.

It is easy to see that the Choquet integral is a Lebesgue integral up to a reordering of the indices. Actually, if the fuzzy measure μ is additive, then the Choquet integral reduces to a Lebesgue integral.

It is shown in Modave and Grabisch (1998) that under rather general assumptions over the set of alternatives X, and over the weak orders $\succ_i$, there exists a unique fuzzy measure μ over I such that:

$$\forall x, y \in X, \qquad x \succcurlyeq y \leftrightarrow u(x) \ge u(y) \quad (13)$$

where

$$u(x) = \sum_{i=1}^{n}\left[u_{(i)}\left(x_{(i)}\right) - u_{(i-1)}\left(x_{(i-1)}\right)\right]\mu\left(A_{(i)}\right) \quad (14)$$

which is simply the aggregation of the mono-dimensional utility functions using the Choquet integral with respect to μ.

Step 6. Aggregate all dimensional performance levels of the location alternatives into overall performance levels, using a hierarchical process applying the two-stage aggregation process of the generalized Choquet integral as represented in Eq. (15). The overall performance level yields a fuzzy number, $\tilde{V}$

$$\left.\begin{array}{l} \text{main criterion}_{(1)} = (C)\int fdg \\ \vdots \\ \text{main criterion}_{(m)} = (C)\int fdg \end{array}\right\} > V = (C)\int \text{main criterion } dg \quad (15)$$

Step 7. Assume that the membership of $\tilde{V}$ is $\mu_{\tilde{V}}(x)$ defuzzify the fuzzy number $\tilde{V}$ into a crisp value v using Eq. (16) and make a comparison of the overall performance levels of alternative locations.

$$F\left(\tilde{A}\right) = \frac{a_1 + a_2 + a_3 + a_4}{4} \quad (16)$$

Lastly, we summarize the proposed three-stage methodology as

(1) use a non-compensatory method to diminish the number of alternatives by preserving the non-dominated alternatives against dominated ones,
(2) use GIS to emphasize the importance of utilizing geographical information,
(3) use a MCDA method to conclude with the most performing choice among some non-dominated alternatives according predetermined criteria.

Following case study describes the effective use of proposed methodology for managing e-waste management operations of EOL/EOU mobile phones in Istanbul.

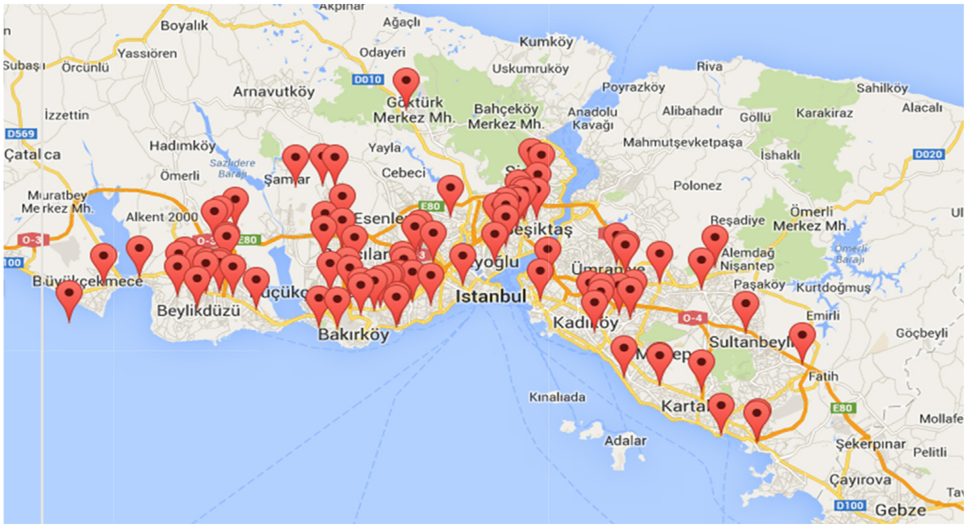

Fig. 3. Location info of 92 shopping malls in Istanbul

5. Case study: The process of initiating e-waste management in Istanbul

In this study, our purpose is to impose city planners/managers to take an immediate action in order to build integrated systems for different types of e-wastes. The problem is dramatically critical for modern crowded cities because of high consumption and turnover rates of electronic products. In order to raise the awareness on environmental and economic extents of e-waste problem, governmental and non-governmental organizations should immediately campaign to inform their residents and initiate the collection of e-waste at hand, before they are treated as municipal waste. In this respect, we suggest to determine these collection nodes in highly accessible and favorable locations by considering the speed of daily city life. As we stated earlier, shopping malls can be efficient candidates to locate these collection nodes for an e-waste campaign in Istanbul. As of January 2014, Fig. 3 shows the location info of 92 shopping malls in Istanbul.

The proposed methodology contains three stages to determine the exact collection nodes for an effective e-waste campaign. The campaign is related to initiate promotional activities and to enlighten people by explaining the importance of separate e-waste collection. With this effort, we determine the superior shopping malls regarding various factors; such as, the number of visitors, total leasable area, total number of stores, geographical data, operating costs, accessibility, growth perspective, and customer perspective.

In the first stage, with the purpose of planning an effective campaign, we decided to define a set of shopping mall to initiate promotional activities and to enlighten people by explaining the importance of separate e-waste collection. Therefore, we conduct a non-compensatory method to make a reduction in the number of shopping malls. In the non-compensatory model, superiority in one attribute cannot be offset by inferiority in some other attribute(s) (Yoon and Hwang, 1995). By use of a non-compensatory method, we endorsed some shopping malls by means of an ordered set of criteria and blocked some unfavorable shopping malls. To evaluate the shopping malls, we consider three evaluation criteria: footfall index (annual number of visitors), total leasable area and total number of stores. By the use of EBA method, we eliminate any shopping mall that has average annual visitors less than 1 million, total leasable area less than 10,000.00 m^2 and total number of stores less than 50, respectively. The method allows us to set a lower limit for shopping malls and with this respect we decreased the number of shopping malls from 92 to 33.

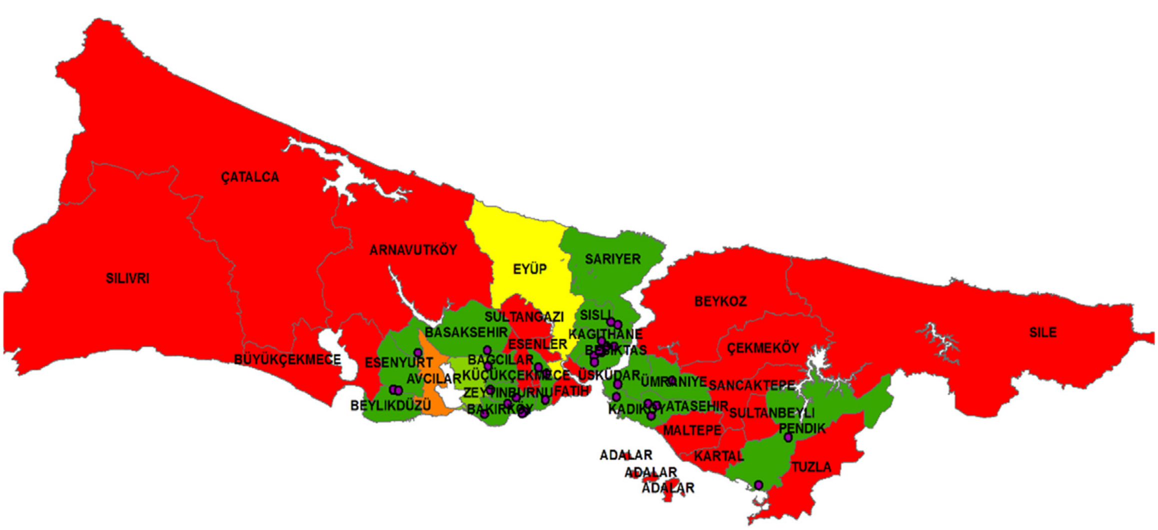

Fig. 4. Density map based on the number of AVMs at each county

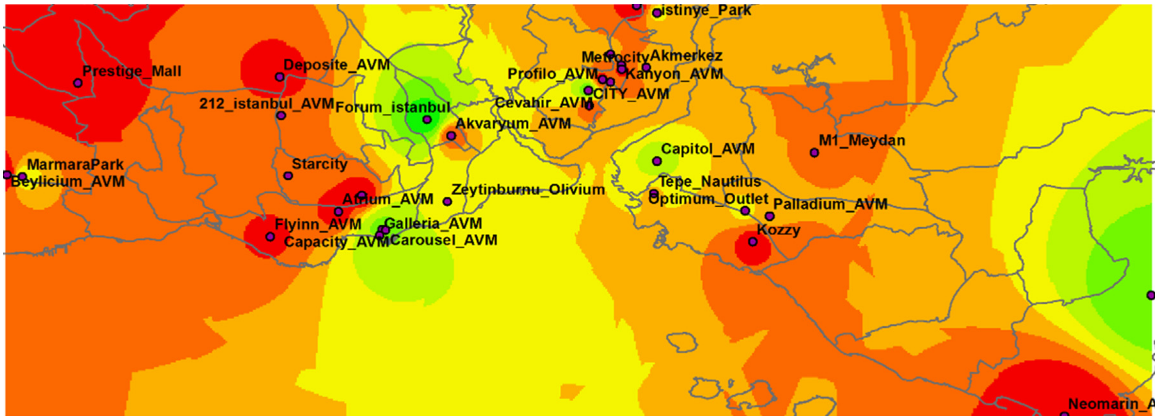

Fig. 5. AVM clustering according to the number of visitors

We refrain to eliminate more candidate location with a non-compansatory method. For the reason that we believe maximum spanning of collection nodes around the city can yield more accessibility from outer counties. Fig. 4 represents the density map based on the number of shopping malls at each county. Therefore, in the second stage, we imply the importance of geographic information in order to assess alternative candidate locations. Otherwise, by utilizing non-geographical criteria to evaluate these candidate locations, it is possible to encourage the threat of eliminating more accessible ones.

In the second stage, we employ geographic information systems (GIS) with the intention of classifying these shopping malls by means of their geographical information and foot-fall index. This stage of the methodology aims to decrease the number of collection nodes to a reasonable number considering these factors by utilizing GIS software. We define the factors as *inverse distance weighted* (IDW) and *foot-fall index* (FFI) to reduce the number of alternatives from the number of 33 to 4. This reduction enables us to examine the remaining alternatives in a more detailed manner.

The alternative locations have been determined as Galleria, Capitol, Forum Istanbul, and Viaport, by ArcGIS programming. In Fig. 5, green shaded areas show the most favorable shopping mall alternatives, and on the contrary, red shaded areas show the least favorable shopping mall alternatives as initial collection nodes. Thus, we decide to set up four initial collection nodes in Galleria, Capitol, Forum Istanbul, and Viaport regarding the criteria of their geographic data and foot-fall index.

Lastly, we focus on where we locate the center of campaign to initiate activities and from which node we manage the campaign. Therefore, we propose to utilize one of the multiple criteria decision analysis (MCDA) methods to determine the center of campaign. Reducing the number of candidate collection nodes by employing GIS based clustering, allows us to use a variety of MCDA methods with less effort. The methodology suggests the use of any MCDA method as final stage; however, we prefer to utilize Choquet integral approach in this study.

Table 2
Evaluation criteria for e-waste collection center and their symbols.

	Criteria	The symbol of each criterion
Operating Costs	O	
1. Rental cost		O_1
2. Transfer- handling cost		O_2
Accessibility	A	
1. Proximity to public transport		A_1
2. Proximity to city center		A_2
Growth Perspective	G	
1. Flexibility of regulations		G_1
2. Ability to horizontal expansion		G_2
Customer Perspective	C	
1. Education		C_1
2. Income		C_2

In this study, a group of three decision makers, including the experts from government institutions and universities, define four main criteria and eight sub-criteria of these main criteria to determine the best location to manage campaign activities. After decision makers provide decision criteria to assist the construction of model, they confirmed on the criteria and sub-criteria in Table 2 with the intention of evaluating demographical, environmental, social and economic factors.

The definitions of the main- and sub-criteria are summarized as follows.

Operating costs refer to the expenses related to the campaign when the promotion, collection, transfer and handling activities are held in shopping mall.

Accessibility stands for describing the proximity to public transport and to city center. Here, we assume that higher accessibility is

Table 3
Linguistic terms of fuzzy numbers (Delgado et al., 1998).

Low/high levels		The degrees of importance		Trapezodial fuzzy numbers
Label	Linguistics terms	Label	Linguistics terms	
EL	Extra low	EU	Extra unimportant	(0, 0, 0, 0)
VL	Very low	VU	Very unimportant	(0, 0.01, 0.02, 0.07)
L	Low	U	Unimportant	(0.04, 0.1, 0.18, 0.23)
SL	Slightly low	SU	Slightly unimportant	(0.17, 0.22, 0.36, 0.42)
M	Middle	M	Middle	(0.32, 0.41, 0.58, 0.65)
SH	Slightly high	SI	Slightly important	(0.58, 0.63, 0.8, 0.86)
H	High	HI	High important	(0.72, 0.78, 0.92, 0.97)
VH	Very high	VI	Very important	(0.93, 0.98, 0.98, 1.0)
EH	Extra high	EI	Extra important	(1, 1, 1, 1)

Table 4
The evaluation form by decision maker 1.

Criteria	Individual importance of criteria	The tolerance zone	Linguistic evaluation			
			Forum Istanbul	Capitol	Galleria	Viaport
Operation Costs	SI					
1. Rental cost	HI	[SL, VH]	L	VH	SL	SH
2. Transportation—handling cost	M	[VL, EH]	M	VL	EH	VH
Accessibility	VI					
1. Proximity to Public Transport	VI	[EL, EH]	EL	EH	L	M
2. Proximity to City Center	EI	[EL, EH]	L	EH	EL	SH
Growth Perspective	VI					
1. Regional Regulation	EI	[VL, VH]	VH	VL	L	VL
2. Ability to horizontal expansion	U	[EL, H]	H	EL	H	VL
Customer Perspective	M					
1. Education	M	[L, VH]	SH	H	L	VH
2. Income	VI	[VL, EH]	SL	SH	VL	EH

Table 5
Compromised evaluations of three experts.

Criteria	Individual importance	The combined tolerance zone	Perceived performance levels of alternative locations			
			Alternative 1	Alternative 2	Alternative 3	Alternative 4
O	(0.43, 0.47, 0.57, 0.61)					
O_1	(0.43, 0.47, 0.57, 0.61)	(0.03, 0.07, 0.65, 0.67)	(0.03, 0.07, 0.12, 0.15)	(0.5, 0.54, 0.59, 0.62)	(0.3, 0.33, 0.43, 0.46)	(0.5, 0.54, 0.59, 0.62)
O_2	(0.21, 0.27, 0.39, 0.43)	(0.01, 0.04, 0.53, 0.55)	(0.12, 0.17, 0.25, 0.29)	(0.06, 0.08, 0.13, 0.16)	(0.44, 0.47, 0.53, 0.55)	(0.42, 0.46, 0.52, 0.55)
A	(0.64, 0.66, 0.66, 0.67)					
A_1	(0.55, 0.59, 0.63, 0.66)	(0.11, 0.14, 0.64, 0.66)	(0.11, 0.14, 0.19, 0.22)	(0.57, 0.59, 0.64, 0.66)	(0.25, 0.29, 0.37, 0.4)	(0.35, 0.4, 0.5, 0.54)
A_2	(0.67, 0.67, 0.67, 0.67)	(0.01, 0.03, 0.64, 0.66)	(0.03, 0.07, 0.12, 0.15)	(0.57, 0.59, 0.64, 0.66)	(0.24, 0.26, 0.31, 0.32)	(0.43, 0.47, 0.57, 0.61)
G	(0.42 ,0.46, 0.52, 0.55)					
G_1	(0.67, 0.67, 0.67, 0.67)	(0, 0.01, 0.63, 0.66)	(0.55, 0.59, 0.63, 0.66)	(0, 0.01, 0.01, 0.05)	(0.01, 0.04, 0.07, 0.1)	(0, 0.01, 0.01, 0.05)
G_2	(0.06, 0.07, 0.12, 0.14)	(0, 0, 0.61, 0.65)	(0.48, 0.52, 0.61, 0.65)	(0, 0, 0, 0)	(0.25, 0.29, 0.37, 0.4)	(0, 0, 0.01, 0.02)
C	(0.3, 0.35, 0.46, 0.5)					
C_1	(0.21, 0.27, 0.39, 0.43)	(0.03, 0.07, 0.65, 0.67)	(0.3, 0.35, 0.46, 0.5)	(0.48, 0.52, 0.61, 0.65)	(0.03, 0.07, 0.12, 0.15)	(0.62, 0.65, 0.65, 0.67)
C_2	(0.64, 0.66, 0.66, 0.67)	(0.01, 0.04, 0.66, 0.67)	(0.16, 0.21, 0.31, 0.36)	(0.39, 0.42, 0.53, 0.57)	(0.01, 0.04, 0.07, 0.1)	(0.64, 0.66, 0.66, 0.67)

Table 6
Evaluation results by the generalized Choquet integral for $\alpha = 0$.

Criteria	Individual importance of criteria	The normalized dicrepancy $\bar{\bar{f}}_i = [f_i^-, f_i^+]$ and location value $\left[(C)\int f^- \mathrm{d}g^-, (C)\int f^+ \mathrm{d}g^+\right]$				Fuzzy measures
		Alternative 1	Alternative 2	Alternative 3	Alternative 4	
O		[0.202, 0.5944]	[0.3238, 0.7092]	[0.3423, 0.7386]	[0.4192, 0.7852]	2.0485; 0.1798
O_1	[0.43, 0.61]	[0.18, 0.56]	[0.415, 0.795]	[0.315, 0.715]	[0.415, 0.795]	
O_2	[0.21, 0.43]	[0.285, 0.64]	[0.255, 0.575]	[0.445, 0.77]	[0.435, 0.77]	
A		[0.207, 0.565]	[0.455, 0.8085]	[0.2928, 0.6517]	[0.3718, 0.772]	−0.6578; −0.7108
A_1	[0.55, 0.66]	[0.225, 0.555]	[0.455, 0.775]	[0.295, 0.645]	[0.345, 0.715]	
A_2	[0.67, 0.67]	[0.185, 0.57]	[0.455, 0.825]	[0.29, 0.655]	[0.385, 0.8]	
G		[0.4351, 0.8284]	[0.1703, 0.5168]	[0.1825, 0.571]	[0.1703, 0.52]	5.5427; 2.6114
G_1	[0.67, 0.67]	[0.445, 0.83]	[0.17, 0.525]	[0.175, 0.55]	[0.17, 0.525]	
G_2	[0.06, 0.14]	[0.415, 0.825]	[0.175, 0.5]	[0.3, 0.7]	[0.175, 0.51]	
C		[0.2597, 0.7008]	[0.3694, 0.7929]	[0.1721, 0.5514]	[0.4814, 0.8267]	0.3926; −0.1944
C_1	[0.21.0.43]	[0.315, 0.735]	[0.405, 0.81]	[0.18, 0.56]	[0.475, 0.82]	
C_2	[0.64, 0.67]	[0.245, 0.675]	[0.36, 0.78]	[0.17, 0.545]	[0.485, 0.83]	

Table 7
Evaluation results by the generalized Choquet integral for $\alpha = 1$.

Criteria	Individual importance of criteria	The normalized dicrepancy $[f_{i,\alpha}^-, f_{i,\alpha}^+]$ and location value $\left[(C)\int f_\alpha^- \mathrm{d}g_\alpha^-, (C)\int f_\alpha^+ \mathrm{d}g_\alpha^+\right]$				Fuzzy measures
		Alternative 1	Alternative 2	Alternative 3	Alternative 4	
O		[0.2397, 0.5562]	[0.3549, 0.6676]	[0.3751, 0.7054]	[0.4504, 0.7514]	2.0485; 0.1798
O_1	[0.47, 0.57]	[0.21, 0.525]	[0.445, 0.76]	[0.34, 0.68]	[0.445, 0.76]	
O_2	[0.27, 0.39]	[0.32, 0.605]	[0.275, 0.545]	[0.47, 0.745]	[0.465, 0.74]	
A		[0.2356, 0.5384]	[0.475, 0.7869]	[0.3188, 0.6318]	[0.4034, 0.7403]	−0.6578; −0.7108
A_1	[0.59, 0.63]	[0.25, 0.525]	[0.475, 0.75]	[0.325, 0.615]	[0.38, 0.68]	
A_2	[0.67, 0.67]	[0.215, 0.545]	[0.475, 0.805]	[0.31, 0.64]	[0.415, 0.77]	
G		[0.4718, 0.8084]	[0.1904, 0.5]	[0.2144, 0.5486]	[0.1904, 0.5006]	5.5427; 2.6114
G_1	[0.67, 0.67]	[0.48, 0.81]	[0.19, 0.5]	[0.205, 0.53]	[0.19, 0.5]	
G_2	[0.07, 0.12]	[0.455, 0.805]	[0.195, 0.5]	[0.34, 0.685]	[0.195, 0.505]	
C		[0.2952, 0.6584]	[0.3948, 0.7548]	[0.1954, 0.5189]	[0.5, 0.8032]	0.3926; −0.1944
C_1	[0.27, 0.39]	[0.35, 0.695]	[0.435, 0.77]	[0.21, 0.525]	[0.5, 0.79]	
C_2	[0.66, 0.66]	[0.275, 0.635]	[0.38, 0.745]	[0.19, 0.515]	[0.5, 0.81]	

Table 8
Defuzzifed overall values of alternative locations using generalized Choquet Integral.

Criteria	$(C)\int \tilde{f}\,d\tilde{g}$				Defuzzified $(C)\int \tilde{f}\,d\tilde{g}$			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	A1	A2	A3	A4
Overall location value	(0.3124, 0.3465, 0.6749, 0.7081)	(0.3999, 0.4221, 0.6846, 0.7141)	(0.2948, 0.3243, 0.5557, 0.5833)	(0.4017, 0.4282, 0.7052, 0.7294)	0.5105	0.5552	0.4395	0.5661
O	(0.202, 0.2397, 0.5562, 0.5944)	(0.3238, 0.3549, 0.6676, 0.7092)	(0.3423, 0.3751, 0.7054, 0.7386)	(0.4192, 0.4504, 0.7514, 0.7852)	0.3981	0.5139	0.5404	0.6016
O_1	(0.18, 0.21, 0.525, 0.56)	(0.415, 0.445, 0.76, 0.795)	(0.315, 0.34, 0.68, 0.715)	(0.415, 0.445, 0.76, 0.795)	0.3688	0.6038	0.5125	0.6038
O_2	(0.285, 0.32, 0.605, 0.64)	(0.255, 0.275, 0.545, 0.575)	(0.445, 0.47, 0.745, 0.77)	(0.435, 0.465, 0.74, 0.77)	0.4625	0.4125	0.6075	0.6025
A	(0.207, 0.2356, 0.5384, 0.565)	(0.455, 0.475, 0.7869, 0.8085)	(0.2928, 0.3188, 0.6318, 0.6517)	(0.3718, 0.4034, 0.7403, 0.772)	0.3865	0.6314	0.4738	0.5719
A_1	(0.225, 0.25, 0.525, 0.555)	(0.455, 0.475, 0.75, 0.775)	(0.295, 0.325, 0.615, 0.645)	(0.345, 0.38, 0.68, 0.715)	0.3888	0.6138	0.47	0.53
A_2	(0.185, 0.215, 0.545, 0.57)	(0.455, 0.475, 0.805, 0.825)	(0.29, 0.31, 0.64, 0.655)	(0.385, 0.415, 0.77, 0.8)	0.3787	0.64	0.4738	0.5925
G	(0.4351, 0.4718, 0.8084, 0.8284)	(0.1703, 0.1904, 0.5, 0.5168)	(0.1825, 0.2144, 0.5486, 0.571)	(0.1703, 0.1904, 0.5006, 0.52)	0.6359	0.3444	0.3791	0.3453
G_1	(0.445, 0.48, 0.81, 0.83)	(0.17, 0.19, 0.5, 0.525)	(0.175, 0.205, 0.53, 0.55)	(0.17, 0.19, 0.5, 0.525)	0.6412	0.3462	0.365	0.3462
G_2	(0.415, 0.455, 0.805, 0.825)	(0.175, 0.195, 0.5, 0.5)	(0.3, 0.34, 0.685, 0.7)	(0.175, 0.195, 0.505, 0.51)	0.625	0.3425	0.5063	0.3463
C	(0.2597, 0.2952, 0.6584, 0.7008)	(0.3694, 0.3948, 0.7548, 0.7929)	(0.1721, 0.1954, 0.5189, 0.5514)	(0.4814, 0.5, 0.8032, 0.8267)	0.4785	0.578	0.3595	0.6528
C_1	(0.315, 0.35, 0.695, 0.735)	(0.405, 0.435, 0.77, 0.81)	(0.18, 0.21, 0.525, 0.56)	(0.475, 0.5, 0.79, 0.82)	0.5237	0.605	0.3688	0.6462
C_2	(0.245, 0.275, 0.635, 0.675)	(0.36, 0.38, 0.745, 0.78)	(0.17, 0.19, 0.515, 0.545)	(0.485, 0.5, 0.81, 0.83)	0.4575	0.5662	0.355	0.6562

only achieved if the number of people -reaching the shopping mall easily- is high.

Growth perspective refers to upcoming opportunities and possible threats could be faced for long time period. Strict regulations and limited expansion capability are said to be undesirable circumstances, while flexibility and growth ability are encouraged.

Customer perspective corresponds to personal characteristics of people (visitors) by means of level of education and level of income. As the level of income and education gets higher, the replacement requirement for new technology rises.

We integrate Fuzzy Choquet Integral method (FCIM) to the proposed methodology for considering the interaction between criteria to determine the proper collection points. For the purpose of adapting FCIM, we require an additional confirmation on the evaluation scale, shown in Table 3.

The decision makers evaluate the importance of main- and sub-criteria and their tolerance zones and the performance of each shopping mall, linguistically. Table 4 gives the evaluations of decision maker 1.

We utilize trapezoidal fuzzy numbers to quantify the linguistic terms in evaluation forms as depicted in Table 5. For each sub-criteria, the tolerance zones are obtained in that way: the first term of tolerance zone is the lowest value among all linguistic evaluations and the second term is the highest value among all linguistic evaluations.

Table 5 presents the compromised evaluations of the expert team which is combined by calculating the arithmetic mean of these separate evaluations.

Table 6 gives the evaluation results by the generalized Choquet Integral for $\alpha = 0$ utilizing Eq. (6) for the sub-criteria and Eq. (7) for the main criteria. For example, $\bar{f}_i$ value of *Alternative 1* with respect to subcriteria O_1 is obtained as follows:

$$f, f_i^{\alpha} = \left[f_{i,\alpha}^{-}, f_{i,\alpha}^{+}\right] = \frac{[0.03, 0.67] - [0.43, 0.61] + [1, 1]}{2} = [0.18, 0.56]$$

The aggregated Choquet integral values for the main criterion O is calculated as in the following:

$$(C)\int \tilde{f}\,d\tilde{g} = [0.202, 0.5944]$$

Table 7 represents the evaluation results by the generalized Choquet Integral for $\alpha = 1$ utilizing Eq. (6) for the sub-criteria and Eq. (7) for the main criteria.

Table 8 includes the normalized discrepancies and alternative values of Choquet integrals. From Table 8, the defuzzified overall values of alternative shopping malls using generalized Chouqet Integral are obtained as 0.5105, 0.5552, 0.4395, and 0.5661.

The descending order of performance rankings is Viaport, Capitol, Forum Istanbul, and Galleria, respectively. The best alternative is determined as Viaport according to the weights derived from Choquet integral stage.

6. Conclusion and recommendations

Since the consumer electronics market is the fastest growing market around the world, as in Turkey, many electronic items are required to be replaced by new ones. Apparently, mobile phones, laptops and tablets are leading electronic products in replacement with their short life cycles. However, unfortunately, regulations in second-hand markets and qualified recycling operations fall behind with this growth. Therefore, we propose a plan for an immediate e-waste management campaign to collect the small e-wastes at hand. Since incorrect sitting of e-waste collection nodes could lead to several environmental and economic costs, appropriate methods are required to plan e-waste management processes, efficiently.

In this study, we propose a three-stage methodology to initiate the e-waste management activities in context of a campaign in Istanbul. We consider that the shopping malls are appropriate places to campaign and collect small e-waste items as mentioned earlier in the second section of the study. We can summarize this methodology as follows: First stage uses a non-compansatory method to eliminate dominated alternatives with respect to pre-determined criteria. This stage provides us a simplified heuristic to reduce the alternative candidates by preserving the non-dominated ones. Considering the large number of shopping malls in İstanbul, this stage excludes unnecessary calculations for $(\boldsymbol{n}-\boldsymbol{k})$ alternative candidates. In the second stage, we prefer utilizing GIS technique in order to imply the geographic information data and footfall index together so as to restrain the risks, which can be caused by high-density counties. This stage determines the shopping malls, -Galleria, Capitol, Forum Istanbul, and Viaport-, where the campaign starts initially. In the final stage, we propose to employ a well-structured method to analyze these four alternative shopping malls in detail. For selecting the center of the campaign, Choquet integral is appropriate to evaluate limited number of alternatives. Studies in literature and the practical implications are still insufficient. As a future research, we encourage authors to investigate subjects as: exploring new recycling technologies, feasibility of e-waste management activities, security of personal data, vehicle routing and capacity planning issues for e-wastes.

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