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Evaluation of metaverse integration alternatives of sharing economy in transportation using fuzzy Schweizer-Sklar based ordinal priority approach

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A R T I C L E I N F O

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A B S T R A C T

Sharing economy transportation applications reduce car ownership and single-vehicle occupancy, contributing to the region's environmental sustainability. Metaverse is a promising new technology that combines sharing economy applications with transportation networks. By combining these two approaches, authorities can improve the sustainability of sharing economy applications. This study aims to assist decision-makers and authorities by developing a multi-criterion decision-making (MCDM) model that prioritizes three sharing economy-based metaverse integration alternatives, namely integrating safety measures, payment systems, and the optimization of operations in the metaverse. A novel multi-criteria framework, including fuzzy Schweizer-Sklar norms based on the Ordinal Priority Approach (OPA) to assess the metaverse integration alternatives, is developed. To rank the alternatives, non-linear processing of information based on the fuzzy Schweizer-Sklar weight assessment method (SWAS) is proposed. A case study is developed to provide a foundation for the experts' evaluations using twelve criteria, which are organized into four aspects namely, economic, user, operational, and advancement. Finally, the results indicate that the most favorable approach is optimized operations via the integration of the sharing economy into the metaverse.

1. Introduction

Climate change has had a significant impact on all living things globally, particularly in the last several decades [22]. Greenhouse gases (GHG) emissions must be avoided by all people and sectors to mitigate the negative consequences of climate change and reverse its propagation to establish a sustainable future [3,13]. There are a variety of implementation options that can improve the sustainability measure of each sector, such as sharing economy applications and improving the sustainability of the transportation system [4]. Car-sharing, ride-sharing, and bike-sharing are examples of sharing economy applications used in the transportation sector. These applications have the potential to minimize the use of single-occupant vehicles and car ownership [7]. By providing such benefits, the region's sustainability measures, in which sharing economy alternatives are used, improve due to lower GHG emissions [14].

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Metaverse is a relatively new technology that has sparked interest among policymakers due to its ability to interface with a variety of industries via the twin cities concept. A promising integration is creating an exact reproduction of the real world in the virtual medium and tracking people's actions through their avatars. This connection can provide numerous benefits in terms of sharing economy applications in transportation networks. For example, with the twin cities, data on human behaviors in sharing economy applications such as frequency of usage, origin and destination places, and so on, may be easily collected via user avatars [30]. The acquired data can be used to optimize the sharing economy applications. Furthermore, with blockchain technology, payments for services may be made conveniently, quickly, and securely [31]. In addition to these advantages, metaverse integration can address safety concerns by sharing economy applications [20].

Authorities and policymakers are seeking solutions to payment and safety challenges, as well as ways to improve the efficiency of sharing economy applications in transportation networks. In this study, three different alternative metaverse integrations are presented to provide different benefits to sharing economy applications, namely incorporating safety solutions into the metaverse to facilitate the sharing economy, incorporating payment systems into the metaverse to facilitate the sharing economy, and optimizing operation through the integration of the sharing economy into the metaverse. The conducted literature survey is then used to select the final 12 criteria. A survey is created, wherein each possibility is appraised on each criterion before face-to-face experts' evaluation. A case study is produced so that these specialists can base their judgments on real-world data. Following the acquisition of expert evaluations, the data are introduced into a novel MCDM model and the advantages of the options are prioritized.

Hence, the goal of this research is to identify and prioritize the alternatives for incorporating sharing economy applications in transportation into the metaverse using the proposed MCDM framework. The mathematical formulation of the proposed explanatory multi-criteria framework enables an easy understanding of the decision-making system and the prospect of defining the strengths and weaknesses of the proposed strategies. That is why the proposed methodology belongs to the field of enhanced decision-making algorithms. Furthermore, it is essential to point out the capability of analyzing the robustness of the proposed solution by simulating different levels of risk when making decisions. Likewise, since the multi-criteria framework is based on fuzzy Schweizer-Sklar norms, which represent the basis for creating an algorithm of approximate reasoning, the proposed system also belongs to the class of explainable artificial intelligence systems. This fact is significant for applying the model in real-world case studies since the explainability of the model helps decision-makers and managers better understand the model's parameters and use them more reliably. Also, the proposed methodology enables managers to present objectively and analytically based decisions to interested subjects.

This study proposes a novel multi-criteria framework for processing uncertain information in a fuzzy environment. The proposed framework contains two modules. The first module presents the improvement of the Ordinal Priority Approach (OPA) linear model and its extension in the fuzzy environment. The OPA algorithm was used in this study because it has flexibility and allows adequate group and unspecified information processing. In case of a lack of knowledge about specific attributes of the decision, the OPA algorithm obtains sufficient and reliable information. Considering the mentioned feature of the OPA modal, it is expected to be applied in dynamic and uncertain environmental conditions. In the second module, a novel methodology for evaluating alternatives is presented, based on the non-linear processing of information based on the fuzzy Schweizer-Sklar weight assessment method (SWAS). By applying non-linear fuzzy Schweizer-Sklar functions, it is possible to adapt the methodological framework of the SWAS method to a dynamic environment. The proposed methodology has advantages that are presented in the following section:

- The fuzzy SWAS method is based on the non-linear processing of the elements of the initial decision matrix with the possibility of considering different degrees of risk in a dynamic environment. This characteristic of the fuzzy SWAS method provides the possibility of more flexible decision-making, which increases its generality and flexibility compared to traditional multi-criteria techniques;
- The fuzzy SWAS method comes with an original algorithm for normalizing the elements of the initial decision matrix, which eliminates the violation of the distribution of normalized values depending on the type of attribute;
- An improved algorithm of the OPA method was proposed, which enables the definition of the weight coefficients of the criteria based on the real preferences of the decision maker;
- The proposed F'OPA algorithm enables the processing of uncertain and incomplete information. This characteristic of the F'OPA algorithm allows for defining the weighting coefficients of the criteria in conditions of incomplete information about specific attributes in the fuzzy linear model;
- The proposed multi-criteria framework enables flexible decision-making, whether group or individual.

Aside from the uniqueness and benefits of the utilized MCDM model, this work makes some other contributions. For example, there are no studies in the literature on the alternatives presented in this study, indicating that the recommended alternatives contribute to the literature. Furthermore, the results of this study can be used by corporations, governments, and decision-makers who want to merge sharing economy applications and the metaverse to determine the most advantageous integration type. As a result, this study has the potential to be used as a guide by sharing economy application decision-makers.

The rest of this study is structured as follows. Section 2 gives a thorough review of the literature. Section 3 presents the definition of the problem, alternatives, and criteria. In section 5, detailed explanations of the proposed methodology are presented. Section 5 gives the case study. In Section 6, the results and an in-depth discussion are presented. In Section 7, detailed policy implications are given. In section 8, the conclusion of the study is presented.

2. Literature review

There are numerous advantages of the integration of sharing economy implementations into transportation systems in the metaverse. The real world can be created identically to the virtual world using the twin city program, and real-world activities can be carried out in the twin city as well. Hence, some benefits of this integration include the simplicity of data collecting offered by the twin city application and the optimization studies that can be conducted using this data, the ease of payment and payment systems, and the provision of security. Some of the most relevant studies in the extant literature are described in Table 1.

Metaverse technology has numerous applications. With metaverse, a new system that may develop sharing economy activities while providing safety solutions can be obtained. A different study in the literature emphasizes the significance of data privacy and security of user avatar material [23]. The authors stated that the use of blockchain technology can provide the ideas of decentralization, data integrity, and transparency and that these concepts can considerably improve the safety aspect. User data may be captured and kept safe using this method. According to another study, the blockchain is the safest approach for metaverse integration [20]. As a result, by incorporating sharing economy applications into the metaverse environment with safety measures, any problems can be avoided before they arise.

Metaverse technology is evolving into a novel and innovative field with growing effectiveness. With the metaverse, which may strengthen its sharing economy activities, payment systems can give convenience and rapid models. A novel rapid and secure payment system based on blockchain technologies is proposed in another study in the literature

Table 1
The related studies in the literature.

Author/ Publication Year	Topic of Study	Aim	Methodology
Gadekallu et al., [23]	Metaverse, Blockchain, data security, and privacy	To discuss how the data of users in the metaverse can be securely and privately acquired, stored, and shared.	Extensively discuss the blockchain-based methods to secure the digital content of metaverse users, provide data privacy, and securely acquire and share metaverse data.
Mishra et al. [20]	Metaverse, Blockchain, Data storage	Since the data acquired from the metaverse cannot be stored in blockchain alone due to the amount of the collected data, new data storage techniques are needed.	A hybrid blockchain-based data storage method is proposed in which the collected data is stored in both the blockchain and data warehouses. This method is a viable option for the integration of different real-life applications into the metaverse.
Hao et al. [31]	Payment through blockchain	To present a novel fast payment system, which utilizes blockchain technology.	In the proposed payment system, a front-end IoT service and a back-end blockchain technology are utilized.
Kim and Kim [19]	Payment, Blockchain	To eliminate the intermediary in payment systems and the payment gateway fees.	Since the current payment systems involve an intermediary, which brings a fee for each payment, usage of blockchain-based payment systems that involve basic cryptocurrency features has the potential to eliminate the intermediary and remove payment gateway fees.
Liu et al. [21]	Safety in data collection and sharing, blockchain	To propose a data collection and sharing method, which is safe and efficient.	Ethereum blockchain network and deep reinforcement learning algorithms are combined to create a blockchain-based high-quality data collection and sharing scheme. The method is stated to be reliable and safe in collecting and sharing data.

[31]. Another study claims that payment methods that use blockchain technologies are more efficient than traditional payment methods since intermediary payment systems are eliminated, lowering the overall payment fee significantly [19]. When blockchain payment methods are linked into the metaverse, they can also be deployed in sharing economy implementations in transportation networks, which overcomes the intermediate fee problem. Therefore, by integrating payment systems into the metaverse reality, payments in sharing economy applications can be made effortlessly and without disturbance.

Various industries rely heavily on optimization research. Since metaverse is a technology, which is running on the blockchain system, the collection of data is important for optimizing the sharing economy applications in transportation systems. Therefore, while the integration of sharing economy applications into the metaverse, optimization studies can be carried out easily and securely using collected data through blockchain technology [6].

3. Problem definition

Transportation is one of the sectors that have a big impact on our daily lives. These activities aid in getting from one location to another swiftly and efficiently. However, if transportation activity increases significantly, it may harm the traffic network. For example, a rise in the number of vehicles in traffic increases traffic density and might cause delays. Sharing economy implementations can help to mitigate and prevent these issues. However, these implementations might also bring additional issues, such as privacy and payment. One of the most recent topics of research in the literature is metaverse technology. Evaluating a new technology, namely metaverse, in conjunction with sharing economy activities can help to lessen the challenges produced by transportation operations. However, some issues may develop during the integration of metaverse technology into the sharing economy. This study proposes three potential metaverse integration alternatives to lessen the consequences of these challenges, and the order of preference of these alternatives was evaluated using 12 different criteria.

3.1. Definition of alternatives

A_1: Incorporating safety solutions into the metaverse for facilitating the sharing economy: People who participate in the sharing economy are worried about their safety. For instance, if users are required to share their personal information with third parties, they might avoid using programs that are part of the sharing economy. Although the sharing economy helps to create a more environmentally friendly and effective transportation network, there is always the issue of safety to consider. Consequently, incorporating metaverse technology into sharing economy activities will result in a paradigm that is both more secure and more environmentally friendly [12].

A_2: Incorporating payment systems into the metaverse for facilitating the sharing economy (attributed to their capacity to modify traditional pricing patterns for individual vehicle use, giving the consumer more flexibility): Mobility implementations, such as car sharing and bike sharing, are beneficial to users participating in the sharing economy. The use of these programs may result in the user being required to pay a predetermined fee. Payments are often processed through the user's account on the online platform. Users' online payment accounts may, however, be compromised as a result of malicious software and hacker activity. Hence, the integration of payment systems with metaverse technology makes it possible to lessen the impact of these drawbacks or possibly eliminate them [24].

A_3: Optimized operation through the integration of sharing economy into the metaverse: In the sharing economy, where operations involving transportation such as car sharing, bike sharing, and other similar endeavors are carried out, sustainability and efficiency are of the utmost importance. When using these applications, you could run across a lot of different issues. The sharing economy may experience undesirable effects as a result of issues such as insufficient data storage, programs that do not perform properly, and inadequacies in data sharing. Implementations within the sharing economy, such as automobile sharing, can have their potential enhanced by the use of Metaverse technology [28].

3.2. Definition of criteria

3.2.1. Economic aspect

C_1: Allowing Decentralized finance for consumers to define their own rules in a decentralized mesh financial network verifying transactions without human intervention (benefit): In the current environment, to carry out any kind of financial transaction, it is required to seek authorization from organizations like banks, decision-makers, and managers, and to adhere

with the regulations that these individuals have established. This may result in delays and will bring the system's efficiency down. Because of these rules, the system may not be as sustainable or effective as it could be. Because of this, the technology of the metaverse allows for the creation of a system that is quick enough to function without the requirement of these permits and regulations [10].

C_2: Providing a secure connection between service providers and financial systems (benefit): In several industries, including transportation and finance, having secure communication is of the utmost importance. Secure communication makes it possible to prevent system breakdowns and ensures that users continue to receive service without interruption. Therefore, users will prefer the system more if the communication between financial systems and service providers is made more secure [8].

C_3: Need for seamless proof-of-delivery, billing, and payment (cost): Users may require certain conditions, such as billing and proof-of-delivery, to acquire any product. These requirements demonstrate that users have purchased the product in question. Because these needs show that customers already possess the product in question and because users can point to these requirements as evidence if there is an issue with product delivery. Since the necessity of this prerequisite, the integration of the metaverse system incurs a particular cost [29].

3.2.2. User aspect

C_4: Need to build social ties and trust to maintain participation (cost): Users could tend to favor the newly constructed economic and transportation system when this system is first put into place. System administrators need to strengthen their relationships with one another to avoid this prejudice. They might use middlemen like advertisements or public relations to accomplish this goal. The added expense that results from this is borne by system administrators [11].

C_5: Need for critical mass (cost): To be successful in a company area that has recently been founded, there must be a certain number of users. To fulfill this essential prerequisite, the recently founded company needs to have effective marketing. Advertising, professional gatherings, and cross-industry cooperation are all helpful tools for accomplishing this goal [9].

C_6: Giving more privacy control to the user (benefit): Although technological advancements make financial systems steadily more dependable, the weaknesses of these systems are still susceptible to being exploited by malicious software. Users' safety is compromised as a result of these systems' susceptibility to being compromised by malicious software. By providing users with increased discretion over their private information, a more secure system can be realized with the assistance of Metaverse technology [25].

3.2.3. Operational aspect

C_7: Allowing dynamic pricing (cost): Users that are interested in purchasing a product may wish for the pricing of that good to remain unchanged at all times. The potential for the product's price to fluctuate in the future could harm the users' ability to prepare for the future. When it comes to dynamic pricing, acquiring the trust of customers can result in additional expenses for system administrators [27].

C_8: Diminishing vehicle life span (cost): The lifespan of every vehicle gradually reduces over time due to the various activities associated with transportation. Even though the car is optimized and any essential repairs are performed, the vehicle still has the potential to become unpleasant once some time has passed. According to [18], the model that is going to be built for the integration of metaverse technology with activities related to transportation would result in expenditures that, in the long run, will demand the replacement of automobiles.

C_9: Ability to measure, monitor, and manage fleets in real-time (benefit): When managers oversee activities that include transportation, such as cargo delivery, they run the risk of experiencing issues such as the goods not arriving when expected or being damaged. As a result of the incorporation of Metaverse technology into transportation operations, all the processes within the system can be instantly monitored, and any potential issues may be identified in advance and resolved before they even arise [21].

3.2.4. Advancement aspect (advancements made within the sector)

C_{10}: Helping small firms compete with larger firms with spare capacity becoming more visible (benefit): In every industry, the strong side can force the weak side out of the system. Stronger businesses have greater financial power, which might lead to more customers. Therefore, small businesses cannot survive in this system over the long term. However, technologies such as the metaverse also enable small businesses to remain in the system in the long run [16].

C_{11}: Allowing pure technology companies to enter the market (benefit): Companies which are industry leaders and possess cutting-edge technology could be hesitant to expand into adjacent markets due to the difficulty of doing so. Because these businesses place a premium on upholding ethical standards, one can expect them to exercise increased caution. On the other hand, due to the numerous safety benefits that metaverse technology offers, traditional technology businesses might be interested in expanding into fields that make use of metaverse technology [1].

C_{12}: Increased-cost network of shared assets or service providers (cost): Integration of Metaverse technology with implementations for the sharing economy creates numerous economic sectors. However, technological and human resources are required to maintain the continuity of these commercial sectors. Therefore, protecting the corporate network incurs additional expenses [2].

4. MCDM framework

The multi-criteria methodology presented in this section is based on applying the OPA method [26] in a fuzzy environment and a new approach for evaluating alternatives based on the application of fuzzy Schweizer-Sklar non-linear functions (SWAS method). Improved fuzzy OPA methodology (F'OPA) was used to determine the weighting coefficients of decision attributes, while fuzzy sets were used to process uncertainty in a multi-criteria framework. The following section presents preliminary settings and some operational lows with fuzzy sets and Schweizer-Sklar norms. After the preliminaries section, the mathematical framework of the F'OPA and fuzzy SWAS model is presented.

4.1. Preliminaries on fuzzy Schweizer-Sklar norms

Schweizer-Sklar norms have parameters that can be dynamically adjusted, which contributes to the additional flexibility of the decision-making model. Also, the stabilization parameters of the Schweizer-Schweizer-Sklar norms were used in this study because they have parameters that can be dynamically adjusted, which contributes to the additional flexibility of the decision-making model. Furthermore, the stabilization parameters of the Schweizer-Sklar functions can be applied to represent the different preferences of decision-makers.

Definition 1. [5]: Suppose that x and y are real numbers, then the Schweizer-Sklar tnorm and tconorm between x and y can be defined as follows:

a) Schweizer-Sklar *tnorm* $t^{\gamma}_{(x,y)}$, where $\gamma \in (-\infty,0) \cup (0,+\infty)$:

$$t^{\gamma}_{(x,y)} = (x^{\gamma} + y^{\gamma} - 1)^{1/\gamma} \tag{1}$$

b) Schweizer-Sklar *tconorm*$tc^{\gamma}_{(x,y)}$, where $\gamma \in (-\infty,0) \cup (0,+\infty)$:

$$tc^{\gamma}_{(x,y)} = 1 - ((1-x)^{\gamma} + (1-y)^{\gamma} - 1)^{1/\gamma} \tag{2}$$

where $(x,y) \in [0,1]$ and $\gamma \in (-\infty,0) \cup (0,+\infty)$.

Based on Definition 1, we can define arithmetic operations with fuzzy numbers [15,32–36] which are based on Schweizer-Sklar norms and conorms.

Definition 2. Suppose that $\widetilde{\upsilon}_1 = \left(\upsilon_1^{(l)}, \upsilon_1^{(m)}, \upsilon_1^{(u)}\right)$ and $\widetilde{\upsilon}_2 = \left(\upsilon_2^{(l)}, \upsilon_2^{(m)}, \upsilon_2^{(u)}\right)$ are two triangular fuzzy numbers, $\alpha \in (0, +\infty)$, $\gamma \in (-\infty, 0) \cup (0, +\infty)$ and $f(\widetilde{\upsilon}_i) = \widetilde{\upsilon}_i / \sum_{i=1}^{n} \widetilde{\upsilon}_i$ represents a fuzzy additive function, then we can define arithmetic rules with fuzzy numbers that are based on Schweizer-Sklar norms:

(1) Addition

$$\widetilde{\upsilon}_1 \oplus \widetilde{\upsilon}_2 = \begin{pmatrix} 1 - \left(\left(1 - \upsilon_1^{(l)}\right)^{\gamma} + \left(1 - \upsilon_2^{(l)}\right)^{\gamma} - 1\right)^{1/\gamma}, \\ 1 - \left(\left(1 - \upsilon_1^{(m)}\right)^{\gamma} + \left(1 - \upsilon_2^{(m)}\right)^{\gamma} - 1\right)^{1/\gamma}, \\ 1 - \left(\left(1 - \upsilon_1^{(u)}\right)^{\gamma} + \left(1 - \upsilon_2^{(u)}\right)^{\gamma} - 1\right)^{1/\gamma} \end{pmatrix} \tag{3}$$

(2) Multiplication

$$\widetilde{\upsilon}_1 \otimes \widetilde{\upsilon}_2 = \begin{pmatrix} \left(\upsilon_1^{(l)\gamma} + \upsilon_2^{(l)\gamma} - 1\right)^{1/\gamma}, \\ \left(\upsilon_1^{(m)\gamma} + \upsilon_2^{(m)\gamma} - 1\right)^{1/\gamma}, \\ \left(\upsilon_1^{(u)\gamma} + \upsilon_2^{(u)\gamma} - 1\right)^{1/\gamma} \end{pmatrix} \tag{4}$$

(3) Multiplying by a constant, where $\alpha \in (0, +\infty)$

$$\alpha \widetilde{\upsilon}_1 = \begin{pmatrix} 1 - \left(\alpha\left(1 - \upsilon_1^{(l)}\right)^{\gamma} - (\alpha - 1)\right)^{1/\gamma}, \\ 1 - \left(\alpha\left(1 - \upsilon_1^{(m)}\right)^{\gamma} - (\alpha - 1)\right)^{1/\gamma}, \\ 1 - \left(\alpha\left(1 - \upsilon_1^{(u)}\right)^{\gamma} - (\alpha - 1)\right)^{1/\gamma} \end{pmatrix} \tag{5}$$

(4) Power, where $\alpha \in (0, +\infty)$

$$\widetilde{\upsilon}_1^{\alpha} = \begin{pmatrix} \left(\alpha \upsilon_1^{(l)\gamma} - (\alpha - 1)\right)^{1/\gamma}, \\ \left(\alpha \upsilon_1^{(m)\gamma} - (\alpha - 1)\right)^{1/\gamma}, \\ \left(\alpha \upsilon_1^{(u)\gamma} - (\alpha - 1)\right)^{1/\gamma} \end{pmatrix} \tag{6}$$

4.2. Fuzzy based OPA method

The fuzzy OPA (F'OPA) method was used to define the weighting coefficients of the decision attributes in the initial decision matrix. The obtained values of the weighting coefficients of the criteria C_j ($j = 1, 2, \ldots, n$) were used for evaluating alternatives in the fuzzy SWAS model. The methodological framework of the F'OPA model is presented in the following part:

Step 1: Determination of the final rank of criteria. After defining the set of criteria used in the multi-criteria model, k experts evaluate the criteria using linguistic variables from the fuzzy scale. Expert assessments are presented in the assessment matrix $\mathbb{C}^t = \left[\widetilde{\partial}_{C_j}^t\right]_{n\times 1}$, $\widetilde{\partial}_{C_j}^t = \left(\partial_{C_j}^{(l)t}, \partial_{C_j}^{(m)t}, \partial_{C_j}^{(u)t}\right)$, $1 \le t \le k$. The aggregated assessment matrix $\mathbb{C} = \left[\widetilde{\partial}_{C_j}\right]_{n\times 1}$, $\widetilde{\partial}_{C_j} = \left(\partial_{C_j}^{(l)}, \partial_{C_j}^{(m)}, \partial_{C_j}^{(u)}\right)$ is defined by the aggregation of expert assessments. Based on the aggregated values of $\widetilde{\partial}_{C_j} = \left(\partial_{C_j}^{(l)}, \partial_{C_j}^{(m)}, \partial_{C_j}^{(u)}\right)$ from the assessment matrix, the final ranking of the criteria is defined, as follows:

$$w_b^{(1)} \ge w_b^{(2)} \ge \ldots \ge w_b^{(r)} \ge w_b^{(r+1)} \ge \ldots \ge w_b^{(n)}; \;\; \forall b \tag{7}$$

where $w_b^{(r)}$ represents the bth criterion assigned rank r.

Since the weighting coefficients must satisfy the condition that $\widetilde{w}_b^{(1)} - \widetilde{w}_b^{(2)} \ge 0; \widetilde{w}_b^{(2)} - \widetilde{w}_b^{(3)} \ge 0; \ldots; \widetilde{w}_b^{(r)} - \widetilde{w}_b^{(r+1)} \ge 0; \ \ldots; \widetilde{w}_b^{(n-1)} - \widetilde{w}_b^{(n)} \ge 0$, then we can define the following condition:

$$\widetilde{\zeta}_b^r \left(\widetilde{w}_b^{(r)} - \widetilde{w}_b^{(r+1)}\right) \ge 0; \;\; \forall b \tag{8}$$

Step 2: Defining the fuzzy linear model for the calculation of weighting coefficients of criteria. For the calculation of the weighting coefficients, a fuzzy linear model was defined for determining the weighting coefficients of the criteria, Eq. (9).

$$\begin{gathered} Max \left(\ell^{(l)} + 2\ell^{(s)} + \ell^{(u)}\right)/4 \\ s.t. \\ \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(l)}\right\}}{\zeta_j^{(u)}}\left(w_j^{(l)(r)} - w_j^{(u)(r+1)}\right) \ge \ell^{(l)}; \; \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(m)}\right\}}{\zeta_j^{(m)}}\left(w_j^{(m)(r)} - w_j^{(m)(r+1)}\right) \ge \ell^{(m)}; \\ \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(u)}\right\}}{\zeta_j^{(l)}}\left(w_j^{(u)(r)} - w_j^{(l)(r+1)}\right) \ge \ell^{(u)}; \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(l)}\right\}}{\zeta_j^{(u)}}\left(w_j^{(u)(n)}\right) \ge \ell^{(l)}; \\ \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(m)}\right\}}{\zeta_j^{(m)}}\left(w_j^{(m)(n)}\right) \ge \ell^{(m)}; \; \frac{\min\limits_{1\le j\le n}\left\{\zeta_j^{(u)}\right\}}{\zeta_j^{(l)}}\left(w_j^{(l)(n)}\right) \ge \ell^{(u)}; \\ \sum_{j=1}^{n} w_j^{(l)} = 0.8; \sum_{j=1}^{n} w_j^{(m)} = 1; \sum_{j=1}^{n} w_j^{(u)} = 1.2 \\ w_j^{(l)}, w_j^{(s)}, w_j^{(u)} \ge 0; \forall j; w_j^{(l)} \le w_j^{(s)} \le w_j^{(u)} \end{gathered} \tag{9}$$

where $\widetilde{w}_j = \left(w_j^{(l)}, w_j^{(s)}, w_j^{(u)}\right)$ represents the fuzzy weight coefficient of the jth criterion.

4.3. Application of the fuzzy OPA-SWAS multi-criteria framework

In the following section, the mathematical base of the new multi-level framework is presented. The proposed methodology is based on the concept of fuzzy Schweizer-Sklar norms, which are used to process uncertain and undetermined information in a dynamic environment. The algorithm of the proposed fuzzy SWAS methodology is presented in the following part.

Step 1: Creating an aggregated home matrix. The evaluation of m alternatives A_i ($i = 1, 2, \ldots, m$) was performed by k experts under n criteria C_j ($j = 1, 2, \ldots, n$). Fuzzy linguistic variables $\widetilde{\psi}_{ij}^t = \left(\psi_{ij}^{(l)t}, \psi_{ij}^{(m)t}, \psi_{ij}^{(u)t}\right)$ represent expert preferences in the initial decision matrix $\mathfrak{I} = \left[\widetilde{\psi}_{ij}\right]_{m\times n}$. The aggregation of expert preferences defines the aggregated home matrix $\mathfrak{I} = \left[\widetilde{\psi}_{ij}\right]_{m\times n}$, $\widetilde{\psi}_{ij} = \left(\psi_{ij}^{(l)}, \psi_{ij}^{(m)}, \psi_{ij}^{(u)}\right)$.

Step 2. Standardization of the elements of the aggregated home matrix. To standardize the elements of the matrix $\mathfrak{I} = \left[\widetilde{\psi}_{ij}\right]_{m\times n}$, it was performed based on the reverse sorting algorithm, Eqs. (10) and (11). The mathematical logic of the reverse sorting algorithm shown allows for preserving the disposition of natural and normalized attribute values.

Also, the proposed methodology eliminates the displacement of the area of normalized values of cost criteria.

a) Benefit criteria:

$$\widetilde{\phi}_{ij} = \frac{\widetilde{\psi}_{ij}}{\psi_j^+} = \left(\frac{\psi_{ij}^{(l)}}{\psi_j^+}, \frac{\psi_{ij}^{(m)}}{\psi_j^+}, \frac{\psi_{ij}^{(u)}}{\psi_j^+} \right) \tag{10}$$

b) Cost criteria:

$$\widetilde{\phi}_{ij} = -\frac{\widetilde{\psi}_{ij}}{\psi_j^+} + \max_{1\le i\le m}\left(\frac{\widetilde{\psi}_{ij}}{\psi_j^+}\right) + \min_{1\le i\le m}\left(\frac{\widetilde{\psi}_{ij}}{\psi_j^+}\right) = \begin{pmatrix} -\frac{\psi_{ij}^{(l)}}{\psi_j^+} + \max_{1\le i\le m}\left(\frac{\psi_{ij}^{(l)}}{\psi_j^+}\right) + \min_{1\le i\le m}\left(\frac{\psi_{ij}^{(l)}}{\psi_j^+}\right), \\ -\frac{\psi_{ij}^{(m)}}{\psi_j^+} + \max_{1\le i\le m}\left(\frac{\psi_{ij}^{(m)}}{\psi_j^+}\right) + \min_{1\le i\le m}\left(\frac{\psi_{ij}^{(m)}}{\psi_j^+}\right), \\ -\frac{\psi_{ij}^{(u)}}{\psi_j^+} + \max_{1\le i\le m}\left(\frac{\psi_{ij}^{(u)}}{\psi_j^+}\right) + \min_{1\le i\le m}\left(\frac{\psi_{ij}^{(u)}}{\psi_j^+}\right) \end{pmatrix} \tag{11}$$

where $\psi_j^+ = \max_{1\le i\le m}(\widetilde{\psi}_{ij})$, and $\widetilde{\phi}_{ij} = \left(\phi_{ij}^{(l)}, \phi_{ij}^{(m)}, \phi_{ij}^{(u)}\right)$ represent the elements of a standardized fuzzy matrix $\aleph = \left[\widetilde{\phi}_{ij}\right]_{m\times n}$.

Step 3: Calculation of preliminary decision strategies. Based on Eqs. (1)–(6) and expressions for arithmetic and geometric weighted averaging, fuzzy non-linear Schweizer-Sklar functions were generated, which define preliminary decision strategies. Fuzzy non-linear Schweizer-Sklar functions are presented in the following section:

1) Fuzzy Schweizer-Sklar weighted averaging function $\Delta_i^{(1)\alpha}$:

Theorem 1. Let it be $\widetilde{\phi}_{ij} = \left(\phi_{ij}^{(l)}, \phi_{ij}^{(m)}, \phi_{ij}^{(u)}\right)$ $(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$ a set of matrix elements $\aleph = \left[\widetilde{\phi}_{ij}\right]_{m\times n}$ and $\widetilde{w}_j = (\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_n)^T$ fuzzy vector of weight coefficients, then we can define a fuzzy function $\Delta_i^{(1)\alpha}$, Eq. (12).

$$\Delta_i^{(1)\alpha} = \sum_{j=1}^{n} \widetilde{\phi}_{ij} \cdot \left(1 - \sum_{j=1}^{n} \widetilde{w}_j \cdot \left(1 - f(\phi_{ij})\right)^{\alpha}\right)^{1/\alpha} = \begin{pmatrix} \sum_{j=1}^{n} \phi_{ij}^{(l)} \cdot \left(1 - \sum_{j=1}^{n} w_j^{(l)} \cdot \left(1 - f\left(\phi_{ij}^{(l)}\right)\right)^{\alpha}\right)^{1/\alpha}, \\ \sum_{j=1}^{n} \phi_{ij}^{(m)} \cdot \left(1 - \sum_{j=1}^{n} w_j^{(m)} \cdot \left(1 - f\left(\phi_{ij}^{(m)}\right)\right)^{\alpha}\right)^{1/\alpha}, \\ \sum_{j=1}^{n} \phi_{ij}^{(u)} \cdot \left(1 - \sum_{j=1}^{n} w_j^{(u)} \cdot \left(1 - f\left(\phi_{ij}^{(u)}\right)\right)^{\alpha}\right)^{1/\alpha} \end{pmatrix} \tag{12}$$

where $f\left(\widetilde{\phi}_{ij}\right) = \widetilde{\phi}_{ij} / \sum_{j=1}^{n} \widetilde{\phi}_{ij}$ and $\alpha \in (0, +\infty)$. The proof of Theorem 1 is presented in Appendix A. 2) Fuzzy Schweizer-Sklar weighted geometric averaging function $\Delta_i^{(2)\alpha}$:

Theorem 2. Let it be $\widetilde{\phi}_{ij} = \left(\phi_{ij}^{(l)}, \phi_{ij}^{(m)}, \phi_{ij}^{(u)}\right)$ $(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$a set of matrix elements $\aleph = \left[\widetilde{\phi}_{ij}\right]_{m\times n}$ and $\widetilde{w}_j = (\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_n)^T$ fuzzy vector of weight coefficients, then we can define a fuzzy function $\Delta_i^{(2)\alpha}$, Eq. (13).

$$\Delta_i^{(2)\alpha} = \sum_{j=1}^{n} \widetilde{\phi}_{ij} \cdot \left(\sum_{j=1}^{n} \widetilde{w}_j \cdot f(\phi_{ij})^{\alpha}\right)^{1/\alpha} = \begin{pmatrix} \sum_{j=1}^{n} \phi_{ij}^{(l)} \cdot \left(\sum_{j=1}^{n} w_j^{(l)} \cdot f\left(\phi_{ij}^{(l)}\right)^{\alpha}\right)^{1/\alpha}, \\ \sum_{j=1}^{n} \phi_{ij}^{(m)} \cdot \left(\sum_{j=1}^{n} w_j^{(m)} \cdot f\left(\phi_{ij}^{(m)}\right)^{\alpha}\right)^{1/\alpha}, \\ \sum_{j=1}^{n} \phi_{ij}^{(u)} \cdot \left(\sum_{j=1}^{n} w_j^{(u)} \cdot f\left(\phi_{ij}^{(u)}\right)^{\alpha}\right)^{1/\alpha} \end{pmatrix} \tag{13}$$

where $f\left(\widetilde{\phi}_{ij}\right) = \widetilde{\phi}_{ij} / \sum_{j=1}^{n} \widetilde{\phi}_{ij}$ and $\alpha \in (0, +\infty)$. The proof of Theorem 2 is presented in Appendix A. *Step 4:* Calculate the final assessment score (Ω_i) and ranking alternatives. The fusion of the preliminary strategies of alternatives (12) and (13) was performed using Eq. (14).

$$\Omega_i = \left(\Delta_i^{(1)\alpha} + \Delta_i^{(2)\alpha}\right) \cdot e^{-\left(\varphi\left(-\ln\left(f(\zeta_j)\right)\right)^{\delta} + (1-\varphi)\left(-\ln\left(f(\zeta_j)\right)\right)^{\delta}\right)^{1/\delta}} \tag{14}$$

where $\varphi \in [0, 1]$, $f\left(\Delta_i^{(1)\alpha}\right) = \frac{\Delta_i^{(1)\alpha}}{\Delta_i^{(1)\alpha} + \Delta_i^{(2)\alpha}}$ and $f\left(\Delta_i^{(2)\alpha}\right) = \frac{\Delta_i^{(2)\alpha}}{\Delta_i^{(1)\alpha} + \Delta_i^{(2)\alpha}}$.

The alternative that has a higher value Ω_i has a better rank.

5. Case study

Metaverse technology is still a novel topic and can provide consumers with several benefits. Users can effortlessly navigate the online world with their avatars and conduct meetings at their current location. Considering the sharing economy, transportation habits can have numerous positive consequences. For instance, multiple passengers on a vehicle trip might lower traffic density and allow people to achieve their immediate transportation activities without delay. However, in the sharing economy, transportation activities may be threatened by third parties, leading to potential security issues. In addition, the security vulnerabilities of the systems used to make payments can lead to complications. Therefore, the integration of a new and more dependable system, such as metaverse technology, into the sharing economy can lessen or eliminate these issues. Additionally, a common system that is more sustainable, efficient, and reliable can be developed. In all alternatives, therefore, the incorporation of metaverse technology into the sharing economy is centered on the data-based digital duplication of the physical world.

During the creation of a case scenario, an imaginary location with characteristics such as a metropolitan city, dense population, significant commercial activity, and openness to technological investments was selected. While filling out the surveys, experts made decisions based on this region. The case study relates to a metaverse-powered sharing economy in transportation. By incorporating metaverse technology into this economy, decision-makers want to solve difficulties and develop a model that is both sustainable and effective. Numerous solutions for the establishment of a positive and sustainable metaverse sharing economy system have been offered. A selection algorithm, the MCDM instrument, was utilized to discover the most advantageous alternative among those proposed.

Six experts took part, and a final set of criteria for judging options was made. Six of the experts were professors with 22 years of experience in transportation engineering, 25 years of experience in computer engineering, and 14 years of experience in electrical engineering. The other three experts had 13 years and 7 years of experience in car-sharing and scooter-sharing companies, respectively, and in automotive engineering (21 years).

Table 2
The criteria list of evaluation of metaverse Integration alternatives.

Main-criteria	Sub-criteria	Types
Economic Aspect (MC_1)		
C_1	Allowing Decentralized Finance	Benefit
C_2	Providing a secure connection between service providers and financial systems	Benefit
C_3	Need for seamless proof-of-delivery, billing, and payment	Cost
User Aspect (MC_2)		
C_4	Need to build social ties and trust to maintain participation	Cost
C_5	Need for critical mass	Cost
C_6	Giving more privacy control to the user	Benefit
Operational Aspect (MC_3)		
C_7	Allowing dynamic pricing	Cost
C_8	Diminishing vehicle lifespan	Cost
C_9	Ability to measure, monitor, and manage fleets in real-time	Benefit
Advancement Aspect (MC_4)		
C_{10}	Helping small firms compete with larger firms with spare capacity becoming more visible	Benefit
C_{11}	Allowing pure technology companies to enter the market	Benefit
C_{12}	Lower-cost network of shared assets or service providers	Benefit

5.1. Application of the fuzzy OPA-SWAS multi-criteria framework

The Fuzzy OPA-SWAS methodology involves the application of two modules: (1) the Fuzzy OPA module used to determine the weighting coefficients of the criteria and (2) the Fuzzy SWAS module used for the final evaluation of alternatives. For the evaluation of metaverse integration alternatives, twelve criteria were used (see Table 2), which are grouped into four clusters: Economic Aspect (MC_1), User Aspect (MC_2), Operational Aspect (MC_3), and Advancement Aspect (MC_4).

The definition of the weighting coefficients of the criteria (see Table 2) is shown in the next section of the study.

a) Application of the fuzzy OPA methodology for determining weight coefficients of criteria.

The weighting coefficients of the criteria using the fuzzy OPA methodology are defined based on the fuzzy linear model.

Step 1: The criteria from Table 2 were evaluated by six experts who presented their preferences using the fuzzy scale from Table 3.

Expert perceptions are presented in the matrix of expert assessments, Table 4.

To define the final ranking of the criteria, expert assessments were aggregated. The fuzzy Einstein weighted averaging operator [16] was used to aggregate expert evaluations. Based on the aggregated values, the final ranking of the criteria is as follows defined:

$$\widetilde{\partial}_{C_j}\,Rank\mathbb{C} = \begin{bmatrix} (7.170, 8.086, 9.085) \\ (7.005, 8.004, 9.004) \\ (6.676, 7.506, 8.505) \\ (5.674, 6.673, 7.672) \\ (6.007, 7.006, 8.005) \\ (5.841, 6.840, 7.839) \\ (6.836, 7.835, 8.835) \\ (4.675, 5.674, 6.673) \\ (7.336, 8.252, 9.252) \\ (4.507, 5.506, 6.505) \\ (5.005, 6.004, 7.004) \\ (5.841, 6.840, 7.839) \end{bmatrix} \begin{array}{c} 2 \\ 3 \\ 5 \\ 9 \\ 6 \\ 7 \\ 4 \\ 11 \\ 1 \\ 12 \\ 10 \\ 8 \end{array}$$

where $\widetilde{\partial}_{C_j} = \left(\partial_{C_j}^{(l)}, \partial_{C_j}^{(m)}, \partial_{C_j}^{(u)}\right)$ $(j = 1, 2, \ldots, 12)$ represents the aggregated significance of the criteria.

Step 2: Based on the defined rank of criteria and Eq. (8), the constraints in the fuzzy linear model, Eq. (9) were formed. The fuzzy linear model is presented in the next part:

$$Max\left(\ell^{(l)} + 2\ell^{(s)} + \ell^{(u)}\right)/4$$

$$s.t.$$

$$0.487\left(w_9^{(l)} - w_1^{(u)}\right) \ge \ell^{(l)}; 0.546\left(w_9^{(m)} - w_1^{(m)}\right) \ge \ell^{(m)}; 0.614\left(w_9^{(u)} - w_1^{(l)}\right) \ge \ell^{(u)};$$
$$0.496\left(w_1^{(l)} - w_2^{(u)}\right) \ge \ell^{(l)}; 0.557\left(w_1^{(m)} - w_2^{(m)}\right) \ge \ell^{(m)}; 0.629\left(w_1^{(u)} - w_2^{(l)}\right) \ge \ell^{(u)};$$
$$0.501\left(w_2^{(l)} - w_7^{(u)}\right) \ge \ell^{(l)}; 0.563\left(w_2^{(m)} - w_7^{(m)}\right) \ge \ell^{(m)}; 0.643\left(w_2^{(u)} - w_7^{(l)}\right) \ge \ell^{(u)};$$
$$0.510\left(w_7^{(l)} - w_3^{(u)}\right) \ge \ell^{(l)}; 0.575\left(w_7^{(m)} - w_3^{(m)}\right) \ge \ell^{(m)}; 0.659\left(w_7^{(u)} - w_3^{(l)}\right) \ge \ell^{(u)};$$
$$0.530\left(w_3^{(l)} - w_5^{(u)}\right) \ge \ell^{(l)}; 0.600\left(w_3^{(m)} - w_5^{(m)}\right) \ge \ell^{(m)}; 0.675\left(w_3^{(u)} - w_5^{(l)}\right) \ge \ell^{(u)};$$
$$0.563\left(w_5^{(l)} - w_6^{(u)}\right) \ge \ell^{(l)}; 0.643\left(w_5^{(m)} - w_6^{(m)}\right) \ge \ell^{(m)}; 0.750\left(w_5^{(u)} - w_6^{(l)}\right) \ge \ell^{(u)};$$
$$\ldots$$
$$0.675\left(w_8^{(l)} - w_{10}^{(u)}\right) \ge \ell^{(l)}; 0.794\left(w_8^{(m)} - w_{10}^{(m)}\right) \ge \ell^{(m)}; 0.964\left(w_8^{(u)} - w_{10}^{(l)}\right) \ge \ell^{(u)};$$
$$0.693\left(w_{10}^{(u)}\right) \ge \ell^{(l)}; 0.819\left(w_{10}^{(m)}\right) \ge \ell^{(m)}; 1.00\left(w_{10}^{(l)}\right) \ge \ell^{(u)};$$
$$\sum_{j=1}^{12} w_j^{(l)} = 0.8; \sum_{j=1}^{12} w_j^{(m)} = 1; \sum_{j=1}^{12} w_j^{(u)} = 1.2$$
$$w_j^{(l)}, w_j^{(s)}, w_j^{(u)} \ge 0; \forall j; w_j^{(l)} \le w_j^{(s)} \le w_j^{(u)}$$

where $\widetilde{w}_j = \left(w_j^{(l)}, w_j^{(s)}, w_j^{(u)}\right)$ represents the fuzzy weight coefficient of the jth criterion.

Lingo 17.0 software was used to solve the model; thus, the fuzzy weight coefficients of the criteria were obtained in Table 5.

b) Application of fuzzy SWAS methodology for evaluation of alternatives.

The weighting coefficients of the criteria defined by applying the fuzzy OPA methodology were used to evaluate three alternatives: Incorporating safety solutions into the metaverse for facilitating the sharing economy (A_1); Incorporating payment systems into the metaverse for facilitating the sharing economy (A_2), and Optimized operation through the integration of sharing economy into the metaverse (A_3). The evaluation of the alternative was carried out through the following steps:

Step 1: Six experts evaluated alternatives under twelve criteria. A fuzzy scale was used to assess the alternatives, which is given in Table 2. Expert evaluations of the alternative in the home matrix are reported in Table 6.

To define the aggregated home matrix, a fusion of expert assessments from Table 6 was performed. The aggregation of expert assessments was performed using the fuzzy Einstein weighted averaging operator [17]. The aggregated home matrix is given in Table 7.

Step 2: The application of fuzzy Schweizer-Sklar functions (*Step 3*) requires the standardization of the elements of the aggregated matrix in the interval [0,1]. The standardization was carried out to prepare information in the home matrix for defining preliminary decision-making strategies using Eqs. (10) and (11). The standardized home matrix is shown in Table 8.

The standardization of the element at positions A_1-C_3 and A_1-C_6 in the home matrix $\mathfrak{I} = \left[\widetilde{\psi}_{ij}\right]_{3\times 12}$ is shown in the next part:

a) Since C_3 belongs to the group of min criteria, standardization was performed by applying Eq. (11):

Table 3
Fuzzy linguistic variables.

Linguistic terms	Linguistic values of TrFNs
Absolutely low (AL)	(1, 1.5, 2.5)
Very low (VL)	(1.5, 2.5, 3.5)
Low (L)	(2.5, 3.5, 4.5)
Medium-low (ML)	(3.5, 4.5, 5.5)
Equal (E)	(4.5, 5.5, 6.5)
Medium-high (MH)	(5.5, 6.5, 7.5)
High (H)	(6.5, 7.5, 8.5)
Extremely high (EH)	(7.5, 8.5, 9.5)
Absolutely high (AH)	(8.5, 9, 10)

Table 4
Matrix of expert assessments.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
C_1	MH	H	VH	AH	VH	VH
C_2	VH	VH	VH	VH	VH	E
C_3	H	H	MH	E	AH	AH
C_4	H	MH	MH	VH	MH	ML
C_5	H	VH	H	ML	H	MH
C_6	VH	H	H	ML	MH	MH
C_7	H	MH	VH	VH	VH	H
C_8	E	L	E	H	E	MH
C_9	VH	AH	VH	MH	VH	VH
C_{10}	E	ML	E	H	E	ML
C_{11}	MH	ML	MH	H	E	E
C_{12}	MH	MH	H	VH	H	ML

Table 5
Final fuzzy values of weighting coefficients.

Criteria	Fuzzy OPA weights	Crisp weights	Rank
C_1	(0.117,0.131,0.131)	0.1274	2
C_2	(0.104,0.117,0.117)	0.1142	3
C_3	(0.079,0.092,0.094)	0.0890	5
C_4	(0.034,0.045,0.051)	0.0440	9
C_5	(0.071,0.079,0.079)	0.0771	6
C_6	(0.057,0.068,0.071)	0.0657	7
C_7	(0.094,0.104,0.104)	0.1016	4
C_8	(0.015,0.025,0.031)	0.0240	11
C_9	(0.131,0.258,0.438)	0.2708	1
C_{10}	(0.015,0.015,0.015)	0.0154	12
C_{11}	(0.031,0.034,0.034)	0.0337	10
C_{12}	(0.051,0.057,0.057)	0.0551	8

$$\widetilde{\phi}_{A1,C3} = \begin{pmatrix} -\dfrac{2.09}{4.00} + \max\limits_{1\le i\le 3}\left(\dfrac{2.09}{4.00}, \dfrac{1.08}{4.00}, \dfrac{1.93}{4.00}\right) + \min\limits_{1\le i\le 3}\left(\dfrac{2.09}{4.00}, \dfrac{1.08}{4.00}, \dfrac{1.93}{4.00}\right), \\ -\dfrac{3.00}{4.00} + \max\limits_{1\le i\le 3}\left(\dfrac{3.00}{4.00}, \dfrac{1.67}{4.00}, \dfrac{2.84}{4.00}\right) + \min\limits_{1\le i\le 3}\left(\dfrac{3.00}{4.00}, \dfrac{1.67}{4.00}, \dfrac{2.84}{4.00}\right), \\ -\dfrac{4.00}{4.00} + \max\limits_{1\le i\le 3}\left(\dfrac{4.00}{4.00}, \dfrac{2.67}{4.00}, \dfrac{3.84}{4.00}\right) + \min\limits_{1\le i\le 3}\left(\dfrac{4.00}{4.00}, \dfrac{2.67}{4.00}, \dfrac{3.84}{4.00}\right) \end{pmatrix}$$
$$= (0.271, 0.417, 0.666)$$

b) Since C_6 belongs to the group of max criteria, the standardization was performed by applying Eq. (10):

$$\widetilde{\phi}_{A1,C3} = \left(\frac{6.17}{8.17}, \frac{7.17}{8.17}, \frac{8.17}{8.17}\right) = (0.755, 0.878, 1.00)$$

The standardization of the remaining elements of the home matrix was carried out similarly.

Step 3: By applying Eqs. (12) and (13), preliminary decision strategies were calculated:

Table 6
Expert evaluations of alternatives.

Criteria	A_1	A_2	A_3
C_1	H; H; H; H; H; VH	VH; VH; VH; VH; VH; VH	H; MH; VH; AH; AH; H
C_2	H; MH; VH; H; H; AH	VH; VH; AH; AH; AH; VH	E; H; H; AH; VH; ML
C_3	L; L; VL; L; L; AL	VL; AL; AL; AL; AL; AL	VL; ML; VL; AL; VL; L
C_4	VL; L; VL; L; L; L	VL; ML; AL; AL; L; MH	E; ML; AL; VL; ML; VL
C_5	E; VH; VL; L; VL; AH	E; E; AL; AL; L; VH	E; AL; AL; VL; AL; AL
C_6	VH; VH; MH; E; MH; H	ML; E; E; E; H; MH	H; MH; ML; E; MH; VL
C_7	L; H; L; ML; L; VH	E; L; VL; VL; AL; AL	VL; AL; AL; AL; VL; AL
C_8	L; VL; L; ML; L; VH	E; ML; L; ML; L; H	L; ML; VL; AL; VL; E
C_9	MH; E; E; MH; H; MH	MH; MH; E; E; MH; MH	AH; AH; VH; AH; AH; AH
C_{10}	MH; MH; MH; MH; H; L	H; H; VH; AH; VH; H	VH; H; H; H; MH; VH
C_{11}	E; E; E; E; MH; VL	H; MH; H; H; H; L	VH; MH; VH; VH; VH; VL
C_{12}	MH; E; MH; H; MH; VL	H; VH; VH; VH; VH; AH	H; MH; H; AH; H; VL

Table 7
Aggregated home matrix.

Crit.	A_1	A_2	A_3
C_1	(6.67,7.67,8.67)	(7.50,8.50,9.50)	(7.17,8.00,9.00)
C_2	(6.84,7.75,8.75)	(8.00,8.75,9.75)	(6.18,7.09,8.09)
C_3	(2.09,3.00,4.00)	(1.08,1.67,2.67)	(1.93,2.84,3.84)
C_4	(2.17,3.17,4.17)	(2.54,3.36,4.36)	(2.60,3.52,4.51)
C_5	(4.39,5.29,6.28)	(3.55,4.38,5.37)	(1.71,2.37,3.36)
C_6	(6.17,7.17,8.17)	(4.84,5.84,6.84)	(4.52,5.51,6.51)
C_7	(4.20,5.19,6.19)	(2.03,2.86,3.85)	(1.17,1.84,2.84)
C_8	(3.38,4.37,5.36)	(3.85,4.85,5.84)	(2.44,3.35,4.35)
C_9	(5.34,6.34,7.34)	(5.17,6.17,7.17)	(8.33,8.92,9.92)
C_{10}	(5.17,6.17,7.17)	(7.17,8.08,9.08)	(6.67,7.67,8.67)
C_{11}	(4.18,5.17,6.17)	(5.68,6.67,7.67)	(6.19,7.18,8.18)
C_{12}	(4.85,5.84,6.84)	(7.50,8.42,9.42)	(5.85,6.77,7.76)

Table 8
Standardized home matrix.

Crit.	A_1	A_2	A_3
C_1	(0.702,0.807,0.912)	(0.789,0.895,1.00)	(0.755,0.842,0.948)
C_2	(0.701,0.795,0.898)	(0.821,0.897,1.00)	(0.634,0.727,0.830)
C_3	(0.271,0.417,0.666)	(0.521,0.751,1.00)	(0.311,0.457,0.707)
C_4	(0.577,0.779,1.00)	(0.495,0.736,0.958)	(0.481,0.702,0.924)
C_5	(0.272,0.377,0.534)	(0.406,0.523,0.680)	(0.699,0.842,1.00)
C_6	(0.755,0.878,1.00)	(0.592,0.714,0.837)	(0.553,0.675,0.797)
C_7	(0.189,0.297,0.458)	(0.540,0.674,0.836)	(0.679,0.839,1.00)
C_8	(0.498,0.655,0.827)	(0.417,0.573,0.744)	(0.659,0.829,1.00)
C_9	(0.538,0.639,0.740)	(0.521,0.622,0.723)	(0.840,0.899,1.00)
C_{10}	(0.570,0.680,0.790)	(0.789,0.890,1.00)	(0.734,0.844,0.954)
C_{11}	(0.510,0.632,0.755)	(0.694,0.816,0.938)	(0.756,0.878,1.00)
C_{12}	(0.515,0.621,0.727)	(0.797,0.894,1.00)	(0.621,0.718,0.824)

$$\Delta_i^{(1)\alpha=2} = \begin{array}{c} A1 \\ A2 \\ A3 \end{array}\begin{bmatrix} (0.504, 0.623, 0.758) \\ (0.752, 0.868, 0.974) \\ (0.831, 0.958, 1.099) \end{bmatrix}; \Delta_i^{(2)\alpha=2} = \begin{array}{c} A1 \\ A2 \\ A3 \end{array}\begin{bmatrix} (0.543, 0.651, 0.773) \\ (0.774, 0.882, 0.986) \\ (0.854, 0.972, 1.106) \end{bmatrix}$$

In the following part, the calculation of preliminary strategies $\Delta_i^{(1)\alpha=2}$ and $\Delta_i^{(2)\alpha=2}$ for alternative A_1 is presented. Applying Eq. (12) we get the fuzzy weighted averaging Schweizer-Sklar function ($\Delta_i^{(1)\alpha=2}$):

$$\Delta_{A1}^{(1)\alpha=2} = \begin{pmatrix} 6.098\left(1-0.117(1-0.115)^2+0.104(1-0.115)^2+\ldots.+0.051(1-0.084)^2\right)^{1/2}, \\ 7.577\left(1-0.131(1-0.107)^2+0.117(1-0.105)^2+\ldots.+0.057(1-0.082)^2\right)^{1/2}, \\ 9.306\left(1-0.131(1-0.098)^2+0.117(1-0.096)^2+\ldots.+0.057(1-0.078)^2\right)^{1/2} \end{pmatrix}$$
$$= (0.504, 0.623, 0.758)$$

Also, by applying Eq. (13), we get the fuzzy weighted geometric averaging Schweiyer-Sklar function ($\Delta_i^{(2)\alpha=2}$):

$$\Delta_{A1}^{(2)\alpha=2} = \begin{pmatrix} 6.098\left(0.117(0.115)^2+0.104(0.115)^2+\ldots.+0.051(0.084)^2\right)^{1/2}, \\ 7.577\left(0.131(0.107)^2+0.117(0.105)^2+\ldots.+0.057(0.082)^2\right)^{1/2}, \\ 9.306\left(0.131(0.098)^2+0.117(0.096)^2+\ldots.+0.057(0.078)^2\right)^{1/2} \end{pmatrix}$$
$$=(0.543,0.651,0.773)$$

Based on the preliminary strategy of strategies $\Delta_i^{(1)\alpha=2}$ and $\Delta_i^{(2)\alpha=2}$ we can define the initial ranks of alternatives within the considered strategies. Based on the obtained results, we can conclude that both strategies propose the same rank, i.e., $A_3 > A_2 > A_1$.

Step 4: By applying Eq. (14), the final assessment score (Ω_i) was defined, and the alternatives were ranked. The fusion of the preliminary strategies of alternatives (12) and (13) was performed using Eq. (14). We get the final assessment score of alternative A_1 as follows:

$$\Omega_i = \begin{pmatrix} (0.504+0.543)\cdot e^{-\left(0.5(-ln(0.481))^1+(1-0.5)(-ln(0.519))^1\right)^{1/1}}, \\ (0.623+0.651)\cdot e^{-\left(0.5(-ln(0.489))^1+(1-0.5)(-ln(0.511))^1\right)^{1/1}}, \\ (0.758+0.773)\cdot e^{-\left(0.5(-ln(0.495))^1+(1-0.5)(-ln(0.505))^1\right)^{1/1}} \end{pmatrix}$$
$$= (0.523, 0.637, 0.765)$$

where $f\left(\Delta_{A1}^{(1)\alpha}\right) = \left(\frac{0.504}{0.504+0.543}, \frac{0.623}{0.623+0.651}, \frac{0.758}{0.758+0.773}\right) = (0.481, 0.489, 0.495)$ and $f\left(\Delta_{A1}^{(2)\alpha}\right) = \left(\frac{0.543}{0.504+0.543}, \frac{0.651}{0.623+0.651}, \frac{0.773}{0.758+0.773}\right) = (0.519, 0.511, 0.505)$.

Similarly, we get the final assessment score of the remaining alternatives, which is shown in the next part:

$$\Omega_i = \begin{array}{c} A1 \\ A2 \\ A3 \end{array} \begin{bmatrix} (0.523, 0.637, 0.765) \\ (0.763, 0.875, 0.980) \\ (0.843, 0.965, 1.103) \end{bmatrix}$$

By analyzing the obtained values, we can conclude that alternative A_3 is ranked best, followed by alternatives A_2 and A_1.

5.2. Sensitivity analysis

In the next section, the sensitivity analysis of the fuzzy SWAS methodology is proposed. In the sensitivity analysis, the stabilization parameters of the fuzzy Schweizer-Sklar functions and the stabilization parameters of the aggregation function were changed.

a) Variation of the parameter α and its influence on the initial results of the model.

The stabilization parameter of the Schweizer-Sklar function can have values from the interval $\alpha \in (-\infty, 0) \cup (0, +\infty)$. During the calculation of preliminary decision-making strategies, the value of the parameter $\alpha = 2$ was arbitrarily adopted. In the following part, the influence of other values of the parameter α on the values of fuzzy Schweizer-Sklar functions and initial results is analyzed. A total of one hundred scenarios were created during which the change of the final assessment score alternatives was monitored. In the first scenario, the value of the parameter $\alpha = 1$ was adopted, while in each subsequent scenario, the parameter's value was increased by one, $1 \le \alpha \le 100$. At the same time, the values of the parameters δ and φ did not change; that is, $\delta = 1$ and $\varphi = 0.5$ were adopted. Figs. 1(a)-(d) shows the change in assessment score alternatives during one hundred scenarios.

Figs. 1(a)-(c) show the change in the assessment score of individual alternatives during 100 scenarios, while Fig. 1(d) illustrates a comparative view of changes in the Schweizer-Sklar function due to a change in the parameter $1 \le \alpha \le 100$. Figs. 1(a)-(c) show that changes in the parameter α cause changes in the Schweizer-Sklar functions that were used to calculate preliminary decision strategies. However, the results from Fig. 1(d) show that changes in the Schweizer-Sklar functions over 100 scenarios do not cause changes in the initial results. Based on the presented analysis, we can conclude that alternative A_3 is the dominant solution and that the initial ranking is credible.

b) Variation of the parameter δ and its influence on the initial results of the model.

The parameter δ was used for the assessment score alternatives, while the value $\delta = 1$ was adopted for the initial solution calculation. The parameter δ can have values from the interval $\delta \in [1, +\infty)$. In the following part, the change of the specified parameter was simulated, and the changes in assessment score alternatives were monitored during the specified simulation.

In the following part, the change of the parameter δ in the interval $\delta \in [1, 100]$ is simulated. During the change of the parameter δ, the values of the parameters α and φ did not change; that is, the values $\alpha = 2$ and $\varphi = 0.5$ were kept. Figs. 2(a)-(c) shows the change in the assessment score of individual alternatives, while Fig. 3 shows a comparative view of the change in the assessment score of all alternatives.

A comparative view of the results from Fig. 3 clearly indicates that the parameter δ significantly impacts the final results of the fuzzy SWAS methodology. The initial rank is confirmed for parameter values $1 \le \delta \le 80$, however, for values $81 \le \delta \le 100$, the initial ranking was violated, i.e., alternatives A_3 and A_2 changed their places. Also, the analysis showed that alternative A_1 is the worst solution since for all values of the parameter $1 \le \delta \le 100$, it remained the worst ranked.

The changes that appeared in the ranks of alternatives A_3 and A_2 are a consequence of the nature of the logarithmic aggregation function, which for higher values of the parameter δ leads to a convergence of the assessment score. Therefore, when higher values of δ are adopted, it is difficult to find out the dominant alternative from the considered set, since the values of assessment scores are getting close. Therefore, it is not recommended to consider higher values of the stabilization parameter δ during the sensitivity analysis, but to consider values from the interval $1 \le \delta \le 10$. This facilitates the calculation of assessment scores, and it is also possible to clearly distinguish the dominant alternative.

The following part shows the statistical dependence of changes during the change of the parameter $1 \le \delta \le 100$. Spearman's coefficient (SCC) was used to determine statistical correlation. Fig. 4 shows the correlation of assessment score alternatives during the change of the parameter $1 \le \delta \le 100$.

The results from Fig. 4 confirm that as the value of the parameter δ increases, the statistical correlation decreases. However, during the presented simulation, a high statistical correlation was shown in the interval $1.00 \le SCC \le 0.974$, and therefore the average correlation is 0.993. Since the correlation is extremely high, we can conclude that the initial rank $A_3 > A_2 > A_1$ is confirmed.

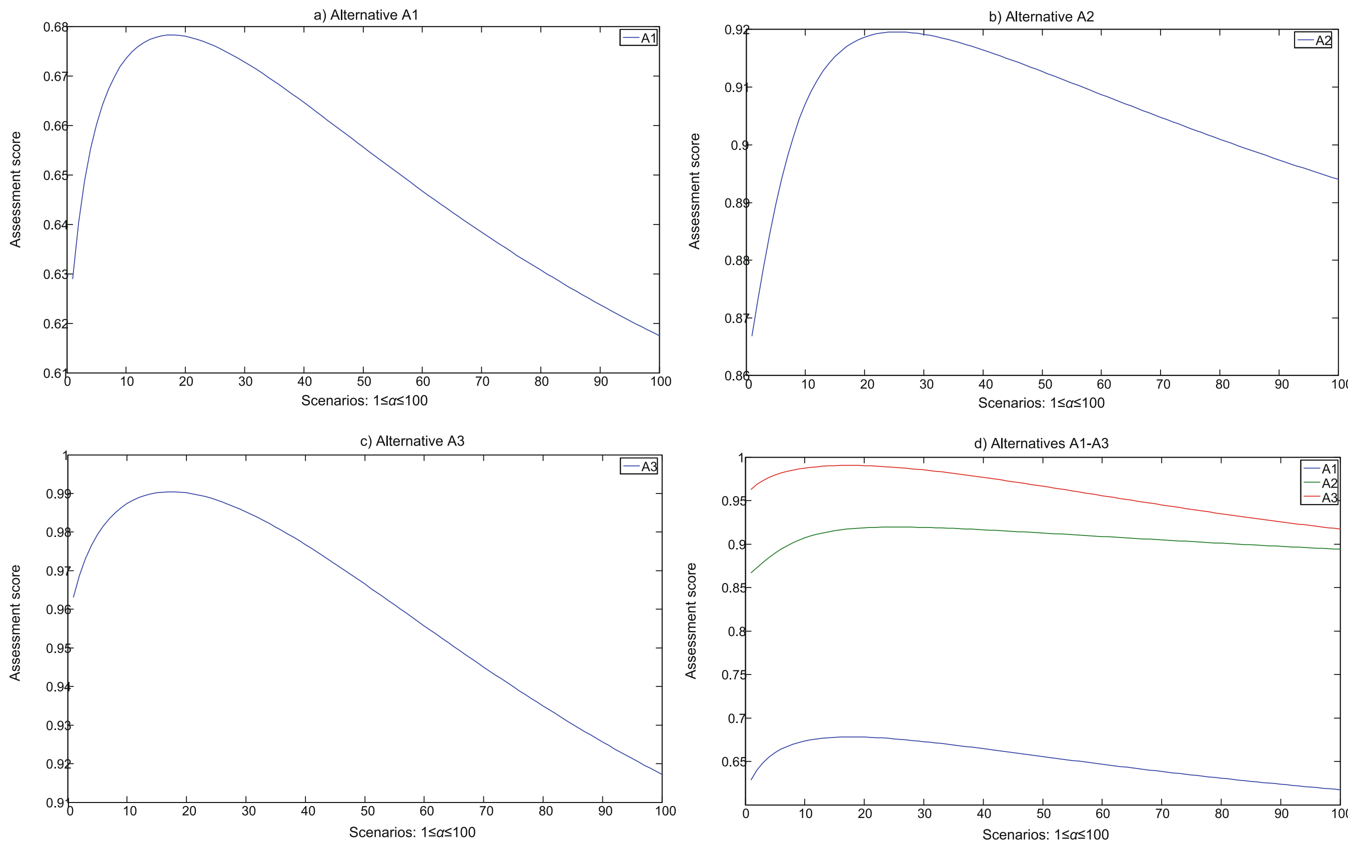

Fig. 1. Alterations of Schweizer-Sklar functions of alternatives.

6. Results and discussion

Using the proposed MCDM tool, the best alternative was determined as an optimized operation through the integration of sharing economy into the metaverse. While sharing economy activities are being carried out, vehicles such as cars and bicycles used in activities may require maintenance, modifications, and updates. It is critical to optimize these activities when incorporating the sharing economy with metaverse technology. As a result, a more sustainable and efficient model can be achieved by improving the operations of these instruments and modifying them to current needs. Furthermore, optimizing the existing system may be less expensive than developing a new system. This option is more financially and environmentally feasible.

The second most advantageous alternative was to include payment systems in the metaverse to facilitate the sharing economy. Users in several areas, such as transportation, must pay in exchange for the service they receive. These payments are made via the systems chosen by the decision-makers. In the digitalized world, online payments are being developed. However, some issues may emerge throughout the payment process. Fraud, theft of user financial information, and hacking are examples of these issues. The benefits of metaverse technology can lessen or perhaps eliminate these issues, which can also be found in the sharing economy. Payments can be made more efficient and sustainable with this technology. When a new payment system is developed, the transfer to this system via the metaverse can be accomplished swiftly and provide consumers with options.

The least advantageous alternative was to integrate safety solutions into the metaverse to facilitate the sharing economy. Ensuring user safety in transportation activities encourages consumers to prefer these activities. It decreases traffic density and enhances socializing, especially when more than one person rides in the same vehicle, such as car sharing. The fact that these people do not know one another, on the other hand, can represent a security risk. People can travel in comfort and efficiency by developing safe solutions using Metaverse technology. However, issues about privacy in the metaverse may make this the least preferred alternative.

7. Policy implications

When participating in activities related to the sharing economy in transportation, the two most crucial factors to take into consideration are efficiency and sustainability. It is important to make the most of the sharing economy to achieve these two goals. To accomplish this goal, both data storage and human resources are needed. The most advantageous alternative is the optimization of the operation by incorporating elements of the sharing economy into the metaverse. It will be possible to obtain transportation that is rapid, productive, reliable, and on time, in addition to being comfortable, if this alternative is incorporated into the sharing economy. The system can be kept up to date through the continuous analysis of data gathered through the use of metaverse technology from implementations within the sharing economy, such as automobile sharing. If this data is collected and achieved, decision-makers will be able to modify their policies to follow the needs of consumers. Therefore, by implementing these regulations, decision-makers can improve the long-term viability and operational effectiveness of activities related to the sharing economy. On the other hand, given that the metaverse is still a relatively new technology, it is uncertain whether people will adopt this technology to a sufficient degree in the foreseeable future. Decision-makers may avoid using this technology if users' trust in the Metaverse continues to decline. As a result, those in positions of authority and decision-making should probably consider the hopes and worries of the community while formulating their policies.

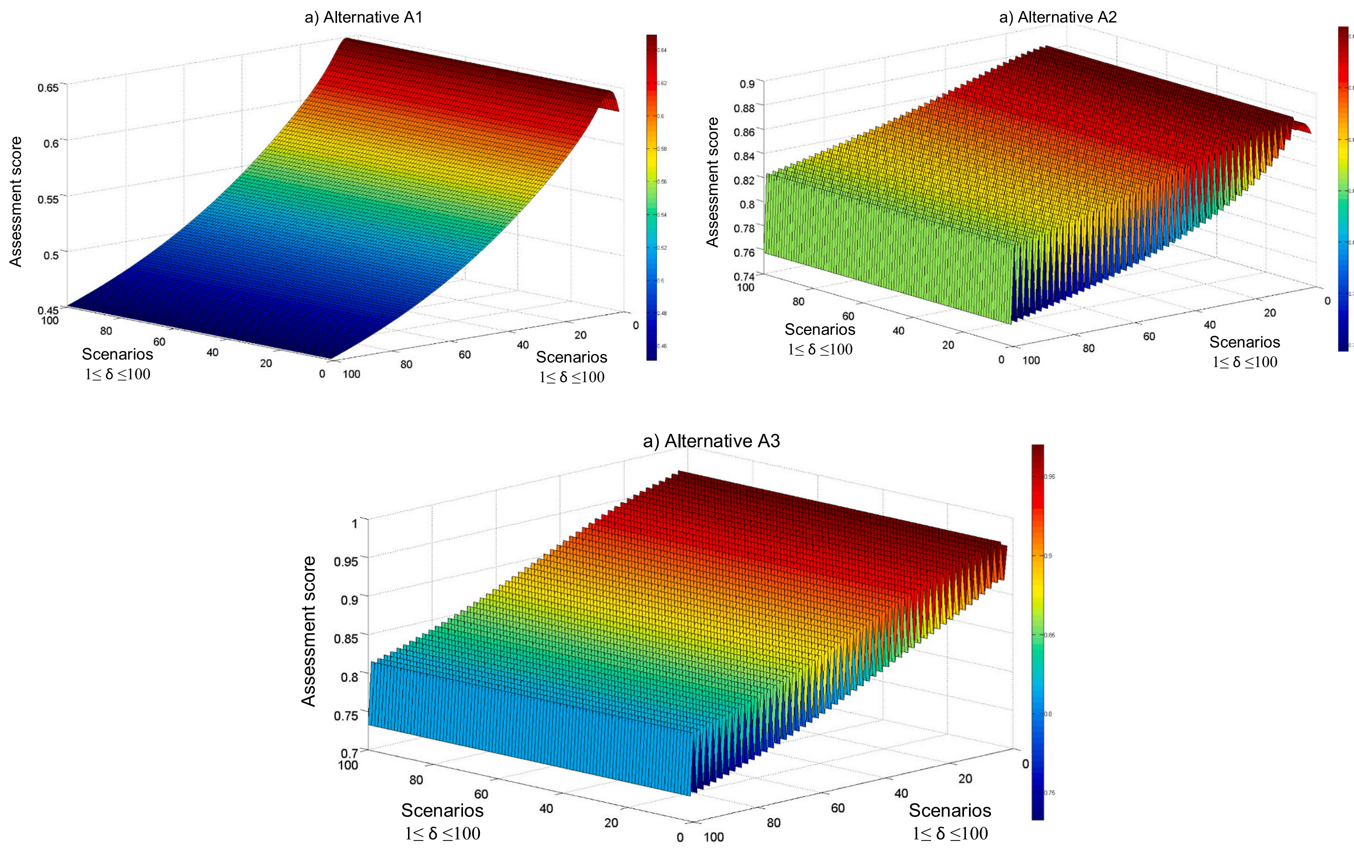

Fig. 2. Changes in assessment score alternatives during parameter change 1 ≤ δ ≤100.

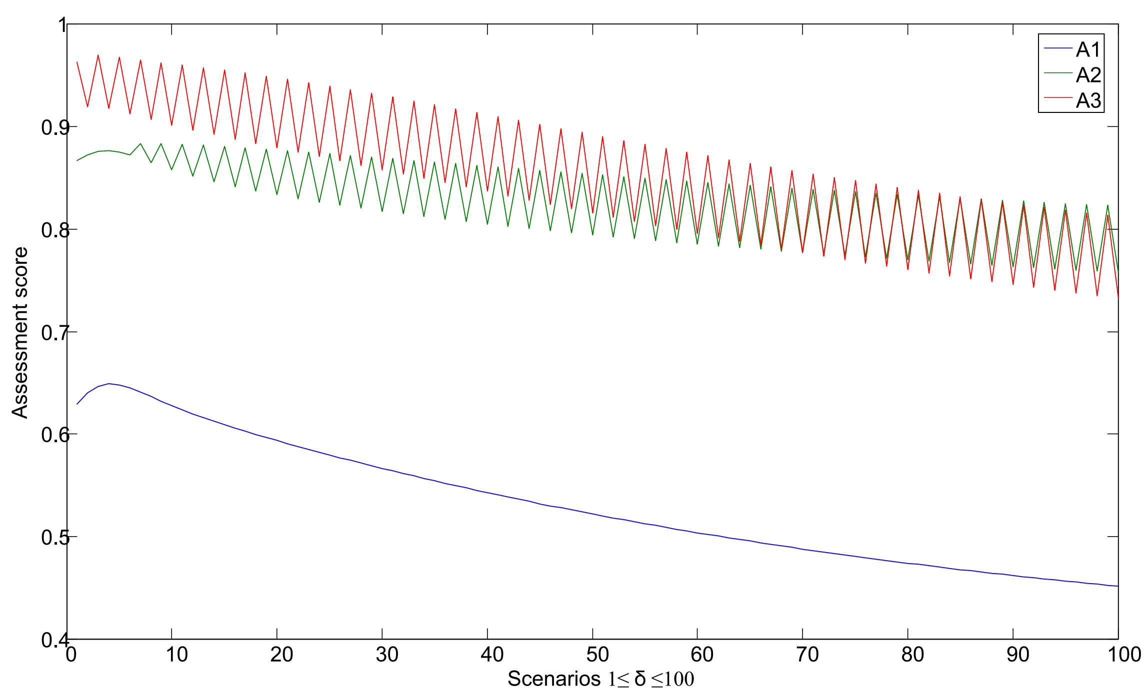

Fig. 3. Comparative presentation of the change in assessment score alternatives.

8. Conclusion

According to the findings of the study, the most beneficial alternative is to optimize operations by incorporating the sharing economy into the metaverse. On the other hand, incorporating safety solutions into the metaverse to make the sharing economy more accessible would be the least beneficial alternative.

One of the significant contributions of this study is the analysis of the sharing economy's integration into the metaverse and its application to the transportation sector. The exploration of the Metaverse, a new

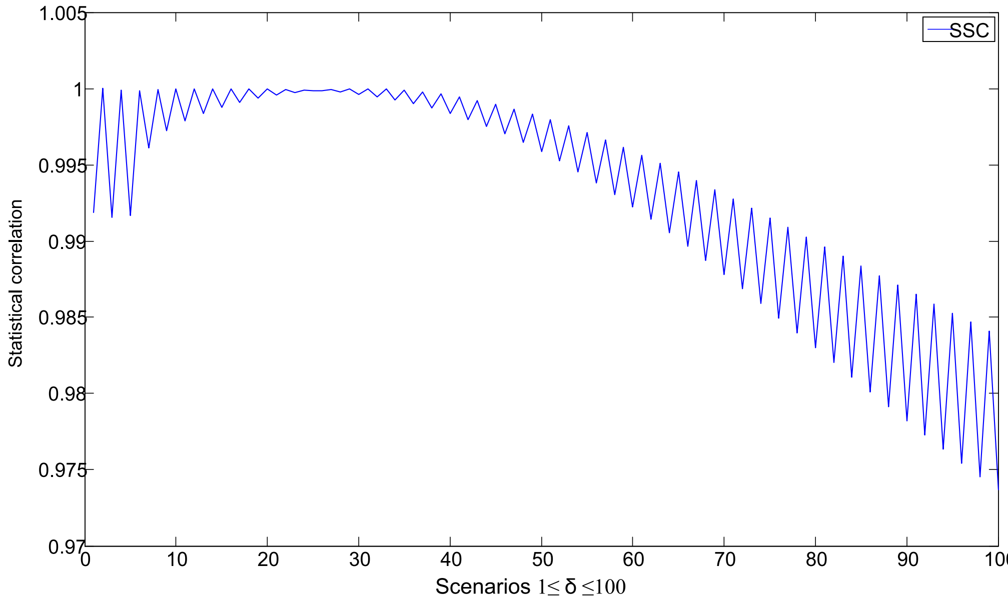

Fig. 4. Correlation assessment score - simulation of parameter change $1 \leq \delta \leq 100$.

technology that offers solutions to the negative aspects that consumers face in the sharing economy, is one of the aspects that distinguishes the study and sets it apart from comparable research. In addition, decision-makers and authorities who are interested in enhancing the effectiveness and long-term viability of the sharing economy in the transportation sector are provided with insights into the findings. On the other hand, given that the metaverse is still a relatively new technology, the number of domains in which it has been implemented is still quite limited. As a result, the suggested alternatives will not likely produce results in the short run. In addition, because this technology is still relatively new, the regulations that are currently in place for the metaverse might not be enough. It is possible that it will not be possible to predict the kind of outcomes that will be brought about if these policies are altered and developed. These circumstances represent the most significant limitations placed on the research.

One of the limitations of the proposed methodology is its mathematical complexity. However, decision support systems that require processing incomplete and uncertain information require the application of partially complex stochastic models. Therefore, mathematical complexity is expected for such systems. This limitation can be successfully eliminated by creating user-oriented software based on the modules presented in this study. Also, future research should improve the proposed methodology in the segment related to the possibility of processing neutral information [37–39]. The introduction of intuitionistic and picture fuzzy sets would open up the possibility of processing neutral information while simultaneously retaining all the existing advantages of the proposed methodology.

Because of the robustness of the proposed methodology, the alternatives and criteria are easily adjustable to the requirements of the authorities and decision-makers for any future applications and research initiatives that may be conducted. It is possible that several nations, each of which having a particular culture and transportation system dynamics, would modify the alternatives and criteria to their requirements. Additionally, metaverse integration of other areas can be investigated in future studies.

CRediT authorship contribution statement

Dragan Pamucar: Methodology, Software, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Muhammet Deveci:** Conceptualization, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Ilgin Gokasar:** Conceptualization, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Dursun Delen:** Writing – original draft, Writing – review & editing. **Mario Köppen:** Writing – original draft, Writing – review & editing. **Witold Pedrycz:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dss.2023.113944.

References

[1] A. Arora, A. Gambardella, The market for technology, in: Handbook of the Economics of Innovation 1, 2010, pp. 641–678, https://doi.org/10.1016/s0169-7218(10)01015-4.
[2] A. Ekeskär, M. Rudberg, Third-party logistics in construction: perspectives from suppliers and transport service providers. Production Planning &amp, Control 33 (9–10) (2020) 831–846, https://doi.org/10.1080/09537287.2020.1837932.
[3] A. Haines, Sustainable policies to improve health and prevent climate change, Soc. Sci. Med. 74 (5) (2012) 680–683, https://doi.org/10.1016/j.socscimed.2011.12.008.
[4] B. Barann, D. Beverungen, O. Müller, An open-data approach for quantifying the potential of taxi ridesharing, Decis. Support. Syst. 99 (2017) 86–95, https://doi.org/10.1016/j.dss.2017.05.008.
[5] B. Schweizer, A. Sklar, Associative functions and statistical triangle inequalities, Publ. Math. Debr. 8 (1961) 169–186.
[6] C.H. Liu, Q. Lin, S. Wen, Blockchain-enabled data collection and sharing for industrial IoT with deep reinforcement learning, IEEE Trans. Indust. Inform. 15 (6) (2019) 3516–3526, https://doi.org/10.1109/tii.2018.2890203.
[7] C. Standing, S. Standing, S. Biermann, The implications of the sharing economy for transport, Transp. Rev. 39 (2) (2018) 226–242, https://doi.org/10.1080/01441647.2018.1450307.

[8] D. Dragomir, L. Gheorghe, S. Costea, A. Radovici, A survey on secure communication protocols for IoT systems, in: 2016 International Workshop on Secure Internet of Things (SIoT), 2016, https://doi.org/10.1109/siot.2016.012.
[9] D.S. Evans, R. Schmalensee, Failure to launch: critical mass in platform businesses, Rev. Netw. Econ. 9 (4) (2010), https://doi.org/10.2202/1446-9022.1256.
[10] F. Fabbrini, Taxing and spending in the Eurozone: legal and political challenges related to the adoption of the financial transaction tax, SSRN Electron. J. (2015), https://doi.org/10.2139/ssrn.2578710.
[11] G.C.C. Shen, J.S. Chiou, C.H. Hsiao, C.H. Wang, H.N. Li, Effective marketing communication via social networking site: The moderating role of the social tie, J. Bus. Res. 69 (6) (2016) 2265–2270, https://doi.org/10.1016/j.jbusres.2015.12.040.
[12] I. Symeonidis, M.A. Mustafa, B. Preneel, Keyless car sharing system: A security and privacy analysis, in: 2016 IEEE International Smart Cities Conference (ISC2), 2016, https://doi.org/10.1109/isc2.2016.7580758.
[13] K.H. Chang, A decision support system for planning and coordination of hybrid renewable energy systems, Decis. Support. Syst. 64 (2014) 4–13, https://doi.org/10.1016/j.dss.2014.04.001.
[14] K.S. Nielsen, K.A. Nicholas, F. Creutzig, T. Dietz, P.C. Stern, The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions, Nat. Energy 6 (11) (2021) 1011–1016.
[15] L.A. Zadeh, The concept of a linguistic variable and its application to approximate reasoning-III, Inf. Sci. 9 (1) (1975) 43–80.
[16] L.C. Leonidou, An analysis of the barriers hindering small business export development, J. Small Bus. Manag. 42 (3) (2004) 279–302, https://doi.org/10.1111/j.1540-627x.2004.00112.x.
[17] M. Deveci, D. Pamucar, I. Gokasar, M. Işık, D. Coffman, An analysis of the economic and societal dynamics of the climate change mitigation strategies in urban mobility planning using the fuzzy Einstein WASPAS approach, Struct. Chang. Econ. Dyn. 61 (2022) 1–17.
[18] M. Vilaca, G. Santos, M.S. Oliveira, M.C. Coelho, G.H. Correia, Life cycle assessment of shared and private use of automated and electric vehicles on interurban mobility, Appl. Energy 310 (2022), 118589, https://doi.org/10.1016/j.apenergy.2022.118589.
[19] S.I. Kim, S.H. Kim, E-commerce payment model using blockchain, J. Ambient. Intell. Humaniz. Comput. 13 (3) (2020) 1673–1685, https://doi.org/10.1007/s12652-020-02519-5.
[20] S. Mishra, H. Arora, G. Parakh, J. Khandelwal, Contribution of blockchain in development of metaverse, in: 2022 7th International Conference on Communication and Electronics Systems (ICCES), 2022, pp. 845–850, https://doi.org/10.1109/ICCES54183.2022.9835986.
[21] S.T.S. Thong, C.T. Han, T.A. Rahman, Intelligent fleet management system with concurrent GPS & GSM real-time positioning technology, in: 2007 7th International Conference on ITS Telecommunications, 2007, https://doi.org/10.1109/itst.2007.4295849.
[22] T.A. Chiang, Z. Che, A decision-making methodology for low-carbon electronic product design, Decis. Support. Syst. 71 (2015) 1–13, https://doi.org/10.1016/j.dss.2015.01.004.
[23] T.R. Gadekallu, T. Huynh-The, W. Wang, G. Yenduri, P. Ranaweera, Q.-V. Pham, D. B. da Costa, M. Liyanage, Blockchain for the Metaverse: A Review, Arxiv, https://arxiv.org/abs/2203.09738, 2022.
[24] V. Chang, L.M.T. Doan, A. Di Stefano, Z. Sun, G. Fortino, Digital payment fraud detection methods in digital ages and industry 4.0, Comput. Electr. Eng. 100 (2022), 107734, https://doi.org/10.1016/j.compeleceng.2022.107734.
[25] X. Xiao, N. Tillmann, M. Fahndrich, J. De Halleux, M. Moskal, User-aware privacy control via extended static-information-flow analysis, in: Proceedings of the 27th IEEE/ACM International Conference on Automated Software Engineering – ASE, 2012, https://doi.org/10.1145/2351676.2351689.
[26] Y. Ataei, A. Mahmoudi, M.R. Feylizadeh, D.-F. Li, Ordinal priority approach (OPA) in multiple attribute decision-making, Appl. Soft Comput. J. 86 (2020), 105893, https://doi.org/10.1016/j.asoc.2019.105893.
[27] Y. Chen, V.F. Farias, Simple policies for dynamic pricing with imperfect forecasts, Oper. Res. 61 (3) (2013) 612–624, https://doi.org/10.1287/opre.2013.1166.
[28] Y. Fu, H. Li, M. Huang, H. Xiao, Bi-objective modeling and optimization for stochastic two-stage open shop scheduling problems in the sharing economy, IEEE Trans. Eng. Manag. 1–15 (2022), https://doi.org/10.1109/tem.2021.3095954.
[29] Y. Kayikci, E-Commerce in Logistics and Supply Chain Management 1015–1026, Advanced Methodologies and Technologies in Business Operations and Management, 2019, https://doi.org/10.4018/978-1-5225-7362-3.ch076.
[30] Z. Allam, A. Sharifi, S. Bibri, D. Jones, J. Krogstie, The Metaverse as a virtual form of smart cities: opportunities and challenges for environmental, economic, and social sustainability in urban futures, Smart Cities 5 (3) (2022) 771–801, https://doi.org/10.3390/smartcities5030040.
[31] Z. Hao, R. Ji, Q. Li, FastPay: a secure fast payment method for edge-IoT platforms using blockchain, in: 2018 IEEE/ACM Symposium on Edge Computing (SEC), 2018, https://doi.org/10.1109/sec.2018.00055.
[32] S. Broumi, R. Sundareswaran, M. Shanmugapriya, G. Nordo, M. Talea, A. Bakali, F. Smarandache, Interval- valued fermatean neutrosophic graphs, Decis. Making 5 (2) (2022) 176–200, https://doi.org/10.31181/dmame0311072022b.
[33] A. Ashraf, K. Ullah, A. Hussain, M. Bari, Interval-valued picture fuzzy maclaurin symmetric mean operator with application in multiple attribute decision-making, Rep. Mech. Eng. 3 (1) (2022) 210–226, https://doi.org/10.31181/rme20020042022a.
[34] M. Riaz, H.M. Athar Farid, Picture fuzzy aggregation approach with application to third-party logistic provider selection process, Rep. Mech. Eng. 3 (1) (2022) 227–236, https://doi.org/10.31181/rme20023062022r.
[35] V.A. Khan, U. Tuba, S.A. Rahaman, Motivations and basics of fuzzy, intuitionistic fuzzy and neutrosophic sets and norms, Yugoslav J. Operat. Res. 32 (3) (2022) 299–323.
[36] S. Kalantari, H. Kazemipoor, F. Movahedi Sobhani, S.M. Hadji Molana, A neutrosophical model for optimal sustainable closed-loop supply chain network with considering inflation and carbon emission policies, Decis. Making 5 (2) (2022) 46–77, https://doi.org/10.31181/dmame03051020224k.
[37] Ç. Karamaşa, D. Karabasevic, D. Stanujkic, A. Kookhdan, A. Mishra, M. Ertürk, An extended single-valued neutrosophic AHP and MULTIMOORA method to evaluate the optimal training aircraft for flight training organizations, Facta Univ. Ser. 19 (3) (2021) 555–578, https://doi.org/10.22190/FUME210521059K.
[38] B. Zhou, J. Chen, Q. Wu, D. Pamucar, W. Wang, L. Zhou, Risk priority evaluation of power transformer parts based on hybrid FMEA framework under hesitant fuzzy environment, Facta Univ. Ser. 20 (2) (2022) 399–420, https://doi.org/10.22190/FUME220223013Z.
[39] S. Sveshnikov, V. Bocharnikov, A. Pavlikovsky, A. Prima, Estimating the potential willingness of the state to use military force based on the Sugeno fuzzy integral, Yugoslav J. Operat. Res. 32 (3) (2022) 325–356.

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