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Neutrosophic Fuzzy Selected Element Reduction Approach (NF-SERA) : Assessment of E-scooter Parking Area

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***Abstract*— Along with awareness of global warming, there have been many developments in recent years on carbon emissions in transportation. The use of micromobility vehicles has become widespread due to reasons such as energy saving, reducing carbon footprint and reducing traffic density in urban transportation. Although there are useful applications, this new concept has brought with it some problems. It is clear that new regulations are needed on issues such as accessibility, parking areas, security, charging stations, city planning etc. and the big cities need to adapt. Therefore, the carbon neutral districts have been started to be tested in small areas in many parts of the world and their effects are observed. This study performs Selected Element Reduction Approach (SERA), which is a Multi Criteria Decision Making (MCDM) criterion weighting method to determine the weight of the criteria to be used to assess the parking area of e-scooters in carbon neutral areas. SERA is a fuzzy environment MCDM method that aims to give weight to the criterion by the absence effect, which occurs by subtracting the criteria from the general evaluation. In this study, SERA is extended for the first time with single-valued neutrosophic fuzzy sets (SVNFS), which is a three-dimensional fuzzy environment. This study contributes to the literature by analyzing the application of NF-SERA with a numerical example. It also assesses the criteria for the e-scooter parking case for the carbon neutral areas that are currently discussed in the sustainable urban transportation literature.**

Keywords—Selected Element Reduction Approach, Single-Valued Neutrosophic Fuzzy Sets, Criteria Weighting, Multi Criteria Decision Making, Fuzzy Set Theory, E-scooter, Mobility.

I. Introduction

Smart and sustainable cities are urban areas that use technology and innovation to improve the quality of life of their residents and to reduce their environmental impact [1]. They use a variety of strategies and technologies to achieve these goals, including energy efficiency, transportation, resource management and data management. In this sense, Mobility as a Service (MaaS) is a concept that involves the integration of different modes of transportation, including public transportation, private transportation, and shared mobility, into a single, seamless system that is accessed through a single platform or service. Micromobility vehicles, such as electric scooters and electric bikes, can be an important component of Mobility as a Service (MaaS) systems. Micromobility vehicles can provide a convenient and efficient way for people to get around in urban areas, particularly for short trips or for the "last mile" of a journey [2]. Formally, micromobility refers to small, lightweight, and low-speed vehicles that are designed for short distance travel. Some examples of micromobility vehicles include electric scooters, electric bikes, and electric skateboards. These vehicles are often used as an alternative to traditional modes of transportation such as cars, buses, and trains, particularly in urban areas where they can be used for short trips to get around the city. Micromobility vehicles are often favored for their convenience, flexibility, and environmentally friendly nature. However, there have been some challenges associated with the growth of micromobility, such as the need to address safety concerns and to ensure that the vehicles are properly maintained and parking and charging areas managed [3-4]. There have also been regulatory challenges, as the government has had to develop new policies and regulations to govern the use of micromobility vehicles in the city. For the right policy, problems can be overcome by making evaluations on alternatives. To assess the alternatives in urban transportation, there are numerous expert opinion-based decision making techniques in the literature. Many of them carried out their work in an environment of uncertainty.

The integration of human nature into mathematical models became possible with the fuzzy set theory introduced by Zadeh [5] in 1965. According to Zadeh's idea, an element's belonging to a set does not have to be exact expressions such as 0 or 1. Membership can be expressed with a belonging in the range of 0 and 1. In this way, fuzzy sets have begun to occupy a large space in the literature to convey incomplete, ambiguous or uncertain expressions and situations. In 1986, Zadeh's theory was expanded by Atanassov [6] with the addition of non-membership to the definition. Atanassov predicted that in addition to belonging to the set, the fact that the element does not belong to the set open a new dimension in linguistic expression. Then, in 1999, Smarandrache [7] presented neutrosophic fuzzy sets and included the existence of the third dimension of uncertainty to fuzzy sets. A large number of fuzzy sets (such as Pythagorean, spherical, hesitant, picture etc.) have been described in the literature so far, and each of them contributes to research in expressing vagueness in different fields. Fuzzy sets are helpful for the uncertainty in human nature and the transfer of linguistic expressions in decision making and evaluation studies. Therefore, fuzzy set extensions have been studied in numerous multi-criteria decision making techniques.

Here are some relevant studies in the literature on micromobility problems in an environment of uncertainty. Deveci et al. evaluate the safety of e-scooter parking operations by fuzzy Dombi based RAFSI model [8] and q-rung orthopair Fuzzy Einstein based WASPAS approach [9]. Altay et al. [10] selected location for e-scooter sharing stations for a university campus by an integrated interval type-2 fuzzy BWM-MARCOS model. Ayyıldız [11] evaluate locations for e-scooter charging station location-selection via new pythagorean fuzzy MCDM. Podesta [12] performed a decision support tool to identify shared mobility hub locations in Amsterdam. Weinreich [13] stressed on bike sharing traffic pattern prediction from urban environment data of New York City.

The main contribution of this study is to demonstrate the new extension of SERA, which is presented as a criterion weighting method, with single-valued neutrosophic fuzzy sets. The SERA has been introduced to the literature as a criterion weighting methodology in fuzzy environment by the authors of this paper and it was stated that it would be adapted to all fuzzy sets [17-18-19]. On the other hand, the evaluation of e-scooter parking areas in carbon neutral district, which is carried out as a numerical example, is a current issue in the sustainable urban transportation literature. The problem of determining the parking area of micromobility devices, which have become widespread in cities in order to reduce carbon gas emissions and prevent traffic congestion, is quite important. For this evaluation, which may depend on many criteria, SERA is a suitable MCDM methodology to determine how important the criteria are by extracting criteria one by one from the whole evaluation, and then to obtain the absence effect. In addition, the scope of linguistic expressions has been expanded with the support of a three-dimensional fuzzy numbers called single-valued neutrosophic fuzzy sets.

This paper is organized as follows: Section 2 gives preliminaries and some definitions on the single-valued neutrosophic fuzzy sets (SVNFS) and introduces the Selected Element Reduction Approach (SERA). In Section 3 the numerical case of assessment of e-scooter parking area is performed by proposed NF-SERA. The last section concludes the research with future studies.

II. Proposed Model

This section gives some preliminary information on the single-valued neutrosophic fuzzy sets (SVNFS), followed by the Selected Element Reduction Approach (SERA) developed to weight criteria for MCDM problems.

A. Single-Valued Neutrosohic Fuzzy Sets

After Zadeh [5] introduced ordinary fuzzy sets in 1965; Atanassov [6] expanded the definition to include non-membership as intuitionistic fuzzy set in 1986. Later in 1999, Smarandrache [7] represented neutrosophic sets to the literature, expressing uncertain, incomplete and indeterminate information as a new fuzzy set.

The preliminaries and some definitions of the single-valued neutrosophic fuzzy sets are given [14-15-16] as follows.

Definition 1: Let X be a space of points (objects) and the generic element in X is denoted by x; $A=\{< x: T_A(x), I_A(x), F_A(x) >, x \in X\}$ is the form of an object that is the neutrosophic set A , where the functions T, I, F: x → $]^-0, 1^+[$ define respectively the truth-membership function, an indeterminacy-membership function and a falsity-membership function of the element x ∈ X to the set A with condition:

$$^-0 \le T_A(x) + I_A(x) + F_A(x) \le 3^+ \quad (1)$$

The function $T_A(x), I_A(x)$ and $F_A(x)$ are real standard or non-standard subset of $]^-0, 1^+[$.

Definition 2: Let X be a space of points (objects) and the generic element in X is denoted by x. A single-valued neutrosophic set A is characterized by truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$. $T_A(x), I_A(x), F_A(x) \in [0,1]$ for each point x in X. A single-valued neutrosophic fuzzy number A is written as $A=\{< x: T_A(x), I_A(x), F_A(x) >, x \in X\}$.

Definition 3: Let $\widetilde{A}_1 = (T_1, I_1, F_1)$ and $\widetilde{A}_2 = (T_2, I_2, F_2)$ be two single valued neutrosophic number. Then, the operations of two single valued neutrosophic numbers are defined as follows:

$$\lambda\widetilde{A}_1 =< 1-(1- T_1)^{\lambda}, (I_1)^{\lambda}, (F_1)^{\lambda} > \quad (2)$$

$$\widetilde{A}_1^{\lambda} = (\widetilde{T}_1^{\lambda}, 1-(1- I_1)^{\lambda}, 1-(1- F_1)^{\lambda}) \quad (3)$$

$$\widetilde{A}_1 \oplus \widetilde{A}_2 =< T_1+T_2 - T_1T_2, I_1I_2, F_1F_2 > \quad (4)$$

$$\widetilde{A}_1 \otimes \widetilde{A}_2 =< T_1T_2, I_1+I_2-I_1I_2, F_1+F_2-F_1F_2 > \quad (5)$$

where λ>0.

Definition 4: 0_n may be defined as 0_n = {<x, (0, 1, 1)>: x ∈ X }. A useful approach for comparing two single-valued neutrosophic numbers is the use of a score function.

Definition 5: Let $\{\widetilde{A}_1, \widetilde{A}_2, \dots, \widetilde{A}_n\}$be the set of n single-valued neutrosophic fuzzy numbers, where $\widetilde{A}_j = (T_{\widetilde{A}_j}, I_{\widetilde{A}_j}, F_{\widetilde{A}_j})$. The single-valued neutrosophic weighted average operator (SVNWA) is defined as follows:

$$\sum_{j=1}^{n} \lambda_j A_j = \left(1-\prod_{j=1}^{n}\left(1- T_{\widetilde{A}_j}\right)^{\lambda_j}, \prod_{j=1}^{n}\left(I_{\widetilde{A}_j}\right)^{\lambda_j}, \prod_{j=1}^{n}\left(F_{\widetilde{A}_j}\right)^{\lambda_j}\right) \quad (6)$$

where λ_j is the weight of A_j (j=1,2,…,n), $\lambda_j \in [0,1]$ and $\sum_{j=1}^{n} \lambda_j = 1$.

Definition 6: Let $\widetilde{A}_1 = (T_1, I_1, F_1)$ be a single-valued neutrosophic fuzzy number. Then, the defuzzification of score function $s(\widetilde{A}_1)$ of $\widetilde{A}_1$ is defined as below:

$$s(\widetilde{A}_1) = \frac{2 + T_1 - I_1 - F_1}{3} \tag{7}$$

B. Selected Element Reduction Approach (SERA)

The Selected Element Reduction Approach (SERA) [17-18-19] is a technique for weighting criteria in a fuzzy environment, regardless of whether the criterion weight is supplied directly from a decision maker or an expert. The impact of reduced criterion can be seen as its importance. The relevance of the criteria is determined by comparing the results obtained when a criterion is removed. Linguistic scales assist experts convey their ideas in a fuzzy context. The approach tries to weight indicators in multi-criteria decision making based on the connection of element reduction. This approach is compatible with any fuzzy set.

The steps of the Selected Element Reduction Approach (SERA) are as follows:

Step 1: Define the case. Identify the sets of alternatives and criteria, and decision-makers (DMs).

Step 2: Based on the criteria, collect fuzzy decision matrices from the DMs.

Step 3: Compute the combined fuzzy decision matrix of options using an aggregation operator.

Step 4: Obtain aggregated fuzzy decisions of options using the aggregation operation. At this stage, the criteria are assumed to have equal weights.

Step 5: To determine the overall score ($S_{i_{OA}}$) of the alternatives, use score (a.k.a. defuzzification) function.

Step 6: Choose a criterion to reduce for each alternative and calculate its score ($S_{i_{RC}}$). It means that the alternatives' scores are calculated without the reduced criterion.

Step 7: Apply the following equation to determine the effect of the reduction criteria.

$$E_{RC_j} = \sum_i |S_{i_{OA}} - S_{i_{RC_j}}| \tag{8}$$

Step 8: Assign the criteria weights by normalizing the reduced criterion's impact.

The aggregation operator and score (defuzzification) function differ depending on the kind of fuzzy collection. The procedure of SERA is depicted in the flowchart in Fig. 1.

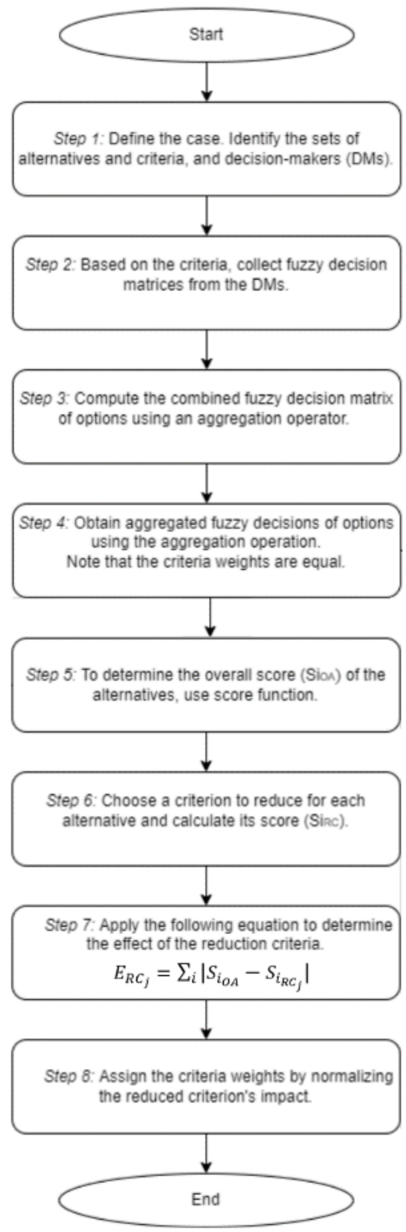

Fig. 1. The flowchart of the Selected Element Reduction Approach (SERA) [17].

III. Numerical Example

The assessment of E-scooter parking on a pilot area in İstanbul is performed to investigate the application of the Neutrosophic Fuzzy Selected Element Reduction Approach (NF-SERA). For the numerical analysis of the proposed model, four alternative e-scooter parking lots were determined for a pilot area in Istanbul, which is considered a carbon neutral zone. Hence, it is necessary to determine the weights of the criteria to be including in the assessment. Based on related research in the literature, four criteria are gathered. The proposed NF-SERA approach has been implemented step by step. Table 1 lists linguistic terms as well as their neutrosophic fuzzy analogues.

TABLE I. SINGLE-VALUED NEUTROSOPHIC FUZZY LINGUISTIC EXPRESSIONS [20].

Scale	***Neutrosophic Fuzzy set***
Extremely High (EH)	(1.0, 0.0, 0.0)
Very Very High (VVH)	(0.90, 0.10, 0.10)
Very High (VH)	(0.80, 0.15, 0.20)
High (H)	(0.70, 0.25, 0.30)
Medium High (MH)	(0.60, 0.35, 0.40)
Medium (M)	(0.50, 0.50, 0.50)
Medium Low (ML)	(0.40, 0.65, 0.60)
Low (L)	(0.30, 0.75, 0.70)
Very Low (VL)	(0.20, 0.85, 0.80)
Very Very Low (VVL)	(0.10, 0.90, 0.90)
Extremely Low (EL)	(0.0, 1.0, 1.0)

Step 1: In the scope of the carbon neutral cities, a company starts a research on the assessment of e-scooter parking area in Istanbul. Four criteria $C = \{C_1: fleet\ management$, C_2: Sustainability of energy efficiency, $C_3: Integration\ with\ public\ transport\ alternatives$, $C_4: Accessibility\ to\ area\}$ [8] are determined by three experts and asked to evaluate the alternative e-scooter parking areas $A = \{A_1, A_2, A_3, A_4\}$ by linguistic expressions given in Table 1. A criterion weighting approach is performed to determine which criteria are more prevalent in the evaluation. Experts use single-valued neutrosophic fuzzy language terms to determine if alternative areas are appropriate for carbon neutral zone characteristics. To weight the criteria, the NF-SERA is applied, which is a new extension of SERA by a three-dimensional fuzzy set called single-valued neutrosophic fuzzy sets.

Step 2: Three decision makers $DM = \{DM_1, DM_2, DM_3\}$ evaluated the alternative e-scooter parking areas according to the criteria as follows, using the single-valued neutrosophic fuzzy scale given in Table 1.

$$DM_1 = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} H & M & VH & VL \\ ML & MH & ML & VVL \\ VL & L & VVL & MH \\ MH & VH & L & ML \end{bmatrix} \end{array}$$

$$DM_2 = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} L & H & M & ML \\ MH & L & VL & L \\ ML & VH & MH & VVL \\ VVL & MH & L & VH \end{bmatrix} \end{array}$$

$$DM_3 = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} MH & VL & ML & VH \\ H & MH & MH & ML \\ L & VH & VVL & L \\ VH & L & H & M \end{bmatrix} \end{array}$$

Step 3: The aggregated single-valued neutrosophic fuzzy decision matrix of alternatives by SVNWA in Eq.(6) is calculated as follows. Assume that DMs' reviews are equally important.

$$DM_{Aggr} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} (0.56,0.40,0.44) & (0.51,0.47,0.49) & (0.61,0.37,0.39) & (0.54,0.44,0.46) \\ (0.58,0.38,0.42) & (0.52,0.45,0.48) & (0.42,0.58,0.58) & (0.28,0.76,0.72) \\ (0.30,0.75,0.70) & (0.70,0.26,0.30) & (0.31,0.66,0.69) & (0.37,0.62,0.63) \\ (0.58,0.36,0.42) & (0.62,0.34,0.38) & (0.47,0.52,0.53) & (0.61,0.37,0.39) \end{bmatrix} \end{array}$$

Step 4: The aggregated single-valued neutrosophic fuzzy decisions of alternative cities obtained by using SVNWA in Eq.(6) is given as follows. Since the goal is to find the criteria weight, the criteria weights are considered equal.

$$\widetilde{D}_{Aggr} = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{bmatrix} (0.56,0.42,0.44) \\ (0.46,0.53,0.54) \\ (0.45,0.53,0.55) \\ (0.57,0.39,0.43) \end{bmatrix}$$

Step 5: The single-valued neutrosophic fuzzy numbers are defuzzified by Eq.(7). Thus, the overall score $(S_{i_{OA}})$ of alternatives are calculated as follows:

$$S_{i_{OA}} = \begin{Bmatrix} S_{A_{1OA}} = 0.565 \\ S_{A_{2OA}} = 0.466 \\ S_{A_{3OA}} = 0.457 \\ S_{A_{4OA}} = 0.586 \end{Bmatrix}$$

Step 6: Alternative scores are calculated by extracting one element at a time from the system. Then, return to Step 2 and search the matrices for the criterion column. The re-evaluation factors are now n-1. As the chosen criterion is extracted, the following alternative scores are computed:

$$S_{i_{RC_1}} = \begin{Bmatrix} S_{A_{1RC_1}} = 0.562 \\ S_{A_{2RC_1}} = 0.415 \\ S_{A_{3RC_1}} = 0.504 \\ S_{A_{4RC_1}} = 0.580 \end{Bmatrix}$$

$$S_{i_{RC_2}} = \begin{Bmatrix} S_{A_{1RC_2}} = 0.581 \\ S_{A_{2RC_2}} = 0.444 \\ S_{A_{3RC_2}} = 0.329 \\ S_{A_{4RC_2}} = 0.569 \end{Bmatrix}$$

$$S_{i_{RC_3}} = \begin{Bmatrix} S_{A_{1RC_3}} = 0.546 \\ S_{A_{2RC_3}} = 0.480 \\ S_{A_{3RC_3}} = 0.496 \\ S_{A_{4RC_3}} = 0.617 \end{Bmatrix}$$

$$S_{i_{RC_4}} = \begin{Bmatrix} S_{A_{1RC_4}} = 0.570 \\ S_{A_{2RC_4}} = 0.520 \\ S_{A_{3RC_4}} = 0.483 \\ S_{A_{4RC_4}} = 0.575 \end{Bmatrix}$$

Step 7: The impacts of the reduced criterion are given by Eq.(8) as follows:

$$E_{RC_j} = \begin{Bmatrix} E_{RC_1} = 0.043 \\ E_{RC_2} = 0.141 \\ E_{RC_3} = 0.239 \\ E_{RC_4} = 0.065 \end{Bmatrix}$$

Step 8: The weights of criterion are calculated by normalizing the criterion effects as follows:

$$w_j = \begin{Bmatrix} w_{C_1} = 0.088 \\ w_{C_2} = 0.290 \\ w_{C_3} = 0.490 \\ w_{C_4} = 0.132 \end{Bmatrix}$$

The result shows that $C3: Integration\ with\ public\ transport\ alternatives$ is the most important indicator to assess the e-scooter parking area in scope of the carbon neutral cities.

IV. Conclusion

This study performs the numerical analysis of the NF-SERA, which is presented for criterion weighting in MCDM cases, in the assessment of e-scooter parking area on carbon neutral cities. The proposed methodology is based on the use of fuzzy numbers and aims to weight the criteria according to its effect on the change in the overall evaluation by removing a criterion from the evaluation. Similarly, it is adaptive to different fuzzy styles with appropriate operators. In this study, the use of neutrosophic fuzzy SERA has been demonstrated, and the 3-dimensional structure of neutrosophic fuzzy sets (uncertain, incomplete and indeterminate expansion) has been utilized. "Accessibility to area, Integration with public transport alternatives, Fleet management, Sustainability of energy efficiency" criteria have been evaluated in order to leave the micromobility devices to be used in carbon-neutral areas in suitable parking spaces for proper city planning. Regular city planning not only improves the quality of life of residents, but also saves energy and eases the workload. Thus, the criteria to be weighted in the assessment of the e-scooter parking area are determined by the NF-SERA.

For further researches, the SERA methodology can be extended with other sets in the literature. Since SERA is a criterion weighting method, it is suitable for use as a hybrid with other MCDM methods for alternative ranking. On the other hand, it is recommended to examine the geometric representations in order to learn the method more deeply. Applicable and comparative studies are recommended to carried out in many MCDM cases without subject limitation.

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