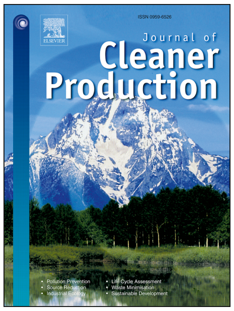

Safe E-scooter operation alternative prioritization using a q-rung orthopair Fuzzy Einstein based WASPAS approach

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Dragan Pamucar: Methodology, Methodology, Software, Validation, Writing - original draft, Writing—review & editing, Visualization

D'Maris Coffman: Supervision, Writing - original draft, Writing—review & editing

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Title Page

Safe E-scooter Operation Alternative Prioritization Using a q-Rung Orthopair Fuzzy Einstein Based WASPAS Approach

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Safe E-scooter Operation Alternative Prioritization Using a q-Rung Orthopair Fuzzy Einstein Based WASPAS Approach

Abstract

E-scooters globally have proven an increasingly popular form of dockless micro-mobility, while also contributing to sustainable urban transportation forms. However, some safety issues arise with e-scooter use in the cities. This study aims to propose a decision-making model based on q-rung orthopair fuzzy sets for prioritizing the safe e-scooter operation alternative. The proposed model consists of two stages: weighting the criteria and ranking the alternatives. First, a fuzzy logarithmic additive assessment of the weight coefficients methodology and fuzzy Einstein weighted averaging operator were applied to define the reference relationships between the criteria and determine their weights. Second, a q-rung orthopair fuzzy sets based decision-making model integrating q-rung orthopair fuzzy Einstein average and q-rung orthopair fuzzy Hamacher geometric mean operator was used to rank the alternatives. A fictional case study is presented to show the practicality of the proposed model. The contribution of the work is as a decision-support system for evaluating safe e-scooter strategies, such as infrastructure placement, user behavior and how e-scooters interact with other transportation means showing that applicability of the proposed model to real-world problems.

Keywords: E-scooter, safety, Q-rung orthopair fuzzy sets, Fuzzy logarithmic additive assessment, Multi-criteria decision making (MCDM).

1. Introduction

E-scooters are one of the most eco-friendly modes of transportation. They also make travel easier for individual users (Ferry, 2019). Yet although e-scooters reduce carbon emissions dramatically, contrary to expectations they do not reduce conflicts and accidents (Todd, et al. 2019). Studies show that e-scooter related injuries increase in frequency and severity when individuals do not take safety precautions. Of the 248 patients who visited the hospital related to e-scooter injuries between July and September 2019 in Berlin (Uluk et al., 2021), approximately 41% of the injury pattern involved head injuries (Uluk et al., 2021). Investigators in Barcelona also carried out a study from May 2019 to May 2020 in the emergency department of patients who went to the hospital because of e-scooter related accidents (Coelho et al., 2021). Similar studies in New

Zealand have identified alcohol as a contributing factor, and have attempted to estimate the health-economic burden (Bekhit et al, 2020), while other studies have been concerned with injuries to non-riders, especially the elderly (Bloomberg, 2019). To cope with the increased e-scooter related accidents, decision-makers should consider all alternatives. Conflicts between transportation modes, invariably causing accidents and injuries, will continue unless governments intervene with adequate regulations to reduce them.

1.1. The motivation of using q-rung orthopair fuzzy sets

The decision-making environment is often uncertain due to information redundancy, ambiguity and noise because of some uncontrollable factors (Tao et al., 2021). To overcome this, the theory of fuzzy sets (FSs) named as the type-1 fuzzy set was proposed by Zadeh (1965) to handle the fuzziness contained in uncertain information; ituses the degree of membership to express knowledge. FSs have been successfully used in many fields, such as multi-criteria decision making (MCDM) problems (Keshavarz et al., 2018; Krishankumar et al., 2021), autonomous robots (Gasós and Saffiotti, 1999), control systems (Osinski et al., 2021), industrial engineering (Kahraman et al., 2006), image processing (Bloch, 2015), and so on. However, two general shortcomings have been noted for FSs theory. First, this fuzzy set focuses only on the membership degrees of an element to a particular set. The second is the questionable reliability of these sets (Shahri et al., 2021). Since the invention of the FSs theory, several forms of a fuzzy set in the literature have been generalized such as rough sets (Pawlak, 1982), intuitionistic fuzzy sets (Atanassov, 1986), type-2 fuzzy sets (Zadeh, 1975), neutrosophic sets (Smarandache, 1999), interval type-2 fuzzy sets (Mendel et al., 2006), hesitant fuzzy sets (Torra, 2010), hesitant fuzzy sets (HFSs) (Rodríguez et al., 2013), pythagorean fuzzy sets (PFSs) (Yager and Abbasov, 2013), picture fuzzy sets (PFSs) (Cuong and Kreinovich, 2013), proportional hesitant fuzzy linguistic term sets (PHFLTSs) (Chen et al., 2016), possibility-distribution-based hesitant fuzzy linguistic-term sets (HFLTSs) (Chen et al., 2021a), hesitant linguistic term set (Chen et al., 2018, 2021b), q-rung orthopair fuzzy sets (q-ROFs) (Yager, 2017), fermatean fuzzy sets (Senapati and Yager, 2020) and so on. These fuzzy sets have been successfully used in many fields.

To expand the application of fuzzy sets, Atanassov (1986) introduced an intuitionistic fuzzy set (IFS), which is an effective tool for expressing vague, uncertain, and ambiguous information. IFSs are characterized by the degree of membership, non-membership, and hesitancy simultaneously. However, the range of IFS information is very narrow with the constraint condition that the sum of membership degree φ and non-membership degree ω should not be greater than one or equal to one $(\varphi+\omega\leq 1)$. For example, when a decision-maker provides the membership degree as $\varphi=0.7$ and non-membership degree, as $\omega=0.6$ with the condition that $0.7+0.6=1.3>1$. It can be seen that IFSs cannot cope effectively with such cases. To better handle this situation, Yager and Abbasov (2013) extended the IFS to PFS by stretching the condition $\varphi+\omega\leq 1$ to $\varphi^2+\omega^2\leq 1$. For example, a pair $(0.7, 0.6)$ is handled with the PFS as $0.7^2+0.6^2=0.85\leq 1$, although it is not possible with IFS as $0.7+0.6=1.3>1$, this issue can be overcome with PFSs. Although PFSs have been extensively studied in the literature by various researchers, due to the increasing complexity of decision-making problems, they can express a more comprehensive range of information (Garg and Chen, 2020). Therefore, the role of IFSs and PFSs in addressing uncertainty is limited, as shown in Fig. 1.

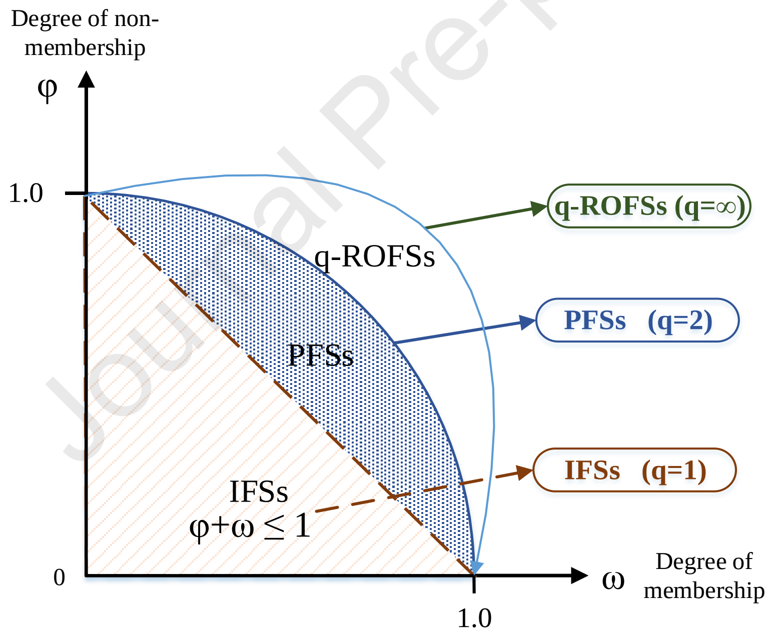


Fig. 1. Comparison of grade spaces of IFSs, PFSs, and q-ROFSs.

To deal with this, Yager (2017) recently introduced the concept of q-rung orthoair FSs (q-ROFSs) as an effective tool for handling uncertainty of the multi-criteria decision making (MCDM) problems, where $q\geq 1$ in which *qth* power sum of φ and ω is not greater than one. q-ROFs as a new generalization of IFSs and PFSs which are specific instances of q-ROFSs by setting $q=1$ and $q=2$, respectively. q-ROFSs have larger fuzzy information space to express uncertain information (see Fig. 1). To express the concept of q-ROFS, consider an example where an expert provides a preference for attribute values with $\varphi = 0.6$ and $\omega = 0.9$. It can be easily seen that $0.6 + 0.9 \not\leq 1$ ($q = 1$) and $0.6^2 + 0.9^2 \not\leq 1$ ($q = 2$), hence this situation cannot be defined by IFSs and PFSs, but $0.6^3 + 0.9^3 = 0.945 \leq 1$ holds. Therefore, the attribute value can be represented by q-ROFSs with $q = 3$. Thus, q-ROFSs allow experts to independently assign the membership degree and the non-membership degree by setting the *q* parameter. This study proposes the concept of qROFs in the decision-making model.

1.2. Objectives of this study

In today's world, e-scooters are a well-known mode of travel. Although they are supposed to make travel easier and safer, they are not effective as expected (Riggs, 2021). Since e-scooter related accidents are increasing day on day (Namiri, 2020). Policymakers should intervene in the current situation. In this study, the aim is to find the best way to design a decision-making model for e-scooter safety with the help of alternative prioritization. The contribution of our study is in developing a decision support system for the evaluation of safe e-scooter strategies. The novelty of our study is threefold. (i) To the best of our knowledge, the literature has not been conducted to evaluate the prioritizing the safe e-scooter operation alternative. Although e-scooters spread worldwide, their efficiency is not as much as expected. For successful and safe usage, it is necessary to change the present hands-off approach of policy-makers. Minimizing accidents and the injuries associated with them depends on formulating the right mix of local programs and regulations. Municipalities should conduct an inquiry into e-scooters related accidents, which are frequently encountered in urban use. With the help of the new strategies, security issues can be minimised. Current regulations are not adequate for tackling and resolving the safety issues. Since e-scooters have recently joined our daily lives, E-scooter studies are in early stages. Some studies are related to injuries from the operation of the equipment and while others investigate the e-scooter as a transportation mode. Studies on the prevention of accidents are still very few. This study is aimed at guiding municipalities and policymakers to create a safe environment in the usage of e-scooters. Owing to this gap in the literature, the major motivation of our study is to evaluate the alternative using q-ROFSs based multi-criteria decision-making model (MCDM) model. (ii) Due to the limitations of Pythagorean fuzzy and intuitionistic fuzzy sets, we present q-ROFSs based decision-making model including integrating q-rung orthopair fuzzy Einstein average (q-ROFEA), and q-rung orthopair fuzzy Hamacher geometric mean (q-ROFHGM). (iii) A detailed stability analysis is performed on the changes in various parameter values of the proposed model to show and validate how the results change.

The rest of this paper is organized as follows: Section 2 contains a thorough investigation of the studies in the literature, which are written on e-scooter safety. In Section 3, the methodology of the study is given. Section 4 contains the description of the case study, the alternatives, and the criteria. Also, the results of the model are presented in Section 4. In section 5, the final results of the advantage prioritization of the alternatives are presented and a discussion of the results follows. Section 6 provides the managerial and policy implications. Finally, in Section 7, the conclusion is presented.

2. Literature Review

2.1. E-scooters and Safety

According to Schellong(2019), there are some safety issues riders and non-riders have encountered and thus the study offers basic suggestions about safety precautions. To reduce the risk of head injury and improve safety, personal protective equipment (PPE) is one of the most important precautions. From the recorded injuries, it is apparent that most e-scooter riders do not use any protective gear. Riders need greater awareness of PPE, which can prevent them from getting serious harm at the accident’s moment. The research in Berlin (Uluk et al., 2021) shows that only 1% of patients wore a helmet, which is an alarming situation that threatens riders’ health, considering the severity of head injuries including traumatic brain injury experienced by riders. To avert e-scooter riders from being critically injured or killed, protective gear, especially helmets, should be compulsory. Wheels, one of the e-bike companies in California, produced e-bikes with an attached helmet with the aim of head protection (Ellingson, 2019). In addition, there are 16 U.S.A. states that have developed rules for e-scooters relating to helmet use (Fang et al., 2019) and it is compulsory for all e-scooter riders in Brisbane, Australia (Haworth et al., 2021).

Addressing the lack of education and training should take priority in improving safety. Informed drivers and e-scooter riders are equally important. For riders, companies should increase their educational efforts, together with the awareness of protective gear. A user should know what an e-scooter is, how it is ridden and maintained. All e-scooter companies can attach cards that include riding instructions and restrictions, as some of them do. A high education level does not correlate with greater knowledge of e-scooter instructions and limitations. For this reason, educational providers can organize e-scooter related workshops for all potential riders. Drivers, particularly in downtown, should get compulsory training, thereby curbing the hazard they pose to e-scooter riders. According to studies, there is not any difference in crash locations between e-scooters and motor vehicles (Shah et al., 2021), so drivers should slow down at the intersections and admit to the existence of e-scooters. Authorized persons in Chicago conducted an e-scooter pilot program to be further deployed in 2019 (Dias et al., 2021). Only those who are aware of the existence of e-scooters and prepared to encounter them on the roads know what they need to do to create a pleasant and safe environment consistent with public health.

2.2. Policy-making gap on e-scooters

The role of rules and regulations as safety precautions is incontrovertible and passing relevant laws depends on the government. Micro-mobility operations are expanding, but the lack of regulation is a matter that still needs urgent action. Indeed, most governmental regulation of e-scooter usageis still deficient. While some of them forbid e-scooter riders from staying on the pavement, some like the UK, have banned them completely (Tuncer et al., 2020). Each government has a different approach to regulating e-scooter. Because of conflicts, other members of a traffic system tend to blame riders for using e-scooters rashly and breaking the rules (Tuncer et al., 2020). However, they disregard the fact that e-scooters are unfamiliar to all people. There are not any formal rules such as wearing protecting gear, not riding under influence, and limiting speed and age restrictions. For instance, 81 patients who had an accident related to e-scooter gave a breath test, and the result showed that 48% of them were under the influence of alcohol (Kobayashi et al., 2019). Nevertheless, nobody paid any fine; and if a motor vehicle driver faces such a situation, their driving license may at minimum be taken away, and in some places criminal penalties accrue. Also, some e-scooter companies have declared their policies as part of their terms and conditions, which include the maximum speed, helmet requirements, and age limits. Whereas the recommended age limit was designated as 18 years old, there are rarely any government regulations (Sikka et al., 2019). Without adequate policies on the usage which governments should formulate, some problems such as conflicts between pedestrians and riders, and serious accidents involving both of them, will continue. After regulations, both conflicts and accidents should decrease, in turn improving the safety of e-scooters.

After people develop a greater awareness of e-scooter usage and the laws are passed, governments should take one more safety precaution to prevent conflicts between members of the traffic and accidents. Inadequate infrastructure is an essential issue as regulation. Improvement of infrastructure can reduce both conflicts and car usage. To this end, e-scooters should become the most effective transport mode. Yet E-scooters with small tires need more regular roads to have a better performance, and there often is not existing transport infrastructure to meet the demand. Apart from rough roads, there are not any exact and adopted routes and parking areas that e-scooter riders are directed to use. Fair road space allocation and increased cycle lanes will provide a safer trip for all passengers. The members of traffic struggle for traffic congestion because each of them uses the same road. Saudi Arabia is an example of a lack of sufficient traffic infrastructure. For passengers who are eager to use e-scooters in Saudi Arabia, the lack of traffic lanes dedicated to e-scooters is a major hindrance (Almannaa et al., 2021). There are also complaints related to e-scooter parking. According to studies, 16% of the 606 recorded e-scooters were inappropriately parked, while 36 of them were restricting pedestrian right-of-ways. (James et al., 2019). The fewer pedestrians and drivers complain the more riders can be encouraged to use e-scooters. With a well-prepared arrangement, urban transport systems can be fairer and easier (Clewlow et al., 2018). For example, Virginia Tech transportation arranged the road types in groups such as cycle lanes, multi-use paths, and one-way roads to stop disagreements and accidents (Zhang et al., 2021).

E-scooters which are eco-friendly modes of transportation are gaining traction worldwide in response to concerns about climatic change and thereby becoming popular in urban transportation. Despite the popularity, some passengers still engage in unsafe behaviour. Unfortunately, because of the lack of safety precautions by riders, the full potential of e-scooters to riders and the other members of traffic has yet to be fully realised. To improve the safety of e-scooter systems, it is necessary to understand the problems exactly. Governments and e-scooter companies should study the issue in-depth. Increased pilot programs and educations will be beneficial to all potential riders. Adequately trained riders will find out why protecting gear is vital for the e-scooter experience and its role in preventing serious injuries. The companies' precautions, which are independent from governments' regulations, do not prevent e-scooter accidents. Problems between pedestrians and e-scooter users cannot be solved unless governments intervene with regulations. After the formulation of better regulations, improved road conditions and parking areas should avert injuries and e-scooter accidents.

2.3. Studies on q-rung orthopair fuzzy sets

Whereas MCDM methods with q-rung orthopair fuzzy sets are not applied to the inherently uncertain the safe e-scooter operation problem, they have been used to better handle uncertainty for various decision-making applications. These studies are reported in Table 1. This study will be the first attempt to implement the fuzzy logarithmic additive assessment of the weight coefficients (LAAW) methodology and fuzzy Einstein weighted averaging operator with q-ROFSs to the prioritizing the safe e-scooter operation alternative. The LAAW method enables decision-makers to better perceive relationships between criteria, since it considers relations between adjacent criteria. Thus, it eliminates the problem of defining relations between remote criteria, which often decreases the consistency of results in subjective models, such as the Analytic Hierarchy Process (AHP) method and Best-Worst Method (BWM) (Asadabadi et al., 2019). LAAW approach has been used in several studies such as evaluation of criteria for site selection of Photovoltaics (PV) using fuzzy sets based LAAW (Deveci et al., 2021a), and evaluation of logistics service providers (Pamucar et al., 2021).

Table 1

Overview of studies on q-ROFSs based MCDM model.

Author(s)	Year	Research focus	MCDM Method	SA	CA	Country	Type
Rani et al.	2020	Fuel technology selection	Novel model	Yes	Yes	United States	Real-life
Tang et al.	2020	Stock investment evaluation	Novel model	Yes	Yes	-	Illustrative example
Garg and Chen	2020	Examples	Novel model	No	Yes	-	Illustrative examples
Darko and Liang	2020	Evaluation of mobile technologies	EDAS	Yes	Yes	-	Illustrative example
Krishankumar et al.	2020	Green supplier selection problem	VIKOR	Yes	Yes	India	Real-life
Joshi and Gegov	2020	Customers’choice problem	Novel model	Yes	Yes	-	Real-life
Gong et al.	2020	Evaluation of the teaching quality of universities	MABAC	No	Yes	China	Real-life
Alkan and Kahraman	2021	Evaluation of government strategies	TOPSIS	Yes	Yes	-	Real-life
Zeng et al.	2021	Smart phone selection	Novel model	Yes	No	-	Illustrative example
Wang et al.	2021	Evaluation of construction companies	MABAC	No	Yes	-	Illustrative example
Jin et al.	2021	Risk evaluation	FMEA and ARAS	Yes	Yes	China	Real-life
Yang and Chang	2021	Garbage disposal site selection	MADM algorithm	Yes	Yes	-	Illustrative example
Yang et al.	2021	Selection of a design scheme	Novel model	Yes	Yes	-	Real-life
Krishankumar et al.	2021	Renewable energy source selection	TODIM	Yes	Yes	India	Real-life
Our study		*Evaluation of safe e-scooter operation*	*LAAW and WASPAS*	*Yes*	*Yes*	*?*	*Real-life*

3. Research Method

The basic definitions related to IFSs, PFS, and Q-ROFs are briefly reviewed in this section.

3.1. Intuitionistic fuzzy sets

Intuitionistic fuzzy sets as an extension of the classical fuzzy set theory were introduced by Atanassov in 1986. IFSs have been used by many researchers in various MCDM problems to handle uncertainty. These sets can be defined in terms of membership degree, non-membership degree, and hesitancy degree.

Definition 3.1. Let a set X be a universe of discourse. An IFS $\tilde{I}$ in X can be described as:

$$\tilde{I} = \left\{ \left(x, \varphi_{\tilde{I}}(x), \omega_{\tilde{I}}(x) \middle| x \in X \right) \right\} \tag{1}$$

where $\varphi_{\tilde{I}}(x) : X \to [0,1]$ and $\omega_{\tilde{I}}(x) : X \to [0,1]$ define the degree of membership and the degree of non-membership of the element $x \in X$ to $\tilde{I}$, respectively, with the condition that $0 \le \varphi_{\tilde{I}}(x) + \omega_{\tilde{I}}(x) \le 1$.

The degree of the hesitancy $\upsilon_{\tilde{I}}(x)$ of the element x to $\tilde{I}$ is defined as $\upsilon_{\tilde{I}}(x) = 1 - \varphi_{\tilde{I}}(x) - \omega_{\tilde{I}}(x)$ and $\upsilon_{\tilde{I}}(x) : X \to [0,1]$.

3.2. Pythagorean fuzzy sets

Pythagorean fuzzy sets were introduced by Yager and Abbasov (2013) as an extension of the intuitionistic fuzzy set. PFSs are characterized by membership degree, non-membership, and hesitancy degree. In PFSs, unlike IFSs, the sum of membership and non-membership degrees can exceed 1, but the sum of squares cannot exceed 1 (Deveci et al. 2021b).

Definition 3.2. Let a set X be a universe of discourse. A PFSs $\tilde{P}$ in X can be described as:

$$\tilde{P} = \left\{ \left(x, \varphi_{\tilde{P}}(x), \omega_{\tilde{P}}(x) \middle| x \in X \right) \right\} \tag{2}$$

where $\varphi_{\tilde{P}}(x)$ and $\omega_{\tilde{P}}(x)$ represent the degree of membership and the degree of non-membership of the element $x \in X$ to $\tilde{P}$, respectively, $\varphi_{\tilde{P}}(x), \omega_{\tilde{P}}(x) : X \to [0,1]$. It satisfies the condition that $0 \le \left(\varphi_{\tilde{P}}(x)\right)^2 + \left(\omega_{\tilde{P}}(x)\right)^2 \le 1$.

The degree of the hesitancy $\upsilon_{\tilde{P}}(x)$ of the element x to $\tilde{P}$ is defined as, $\upsilon_{\tilde{P}}(x)=\sqrt{1-\left(\varphi_{\tilde{P}}(x)\right)^{2}-\left(\omega_{\tilde{P}}(x)\right)^{2}}$, and $\upsilon_{\tilde{P}}(x):X\rightarrow[0,1]$.

3.3. Q-runq orthopair fuzzy sets

Q-rung orthopair fuzzy sets proposed by Yager (2017) are represented by the degree of membership and non-membership. In q-ROFSs, the sum of the *q*th power of the membership and non-membership degrees must be less than or equal to one (Alkan and Kahraman, 2021).

Definition 3.3. Let X be a finite nonempty set. A q-ROFSs $\tilde{Q}$ in X can be described as:

$$\tilde{Q}=\left\{\left(x,\varphi_{\tilde{Q}}(x),\omega_{\tilde{Q}}(x)\middle|x\in X\right)\right\} \tag{3}$$

where $\varphi_{\tilde{Q}}(x):X\rightarrow[0,1]$ and $\omega_{\tilde{Q}}(x):X\rightarrow[0,1]$ define the degree of membership and the degree of non-membership of the element $x\in X$ to $\tilde{Q}$, respectively, with the conditions $0\leq\left(\varphi_{\tilde{Q}}(x)\right)^{q}+\left(\omega_{\tilde{Q}}(x)\right)^{q}\leq 1$, $q\geq 1$. For each $x\in X$, the degree of hesitancy $\upsilon_{\tilde{Q}}(x)$ is defined as $\upsilon_{\tilde{Q}}(x)=\sqrt[q]{1-\left(\varphi_{\tilde{Q}}(x)\right)^{q}-\left(\omega_{\tilde{Q}}(x)\right)^{q}}$, and $\upsilon_{\tilde{Q}}(x):X\rightarrow[0,1]$.

For simplicity, $\kappa=(\varphi,\omega)$ is called a q-rung orthopair fuzzy number (q-ROFN).

Definition 3.4. Let $\kappa=(\varphi,\omega)$, $\kappa_1=(\varphi_1,\omega_1)$ and $\kappa_2=(\varphi_2,\omega_2)$ be the q-ROFNs, and their operations are expressed as follows (Darko and Liang, 2020):

$$\kappa_1\oplus\kappa_2=\left(\sqrt[q]{(\varphi_1)^q+(\varphi_2)^q-(\varphi_1)^q(\varphi_2)^q},\omega_1\omega_2\right); \tag{4}$$

$$\kappa_1\otimes\kappa_2=\left(\varphi_1\varphi_2,\sqrt[q]{(\omega_1)^q+(\omega_2)^q-(\omega_1)^q(\omega_2)^q}\right); \tag{5}$$

$$\kappa_1-\kappa_2=\left(\sqrt[q]{\frac{\varphi_1^q-\varphi_2^q}{1-\varphi_2^q}},\frac{\omega_1}{\omega_2}\right),\text{ if }0\leq\frac{\omega_1}{\omega_2}\leq\left[\frac{1-\varphi_1^q}{1-\varphi_2^q}\right]\leq 1,\text{ otherwise }0; \tag{6}$$

$$\tau\kappa=\left(\sqrt[q]{1-(1-\varphi^q)^\tau},\omega^\tau\right),\text{ where }\tau>0; \tag{7}$$

$$\kappa^\tau=\left(\varphi^\tau,\sqrt[q]{1-(1-\omega^q)^\tau}\right),\text{ where }\tau>0; \tag{8}$$

Definition 3.5. For a q-ROFN $\kappa = (\varphi, \omega)$, the score function $S(\tilde{\kappa})$ and accuracy function $H(\tilde{\kappa})$ of $\tilde{Q}$ can be defined as, respectively (Wei et al., 2018).

$$S(\tilde{\kappa}) = \frac{(1+\varphi_{\tilde{\kappa}}^{q} - \omega_{\tilde{\kappa}}^{q})}{2} \tag{9}$$

$$H(\tilde{\kappa}) = \varphi_{\tilde{\kappa}}^{q} + \omega_{\tilde{\kappa}}^{q} \tag{10}$$

An innovative score function is also defined by Garg and Chen (2020):

$$S(\tilde{\kappa}) = \frac{e^{\varphi_{\tilde{\kappa}}^{q} - \omega_{\tilde{\kappa}}^{q}}}{1+\upsilon_{\kappa}^{q}} \tag{11}$$

Definition 3.6. Let $\tilde{\kappa}_i = \left(\varphi_{\tilde{\kappa}_i}, \omega_{\tilde{\kappa}_i}\right) (i = 1, 2, \ldots, n)$ be set of q-ROFNs and $w = (w_1, w_2, \ldots, w_n)^T$ be the weight of vector of $\tilde{\kappa}_i$ with the condition $\sum_{i=1}^{n} w_i = 1$, then a q-rung orthopair fuzzy weighted average (q − ROFWA) and q-rung orthopair fuzzy weighted geometric (q − ROFWG) operator are defined as follows (Liu and Wang, 2018):

$$q-ROFWA(\tilde{\kappa}_1, \tilde{\kappa}_2, \ldots \tilde{\kappa}_n) = \left(\left(1 - \prod_{i=1}^{n} \left(1 - \varphi_{\tilde{\kappa}_i}^{q}\right)^{w_i}\right)^{\frac{1}{q}}, \prod_{i=1}^{n} \omega_{\tilde{\kappa}_i}^{w_i} \right) \tag{12}$$

$$q-ROFWG(\tilde{\kappa}_1, \tilde{\kappa}_2, \ldots \tilde{\kappa}_n) = \left(\prod_{i=1}^{n} \varphi_{\tilde{\kappa}_i}^{w_i}, \left(1 - \prod_{i=1}^{n} \left(1 - \omega_{\tilde{\kappa}_i}^{q}\right)^{w_i}\right)^{\frac{1}{q}} \right) \tag{13}$$

3.4. Proposed methodology

The details of the proposed q-rung orthopair fuzzy Einstein operator based WASPAS model are composed of the following steps:

Step 1. Identify the alternatives, decision criteria, and experts to build the proposed model. The alternatives of a set $L_i = \{L_1, L_2, \ldots L_m\} (i = 1, 2, \ldots, m)$, the criteria of the set $T_j = \{T_1, T_2, \ldots T_n\} (j = 1, 2, \ldots, n)$, and the experts of the set $E_p = (p = 1, 2, \ldots, e)$ are stated.

Step 2. Determining the linguistic variables and their corresponding values.

Step 3. Calculation of the criteria weight by applying the logarithmic additive evaluation. The criteria weights are represented by $w_j = (j = 1, 2, \ldots, n)$.

Step 3.1. Defining priority vectors. The priority vector $\psi^{l} = \left(\square_{T_1}^{l}, \square_{T_2}^{l}, \ldots, \square_{T_n}^{l}\right)$ is created according to expert preferences. Expert $E_l (1 \le l \le e)$ evaluates each criterion from the set $T_j (j = 1, 2, \ldots, n)$

and assigns a value from the fuzzy scale. If a criterion is highly important, the expert assigns the highest value from the fuzzy scale to that criterion, while it assigns the lowest value from the scale to the criterion with the lowest degree of importance. These values are denoted as values based on $\tilde{\phi}_{ij} = \left(\phi_{ij}^{(a)}, \phi_{ij}^{(b)}, \phi_{ij}^{(c)}\right)$ the fuzzy linguistic scale.

Step 3.2. Determine the absolute anti-ideal point $\left(\varpi_{AAIP}\right)$. The absolute anti-ideal point is defined as follows:

$$\varpi_{AAIP} < \min\left(\square_{T_1}^{l}, \square_{T_2}^{l}, \ldots, \square_{T_n}^{l}\right) \tag{14}$$

Step 3.3. Determining the ratio vector ς^{l} for the expert $E_l (1 \le l \le e)$. The relationship between the elements of the vector ψ^{l} and ϖ_{AIP} is defined as follows:

$$\Delta_{T_j}^{l} = \frac{\square_{T_j}^{l}}{\varpi_{AIP}} \tag{15}$$

, where $\square_{T_j}^{l} (j = 1, 2, \ldots, n)$ represents the element of the priority vector ψ^{l} for the expert $E_l (1 \le l \le e)$. Therefore, the vector of the relation $\varsigma^{l} = \left(\Delta_{T_1}^{l}, \Delta_{T_2}^{l}, \ldots, \Delta_{T_n}^{l}\right)$ for the expert is calculated.

Step 3.4. Defining the weights vector $w = \left(w_1, w_2, \ldots, w_n\right)^{T}$ with the help of Eq. (16). The values of the weighting coefficients of the criteria for the expert $E_l (1 \le l \le e)$ are obtained:

$$w_j^{l} = \frac{\ln\left(\Delta_{T_j}^{l}\right)}{\ln\left(\rho^{l}\right)} \tag{16}$$

, where $\rho^{l} = \prod_{j=1}^{n} \Delta_{T_j}^{l}$, and $\Delta_{T_j}^{l}$ denotes the element of the relation vector ς^{l} for the expert $E_l (1 \le l \le e)$.

Step 3.5. The aggregated fuzzy vector of weight coefficients is determined $w = \left(w_1, w_2, \ldots, w_n\right)^{T}$ with the help of the fuzzy Einstein weighted averaging operator as given in Eq. (17).

$$w_j = \left(\begin{array}{l} \sum_{j=1}^{e} (w_{ij}^{(a)l}) \dfrac{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(a)l}\right)\right)^{1/e} - \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(a)l}\right)\right)^{1/e}}{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(a)l}\right)\right)^{1/e} + \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(a)l}\right)\right)^{1/e}}, \\ \sum_{j=1}^{e} (w_{ij}^{(b)l}) \dfrac{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(b)l}\right)\right)^{1/e} - \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(b)l}\right)\right)^{1/e}}{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(b)l}\right)\right)^{1/e} + \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(b)l}\right)\right)^{1/e}}, \\ \sum_{j=1}^{e} (w_{ij}^{(c)l}) \dfrac{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(c)l}\right)\right)^{1/e} - \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(c)l}\right)\right)^{1/e}}{\prod_{j=1}^{e}\left(1+f\left(w_{ij}^{(c)l}\right)\right)^{1/e} + \prod_{j=1}^{e}\left(1-f\left(w_{ij}^{(c)l}\right)\right)^{1/e}} \end{array} \right), (i = 1, 2, \ldots, m;\ j = 1, 2, \ldots n) \tag{17}$$

where e $(1 \le l \le e)$ represents the number of experts.

Step 3.6. Crisp weights are computed through the defuzzification process given Eq. (18) to represent the triangular fuzzy number more simply.

$$s_j = \frac{(a_j + 4b_j + c_j)}{6} \tag{18}$$

Step 4. Structure the q-ROF decision matrix $\tilde{Y}_e$ in terms of experts' opinions by using the linguistic terms scale. m called $L_i = \{L_1, L_2, \ldots L_m\} (i = 1, 2, \ldots, m)$ alternatives which are to be evaluated by e decision-makers against n criteria.

$$\tilde{Y}_e = \left(\tilde{y}_{ije}\right)_{nxm} = \begin{array}{c|cccc} & L_1 & L_2 & \cdots\cdots & L_m \\ \hline T_1 & \langle[\varphi_{11e}, \omega_{11e}]\rangle & \langle[\varphi_{12e}, \omega_{12e}]\rangle & \cdots\cdots & \langle[\varphi_{1me}, \omega_{1me}]\rangle \\ T_2 & \langle[\varphi_{21e}, \omega_{21e}]\rangle & \langle[\varphi_{12e}, \omega_{12e}]\rangle & \cdots\cdots & \langle[\varphi_{2me}, \omega_{2me}]\rangle \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ T_n & \langle[\varphi_{n1e}, \omega_{n1e}]\rangle & \langle[\varphi_{n2e}, \omega_{n2e}]\rangle & \cdots\cdots & \langle[\varphi_{nme}, \omega_{nme}]\rangle \end{array} \tag{19}$$

where $\tilde{y}_{ije}$ represents the linguistic evaluation of alternative L_i concerning the criterion T_j of *e*th expert.

Step 5. Calculate the aggregated q-ROF decision matrix $\tilde{Y}$. The individual decision matrices are aggregated by using q – ROFWA presented in Eq. (12).

$$
\tilde{Y} = \left(\tilde{y}_{ij}\right)_{nxm} = \begin{array}{c} \\ T_1 \\ T_2 \\ \vdots \\ T_n \end{array}
\begin{array}{c} \begin{array}{cccc} L_1 & L_2 & \ldots\ldots & L_m \end{array} \\
\begin{pmatrix}
\left\langle\left[\varphi_{11}, \omega_{11}\right]\right\rangle & \left\langle\left[\varphi_{12}, \omega_{12}\right]\right\rangle & \ldots\ldots & \left\langle\left[\varphi_{1m}, \omega_{1m}\right]\right\rangle \\
\left\langle\left[\varphi_{21}, \omega_{21}\right]\right\rangle & \left\langle\left[\varphi_{12}, \omega_{12}\right]\right\rangle & \ldots\ldots & \left\langle\left[\varphi_{2m}, \omega_{2m}\right]\right\rangle \\
\vdots & \vdots & \ddots & \vdots \\
\left\langle\left[\varphi_{n1}, \omega_{n1}\right]\right\rangle & \left\langle\left[\varphi_{n2}, \omega_{n2}\right]\right\rangle & \ldots\ldots & \left\langle\left[\varphi_{nm}, \omega_{nm}\right]\right\rangle
\end{pmatrix} \end{array} \tag{20}
$$

where $\tilde{y}_{ij} = \left[\varphi_{ij}, \omega_{ij}\right]$ represents the aggregated q-ROFSs of *i*th alternative in terms of to *j*th criterion.

Step 6. Normalize the decision matrix $\tilde{Y}$ to the form of $\tilde{U} = \left(\tilde{u}_{ij}\right)_{nxm}$. The normalized q-ROF decision matrix is determined using Eq. (21) based on the criterion of benefit and cost type.

$$
\tilde{U} = \tilde{u}_{ij} = \left(\varphi_{ij}, \omega_{ij}\right) = \begin{cases} \left(\varphi_{ij}, \omega_{ij}\right), & Benefit \\ \left(\omega_{ij}, \varphi_{ij}\right), & \mathrm{Cos}\,t \end{cases} \tag{21}
$$

Step 7. Find the measures of weighted sum (WSM) α_i^1 for each alternative with the help of the q-rung orthopair fuzzy Einstein average (q-ROFEA) operator. q-ROFHA operator is defined by Darko and Liang (2020):

$$
q - ROFEA = \alpha_i^1 = \left(\sqrt[q]{\frac{\prod_{j=1}^{n}\left(1+(\varphi_j)^q\right)^{w_j} - \prod_{j=1}^{n}\left(1-(\varphi_j)^q\right)^{w_j}}{\prod_{j=1}^{n}\left(1+(\varphi_j)^q\right)^{w_j} + \prod_{j=1}^{n}\left(1-(\varphi_j)^q\right)^{w_j}}}, \frac{\sqrt[q]{\gamma}\prod_{j=1}^{n}\left(\omega_j\right)^{w_j}}{\sqrt[q]{\prod_{j=1}^{n}\left(\gamma-(\omega_j)^q\right)^{w_j} + \prod_{j=1}^{n}\left(\omega_i\right)^{qw_j}}} \right) \tag{22}
$$

When $\gamma = 2$, the weighted q-rung orthopair fuzzy Hamacher average (q-ROFHA) operator transforms into the q-rung orthopair fuzzy Einstein average operator.

Step 8. Find the measures of the weighted product (WPM) β_i^2 for each alternative using the q-rung orthopair fuzzy Hamacher geometric mean (q-ROFHGM) operator. The q-ROFHGM operator is defined by Darko and Liang (2020):

$$q-ROFHGM=\beta_i^2=\left(\frac{\sqrt[q]{\gamma}\prod_{j=1}^{n}\left(\varphi_j\right)^{w_j}}{\sqrt[q]{\prod_{j=1}^{n}\left(1+(\gamma-1)\left(1-(\varphi_j)^q\right)\right)^{w_j}+(\gamma-1)\prod_{j=1}^{n}\left((\varphi_i)^q\right)^{w_j}}},\ \sqrt[q]{\frac{\prod_{j=1}^{n}\left(1+(\gamma-1)(\omega_j)^q\right)^{w_j}-\prod_{j=1}^{n}\left(1-(\omega_j)^q\right)^{w_j}}{\prod_{j=1}^{n}\left(1+(\gamma-1)(\omega_j)^q\right)^{w_j}+(\gamma-1)\prod_{j=1}^{n}\left(1-(\omega_j)^q\right)^{w_j}}}\right) \tag{23}$$

Step 9. The score values of WSM and WPM for each alternative are calculated by using Eq. (9).

Step 10. The aggregated measure δ_i for each alternative is calculated by Zavadskas et al. (2012):

$$\delta_i=\theta\alpha_i^1+(1-\theta)\beta_i^2 \tag{24}$$

, where θ is the range of 0 and 1. If $\theta=1$, the WASPAS method is converted into WSM, and $\theta=0$ is WPM.

Step 11. According to a descending order of δ_i, alternatives are ranked.

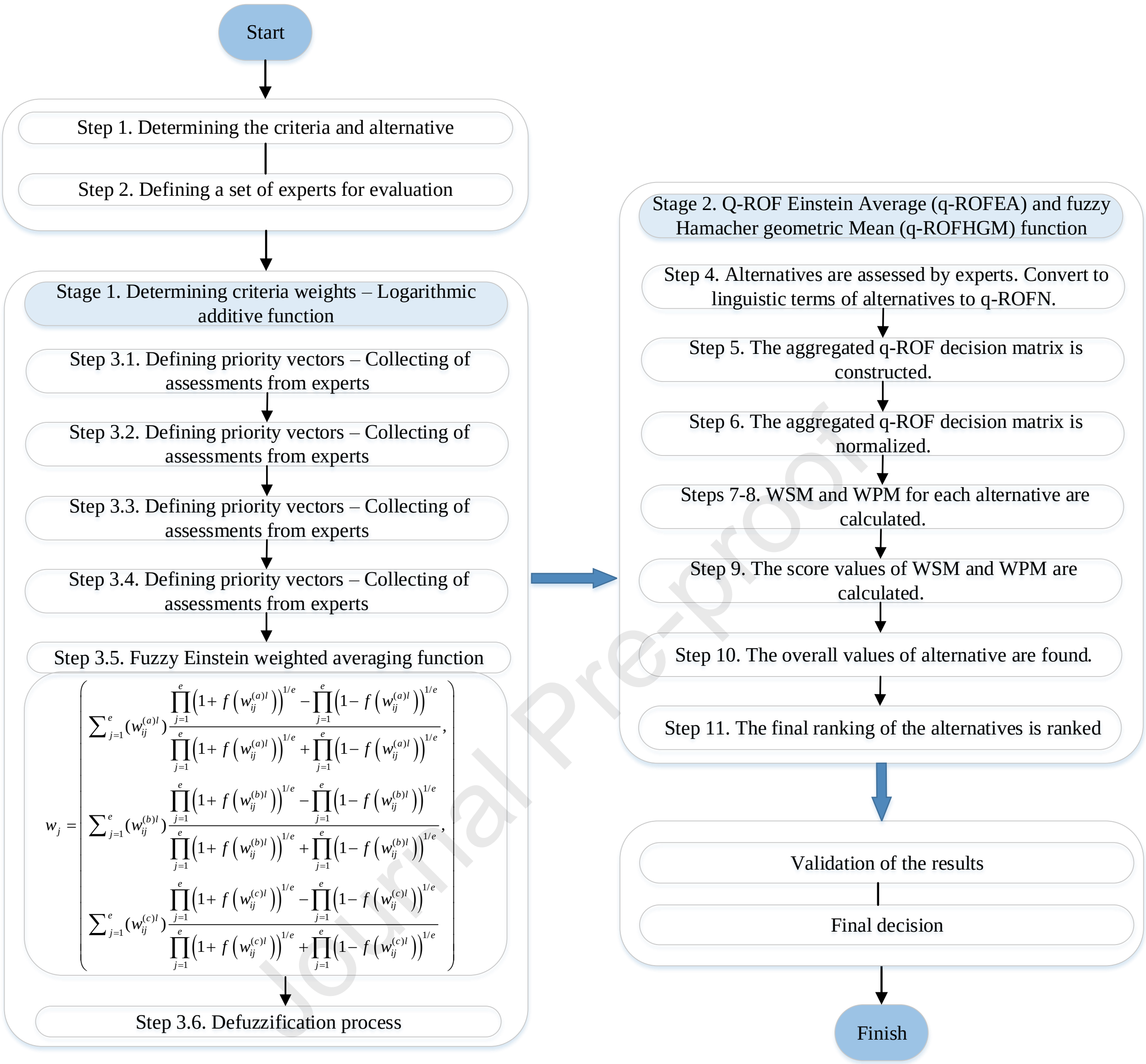


Fig. 2. The flowchart of the proposed model.

4. Case Study

While the number of accidents is increasing, policymakers should evaluate all alternatives to avert them. We consider a big city in a high-middle income developing country in which increasing e-scooter incidents are an issue. The governing authority in the city is ready to take action, yet it is required to prioritize the alternatives. Through extensive research on the existing literature, three different policies idenitfied that aim at providing safety for e-scooter use, namely infrastructure, safety training, and safe operation regulations, are included in our scenario. Then, we test the problem by taking experts' opinions whose reputations are also integrated into the analysis. The evaluation of alternatives was performed by five experts: Expert 1—An owner of an e-scooter sharing company (7 years), Expert 2—A manager from a traffic control center of a city (16 years), Expert 3—A manager at the metropolitan planning center of a city (15 years), Expert 4—A regional director in General Directorate of Highways (25 years), Expert 5—Transportation Engineer-Academician (21 years). The decision hierarchy of the structure of our decision-making problem is shown in Fig. 3.

(1) Definition of alternatives:

A_1: Infrastructure: Adequate infrastructure can affect users' willingness to switch their transportation modes (Glavic et al., 2021). Local administrators who try to adjust the transportation system for e-scooters should understand usage models and user demands (Zhang et al., 2021). E-scooter users can demand different infrastructure compared with the other modes' users (Zhang et al., 2021). For example, in Serbia, regulations do not recognize e-scooters and their users, where there is no appropriate infrastructure (Glavic et al., 2021). Infrastructure is one of the most crucial issues for e-scooter usage. The physical conditions of the road profile, the different arrangements, base surfaces, and the current separation represent obstacles to safe usage (Glavic et al., 2021). Different micro-mobility modes have different methods to draw the map. It is essential to have strategies leading to better results for cities (Moran, 2020).

A_2: Safety training: To improve safety, proper education and training should be provided. People who have not used e-scooters previously often ride them on crowded streets without training (Löcken et al., 2020). Policymakers should inform people about e-scooters to decrease e-scooter related injuries and also emphasize the importance of using helmets and safety education (Farley et al., 2020). Training can be a part of renting an e-scooter for the first time because it is required basic training for the users (Löcken et al., 2020). There are e-scooter pilot programs in Chicago and many cities which aim at training e-scooter riders and estimating the time savings (Smith, 2020).

A_3: Safe operation regulations: The role of rules and regulations as safety precautions is incontrovertible. Each government has a different approach to using e-scooter. Because of conflicts, the other members of traffic blame riders for using e-scooters rashly and breaking the rules (Tuncer et al., 2020). There are not any formal rules such as wearing protecting gear, not riding under influence, and limiting speed and age. E-scooters are unfamiliar to all people. So, policymakers should intervene in regulations to provide safety.

(2) Aspects and criteria:

(i) Safety aspects

C_1: Impact on vehicular traffic flow: Traffic congestion has become oneunpleasant feature of modern life in a city (Arnott et al., 1994). In both developed and developing countries, population growth causes traffic congestion (Chowdhury, 2013). With proper regulation, planners expect that e-scooters can reduce congestion (Schellong et al., 2019). E-Scooters have shown a high potential to help ease traffic congestion by decreasing trips made by vehicles (Yang et al., 2020). According to a search in Boise, e-scooters reduce the density of traffic (Islam, 2019). Hence, safety issues are also mitigated.

C_2: Impact on the pedestrian flow: Lack of regulations causes safety concerns from pedestrians. Local governments should launch pilot programs and establish agreements to prevent this situation. According to a study, e-scooters block pedestrian ways (James et al., 2019). Poor regulations result in e-scooter riders invading public spaces meant for pedestrians, therefore causing notable safety issues both for the users and the pedestrians (Maiti et al., 2020).

C_3: The number of mixed traffic (e-scooter and vehicular traffic) accidents: Governments are an essential part in setting the rules of e-scooter usage such as forbidding riding within pedestrian zones (Schellong et al., 2019). There are already cities with expanded bicycle lanes. On the other hand, riders are often forced to share the streets with vehicles, which increases traffic congestion and leads to accidents (Schellong et al., 2019). According to a study in the U.S., the number of recorded e-scooter injuries increased by 161% (Wüster et al., 2020). E-scooter-related accidents and injuries affect the whole body with external soft muscle injuries, major and minor musculoskeletal injuries represented the most common ones (Badeau et al., 2019).

C_4: The severity of the injuries from incidents between e-scooter and pedestrians: Frequent e-scooter riders experience greater injury severity. Also, cycling frequency is associated with injury severity (Cripton et al., 2015; Heesch et al., 2011). The severity of injuries is lower on pavement but sharing it with pedestrians can lead to more disagreements (Cicchino et al. 2021).

C_5. The severity of the injuries from incidents between e-scooter and vehicles: Vehicle crashes with e-scooters are rare (Bekhit et al., 2020; Blomberg et al., 2019; English et al., 2020; Trivedi et al., 2019), and when they happen, injuries are minor. Still, most fatally injured e-scooter users worldwide are hit by vehicles (Collaborative Sciences Center for Road Safety, 2020). Most of the

vehicle crashes occur at intersections (Dill et al., 2012; National Association of City Transportation Officials, 2014).

(ii) *Infrastructure (traffic management) aspects*

C_6: Proper road signs and displays for the safe operation of e-scooters: Breaking of basic traffic rules is one of the major factors connected to crashes. Researches propose that the signaling of turns can allow car drivers to expect and avoid potential conflicts with e-scooters (Löcken et al., 2020). Many countries require e-scooter users to signal turns by hand, and all users should be able to operate hand signals without problems (Löcken et al., 2020). However, e-scooter users still have to use bike lanes or pavements because of a lack of infrastructure.

C_7: Available lane for the e-scooter operation: There are not any exact and adopted routes and parking areas that e-scooter riders use. The Virginia Tech transportation authority arranged the road types in groups, such as cycle lanes, multi-use paths, and one-way roads to stop disagreements and accidents (Zhang et al., 2021). Unlike vehicle facilities, which take a comparably extensive method for construction and services, each existing infrastructure shared by e-scooters is designated for other uses (Ma et al., 2021). Without an available lane for e-scooters, there will be disagreements between users and the other transportation mode users (Ma et al., 2021).

C_8: Available parking space for the e-scooter operation: Because of the lack of dedicated road space, riders often use pavement or bike lanes to park. To prevent conflicts, e-scooter operators began performing geofencing techniques to control the usage (Jiao et al., 2020). To regulate parking issues, the Austin Transportation Department requires each e-scooter topark in chosen parking zones (Jiao, 2020).

(iii) *Cost Aspect*

C_9: E-scooter audit cost for safe operation: E-scooter contracts include a license fee, an application fee, and a per-vehicle fee. In some cities, the per-vehicle fee discounts by a profit of $5 each month after the first month. The amount can change from a city to another. For instance, Denver, Colorado requires both public property repair and maintenance bonds of $30 per vehicle, which the city can draw upon as required for costs connected to auditing and storing improperly parked vehicles (Blickstein et al., 2019). Some municipalities need to subsidize the cost of renting to develop e-scooter usage among the low-income groups (Blickstein et al., 2019).

C_{10}: Maintenance of the infrastructure: Transportation infrastructures need monitoring to estimate their situation and to produce proper maintenance strategies (Seraj et al., 2017). Traffic administration systems of sustainable mobility challenge obtaining traffic requirements while supporting a high level of environmental quality (Nathanail et al., 2021). E-scooters need different maintenance of the temporary area for parking. The current infrastructure is not available for these changes, because its main elements are missing. Consequently, it is hard for e-scooters to struggle with harmful modes of transport (Nikolaev et al., 2021).

C_{11}: Surveillance (cameras, etc.) requirement: Surveillance provides public safety and reduces congestion. Sensors and traffic control technologies are important for improving travel information (Mimbela et al., 2007). Improved surveillance technologies contribute to enhanced monitoring, traffic counting, and detection (Mimbela et al., 2007).

(iv) Sustainability Aspect

C_{12}: E-scooter ridership: E-scooters are an alternative for green mode from the sustainability view. Sustainable urban development's aim to encourage people to use public transportation and micro-mobility modes (Hosseinzadeh et al., 2021). E-scooter usage can reduce private vehicle use, especially for short-distance travel. So, it is an integrated part of sustainable urban transportation (Abduljabbar et al., 2021).

C_{13}: GHG emissions: In recent years, e-scooters have gained importance among planners because private car usage affects health, congestion, and air quality negatively (Abduljabbar et al., 2021). Their benefits, include health benefits, reduced emissions, and less pollution. (Abduljabbar et al., 2021). Investigators have determined the environmental benefits of e-scooters. They prove to help reduce carbon emissions only when they replace automobile travel (Tuncer and Brown, 2020). Studies have shown that e-scooters provide cost-saving by decreasing private vehicle use, which leads to GHG emission reductions (Shaheen et al., 2020).

C_{14}: Safe and accessible transportation opportunities for society: Accessibility is one of the most essential issues of a transportation system (Saif et al., 2019). E-scooters have a positive effect on both health aspects and social aspects such as safety and accessibility. With adequate regulations, e-scooters can provide safe and accessible transportation opportunities (Gössling, 2020).

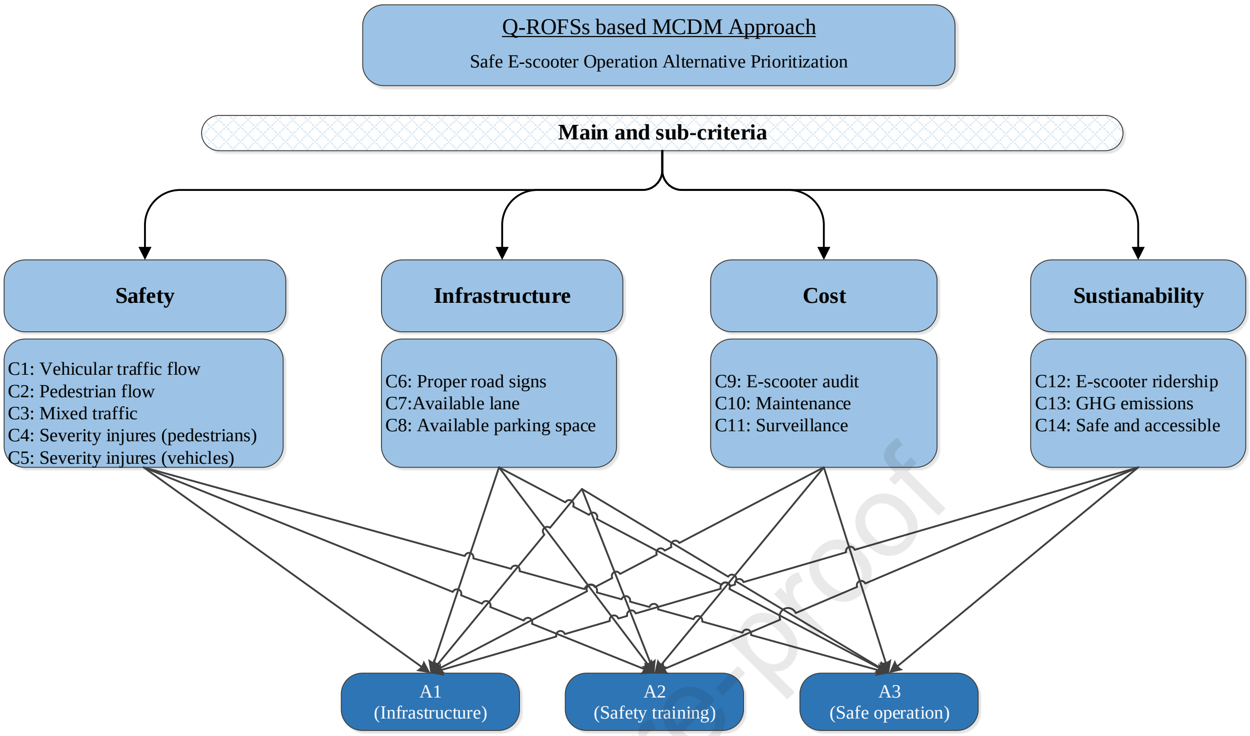


Fig. 3. The decision hierarchy of prioritizing the safe e-scooter operation alternative.

4.1. The proposed model results

Step 1. Three alternatives $(i = 1, 2, 3)$ and fourteen criteria $(j = 1, 2, \ldots, 14)$ are determined. A set of five experts $(p = 1, 2, \ldots, 5)$ is defined.

Step 2. Linguistic terms and their corresponding values for the evaluation of alternatives are identified as given in Table 2.

Table 2

Linguistic terms for rating alternatives and their corresponding values (Pınar and Boran, 2020).

Linguistic terms	q-ROFSs	
	φ	ω
Extremely low (EL)	0.15	0.95
Very low (VL)	0.25	0.85
Low (L)	0.35	0.75
Medium low (ML)	0.45	0.65
Medium (M)	0.55	0.55
Medium high (MH)	0.65	0.45
High (H)	0.75	0.35
Very high (VH)	0.85	0.25
Extremely high (EH)	0.95	0.15

Step 3. The weight coefficients of the criteria are calculated using the fuzzy logarithmic additive methodology:

Step 3.1. A priority vector $\psi^l = \left(\square^l_{T_1}, \square^l_{T_2}, \ldots, \square^l_{T_n} \right)$ $(1 \le l \le 5)$ is expressed for each expert. The five-point linguistic terms are presented in Table 3.

Table 3
Linguistic terms for weighting criteria and their corresponding fuzzy numbers.

Linguistic terms	Membership function
Very low (VL)	(1, 1, 2)
Low (L)	(1, 2, 3)
Medium (M)	(2, 3, 4)
High (H)	(3, 4, 5)
Very high (EH)	(4, 5, 5)

Later, the criteria are evaluated by five experts using the linguistic terms given in Table 3. The linguistic evaluations of criteria are stated in Table 4. Afterward, the linguistic terms in Table 4 are transformed into triangular fuzzy numbers with the help of Table 3.

Table 4
The linguistic evaluations of criteria for each expert.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
C_1	EH	EH	H	H	EH
C_2	VL	H	L	L	H
C_3	EH	H	EH	H	EH
C_4	EH	H	M	M	H
C_5	EH	EH	EH	EH	H
C_6	H	M	H	H	H
C_7	H	H	H	EH	M
C_8	M	H	M	L	M
C_9	H	H	L	M	H
C_{10}	H	EH	H	H	L
C_{11}	L	H	H	M	EH
C_{12}	H	M	H	M	L
C_{13}	H	EH	M	H	M
C_{14}	EH	EH	EH	H	H

Step 3.2. Absolute anti-ideal point $\varpi_{AAIP} = (0.4, 0.5, 0.6)$ is determined using Eq. (14).

Step 3.3. The vectors of the ratio $\varsigma^l = \left(\Delta^l_{T_1}, \Delta^l_{T_2}, \ldots, \Delta^l_{T_n} \right)$ $(1 \le l \le 5)$ are calculated by Eq. (15) using Table 4. The aggregated vectors are reported in Table 5.

Table 5
The vectors of the ratio.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
C_1	(6.67,10,12.5)	(6.67,10,12.5)	(5,8,12.5)	(5,8,12.5)	(6.67,10,12.5)
C_2	(1.67,2,5)	(5,8,12.5)	(1.67,4,7.5)	(1.67,4,7.5)	(5,8,12.5)
C_3	(6.67,10,12.5)	(5,8,12.5)	(6.67,10,12.5)	(5,8,12.5)	(6.67,10,12.5)
C_4	(6.67,10,12.5)	(5,8,12.5)	(3.33,6,10)	(3.33,6,10)	(5,8,12.5)
C_5	(6.67,10,12.5)	(6.67,10,12.5)	(6.67,10,12.5)	(6.67,10,12.5)	(5,8,12.5)
C_6	(5,8,12.5)	(3.33,6,10)	(5,8,12.5)	(5,8,12.5)	(5,8,12.5)
C_7	(5,8,12.5)	(5,8,12.5)	(5,8,12.5)	(6.67,10,12.5)	(3.33,6,10)
C_8	(3.33,6,10)	(5,8,12.5)	(3.33,6,10)	(1.67,4,7.5)	(3.33,6,10)
C_9	(5,8,12.5)	(5,8,12.5)	(1.67,4,7.5)	(3.33,6,10)	(5,8,12.5)
C_{10}	(5,8,12.5)	(6.67,10,12.5)	(5,8,12.5)	(5,8,12.5)	(1.67,4,7.5)
C_{11}	(1.67,4,7.5)	(5,8,12.5)	(5,8,12.5)	(3.33,6,10)	(6.67,10,12.5)
C_{12}	(5,8,12.5)	(3.33,6,10)	(5,8,12.5)	(3.33,6,10)	(1.67,4,7.5)
C_{13}	(5,8,12.5)	(6.67,10,12.5)	(3.33,6,10)	(5,8,12.5)	(3.33,6,10)
C_{14}	(6.67,10,12.5)	(6.67,10,12.5)	(6.67,10,12.5)	(5,8,12.5)	(5,8,12.5)

Steps 3.4 and 3.5. Fuzzy vectors of weight coefficients of the criteria are calculated by Eqs. (16) and (17) using Table 5. The fuzzy weights (local values) are provided in Table 6.

Table 6
Aggregated and defuzzified by weight coefficients of the criteria.

Criteria	Local values	Score values
C_1	(0.053, 0.079, 0.122)	0.0820
C_2	(0.028, 0.055, 0.103)	0.0584
C_3	(0.053, 0.079, 0.122)	0.0821
C_4	(0.044, 0.072, 0.118)	0.0750
C_5	(0.054, 0.081, 0.122)	0.0834
C_6	(0.045, 0.073, 0.12)	0.0760
C_7	(0.047, 0.074, 0.12)	0.0772
C_8	(0.034, 0.063, 0.11)	0.0662
C_9	(0.039, 0.067, 0.115)	0.0705
C_{10}	(0.043, 0.071, 0.117)	0.0740
C_{11}	(0.04, 0.069, 0.115)	0.0720
C_{12}	(0.036, 0.066, 0.113)	0.0685
C_{13}	(0.044, 0.072, 0.118)	0.0750
C_{14}	(0.053, 0.079, 0.122)	0.0820

Step 3.6. The defuzzification process is given in Eq. (18) is used to convert the fuzzy weights into crisp weights. Crisp weights called score values are provided in Table 7.

Step 4. The experts expressed their opinions about the ratings of five alternatives in terms of fourteen criteria using the linguistic terms given in Table 2. The linguistic evaluations of alternatives are presented in Table 7. The linguistic evaluations of experts are converted to the corresponding q-ROFNs based on the scale in Table 2.

Table 7
Linguistic terms of alternatives using experts' opinions.

Alt.	Experts	Criteria													
		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}
A_1	E_1	EL	EL	L	L	L	EH	EH	EH	L	EL	EL	EH	EL	EH
	E_2	VL	L	EL	VL	EL	MH	VH	H	ML	EL	VL	M	VL	EL
	E_3	VL	L	VL	ML	EL	H	VH	H	VH	VL	ML	EH	EL	VH
	E_4	VL	MH	L	VL	EL	VH	EH	M	L	EL	L	H	VL	EH
	E_5	EL	VL	EL	L	EL	VH	EH	VH	MH	EL	VL	H	M	EH
A_2	E_1	L	L	EL	EL	EL	H	VH	H	VL	VL	L	H	M	VH
	E_2	M	ML	L	ML	L	H	H	M	L	MH	VH	H	M	L
	E_3	L	L	L	VL	VL	MH	H	H	VH	EH	EH	MH	ML	MH
	E_4	L	M	M	L	VL	H	M	H	M	L	MH	VH	L	VH
	E_5	ML	EL	M	VL	M	H	ML	M	M	MH	MH	VH	ML	MH
A_3	E_1	VL	VL	VL	VL	VL	VH	H	VH	EL	L	VL	VH	MH	H
	E_2	L	L	VL	L	ML	VH	MH	ML	VH	ML	M	MH	L	ML
	E_3	EL	VL	EL	VL	EL	H	MH	MH	EL	ML	EL	ML	MH	VH
	E_4	M	VH	ML	ML	L	L	VL	VH	VL	H	VH	M	ML	MH
	E_5	VL	EL	ML	L	L	EH	M	MH	EL	VH	EL	M	ML	H

Step 5. Individual q-ROF decision matrices are aggregated to obtain the q-ROF decision matrix by Eq. (12) with the help of Table 7. The aggregated q-ROF decision matrix $\tilde{Y}$ is given in Table 8.

Table 8
The aggregated q-ROF decision matrix.

Criteria	Alternatives

	A_1	A_2	A_3
C_1	(0.228,0.889)	(0.443,0.685)	(0.411,0.777)
C_2	(0.484,0.728)	(0.438,0.718)	(0.645,0.664)
C_3	(0.297,0.845)	(0.468,0.695)	(0.379,0.781)
C_4	(0.362,0.766)	(0.349,0.803)	(0.362,0.766)
C_5	(0.257,0.906)	(0.411,0.777)	(0.36,0.783)
C_6	(0.855,0.272)	(0.735,0.368)	(0.85,0.301)
C_7	(0.925,0.184)	(0.734,0.405)	(0.64,0.506)
C_8	(0.838,0.302)	(0.699,0.419)	(0.758,0.383)
C_9	(0.672,0.528)	(0.665,0.545)	(0.644,0.711)
C_{10}	(0.191,0.929)	(0.783,0.454)	(0.697,0.488)
C_{11}	(0.349,0.803)	(0.82,0.356)	(0.654,0.638)
C_{12}	(0.874,0.273)	(0.79,0.322)	(0.687,0.467)
C_{13}	(0.403,0.815)	(0.492,0.626)	(0.562,0.577)
C_{14}	(0.913,0.24)	(0.757,0.394)	(0.742,0.389)

Step 6. The normalized q-ROF decision matrix $\tilde{U} = \left(\tilde{u}_{ij}\right)_{nxm}$ is established by Eq. (21) using Table 8 and is reported in Table 9.

Table 9
The normalized decision matrix.

Criteria	Alternatives		
	A_1	A_2	A_3
C_1	(0.889,0.228)	(0.685,0.443)	(0.777,0.411)
C_2	(0.728,0.484)	(0.718,0.438)	(0.664,0.645)
C_3	(0.845,0.297)	(0.695,0.468)	(0.781,0.379)
C_4	(0.766,0.362)	(0.803,0.349)	(0.766,0.362)
C_5	(0.906,0.257)	(0.777,0.411)	(0.783,0.36)
C_6	(0.855,0.272)	(0.735,0.368)	(0.85,0.301)
C_7	(0.925,0.184)	(0.734,0.405)	(0.64,0.506)
C_8	(0.838,0.302)	(0.699,0.419)	(0.758,0.383)
C_9	(0.528,0.672)	(0.545,0.665)	(0.711,0.644)
C_{10}	(0.929,0.191)	(0.454,0.783)	(0.488,0.697)
C_{11}	(0.803,0.349)	(0.356,0.82)	(0.638,0.654)
C_{12}	(0.874,0.273)	(0.79,0.322)	(0.687,0.467)
C_{13}	(0.815,0.403)	(0.626,0.492)	(0.577,0.562)
C_{14}	(0.913,0.24)	(0.757,0.394)	(0.742,0.389)

Steps 7-8. The measures of weighted sum (WSM) α_i^1 are calculated by the Wq-ROFEA operator given in Eq. (22) with the help of Table 9. The results of the Wq-ROFEA operator are given in Table 10. The measures of the weighted product (WPM) β_i^2 for each alternative are calculated by Eq. (23) using the q-ROFHGM operator presented in Eq. (23) with the help of Table 9. The acquired results from the q-ROFHGM operator are presented in Table 10.

Table 10
The q-ROF values of WSM and WPM for each alternative.

Alternatives	WSM		WPM	
	φ	ω	φ	ω
A1	0.865	0.282	0.825	0.424
A2	0.713	0.448	0.646	0.587
A3	0.736	0.444	0.690	0.543

Step 9. The score values of WSM and WPM for each alternative are found by Eq. (9) using the q-ROF values in Table 10. The results of α^1 and β^1 are listed in Table 11.

Table 11
The q-ROF values of WSM and WPM for each alternative.

Alternatives	α^1	β^1	δ_i	Rank
A_1	0.742	0.685	0.713	1
A_2	0.583	0.522	0.552	3
A_3	0.600	0.555	0.577	2

Step 10. The WASPAS measure δ_i is computed using Eq. (24) with the help of the values of α^1, and β^1. The overall values of the proposed model are given in Table 11.

Step 11. The final ranking of the alternatives is ranked by δ_i values. The ranking of alternatives is $A_1 > A_3 > A_2$.

4.2. Checking the stability of the results

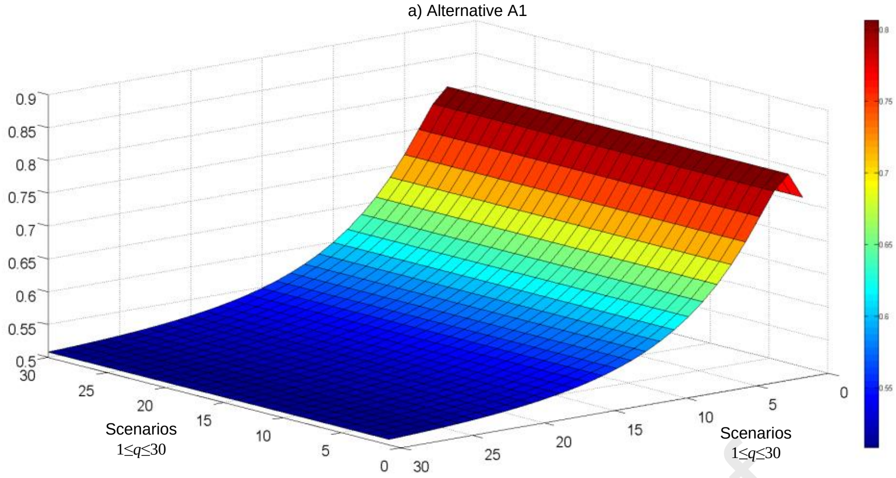
In the model presented in this paper, it is necessary to define several subjective parameters by the decision-maker. The values of these parameters are not unique and predetermined but depend on the conditions in which the system is modeled and the decision maker’s perceptions. Therefore, it can be expected that the values of these parameters change in dynamic situations, so it is necessary to analyze the stability of the solution in the event of a change in subjectively defined parameters. Such an analysis will enable us to consider the influence of these parameters on the final results of the model.

In the Q-Rung orthopair based multi-criteria framework, three subjective parameters $\left(q,\gamma,\varpi_{AAIP}\right)$ were identified. In the next section, the analysis of the stability of the solution was performed through three phases. In the first two phases, the influence of the parameters q and γ on the transformation of the values of Q-Rung orthopair Hamacher functions is presented. In the third phase, the influence of ϖ_{AAIP} values on the change of criterion weight coefficients is presented.

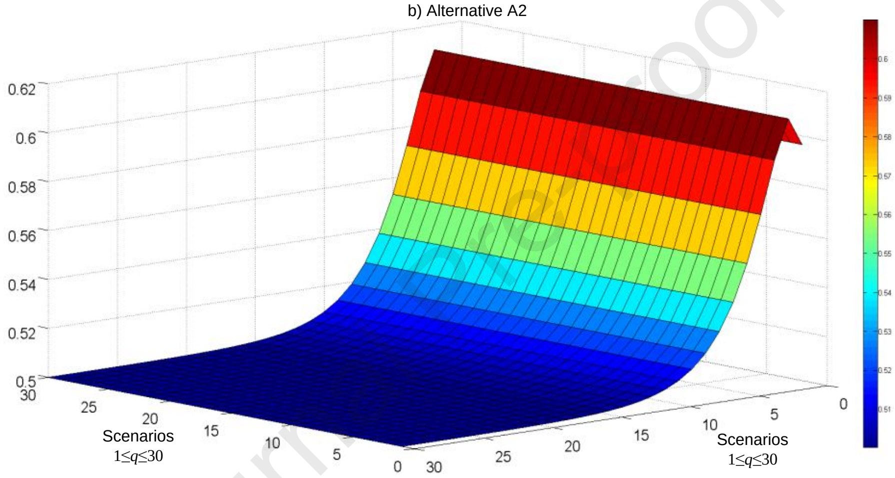
Phase 1: Influence of parameter q on ranking results

In the initial solution, the value of the parameter $q=5$ was adopted. The stated value was assumed based on the consensus of the decision-makers. In the following section, the change of parameter q in the interval $1\leq q\leq 30$ is simulated. Fig. 4 shows the influence of parameter q on the change of the weighted Q-Rung orthopair fuzzy Einstein function.

a) Alternative A1



b) Alternative A2



c) Alternative A3

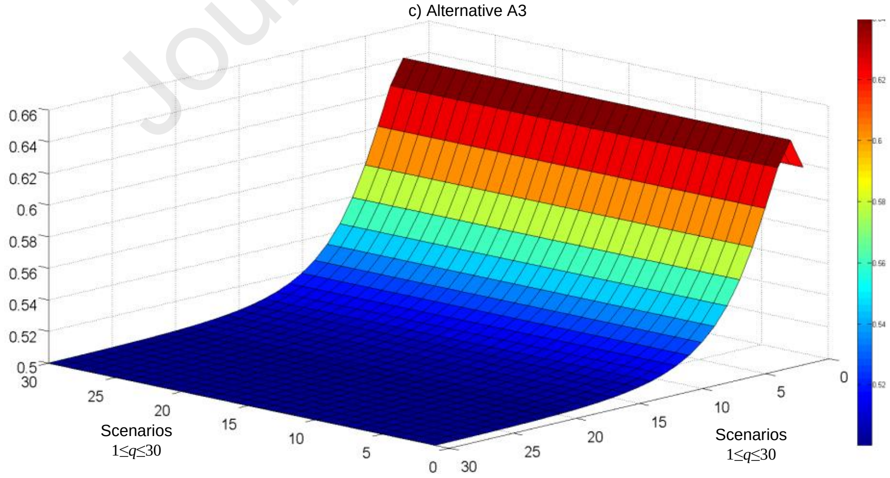
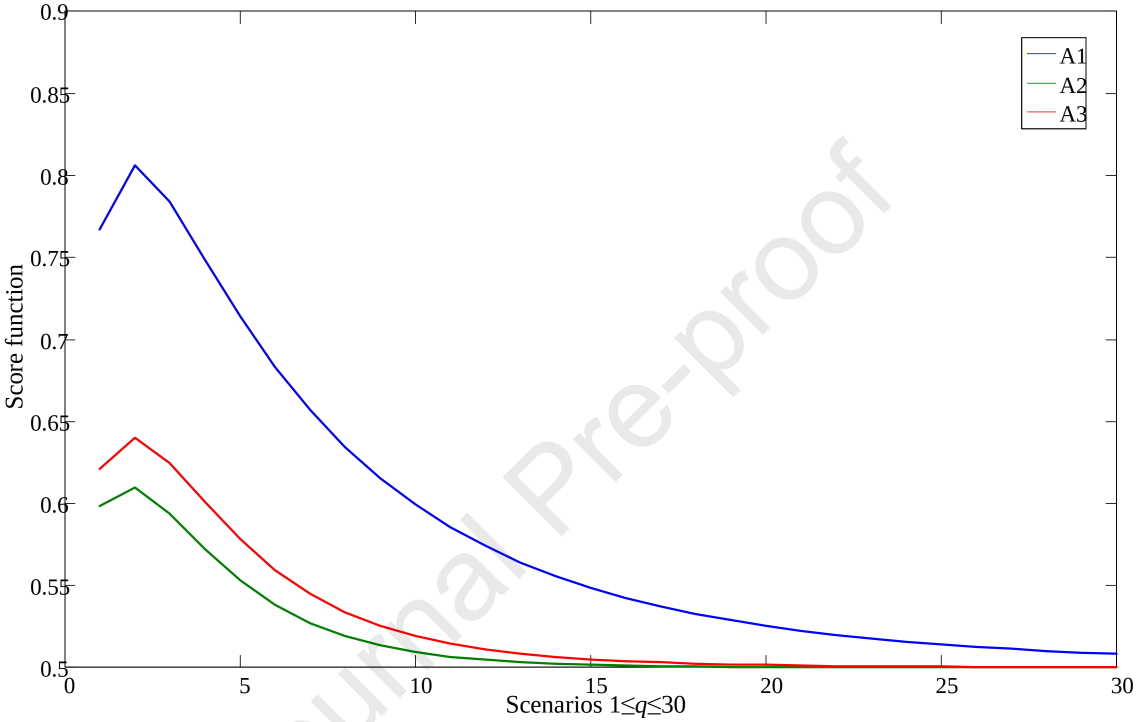
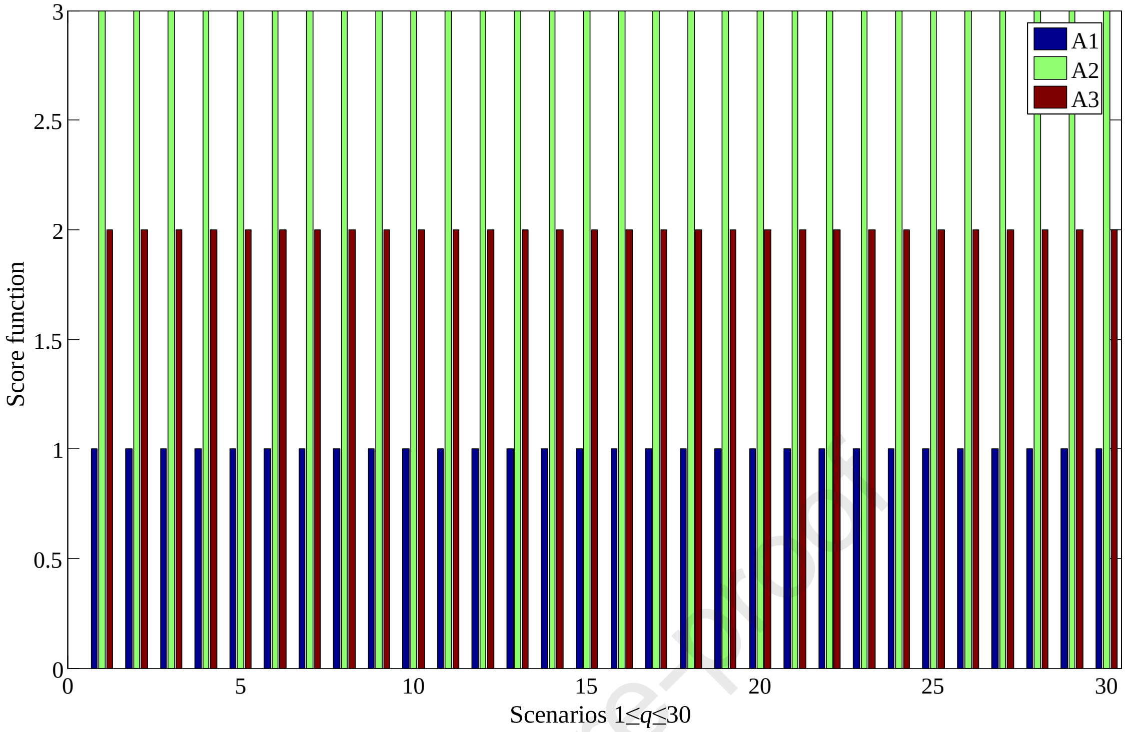


Fig. 4. Influence of parameter q on change of weighted Q-Rung orthopair fuzzy Einstein function.

The simulation was performed through 30 scenarios. In the first scenario, the value $q=1$ was adopted, while in each subsequent scenario, the value q was increased by one. The results in Fig. 4 show that the change in the value of the parameter q significantly affects the change in the integrated score functions of the alternatives. An increase in the value of the parameter q in the interval $1 \le q \le 30$ causes a decrease in the integrated score functions of all three alternatives. Also, the gap between the integrated score functions is narrowed through the scenarios, which can be seen in Fig. 4. Such changes can lead to a change in the initial rank, which is analyzed in the next section, Fig. 5.



(a) Changing score functions



(b) Changing ranks

Fig. 5. Influence of parameter q on change of rank of alternatives.

Fig. 5(a) compares the changes in the integrated score functions of the alternatives over 30 scenarios. The results show that the increase in the value of the parameter q affects the approximation of the score functions of the alternatives, which significantly complicates the decision. The values $1 \le q \le 10$ enable a clear definition of the advantages between the alternatives, so it is recommended that when defining the initial solution, the values of the parameters from the interval $1 \le q \le 10$ be considered. From the presented analysis, we can conclude that the initial rank $A_1 > A_3 > A_2$ is confirmed (Fig. 5 (b)), i.e., that alternative A_1 stands out as the dominant solution from the set.

Phase 2: Influence of parameters γ on ranking results

The Hamacher function was used to define the weighted sequences in the multi-criteria framework, and in the function, the parameter $\gamma = 2$ was adopted. By adopting the value $\gamma = 2$, the Hamacher function is transformed into an Einstein function based on which the initial solution is defined. Since the value of the parameter γ is determined based on subjective assessments of experts, it is necessary to analyze the dependence of the initial solution on the change in the value of that parameter. Fig. 6 shows the changes in the value of the weighted Q-Rung orthopair Hamacher function caused by the change in the parameter γ in the interval $1 \le \gamma \le 100$.

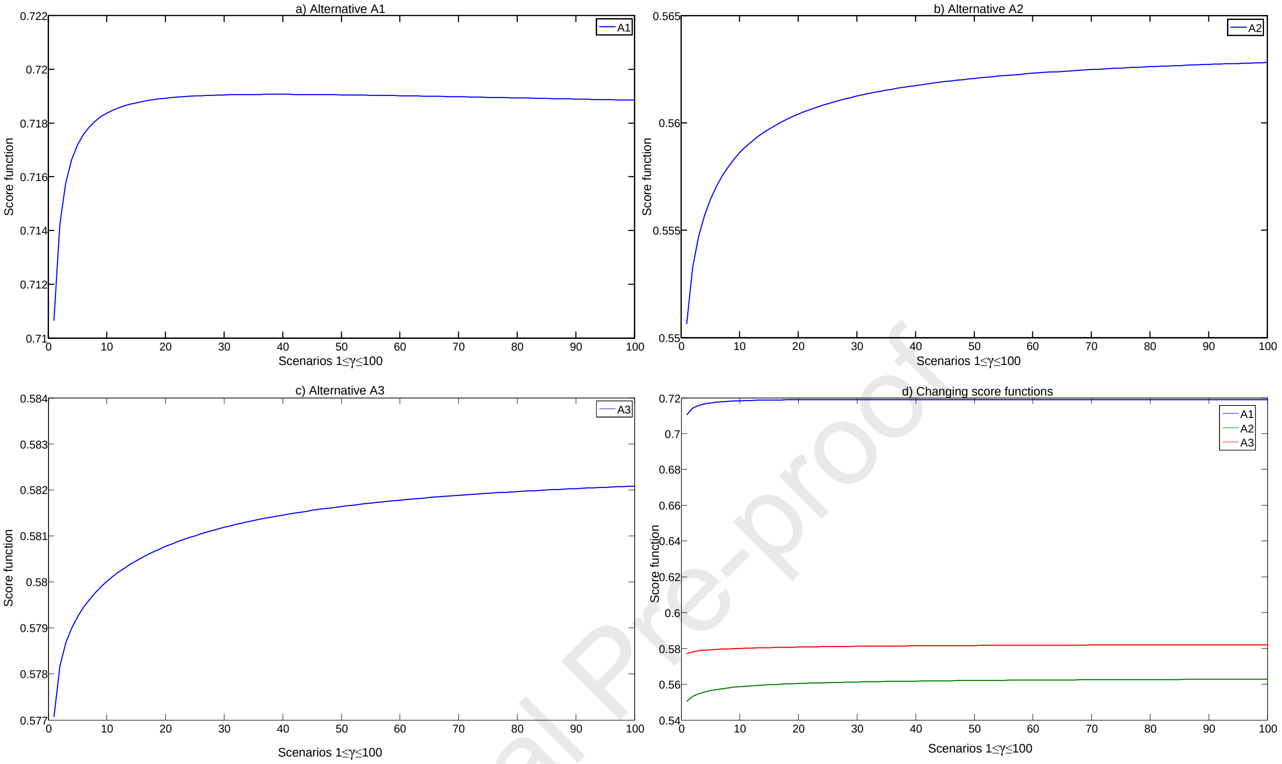


Fig. 6. Influence of parameter γ on change of weighted Q-Rung orthopair fuzzy function.

The results in Fig. 6 (a-c) indicate that the increase in the parameter $1 \le \gamma \le 100$ affects the increase in the integrated score function (ISF) of all alternatives according to the following: for alternatives, A_1 there is an increase in ISF in the interval $[0.711, 0.719]$; for A_2 in the interval $[0.551, 0.563]$, and for A_3 in the interval $[0.577, 0.582]$. Based on the presented changes in the ISF value, changes in the parameter γ are observed and do not affect the difference in the initial rank of the alternatives. Therefore, based on the presented analysis, we can conclude that the initial rank $A_1 > A_3 > A_2$ is confirmed and the alternative A_1 is the dominant solution.

Phase 3: Use absolute anti-ideal point (ϖ_{AAIP}) *on model results*

Absolute anti-ideal point (AAIP) was used in fuzzy logarithmic additive assessment of the weight coefficients (LAAW) methodology to define the reference relationships between the criteria. For the calculation of the initial fuzzy vector of weight coefficients, the fuzzy value $\varpi_{AAIP} = (0.4, 0.5, 0.6)$ was adopted. Since AAIP can have any value from the interval $0 < \varpi_{AAIP} < 1$, it is necessary to answer the question, Is the initial solution valid for other values of AAIP from the interval $0 < \varpi_{AAIP} < 1$?

In the following section, thirty-three scenarios were formed during which new vectors of weight coefficients for AAIP values from the interval $0 < \varpi_{AAIP} < 1$ were formed. In the first scenario, the value $\varpi_{AAIP} = 0.010$ is adopted. In each subsequent scenario, the value of AAIP is increased by 0.03 by applying the expression $\varpi^{s}_{AAIP} = \varpi^{s-1}_{AAIP} + 0.03$, where *s* denotes the number of scenarios. For each newly formed value of AAIP, a new vector of weight coefficients was created, Fig. 7.

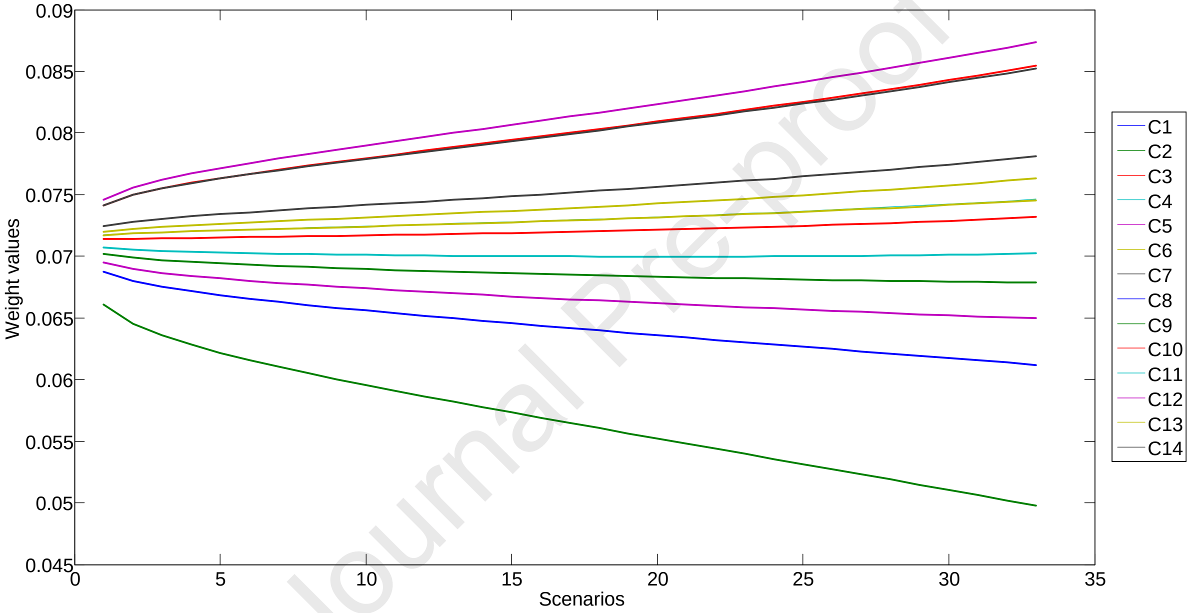


Fig. 7. Dependence of weights vector on AAIP change.

It can be seen from Fig. 7 that there is a significant dependence of the weight coefficients of the criteria on the adopted AAIP reference value. In the following part, we considered the dependence of ISF alternatives to AAIP changes. For each newly generated vector of the weight coefficients of the criteria, a new value of the alternative ISF is defined, Fig. 8.

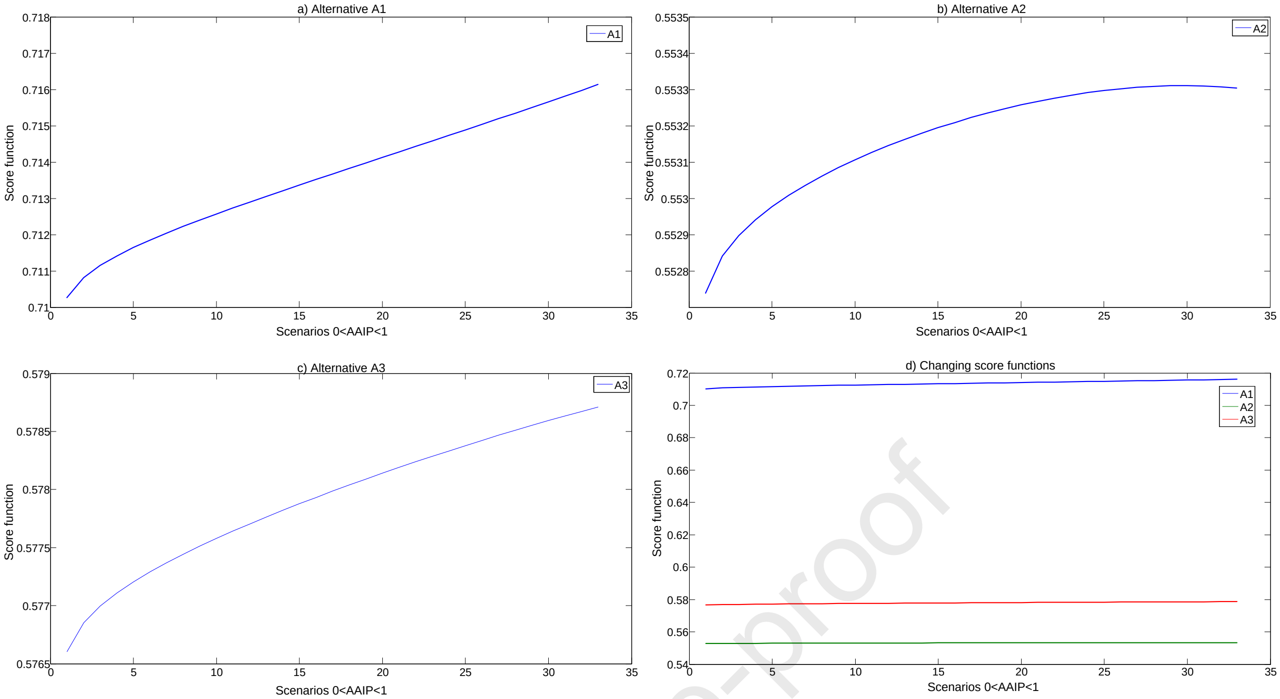


Fig. 8. Dependence of ISF alternatives to AAIP changes

We can see that simulation of the increase in AAIP values through scenarios leads to increasing ISF (Fig. 8(a-c)). Thus, increasing the value of AAIP influence increasing the value of the ISF of all alternatives. However, the increases in the ISF of the simulation are gradual, so there is no change in the rankings of the alternatives, which is confirmed by Fig. 8(d). Therefore, based on the presented analysis, we can conclude that alternative A_1 is the dominant solution and that the initial rank is confirmed and credible.

4.3. Comparative analysis

To test and validate the proposed model, it has been compared with other q-ROFSs based TOPSIS approach (Alkan and Kahraman, 2021). The ranking results for proposed model and existing MCDM model are reported in Table 12. According to the results obtained, it can be seen that there is no difference in the alternative ranking order obtained between the proposed and the existing method. It is seen that the A_1 alternative is the best, while the A_2 alternative is the worst.

Table 12
The comparison ranking of the proposed model and one existing q-ROFSs based MCDM model.

Alternatives	Proposed Model		Existing MCDM (Alkan and Kahraman, 2021)	
	Score	Ranking	Score	Ranking
A_1	0.713	1	0.679	1
A_2	0.552	3	0.188	3

A$_3$	0.577	2		0.366	2

In the next part (see Table 13), a comparison of multi-criteria techniques was performed and their specifics were pointed out.

Table 13

Comparisons of methods

Characteristics	Proposed Model	Existing MCDM
Flexible decision making due to decision makers' risk attitude	Yes	No
Allows input parameters supporting each other	Yes	No
Flexibility in real applications	Yes	Partialy
Clearly defined range of alternatives	Yes	Yes
Algorithm complexity	Partialy	Partialy

Based on the comparison of the results, it can be concluded that A$_1$ is the best alternative according to all methodologies. However, unlike the classic extensions of MCMD techniques to the fuzzy environment, q-ROFS Enistein WASPAS allow for flexible decision-making due to decisionmakers' risk attitude and representation of the interrelationships between decision-making matrix parameters. These characteristics of the q-ROFS Enistein WASPAS model represent a significant advantage that affects the flexibility of the presented methodology when applied in real applications.

5. Results and Discussion

Following the determination of the alternatives and the criteria, a survey was prepared. Then, experts filled in the survey questionnaire. Based on the answers received from the experts, an advantage prioritization of the three alternatives was arranged. According to the results, it was perceived that the safety training alternative is the least advantageous, followed by safe operation regulations. Finally, infrastructure planning is the best alternative among the others.

At the point of decision-making, decision-makers should try to integrate e-scooters into urban transportation. Safety concerns and practical considerations among the people should be observed. So, they can find the main reason for motivating and demotivating factors of e-scooter usage. Also, governments should find a way to justify replacing car usage in environmental terms. Knowing the general information about users and their opinions about e-scooter usage can be beneficial before making laws and regulations. The process can start with informing all transportation modes of the increasing presence of e-scooters. Then, improving road conditions and creating parking areas should be pursued.

Among the alternatives, safety training is the least effective way to make e-scooter usage safer. Although people know how to use e-scooters, training is not enough to create a safe environment. Merely wearing protective gear cannot protect people if other members of the transport system are unaware of how to interact with e-scooter users. While informative initiatives and safety training can improve awareness, being aware of safety issues and carefully behaving are inadequate to decrease accidents and injuries. As mentioned above, some companies attach cards including riding instructions and restrictions, and also there are pilot programs, but safety issues are still ongoing. Other alternatives are needed to provide safer riding conditions. All these considered, the alternative of training and informing is the least advantageous one among them.

Rules and regulations are seen to be the second most advantageous alternative. As a safety precaution, regulations have a crucial role. Lack of regulations causes conflicts among the members of traffic using different transportation means. Rules such as limiting speed and age can improve the safety of e-scooter usage. Although some companies indicated the speed limit and requirements, more needs to be done. Even if adequate arrangements are made, there would be a lack of adequate infrastructure. Without enhanced and sufficient infrastructure enhancement, it is impossible to have safe travel conditions. As a result of these reasons, regulations are the second most advantageous alternative.

It is seen that infrastructure planning is the most advantageous alternative to provide a safe environment. With the upgraded and changed infrastructure, e-scooter usage and conflicts among the other modes can decrease dramatically. Properly chosen roads and also parking areas for e-scooters provide a safe trip for each transport mode. Extended cycle lanes and sufficient road space lead to reduced traffic jams. Arranged road types can prevent disagreements and accidents. Better road conditions can overcome the safety issues and conflicts between pedestrians and e-scooter users. Considering all these alternatives, enhanced infrastructure is the most encouraging alternative to create a safe environment by solving the problem.

6. Managerial and Policy Implications

E-scooters are one of the most eco-friendly modes of transportation. Also, because of their accessibility and low-cost options, they have become increasingly popular since their introduction, especially in emerging markets and lower-middle-income countries. E-scooters respond to the public’s requirements, but with their introduction, e-scooter associated injuries have occurred. When e-scooters were first introduced, countries lacked proper policies. To prevent conflicts, some governments made regulations on the organization of e-scooters. Parking inappropriately and blocking pavements are well-known complaints about shared e-scooters. Many countries have created regulations about parking (James et al., 2019; Zou et al., 2020). Some countries banned to use of e-scooter, and some of them were limited to age and speed or redesigning parking zones (Sikka et al., 2019; Nikiforiadis et al., 2021; Latinopoulos et al., 2021; Bozzi and Aguilera, 2021). While some classified them as a bicycle, some classified them as a motor vehicle (Latinopoulos et al., 2021). All countries try to improve regulations, but their policies are very diverse (Button et al., 2020; Sareen et al., 2021). Infrastructure planning is the most advantageous alternative in terms of safety issues. Studies about e-scooter often take a narrow look at security issues and don't offer policymakers a way to resolve the problem (James et al., 2019; Liew et al., 2020; Yang et al., 2020). To this end, olicymakers must take action to lessen e-scooter accidents. While there are countries like England banning e-scooters, this is not a beneficial method for sustainable transportation. Implementations should regard the aim of sustainable cities and public health. Municipalities and policymakers can examine the suggested alternatives during the decision-making process. If they do not take relevant measures, the unsafe environment in the traffic already caused by motor vehicles will continue. Then it will be harder to fix the situation. Laws that people will obey must be made to avoid such a situation. Afterward, infrastructure planning should develop so that people can precisely apply these laws. Certain roads can be built for e-scooters or at least, existing roads can be improved to provide the usage of e-scooters and indeed sustainable transportation.

A safe environment means safe driving conditions. The welfare of all transportation modes can be provided with optimized infrastructure. All traffic conflicts led by e-scooters can reduce with that way. For example, decision-makers should investigate the relationship between speed and safety for e-scooters. Also, they should investigate some characteristics, such as health conditions and age, before taking precautions. The enforcement of wearing a helmet, limited age, and speed can be those precautions. With the arrangements to be made in the parking areas, the health of riders and non-riders will be secured. All alternatives can be considered; however, decision-makers should choose the best alternative to apply according to countries' requirements and financial situation.

7. Conclusion

This study set out to propose a decision-making model based for prioritizing alternatives for safe e-scooter operation. The results showed that among the three alternatives of infrastructure (A1), safety training (A2) and safe operation regulations (A3), safety training with informative actions is the least advantageous alternative, followed by the alternative of rules and regulations for e-scooters. The most advantageous alternative is enhanced infrastructure. By introducing e-scooter, traffic conflicts have increased. This creates challenges for all governments. Most countries have responded by taking safety precautions. Recorded injuries associated with e-scooters show that evaluating the alternatives will be beneficial for everyone. These alternatives and criteria, especially infrastructure-related ones, will improve the safety on the roads and decrease the conflicts among the modes. Governments should intervene in the issue and enhance the current infrastructure.

In this study, we presented an efficient q-ROFSs based decision-making model for solving the safe e-scooter operation alternative prioritization problem. The proposed model is composed of two main stages. In the first stage, a fuzzy logarithmic additive assessment of the weight coefficients methodology and fuzzy Einstein weighted averaging operator are used to determine the criteria weights. In the first stage, the concept of q-ROFSs is used to handle the uncertainty in the information. Later, q-rung orthopair fuzzy sets (q-ROFSs) based decision-making model integrating q-rung orthopair fuzzy Einstein average (q-ROFEA), q-rung orthopair fuzzy Hamacher geometric mean (q-ROFHGM) operator applies to rank the alternatives and choose the best alternative among three alternatives.

This research fills a gap regarding the selection process of the best policy towards taking safety precautions for e-scooter usage. In this study, the best alternative is seen to enhance infrastructure. Still, considering the suitability of the location and the requirements of the time, alternatives and the criteria may vary and results may be different, but the methodology stays the same. Therefore, the proposed methodology of this study provides a guide for authorities when selecting the optimal policies in the struggle with safety issues of e-scooters in particular and in new modes of transportation in general.

The proposed model can easily adapt to the practical situations of different multi-criteria decision-making problems. In future studies, the proposed model can be extended with various multi-criteria decision-making models, such as Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH), Measurement Alternatives and Ranking according to the COmpromise Solution (MARCOS), mulTi-noRmalization mUlti-distance aSsessmenT (TRUST), (ELimination Et Choix Traduisant la REalité (ELECTRE III), and so on. Each method has a different mathematical background. This can complicate the solution of the model according to the number of criteria and alternatives. The proposed method can be extended to other types of ordinary fuzzy sets, such as linear Diphantine fuzzy, hesitant fuzzy sets, type-2 fuzzy sets, rough sets, and neutrosophic sets. Generalized comparative linguistic (Chen et al., 2021) can be implemented to determine criterion weights. More attention could be paid to interactions between criteria, which can be supported by various methods. The number of criteria and alternatives can be increased to indicate the robustness of the proposed model. In order to better reflect the interactive effect between the degree of membership and the degree of non-membership, the operators proposed by Wang and Garg (2021) can be applied.

One of the main limitations is its mathematical complexity, which is the result of applying Einstein and Hamacher norms to transform the WS and WP functions. The mathematical complexity of the proposed model is a potential limiting factor for implementation by many experts. As this is a model with a clear potential for the rational processing of complex, ambiguous and group information, the Fuzzy Einstein-based WASPAS model is expected to be implemented as part of future decision support systems. Therefore, further research should be conducted on the development of the Fuzzy Einstein-based WASPAS decision support system. This will remove the limitations of the mathematical complexity of the model will become acceptable with more experts.

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Highlights

- We present q-ROFSs based decision-making model, including integrating q-ROFEA, and q-ROFHGM.
- Four safe e-scooter operation alternatives are prioritized based on the MCDM model.
- 14 different criteria grouped under 4 main criteria aspects were determined.
- A detailed stability analysis is performed on the changes in parameter values of the proposed model.

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

On behalf of all co-authors
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