An International Journal of Optimization and Control: Theories & Applications
ISSN: 2146-0957 eISSN: 2146-5703
Vol.7, No.1, pp.16-27 (2017)
https://doi.org/10.11121/ijocta.01.2017.00358

RESEARCH ARTICLE

Constructing small WEEE collection system in Istanbul: A decision support system and conceptual design proposal

Vildan Çetinsaya Özkir*

Department of Industrial Engineering, Yildiz Technical University, Turkey
cvildan@yildiz.edu.tr

ARTICLE INFO

Article history:
Received: 16 June 2016
Accepted: 22 September 2016
Available Online: 12 October 2016

Keywords:
Collection network
multiple objectives
conceptual WEEE management system design
bi-objective spanning tree

AMS Classification 2010:
90B10, 90B50

ABSTRACT

The technological advances decrease electrical/electronic product lifecycles and boost consumption of high-tech products. The rapid growth in the electronic market produces electronic waste streams and potential threats arise on sustainability in terms of depleting natural resources and improper disposal. End-of-life electrical/electronic equipment (EEEs) involves complex mixture of materials, has hazardous content, and if not properly disposed, they can cause major environmental and health problems. To prevent the consequences of improper disposal, authorities and researchers conduct large-scale projects aligned with European union legislations. However, these efforts are still not sufficient to establish effective and organized systems due to the problem complexity and the need for specialized arrangements. This study proposes conceptual decision support framework and a bi-objective mathematical model to construct an effective collection network for end-of-life mobile phones. A real case study is presented for constructing an effective collection system in Istanbul. The main reason that we select Istanbul, is the requirement of urgency to deal with the large quantities of e-wastes. The result of this study will encourage academicians to conduct further research studies and strongly assist the authorities to configure well-structured e-waste collection system.

1. Introduction

The electronics industry is very dynamic and one of the fastest growing sectors of the world economy. This rapid growth of the electronics industry has serious effects on daily life in context of social, economic and environmental concerns. The rapid change in technology reduces product lifecycles and increases consumption of high-tech products. Besides the advantages of having technological products, many managerial problems arise for local authorities to solve, such as, Waste Electrical/Electronic Equipment (WEEE) management, social and economic consequences, etc.

An EEE completes its life cycle by passing through introduction, growth, maturity, decline, phase-out, and obsolescence stages, respectively [21]. Each stage has its own specific characteristics to manage effectively. Managing the opportunities and threats in the last phase requires the multidisciplinary effort, which incorporates legal, environmental, social, economic, and engineering views.

WEEEs are described as loosely discarded, surplus, obsolete, or broken electrical or electronic device in WEEE Directive (2002/96/EC). These useless devices often include both valuable and hazardous materials. Widmer et al. [23] emphasized that the ratio of valuable content in e-wastes is over %60 (gold, iron, copper, aluminum and other metal). Together with these valuable contents, e-wastes can contain many toxic materials such as lead, cadmium, beryllium, mercury, and brominated flame-retardants. The informal processing of these toxic materials can cause serious health problems. Regarding the opportunity of recovering valuable ingredients for reuse and diminishing threats of toxic materials on biological life, it is a mandatory requirement to design efficient e-waste management systems. WEEE Directive (2002/96/EC) and RoHS (the Restriction of Hazardous Substances) Directive (2002/96/EC) encourage systems aimed at improving the environmental performance of EEEs and reducing extravagant use of intact natural resources. WEEE directives encourage consumers, governments and producers to explore novel methods for reducing both the amount and

*Corresponding author

undesirable effects of e-wastes. Directive 2002/96/EC aimed at protecting the environment and human health by adapting environmentally conscious management strategies such as product design, separate collection, selective treatments and recycling, technical requirements of storage and treatment sites. Furthermore, Directive 2012/19/EU emphasizes the necessities for a separate e-waste collection system. Separate collection is a requirement for ensuring specific treatment and recycling of WEEE in order to achieve protection of human health and the environment. WEEEs, especially mobile phones, require specific treatment regarding to their users' behavior, material content, high consumption rates, and small sizes.

Owners generally discard their end-of-use EEEs in two different ways. Primarily, people often seek secondary markets if it is believed to preserve its inherent characteristics to fulfill functions in order to make value. Contrarily, if it is believed to be incapable of producing value, it is called an end-of-life product. The distinction between end-of-use EEE and end-of life EEE can mainly be explained related to this behavior. Goodship and Stevels [11] discussed that encouraging secondary market can offset the societal and environmental disadvantages of EEE industry. Thus, the extension of EEEs lifetime via secondary market generates both environmental benefits, in terms of reducing e-waste quantity and use of resources societal benefits, and societal benefits, in terms of employment and affordability of low-income individuals.

This study proposes a decision support model for constructing a WEEE collection system in Istanbul. This study contributes to an understanding of the literature on the association of user behaviors, legislations and regulations of legal authorities, system design and decision making issues. Additionally, the study assists decision makers in constructing coordinated separate collection system by providing a real case study. The rest of the paper is organized as follows: Section 2 presents a brief explanation of WEEE problem, particularly in Turkey. In Section 3, we explain conceptual decision support model and a bi-objective mathematical model to construct an effective collection network. In Section 4, a real case study is presented for constructing WEEE collection system in Istanbul. Obtained results and corresponding assessments are presented in this section. Finally, we conclude by summarizing the findings and present future research suggestions in Section 5.

2. Problem statement

2.1. WEEE material content

EEEs are mainly composed of valuable materials and toxic substances. Particularly, a mobile phone contains more than 40 elements, including N, O, F, S, B, C, H, K, Co, In, Zn, Al, Pb, Ag, Au, Ti, Pd, Cu, Ni, Fe, Mn, Sn and Sb. The metal content of a mobile phone is about 23% of total weight and the remaining is generally composed of plastics [2]. The plastic parts of mobile phones can also include heavy metal levels (Pb, Cd, Ni, and Ag). Nronom and Osibanjo [15] reported that, if managed appropriately, the levels in waste plastic housing of mobile phones do not constitute significant danger. The metals present in parts of mobile phone include precious metals (gold, silver, and palladium) as well as toxic metals such as iron, arsenic, cadmium, copper, lead, antimony, tin, palladium, gold, silver and bromine [23]. These metals can leach into soil and water when mobile phones are dumped in open landfill sites with municipal solid waste and pollute the natural environment [16]. Additionally, Goodship and Stevels [11] imply that a mobile phone has 15 or more high-tech materials that make separation challenging and volumes are not high enough to make reuse practical from a technical and economic point of view. However, UN Report [19] implies the economic benefits and environmental importance of urban mining for metal recovery, especially gold, silver and platinum. The precious metal content of a phone handset is in the order of milligrams only: 250 mg silver, 24 mg gold, 9 mg platinum while 9 g copper is present on average. Furthermore, the Li-ion battery of a phone contains approximately 3.5 g cobalt.

WEEE streams can be considered as precious metal mines. Approximately 250 mg silver, 24 mg gold, 9 mg palladium and 9 g. of copper can be obtained by parsing a scrap mobile phone without its battery. Hagelüken [13] implies that urban mining deposits can be much richer than primary mining ores. Considering the current available gold grade data varying between 1.04 g/ton and 14.44 g/ton in the gold reserves of Turkey, these streams require attention by means of innovative thinking, policy development and strategic planning. To take the advantage of recovering WEEE streams, considerable amount of multidisciplinary effort is needed. Accumulation of millions of discarded EOL product into urban mines of a reasonable size and recovery of low concentrated technology metals from complex products are challenging issues [13]. Moreover, the support of official policies and legislations plays a major role while settling up reliable collection and recovery systems. Assuring the security of personal data in data storing EEEs; such as laptops, mobile phones, etc., and ensuring people's trust to donate/leave their personal EOL products are further challenging subjects.

2.2. Challenges in WEEE management

WEEE Directive (2002/96/EC) categorizes EEEs in 10 different categories. Table 1 introduces these EEE categories and shows the distribution of tonnage of EEE placed on the market in 2010 by EEE categories. The first four categories - large household appliances, small household appliances, IT and telecommunications equipment and consumer equipment - accounts for almost %95 of the WEEE generated [21]. The main purpose of this classification is to support separate collection in order to facilitate e-waste management and appropriate disposal of EEEs with similar risks to the environment and human health. Although these four e-waste categories constitute the vast majority of electronic waste, each category should be studied extensively due to their content, disposal options and collection strategy. Obviously, the content of each e-waste category, quantities and existent product recovery processes play a determining role while deciding on its management system design. For reducing the amount of any kind of resource needed for production, consumption, and waste disposal, Özkır and Başlıgil [18] introduced the process of efficient product recovery options.

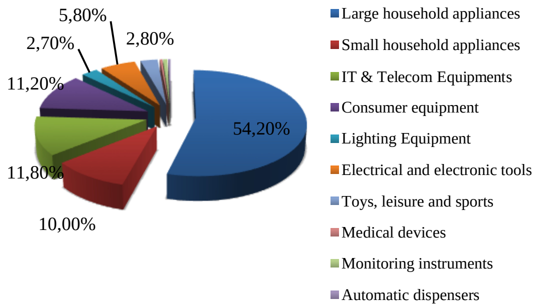

Figure 1. Distribution of tonnage of household and professional EEE placed on the market in 2010 (1,609 kt) by categories of equipment [1].

An extensive analysis on potential threats and opportunities of WEEEs is required before WEEE management system design. These threats and the opportunities can mainly be grouped under economic, societal and healthcare subjects. The main economic opportunity is the recovery of scarce and expensive materials needed for EEE production. The societal opportunities can be summarized as: new businesses on recovery, reuse and disposal operations can be created, new jobs can be described and accordingly unemployment can be decreased. Healthcare related opportunities are the vital ones, which is to prevent diseases emanated from improper disposal of WEEEs. The threats can be summarized as: destruction of scarce resources, compromise to sustainability and incurable diseases.

2.3. Challenges in Turkey and in worldwide

Turkey is officially recognized as a candidate country for full membership to European Union since 1999. Thus, design for WEEE management systems in Turkey is appealing for many researchers. Since the first four of WEEE categories constitutes the vast majority, we will analyze the problems for these categories in Turkey. A WEEE management system, fulfilling the requirements of WEEE Directive, has fundamental importance for Turkey, which is on the edge of European Union. Numerous challenges arise during the implementation phase of WEEE Directive, due to unequal development in operational and legislative progresses in member states [25]. On the other hand, socio-cultural factors play an important role while constructing a service system for a community. For example, people in city X may internalize the throwing-away culture for EEE products, while people in city Y prefer keeping-aside. Thus, the design of WEEE management systems for these cities can substantially be different each other.

Before submitting a system for people to use, the behaviors of people who will use this system need to be understood. Traditionally, Turkish people primarily prefer to give their end-of-use (working) EEEs to their relatives/ acquaintances. Secondarily, people generally follows ‘bring the old one and get the new one’ campaigns of companies. They leave their products and get new items to meet their requirements. Lastly, secondary market (generally, one of local repairmen) buys these products at low prices and sells them as second hand after minor refurbishments. If the case is for end-of-life EEEs, then secondary market works for component recovery to reuse (working) EEE parts. This process is valid for these four WEEE categories. This spontaneous process flow has several advantages like longer product lifecycles and some disadvantages while implementing regulations. However, this setting is slightly different in size from other WEEEs, ie. mobile phones. People do not assess enough about their end-of-use (working) mobile phones whether to keep it for contingency or to send it to trash. Due to their small size, it is more difficult to create control mechanisms to prevent the thrown away with normal household waste than the large appliances. So, instead of preventing the thrown away to household waste by banning, events should be organized to realize the change this behavior. Mobile phones can be easily stored and forgotten or thrown away with normal household waste due to their relatively small dimensions [4, 7].

Though technological developments increase WEEE amount, these advances, especially in recovery and logistics means, can be employed to reduce it. Ongondo et al. [17] stated that whereas advances in technology can help prevent waste at the production line, effecting change in human behavior is more difficult; therefore, their expectation is more WEEE to be generated rather than prevented at the consumer end of the spectrum. We refer Ongondo et al. [17] for further analysis and reading on the existing and the future perspectives of WEEE management.

World population has reached 7 billion. Considering the global mobile phone sales, the average volume of the last 6 years is around 1.5 billion/year as depicted in Figure 2, with the obsolescence rate about 2 years; the amount of EOL mobile phone is significantly high. The average volume of the last 6 years’ mobile phone sales in Turkey is around 14 million/year. Considering the Turkey population is about 70 million, the amount of EOL mobile phone is considerably high.

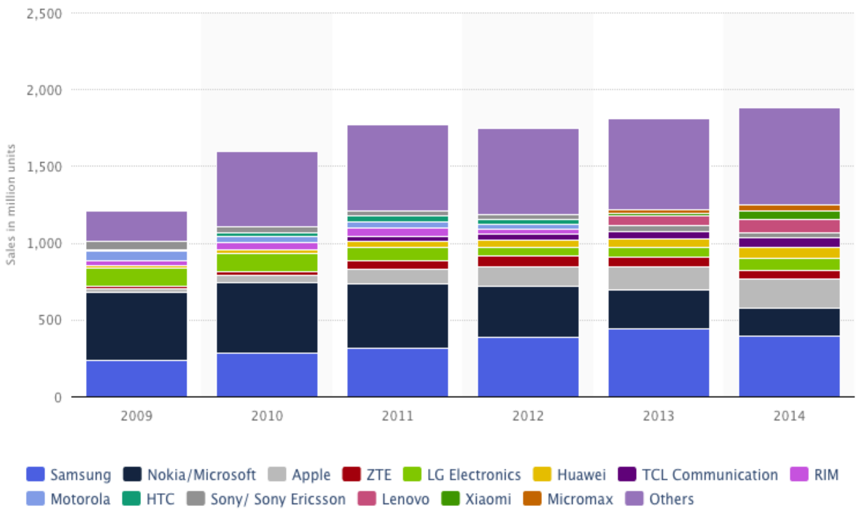

Figure 2. Global mobile phone sales to end-users each year from 2009 to 2014, broken down by vendor [26].

Consequently, the vast number of EOL mobile phones, the striking material content and other mentioned reasons attract the attention of researchers and practitioners in Turkey and Worldwide. Although the number of scientific studies and the founded organizations increase, the efforts are still not sufficient to establish organized systems due to the need for specialized arrangements. By considering the traditional Turkish behaviors, this study aims to support to establish an organized system for WEEE collection in İstanbul, Turkey.

3. Decision support model for WEEE collection system

Owing to fast consumption and obsolescence rates of EEEs, the volume of WEEEs is significantly increasing. Government institutions face compelling problems while constructing integrated systems for different WEEE types. The problem is dramatically critical and urgent for modern crowded cities because of high consumption and turnover rates of electronic products [5]. Therefore, the requirement for constructing an effective decision support system is more critical for metropolitan cities dealing with the large quantities of WEEE.

The relevant literature of WEEE collection network design and corresponding decision support models are investigated in Subsection 3.1. Then, in the proceeding subsections, conceptual framework and proposed decision support model for constructing WEEE collection network are explained, in detail, respectively.

3.1. Literature review

Collection is a critical stage to aggregate and divert the e-waste streams to the desirable treatment facilities. A reliable, safe and efficient collection system will motivate recycling activities and reduce costs [6]. Figueiredo and Mayerle [9] present a conceptual framework, an analytical model, and a three-stage algorithmic solution for the problem of designing minimum-cost recycling networks in in southern states of Brazil. Grunow and Gobbi [12] propose a modeling approach and the corresponding decision support tool aid the government agency in the assignment of collective schemes to municipalities where consumers deliver the waste in Denmark. Ongondo et al. [17] present an extensive research on WEEE management practices around the world. Gomes et al. [10] develop a generic model, which is applied to the design and planning of the Portuguese WEEE recovery network allowing for the definition of the best locations for collection and sorting centers that were chosen simultaneously with the definition of a tactical network planning. Kiddee et al. [14] investigate literature on e-waste management tools; such as, life cycle assessment, material flow analysis, multi-criteria analysis and extended producer responsibility and describes the distinctive features of approaches in different countries. Chi et al. [6] investigate the WEEE collection channels and household recycling behaviors in Taizhou city of China. Çetinsaya Özkır et al. [5] propose a three-stage methodology to initiate the e-waste management activities in Istanbul, Turkey, evaluates the status of current e-waste management efforts and encourages successive studies on creating guidelines and operations management.

3.2. Conceptual design for separate collection in metropolitan cities

WEEE directive (2012/19/EU) includes the provision of national WEEE collection points and processing systems, which allows consumers to put WEEE into a separate waste stream to other waste, resulting in it being processed, accounted for and reported to the national enforcement authority. The directive explains 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. Therefore, directive encourages consumers to actively contribute to the success of such collection to return their end-of-use EEEs. For this purpose, convenient facilities should be set up for the return of WEEE, including public collection points, where private households should be able to return their waste at least free of charge (WEEE Directive - 2012/19/EU).

Setting up effective regulations and provisions concerning the organization of separate WEEE collection is problematic in metropolitan cities due to high population and their consumption behaviors. Daily life routine in a metropolitan city -getting to work, school, and appointments, shopping and socializing- is often exhausting for its residents. For this reason, while establishing an effective collection system for a metropolitan, the frequency and ease of access should also be considered for people living in the metropolis. In particular, the significant paradigm is to make WEEE holders being involved in the collection system without incurring cost and burden. As local authorities realize the importance of this paradigm, the collection system works efficiently by means of diverting material away from landfill and increasing contribution of these holders. Therefore, WEEE collection system should have collection points in public places such as, retail shops, central stations, shopping centers, etc. These points can boost WEEE holders' awareness of the need for separate collection. Figure 3 illustrates the flow of goods in WEEE collection system. If an end-of-use EEE is believed to be an EOL product, then it is accumulated in collection points for further processes, otherwise it is evaluated in the secondary market. Collection points collects the EOL products from users and delivers them to the inspection facilities for further exploration of available product recovery options. In inspection facilities, EOL products are inspected, classified and dispatched for landfill, hazardous waste treatment and recovery operations. In recovery facilities, the appropriate recovery decision is made for each WEEE regarding its current condition, and the result of the decision is concluded by demanufacturing, disassembling or refurbishing processes.

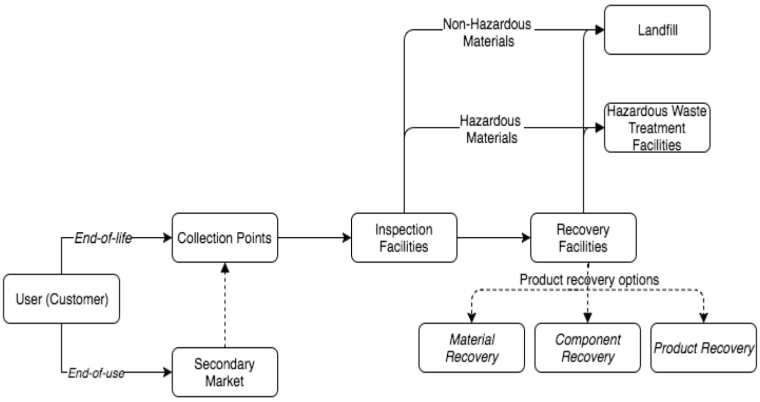

Figure 3. WEEE collection system.

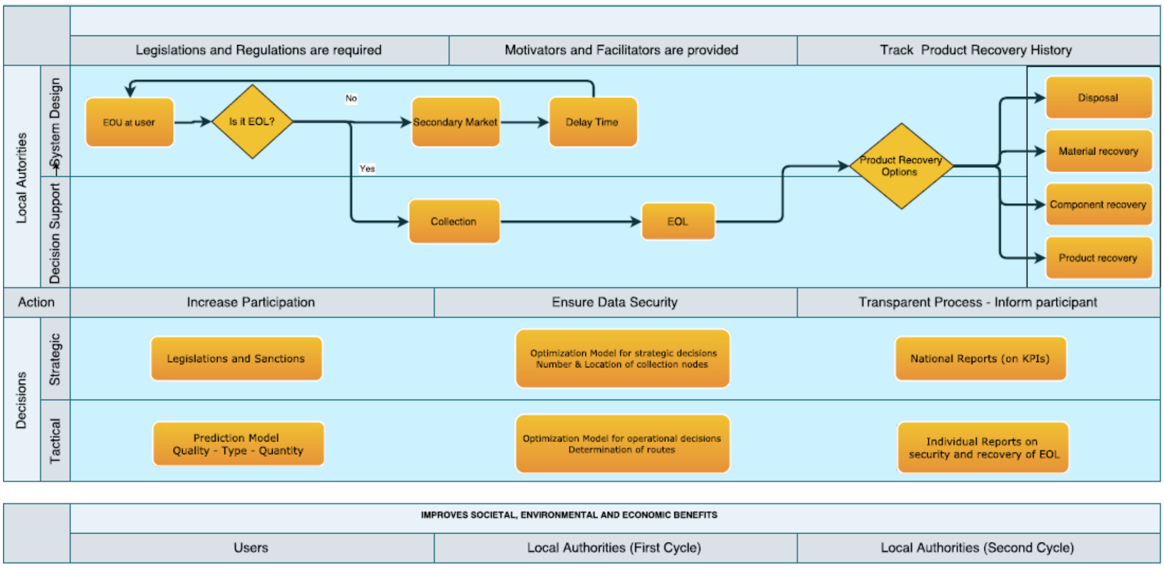

Figure 4. Conceptual design for WEEE collection system..

Moreover, only making legislations is not an adequate effort to prevent small WEEEs going into a landfill. Setting up effective control mechanisms and giving instructions on WEEE collection (leaflets, meetings and panels) are some of the required efforts to be conducted by authorities. Figure 4 summarizes the process, the objectives and related KPIs for a WEEE collection system.

KPIs are defined regarding the concerns of both WEEE holders and authorities. Ensuring data security and the transparent EOL product recovery processes are key expectations for WEEE holders. Furthermore, for authorities, increasing participation is the fundamental element to define the efficiency of the collection system. Additionally, we summarize tactical and strategic issues on modeling and designing the system components. Transparent process phase requires a front-end technology for informing WEEE holders about his individual processes and also for informing second cycle local authorities on system KPIs.

Furthermore, there are many opportunities in a WEEE collection system for authorities. They can support secondary market operations by providing regulations and legislations. Effective and organized secondary market operations can yield benefit to society by means of societal, environmental and economic benefits.

3.3. Multiple objective spanning tree model

The multi-objective minimum spanning tree problem is one of the best-known multi-objective combinatorial optimization problems (Neumann, 2007). In contrast to the single objective spanning tree problem, the objective function $f: \mathcal{T} \rightarrow \mathbb{R}^p$ is vector-valued, i.e., composed of component functions $f_k: \mathcal{T} \rightarrow \mathbb{R}$. We refer reader the survey of Ruzika and Hamacher [20] for an extensive literature review of algorithms for the MOST problem, and Ehrgott and Gandibleux [8] for further mathematical background of multiple objective combinatorial optimization problems.

Let $G = (V, E)$ be an undirected graph with vertex set $V = \{v_1, \dots, v_n\}$ and the edge set $E = \{e_1, \dots, e_m\}$ where $e_j = (v_{i1}, v_{i2})$ is an unordered pair of vertices. Let $c: E \rightarrow \mathbb{R}^p$ be the vector-valued cost function on the edge set. A spanning tree of G is a connected, acyclic subgraph $T \sqsubseteq G$, $T = (V(T), E(T))$, with vertex set $V(T) = V$. Let $\mathcal{T}$ denote the set of spanning trees of a given graph G. The general multi-objective minimum spanning tree (MOST) problem is defined as:

$$\begin{aligned} & Minimize\ f(T) = \left(f_1(T), \dots, f_p(T)\right) \\ & s.t. \qquad T \in \boldsymbol{\mathcal{T}} \end{aligned} \tag{1}$$

Minimum spanning tree models are widely studied in the literature. In this study, we propose a bi-objective spanning tree model for WEEE collection design. Let x_{ij} be 1 if the edge ij is in the tree T. Any subset of k vertices must have at most $(k-1)$ edges contained in that subset S.

$$Min. Z_1 = \sum_{ij \in E} d_{ij} x_{ij} \tag{2}$$

$$Min. Z_2 = \sum_{ij \in E} p_{ij} x_{ij} \tag{3}$$

$$s.t. \quad \sum_{ij \in E} x_{ij} = n - 1 \tag{4}$$

$$\sum_{ij \in E: i \in S, j \in S} x_{ij} \leq |S| - 1 \qquad \forall S \subseteq V \tag{5}$$

$$x_{ij} \in \{0,1\} \qquad \forall i, j \in E \tag{6}$$

where d_{ij} is the distance between vertex i and vertex j, and p_{ij} is the total population size in vertices i and j. Equation (2) presents the primary objective function aiming to minimize the total distance. In Equation (3), total population covered by the edges is maximized in order to imply the contribution of individuals to the collection system. The district population data encourages constructing a demographically informed spanning Equation (4) ensures $(n-1)$ edges in T and Equation (5) is the sub-tour elimination constraint. Finally, binary variables are introduced in Equation 6.

3.4. Entropy embedded fuzzy AHP

The analytical hierarchy process is a well-known multiple criteria decision making method that is used for complex decision making problems. In the literature, several fuzzy extensions of the AHP method are presented in order to evaluate alternative candidates regarding individual subjective decision criteria under an uncertain decision environment.

The computational procedure of entropy embedded fuzzy AHP is summarized as follows:

Step 1. *Determine the alternatives* by ensuring that all the potential alternatives are listed.

Step 2. *Determine the evaluation criteria* by ensuring that all criteria are distinct and required for assessing alternatives through the goal definition.

Step 3. *Employ data acquisition process* by providing contribution of each decision maker as in the following:
Decision makers are asked to express their assessments in pairwise comparison (PC) using the scale in Table 1.

Corresponding assessment are represented in triangular fuzzy numbers, since these numbers are generally utilized to improve fuzzy decision making methods in order to handle uncertainty. A triangular fuzzy number is generally determined by the triplet $\widetilde{M} = [l, m, u]$ of crisp number with $(l \leq m \leq u)$ and whose membership function is given by

$$\mu_M(x) = \begin{cases} \dfrac{(x-l)}{(m-l)}, & if\ l \leq x \leq m \\ \dfrac{(u-x)}{(u-m)}, & if\ m \leq x \leq u \\ 0, & otherwise \end{cases} \tag{7}$$

Table 1. Fuzzified nine-point scale.

Intensity of Importance		Fuzzy Triangular Form of Importance	
		$\alpha = 0{,}50$	$\alpha = 0{,}75$
$\tilde{1}$	[1,2]	(1,1,1) / (1,1,2)	(1,1,1) / (1,1,3/2)
$\tilde{3}$	[2,4]	(2,3,4)	(5/2,3,7/2)
$\tilde{5}$	[4,6]	(4,5,6)	(9/2,5,11/2)
$\tilde{7}$	[6,8]	(6,7,8)	(13/2,7,15/2)
$\tilde{9}$	[8,9]	(8,9,9)	(17/2,9,9)

Triangular fuzzy numbers in (l, m, u) form can be expressed as an interval of confidence level is $\alpha\ \forall\alpha \in [0,1]$, as in the following Equation 8.

$$\widetilde{M} = [l^{\alpha}, u^{\alpha}] = [(m-l)\alpha + l, -(u-m)\alpha + u] \quad (8)$$

Here, we employ the interval weight normalization procedure proposed by Wang and Elhag [22]. Let $w_i = [w_i^L, w_i^U]$ be interval weights where $0 \le w_i^L \le w_i^U$, $i = 1, \ldots, n$ and N be a set of normalized weight vectors, based on the following definition of normalization for interval weights, where $N = \{X = (x_1, \ldots, x_n,)\ |w_i^L \le x_i \le w_i^U,\ i = 1, \ldots, n,\ \sum_{i=1}^{n} x_i = 1\}$. For more detailed information, we refer the reader to Wang and Elhag [22]. Here, c denotes the number of sub-criteria under the main criterion s. We denote an importance weight vector for each main criterion by $\widetilde{W}_{sc} = [w_1, w_2, \cdots, w_c]$, where S is the total number of main criteria.

Step 4. *Aggregation of decision makers' assessments.* Let $\tilde{x}_{ac}^{d} = (l_{ac}^{d}, m_{ac}^{d}, u_{ac}^{d})$ represents the triangular fuzzy number corresponding assessment of decision maker d on alternative a regarding the criterion c. We associate all assessments of decision makers' by introducing a new fuzzy number, say $\tilde{x}_{as}$, for the assessment of alternative a regarding criterion c.

$$\tilde{x}_{ac} = [\min(l_{ac}^{d}), E(m_{ac}^{d}), \max(u_{ac}^{d})] \quad \forall d \in D \quad (9)$$

Step 5. *Utilize Fuzzy AHP Method to assemble the total fuzzy judgment matrix $\tilde{A}$.* We multiply the importance weight vector w_{sc} by the corresponding column of fuzzy judgment matrix $\tilde{X}$.

$$\tilde{A} = [\tilde{a}_{ij}]_{S \times A} \quad (10)$$

$$\tilde{a}_{sa} = \sum_{s} W_{sc} \sim x_{ac} \quad (11)$$

Step 6. *Employ interval arithmetic and optimism index* to perform fuzzy number multiplications and additions using the interval arithmetic and cuts. For any α-cut, we set an optimism index λ to understand the interaction between the decision maker's behavior and the selection process.

$$\hat{a}_{ij}{}^{\alpha} = (1-\lambda)\hat{a}_{ij}{}^{\alpha} + \lambda\hat{a}_{ij}{}^{\alpha} \quad \forall\lambda \in [0,1] \quad (12)$$

Step 7. *Utilize Shannon's entropy to find the aggregated weights.* The matrix $\hat{A}$ is normalized to obtain the matrix $A = [a_{ij}]$ by using Eq.13. Next; the entropies are calculated as in Eq.14.

$$A = [a_{ij}] = \left[\frac{\hat{a}_{ij}{}^{\alpha}}{\sum_{j=1}^{m} \hat{a}_{ij}{}^{\alpha}}\right] \quad (13)$$

$$H_i = -\sum_{j=1}^{n} a_{ij}{}^{\alpha} log_2\left(a_{ij}{}^{\alpha}\right) \quad (14)$$

Step 8. *Rank alternatives.* Alternatives are listed in accord to their entropy values in decreasing order. The higher entropy value means the better alternative; the highest is the best.

The entropy-embedded fuzzy AHP approach is appropriate for selecting the best alternative among a number of candidates.

4. Case Study: Constructing WEEE collection network in Istanbul

Istanbul is the economic, cultural, and historical metropolitan in Turkey, with the population of 14.03 million. The city possesses many qualified historical and modern malls. These shopping centers can be potential collection points considering their annual and daily number of visitors. The daily average number of visitors varies between 30,000 and 150,000. There are also many possible locations to set up collection points, such as central stations, squares, and etc. However, these alternative locations require extra investment in terms of security, controllability, and infrastructure. Considering security and structural investments of shopping centers, they satisfy the major requirements for a collection point, by default.

Çalışkan et al. [3] investigated the spatial diffusion of capital accumulation regime together with its triggering factors with special emphasis to the relations in between and revealed that in terms of spatial proximity, shopping centers set up the greatest relationship with luxury estates, residences and public housing areas, respectively. Considering these findings, the popularity of shopping centers and listed cost criteria, supports the idea of setting up collection points in shopping centers. In Figure 5, red-dots show shopping centers and the general distribution among the city, İstanbul.

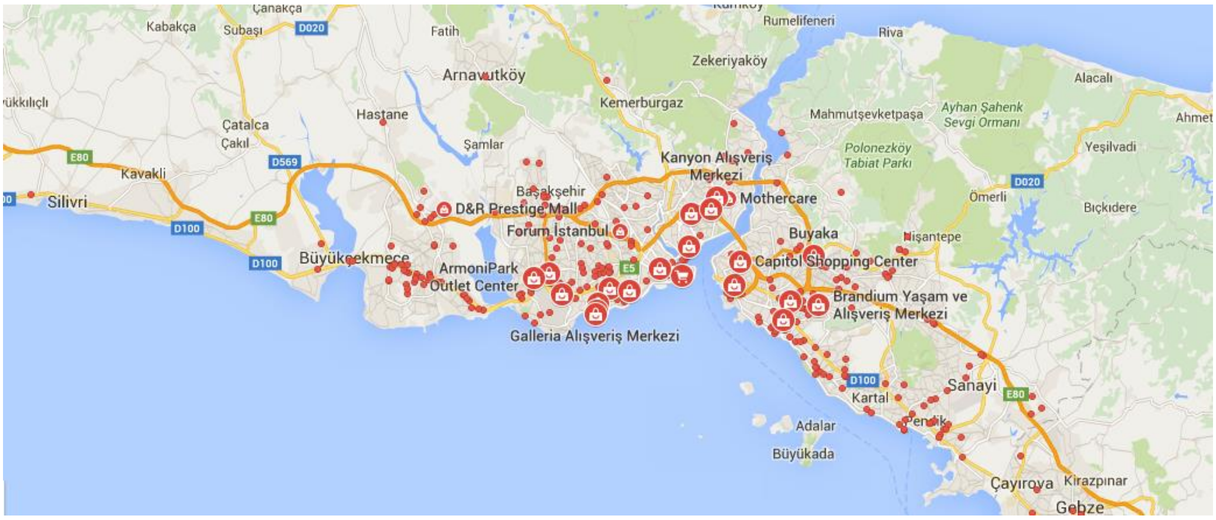

Figure 5. The locations of shopping centers in Istanbul.

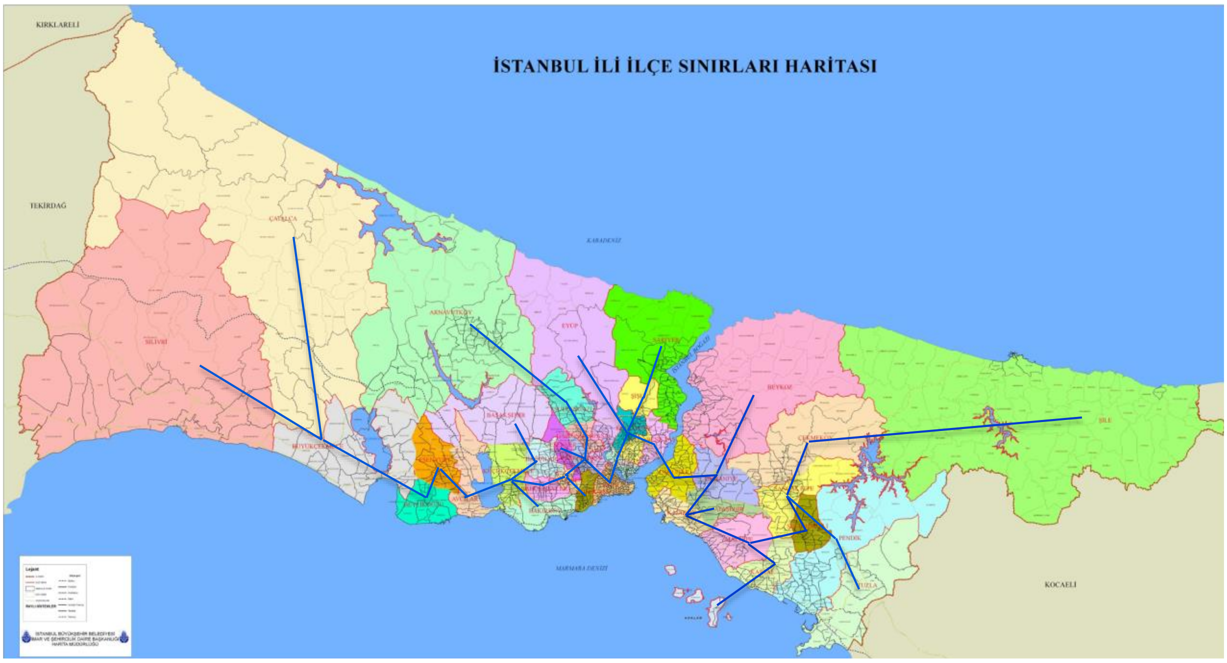

Figure 6. The spanning tree of small WEEE collection network.

In this study, we propose to collect EOL mobile phones due to its vast quantity, small size and remarkable material content. Therefore, the number of scientific studies and the founded organizations increase in the field. However, the efforts are still not sufficient to establish organized systems due to the need for specialized arrangements [5]. District municipalities are performing collection activities independently from each other. They collect nearly all kinds of WEEEs together in a truck by travelling in their district.

Furthermore, these collected items do not follow a systematic and organized route along their reverse flow in the supply chain.

This case study includes two consecutive decision aiding methods to solve the problem. The main objective of this study is to construct a connected network among districts of Istanbul. The network model constructs minimum spanning tree with maximum population weighted arcs.

As a consequence of the problem definition, the results of prior analysis have raised a new problem domain that needs continued investigation. In case of determining any district that have more shopping centers, then a further analysis is required to select among them. Therefore, a multiple criteria decision aid method is utilized introducing new set of criteria except previously considered criteria: distance and population.

4.1. The bi-objective spanning tree model for Istanbul

Primarily, a bi-objective spanning tree model is employed to construct a collection network for these WEEEs. Istanbul has totally 39 districts in its borderlines. The 25 of 39 are in European side and the remaining 14 are located in the Asian side. The distances between districts are obtained from the

Google Maps Directions API. The populations of each district are obtained from Turkish Statistical Institute (http://www.turkstat.gov.tr/). The mathematical model can be given as in the following:

$$Min.\ Z_1 = \sum_{ij \in E} d_{ij} x_{ij} \quad (15)$$

$$Max. Z_2 = \sum_{ij \in E} p_{ij} x_{ij} \quad (16)$$

$$s.t. \quad \sum_{ij \in E} x_{ij} = 39 - 1 \quad (17)$$

$$\sum_{ij \in E: i \in S, j \in S} x_{ij} \leq |S| - 1 \quad \forall S \subseteq V \quad (18)$$

$$x_{ij} \in \{0,1\} \quad \forall ij \in E \quad (19)$$

where x_{ij} be 1 if the district i is connected to district j, 0 otherwise. Here, d_{ij} is the distance between the district i and j, and p_{ij} is the total population size in the district i and district j.

We have utilized ∈-constraint method to solve multiple objective mathematical method. The main reason that we use ∈-constraint method is to eliminate the scaling problem. Additionally, we prefer to present the results of mathematical model with an illustration of connected network on the city map as in Figure 6. Figure 6 implies the shopping centers close to these intersection nodes have high potential in the sense of collecting more small WEEEs. In the European side of the city, the shopping centers in Büyükçekmece, Bayrampaşa, Güngören and Kağıthane districts are superior to the others in terms of population coverage and accessibility cost (defined in kilometers). In the Asian side of the city, the shopping centers in Ümraniye, Kadıköy, Maltepe and Sancaktepe districts has more potential in terms of these criteria. Here, we can list our assumptions as:

1. Shopping centers in the same district have equal population coverage.

2. Population in a district lives in the geographical center of this district.

3. People visit the shopping centers more frequently in the same district that they live.

Regarding these results, we investigated shopping centers in the determined districts. Before, we listed the shopping centers in these districts. Sancaktepe, Maltepe and Kağıthane districts have only one shopping center in its borderlines. Bayrampaşa and Güngören are the districts, which each has two shopping centers in its borderlines. Kadıköy and Ümraniye has respectively four and five shopping centers in their borderlines. According to the quantities of shopping centers in each district, Kadıköy and Ümraniye requires an additional analysis to select the best location. Consequently, we utilized a fuzzy multiple criteria decision aid method to select the appropriate shopping centers for Kadıköy and Ümraniye districts. Rather than utilizing the crisp methods, fuzzy extension is utilized in order to handle uncertainty in the decision environment.

4.2. Entropy embedded fuzzy AHP model for Kadıköy and Ümraniye districts

For further analysis, a group of five decision makers, including 3 experts from metropolitan municipality and 2 experts from a university provide the evaluation criteria and judgments in pairwise comparisons. For ranking alternative shopping centers, they define 4 criteria in regard to previous objectives: distance and population coverage weight. These criteria are rental fee, public transport availability, attractiveness, variety of shops and financial strength. Figure 7 illustrates the AHP decision hierarchy for Ümraniye district. The only difference between two districts' decision hierarchy is that the number of alternatives becomes 4 for Kadıköy.

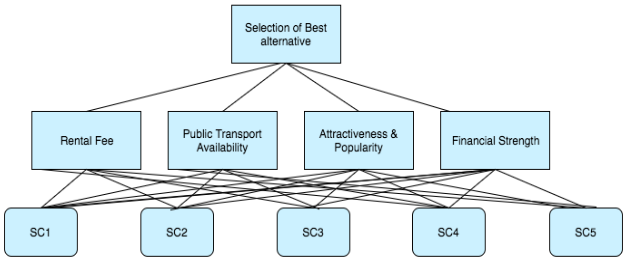

Figure 7. Decision hierarchy for selecting the best location in Ümraniye.

A brief explanation of evaluation criteria can be given as in the following: *Rental fees (RF)* are associated with cost. *Public transport availability (PT)* describes the proximity of shopping center to public transport node. Some shopping centers may also have metro/bus stations in it. A shopping center is said to be *attractive and popular (AP)*, if it has a variety of shopping options and entertainment facilities; such as gourmet concepts, theatres, cinema saloons, play lands for kids, performing arts showplaces etc. *Financial strength (FS)* is a vital concern of business owners, corporate managers and investors. Financial strength can be evaluated as an aggregated performance of a shopping center in terms of profitability, liquidity and investments.

For deciding on the most appropriate shopping centers in both Ümraniye and Kadıköy, we first asked decision makers to provide associated judgments on criteria evaluations. The fuzzy PC matrix is given in Eq. 20.

$$\tilde{X} = \begin{bmatrix} \tilde{1} & \tilde{3} & \tilde{5} & \tilde{3}^{-1} \\ \tilde{3}^{-1} & \tilde{1} & \tilde{1} & \tilde{3}^{-1} \\ \tilde{5}^{-1} & \tilde{1} & \tilde{1} & \tilde{7}^{-1} \\ 3 & \tilde{3} & 7 & \tilde{1} \end{bmatrix} \quad (20)$$

By employing the interval weight normalization procedure [22], we calculate the importance weight vector as: $W_s = [0.2667, 0.1333, 0.0667, 0.5333]$. We collected the decision makers' assessments on each shopping centers regarding four main criteria. They assigned degrees of importance by using a nine-point scale in regard to scale in Table 1and these assessments are consolidated by using Eq. 9. Then; we utilized fuzzy AHP method assemble the total fuzzy judgment matrix.

After that, we investigate the changes in results for varying alpha and lambda levels, which correspond to varying confidence levels and the risk attitudes, respectively. In appendix A, we provide final aggregated entropy weights to rank the alternatives for varying levels of alpha (0.1, 0.25, 0.50, 0.75, 0.9) and for varying levels of lambda (0, 0.25, 0.50, 0.75, 1.00) in Table 2 and Table 3. We illustrate our findings for each lambda level with column charts in Fig.8 and Fig.9 for Ümraniye and Kadıköy districts, respectively.

For Ümraniye, the best alternative is determined as U-SC3 according to the weights derived from entropy based fuzzy AHP. For the most levels of lambda, U-SC3 is superior to remaining alternatives.

The best alternative for Kadıköy is determined as K-SC2 according to the weights derived from entropy based fuzzy AHP. According to the rankings for any lambda level, K-SC2 is superior to remaining alternatives.

5. Conclusion and recommendations

Electronics market is the fastest growing market around the world, as in Turkey. Mobile phones are one of the leading electronic products in replacement with their short life cycles. Constructing separate streams for EOL mobile phones is crucial for preventing them thrown away with normal household waste and ensuring product/data security issues. The vast amount, the precious material content, the ease of portability and storability of EOL mobile phones are some of the striking characteristics of these products to take urgent action. These reasons attract the attention of researchers and practitioners in Turkey and in Worldwide.

However, setting effective regulations to manage separate WEEE streams, especially small sized WEEEs, is very challenging in a metropolis due to high population and complex demographics of residents'. A reliable, safe and efficient collection system will initiate the reverse flow of EOL products and will encourage product recovery activities by reducing costs.

In Istanbul, the reverse flow of EOL products do not follow a systematic and organized route and reverse logistic activities of district municipalities are not coordinated. The main contribution of this study is to support decision makers in constructing coordinated separate collection system in the districts of Istanbul. This study proposes to utilize shopping malls as collection points for EOL mobile phones. In this study, we investigate the challenges in WEEE management both in Turkey and worldwide. Next, we propose a conceptual design framework including key performance indicators, strategic and tactical decisions, system design and decision support concerns for constructing WEEE collection system. Then, we solved a bi-objective spanning tree model and entropy embedded fuzzy AHP method for determining the locations of collection nodes and understanding the possible flow of EOL product. Finally, we conclude by introducing the potential districts.

We encourage future research studies and practical implications since both efforts are still insufficient. Further practical implication of this study is to determine the collection and truck capacities for partial routes. Future research studies, the subjects can be listed as in the following: feasibility studies for separate WEEE collection, WEEE management strategies, data security, WEEE specialized vehicle routing and capacity planning problems.

Acknowledgments

The authors would like to thank the anonymous reviewers for their valuable comments.

Appendices

Table 2. Final aggregated entropies to rank shopping centers in Ümraniye

Lambda	***0***					***0.25***					***0.5***					***0.75***					***1***				
Alpha	*0.1*	*0.25*	*0.5*	*0.75*	*0.9*	*0.1*	*0.25*	*0.5*	*0.75*	*0.9*	*0.1*	*0.25*	*0.5*	*0.75*	*0.9*	*0.1*	*0.25*	*0.5*	*0.75*	*0.9*	*0.1*	*0.25*	*0.5*	*0.75*	*0.9*
U-SC1	1.54	1.55	1.56	1.56	1.56	1.56	1.57	1.57	1.57	1.57	1.58	1.58	1.58	1.58	1.57	0.92	0.91	0.89	0.85	0.83	1.61	1.61	1.60	1.60	1.59
U-SC2	1.47	1.53	1.60	1.66	1.69	1.58	1.60	1.62	1.65	1.68	1.64	1.64	1.64	1.65	1.67	1.38	1.33	1.24	1.16	1.15	1.71	1.70	1.67	1.64	1.61
U-SC3	1.60	1.62	1.65	1.67	1.68	1.66	1.67	1.67	1.68	1.69	1.70	1.70	1.70	1.69	1.69	1.54	1.53	1.50	1.46	1.44	1.75	1.74	1.73	1.71	1.70
U-SC4	1.58	1.59	1.60	1.60	1.61	1.60	1.60	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.17	1.18	1.20	1.22	1.23	1.62	1.62	1.62	1.62	1.61
U-SC5	1.64	1.64	1.65	1.65	1.65	1.63	1.64	1.64	1.65	1.65	1.63	1.63	1.64	1.64	1.65	1.27	1.23	1.19	1.22	1.31	1.62	1.62	1.63	1.63	1.65

Table 3. Final aggregated entropies to rank shopping centers in Kadıköy

Lambda	***0***					***0,25***					***0,5***					***0,75***					***1***				
Alpha	*0,1*	*0,25*	*0,5*	*0,75*	*0,9*	*0,1*	*0,25*	*0,5*	*0,75*	*0,9*	*0,1*	*0,25*	*0,5*	*0,75*	*0,9*	*0,1*	*0,25*	*0,5*	*0,75*	*0,9*	*0,1*	*0,25*	*0,5*	*0,75*	*0,9*
K-SC1	1,81	1,79	1,74	1,69	1,66	1,73	1,73	1,71	1,68	1,66	1,67	1,68	1,68	1,67	1,67	0,97	1,04	1,12	1,19	1,22	1,58	1,60	1,63	1,65	1,67
K-SC2	1,71	1,72	1,73	1,74	1,75	1,73	1,73	1,73	1,74	1,75	1,74	1,73	1,73	1,73	1,73	1,58	1,55	1,50	1,45	1,45	1,75	1,74	1,72	1,70	1,68
K-SC3	1,42	1,47	1,53	1,57	1,59	1,53	1,55	1,57	1,59	1,60	1,60	1,60	1,60	1,60	1,60	1,30	1,28	1,24	1,20	1,17	1,67	1,66	1,65	1,63	1,61
K-SC4	1,53	1,53	1,53	1,53	1,52	1,59	1,58	1,56	1,54	1,53	1,62	1,61	1,58	1,55	1,53	1,19	1,13	1,01	0,87	0,77	1,66	1,64	1,61	1,57	1,54

References

[1] ADEME Annual report. Electrical and electronic equipments. Data 2010. [Accessed on 20 June 2015]. http://www2.ademe.fr/servlet/getBin?name=C1D8D3FB0D6D41BC332B8322BD6CDB1F_tomcatlocal1320332164546.pdf (2010).

[2] Arshadi, M. and S.M. Mousavi, Multi-objective optimization of heavy metals bioleaching from discarded mobile phone PCBs: Simultaneous Cu and Ni recovery using Acidithiobacillus ferrooxidans, Separation and Purification Technology, 147, 210-219 (2015).

[3] Çalışkan, Ç.O., Çılgın, K., Dündar, U. and M.C. Yalçıntan, İstanbul Dönüşüm Coğrafyası, Kentsel ve Bölgesel Araştırmalar Sempozyumu, 6-7 December 2012, Ankara, https://istanbuldonusumcografyasi.wordpress.com/bildiri-tam-metni/, [Accessed on December 13, 2015] (2012).

[4] Canning, L., Rethinking market connections: mobile phone recovery, reuse and recycling in the UK, Journal of Business & Industrial Marketing, 21 (5), 320–329, (2006).

[5] Çetinsaya Özkır, V., Efendigil, T., Demirel, T., Çetin Demirel, N., Deveci, M. and B. Topçu, A three-stage methodology for initiating an effective management system for electronic waste in Turkey, Resources, Conservation and Recycling, 96, 61-70, (2015).

[6] Chi, X., Wang M.Y.L., and M.A. Reuter, E-waste collection channels and household recycling behaviors in Taizhou of China, Journal of Cleaner Production, 80, 87-95, (2014).

[7] Darby, L. and L. Obara, Household recycling behaviour and attitudes towards the disposal of small electrical and electronic equipment, Resources Conservation and Recycling, 44 (1), 17–35, (2005).

[8] Ehrgott, M. and X. Gandibleux, Multiple Criteria Optimization: State of the Art Annotated Bibliographic Surveys, Kluwer Academic Publishers, Boston, (2002).

[9] Figueiredo, J.N., and S.F. Mayerle, Designing minimum-cost recycling collection networks with required throughput, Transportation Research Part E: Logistics and Transportation Review, 44 (5), 731-752, (2008).

[10] Gomes, M.I., Barbosa-Povoa, A.P., and A.Q. Novais, Modelling a recovery network for WEEE: A case study in Portugal, Waste Management, 31(7), 1645-1660, (2011).

[11] Goodship, V. and A. Stevels, Waste electrical and electronic equipment (WEEE) handbook“, Woodhead publishing, Cambridge, UK, (2012).

[12] Grunow, M. and C. Gobbi, Designing the reverse network for WEEE in Denmark, CIRP Annals - Manufacturing Technology, 58(1), 391-394, (2009).

[13] Hagelüken, C., Towards bridging the materials loop – how producers and recyclers can work together, EU-US Workshop on Mineral Raw Material Flows & Data, 13, 2012, Brussels. (http://ec.europa.eu/enterprise/policies/rawmaterials/files/docs/three_hagelueken_eu_us_2012_09_en.pdf). [Accessed on July 7, 2015] (2012).

[14] Kiddee, P., Naidu, R., and M. H. Wong, Electronic waste management approaches: An overview, Waste Management, 33(5), 1237-1250, (2013).

[15] Nnorom, I.C. and O. Osibanjo, Toxicity characterization of waste mobile phone plastics, Journal of Hazardous Material, 161, 183–188, (2009).

[16] Oguchi, M., Sakanakura, H., Terazono, A., and H. Takigami, Fate of metals contained in waste electrical and electronic equipment in a municipal waste treatment process, Waste Management, 32, 96–103, (2011).

[17] Ongondo, F.O. Williams, I.D. and T.J. Cherrett, How are WEEE doing? A global review of the management of electrical and electronic wastes, Waste Management, 31(4), 714-730, (2011).

[18] Özkır, V. and H. Başlıgil, Modeling Product Recovery Processes in Closed Loop Supply Chain Network Design. International Journal of Production Research, 50(8), 2218-2233, (2012).

[19] Reuter, M. A., Hudson, C., van Schaik, A., Heiskanen, K., Meskers, C., Hagelüken, C., UNEP Metal Recycling: Opportunities, Limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the International Resource Panel, (2013).

[20] Ruzika, S., and Hamacher, H.W., “A survey on multiple objective minimum spanning tree problems“. In J. Lerner, D. Wagner, and K. A. Zweig (Eds.), Algorithmics of Large and Complex Networks, Lecture Notes in Computer Science, 5515, 104–116, Springer, (2009).

[21] Solomon, R., Sandborn, P. and M. Pecht, Electronic Part Life Cycle Concepts and Obsolescence Forecasting, IEEE Transaction on Components and Packaging Technologies, 707-717, (2000).

[22] Wang, Y. and T.M.S. Elhag, “On the normalization of interval and fuzzy weights”, Fuzzy Sets and Systems, 157, 2456 – 2471, (2006).

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

[24] Yadav, S., Yadav,S. and P. Kumar, Metal toxicity assessment of mobile phone parts using Milli Q water, Waste Management, 34(7), 1274-1278, (2014).

[25] Ylä-Mella, J., Keiski, R.L., and E. Pongrácz, Electronic waste recovery in Finland: Consumers' perceptions towards recycling and re-use of mobile

phones, Waste Management, 45, 374-384, (2015).

[26] http://www.statista.com/statistics/270243/global-mobile-phone-sales-by-vendor-since-2009/ Statistica - Global mobile phone sales data [Accessed, 13 July 2015].

Vildan Çetinsaya Özkır (PhD) *is currently assistant professor in the Department of Industrial Engineering where she is teaching Operations Research 1-2, Numerical Analysis, Economics and Multiple Objective Decision Making courses. She received her BSc degree in industrial engineering, MSc in Systems Engineering and PhD in Industrial Engineering at Yıldız Technical University, Istanbul, Turkey. Her research interests are network models, multiple objective decision analysis, and environmentally conscious manufacturing/logistic systems.*

An International Journal of Optimization and Control: Theories & Applications (http://ijocta.balikesir.edu.tr)