# An interval type-2 fuzzy sets based Delphi approach to evaluate site selection indicators of sustainable vehicle shredding facilities

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# Interval Type-2 Fuzzy ARAS Method for Recycling Facility Location Problems

## ABSTRACT

The management of end-of-life vehicles (ELVs) is currently one of the most important ecological topics. The recycling process has essential importance for the environmental and economic sustainability of the ELV management. Istanbul has the highest rate of car ownership population in Turkey as well as an old vehicle fleet. There is a strong motivation to open an additional ELV recycling facility in this mega-city. Facility location is one of the crucial strategic problems for decision-makers. Addressing multi-criteria and highly uncertain nature of the ELV recycling facility location problem, this paper introduces a novel approach to support the facility location process. For the first time, an extension of the Additive ratio assessment (ARAS) method under the interval type-2 fuzzy environment is presented. The novel method is utilized for solving the ELV recycling facility location problem. The potentials and applicability of the presented interval type-2 fuzzy ARAS method are demonstrated throughout the real-life case study of Istanbul. The comparison with the available state-of-the-art interval type-2 fuzzy set based MCDM methods approves its validity and consistency.

***Keywords:*** End-of-life vehicle; Recycling facility location selection; Interval type-2 fuzzy set; ARAS; Multi-criteria decision-making.

## 1. Introduction

The automotive sector is generating about 5% of industrial waste in the entire world [1]. End-of-life vehicles (ELVs) are the single largest hazardous waste category from households [2]. Besides, ELVs comprise a large portion of waste disposed into nature and relevant figures demonstrate an exponentially growing positive trend [3]. Therefore, the management of ELVs is currently one of the most important ecological topics [4].

The ELV management is crucial for developing countries like Turkey. The Turkish Directive on ELVs was enforced on January 1, 2011. According to this directive, by January 1, 2020, vehicle recovery must reach a minimum of 95% by weight per vehicle, of which a minimum of 85% will have to be reusable and recyclable material [5]. In 2019, over 23.1

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million motor vehicles are registered in Turkey whereas it was below 20 million in 2015 [6]. According to the latest data, around 260.000 ELVs were deregistered in 2018 [7]. However, this is far from the actual figure because numerous cases of the deregistration process are not reported [3].

In Turkey, passenger cars are on average 13 years old [8]. For instance, the average age of passenger cars in the UK is 7.8 years [9]. Istanbul has the highest rate of car ownership population in Turkey as well as an old vehicle fleet [10]. There are only three licensed ELV recycling facilities in Istanbul. Their processing capacity is not sufficient. The recycling process has essential importance for the environmental and economic sustainability of the ELV management in this mega-city. Hence, there is a strong motivation to open an additional ELV recycling facility in Istanbul.

The selection of ELV recycling facility locations can be considered as a multi-criteria decision-making (MCDM) problem which may have quantitative and qualitative criteria. Facility location is one of the crucial strategic problems for decision-makers. In addition to its being irrevocable and a high costing problem, it has many uncertain data that decision-makers need to work with. There are various kinds of MCDM techniques for location selection problems [11]. One of them is the Additive ratio assessment (ARAS) method. It was proposed by Turskis and Zavadskas [12] and can be classified as a newly formed, but effective and easy to use MCDM method. However, decision-makers may be subjective and biased due to incomplete information or knowledge [13]. The fuzzy set theory is used as a tool to provide a framework for a decision-making process that includes specific judgments [14]. The fuzzy sets reflect uncertainties in human judgment and effectively solve the uncertainties in a poorly defined MCDM environment [15].

This study proposes an interval type-2 set based ARAS method to evaluate ELV recycling facility locations. The proposed method has several advantages: (1) type-2 fuzzy sets are preferred because they can better reflect uncertainties of inaccurate information compared to type-1 fuzzy sets; (2) it can better manage and understand the uncertainty; (3) the implementation procedure is not complex and provides less computational time; (4) it concurrently maximizes benefit and minimizes cost criteria.

The rest of the paper is organized as follows: Section 2 provides a review of related research. Section 3 presents the used methodology and developed the interval type-2 fuzzy ARAS method. A real-life case study of Istanbul is described in Section 4. Section 5 presents the case study results and discussions. Section 6 presents the conclusions of the work and indicates possible extension areas.

## 2. Literature review

The literature review is organized into two subsections to provide better insights into the concepts under this research and more clearly address the contributions of this study. The first subsection explores existing MCDM models for the ELV management. The second subsection investigates the available applications of the ARAS method.

### *2.1. Multi-criteria decision-making models for the ELV management*

The ELV management is of vital importance for environment conservation, circular economy, and sustainable development. Previously, several research works have been undertaken for solving various issues of the ELV management problem by using different MCDM methods (Table 1).

### *2.2. Applications of the ARAS method*

The ARAS method uses simple relative comparisons to help decision-makers understand the phenomena of the complex world. It is one of the compensatory methods in which qualitative attributes should be converted into quantitative attributes [16]. Although the ARAS method is a new approach in the MCDM literature, it is appreciated by many authors as advantageous (Table 2).

**Table 1**
Summary of the available MCDM models for the ELV management.

| Author(s) | Year | Research focus | Method | Parameter type |
|---|---|---|---|---|
| Tian et al. [17] | 2014 | Remanufacturing technology | AHP | Deterministic |
| Abdulrahman et al. [18] | 2015 | Auto-parts remanufacturers | AHP | Deterministic |
| Ahmed et al. [19] | 2016 | ELV management strategies | DEMATEL+Fuzzy AHP | Fuzzy |
| Desnica et al. [20] | 2016 | Equipment selection | AHP | Deterministic |
| Kannan et al. [21] | 2016 | Barriers of auto-parts remanufacturing | Fuzzy ANP | Fuzzy |
| Pourjavad and Mayorga [22] | 2016 | ELV management strategies | Fuzzy AHP-TOPSIS | Fuzzy |
| Schmid et al. [23] | 2016 | Dismantling scenarios | PROMETHEE | Deterministic |
| Tian and Chen [24] | 2016 | Manual dismantling scenarios | Fuzzy AHP | Fuzzy |
| Zhou et al. [25] | 2016 | Service providers | VIKOR | Deterministic |
| Tian et al. [26] | 2017 | Auto-parts remanufacturing operations | Fuzzy AHP-TOPSIS | Fuzzy |
| Raja Mamat et al. [2] | 2018 | ELV management performances | AHP | Deterministic |
| Zhang and Chen [27] | 2018 | Dismantling scenarios | AHP | Deterministic |
| Tian et al. [28] | 2019 | Take-back patterns | Grey DEMATEL+Fuzzy VIKOR | Interval or fuzzy |
| Wang et al. [29] | 2019 | Improving resource utilization efficiency | DEA-TOPSIS | Deterministic |
| Yang et al. [30] | 2019 | ELV management criteria selection | Picture hesitant fuzzy TOPSIS | Picture hesitant fuzzy |
| Pavlović et al. [31] | 2020 | Recycling technology | Fuzzy TOPSIS | Fuzzy |
| *Our study* | | *Recycling facility location* | *IT2F ARAS* | *Interval type-2 fuzzy* |

**Table 2**
Summary of the available applications of the ARAS method.

| Author(s) | Year | Research focus | Application type | Parameter type | |
|---|---|---|---|---|---|
| | | | | Criterion | Alternative |
| Tupenaite et al. [32] | 2010 | Built and human environment renovation | Real-life | Deterministic | |
| Turskis and Zavadskas [12] | 2010 | Logistics center location | Illustrative example | Deterministic | Fuzzy |
| Turskis and Zavadskas [33] | 2010 | Supplier selection | Illustrative example | Interval | |
| Zavadskas and Turskis [34] | 2010 | Micro-climate in offices | Illustrative example | Deterministic | |
| Zavadskas et al. [35] | 2010 | Foundation installment | Illustrative example | Deterministic | |
| Keršulienė and Turskis [36] | 2011 | Personnel selection | Illustrative example | Deterministic | Fuzzy |
| Baležentis et al. [37] | 2012 | Economic sectors comparison | Real-life | Fuzzy | |
| Dadelo et al. [38] | 2012 | Personnel selection | Illustrative example | Deterministic | |
| Zavadskas et al. [39] | 2012 | Construction technology | Real-life | Deterministic | |
| Zavadskas et al. [40] | 2012 | Personnel selection | Illustrative example | Deterministic | |
| Turskis et al. [41] | 2013 | Built heritage | Real-life | Deterministic | Interval |
| Keršulienė and Turskis [42] | 2014 | Personnel selection | Illustrative example | Deterministic | Fuzzy |
| Kutut et al. [43] | 2014 | Historic buildings preservation | Real-life | Deterministic | |
| Zamani et al. [44] | 2014 | Brand extension strategy selection | Real-life | Deterministic | Fuzzy |
| Medineckiene et al. [45] | 2015 | Sustainable building certification | Illustrative example | Deterministic | |
| Stanujkic [46] | 2015 | Websites evaluation | Illustrative example | Fuzzy | Interval fuzzy |
| Zavadskas et al. [47] | 2015 | Seaport location | Real-life | Deterministic | Fuzzy |
| Liao et al. [48] | 2016 | Green supplier selection | Illustrative example | Deterministic | Fuzzy |
| Nguyen et al. [49] | 2016 | Conveyor selection | Illustrative example | Fuzzy | |
| Štreimikienė et al. [50] | 2016 | Electricity generation technology | Real-life | Deterministic | |
| Rostamzadeh et al. [51] | 2017 | Supply chain performance measurement | Illustrative example | Fuzzy | |
| Büyüközkan and Göçer [52] | 2018 | Digital supply chain supplier selection | Real-life | Interval intuitionistic fuzzy | |
| Dahooie et al. [53] | 2018 | Personnel selection | Illustrative example | Deterministic | Interval |
| Dahooie et al. [54] | 2018 | Oil and gas well-drilling | Real-life | Deterministic | Interval fuzzy |
| Radović et al. [55] | 2018 | Transportation company | Real-life | Deterministic | Rough interval |
| Bahrami et al. [56] | 2019 | Mineral potential mapping | Real-life | Deterministic | |
| Dahooie et al. [57] | 2019 | Financial performances | Real-life | Deterministic | Fuzzy |
| Fu (2019) [58] | 2019 | Catering supplier selection | Real-life | Deterministic | |
| Naicker and Thopil [59] | 2019 | Renewable energy systems | Real-life | Deterministic | |
| Turskis et al. [60] | 2019 | Structural solutions for buildings | Real-life | Deterministic | Fuzzy |
| Pehlivan and Gürsoy [62] | 2019 | Life satisfaction | Real-life | Fuzzy | |
| Ghenai et al. [61] | 2020 | Renewable energy systems | Illustrative example | Deterministic | |
| *Our study* | | *Recycling facility location* | *Real-life* | *Interval type-2 fuzzy* | |

Tupenaite et al. [32] utilized the ARAS method to evaluate alternatives for built and human environment renovation. Turskis and Zavadskas [12] developed the fuzzy ARAS method for locating logistics centers. The AHP method was used to determine crisp criteria weights. Turskis and Zavadskas [33] presented the grey ARAS method to solve the supplier selection problem. Zavadskas et al. [35] applied the ARAS method to find the most appropriate and safe foundation installment alternative.

Keršulienė and Turskis [36] combined the Step-wise weight assessment ratio analysis (SWARA) and the fuzzy ARAS methods to overcome difficulties in the personnel selection process. Baležentis et al. [37] utilized the fuzzy ARAS method to compare the efficiency of Lithuanian economic sectors. Dadelo et al. [38] used the ARAS method for solving the personnel selection problem. Zavadskas et al. [39] adopted the ARAS method to generate a decision on the most suitable construction technology for installing pile-columns. Zavadskas et al. [40] applied the AHP-ARAS approach to assess project managers in construction processes.

Turskis et al. [41] coupled the AHP and grey ARAS methods to rank built heritage projects. Keršulienė and Turskis [42] combined the AHP and the fuzzy ARAS methods, and the fuzzy weighted-product model to assess chief accounting officers. Kutut et al. [43] used the AHP-ARAS approach to prioritize cultural heritage buildings. Zamani et al. [44] integrated the ANP and fuzzy ARAS methods to solve the brand extension strategy selection problem in the dairy food industry.

Medineckiene et al. [45] applied the AHP-ARAS approach for solving the sustainable building certification problem. Stanujkic [46] proposed an interval-valued fuzzy set based ARAS method. Zavadskas et al. [47] coupled the AHP and the fuzzy ARAS methods to rank seaport locations. Liao et al. [48] integrated the AHP-ARAS approach and the multi-segment goal programming for solving the green supplier selection problem. Nguyen et al. [49] used the fuzzy AHP-ARAS approach to solve the conveyor selection problem. Štreimikienė et al. [50] applied the AHP-ARAS approach for assessing electricity generation technologies in Lithuania. Rostamzadeh et al. [51] used the fuzzy ARAS method for evaluating supply chain management performance measurement of small-medium sized enterprises.

Büyüközkan and Göçer [52] developed an interval-valued intuitionistic fuzzy set based AHP-ARAS approach to support the supplier selection process in a digital supply chain. Dahooie et al. [53] combined the SWARA and the grey ARAS methods for choosing the best information technology expert. Dahooie et al. [54] used the interval-valued fuzzy ARAS method to evaluate oil and gas well-drilling projects. The fuzzy Delphi and the

SWARA methods were used to identify and determine criteria and weights, respectively. Radović et al. [55] suggested a rough ARAS method for evaluating performance indicators of transportation companies.

Bahrami et al. [56] utilized the Best worst method and the ARAS method to calculate weights of criteria and rank mineral deposits, respectively. Dahooie et al. [57] integrated the fuzzy c-means clustering algorithm and the ARAS method to evaluate the financial performances of manufacturing companies. Fu [58] coupled the AHP-ARAS approach and the multi-choice goal programming to rank catering suppliers in the airline industry. Naicker and Thopil [59] used the AHP-ARAS approach to highlight renewable technology options. Turskis et al. [60] integrated the AHP and the fuzzy ARAS methods, and fuzzy multiplicative utility function for analyzing structural elements of buildings. Ghenai et al. [61] applied the SWARA-ARAS approach to rank renewable energy systems. Pehlivan and Gürsoy [62] utilized the fuzzy ARAS method to assess life satisfaction levels.

According to the performed review, the following gaps are noticed:

- Little has been done to address the evaluation of various alternatives for locating ELV recycling facilities.
- No earlier work has elucidated the criteria for solving the ELV recycling planning problem.
- Uncertainty is the key factor influencing the ELV management. However, uncertainty analysis is mainly ignored in the available studies.
- Advanced methodological approaches for locating not only recycling facilities but also ELV management network entities, which can capture more degrees of uncertainty and account multiple conflicting evaluation criteria, are missing.
- The available system analysis methods for the ELV management are unable to handle higher degrees of uncertainty.
- No previous research applied an interval type-2 fuzzy set based MCDM approach for solving waste management problems.
- The ARAS method has not been extended before using interval type-2 fuzzy sets.

Hence, to fill these gaps with the aid of the proposed interval type-2 fuzzy ARAS method, this paper will evaluate the ELV recycling facility locations in the Istanbul scenario. On the other hand, the literature on location selection problems under subjectivity is wide. Since this study applies IT2F ARAS and compares the results with the IT2F EDAS, IT2F

WASPAS, and IT2F COPRAS the literature review section is devoted to these methods. Han and Mendel [63] proposed a new methodology called Perceptual Computer based on a centroid-based ranking method to rank locations and a Jaccard similarity measure to obtain their similarities under IT2F conditions. Still, this study has meaningful differences from the work done in [63]. Particularly, this paper introduces a novel approach to support the location choice problem. For the first time, an extension of the ARAS method under the IT2F environment is presented. The ARAS method can be classified as a newly formed, but effective and easy to use MCDM method. It is one of the compensatory methods in which qualitative attributes should be converted into quantitative attributes. It uses simple relative comparisons to help decision-makers understand the phenomena of the complex world. Therefore, in this study, the IT2F ARAS method is preferred.

## 3. Methodology

In this section, some definitions of fuzzy sets, interval type-2 fuzzy sets, and the developed interval type-2 fuzzy ARAS method are provided.

### *3.1. Interval type-2 fuzzy sets*

A fuzzy set that was presented by Zadeh [64] in the universe of discourse $U$ is a classical type-1 fuzzy set denoted by $A$. It can be defined as [65-66] in equation (1):

$$A = \{(x, \mu_A(x)) \mid \forall x \in X\}, \tag{1}$$

where a type-1 membership function $\mu_A(x)$ is constrained to be between 0 and 1 for all $x \in X$. Type-1 fuzzy sets can also be defined as type-2 fuzzy sets and denoted as $\tilde{A}$. Type-2 fuzzy sets are characterized by a membership function $\mu_{\tilde{A}}(x, u)$, where $x \in X$ in $\tilde{A}$ and $u \subseteq [0, 1]$ [67]:

$$\tilde{A} = \{((x, u),\ \mu_{\tilde{A}}(x, u)) \mid \forall x \in X,\ \forall u \subseteq [0,1]\}, \tag{2}$$

where $0 \leq \mu_{\tilde{A}}(x,u) \leq 1$. When $\mu_{\tilde{A}}(x,u) = 1$ for $\forall x \in X$, then $\tilde{A}$ is named as an interval type-2 fuzzy set [68]:

$$\tilde{A} = \int_{x \in X} \int_{u \in [0,1]} 1/(x,u), \tag{3}$$

The interval type-2 fuzzy set $\tilde{A}$ is completely determined by the primary membership which is called the footprint of uncertainty (FOU). Since the operations on interval type-2 fuzzy sets are computationally demanding, they are usually considered in some simplified form. In this paper, we follow the results of Chen [69], who adopted trapezoidal interval type-2 fuzzy sets for solving MCDM problems. A trapezoidal interval type-2 fuzzy set can be defined as follows:

$$\tilde{A} = (A^U,\ A^L) = ((a_l^U;\ h_1(A^U),\ h_2(A^U)),\ (a_l^L;\ h_1(A^L),\ h_2(A^L) \mid l = 1, ..., 4), \tag{4}$$

where $A^U$ and $A^L$ are type-1 fuzzy sets; $a_1^U$, $a_2^U$, $a_3^U$, $a_4^U$, $a_1^L$, $a_2^L$, $a_3^L$, and $a_4^L$ are the reference points of the interval type-2 fuzzy set $\tilde{A}$, which satisfy the inequalities $a_1^U \le a_2^U \le a_3^U \le a_4^U$ and $a_1^L \le a_2^L \le a_3^L \le a_4^L$; $h_k(A^U) \in [0,\ 1]$ and $k$=1, 2, denotes the membership value of the element $a_{k+1}^U$ in the upper trapezoidal membership function $A^U$; $h_k(A^L) \in [0,\ 1]$ and $k$=1, 2, denotes the membership value of the element $a_{k+1}^L$ in the lower trapezoidal membership function $A^L$.

*3.2. Interval type-2 fuzzy ARAS method*

This study aims to develop an interval type-2 fuzzy extension of the ARAS method. The steps of the developed interval type-2 fuzzy ARAS method are given as follows:

***Step 1.*** Construct the interval type-2 fuzzy decision matrices $\tilde{X}^\delta = [\tilde{x}_{ij}^\delta]_{m\times n}$.

$$\tilde{X}^\delta = \begin{bmatrix} \tilde{x}_{11}^\delta & \tilde{x}_{12}^\delta & \cdots & \tilde{x}_{1n}^\delta \\ \tilde{x}_{21}^\delta & \tilde{x}_{22}^\delta & \cdots & \tilde{x}_{2n}^\delta \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^\delta & \tilde{x}_{m2}^\delta & \cdots & \tilde{x}_{mn}^\delta \end{bmatrix}, \tag{5}$$

where $\tilde{x}_{ij}^\delta$ is the evaluation value of the $i$-th alternative ($i$=1, 2, ..., $m$) with respect to $j$-th criterion ($j$=1, 2, ..., $n$) by the $\delta$-th decision-maker ($\delta$=1, 2, ..., $d$). Note that the elements in Eq. (5) are intervals.

***Step 2.*** Determine the interval type-2 fuzzy average decision matrix $\tilde{X} = [\tilde{x}_{ij}]_{m\times n}$ as follows:

$$\tilde{x}_{ij} = \frac{\tilde{x}_{ij}^1 \oplus \tilde{x}_{ij}^2 \oplus \cdots \oplus \tilde{x}_{ij}^d}{d} = \frac{\sum_{\delta=1}^d \tilde{x}_{ij}^\delta}{d},\ \ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n, \tag{6}$$

where $\tilde{x}_{ij}$ denotes the average rating value of the $i$-th alternative with respect to $j$-th criterion.

***Step 3.*** Construct the interval type-2 fuzzy weight matrices $\tilde{W}^\delta = [\tilde{w}_j^\delta]_{n\times 1}$.

$$\tilde{W}^{\delta} = \begin{bmatrix} \tilde{w}_1^{\delta} \\ \tilde{w}_2^{\delta} \\ \vdots \\ \tilde{w}_n^{\delta} \end{bmatrix}, \quad \delta = 1, 2, \ldots, d, \tag{7}$$

where $\tilde{w}_j^{\delta}$ denotes the weight of the *j*-th criterion evaluated by the $\delta$-th decision-maker.

***Step 4.*** Determine the interval type-2 fuzzy average weight matrix $\tilde{W} = [\tilde{w}_j]_{n\times 1}$ as follows:

$$\tilde{w}_j = \frac{\tilde{w}_j^1 \oplus \tilde{w}_j^2 \oplus \cdots \oplus \tilde{w}_j^d}{d} = \frac{\sum_{\delta=1}^{d} \tilde{w}_j^{\delta}}{d}, \quad j = 1, 2, \ldots, n, \tag{8}$$

where $\tilde{w}_j$ denotes the *j*-th criterion weight.

***Step 5.*** Construct the interval type-2 fuzzy normalized average decision matrix $\tilde{N} = [\tilde{n}_{ij}]_{m\times n}$, where $\tilde{n}_{ij}$ denotes the normalized average rating value of the *i*-th alternative with respect to *j*-th criterion.

To avoid the complexity of mathematical operations in a decision process, normalization based on the characteristics of criteria, namely larger-the-better (benefit), smaller-the-better (cost) is used here to transform the various criteria scales into comparable scales. Therefore, the normalized trapezoidal interval type-2 fuzzy sets for benefit criteria ($\tilde{n}_{ij}^{*}$) can be defined as:

$$\tilde{n}_{ij}^{*} = \left(\left(\frac{x_{ij1}^U}{x_{j*}^U}, \frac{x_{ij2}^U}{x_{j*}^U}, \frac{x_{ij3}^U}{x_{j*}^U}, \frac{x_{ij4}^U}{x_{j*}^U}; h_1(X_{ij}^U), h_2(X_{ij}^U)\right), \left(\frac{x_{ij1}^L}{x_{j*}^U}, \frac{x_{ij2}^L}{x_{j*}^U}, \frac{x_{ij3}^L}{x_{j*}^U}, \frac{x_{ij4}^L}{x_{j*}^U}; h_1(X_{ij}^L), h_2(X_{ij}^L)\right), \quad i = 1, 2, \ldots, m;\ j \in B, \tag{9}$$

while the normalized trapezoidal interval type-2 fuzzy sets for cost criteria ($\tilde{n}_{ij}^{-}$) can be defined as:

$$\tilde{n}_{ij}^{-} = \left(\left(\frac{x_{j-}^U}{x_{ij4}^U}, \frac{x_{j-}^U}{x_{ij3}^U}, \frac{x_{j-}^U}{x_{ij2}^U}, \frac{x_{j-}^U}{x_{ij1}^U}; h_1(X_{ij}^U), h_2(X_{ij}^U)\right), \left(\frac{x_{j-}^U}{x_{ij4}^L}, \frac{x_{j-}^U}{x_{ij3}^L}, \frac{x_{j-}^U}{x_{ij2}^L}, \frac{x_{j-}^U}{x_{ij1}^L}; h_1(X_{ij}^L), h_2(X_{ij}^L)\right), \quad i = 1, 2, \ldots, m;\ j \in C, \tag{10}$$

where $x_{j*}^U = \max_{i=1,\ldots,m,\, l=1,\ldots,4} x_{ijl}^U,\ j \in B$, and $x_{j-}^U = \min_{i=1,\ldots,m,\, l=1,\ldots,4} x_{ijl}^U;\ j \in C$, are the best average rating values of the *j*-th benefit and cost criteria, respectively; *B* is the set of benefit criteria; and *C* is the set of cost criteria.

***Step 6.*** Determine the interval type-2 fuzzy weighted normalized average decision matrix

$\tilde{F} = [\tilde{f}_{ij}]_{m \times n}$ as follows:

$$\tilde{f}_{ij} = \tilde{w}_j \otimes \tilde{n}_{ij}, \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \tag{11}$$

where $\tilde{f}_{ij}$ is the weighted normalized average rating value of the $i$-th alternative with respect to $j$-th criterion.

***Step 7.*** Determine the optimality function of benefit criteria $\tilde{P}_i^*$ of each alternative:

$$\tilde{P}_i^* = \sum_{j \in B} \tilde{f}_{ij}, \quad i = 1, 2, \ldots, m, \tag{12}$$

and the optimality function of cost criteria $\tilde{P}_i^-$ of each alternative:

$$\tilde{P}_i^- = \sum_{j \in C} \tilde{f}_{ij}, \quad i = 1, 2, \ldots, m. \tag{13}$$

***Step 8.*** Determine the utility degree of benefit criteria $\tilde{R}_i^*$ of each alternative:

$$\tilde{R}_i^* = \frac{\tilde{P}_i^*}{\max\limits_{i'=1,\ldots,m,\, l=1,\ldots,4} p_{i'l}^*}, \quad i = 1, 2, \ldots, m, \tag{14}$$

and the utility degree of cost criteria $\tilde{R}_i^-$ of each alternative:

$$\tilde{R}_i^- = \frac{\min\limits_{i'=1,\ldots,m,\, l=1,\ldots,4} p_{i'l}^-}{\tilde{P}_i^-}, \quad i = 1, 2, \ldots, m. \tag{15}$$

***Step 9.*** We propose a utility degree of trapezoidal interval type-2 fuzzy sets based on the concept proposed by Chen et al. [70]. The defuzzified values of the utility degree of benefit criteria $D_i^*$ for each alternative is calculated as follow:

$$D_i^* = \left[\frac{r_{i1^*}^U + r_{i4^*}^U}{2} + \frac{h_1(R_{i^*}^U) + h_2(R_{i^*}^U) + h_1(R_{i^*}^L) + h_2(R_{i^*}^L)}{4}\right] \frac{\sum_{l=1}^{4}(r_{il^*}^U + r_{il^*}^L)}{8}, \quad i = 1, 2, \ldots, m, \tag{16}$$

and the defuzzified values of the utility degree of cost criteria $D_i^-$ for each alternative is:

$$D_i^- = \left[\frac{r_{i1^-}^U + r_{i4^-}^U}{2} + \frac{h_1(R_{i^-}^U) + h_2(R_{i^-}^U) + h_1(R_{i^-}^L) + h_2(R_{i^-}^L)}{4}\right] \frac{\sum_{l=1}^{4}(r_{il^-}^U + r_{il^-}^L)}{8}, \quad i = 1, 2, \ldots, m, \tag{17}$$

***Step 10.*** The appraisal score $Q_i$ of each alternative are formulated as follow:

$$Q_i = \frac{D_i^* + D_i^-}{2}, \quad i = 1, 2, \ldots, m. \tag{18}$$

***Step 11.*** The normalized appraisal score $\Theta_i$ of each alternative are defined as follow:

$$\Theta_i = \frac{Q_i}{\max\limits_{i'=1,\ldots,m} Q_{i'}}, \quad i = 1, 2, \ldots, m. \tag{19}$$

***Step 12.*** Rank the alternatives according to their normalized appraisal score. The highest value is the most desirable alternative.

## 4. Case study

Fig. 1 summarizes the material flow of the ELV management process in Turkey. Due to the Turkish Directive on ELVs [5], vehicle last owners are responsible for the transportation of ELVs to collection or dismantling centers. ELVs in collection centers are supposed to be transferred to authorized dismantling centers within sixty days. After toxic and noxious fluids, oils, coolant, and fuel were drained, the dismantling operation starts. Reusable parts are sold to the second-hand market, while recyclable parts are sent to ELV recycling facilities. The rest of the ELV, which is called hulk, is sent to shredding centers to be shredded into fist-size chunks to liberate metals from everything else. The shredding process results with the recovery of metals from vehicles to components that cannot be brought back to reutilization, called automobile shredding residue (ASR).

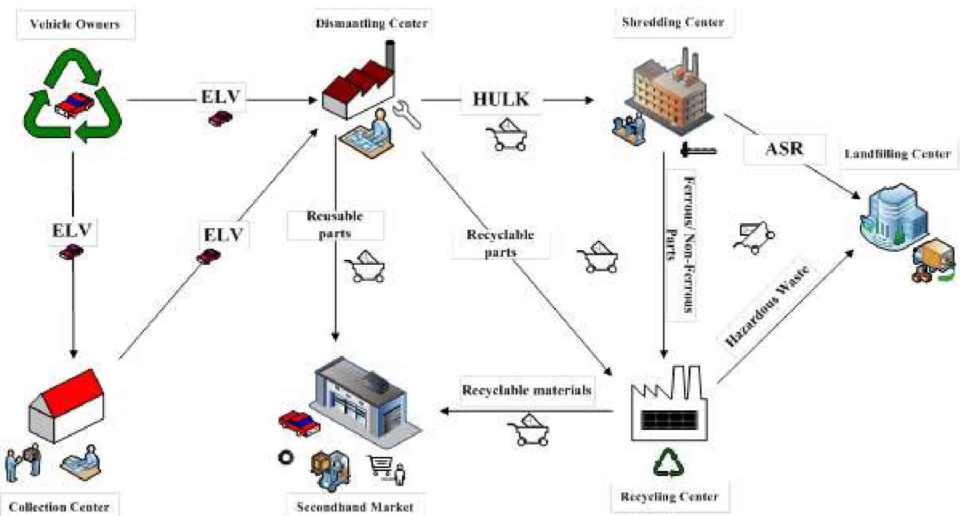


**Fig. 1.** The network flow for the ELV recycling process in Turkey.

In Turkey, ASR could be either land-filled or incinerated. ELV recycling facilities, the most important network entity, are responsible for the separation of recyclable parts received from dismantling and shredding centers. They mechanically recycle parts received from dismantling and shredding centers, by using eddy current sorters, magnetic sorters, heavy media sorters, and other advanced sorting equipment. Finally, isolated metals like aluminum, copper, etc., are sold to second-hand markets, while hazardous waste is land-filled.

Fig. 2 presents the clustering counties of Istanbul according to the amount of collected ELVs. The data of Fig. 3 was obtained from the study of Cin [71]. The inverse distance weighted method was used for the presentation of the Geographic Information System.

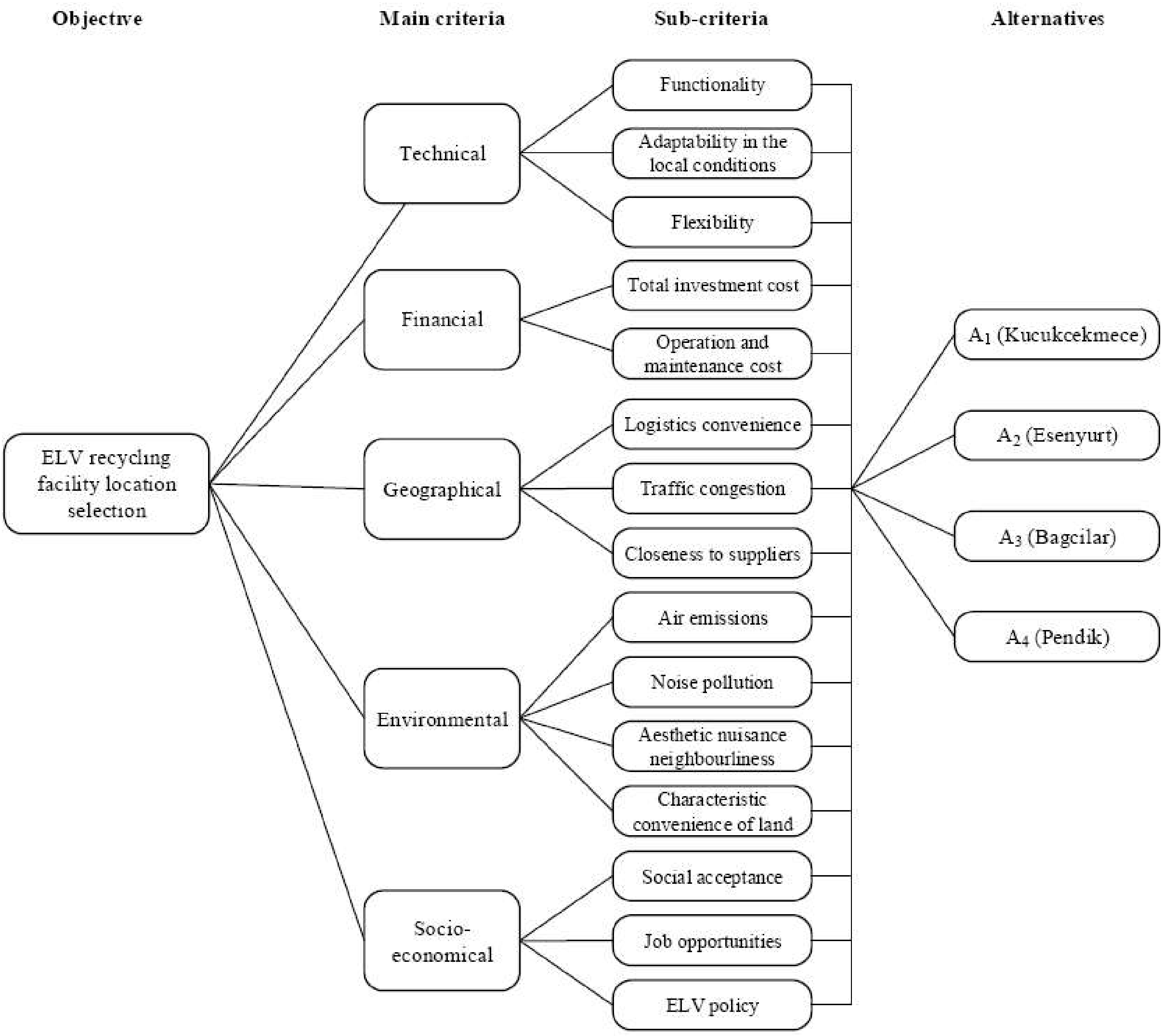


**Fig. 2.** The schematic diagram for the hierarchical structure of the ELV recycling facility location problem.

According to Fig. 2, the location and capacity information of existing facilities, and expert opinions, the following alternative locations for a new ELV recycling facility in Istanbul are (Fig. 3): (1) Kucukcekmece, (2) Esenyurt, (3) Bagcilar, and (4) Pendik.

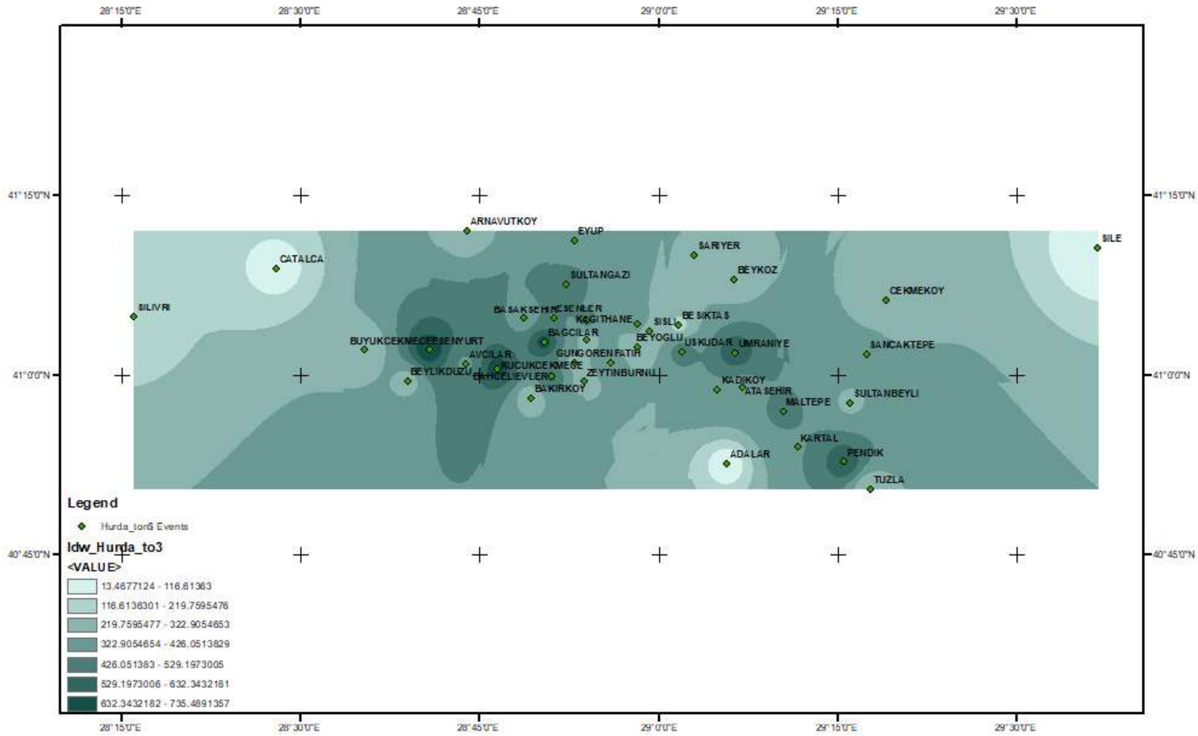


**Fig. 3.** Clustering counties of Istanbul according to the amount of collected ELV (tonnes/year).

As an important step of the MCDM process, qualitative-quantitative criteria and hierarchical structure must be defined clearly. The schematic diagram of the highlighted ELV recycling facility location problem is shown in Fig. 4. The criteria that are used in this real-life case study fall into the following five categories that are technical, financial, geographical, environmental, and socio-economical. Under these five categories, a total of 15 different evaluation criteria were defined.


**Fig. 4.** Alternative locations for the new ELV recycling facility in Istanbul.

The technical category (T) has three evaluation criteria:

- ($T_1$) *Functionality*. The recycling ELV process consists of different recycling activities (i.e., tire recycling, ferrous and non-ferrous material recycling, etc.), which need different pieces of equipment, skilled workers, land, etc.
- ($T_2$) *Adaptability in the local conditions*. Technical and geographical conditions (i.e., land structure, geometrical feasibility of land, the distance of land to the neighborhood, etc.) to build an ELV recycling facility.
- ($T_3$) *Flexibility*. The possibility of alternative recycling scenarios to the potential variations in quantity and the composition of the supply.

The financial category (F) is devoted to costs from the recycling process. It has two evaluation criteria:

- ($F_1$) *Total investment cost.* It consists of capital cost (e.g., fixed investment, land lease, building, and civil work, etc.), working capital, and pre-operating cost (i.e., project implementation cost).
- ($F_2$) *Operation and maintenance cost*. It consists of operational costs to run a facility (i.e., labor cost, energy cost, etc.) and total cost needs to be spent on maintenance and repair activities.

The viability of each alternative location is heavily dependent on its geographical attributes. The geographical category (G) has three evaluation criteria:

- ($G_1$) *Logistics convenience*. Feasibility and accessibility of the location according to transportation and logistics activities for ELV's recycling process.
- ($G_2$) *Traffic congestion*. Longer trip times and increased vehicular queuing decrease operational capacity and transportation costs of ELV's recycling facilities.
- ($G_3$) *Closeness to suppliers*. The short distance of a recycling facility to its suppliers (i.e., dismantlers, shredders, secondary hand markets, etc.) is important to avoid high transportation costs and air pollution.

The environmental category (E) is related to pollutant releases, their impact on the environment, and environmental risk. It has four evaluation criteria:

- ($E_1$) *Air emission.* Emissions could vary in proportion to the alternative location which is selected.
- ($E_2$) *Noise pollution*. It is viewed as an escalating problem and may result from not only waste collection and shipping, but also all the dismantling activities in ELV's recycling facility.
- ($E_3$) *Aesthetic nuisance neighbourliness.* Minimal changes to the natural landscape of an alternative location caused by the installation and operation of a new recycling facility.
- ($E_4$) *Characteristic convenience of land*. Geographical convenience of candidate land to install a recycling facility (e.g., its distance from natural disaster areas).

The socio-economical category (S) has three evaluation criteria:

- ($S_1$) *Social acceptance*. The public level of knowledge and awareness of the ELV management problem and its importance for the local society are dependent on existing waste management practices, environmental repercussions, and their prevention, etc.
- ($S_2$) *Job opportunities*. The number and quality of jobs created due to the opening of an ELV's recycling facility.
- ($S_3$) *ELV policy*. Evaluation of local policies; e.g., mandatory annual inspections and road taxes for old vehicles

## 5. Experimental Results

Fifteen criteria are evaluated by six decision-makers using linguistic terms provided in Fig. 5. The decision-makers also evaluated four considered alternatives for each of the criteria by using the rating scale presented in Table 3. In order to evaluate criteria and alternatives, there are other viable linguistic rating systems for interval type-2 fuzzy numbers including three-point [63], four-point [72], five-point [73], and nine-point scales [74]. Based on the literature, we selected the FOUs from Chen and Lee [70].

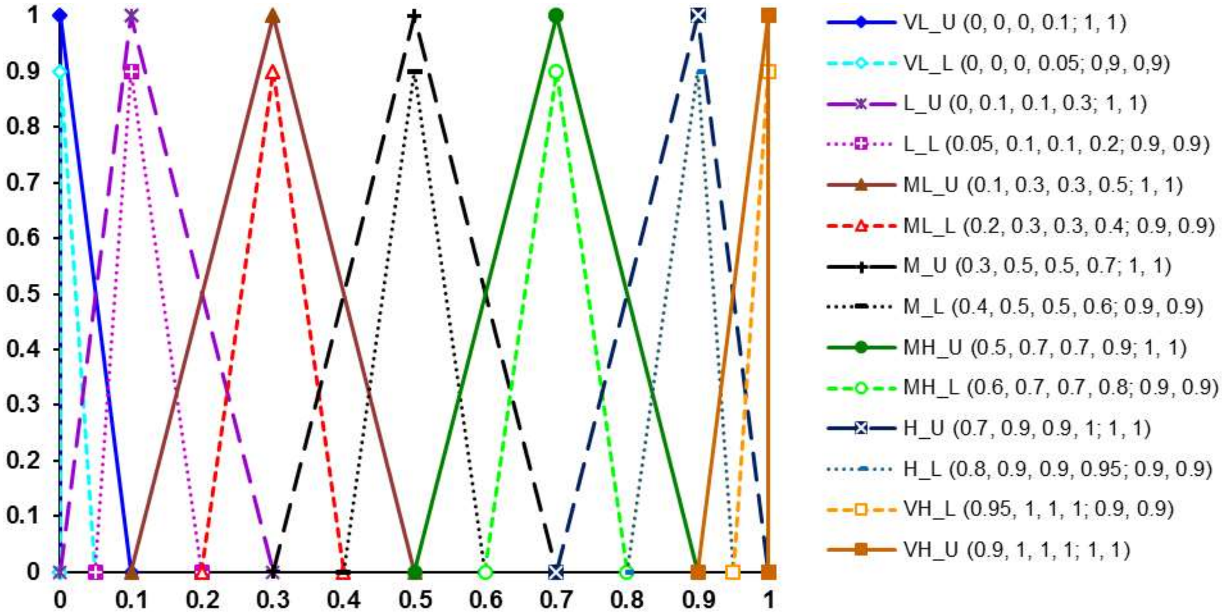


**Fig. 5.** Linguistic terms and corresponding interval type-2 fuzzy numbers for the evaluation of criteria (Very low upper: VL_U; Very low lower: VL_L; Low: L; Medium low: ML; Medium: M; Medium high: MH; High: H; Very high: VH).

**Table 3**
Linguistic terms and corresponding interval type-2 fuzzy numbers for the evaluation of alternatives.

| Linguistic term | $A^U$ | | | | | | $A^L$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $a_1^u$ | $a_2^u$ | $a_3^u$ | $a_4^u$ | $h_1(A^U)$ | $h_2(A^U)$ | $a_1^l$ | $a_2^l$ | $a_3^l$ | $a_4^l$ | $h_1(A^L)$ | $h_2(A^L)$ |
| Very poor (VP) | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0.5 | 0.9 | 0.9 |
| Poor (P) | 0 | 1 | 1 | 3 | 1 | 1 | 0.5 | 1 | 1 | 2 | 0.9 | 0.9 |
| Medium poor (MP) | 1 | 3 | 3 | 5 | 1 | 1 | 2 | 3 | 3 | 4 | 0.9 | 0.9 |
| Fair (F) | 3 | 5 | 5 | 7 | 1 | 1 | 4 | 5 | 5 | 6 | 0.9 | 0.9 |
| Medium good (MG) | 5 | 7 | 7 | 9 | 1 | 1 | 6 | 7 | 7 | 8 | 0.9 | 0.9 |
| Good (G) | 7 | 9 | 9 | 10 | 1 | 1 | 8 | 9 | 9 | 9.5 | 0.9 | 0.9 |
| Very good (VG) | 9 | 10 | 10 | 10 | 1 | 1 | 9.5 | 10 | 10 | 10 | 0.9 | 0.9 |

The linguistic assessments for the criteria and alternatives are presented in Table 4 and Table 5, respectively.

**Table 4**
The criteria evaluations made by decision-makers.

| Decision maker | Criterion | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ |
| DM1 | VH | H | MH | MH | H | M | M | MH | H | H | H | L | M | H | MH |
| $DM_2$ | M | H | H | VH | H | M | H | VL | L | VL | L | VL | H | VH | M |
| $DM_3$ | MH | ML | MH | VH | VH | VH | M | VH | ML | L | VL | MH | L | M | VH |
| $DM_4$ | M | VH | H | VH | VH | MH | H | ML | M | M | L | L | M | MH | VH |
| $DM_5$ | H | MH | VH | VH | H | VH | L | VH | H | VL | VL | VH | H | VH | VH |
| $DM_6$ | MH | MH | M | VH | VH | MH | VH | M | ML | ML | M | ML | ML | VH | ML |

**Table 5**
The linguistic assessments made by decision-makers for the four alternatives in terms of criteria.

| **Alternative** | **Decision maker** | **Criterion** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ |
| $A_1$ | $DM_1$ | MG | F | MG | G | G | G | F | MG | G | F | VG | G | G | G | G |
| | $DM_2$ | F | F | P | VG | G | P | VG | G | G | G | F | F | F | G | F |
| | $DM_3$ | F | MG | MP | MG | F | MG | MP | MG | P | P | P | G | F | G | F |
| | $DM_4$ | F | VG | VP | F | F | VG | VP | F | F | F | MG | F | P | F | F |
| | $DM_5$ | G | F | F | P | G | F | VG | F | G | MG | VP | VG | VG | VG | VG |
| | $DM_6$ | MG | MG | G | VG | VG | MG | VG | F | G | MG | F | MG | MG | VG | MG |
| $A_2$ | $DM_1$ | G | G | VG | G | VG | F | VG | F | F | MP | F | G | MG | G | G |
| | $DM_2$ | F | F | VG | P | G | VP | G | P | VP | VP | G | G | F | G | F |
| | $DM_3$ | MG | G | VG | G | F | MG | G | F | G | G | G | G | VG | MG | F |
| | $DM_4$ | MG | VG | VG | F | F | F | F | G | MP | F | VP | F | VG | VG | F |
| | $DM_5$ | G | G | G | VG | G | MG | P | F | G | VP | MG | VG | VG | VG | VG |
| | $DM_6$ | MG | F | MG | VG | F | MG | MG | MP | VG | G | MP | MP | MP | VG | MP |
| $A_3$ | $DM_1$ | G | MG | F | F | G | G | VG | G | G | MP | VP | P | G | G | G |
| | $DM_2$ | F | F | P | G | G | F | G | F | G | F | F | F | F | VG | F |
| | $DM_3$ | G | G | P | MG | F | G | MP | G | MP | MP | MP | G | G | G | F |
| | $DM_4$ | F | VG | F | F | F | F | F | VP | F | F | P | F | VG | VG | F |
| | $DM_5$ | G | P | P | F | G | F | G | F | G | MG | VP | VG | VG | VG | VG |
| | $DM_6$ | MG | F | P | VG | F | MG | MG | MP | VP | P | P | MP | MP | VG | F |
| $A_4$ | $DM_1$ | F | P | F | MP | F | G | VP | P | F | F | G | VG | G | MG | G |
| | $DM_2$ | F | F | VP | VG | G | G | P | G | F | F | P | VP | F | G | F |
| | $DM_3$ | MG | G | F | F | F | MG | P | MG | F | F | F | G | G | MG | F |
| | $DM_4$ | MG | VG | G | F | F | VG | G | MG | G | F | F | F | MG | G | F |
| | $DM_5$ | G | MG | MG | F | G | VG | VP | VG | G | MG | VP | VG | VG | G | VG |
| | $DM_6$ | MG | F | P | VG | F | MG | MG | G | VG | MP | F | F | MP | VG | MP |

***Steps 1-2.*** In order to form the interval type-2 fuzzy decision matrices, the linguistic assessments made by six decision-makers for the four alternatives in terms of criteria (Table 5) are converted to interval type-2 fuzzy numbers using the second rating scale (Table 3). Table 6 presents the interval type-2 fuzzy average decision matrix. It is constructed based on the six interval type-2 fuzzy decision matrices with the help of Eq. (6).

**Table 6**
The interval type-2 fuzzy average decision matrix.

| Criterion | Alternative | |
|---|---|---|
| | $A_1$ | $A_2$ |
| $C_1$ | ((4.33, 6.33, 6.33, 8.17; 1, 1), (5.33, 6.33, 6.33, 7.25; 0.9, 0.9)) | ((5.33, 7.33, 7.33, 9; 1, 1), (6.33, 7.33, 7.33, 8.17; 0.9, 0.9)) |
| $C_2$ | ((4.67, 6.5, 6.5, 8.17; 1, 1), (5.58, 6.5, 6.5, 7.33; 0.9, 0.9)) | ((6, 7.83, 7.83, 9; 1, 1), (6.92, 7.83, 7.83, 8.42; 0.9, 0.9)) |
| $C_3$ | ((2.67, 4.17, 4.17, 5.83; 1, 1), (3.42, 4.17, 4.17, 5; 0.9, 0.9)) | ((8, 9.33, 9.33, 9.83; 1, 1), (8.67, 9.33, 9.33, 9.58; 0.9, 0.9)) |
| $C_4$ | ((5.5, 7, 7, 8.17; 1, 1), (6.25, 7, 7, 7.58; 0.9, 0.9)) | ((5.83, 7.33, 7.33, 8.33; 1, 1), (6.58, 7.33, 7.33, 7.83; 0.9, 0.9)) |
| $C_5$ | ((6, 7.83, 7.83, 9; 1, 1), (6.92, 7.83, 7.83, 8.42; 0.9, 0.9)) | ((5.33, 7.17, 7.17, 8.5; 1, 1), (6.25, 7.17, 7.17, 7.83; 0.9, 0.9)) |
| $C_6$ | ((4.83, 6.5, 6.5, 8; 1, 1), (5.67, 6.5, 6.5, 7.25; 0.9, 0.9)) | ((3.5, 5.17, 5.17, 7; 1, 1), (4.33, 5.17, 5.17, 6.08; 0.9, 0.9)) |
| $C_7$ | ((5.17, 6.33, 6.33, 7.17; 1, 1), (5.75, 6.33, 6.33, 6.75; 0.9, 0.9)) | ((5.17, 6.83, 6.83, 8.17; 1, 1), (6, 6.83, 6.83, 7.5; 0.9, 0.9)) |
| $C_8$ | ((4.33, 6.33, 6.33, 8.17; 1, 1), (5.33, 6.33, 6.33, 7.25; 0.9, 0.9)) | ((2.83, 4.67, 4.67, 6.5; 1, 1), (3.75, 4.67, 4.67, 5.58; 0.9, 0.9)) |
| $C_9$ | ((5.17, 7, 7, 8.33; 1, 1), (6.08, 7, 7, 7.67; 0.9, 0.9)) | ((4.5, 6, 6, 7.17; 1, 1), (5.25, 6, 6, 6.58; 0.9, 0.9)) |
| $C_{10}$ | ((3.83, 5.67, 5.67, 7.5; 1, 1), (4.75, 5.67, 5.67, 6.58; 0.9, 0.9)) | ((3, 4.33, 4.33, 5.67; 1, 1), (3.67, 4.33, 4.33, 5; 0.9, 0.9)) |
| $C_{11}$ | ((3.33, 4.67, 4.67, 6.17; 1, 1), (4, 4.67, 4.67, 5.42; 0.9, 0.9)) | ((3.83, 5.5, 5.5, 7; 1, 1), (4.67, 5.5, 5.5, 6.25; 0.9, 0.9)) |
| $C_{12}$ | ((5.67, 7.5, 7.5, 8.83; 1, 1), (6.58, 7.5, 7.5, 8.17; 0.9, 0.9)) | ((5.5, 7, 7, 8; 1, 1), (6.25, 7, 7, 7.5; 0.9, 0.9)) |
| $C_{13}$ | ((4.5, 6.17, 6.17, 7.67; 1, 1), (5.33, 6.17, 6.17, 6.92; 0.9, 0.9)) | ((6, 7.5, 7.5, 8.5; 1, 1), (6.75, 7.5, 7.5, 8; 0.9, 0.9)) |
| $C_{14}$ | ((7, 8.67, 8.67, 9.5; 1, 1), (7.83, 8.67, 8.67, 9.08; 0.9, 0.9)) | ((7.67, 9.17, 9.17, 9.83; 1, 1), (8.42, 9.17, 9.17, 9.5; 0.9, 0.9)) |
| $C_{15}$ | ((5, 6.83, 6.83, 8.33; 1, 1), (5.92, 6.83, 6.83, 7.58; 0.9, 0.9)) | ((4.33, 6.17, 6.17, 7.67; 1, 1), (5.25, 6.17, 6.17, 6.92; 0.9, 0.9)) |
| **Criterion** | $A_3$ | $A_4$ |
| $C_1$ | ((5.33, 7.33, 7.33, 8.83; 1, 1), (6.33, 7.33, 7.33, 8.08; 0.9, 0.9)) | ((4.67, 6.67, 6.67, 8.5; 1, 1), (5.67, 6.67, 6.67, 7.58; 0.9, 0.9)) |
| $C_2$ | ((4.5, 6.17, 6.17, 7.67; 1, 1), (5.33, 6.17, 6.17, 6.92; 0.9, 0.9)) | ((4.5, 6.17, 6.17, 7.67; 1, 1), (5.33, 6.17, 6.17, 6.92; 0.9, 0.9)) |
| $C_3$ | ((0.5, 1.67, 1.67, 3.67; 1, 1), (1.08, 1.67, 1.67, 2.67; 0.9, 0.9)) | ((3, 4.5, 4.5, 6.17; 1, 1), (3.75, 4.5, 4.5, 5.33; 0.9, 0.9)) |
| $C_4$ | ((5, 6.83, 6.83, 8.33; 1, 1), (5.92, 6.83, 6.83, 7.58; 0.9, 0.9)) | ((4.67, 6.33, 6.33, 7.67; 1, 1), (5.5, 6.33, 6.33, 7; 0.9, 0.9)) |
| $C_5$ | ((5, 7, 7, 8.5; 1, 1), (6, 7, 7, 7.75; 0.9, 0.9)) | ((4.33, 6.33, 6.33, 8; 1, 1), (5.33, 6.33, 6.33, 7.17; 0.9, 0.9)) |
| $C_6$ | ((4.67, 6.67, 6.67, 8.33; 1, 1), (5.67, 6.67, 6.67, 7.5; 0.9, 0.9)) | ((7, 8.67, 8.67, 9.67; 1, 1), (7.83, 8.67, 8.67, 9.17; 0.9, 0.9)) |
| $C_7$ | ((5.33, 7.17, 7.17, 8.5; 1, 1), (6.25, 7.17, 7.17, 7.83; 0.9, 0.9)) | ((2, 3, 3, 4.5; 1, 1), (2.5, 3, 3, 3.75; 0.9, 0.9)) |
| $C_8$ | ((3.5, 5.17, 5.17, 6.67; 1, 1), (4.33, 5.17, 5.17, 5.92; 0.9, 0.9)) | ((5.5, 7.17, 7.17, 8.5; 1, 1), (6.33, 7.17, 7.17, 7.83; 0.9, 0.9)) |
| $C_9$ | ((4.17, 5.83, 5.83, 7.17; 1, 1), (5, 5.83, 5.83, 6.5; 0.9, 0.9)) | ((5.33, 7.17, 7.17, 8.5; 1, 1), (6.25, 7.17, 7.17, 7.83; 0.9, 0.9)) |
| $C_{10}$ | ((2.17, 4, 4, 6; 1, 1), (3.08, 4, 4, 5; 0.9, 0.9)) | ((3, 5, 5, 7; 1, 1), (4, 5, 5, 6; 0.9, 0.9)) |
| $C_{11}$ | ((0.67, 1.67, 1.67, 3.33; 1, 1), (1.17, 1.67, 1.67, 2.5; 0.9, 0.9)) | ((2.67, 4.17, 4.17, 5.83; 1, 1), (3.42, 4.17, 4.17, 5; 0.9, 0.9)) |
| $C_{12}$ | ((3.67, 5, 5, 6.33; 1, 1), (4.33, 5, 5, 5.67; 0.9, 0.9)) | ((5.17, 6.5, 6.5, 7.5; 1, 1), (5.83, 6.5, 6.5, 7; 0.9, 0.9)) |
| $C_{13}$ | ((6, 7.67, 7.67, 8.67; 1, 1), (6.83, 7.67, 7.67, 8.17; 0.9, 0.9)) | ((5.33, 7.17, 7.17, 8.5; 1, 1), (6.25, 7.17, 7.17, 7.83; 0.9, 0.9)) |
| $C_{14}$ | ((8.33, 9.67, 9.67, 10; 1, 1), (9, 9.67, 9.67, 9.83; 0.9, 0.9)) | ((6.67, 8.5, 8.5, 9.67; 1, 1), (7.58, 8.5, 8.5, 9.08; 0.9, 0.9)) |
| $C_{15}$ | ((4.67, 6.5, 6.5, 8; 1, 1), (5.58, 6.5, 6.5, 7.25; 0.9, 0.9)) | ((4.33, 6.17, 6.17, 7.67; 1, 1), (5.25, 6.17, 6.17, 6.92; 0.9, 0.9)) |

For example, evaluations of the first alternative with respect to the first criterion are defined as "Medium good", "Fair", "Fair", "Fair", "Good", and "Medium good" (Table 5). The corresponding interval type-2 fuzzy numbers are given in Table 7. Besides, the average value of $x_{111}^{U}$ is calculated as (5+3+3+3+7+5)/6=4.33.

**Table 7**
An example for the alternative $A_1$ in terms of the criterion $C_1$.

| **Decision maker** | | | $X_{11}^{U}$ | | | | | | $X_{11}^{L}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $x_{111}^{U}$ | $x_{112}^{U}$ | $x_{113}^{U}$ | $x_{114}^{U}$ | $h_1(X_{11}^{U})$ | $h_2(X_{11}^{U})$ | $x_{111}^{L}$ | $x_{112}^{L}$ | $x_{113}^{L}$ | $x_{114}^{L}$ | $h_1(X_{11}^{L})$ | $h_2(X_{11}^{L})$ |
| $DM_1$ | 5 | 7 | 7 | 9 | 1 | 1 | 6 | 7 | 7 | 8 | 0.9 | 0.9 |
| $DM_2$ | 3 | 5 | 5 | 7 | 1 | 1 | 4 | 5 | 5 | 6 | 0.9 | 0.9 |
| $DM_3$ | 3 | 5 | 5 | 7 | 1 | 1 | 4 | 5 | 5 | 6 | 0.9 | 0.9 |
| $DM_4$ | 3 | 5 | 5 | 7 | 1 | 1 | 4 | 5 | 5 | 6 | 0.9 | 0.9 |
| $DM_5$ | 7 | 9 | 9 | 10 | 1 | 1 | 8 | 9 | 9 | 9.5 | 0.9 | 0.9 |
| $DM_6$ | 5 | 7 | 7 | 9 | 1 | 1 | 6 | 7 | 7 | 8 | 0.9 | 0.9 |
| *Average* | 4.33 | 6.33 | 6.33 | 8.17 | 1 | 1 | 5.33 | 6.33 | 6.33 | 7.25 | 0.9 | 0.9 |

***Steps 3-4.*** In order to create the interval type-2 fuzzy weight matrices, the criteria evaluations made by decision-makers (Table 4) are converted to interval type-2 fuzzy numbers using the linguistic terms for the criteria weights depicted in Fig. 5. The criteria weights are calculated with the help of Eq. (8), and these values are given in Table 8. As shown in the interval type-2 fuzzy average weight matrix (Table 8), the criteria are ranked according to their importance as: total investment cost ($C_4$), operation and maintenance cost ($C_5$), job opportunities ($C_{14}$), flexibility ($C_3$), ELV policy ($C_{15}$), and so on.

**Table 8**
The interval type-2 fuzzy weights of each criterion.

| **Criterion** | | | $W_j^{U}$ | | | | | | $W_j^{L}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $w_{j1}^{U}$ | $w_{j2}^{U}$ | $w_{j3}^{U}$ | $w_{j4}^{U}$ | $h_1(W_j^{U})$ | $h_2(W_j^{U})$ | $w_{j1}^{L}$ | $w_{j2}^{L}$ | $w_{j3}^{L}$ | $w_{j4}^{L}$ | $h_1(W_j^{L})$ | $h_2(W_j^{L})$ |
| $C_1$ | 0.53 | 0.72 | 0.72 | 0.87 | 1 | 1 | 0.63 | 0.72 | 0.72 | 0.79 | 0.9 | 0.9 |
| $C_2$ | 0.57 | 0.75 | 0.75 | 0.88 | 1 | 1 | 0.66 | 0.75 | 0.75 | 0.82 | 0.9 | 0.9 |
| $C_3$ | 0.60 | 0.78 | 0.78 | 0.92 | 1 | 1 | 0.69 | 0.78 | 0.78 | 0.85 | 0.9 | 0.9 |
| $C_4$ | 0.83 | 0.95 | 0.95 | 0.98 | 1 | 1 | 0.89 | 0.95 | 0.95 | 0.97 | 0.9 | 0.9 |
| $C_5$ | 0.8 | 0.95 | 0.95 | 1 | 1 | 1 | 0.88 | 0.95 | 0.95 | 0.98 | 0.9 | 0.9 |
| $C_6$ | 0.57 | 0.73 | 0.73 | 0.87 | 1 | 1 | 0.65 | 0.73 | 0.73 | 0.8 | 0.9 | 0.9 |
| $C_7$ | 0.48 | 0.65 | 0.65 | 0.78 | 1 | 1 | 0.57 | 0.65 | 0.65 | 0.72 | 0.9 | 0.9 |
| $C_8$ | 0.45 | 0.58 | 0.58 | 0.7 | 1 | 1 | 0.52 | 0.58 | 0.58 | 0.64 | 0.9 | 0.9 |
| $C_9$ | 0.32 | 0.5 | 0.5 | 0.67 | 1 | 1 | 0.41 | 0.5 | 0.5 | 0.58 | 0.9 | 0.9 |
| $C_{10}$ | 0.18 | 0.3 | 0.3 | 0.45 | 1 | 1 | 0.24 | 0.3 | 0.3 | 0.38 | 0.9 | 0.9 |
| $C_{11}$ | 0.17 | 0.27 | 0.27 | 0.42 | 1 | 1 | 0.22 | 0.27 | 0.27 | 0.34 | 0.9 | 0.9 |
| $C_{12}$ | 0.25 | 0.37 | 0.37 | 0.52 | 1 | 1 | 0.31 | 0.37 | 0.37 | 0.44 | 0.9 | 0.9 |
| $C_{13}$ | 0.35 | 0.53 | 0.53 | 0.7 | 1 | 1 | 0.44 | 0.53 | 0.53 | 0.62 | 0.9 | 0.9 |
| $C_{14}$ | 0.7 | 0.85 | 0.85 | 0.93 | 1 | 1 | 0.78 | 0.85 | 0.85 | 0.89 | 0.9 | 0.9 |
| $C_{15}$ | 0.6 | 0.75 | 0.75 | 0.85 | 1 | 1 | 0.68 | 0.75 | 0.75 | 0.8 | 0.9 | 0.9 |

***Step 5.*** Total investment cost ($C_4$), operation and maintenance cost ($C_5$), traffic congestion ($C_7$), air emission ($C_9$), and noise pollution ($C_{10}$) are members of the set of cost criteria. The other 10 criteria are benefit type. The interval type-2 fuzzy normalized average decision matrix is presented in Table 9. It is constructed by using Eqs. (9)-(10). For example, the normalized average rating value of the alternative $A_1$ with respect to the benefit criterion $C_1$ is obtained as follows: $\tilde{n}_{11} = ((\frac{4.33}{9}, \frac{6.33}{9}, \frac{6.33}{9}, \frac{8.17}{9}; 1, 1), (\frac{5.33}{9}, \frac{6.33}{9}, \frac{6.33}{9}, \frac{7.25}{9}; 0.9, 0.9) =$ ((0.48, 0.7, 0.7, 0.91; 1, 1), (0.59, 0.7, 0.7, 0.81; 0.9, 0.9)), where $x_{1*}^{U} = x_{214}^{U} = 9$.

***Step 6.*** By using Eq. (11), the criteria weights (Table 8) and the normalized average rating values (Table 9) are utilized to calculate the interval type-2 fuzzy weighted normalized average decision matrix. The results of this step are presented in Table 10. For example, the weighted normalized average rating value of the first alternative with respect to the first criterion is calculated as follows: $\tilde{f}_{11} = \tilde{w}_1 \otimes \tilde{n}_{11} =$((0.53, 0.72, 0.72, 0.87; 1, 1), (0.63, 0.72, 0.72, 0.79; 0.9, 0.9)) $\otimes$ ((0.48, 0.7, 0.7, 0.91; 1, 1), (0.59, 0.7, 0.7, 0.81; 0.9, 0.9))= ((0.26, 0.5, 0.5, 0.79; 1, 1), (0.37, 0.58, 0.58, 0.87; 0.9, 0.9)).

**Table 9**
The interval type-2 fuzzy normalized average decision matrix.

| Criterion | Alternative | |
|---|---|---|
| | $A_1$ | $A_2$ |
| $C_1$ | ((0.48, 0.7, 0.7, 0.91; 1, 1), (0.59, 0.7, 0.7, 0.81; 0.9, 0.9)) | ((0.59, 0.81, 0.81, 1; 1, 1), (0.7, 0.81, 0.81, 0.91; 0.9, 0.9)) |
| $C_2$ | ((0.52, 0.72, 0.72, 0.91; 1, 1), (0.62, 0.72, 0.72, 0.81; 0.9, 0.9)) | ((0.67, 0.87, 0.87, 1; 1, 1), (0.77, 0.87, 0.87, 0.94; 0.9, 0.9)) |
| $C_3$ | ((0.27, 0.42, 0.42, 0.59; 1, 1), (0.35, 0.42, 0.42, 0.51; 0.9, 0.9)) | ((0.81, 0.95, 0.95, 1; 1, 1), (0.88, 0.95, 0.95, 0.97; 0.9, 0.9)) |
| $C_4$ | ((0.57, 0.67, 0.67, 0.85; 1, 1), (0.62, 0.67, 0.67, 0.75; 0.9, 0.9)) | ((0.56, 0.64, 0.64, 0.8; 1, 1), (0.6, 0.64, 0.64, 0.71; 0.9, 0.9)) |
| $C_5$ | ((0.48, 0.55, 0.55, 0.72; 1, 1), (0.51, 0.55, 0.55, 0.63; 0.9, 0.9)) | ((0.51, 0.6, 0.6, 0.81; 1, 1), (0.55, 0.6, 0.6, 0.69; 0.9, 0.9)) |
| $C_6$ | ((0.5, 0.67, 0.67, 0.83; 1, 1), (0.59, 0.67, 0.67, 0.75; 0.9, 0.9)) | ((0.36, 0.53, 0.53, 0.72; 1, 1), (0.45, 0.53, 0.53, 0.63; 0.9, 0.9)) |
| $C_7$ | ((0.28, 0.32, 0.32, 0.39; 1, 1), (0.3, 0.32, 0.32, 0.35; 0.9, 0.9)) | ((0.24, 0.29, 0.29, 0.39; 1, 1), (0.27, 0.29, 0.29, 0.33; 0.9, 0.9)) |
| $C_8$ | ((0.51, 0.75, 0.75, 0.96; 1, 1), (0.63, 0.75, 0.75, 0.85; 0.9, 0.9)) | ((0.33, 0.55, 0.55, 0.76; 1, 1), (0.44, 0.55, 0.55, 0.66; 0.9, 0.9)) |
| $C_9$ | ((0.5, 0.6, 0.6, 0.81; 1, 1), (0.54, 0.6, 0.6, 0.68; 0.9, 0.9)) | ((0.58, 0.69, 0.69, 0.93; 1, 1), (0.63, 0.69, 0.69, 0.79; 0.9, 0.9)) |
| $C_{10}$ | ((0.29, 0.38, 0.38, 0.57; 1, 1), (0.33, 0.38, 0.38, 0.46; 0.9, 0.9)) | ((0.38, 0.5, 0.5, 0.72; 1, 1), (0.43, 0.5, 0.5, 0.59; 0.9, 0.9)) |
| $C_{11}$ | ((0.48, 0.67, 0.67, 0.88; 1, 1), (0.57, 0.67, 0.67, 0.77; 0.9, 0.9)) | ((0.55, 0.79, 0.79, 1; 1, 1), (0.67, 0.79, 0.79, 0.89; 0.9, 0.9)) |
| $C_{12}$ | ((0.64, 0.85, 0.85, 1; 1, 1), (0.75, 0.85, 0.85, 0.92; 0.9, 0.9)) | ((0.62, 0.79, 0.79, 0.91; 1, 1), (0.71, 0.79, 0.79, 0.85; 0.9, 0.9)) |
| $C_{13}$ | ((0.52, 0.71, 0.71, 0.88; 1, 1), (0.62, 0.71, 0.71, 0.8; 0.9, 0.9)) | ((0.69, 0.87, 0.87, 0.98; 1, 1), (0.78, 0.87, 0.87, 0.92; 0.9, 0.9)) |
| $C_{14}$ | ((0.7, 0.87, 0.87, 0.95; 1, 1), (0.78, 0.87, 0.87, 0.91; 0.9, 0.9)) | ((0.77, 0.92, 0.92, 0.98; 1, 1), (0.84, 0.92, 0.92, 0.95; 0.9, 0.9)) |
| $C_{15}$ | ((0.6, 0.82, 0.82, 1; 1, 1), (0.71, 0.82, 0.82, 0.91; 0.9, 0.9)) | ((0.52, 0.74, 0.74, 0.92; 1, 1), (0.63, 0.74, 0.74, 0.83; 0.9, 0.9)) |
| **Criterion** | $A_3$ | $A_4$ |
| $C_1$ | ((0.59, 0.81, 0.81, 0.98; 1, 1), (0.7, 0.81, 0.81, 0.90; 0.90, 0.9)) | ((0.52, 0.74, 0.74, 0.94; 1, 1), (0.63, 0.74, 0.74, 0.84; 0.9, 0.9)) |
| $C_2$ | ((0.5, 0.69, 0.69, 0.85; 1, 1), (0.59, 0.69, 0.69, 0.77; 0.9, 0.9)) | ((0.5, 0.69, 0.69, 0.85; 1, 1), (0.59, 0.69, 0.69, 0.77; 0.9, 0.9)) |
| $C_3$ | ((0.05, 0.17, 0.17, 0.37; 1, 1), (0.11, 0.17, 0.17, 0.27; 0.9, 0.9)) | ((0.31, 0.46, 0.46, 0.63; 1, 1), (0.38, 0.46, 0.46, 0.54; 0.9, 0.9)) |
| $C_4$ | ((0.56, 0.68, 0.68, 0.93; 1, 1), (0.62, 0.68, 0.68, 0.79; 0.9, 0.9)) | ((0.61, 0.74, 0.74, 1; 1, 1), (0.67, 0.74, 0.74, 0.85; 0.9, 0.9)) |
| $C_5$ | ((0.51, 0.62, 0.62, 0.87; 1, 1), (0.56, 0.62, 0.62, 0.72; 0.9, 0.9)) | ((0.54, 0.68, 0.68, 1; 1, 1), (0.6, 0.68, 0.68, 0.81; 0.9, 0.9)) |
| $C_6$ | ((0.48, 0.69, 0.69, 0.86; 1, 1), (0.59, 0.69, 0.69, 0.78; 0.9, 0.9)) | ((0.72, 0.9, 0.9, 1; 1, 1), (0.81, 0.9, 0.9, 0.95; 0.9, 0.9)) |
| $C_7$ | ((0.24, 0.28, 0.28, 0.38; 1, 1), (0.26, 0.28, 0.28, 0.32; 0.9, 0.9)) | ((0.44, 0.67, 0.67, 1; 1, 1), (0.53, 0.67, 0.67, 0.8; 0.9, 0.9)) |
| $C_8$ | ((0.41, 0.61, 0.61, 0.78; 1, 1), (0.51, 0.61, 0.61, 0.7; 0.9, 0.9)) | ((0.65, 0.84, 0.84, 1; 1, 1), (0.75, 0.84, 0.84, 0.92; 0.9, 0.9)) |
| $C_9$ | ((0.58, 0.71, 0.71, 1; 1, 1), (0.64, 0.71, 0.71, 0.83; 0.9, 0.9)) | ((0.49, 0.58, 0.58, 0.78; 1, 1), (0.53, 0.58, 0.58, 0.67; 0.9, 0.9)) |
| $C_{10}$ | ((0.36, 0.54, 0.54, 1; 1, 1), (0.43, 0.54, 0.54, 0.7; 0.9, 0.9)) | ((0.31, 0.43, 0.43, 0.72; 1, 1), (0.36, 0.43, 0.43, 0.54; 0.9, 0.9)) |
| $C_{11}$ | ((0.1, 0.24, 0.24, 0.48; 1, 1), (0.17, 0.24, 0.24, 0.36; 0.9, 0.9)) | ((0.38, 0.6, 0.6, 0.83; 1, 1), (0.49, 0.6, 0.6, 0.71; 0.9, 0.9)) |
| $C_{12}$ | ((0.42, 0.57, 0.57, 0.72; 1, 1), (0.49, 0.57, 0.57, 0.64; 0.9, 0.9)) | ((0.58, 0.74, 0.74, 0.85; 1, 1), (0.66, 0.74, 0.74, 0.79; 0.9, 0.9)) |
| $C_{13}$ | ((0.69, 0.88, 0.88, 1; 1, 1), (0.79, 0.88, 0.88, 0.94; 0.9, 0.9)) | ((0.62, 0.83, 0.83, 0.98; 1, 1), (0.72, 0.83, 0.83, 0.9; 0.9, 0.9)) |
| $C_{14}$ | ((0.83, 0.97, 0.97, 1; 1, 1), (0.9, 0.97, 0.97, 0.98; 0.9, 0.9)) | ((0.67, 0.85, 0.85, 0.97; 1, 1), (0.76, 0.85, 0.85, 0.91; 0.9, 0.9)) |
| $C_{15}$ | ((0.56, 0.78, 0.78, 0.96; 1, 1), (0.67, 0.78, 0.78, 0.87; 0.9, 0.9)) | ((0.52, 0.74, 0.74, 0.92; 1, 1), (0.63, 0.74, 0.74, 0.83; 0.9, 0.9)) |

**Table 10**
The interval type-2 fuzzy weighted normalized average decision matrix.

| Criterion | Alternative | |
|---|---|---|
| | $A_1$ | $A_2$ |
| $C_1$ | ((0.26, 0.5, 0.5, 0.79; 1, 1), (0.37, 0.5, 0.5, 0.64; 0.9, 0.9)) | ((0.32, 0.58, 0.58, 0.87; 1, 1), (0.44, 0.58, 0.58, 0.72; 0.9, 0.9)) |
| $C_2$ | ((0.29, 0.54, 0.54, 0.8; 1, 1), (0.41, 0.54, 0.54, 0.67; 0.9, 0.9)) | ((0.38, 0.65, 0.65, 0.88; 1, 1), (0.51, 0.65, 0.65, 0.76; 0.9, 0.9)) |
| $C_3$ | ((0.16, 0.33, 0.33, 0.54; 1, 1), (0.24, 0.33, 0.33, 0.43; 0.9, 0.9)) | ((0.49, 0.74, 0.74, 0.92; 1, 1), (0.61, 0.74, 0.74, 0.83; 0.9, 0.9)) |
| $C_4$ | ((0.48, 0.63, 0.63, 0.83; 1, 1), (0.55, 0.63, 0.63, 0.72; 0.9, 0.9)) | ((0.47, 0.6, 0.6, 0.79; 1, 1), (0.53, 0.6, 0.6, 0.69; 0.9, 0.9)) |
| $C_5$ | ((0.39, 0.53, 0.53, 0.72; 1, 1), (0.45, 0.53, 0.53, 0.61; 0.9, 0.9)) | ((0.41, 0.57, 0.57, 0.81; 1, 1), (0.48, 0.57, 0.57, 0.68; 0.9, 0.9)) |
| $C_6$ | ((0.28, 0.49, 0.49, 0.72; 1, 1), (0.38, 0.49, 0.49, 0.60; 0.9, 0.9)) | ((0.21, 0.39, 0.39, 0.63; 1, 1), (0.29, 0.39, 0.39, 0.5; 0.9, 0.9)) |
| $C_7$ | ((0.13, 0.21, 0.21, 0.3; 1, 1), (0.17, 0.21, 0.21, 0.25; 0.9, 0.9)) | ((0.12, 0.19, 0.19, 0.3; 1, 1), (0.15, 0.19, 0.19, 0.24; 0.9, 0.9)) |
| $C_8$ | ((0.23, 0.43, 0.43, 0.67; 1, 1), (0.32, 0.43, 0.43, 0.55; 0.9, 0.9)) | ((0.15, 0.32, 0.32, 0.54; 1, 1), (0.23, 0.32, 0.32, 0.42; 0.9, 0.9)) |
| $C_9$ | ((0.16, 0.3, 0.3, 0.54; 1, 1), (0.22, 0.3, 0.3, 0.4; 0.9, 0.9)) | ((0.18, 0.35, 0.35, 0.62; 1, 1), (0.26, 0.35, 0.35, 0.46; 0.9, 0.9)) |
| $C_{10}$ | ((0.05, 0.11, 0.11, 0.25; 1, 1), (0.08, 0.11, 0.11, 0.17; 0.9, 0.9)) | ((0.07, 0.15, 0.15, 0.33; 1, 1), (0.1, 0.15, 0.15, 0.22; 0.9, 0.9)) |
| $C_{11}$ | ((0.08, 0.18, 0.18, 0.37; 1, 1), (0.12, 0.18, 0.18, 0.26; 0.9, 0.9)) | ((0.09, 0.21, 0.21, 0.42; 1, 1), (0.14, 0.21, 0.21, 0.31; 0.9, 0.9)) |
| $C_{12}$ | ((0.16, 0.31, 0.31, 0.52; 1, 1), (0.23, 0.31, 0.31, 0.41; 0.9, 0.9)) | ((0.16, 0.29, 0.29, 0.47; 1, 1), (0.22, 0.29, 0.29, 0.38; 0.9, 0.9)) |
| $C_{13}$ | ((0.18, 0.38, 0.38, 0.62; 1, 1), (0.27, 0.38, 0.38, 0.49; 0.9, 0.9)) | ((0.24, 0.46, 0.46, 0.69; 1, 1), (0.34, 0.46, 0.46, 0.57; 0.9, 0.9)) |
| $C_{14}$ | ((0.49, 0.74, 0.74, 0.89; 1, 1), (0.61, 0.74, 0.74, 0.81; 0.9, 0.9)) | ((0.54, 0.78, 0.78, 0.92; 1, 1), (0.65, 0.78, 0.78, 0.85; 0.9, 0.9)) |
| $C_{15}$ | ((0.36, 0.62, 0.62, 0.85; 1, 1), (0.48, 0.62, 0.62, 0.73; 0.9, 0.9)) | ((0.31, 0.56, 0.56, 0.78; 1, 1), (0.43, 0.56, 0.56, 0.66; 0.9, 0.9)) |
| **Criterion** | $A_3$ | $A_4$ |
| $C_1$ | ((0.32, 0.58, 0.58, 0.85; 1, 1), (0.44, 0.58, 0.58, 0.71; 0.9, 0.9)) | ((0.28, 0.53, 0.53, 0.82; 1, 1), (0.39, 0.53, 0.53, 0.67; 0.9, 0.9)) |
| $C_2$ | ((0.28, 0.51, 0.51, 0.75; 1, 1), (0.39, 0.51, 0.51, 0.63; 0.9, 0.9)) | ((0.28, 0.51, 0.51, 0.75; 1, 1), (0.39, 0.51, 0.51, 0.63; 0.9, 0.9)) |
| $C_3$ | ((0.03, 0.13, 0.13, 0.34; 1, 1), (0.08, 0.13, 0.13, 0.23; 0.9, 0.9)) | ((0.18, 0.36, 0.36, 0.57; 1, 1), (0.26, 0.36, 0.36, 0.46; 0.9, 0.9)) |
| $C_4$ | ((0.47, 0.65, 0.65, 0.92; 1, 1), (0.55, 0.65, 0.65, 0.76; 0.9, 0.9)) | ((0.51, 0.7, 0.7, 0.98; 1, 1), (0.59, 0.7, 0.7, 0.82; 0.9, 0.9)) |
| $C_5$ | ((0.41, 0.59, 0.59, 0.87; 1, 1), (0.49, 0.59, 0.59, 0.7; 0.9, 0.9)) | ((0.43, 0.65, 0.65, 1; 1, 1), (0.53, 0.65, 0.65, 0.79; 0.9, 0.9)) |
| $C_6$ | ((0.27, 0.51, 0.51, 0.75; 1, 1), (0.38, 0.51, 0.51, 0.62; 0.9, 0.9)) | ((0.41, 0.66, 0.66, 0.87; 1, 1), (0.53, 0.66, 0.66, 0.76; 0.9, 0.9)) |
| $C_7$ | ((0.11, 0.18, 0.18, 0.29; 1, 1), (0.14, 0.18, 0.18, 0.23; 0.9, 0.9)) | ((0.21, 0.43, 0.43, 0.78; 1, 1), (0.3, 0.43, 0.43, 0.57; 0.9, 0.9)) |
| $C_8$ | ((0.19, 0.35, 0.35, 0.55; 1, 1), (0.26, 0.35, 0.35, 0.45; 0.9, 0.9)) | ((0.29, 0.49, 0.49, 0.7; 1, 1), (0.38, 0.49, 0.49, 0.59; 0.9, 0.9)) |
| $C_9$ | ((0.18, 0.36, 0.36, 0.67; 1, 1), (0.26, 0.36, 0.36, 0.49; 0.9, 0.9)) | ((0.16, 0.29, 0.29, 0.52; 1, 1), (0.22, 0.29, 0.29, 0.39; 0.9, 0.9)) |
| $C_{10}$ | ((0.07, 0.16, 0.16, 0.45; 1, 1), (0.1, 0.16, 0.16, 0.26; 0.9, 0.9)) | ((0.06, 0.13, 0.13, 0.33; 1, 1), (0.09, 0.13, 0.13, 0.2; 0.9, 0.9)) |
| $C_{11}$ | ((0.02, 0.06, 0.06, 0.2; 1, 1), (0.04, 0.06, 0.06, 0.12; 0.9, 0.9)) | ((0.06, 0.16, 0.16, 0.35; 1, 1), (0.11, 0.16, 0.16, 0.24; 0.9, 0.9)) |
| $C_{12}$ | ((0.1, 0.21, 0.21, 0.37; 1, 1), (0.15, 0.21, 0.21, 0.28; 0.9, 0.9)) | ((0.15, 0.27, 0.27, 0.44; 1, 1), (0.2, 0.27, 0.27, 0.35; 0.9, 0.9)) |
| $C_{13}$ | ((0.24, 0.47, 0.47, 0.7; 1, 1), (0.35, 0.47, 0.47, 0.58; 0.9, 0.9)) | ((0.22, 0.44, 0.44, 0.69; 1, 1), (0.32, 0.44, 0.44, 0.56; 0.9, 0.9)) |
| $C_{14}$ | ((0.58, 0.82, 0.82, 0.93; 1, 1), (0.7, 0.82, 0.82, 0.88; 0.9, 0.9)) | ((0.47, 0.72, 0.72, 0.9; 1, 1), (0.59, 0.72, 0.72, 0.81; 0.9, 0.9)) |
| $C_{15}$ | ((0.34, 0.59, 0.59, 0.82; 1, 1), (0.45, 0.59, 0.59, 0.7; 0.9, 0.9)) | ((0.31, 0.56, 0.56, 0.78; 1, 1), (0.43, 0.56, 0.56, 0.66; 0.9, 0.9)) |

***Step 7.*** The interval type-2 optimality functions of benefit and cost criteria in terms of alternatives are calculated based on Table 10 and with the help of Eqs. (12)-(13). These values can be found in Table 11. For example, the optimality function $p_{i1*}^U$ of $A_1$ for the benefit criteria is 0.257+0.294+0.163+0.283+0.229+0.079+0.160+0.182+0.490+0.360=2.5. On the other hand, the optimality function $p_{i1-}^U$ of $A_1$ for the cost criteria is 0.476+0.385+0.135+0.158+0.053=1.21.

**Table 11**
The interval type-2 optimality functions of the benefit and cost criteria of the alternatives.

| Alternative | $P_{i*}^U$ | | | | | | $P_{i*}^L$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $p_{i1*}^U$ | $p_{i2*}^U$ | $p_{i3*}^U$ | $p_{i4*}^U$ | $h_1(P_{i*}^U)$ | $h_2(P_{i*}^U)$ | $p_{i1*}^L$ | $p_{i2*}^L$ | $p_{i3*}^L$ | $p_{i4*}^L$ | $h_1(P_{i*}^L)$ | $h_2(P_{i*}^L)$ |
| $A_1$ | 2.5 | 4.53 | 4.53 | 6.76 | 1 | 1 | 3.44 | 4.53 | 4.53 | 5.59 | 0.9 | 0.9 |
| $A_2$ | 2.88 | 4.99 | 4.99 | 7.1 | 1 | 1 | 3.86 | 4.99 | 4.99 | 6 | 0.9 | 0.9 |
| $A_3$ | 2.37 | 4.24 | 4.24 | 6.26 | 1 | 1 | 3.24 | 4.24 | 4.24 | 5.2 | 0.9 | 0.9 |
| $A_4$ | 2.65 | 4.7 | 4.7 | 6.87 | 1 | 1 | 3.6 | 4.7 | 4.7 | 5.73 | 0.9 | 0.9 |
| **Alternative** | $P_{i-}^U$ | | | | | | $P_{i-}^L$ | | | | | |
| | $p_{i1-}^U$ | $p_{i2-}^U$ | $p_{i3-}^U$ | $p_{i4-}^U$ | $h_1(P_{i-}^U)$ | $h_2(P_{i-}^U)$ | $p_{i1-}^L$ | $p_{i2-}^L$ | $p_{i3-}^L$ | $p_{i4-}^L$ | $h_1(P_{i-}^L)$ | $h_2(P_{i-}^L)$ |
| $A_1$ | 1.21 | 1.78 | 1.78 | 2.65 | 1 | 1 | 1.47 | 1.78 | 1.78 | 2.15 | 0.9 | 0.9 |
| $A_2$ | 1.25 | 1.87 | 1.87 | 2.84 | 1 | 1 | 1.53 | 1.87 | 1.87 | 2.28 | 0.9 | 0.9 |
| $A_3$ | 1.24 | 1.94 | 1.94 | 3.19 | 1 | 1 | 1.55 | 1.94 | 1.94 | 2.45 | 0.9 | 0.9 |
| $A_4$ | 1.37 | 2.2 | 2.2 | 3.61 | 1 | 1 | 1.73 | 2.2 | 2.2 | 2.78 | 0.9 | 0.9 |

***Step 8.*** The interval type-2 utility degrees of the benefit and cost criteria of each alternative are given in Table 12. They are determined by using the interval type-2 optimality functions of the benefit and cost criteria of the alternatives (Table 11) with the help of Eqs. (14)-(15).

**Table 12**
The interval type-2 utility degrees of the benefit and cost criteria of the alternatives.

| Alternative | $R_{i*}^U$ | | | | | | $R_{i*}^L$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $r_{i1*}^U$ | $r_{i2*}^U$ | $r_{i3*}^U$ | $r_{i4*}^U$ | $h_1(R_{i*}^U)$ | $h_2(R_{i*}^U)$ | $r_{i1*}^L$ | $r_{i2*}^L$ | $r_{i3*}^L$ | $r_{i4*}^L$ | $h_1(R_{i*}^L)$ | $h_2(R_{i*}^L)$ |
| $A_1$ | 0.35 | 0.64 | 0.64 | 0.95 | 1 | 1 | 0.48 | 0.64 | 0.64 | 0.79 | 0.9 | 0.9 |
| $A_2$ | 0.4 | 0.7 | 0.7 | 1 | 1 | 1 | 0.54 | 0.7 | 0.7 | 0.84 | 0.9 | 0.9 |
| $A_3$ | 0.33 | 0.6 | 0.6 | 0.88 | 1 | 1 | 0.46 | 0.6 | 0.6 | 0.73 | 0.9 | 0.9 |
| $A_4$ | 0.37 | 0.66 | 0.66 | 0.97 | 1 | 1 | 0.51 | 0.66 | 0.66 | 0.81 | 0.9 | 0.9 |
| **Alternative** | $R_{i-}^U$ | | | | | | $R_{i-}^L$ | | | | | |
| | $r_{i1-}^U$ | $r_{i2-}^U$ | $r_{i3-}^U$ | $r_{i4-}^U$ | $h_1(R_{i-}^U)$ | $h_2(R_{i-}^U)$ | $r_{i1-}^L$ | $r_{i2-}^L$ | $r_{i3-}^L$ | $r_{i4-}^L$ | $h_1(R_{i-}^L)$ | $h_2(R_{i-}^L)$ |
| $A_1$ | 0.46 | 0.68 | 0.68 | 1 | 1 | 1 | 0.56 | 0.68 | 0.68 | 0.82 | 0.9 | 0.9 |
| $A_2$ | 0.42 | 0.65 | 0.65 | 0.97 | 1 | 1 | 0.53 | 0.65 | 0.65 | 0.79 | 0.9 | 0.9 |
| $A_3$ | 0.38 | 0.62 | 0.62 | 0.97 | 1 | 1 | 0.49 | 0.62 | 0.62 | 0.78 | 0.9 | 0.9 |
| $A_4$ | 0.33 | 0.55 | 0.55 | 0.88 | 1 | 1 | 0.43 | 0.55 | 0.55 | 0.7 | 0.9 | 0.9 |

***Step 9.*** The interval type-2 utility degrees of the benefit and cost criteria of each alternative

are defuzzified by using Eq. (16) and Eq. (17), respectively. The obtained crisp values are presented in Table 13. For example, the defuzzified values of the utility degree of benefit ($D_i^*$) and cost criteria ($D_i^-$) of $A_1$ are computed as follows:

$$D_1^* = [\frac{0.35+0.95}{2} + \frac{1+1+0.9+0.9}{4}]\frac{0.35+0.64+0.64+0.95+0.48+0.64+0.64+0.79}{8} = 1.026,$$

$$D_1^- = [\frac{0.46+1}{2} + \frac{1+1+0.9+0.9}{4}]\frac{0.46+0.68+0.68+1+0.56+0.68+0.68+0.82}{8} = 1.166.$$

**Table 13**
The defuzzified values of the utility degree of benefit and cost criteria, appraisal score, normalized appraisal score, and the ranking of the alternatives.

| Alternative | $D_i^*$ | $D_i^-$ | $Q_i$ | $\Theta_i$ | Rank |
|---|---|---|---|---|---|
| $A_1$ – Kucukcekmece | 1.026 | 1.166 | 1.096 | 0.975 | 2 |
| $A_2$ – Esenyurt | 1.157 | 1.09 | 1.124 | 1.0 | 1 |
| $A_3$ – Bagcilar | 0.933 | 1.041 | 0.987 | 0.878 | 3 |
| $A_4$ – Pendik | 1.074 | 0.885 | 0.979 | 0.871 | 4 |

***Steps 10-11.*** The appraisal scores of the four analyzed alternatives are provided in Table 13. They are calculated based on Eq. (18). Then, the appraisal score values are normalized by using Eq. (19). For example, the appraisal score of $A_1$ is $Q_1$=(1.026+1.166)/2=1.096, and its normalized appraisal score is $\Theta_1$=1.096/1.124=0.975.

***Step 12.*** The alternatives are ranked according to the decreasing value of the normalized appraisal score (Table 13). The ranking order of four analyzed alternatives is Esenyurt>Kucukcekmece>Bagcilar>Pendik. Therefore, according to the proposed interval type-2 fuzzy ARAS method, "Esenyurt" is the best alternative for opening the new ELV recycling facility in Istanbul.

Applicability and flexibility of the proposed interval type-2 fuzzy ARAS method were tested by comparing the results of this novel method with the results of the three other interval type-2 fuzzy sets based MCDM approaches, which are the interval type-2 fuzzy EDAS method [75], the interval type-2 fuzzy WASPAS method [76], and the interval type-2 fuzzy COPRAS method [77].

Fig. 6 shows the results of the rankings. According to the presented results, $A_2$ was selected as the best alternative by three methods. The rankings of the considered interval type-2 fuzzy set based MCDM methods are: ARAS ($A_2$>$A_1$>$A_3$>$A_4$), EDAS ($A_2$>$A_1$>$A_4$>$A_3$), WASPAS ($A_2$>$A_1$>$A_4$>$A_3$), and COPRAS ($A_1$>$A_2$>$A_3$>$A_4$).

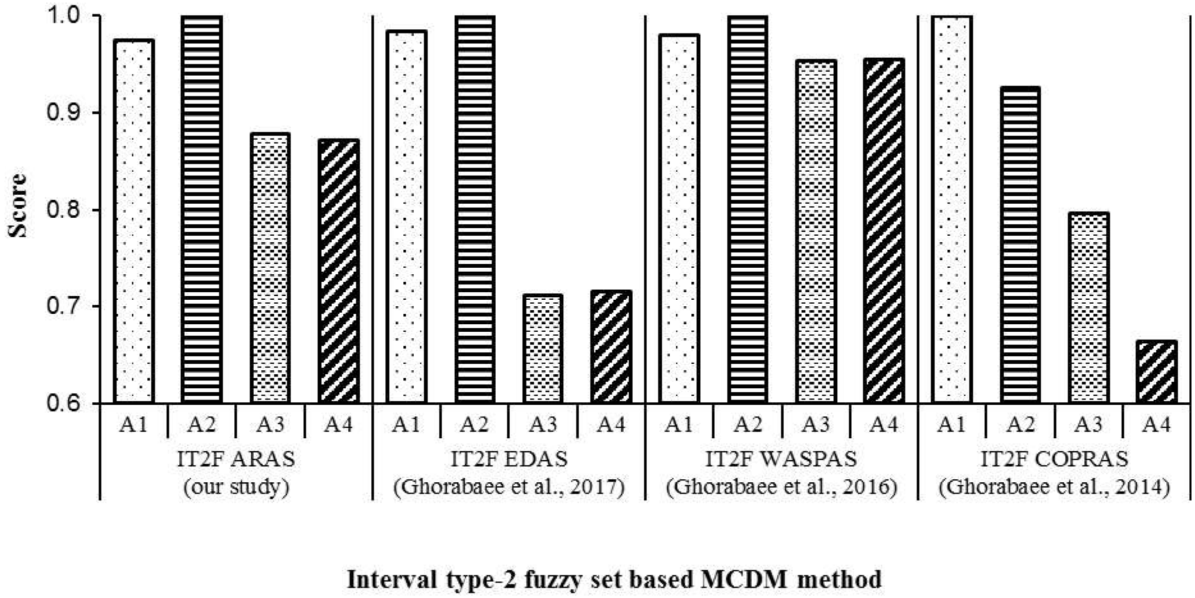


**Fig. 6.** The ranking of alternatives for the new ELV recycling facility in Istanbul.

Table 14 gives the ranking and score results of the considered interval type-2 fuzzy set based MCDM methods. According to Table 14, it can be identified that the most preferred alternative is $A_2$ (Esenyurt), and then the alternative $A_1$ (Kucukcekmece). However, the interval type-2 fuzzy COPRAS method selects "Kucukcekmece" as the best alternative. This method compares the alternatives based on their degree of cost and benefit. The interval type-2 fuzzy EDAS and WASPAS methods put alternatives $A_4$ (Pendik) and $A_3$ (Bagcilar) in the third and fourth place. The WASPAS method combines the results of weighted sum and weighted product to rank the alternatives, while the similarity ratio technique was improved in the EDAS method to rank the alternatives.

**Table 14**
The scores and ranking of the alternatives for the considered interval type-2 fuzzy set based MCDM methods.

| Method | | Alternative | | | |
|---|---|---|---|---|---|
| | | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
| **IT2F ARAS** (our study) | Score | 0.975 | 1.0 | 0.878 | 0.871 |
| | Rank | 2 | 1 | 3 | 4 |
| **IT2F EDAS** [75] | Score | 0.984 | 1.0 | 0.712 | 0.715 |
| | Rank | 2 | 1 | 4 | 3 |
| **IT2F WASPAS** [76] | Score | 0.98 | 1.0 | 0.954 | 0.955 |
| | Rank | 2 | 1 | 4 | 3 |
| **IT2F COPRAS** [77] | Score | 1.0 | 0.925 | 0.796 | 0.664 |
| | Rank | 1 | 2 | 3 | 4 |

Interval type-2 fuzzy: IT2F.

Table 15 presents Spearman's correlation coefficients between four interval type-2 fuzzy MCDM methods. These values were calculated to check the similarity between different ranking methods. According to Table 15, Spearman's correlation coefficients between our method and three existing methods are equal to 0.8. Since the proposed interval type-2 fuzzy ARAS method has a similarity of 80% with all other interval type-2 fuzzy set based MCDM methods, it can be outlined that a very strong correlation exists. Accordingly, the results of the developed interval type-2 fuzzy ARAS method are consistent with the available methods.

**Table 15**
Ranking similarity for the considered interval type-2 fuzzy set based MCDM methods.

| **Method** | IT2F ARAS | IT2F EDAS | IT2F WASPAS | IT2F COPRAS |
|---|---|---|---|---|
| IT2F ARAS (our study) | – | **0.8** | **0.8** | **0.8** |
| IT2F EDAS [75] | | – | 1 | 0.6 |
| IT2F WASPAS [76] | | | – | 0.6 |
| IT2F COPRAS [77] | | | | – |

Interval type-2 fuzzy: IT2F.

In Istanbul, ELV recycling facilities are mainly located on the Anatolian side, whereas Esenyurt is a county located on the European side (Fig. 4). Furthermore, high industrialization, high and technical qualified population, closeness to the ports, logistics convenience, and many other reasons support that $A_2$ (Esenyurt) should be selected as the best alternative for opening the new ELV recycling facility. This result was reviewed and analyzed by the experts who were involved in the study and its consistency was approved once more. Finally, this study demonstrated that the combination of the ARAS method and interval type-2 fuzzy sets produces successful and consistent results.

## 6. Conclusions

This study aims to propose an extension of the ARAS method based on a novel interval type-2 fuzzy set for solving the location selection problem of a recycling facility in Turkey. The proposed approach consists of three phases as follows: (i) identify various siting criteria for end-of-life vehicles, (ii) present a solution model for site selection problem, and (iii) compare existing methods with the proposed model.

Future research can be divided into several directions. The first one is the integration of the ANP method into the presented decision-making framework to determine the interdependencies among criteria and sub-criteria. On the other hand, interval intuitionistic type-2 fuzzy sets can be used to represent even more complex uncertainties which exist in real-life waste management problems, because they have different infrastructure and characteristics. For instance, intuitionistic fuzzy sets have a degree of membership and nonmembership. Finally, the developed interval type-2 fuzzy ARAS method can also be applied to many other MCDM problems such as personnel, technology, supplier, and material selection, and so on.

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