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RESEARCH ARTICLE

Transformative Pathways to Metaverse Integration in Intelligent Transportation Systems Using Pythagorean Fuzzy CRITIC-AROMAN Method

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ABSTRACT The dynamic Metaverse, a hybrid of virtual reality and immersive simulations, has transcended its origins in gaming and has become ingrained in many facets of everyday life. This innovation has an interesting prospect for the integration of the Metaverse, as it is affecting the intricate sector of intelligent transportation systems. However, as there are a variety of implementation strategies in this ecosystem, there are intricate roadblocks that must be carefully considered while making decisions. In this paper, the Pythagorean fuzzy (PyF) with CRITIC-AROMAN evaluation model provides cutting-edge for comprehensively rank alternative implementation approaches. CRITIC (criteria importance through intercriteria correlation) is one of the decision-making models that is used to find importance of each criterion within the context of Metaverse integration. This abstract, which emphasizes of the PyF with CRITIC-AROMAN model and the critical role of CRITIC in enhancing decision-making precision, provides a major new contribution to the subject. With intelligent transportation systems playing a major role in the Metaverse movement, this research offers policymakers crucial insights into this field. Through the complex web of human experiences, it seeks to assist people in making informed decisions.

INDEX TERMS CRITIC-AROMAN, Pythagorean fuzzy set (PyFS), MCDM, metaverse.

I. INTRODUCTION

The metaverse is a revolutionary digital domain that blurs the border between the real and the virtual, ushering in a new era of experiences that are interconnected with one another. Players are able to do more than simply explore vast virtual landscapes; they are also able to cultivate real-time interactions with other players and cultivate an online community that is limitless. Even when no one is actively engaging, the metaverse is a real ecosystem that continues to develop and evolve. In addition to being a pleasant place to play, the metaverse is also an ongoing ecology. In the metaverse, people have the ability to construct everything from intricate virtual goods to whole virtual cities. This is made possible by the metaverse's democratic nature, which implies that anybody may have an impact on the basic structure of the virtual reality. It is possible for users to travel freely between the digital and physical worlds in an ever-changing environment because it brings together diverse technologies such as virtual reality and

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augmented reality. Users are not restricted by any one device. In addition to being a fanciful world to explore, it also possesses its very own vibrant economy, replete with virtual currencies and marketplaces where digital entrepreneurs have the opportunity to make a tremendous amount of money by buying, selling, and trading digital goods and services. The development of the metaverse is drawing the attention of major players in the technology industry, who are enthusiastic about the possibility of new dimensions for gaming, social interactions, and entertainment.

The video gaming industry was highly enthusiastic about the introduction of the metaverse; however, the focus swiftly switched to the way it could be utilized in the industrial sector. Despite the fact that the initial enthusiasm has subsided, the metaverse has had a substantial impact on a number of different enterprises [1]. Many individuals continue to be concerned about the moral implications of the virtual world, despite the fact that it offers a great deal of potential for advancement. While this is the case, Abdari et al. [2] asserts that the metaverse has already established a genuine economy that is currently valued at around 65 billion dollar and is anticipated to approach 900 billion dollar by the year 2030. Legislators are placing an increasing amount of importance on traffic planning as a method of addressing the issues that are brought about by modern transportation networks and the fast expansion of urban regions. It is necessary to develop innovative technologies in order to manage mobility in a manner that is both safer and more effective. This is because the growing population of cities has produced transportation inefficiencies. Intelligent transportation systems have been developed as a consequence, which have resulted in improvements to traffic flow, trip times, and safety.As it continues to develop and provide fresh solutions to several aspects of contemporary life, the metaverse might be compared to a virtual reproduction of the real world that incorporates variable temporal variables. The fast growth of transportation infrastructure and the growing number of urban regions are two factors that are causing policymakers to become increasingly worried about traffic planning, as stated by Dimitrakopoulos and Demestichas [3]. Taking use of the immense potential of the metaverse presents a once-in-a-lifetime opportunity to address these concerns. Due to the inefficiencies in transportation that are induced by urbanization, intelligent transportation systems are very necessary for effective mobility management in today's cities. These systems contribute to sustainability by lowering carbon emissions and air pollution, both of which have a negative impact on the environment and the health of people. In addition to boosting traffic safety, travel speeds, and flow, these systems also contribute to sustainability by reducing carbon emissions.

Introducing intelligent transportation systems into the metaverse is one approach that might be used to address the challenges that are associated with transportation. Digital twins, mirror-worlds, and extended reality (XR) are some of the powerful tools that are available in the metaverse. These technologies may be used to test and develop potential solutions to social, economic, and environmental problems. Even if the metaverse is still in its infancy, the enormous investments that have already been made in it indicate that it has the potential to facilitate the development of solutions that are of the next generation shortly. During the next several years, game-changing breakthroughs in transportation solutions are on the horizon, and they will be brought about by the progressive development of the metaverse. In addition to these benefits, they contribute to the preservation of the environment by addressing issues like as the pollution of the air and the release of carbon. Allam et al. [4] suggests that integrating intelligent transportation systems into the metaverse is a novel approach to addressing the challenges that are commonly associated with transportation. Through the utilization of components such as digital twins, mirror-worlds, and extended reality (XR), the metaverse provides strong resources that may be utilized for the purpose of analyzing potential solutions to social, economic, and environmental complications. Because of the significant amount of money that has been invested in this area, even if the metaverse is still in its first phases of development, we should anticipate the introduction of innovative solutions within the next several years. The literature is accumulating more and more data that suggests there is a connection between the transportation industry and the metaverse. In a number of studies, the advantages and disadvantages of a variety of strategies for the implementation of intelligent transportation systems have been brought to light. The study, however, does not compare the various approaches to implementation, which is a significant limitation.

In order to bridge that knowledge gap, this research investigates the process of implementing the metaverse transportation system from a number of different perspectives, taking into consideration conflicting restrictions that impact success on a number of different fronts. We provide a novel model for making decisions based on numerous aspects, particularly adapted to investigate the sophisticated technique of constructing transit networks in the metaverse. This model is presented in order to address this issue for which we are responsible.

A. LITERATURE REVIEW

Despite the fact that classical set theory has been the topic of a significant amount of research, conventional techniques of data analysis are ineffective when dealing with information that is ambiguous or imprecise. For the purpose of addressing these challenges, Zadeh [5] put up the concept of fuzzy set theory, which combines membership degree (MBSD). Molodtsov [6] is the one who brought forth the concept of soft set theory, whereas Pawlak [7] is the one who came up with rough set theory. In the year 1986, Atanassov [8] put up the idea of intuitionistic fuzzy sets (IFS). These sets are distinguished by their MBSD and non-membership degree

(N-MBSD), both of which satisfy the criteria that their sum cannot be more than one. IFS has evolved into a technique that is important for dealing with challenges that are encountered in the actual world, such as ambiguity or fuzziness. The concept was further extended by Yager [9], [10], [11] through the utilization of PyFS, which is defined by MBSD and N-MBSD, whereby the sum of the squares of these degrees must be equal to one. As a consequence of this, when it comes to dealing with the uncertainty and imprecision of data that is acquired from real-world issues, PyFSs are noticeably superior to IFSs. Studies that were conducted not too long ago have looked into a variety of perspectives about PyFSs.

There are many different sectors that can benefit from the consolidation of data for the purpose of making decisions. These fields include business, administration, medicine, social work, technology, psychology, and intelligent systems. The concept of alternative consciousness has been conceptualized by individuals in the past as either a verbal number or a quantitative accumulation. However, due to the unpredictability of the data, combining them is not a simple task. Aggregation operators, also known as AOs, are extremely important for dealing with issues that are associated with MCDM, particularly because the primary objective is to integrate many inputs into a single input. Moslem proposed the implementation of a spherical fuzzy analytic hierarchy approach in order to take into account the challenges that are associated with urban transportation [13]. The authors Peng and Yuan [12] and Rehman et al. [14] proposed geometric AOs and PyF averaging AOs, respectively. Both of these writers submitted their work. Wang and Garg [15] described fuzzy AOs that were derived from the Archimedean norm.

The CRITIC approach, which was developed by Diakoulaki et al. [16] stands out as a dependable and powerful solution for the difficult task of assigning weights to a large number of criteria in the expansive and complicated field of Multi-Criteria Decision Making (MCDM). The introduction of this approach. Through the utilization of paired comparisons, this approach, which is founded on comparative ratio analysis, is able to determine the weight of each criterion, so producing a trustworthy result. This approach's versatility and utility in a number of situations is demonstrated by the extensive body of literature that covers this method, which covers a wide range of subjects. As a result of its human-like nuanced approach to weighting criteria, which goes beyond mere mathematical computations, this methodology has become an essential component in the decision-making process. In the research that Kaur et al. [17] conducted on aircraft selection, they extended the CRITIC methodology to a Neutrosophic environment. The fact that this is the case demonstrates that the CRITIC approach is adaptable and can deal with a wide variety of decision-making scenarios. Neutrosophic CRITIC MCDM was utilized by Sleem et al. [18] in order to rate the factors and customer desires that were present within the global virtual reality metaverse. This is an example of how CRITIC is being utilized in virtual reality and new technology environments.

The authors Mishra et al. [19] proposed a new scoring function for Fermatean fuzzy numbers in MCDM by combining the CRITIC and GLDS approaches. This approach involves the utilization of new scoring systems, which results in improved decision-making processes. A hybrid model for mixed-criteria decision making (MCDM) that combines Monte Carlo simulation was presented by Cui et al. [20] with the purpose of improving the reliability and consistency of decision-making practices. By demonstrating how CRITIC is combined with a variety of methodologies, this demonstrates how decision help may be improved. Through the utilization of MCDM approaches in the assessment of surface water quality. Das [21] provided evidence of the practical application of these methodologies in environmental management. For the purpose of optimizing logistical operations, Jusufbašić [22] provided a succinct review of MCDM approaches that are utilized in the process of selecting equipment for logistics. Ertemel et al. [23] illustrated the application of MCDM in behavioral research and healthcare by utilizing CRITIC-TOPSIS to analyze smartphone addiction. This was done in their study. Ranjan et al. [24] demonstrated in their research how MCDM can be applied in engineering in a practical manner by using a CRITIC-MARCOS model to the process of selecting materials for usage in the automotive industry. Mukhametzyanov [25] made a significant contribution to the theoretical understanding of weight determination by conducting a comprehensive evaluation of objective approaches to the resolution of MCDM problems. These techniques included entropy, CRITIC, and SD methods. The PyF MCDM technique, which is built upon CoCoSo and CRITIC, was presented by Peng et al. [26] with the intention of evaluating the 5G industry. We can observe the application of MCDM in this context in domains where new technologies are only beginning to gain traction.

While evaluating chicken soup, Cao et al. [27] illustrated the efficacy of the entropy weight approach in determining the quality of food. They used this approach in conjunction with the grey correlation degree method to determine the quality of the chicken soup. This methodological technique was improved by He et al. [28] in order to investigate the structural impact of PEM water electrolyzers on mass transfer performance. They emphasised the relevance of this technique in increasing the efficiency of technical designs.Furthermore, in order to evaluate the sustainability indicators in Liaoning, China, Yi et al. [29] utilised the entropy weight approach in conjunction with sentiment analysis for the purpose of urban sustainability evaluation. These studies, when taken as a whole, shed insight on the ways in which the entropy weight approach can be effectively utilised in a variety of sectors, showing the ways in which it can improve analytical techniques and decision-making frameworks.

Contributing to the field of blockchain technology assessment, Zafar et al. [30] suggested a methodology for evaluating blockchains that utilizes the entropy-CRITIC weight approach and MCDM methodologies. Bączkiewicz et al. [31] highlighted the relevance of MCDM in enhancing recommendation algorithms by discussing methodical elements of MCDM in the context of an E-commerce recommender system. In their study, Hassan et al. [32] demonstrated the utilization of MCDM in renewable energy planning by applying a CRITIC-TOPSIS strategy to optimally identify sites for solar PV farms. In their study, Kumar and Singh [33] showed how MCDM can be applied in manufacturing processes by using an integrated MCDM strategy to optimize powder mixed Green-EDM parameters for several objectives. To improve software engineering and reliability, Saxena et al. [34] suggested a new CRITIC-TOPSIS method for choosing the best growth models for software dependability. Emphasizing the importance of MCDM in fostering sustainability within supply chain management, Vadivel et al. [35] utilized the CRITIC technique to pick environmentally conscious suppliers. The literature analysis highlights the extensive use of the CRITIC approach and MCDM techniques in many domains, demonstrating their adaptability and efficacy in handling intricate decision-making issues. This study shows how MCDM approaches are constantly evolving in many fields, and it also makes a theoretical and practical contribution to those fields.

In the year 2023, Bošković et al. [36] presented the AROMAN method, which offered a fresh perspective on the decision-making process and ideas for the delivery of cargo bikes. In addition to paving the way for more broad applications in this industry, their emphasis on adaptation and flexibility also cleared the door for new ways of thinking about things. While this was going on, Kara et al. [37] proposed the MEREC-AROMAN approach as a means of determining the extent of sustainable competitiveness. By analyzing a case study that was conducted in Turkey, they were able to provide light on how the MEREC and AROMAN methodologies functioned together, which resulted in the production of information that was helpful for social and economic planners. For the purpose of analyzing port performance, Yalçın et al. [38] adopted an innovative approach by incorporating an IF-based model into the existing approaches. For the purpose of analyzing the lifespan and efficacy of port operations, this all-encompassing technique utilized IFSs, which provided a convincing image of the unknowns involved in evaluating performance. The comparison table provides a summary of this method. This body of work demonstrates important breakthroughs in decision-making processes and performance evaluation across a number of contexts, regardless of the context in which they are used. **AROMAN** [36], when compared to other techniques such as **MABAC** [39], **TOPSIS** [40], **ARAS** [41], **WASPAS**, **CODAS** [42], **MAUT** [43], **VIKOR** [44], **CoCoSo** [45], and **SWARA** [46] exhibits notable differences. The use of an initial decision-making matrix that comprises numerous possibilities assessed against distinct criteria, which are frequently in competition with one another, is the primary premise that these techniques adhere to when it comes to decision-making. The conclusion of any Multiple Criteria Decision Making (MCDM) approach is a final ranking of the available alternatives, which provides decision-makers with a basis for selecting the option that is most suitable for their needs. The comprehensive ranking of each approach is presented in a manner that contains a considerable deal of detail.

$$\textit{TOPSIS}: \quad \mathrm{K_i} = \frac{\mathrm{N_i^-}}{\mathrm{N_i^-} + \mathrm{N_i^+}} \tag{1}$$

Description: Proximity to the optimal positive solution.

$$\textit{MAUT}: \quad \mathrm{K_i} = \sum_{j=1}^{BF} \mathrm{N_{ij}} \cdot \mathrm{w_j} \tag{2}$$

Description: Final utility score for each alternative based on assigned utility score values.

$$\textit{ARAS}: \quad \mathrm{K_i} = \frac{\mathrm{S_i}}{\mathrm{S_0}} \tag{3}$$

Description: Level of utility associated with alternatives.

$$\textit{WASPAS}: \quad \mathrm{K_i} = \lambda \mathrm{N_1^{(1)}} + (1-\lambda)\mathrm{N_1^{(2)}} \tag{4}$$

Description: Combined measure for each alternative, where λ represents the parameter in the WASPAS method.

$$\textit{MABAC}: \quad \Omega_i = \sum_{j=1}^{m} \mathrm{N_{ij}} \tag{5}$$

Description: Ranking options based on distances from the approximate border.

$$\textit{CoCoSo}: \quad \mathrm{K_i} = (\mathrm{K_{ia}} \cdot \mathrm{K_{ib}} \cdot \mathrm{K_{ic}})^{\frac{1}{3}} + \frac{1}{3}(\mathrm{K_{ia}} + \mathrm{K_{ib}} + \mathrm{K_{ic}}) \tag{6}$$

Description: Optimal ranking $\mathrm{K_i}$ considering Total Utility Strategies for all alternatives.

$$\textit{EDAS}: \quad \mathrm{K_i} = \frac{1}{2}(\mathrm{KP_i} + \mathrm{KN_i}) \tag{7}$$

Description: Appraisal score for each alternative, with $\mathrm{KP_i}$ and $\mathrm{KN_i}$ as normalized values of the weighted Positive Distance from Average (PDA) and weighted Negative Distance from Average (NDA).

$$\textit{SWARA}: \quad \mathrm{w_j} = \frac{\mathrm{N_j}}{\sum_{j=1}^{n} \mathrm{N_j}} \tag{8}$$

Description: Final ranking of alternatives sorted by arranging values in descending order, considering the relative weight of each attribute.

$$\textit{AROMAN}: \quad \mathrm{K_i} = \beth_i^{\lambda} + \beth_i^{(1-\lambda)} \tag{9}$$

Description: Conclusive ranking of alternatives denoted as K_1, determined with the influence of the coefficient λ, signifying the degree of the criterion type.

The Metaverse, a dynamic fusion of extended reality (XR), digital twins, and mirror-world features, stands as a groundbreaking arena for the development of sophisticated systems, particularly in the realm of Intelligent Transportation Systems. Within the vast landscape of literature, several promising models have emerged, harnessing the capabilities of the Metaverse to revolutionize transportation systems. Among these, addressing the paramount concern of traffic safety [47], the advent of Data-Driven Intelligent Transport Systems (DDITS) has ushered in a new era. Through the adoption of a people-centered design philosophy and the prioritization of privacy as a key concern, DDITS transcends the capabilities of traditional approaches. The method that it employs involves the incorporation of data from a variety of sources, such as microphones, GPS, and sensors. These datasets are utilized for the purpose of training artificial intelligence systems, which are then prepared to address the particular challenges that are presented by DDITS [48].

In addition to being an innovative move in the transportation industry, the Metaverse Transportation System (MTS) is a system that integrates transportation technology into the Metaverse in a seamless manner. This integration creates new opportunities for research and enhances the intelligence of existing transportation systems [49]. Additionally, it opens up new options for transportation improvement. As a result of the advanced processing and networking capabilities of modern autos, the existing landscape makes it possible to establish a miniature metaverse within these vehicles. There is a significant potential for the integration of data through in-car technology, which eventually led to the formation of a robust alliance known as Vetaverse. This relationship exemplifies the mutually beneficial link that exists between the Metaverse and the automotive industry [50].

B. JUSTIFICATION FOR METHOD'S SELECTION

1) In comparison to fuzzy logic approaches that are more rigid, the PyF provides a structure that is more adaptable for coping with the uncertainty that is associated with decision-making. This versatility makes it possible to depict uncertainty in a nuanced manner, which is particularly useful given the complex and ever-evolving nature of technological integration.
2) For the purpose of ranking the relevance of choice criteria, our model takes use of the CRITIC methodology, which offers an organised method of undertaking this task. In contrast to other models, such as AHP and VIKOR, which employ subjective weighting techniques, CRITIC provides a more accurate and objective evaluation by taking into consideration the interdependencies between criteria. This is in contrast to other models.
3) The incorporation of the AROMAN methodology into CRITIC-AROMAN results in an improvement in alternative ranking and offers a comprehensive analysis of the available implementation choices. Using this feature, the inadequacies of methods such as TOPSIS and ARAS, which primarily prioritise ranking without rigours criterion weighing, are corrected. These methods are primarily concerned with ranking.
4) A complete approach for intelligent transportation systems and Metaverse integration is provided by the PyF with CRITIC-AROMAN model. This method creates an environment in which several criteria and unknown elements interact with one another. Based on the fact that it combines the benefits of fuzzy logic, which include the ability to handle ambiguity, with severe criterion analysis and ranking refinement, it is well suited for scenarios that need complex decision-making.

Meta-enterprises/Meta cities propounds a comprehensive model aimed at refining decision-making processes for digital twins of actual enterprises and cities. The interactive engagement between Meta-enterprises/Meta-cities and their real-world counterparts stands as a testament to the potential improvements in decision quality within enterprises and cities [52]. Despite the evident opportunities that the Metaverse brings to the table for transportation system design, the creation of precise virtual twins for real systems remains a formidable challenge. The Metaverse, while advancing at an accelerated pace, has not reached full maturity, and its reliance on a myriad of auxiliary technologies introduces layers of complexity. The increasing interaction between physical entities and their digital twins adds another dimension of intricacy. Developing real-time digital twins for vehicles and drivers necessitates extensive sensing and interpretation, both from within and outside the system [50]. However, the Metaverse, propelled by rapid advancements, showcases promising potential. Virtual Reality (VR) technologies, particularly in simulation-based instruction, yield highly efficient results. The creation of interactive simulations within 3D VR environments, complete with interfaces and control surfaces, underscores the effectiveness of these technologies in the pursuit of immersive and human-centric design [53]. The Metaverse is quickly becoming an essential part of the design of state-of-the-art transportation systems due to its ability to address current problems. Connecting the Metaverse to intelligent transportation networks is a game-changing innovation that may radically alter how city dwellers use public transit. To handle the interdependencies and uncertainties that come with this intersection, though, advanced decision-making frameworks are required. For the simple reason that the issues it raises are quite nuanced. The current processes have their uses, but they don't always provide enough data to compare different implementation strategies as they should. For example, when it comes to capturing complex relationships between criterion and providing reliable ways to evaluate criteria that account for their dynamic interactions, well-established methodologies like fuzzy logic and MCDM could fall short.

By providing and validating the PyF with CRITIC-AROMAN evaluation technique, this work fills in these gaps in knowledge. In addition to incorporating the adaptability of PyF Sets, the innovative framework improves the objective criterion weighing capabilities of the CRITIC approach by including the ranking refinement of AROMAN. Through the utilisation of AROMAN, CRITIC methodology, and PyFSs theory, this model endeavours to enhance the precision of decision-making while simultaneously evaluating the incorporation of the Metaverse into intelligent transportation systems.

The primary purpose of this study is to fill existing gaps in the literature by providing a more advanced and integrated approach to decision-making in this evolving technological landscape. Specifically, our research seeks to:

1) For the purpose of overcoming the limits of the approaches that are now in use, it is necessary to perform a comprehensive assessment of alternative implementation choices that incorporate robust criterion weighting and ranking procedures.
2) Investigate the accuracy of the model by carrying out empirical research and applying it to situations that occur in the actual world; demonstrate how effectively it deals with the difficulties that arise while integrating the Metaverse.
3) It is important to encourage methods that improve existing frameworks, since this will lead to a greater understanding of how new technologies, such as the Metaverse, may be integrated into municipal transportation systems in a seamless manner.

C. MOTIVATION AND CONTRIBUTION

We began out on a journey to examine the inclusion of the Metaverse into our everyday lives since we were aware of the astonishing growth of the Metaverse from its gaming beginnings to a powerful influence in many aspects of our human experience, particularly within intelligent transportation systems. As a result of the complicated issues that arise as a result of incorporating the Metaverse into transportation, we decided to work on developing a robust evaluation technique. In order to guide you through the complex decision-making process that occurs at the dynamic intersection of technology and human existence, our objective in presenting the PyF with CRITIC-AROMAN model is to evaluate the many implementation alternatives in an artistic manner. In order to ensure that our choices are as accurate as possible, we have a strong regard for CRITIC, which serves as our source of inspiration. By drawing attention to the significant part that intelligent transportation systems play in the metaverse's ongoing evolution, we hope to present policymakers with knowledge that is both informative and necessary. Within the intricate framework of our shared human experiences, the purpose of our research is to offer decision-makers nuanced insights that will enable them to guide the course of the Metaverse. The most important addition that this study makes is the development of the PyF with CRITIC-AROMAN model, which is a well-developed assessment framework that compares various methods of integrating the Metaverse, particularly in smart transportation systems. The innovative character of this model makes it possible to have a comprehensive and detailed instrument that can be used to address the severe decision-making challenges that are present in this fast-paced technological environment. CRITIC is an excellent feature that significantly enhances the total value. It accomplishes this by analyzing the correlations between different criteria and assessing the relevance of each criterion within the context of Metaverse integration. By establishing a framework for making strategic and refined judgments, this article contributes to the improvement of the accuracy of assessing various implementation options. This contribution is more significant than it has ever been before since intelligent transportation systems are at the core of the ongoing development of the Metaverse. In addition to providing policymakers with valuable information, it will also help guide the trajectory of this transformative technology within the complex fabric of human experiences.

D. GOALS OF THE MANUSCRIPT

1) For the purpose of evaluating the incorporation of the Metaverse into intelligent transportation systems, the PyF with CRITIC-AROMAN assessment technique is presented and validated.
2) Using CRITIC to address the uncertainties and interdependencies that arise as a result of linking the Metaverse with transportation networks is one way to ensure that judgements are as accurate as possible. Interdependencies and relative significance of criteria are taken into consideration by CRITIC, which results in an improvement in accuracy.
3) To demonstrate that the model is applicable to real-world situations, you should make use of empirical validation and case study applications.
4) It is important to provide academics, managers, and policymakers with assistance in comprehending the dynamic interaction that exists between transportation infrastructure and information technology.
5) Within the context of intelligent transportation systems, it is important to encourage the development of environmentally friendly solutions that can facilitate the integration of technology and rational decision-making.

II. ADVANTAGES AND DISADVANTAGES OF EXISTING MODELS

1)
   - **Advantages:** Capable of adjusting to circumstances that involve vagueness and unspecific facts.
   - **Disadvantages:** It can be difficult to accurately calculate criteria weighting and to accurately capture complex interdependencies.
2)
   - **Advantages:** An approach that is methodical in nature and is used to evaluate possibilities in

accordance with a variety of established standards (for example, AHP and TOPSIS).

- **Disadvantages:** It is possible to oversimplify the interaction between the criteria, which might result in key implementation details being overlooked.

3) **Methods like VIKOR and WASPAS:**

- **Advantages:** Consider conflicting criteria and offer compromise solutions.
- **Disadvantages:** Less effective in handling the dynamic and evolving nature of technology integration into transportation systems.

A. STRUCTURE OF THE PAPER

This academic work is organized in the following manner, with the following sections following: A comprehensive introduction to PyFS is provided in Section III, which is an important part of our research. Subsequently, in Section IV, we construct an approach that utilizes PyFS in order to resolve issues with Multiple Attribute Decision Making (MADM). It can assist you in making more informed decisions in situations that are difficult and unpredictable. Following this, we will go to Section V, in which we will apply the CRITIC-AROMAN paradigm to MADM in practice. We walk through a case study to show how our approach can play out in real-world decision-making scenarios, bringing out the practical side and potential benefits. Lastly, in Section VII, we wrap things up by summarizing what we found and sharing some closing thoughts on why our work matters. We also toss in some ideas for future research, hoping to keep the ball rolling in the world of MADM and its applications.

III. PRELIMINARIES

Definition 1 [5]: Let $\mathtt{U}$ denote the universal set. A fuzzy set $\mathtt{B}$ in $\mathtt{U}$ is formally expressed as

$$\mathtt{B} = \{(b, \mu_F(b)) : b \in \mathtt{U}\},$$

where $\mu_F(b)$ signifies the membership degree of the element b in the universal set $\mathtt{U}$.

Definition 2 [8]: An IFS in $\mathtt{U}$ is defined as

$$\Omega_F = \{\langle \breve{b}, \mu_F(\breve{b}), \nu_F(\breve{b}) | \breve{b} \in \mathtt{U}\rangle\}, \tag{10}$$

where $\mu_F(\breve{b}), \nu_F(\breve{b}) \in [0,1]$, such that $0 \leq \mu_F(\breve{b}) + \nu_F(\breve{b}) \leq 1$ for all $\breve{b} \in \mathtt{U}$. $\mu_F(\breve{b}), \nu_F(\breve{b})$ represent MD and NMD separately for some $\breve{b} \in X$. we denote this pair as $F = (\mu_F, \nu_F)$, the entirety of this research, and called as IFN satisfying the requirements $\mu_F, \nu_F \in [0,1]$ and $\mu_F + \nu_F \leq 1$.

Definition 3 [9], [10], [11]: Consider, a PyFS $\mathtt{B}$ in $\mathtt{U}$ is defined as

$$\mathtt{B} = \{\langle \psi, {}^{\mu_F}\delta_{\mathtt{B}}(\psi), {}^{\daleth}\nu_{F\,\mathtt{B}}(\psi)\rangle : \psi \in \mathtt{U}\}$$

where ${}^{\mu_F}\delta_{\mathtt{B}}, {}^{\daleth}\nu_{F\,\mathtt{B}} : \mathtt{U} \to [0,1]$ defines the MBSD and the N-MBSD of the alternative $\psi \in \mathtt{U}$ and for every ψ we have

$$0 \leq {}^{\mu_F}\delta^2_{\mathtt{B}}(\psi) + {}^{\daleth}\nu_{F\,\mathtt{B}}^{\,2}(\psi) \leq 1.$$

Furthermore, $\pi_{\mathtt{B}}(\psi) = (1 - {}^{\mu_F}\delta^2_{\mathtt{B}}(\psi) - {}^{\daleth}\nu_{F\,\mathtt{B}}^{\,2}(\psi))^{1/2}$ is called the indeterminacy degree of ψ to $\mathtt{B}$.

Definition 4 [9]: Let $\kappa^{\daleth}{}_1 = \langle {}^{\mu_F}\delta_1, {}^{\daleth}\nu_{F\,1}\rangle$ and $\kappa^{\daleth}{}_2 = \langle {}^{\mu_F}\delta_2, {}^{\daleth}\nu_{F\,2}\rangle$ be PyFNs. Then

(1) $\overline{\kappa^{\daleth}}{}_1 = \langle {}^{\daleth}\nu_{F\,1}, {}^{\mu_F}\delta_1\rangle$

(2) $\kappa^{\daleth}{}_1 \vee \kappa^{\daleth}{}_2 = \langle max\{{}^{\mu_F}\delta_1, {}^{\daleth}\nu_{F\,1}\}, min\{{}^{\mu_F}\delta_2, {}^{\daleth}\nu_{F\,2}\}\rangle$

(3) $\kappa^{\daleth}{}_1 \wedge \kappa^{\daleth}{}_2 = \langle min\{{}^{\mu_F}\delta_1, {}^{\daleth}\nu_{F\,1}\}, max\{{}^{\mu_F}\delta_2, {}^{\daleth}\nu_{F\,2}\}\rangle$

(4) $\kappa^{\daleth}{}_1 \oplus \kappa^{\daleth}{}_2 = \langle ({}^{\mu_F}\delta_1^2 + {}^{\mu_F}\delta_2^2 - {}^{\mu_F}\delta_1^2\,{}^{\mu_F}\delta_2^2)^{1/2}, {}^{\daleth}\nu_{F\,1}{}^{\daleth}\nu_{F\,2}\rangle$

(5) $\kappa^{\daleth}{}_1 \otimes \kappa^{\daleth}{}_2 = \langle {}^{\mu_F}\delta_1\,{}^{\mu_F}\delta_2, ({}^{\daleth}\nu_{F\,1}^{\,2} + {}^{\daleth}\nu_{F\,2}^{\,2} - {}^{\daleth}\nu_{F\,1}^{\,2}\,{}^{\daleth}\nu_{F\,2}^{\,2})^{1/2}\rangle$

(6) $\sigma\kappa^{\daleth}{}_1 = \langle (1 - (1 - {}^{\mu_F}\delta_1^2)^{\sigma})^{1/2}, {}^{\daleth}\nu_{F\,1}^{\,\sigma}\rangle$

(7) $\kappa^{\daleth\sigma}_{\;1} = \langle {}^{\mu_F}\delta_1^{\sigma}, (1 - (1 - {}^{\daleth}\nu_{F\,1}^{\,2})^{\sigma})^{1/2}\rangle$

Definition 5 [9]: Consider $\widetilde{B} = \langle {}^{\mu_F}\delta, {}^{\daleth}\nu_F\rangle$ is a PyFN, then the score function $\mathtt{E}$ of $\widetilde{B}$ is chractrized as

$$\mathtt{E}(\widetilde{B}) = {}^{\mu_F}\delta^2 - {}^{\daleth}\nu_F^{\,2} \tag{11}$$

$\mathtt{E}(\widetilde{B}) \in [-1, 1]$. The ranking of a PyFN is typically determined by its score, where a higher score indicates a stronger preference for the PyFN in a given query. However, in various applications of PyFN, the score function may not be applicable or useful. Therefore, it is not mandatory to rely on the score function when comparing PyFNs.

Definition 6: Consider $\widetilde{B} = \langle {}^{\mu_F}\delta, {}^{\daleth}\nu_F\rangle$ is a PyFN, then an accuracy function $\mathtt{U}$ of $\widetilde{B}$ is defined as

$$\mathtt{U}(\widetilde{B}) = {}^{\mu_F}\delta^2 + {}^{\daleth}\nu_F^{\,2}$$
$$\mathtt{U}(\widetilde{B}) \in [0, 1].$$

Definition 7: Let $\mathtt{R} = \langle {}^{\mu_F}\delta_{\mathtt{R}}, {}^{\daleth}\nu_{F\,\mathtt{R}}\rangle$ and $\mathtt{M} = \langle {}^{\mu_F}\delta_{\mathtt{M}}, {}^{\daleth}\nu_{F\,\mathtt{M}}\rangle$ are any two PyFN, and $\mathtt{E}(\mathtt{R})$, $\mathtt{E}(\mathtt{M})$ are the score function of $\mathtt{R}$ and $\mathtt{M}$, and $\mathtt{U}(\mathtt{R})$, $\mathtt{U}(\mathtt{M})$ are the accuracy function of $\mathtt{R}$ and $\mathtt{M}$, respectively, then

(1) If $\mathtt{E}(\mathtt{R}) > \mathtt{E}(\mathtt{M})$, then $\mathtt{R} > \mathtt{M}$

(2) If $\mathtt{E}(\mathtt{R}) = \mathtt{E}(\mathtt{M})$, then

If $\mathtt{U}(\mathtt{R}) > \mathtt{U}(\mathtt{M})$ then $\mathtt{R} > \mathtt{M}$,

If $\mathtt{U}(\mathtt{R}) = \mathtt{U}(\mathtt{M})$, then $\mathtt{R} = \mathtt{M}$.

Always keep in mind that the score function value falls between -1 and 1. In assistance of the following investigation, we present another scoring function, $\mathtt{H}(B) = \frac{1 + {}^{\mu_F}\delta_B^2 - {}^{\daleth}\nu_{F\,B}^{\,2}}{2}$. We can see that $0 \leq \mathtt{H}(B) \leq 1$.

A. PyF AGGREGATION OPERATORS

Definition 8 [12]: Assume that $\kappa^{\daleth}{}_k = \langle {}^{\mu_F}\delta_k, {}^{\daleth}\nu_{F\,k}\rangle$ is a assortment of PyFNs, and PyFWA: $\Lambda^n \to \Lambda$, if

$$PyFWA(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots \kappa^{\daleth}{}_{BF}) = \mathtt{G}^{\psi}{}_1\kappa^{\daleth}{}_1 \oplus \mathtt{G}^{\psi}{}_2\kappa^{\daleth}{}_2 \oplus \ldots, \mathtt{G}^{\psi}{}_{BF}\kappa^{\daleth}{}_{BF}$$

where Λ^n is the set of all PyFNs, and $\mathtt{G}^{\psi} = (\mathtt{G}^{\psi}{}_1, \mathtt{G}^{\psi}{}_2, \ldots, \mathtt{G}^{\psi}{}_n)^T$ is weight vector (WV) of $(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots, \kappa^{\daleth}{}_{BF})$, such that $0 \leqslant \mathtt{G}^{\psi}{}_k \leqslant 1$ and $\sum_{k=1}^{BF} \mathtt{G}^{\psi}{}_k = 1$. Then, the PyFWA is called the PyF weighted average operator.

Theorem 1 [12]: Let $\kappa^{\daleth}{}_k = \langle {}^{\mu_F}\delta_k, {}^{\daleth}\nu_{F\,k}\rangle$ be the assortment of PyFNs, we can find *PyFWA* by

$$PyFWA(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots \kappa^{\daleth}{}_{BF}) = \left\langle \sqrt{(1-\prod_{k=1}^{n}(1-{}^{\mu_F}\delta_k^2)^{\mathrm{G}^{\psi}{}_k})}, \prod_{k=1}^{n}{}^{\daleth}\nu_{F\,k}{}^{\mathrm{G}^{\psi}{}_k} \right\rangle$$

Definition 9 [14]: Assume that $\kappa^{\daleth}{}_k = \langle {}^{\mu_F}\delta_k, {}^{\daleth}\nu_{F\,k}\rangle$ is the assortment of *PyFN*, and $PyFWG : \Lambda^n \to \Lambda$, if

$$PyFWG(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots \kappa^{\daleth}{}_{BF}) = \kappa^{\daleth}{}_1^{\mathrm{G}^{\psi}{}_1} \otimes \kappa^{\daleth}{}_2^{\mathrm{G}^{\psi}{}_2} \otimes \ldots, \kappa^{\daleth}{}_{BF}^{\mathrm{G}^{\psi}{}_{BF}}$$

where Λ^n is the set of all *PyFNs*, and $\mathrm{G}^{\psi} = (\mathrm{G}^{\psi}{}_1, \mathrm{G}^{\psi}{}_2, \ldots, \mathrm{G}^{\psi}{}_n)^T$ is WV of $(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots, \kappa^{\daleth}{}_{BF})$, such that $0 \leqslant \mathrm{G}^{\psi}{}_k \leqslant 1$ and $\sum_{k=1}^{BF}\mathrm{G}^{\psi}{}_k = 1$. Then, the *PyFWG* is called the PyF weighted geometric operator.

Based on PyFNs operational rules, we can also consider PyFWG by the theorem below.

Theorem 2 [14]: Let $\kappa^{\daleth}{}_k = \langle {}^{\mu_F}\delta_k, {}^{\daleth}\nu_{F\,k}\rangle$ be the assortment of PyFNs, we can find *PyFWG* by

$$PyFWG(\kappa^{\daleth}{}_1, \kappa^{\daleth}{}_2, \ldots \kappa^{\daleth}{}_{BF}) = \left\langle \prod_{k=1}^{n}{}^{\mu_F}\delta_k^{\mathrm{G}^{\psi}{}_k}, \sqrt{(1-\prod_{k=1}^{n}(1-{}^{\daleth}\nu_{F\,k}^2)^{\mathrm{G}^{\psi}{}_k})} \right\rangle$$

IV. ALGORITHM

Step 1: Introducing the PyFNs dataset, where AL_k (for $k = 1, 2, \ldots, r$) represents alternatives evaluated across multiple criteria CT_k (for $k = 1, 2, \ldots, s$). Decision-makers provide input in the form of decision matrices denoted by $Cr = [CT_{ij}]_{s\times r}$.

In our dataset, named PyFNs, each CT_{ij} is a triplet $(\mathrm{BF}_{ij}, \mathrm{BF}_{ij}, \mathrm{BF}_{ij})$. This dataset encompasses details about alternatives assessed across various criteria, where the criteria are labeled by indices i and j. Here, i ranges from 1 to r, and j ranges from 1 to s. For every alternative, we've defined eight specific linguistic terms, outlined in Table 1. Furthermore, we've enriched these terms with linguistic expressions related to expertise, as illustrated in Table 2. This diverse set of linguistic expressions provides a thorough representation of the entire information evaluation process.

Step 2: The decision-maker's weights can be obtained by employing the scoring function expressed in Equation 11. In the event that you obtain the scores, enter them into Equation 12.

$$\xi^{\gamma}{}_{ij} = \frac{\sum_i^3(\mu_{F_{\breve{U}_i}} - \nu_{F_{\breve{U}_i}})}{\sum_j^3(\sum_i^3(\mu_{F_{\breve{U}_i}} - \nu_{F_{\breve{U}_i}}))} \tag{12}$$

Step 3: Using the formula presented in Equation 3, compute the combined decision matrix $M = [M_{ij}]_{r\times s}$ according to the above equation. This entails using the algorithm in a methodical manner in order to collect all of the pertinent data together and create the unified decision matrix.

$$= \left\langle \prod_{k=1}^{n}{}^{\mu_F}\delta_k^{\mathrm{G}^{\psi}{}_k}, \sqrt{(1-\prod_{k=1}^{n}(1-{}^{\daleth}\nu_{F\,k}^2)^{\mathrm{G}^{\psi}{}_k})} \right\rangle$$

Step 4: CRITIC Method In the context of Multiple Criteria Decision Making (MCDM), the CRITIC technique is an effective instrument that may be used to determine which criteria are the most essential. It would be much simpler for you to comprehend the computing process if you follow these procedures, which will assist you in evaluating and contrasting the criteria in a meticulous manner. The fact that this method provides a methodical and rational approach to ranking and evaluating the significance of the criteria makes it particularly useful in situations when more than one of them are concerned.

Step 4.1: By using the previously given Equation (13), we can determine the score for the combined decision matrix.

$$S(\breve{U}) = \mu_{F_{\breve{U}}} - \nu_{F_{\breve{U}}} \tag{13}$$

Step 4.2: By applying the defined procedure outlined in Equation (14), the resulting matrix reflects the standardized representation of PyFNs.

$$\widetilde{\xi^{\gamma}}_{ij} = \begin{cases} \dfrac{\xi^{\gamma}{}_{ij} - \xi^{\gamma}{}_j^-}{\xi^{\gamma}{}_j^+ - \xi^{\gamma}{}_j^-}, & j \in \mathrm{CT}_b \\ \dfrac{\xi^{\gamma}{}_j^+ - \xi^{\gamma}{}_{ij}}{\xi^{\gamma}{}_j^+ - \xi^{\gamma}{}_j^-}, & j \in \mathrm{CT}_c \end{cases} \tag{14}$$

where $\xi^{\gamma}{}_j^+ = \max_i \xi^{\gamma}{}_{ij}$, $\xi^{\gamma}{}_j^- = \min_i \xi^{\gamma}{}_{ij}$, CT_b and CT_c represents the benefit-type and cost-type criteria, respectively.

Step 4.3 Calculate an approximation of the standard deviations for the criteria employing the given equation (15).

$$F_j = \sqrt{\frac{\sum_{i=1}^{n}(\xi^{\gamma}{}_{ij} - \bar{\xi^{\gamma}}_j)^2}{BF}}. \tag{15}$$

where $\bar{\xi^{\gamma}}_j = \sum_{i=1}^{n}\widetilde{\xi^{\gamma}}_{ij}/n$

Step 4.4: In order to get the correlation coefficient of the criteria, which may serve as a standard for evaluating the relationship within the dataset, the equation (16) can be utilized. An accurate and dependable approach for determining the correlation may be ensured by employing this equation.

$$k_{jt} = \frac{\sum_{i=1}^{n}(\xi^{\gamma}{}_{ij} - \bar{\xi^{\gamma}}_j)(\xi^{\gamma}{}_{ij} - \bar{\xi^{\gamma}}_t)}{\sqrt{\sum_{i=1}^{n}(\xi^{\gamma}{}_{ij} - \bar{\xi^{\gamma}}_j)^2(\xi^{\gamma}{}_{ij} - \bar{\daleth}_t)^2}} \tag{16}$$

Step 4.5: In order to assess the pertinent data information and relationships contained within the dataset, it is advisable to

TABLE 1. Linguistic terms for evaluation in metaverse integration.

Linguistic Term	Description	PyF numbers
Very High ($\mathbb{VH}$)	Integration achieves exceptional effectiveness with minimal issues. The system operates seamlessly, meeting or exceeding all expectations.	$(\langle 0.90, 0.05\rangle)$
High ($\mathbb{H}$)	Integration is clear and efficient, easily understood by stakeholders. It demonstrates robust functionality with minor, easily manageable issues.	$(\langle 0.85, 0.10\rangle)$
Moderate ($\mathbb{M}$)	Integration requires reasonable resources for successful implementation. It performs well under normal conditions with occasional, manageable challenges.	$(\langle 0.80, 0.15\rangle)$
Adequate ($\mathbb{AD}$)	Integration maintains consistent performance across diverse scenarios, handling uncertainties well. It exhibits reliability but may encounter occasional, manageable issues.	$(\langle 0.75, 0.20\rangle)$
Acceptable ($\mathbb{AC}$)	Integration can handle varying complexities and is scalable to evolving environments. While generally reliable, it may face occasional challenges under specific conditions.	$(\langle 0.65, 0.30\rangle)$
Limited ($\mathbb{L}$)	Integration adapts quickly to changing conditions with moderate resource requirements. It demonstrates agility but may face moderate challenges under certain circumstances.	$(\langle 0.60, 0.50\rangle)$
Poor ($\mathbb{P}$)	Integration experiences minimal instances of issues. Overall, the system is stable, with occasional, easily resolvable challenges.	$(\langle 0.50, 0.45, 0.55\rangle)$
Inadequate ($\mathbb{ID}$)	Integration encounters very low instances of significant challenges. While generally robust, it may face rare, complex issues that require careful consideration.	$(\langle 0.40, 0.65\rangle)$

TABLE 2. Role of decision makers.

Decision Maker	Role	Responsibilities
Decision Maker 1	Technology Expert	- Assess the technological feasibility of Metaverse integration. - Evaluate the cost-effectiveness of proposed implementations. - Provide expertise on user experience and security measures.
($\mathbb{VH}$)	($\mathbb{H}$)	($\mathbb{M}$)
Decision Maker 2	Financial Analyst	- Analyze the financial implications of different approaches. - Evaluate the cost-effectiveness and budgetary considerations. - Assess the economic impact and feasibility of the project.
($\mathbb{H}$)	($\mathbb{M}$)	($\mathbb{AD}$)
Decision Maker 3	Strategic Planner	- Align Metaverse integration with long-term organizational goals. - Evaluate the flexibility and adaptability of proposed solutions. - Assess the strategic implications of Metaverse integration.
($\mathbb{M}$)	($\mathbb{AD}$)	($\mathbb{AC}$)

employ a methodical approach. Additionally, Equation (17) should be utilized in order to analyze the information for each need.

$$\mathtt{CT_j} = \beth \sum_{t=1}^{m} \left(1 - k_{jt}\right) \tag{17}$$

Step 4.6: Determine the suitable weight for each criterion by employing the specified equation(18).

$$\mathtt{w}_j = \frac{\mathtt{CT_j}}{\sum_{j=1}^{p} \mathtt{CT_j}} \tag{18}$$

A. AROMAN

Step 5: It is necessary to apply normalization to the input data of the decision-making matrix. After you have first generated the matrix by utilizing the input data, the next step is to sort the data into intervals ranging from 0 to 1. Two distinct methods are utilized in order to normalize the data through the process of standardizati Equation 19 and 20

Step 5.1: Normalization 1 (**Linear**):

$$\gimel_{ij} = \frac{\xi\gamma^{\Lambda}_{ij} - min(\xi\gamma^{\Lambda}_{ij})}{max(\xi\gamma^{\Lambda}_{ij}) - min(\xi\gamma^{\Lambda}_{ij})}, \quad i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n; \tag{19}$$

Step 5.2: Normalization 2 (**Vector**):

$$\gimel^{*}_{ij} = \frac{\xi\gamma^{\Lambda}_{ij}}{\sqrt{\sum_{i=1}^{m} \xi\gamma^{\Lambda\,2}_{ij}}}, \quad i = 1, 2, \ldots, r;\ j = 1, 2, \ldots, s; \tag{20}$$

Step 6: Utilizing Averaged Aggregation Normalization is the best way to ensure that the input data is consistent. For the purpose of doing aggregated averaged normalization, it is necessary to utilize Equation 21.

$$\gimel^{\mathrm{norm}}_{ij} = \frac{\chi\gimel_{ij} + (1-\chi)\gimel^{*}_{ij}}{2}, \quad i = 1, 2, \ldots, r;\ j = 1, 2, \ldots, s; \tag{21}$$

where $\gimel^{\mathrm{norm}}_{ij}$ denotes the result of aggregated average normalization, where χ functions as a weighting factor within the range of 0 to 1. In our specific context, we assign the value of χ as 0.5.

Step 7: Multiplying the aggregated averaging normalized decision-making matrix by the criteria weights should be done in accordance with Equation 22 in order to get a weighted decision-making matrix.

$$\hat{\gimel}_{ij} = W_{ij} \cdot \gimel^{\mathrm{norm}}_{ij}, \quad i = 1, 2, \ldots, r;\ j = 1, 2, \ldots, s \tag{22}$$

Step 8: The normalized weighted values distinctly for the criteria type $\min(\omega_i)$ and the max type (Ω_i) utilizing

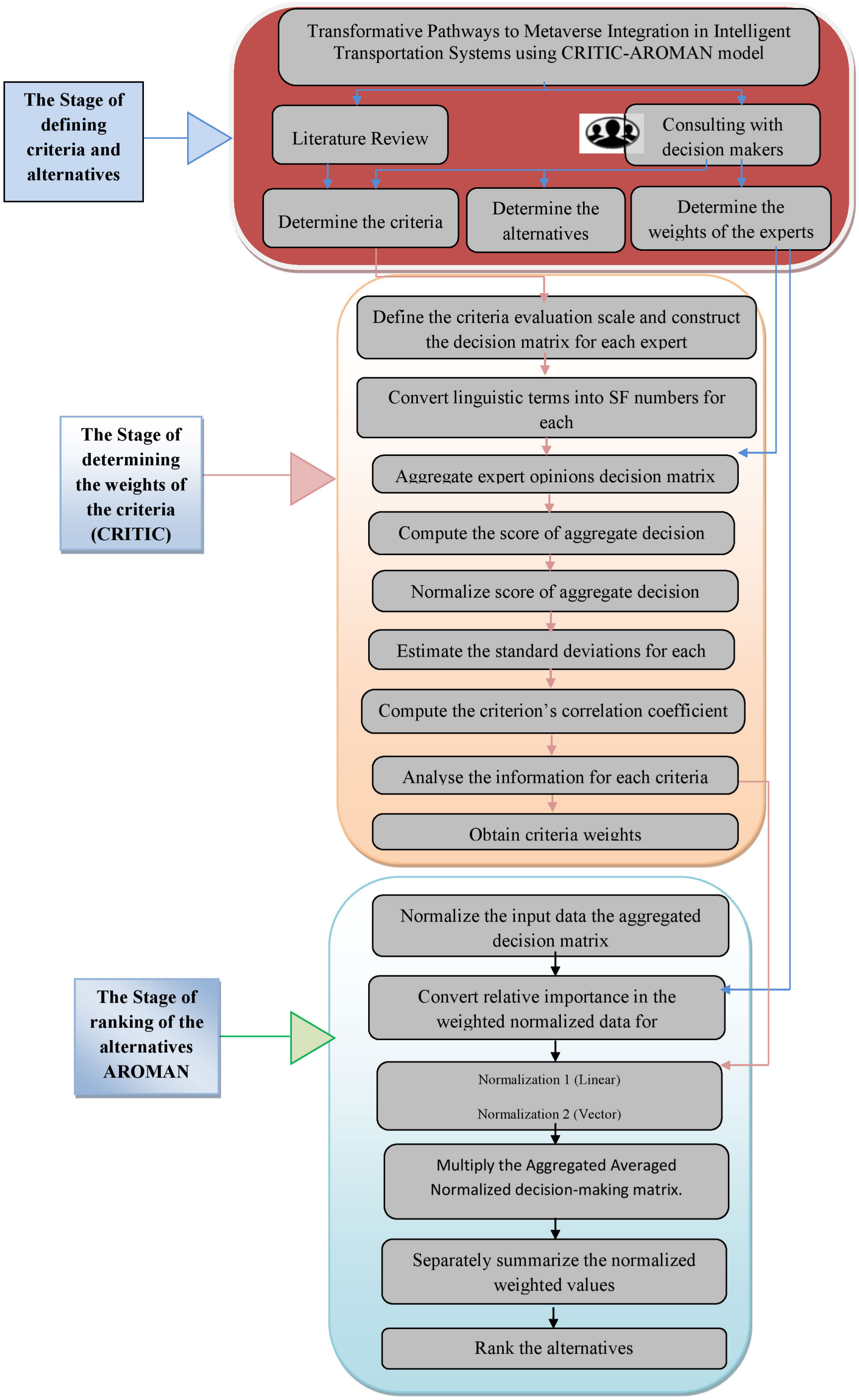

FIGURE 1. Algorithm of model.

Equation 23.

$$\omega_{\gimel(i)} = \sum_{j=1}^{n} \widehat{\gimel}_{ij}^{(\min)}, \quad i = 1, 2, \ldots, r;\; j = 1, 2, \ldots, s;$$
$$\Omega_{\gimel(i)} = \sum_{j=1}^{n} \widehat{\gimel}_{ij}^{(\max)}, \quad i = 1, 2, \ldots, r;\; j = 1, 2, \ldots, s; \tag{23}$$

Step 9: Determine the ranking of alternatives by using Equation 24.

$$R_i = \omega^{\xi^{\gamma\Lambda}} + \Omega_i^{(1-\xi^{\gamma\Lambda})}, \quad i = 1, 2, \ldots, r; \tag{24}$$

Here, (R_i) denotes the label for the ranked alternatives, and $\xi^{\gamma\Lambda}$ denotes the coefficient degree linked to the criteria type. For $\xi^{\gamma\Lambda}$, a value of 0.5 is assigned after considering both sorts of criteria. The entire framework of the model is illustrated in Figure 1.

V. CASE STUDY

In order to handle the complex issues that have arisen as a result of urbanization and the expansion of modern transportation networks, policymakers are placing a greater focus on innovative solutions for traffic planning. Considering the fact that contemporary cities are in a state of perpetual flux, it is more essential than ever before to implement new solutions that enhance mobility management. Intelligent transportation systems have arisen as a crucial choice for the purpose of enhancing the safety of traffic, decreasing travel speeds, and increasing the overall mobility of vehicles. When it comes to sustainability, these systems make a significant impact since they address significant problems such as carbon emissions and air pollution with their solutions. Including intelligent transportation systems in the metaverse is a novel and forward-thinking approach to resolving issues that arise in the transportation sector. By integrating components such as digital twins, mirror-world, and extended reality (XR), the metaverse offers strong resources that may be utilized for the purpose of analyzing potential solutions to social, economic, and environmental issues. Despite the fact that the metaverse is still in its infant stage, many people are looking forward to the arrival of novel solutions in the near future. This is because there has been a significant amount of investment in this rapidly evolving subject. The literature lends credence to the notion that the transportation industry is becoming increasingly linked with the metaverse. In a great number of studies, the advantages and disadvantages of a variety of approaches to the implementation of intelligent transportation systems have been articulated. The comparative examination of these various implementation approaches, on the other hand, continues to be a significant topic of research that has not yet been addressed. This study examines the implementation of transportation systems in the metaverse in great depth, taking into mind conflicting limits that greatly impact performance on numerous fronts. The purpose of this research is to fill the information vacuum that has been created.

In order to solve this analytical difficulty, we have developed a novel approach to decision-making that takes into account many factors. The creation of this paradigm was undertaken with the intention of making the laborious process of constructing transportation networks in the metaverse even more manageable. A comprehensive case study illustrates the actual use of the concept by contrasting three distinct approaches to the development of transportation systems. The comparison is made using twelve criteria that were selected with great care, and they include issues of management, safety, user experience, and urban mobility. This extensive research endeavors to provide in-depth insights into the myriad of factors that influence the achievement of success in the implementation of transportation systems in the metaverse. It significantly contributes to the ever-changing landscape of this cutting-edge technology, which is a substantial contribution. In this extensive review of the relevant literature, we focus on the expanding relationship that exists between transportation and the metaverse. In a number of studies, several models have been given, and the advantages and disadvantages of integrating transportation systems have been discussed. In spite of this, there is a conspicuous absence in the existing body of literature of a comparative research that investigates implementation strategies across a number of different aspects. By deconstructing the complicated process of bringing transportation systems into the metaverse, this study is attempting to fill that gap. It does so by taking into consideration conflicting limits that impact its performance in a variety of different ways. In proportion to the growing number of constraints, the analysis becomes ever more challenging. Over the past several years, urban transportation has arisen as a significant concern for governments, as they strive to provide their residents with a lifestyle that is both more positive and healthier. If we want to see improvements in urban transportation, one of the most important things that we should focus on is increasing the percentage of individuals who drive in a safe manner. This strategy emphasis has a number of key goals, two of which are to reduce the number of accidents and the amount of traffic congestion. The emergence of the Metaverse is a revolutionary force that has the potential to shed light on the path that leads to the achievement of these objectives.

There is an imminent need for decision-makers to expedite the adoption of the Metaverse into local transportation, and three distinct ideas are now being studied as potential answers to this problem. The first strategy involves implementing mobility-centric solutions within the Metaverse. This strategy is based on the theoretical knowledge that scientists have created. Making use of the capabilities offered by the Metaverse is the objective of this approach, which aims to enhance urban transportation facilities. Utilizing the Metaverse as a means to implement traffic safety measures is the second alternative that might be considered. This choice is being made with the intention of including safety-focused aspects into the Metaverse, with the primary goal of simultaneously lowering the number of accidents and increasing overall safety. The improvement of human health and welfare is the primary objective of scientific advancements, and this is in line with that objective. Thirdly, we may investigate the ways in which traffic management systems can be included into the Metaverse in order to anticipate the growing complexity of urban mobility. This alternative strategy takes use of the technology that is available in the Metaverse in an effort to cope with emerging dangers in a proactive manner. There are twelve distinct criteria that have been devised in order to rank these possibilities in order to ensure that the decision-making process is effectively navigated. These guidelines provide a comprehensive framework for evaluating and comparing the effectiveness of each alternative, taking into consideration aspects like as safety, efficiency, and the overall impact on urban transportation.

VI. PROCESS OF INDICATOR SELECTION

1) • Conduct a comprehensive literature review to identify existing indicators and frameworks used in similar studies.
2) • Engage with stakeholders including policymakers, transportation planners, technology developers, and end-users to gather diverse perspectives on critical aspects of Metaverse integration.
3) • Define a preliminary set of criteria based on identified themes and stakeholder input. Refine criteria through expert consultations to ensure they are specific, measurable, relevant, and actionable.
4) • Apply methods like the CRITIC to objectively determine importance and interdependencies of selected indicators. Weight indicators based on their relative significance in achieving research goals and addressing stakeholder concerns.
5) • Finalize selected indicators through validation exercises, such as expert reviews, to ensure they effectively measure intended aspects of Metaverse integration. Validate indicators against real-world scenarios and adjust as necessary.

A. DEFINITION OF ALTERNATIVES

1) (AT_{Δ})**:** The incorporation of mobility-based solutions into the metaverse is a step in the right direction. One of the most promising areas for testing and implementing results that can be confirmed is the ability of the metaverse to visually and convincingly simulate the behavior of automobiles. Applications that are focused on mobility might potentially benefit from this in particular. The implementation of this technology might potentially result in enhancements to the Intelligent Transportation System (ITS) applications utilized by the nation. Providing comprehensive route instructions, ensuring that shared cars are available, and making it simple to interact with various modes of transportation are all things that need to be done in order to make better use of the metaverse for mobility. This groundbreaking use of the metaverse is in line with the growing prospect that technology will have a positive influence on the transportation solutions of the future.
2) (AT_{Θ})**:** Incorporating solutions that are especially focused on traffic safety into the metaverse is a concentrated strategy that may be used to improve both the safety of vehicles and the safety of traffic in general. It is necessary to place a priority on traffic safety, particularly in the beginning phases of deploying new technology, because the primary objective of traffic improvements is to improve the health and welfare of people. Throughout the course of history, regulations and guidelines have, for the most part, adhered to these goals, with a greater emphasis placed on road safety following World War II. Taking into consideration this context, it is of utmost need to implement traffic safety measures in the metaverse. This approach ensures that a comprehensive perspective on mobility enhancements is taken, with a particular focus on safeguarding human health and adhering to preset regulatory criteria.
3) (AT_{Λ})**:** Providing a comprehensive solution is accomplished by incorporating traffic control systems into the metaverse. Providing both data and optimization tools for effective traffic management, the metaverse serves as a useful asset that may be utilized. When the negative impacts of traffic congestion on road networks are taken into consideration, such as decreased speeds, longer travel times, and increased vehicle lineups, it is clear that new solutions are not only necessary but also necessary. There is a possibility that traditional approaches to traffic management will not be able to successfully address the prevailing traffic problems throughout the world, which might result in an increase in congestion. In order to efficiently solve current traffic concerns, give real-time control, and enable prompt emergency responses, it is possible to make use of the metaverse system. Taking into account the dynamic nature of the traffic management environment, this integration demonstrates forward-thinking and compliant thinking. Additionally, it makes use of the opportunities offered by the metaverse in order to present solutions that are more effective and responsive.

B. DEFINITION OF CRITERIA

The purpose of this study is to examine the evaluation of twelve criteria, which are then separated into four categories. For the purpose of developing intelligent transportation system solutions, the objective is to identify the most suitable alternative for society and governments to implement in the metaverse.

1) **Network Resilience Aspect**
Enhanced Continuity of Traffic Data (Benefit) ($\mathfrak{CT}_1$)**:** Continuity of traffic data over time is becoming increasingly crucial as the number of individuals who rely on traffic data for decision-making continues to rise. It is possible to significantly improve the consistency of traffic statistics, which is a wonderful opportunity given the increasing expansion of the Internet and the exchange of data. Further, the metaverse offers a platform that allows for the uninterrupted and seamless flow of data, which paves the way for the potential of continuous data processing.
Improved Emergency Management (Benefit) ($\mathfrak{CT}_2$)**:** The administration of the public sector in the present day needs to be more robust than it has ever been in order to be able to resist severe occurrences, significant crises, and catastrophic disasters. A concept that is fascinating is the possibility that the metaverse may play a part in the management of disasters. Now, in this extremely critical circumstance, the metaverse could

be able to assist in optimizing emergency services even more. Through improved coordination and efficiency in emergency management and response, it may be possible to create a system that is more resilient and responsive.

Cost of Restoration Activities in the Network (Cost) ($\mathfrak{C}\mathfrak{T}_3$)**:** For the purpose of establishing a collaborative system that seamlessly connects the metaverse with Intelligent Transportation Systems (ITS), it is important to improve and restore the network. This is a necessary necessity because of the requirements for optimizing and confirming the data. A rapid response is also required in instances when uncontrolled traffic poses a risk to human health. This is because such situations require immediate intervention. After significant damage, those in control of the network are obligated to take prompt action in order to restore "normal" service and repair any interconnected infrastructure that has lost service as a consequence of the damage. The fact that this is the case makes it abundantly evident that there are financial considerations that need to be taken into account when constructing and operating a network that successfully integrates ITS with the metaverse.

2) **Traffic Operation Dimension Optimized Traffic Flow (Benefit)** ($\mathfrak{C}\mathfrak{T}_4$)**:** There have been a lot of issues that have surfaced as a result of the significant surge in the number of people who possess their own private automobiles. These include the pollution of the air, the congestion of traffic, the depletion of energy, and the change in climate that is brought about by the excessive production of carbon dioxide. The use of Intelligent Transportation Systems (ITS) has been a significant contributor to the enhancement of traffic flow and the reduction of congestion within the environment. This is the inevitable evolution toward even better traffic flow, and the metaverse is the next step. It has the potential to revolutionize existing concepts and contribute to the creation of a traffic operation that is more efficient and streamlined. This is a solution to the challenges that are produced by an increase in the number of people who own automobiles.

Enhanced Traffic Surveillance in the City (Benefit) ($\mathfrak{C}\mathfrak{T}_5$)**:** Although governments utilize intelligent transportation systems (ITS) for effective traffic monitoring, the industry of traffic surveillance has a significant challenge in the form of the requirement for data collection that is exhaustive, diverse, and accurate. Incorporating ITS into the metaverse has the potential to significantly improve urban control systems, which would allow for the hurdle to be surmounted. By merging Intelligent Transportation System (ITS) capabilities with the metaverse, there is the potential to enhance traffic monitoring and contribute to decision-making that is both more robust and more informed.

Enhanced Road Safety (Benefit) ($\mathfrak{C}\mathfrak{T}_6$)**:** Transport planners in urban areas place a high priority on addressing issues related to road safety. Every single person in the scientific community is in agreement that accidents on the road are not occurring out of the blue; rather, they are preventable if individuals take the appropriate safety measures into consideration. There is a strong possibility that the incorporation of the metaverse might lead to some improvements in the safety of driving on public roads. As part of the greater goal of making city transportation safer, the integration of this system has the potential to bring about new ways of thinking and technology that assist in predicting and preventing accidents. This is in line with the larger mission of making city transportation safer.

3) **Implementation Requirement Aspect. Need for Advanced Standards, Regulations, and Legislations (Cost)** ($\mathfrak{C}\mathfrak{T}_7$)**:** For the purpose of facilitating the absorption of advanced technologies, standards need to be regularly updated and implemented in order to guarantee that they coincide with the most recent advancements. In most cases, the data in question contains individually identifiable information; hence, any type of exposure might potentially have devastating effects. In light of the fact that it is occasionally required to send sensitive information to third parties that can be trusted when conducting business, there have to be laws and regulations that are both explicit and stringent. The necessity of the establishment of comprehensive and stringent standards and guidelines in order to prevent data breaches and guarantee data security has an impact on the overall cost of maintaining a system that is both secure and compliant.

Need for Specialized Equipment (Cost) ($\mathfrak{C}\mathfrak{T}_8$)**:** In spite of the fact that technological advancements make people's lives better in a variety of ways, they also bring about changes in the sorts of items that people require, such as specialized equipment. For accurate data gathering and processing, it is vital to have devices that are capable of communicating with both the metaverse and the ITS infrastructure. There is a correlation between the purchase and maintenance of such specialized equipment and the overall cost of establishing and maintaining an integrated system.

Need for Specialized Experts (Cost) ($\mathfrak{C}\mathfrak{T}_9$)**:** Integrating intelligent transportation systems into the metaverse introduces a new feature that requires expertise in several domains. Experts in transportation engineering, metaverse engineering, and other related fields will be required to evaluate the findings and run the system smoothly because of the novel character of this upgrade. Experts from several fields must be relied upon to gain and keep the necessary knowledge for the system's efficient integration and functioning. This adds to the overall expense worries associated with carrying out these duties.

4) **Travel Behavior Aspect. Reduced Need for Transportation (Benefit)** ($\mathfrak{CT}_{10}$)**:** People and organizations in the modern world utilize the Internet for a broad variety of digital activities, such as working, studying, having fun, and locating specialized resources. Online activities include all of these things. Taking this strategy is something that even the transportation industry does. Due to the fact that the metaverse is capable of autonomously tracking data and errors, there is no longer any requirement for human staff interaction. Due to the fact that there is less need for human connection, there is also less need for physical exertion, and thus, there is less demand for transportation.
Reluctance to Share Private Information (Cost) ($\mathfrak{CT}_{11}$)**:** The adoption of data security measures is threatened by a number of factors, including compliance, privacy, trust, and the complexity of the legal system. When it comes to the development of any new system that makes use of people's data, the flawless administration of rules and regulations is very necessary. individuals may be reluctant to accept the technology if they have mistrust in the data security procedures due to concerns about privacy and compliance. This is a genuine risk that individuals may be hesitant to adopt the technology. It is of the utmost importance to address these issues and earn the confidence of customers in order to overcome any difficulties that may be produced by the consumers' hesitancy to share personal information.
Need for Alternate Solutions to Accommodate Recent Travel Behavior Trends (Cost) ($\mathfrak{CT}_{12}$)**:** Simulators have a tough time precisely forecasting the results of traffic situations because of the immense diversity of activities that humans engage in. Depending on their own personality qualities and preconceived notions, drivers do not always choose to go along the road that is specifically indicated. As a result, it is essential to simulate these scenarios and investigate the results of such acts, even if, in the end, drivers are required to adhere to the same traffic patterns due to the rules that govern traffic. It is possible that the incorporation of the metaverse will result in additional changes to traffic patterns, which have already been altered as a result of the introduction of Intelligent Transportation Systems (ITS). The ever-evolving nature of this scenario necessitates the implementation of flexible solutions, which in turn brings about the consideration of new aspects and the incurrence of new costs in order to keep up with the shifting travel patterns.

Step 1: Experts leverage the PyFNs dataset, incorporating linguistic terms from Table 1 for each alternative $\mathfrak{AT}_p$ (where $p = 1, 2, \ldots, r$), while considering diverse criteria $\mathfrak{Cr}_{rs}$, as outlined in Tables 3.

Step 2: Determine the significance of decision makers (DMs) by evaluating their weights through the application of the scoring function detailed in Equation 11. Subsequently, employ the derived scores in Equation 12 to calculate the overall impact, and eloquently present the resulting values in the form of a comprehensive and informative Table 4. This holistic approach ensures a nuanced understanding of the varied contributions of decision makers in the given context.

Step 3: Calculating the aggregated decision matrix, symbolized as $M = \left[M_{ij}\right]_{q\times p}$. This matrix holds the essence of our decision-making framework, and its elements are determined through the intricate interplay of the components captured in Equation 3. This equation encapsulates a sophisticated blend of factors, each contributing uniquely to the overall decision-making process.

Step 4.1: Compute the score of the decision matrix using Equation (13) in Table 6.

Step 4.2: Transform the matrix $\bar{\beth}$ into a standard PyFNs matrix using Equation (14) in Table 7.

Step 4.3: Compute an estimate of the standard deviations for the criterion using the formula provided in Equation (15) in Table 8.

Step 4.4: Calculate the correlation coefficient for the criteria in Table 9 using the provided Equation (16).

Step 4.5: Assess the specifics of each criterion by employing Equation (17) as outlined in Table 10.

Step 4.6: Determine the weight assigned to each criterion by calculating the objective weight using Equation (18), as detailed in Table 11.

Step 5:

Step 5.1: Perform linear normalization, denoted as Normalization 1, using Equation (19) as specified in Table 12.

Step 5.2: Apply Vector Normalization, referred to as Normalization 2, utilizing Equation (20) as outlined in Table 13.

Step 6: The process of aggregated averaged normalization entails utilizing the equation (21) presented in Table 14.

The variation in β from 0.1 to 0.8 is depicted in Figure 2.

Step 7: Calculate the weighted decision-making matrix by multiplying the aggregated averaged normalized decision-making matrix with the criteria weights, as described in Equation (22) presented in Table 15. Utilize the specified formula to obtain the weighted decision-making matrix.

Step 8: Distinguish the normalized weighted values for the criteria types $\min(\omega_i)$ and $\max(\Omega_i)$ by employing Equation (23). Determine the final ranking of alternatives using the provided Equation (24) as outlined in Table 16.

C. SENSITIVITY ANALYSIS

The sensitivity analysis of the decision outcomes in Table 17 consistently ranks the alternatives from $\mathfrak{AT}_1$ to $\mathfrak{AT}_3$. This is due to the fact that the parameter Λ can vary from 0.1 to 0.8. The decision-making model is shown to be robust and dependable as a result of this. To be more specific, the

TABLE 3. Linguistic terms for evaluation.

Decision Maker 1												
Alternatives	$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
$\mathfrak{AT}_1$	VH	H	M	AD	AC	L	P	ID	VH	H	M	AD
$\mathfrak{AT}_2$	AC	L	P	ID	VH	H	M	AD	AC	L	P	ID
$\mathfrak{AT}_3$	L	P	ID	VH	H	M	AD	AC	L	P	ID	VH

Decision Maker 2												
Alternatives	$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
$\mathfrak{AT}_1$	ID	P	M	AC	VH	L	H	AD	VH	ID	L	AC
$\mathfrak{AT}_2$	P	AC	H	VH	ID	AD	L	M	P	VH	M	ID
$\mathfrak{AT}_3$	VH	ID	M	H	P	AD	L	AC	H	M	L	AC

Decision Maker 3												
Alternatives	$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
$\mathfrak{AT}_1$	H	AD	M	AC	L	ID	P	VH	VH	L	M	AC
$\mathfrak{AT}_2$	AC	ID	P	M	L	H	VH	AD	P	AC	H	ID
$\mathfrak{AT}_3$	ID	VH	M	H	L	AC	P	AD	H	VH	ID	L

TABLE 4. Role of decision makers.

Decision Makers	Role	Responsibilities	Weights
Decision Maker 1	Technology Expert	- Assess the technological feasibility of Metaverse integration. - Evaluate the cost-effectiveness of proposed implementations. - Provide expertise on user experience and security measures.	
$(\mathbb{VH})$	$(\mathbb{H})$	$(\mathbb{M})$	0.2639
Decision Maker 2	Financial Analyst	- Analyze the financial implications of different approaches. - Evaluate the cost-effectiveness and budgetary considerations. - Assess the economic impact and feasibility of the project.	
$(\mathbb{H})$	$(\mathbb{M})$	$(\mathbb{AD})$	0.3321
Decision Maker 3	Strategic Planner	- Align Metaverse integration with long-term organizational goals. - Evaluate the flexibility and adaptability of proposed solutions. - Assess the strategic implications of Metaverse integration.	
$(\mathbb{M})$	$(\mathbb{AD})$	$(\mathbb{AC})$	0.4039

TABLE 5. Aggregated decision matrix.

$\mathfrak{AT}_i$	$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
$\mathfrak{AT}_1$	$\langle 0.8312, 0.4685\rangle$	$\langle 0.6663, 0.4229\rangle$	$\langle 0.7072, 0.1500\rangle$	$\langle 0.6979.0.2017\rangle$	$\langle 0.4975, 0.4185\rangle$	$\langle 0.7035, 5123\rangle$	$\langle 0.6440, 0.4110\rangle$	$\langle 0.4233, 0.5461\rangle$	$\langle .5586, 0.4321\rangle$	$\langle 0.6022, 0.3421\rangle$	$\langle 0.5779, 4320\rangle$	$\langle 0.6379, 0.3670\rangle$
$\mathfrak{AT}_2$	$\langle 0.7207, 0.5421\rangle$	$\langle 0.7021, 4580\rangle$	$\langle 0.7420, 3210\rangle$	$\langle 0.7101, 0.2240\rangle$	$\langle 0.7076, 0.3010\rangle$	$\langle 0.7297, 0.2410\rangle$	$\langle 0.6641, 0.3321\rangle$	$\langle 0.5181, 0.5463\rangle$	$\langle 0.5674, 0.3976\rangle$	$\langle 0.5501, 0.2389\rangle$	$\langle 0.4813, 0.5578\rangle$	$\langle 0.8345, 0.1240\rangle$
$\mathfrak{AT}_3$	$\langle 0.6107, 0.5130\rangle$	$\langle 0.6140, 0.3321\rangle$	$\langle 0.6025, 0.3221\rangle$	$\langle 0.5576, 0.5031\rangle$	$\langle 0.5923, 0.4321\rangle$	$\langle 0.4930, 0.6123\rangle$	$\langle 0.7035, 0.3420\rangle$	$\langle 0.7273, 2220\rangle$	$\langle 0.6633, 0.3210\rangle$	$\langle 0.5918, 0.4321\rangle$	$\langle 0.6333, 0.2340\rangle$	$\langle 0.6722, 0.3210\rangle$

sequence that is wanted is $\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$. When various Λ values are investigated, the joint generalized criteria indicates a pattern that may be seen. As Λ comes closer to 1, the relative importance of values tends to be additive, and as it gets closer to 0, it tends to be multiplicative. The graphic that can be found in reference yy120 illustrates how the influence of various Λ values on the decision-making process inside the PyFS framework demonstrates the adaptability of the model.

TABLE 6. Score matrix.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.107	0.031	0.214	0.446	-0.058	0.476	0.454	-0.093	0.527	-0.130	0.015	0.406
0.484	0.495	0.454	0.015	-0.015	0.264	0.091	0.122	0.484	-0.003	-0.034	0.451
0.339	0.264	0.146	0.424	-0.076	0.077	0.379	0.505	0.087	0.038	0.490	0.102

TABLE 7. Standard PyFNs matrix.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
1	0	0.218	1	0.293	1	1	0	1	0	0.093	0.870
0	1	1	0	1	0.468	0	0.360	0.903	0.753	0	1
0.383	0.502	0	0.948	0	0	0.792	1	0	1	1	0

TABLE 8. Standard deviations for the criterion.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.505	0.500	0.526	0.563	0.514	0.500	0.528	0.507	0.551	0.521	0.552	0.544

TABLE 9. Correlation matrix.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
1	-0.991	-0.647	0.819	-0.584	0.640	0.896	-0.477	0.220	-0.809	-0.049	0.014
-0.991	1	0.742	-0.887	0.686	-0.533	-0.947	0.357	-0.091	0.725	-0.082	0.117
-0.647	0.742	1	-0.968	0.997	0.172	-0.918	-0.361	0.601	0.075	-0.729	0.753
0.819	-0.887	-0.968	1	-0.944	0.083	0.988	0.114	-0.379	-0.325	0.533	-0.562
-0.584	0.686	0.997	-0.944	1	0.250	-0.884	-0.435	0.663	-0.005	-0.782	0.803
0.640	-0.533	0.172	0.083	0.250	1	0.233	-0.981	0.891	-0.969	-0.799	0.778
0.896	-0.947	-0.918	0.988	-0.884	0.233	1	-0.037	-0.235	-0.464	0.399	-0.430
-0.477	0.357	-0.361	0.114	-0.435	-0.981	-0.037	1	-0.963	0.902	0.901	-0.886
0.220	-0.091	0.601	-0.379	0.663	0.891	-0.235	-0.963	1	-0.752	-0.985	0.978
-0.809	0.725	0.075	-0.325	-0.005	-0.969	-0.464	0.902	-0.752	1	0.627	-0.600
-0.049	-0.082	-0.729	0.533	-0.782	-0.799	0.399	0.901	-0.985	0.627	1	-0.999
0.014	0.117	0.753	-0.562	0.803	0.778	-0.430	-0.886	0.978	-0.600	-0.999	1

TABLE 10. Weights.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
6.038	5.953	5.933	7.053	5.776	5.622	6.543	6.516	6.093	6.561	7.161	6.001

TABLE 11. Normalize weights.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.080	0.079	0.079	0.094	0.077	0.075	0.087	0.087	0.081	0.087	0.095	0.080

The conclusion that can be drawn from these findings is that the decision-making model is not only dependable but also adaptable with regard to the range of Λ values. The ranking details furnish decision-makers with insights into alternatives adapt to variations in the assigned importance of decision criteria. The noteworthy and consistent performance

TABLE 12. Linear normalization.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0	0	0.218	1	0.293	1	1	0	1	0	0.094	0.870
1	1	1	0	1	0.468	0	0.360	0.903	0.753	0	1
0.617	0.502	0	0.948	0	0	0.792	1	0	1	1	0

TABLE 13. Vector normalization.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.178	0.055	0.409	0.725	-0.600	0.866	0.759	-0.176	0.731	-0.959	0.030	0.660
0.806	0.881	0.869	0.024	-0.158	0.480	0.153	0.231	0.672	-0.022	-0.069	0.733
0.565	0.470	0.280	0.689	-0.784	0.140	0.633	0.957	0.121	0.284	0.997	0.166

TABLE 14. Aggregated averaged normalization matrix.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.044	0.014	0.157	0.431	-0.077	0.467	0.440	-0.044	0.433	-0.240	0.031	0.382
0.451	0.470	0.467	0.006	0.210	0.237	0.038	0.148	0.394	0.183	-0.017	0.433
0.295	0.243	0.070	0.409	-0.196	0.035	0.356	0.489	0.030	0.321	0.499	0.042

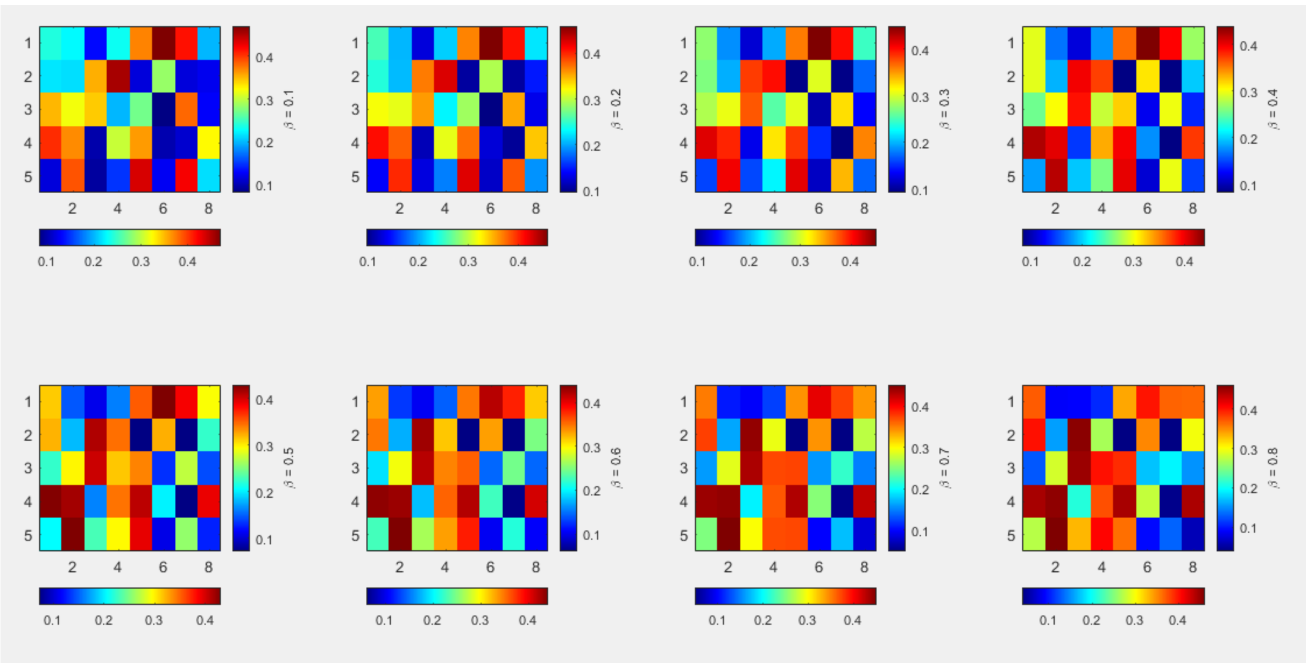

FIGURE 2. Variation in β.

of $\mathfrak{AT}_2$ under diverse decision scenarios underscores its resilience, providing valuable guidance for selecting the optimal alternative tailored to specific decision-making priorities.

D. COMPARATIVE ANALYSIS

In the course of our comprehensive comparison investigation, we had the opportunity to investigate the efficiency and applicability of various decision-making procedures in

TABLE 15. Multiplying the aggregated averaged normalized decision-making matrix.

$\mathfrak{CT}_1$	$\mathfrak{CT}_2$	$\mathfrak{CT}_3$	$\mathfrak{CT}_4$	$\mathfrak{CT}_5$	$\mathfrak{CT}_6$	$\mathfrak{CT}_7$	$\mathfrak{CT}_8$	$\mathfrak{CT}_9$	$\mathfrak{CT}_{10}$	$\mathfrak{CT}_{11}$	$\mathfrak{CT}_{12}$
0.004	0.001	0.012	0.040	-0.006	0.035	0.038	-0.004	0.035	-0.021	0.003	0.031
0.036	0.037	0.037	0.001	0.016	0.018	0.003	0.013	0.032	0.016	-0.002	0.035
0.024	0.019	0.006	0.038	-0.015	0.003	0.031	0.042	0.002	0.028	0.048	0.003

TABLE 16. Final ranking of alterntives.

Alternatives	sum of all min criteria	sum of all max criteria	final ranking of alternatives
$\mathfrak{AT}_1$	0.0104	0.0514	0.4833
$\mathfrak{AT}_2$	0.0318	0.0151	0.5443
$\mathfrak{AT}_3$	0.0256	0.0431	0.4688

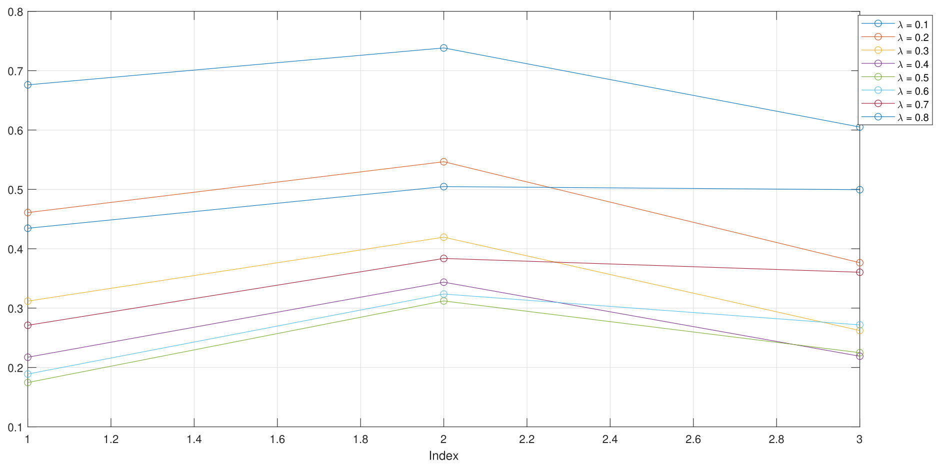

FIGURE 3. Visualizing Variations with Changing Parameter (Λ).

PyFNs. Throughout the course of our study, we subjected each component to a comprehensive examination and carried out stringent validation and robustness checks. Our goal was to significantly improve the reliability and consistency of our findings. These methodological concerns not only contribute to the expansiveness and depth of our research, but they also serve as the basis for the findings that we arrive at. The most important findings, which provide a compelling summary of our research, are tabled in Table 18. Due to the fact that our analysis was so thorough, we were able to obtain a comprehensive understanding of the advantages and disadvantages associated with the various decision-making strategies that are utilized in PyFNs. As a whole, our research enhances our comprehension of decision-making within the PyFS framework and equips decision-makers with trustworthy insights, which they can then put to use in order to strategically incorporate PyFNs.

When compared to other methodologies, CRITIC-AROMAN consistently demonstrates superior performance in evaluating and ranking predictive maintenance models within the manufacturing sector.

E. DISCUSSION

This study explores the intriguing intersection of ITS and the metaverse, providing an in-depth examination of their merging and its implications. As a first step in addressing the problems caused by urbanization and the increasing reach of contemporary transportation systems, it begins by showcasing the increasing focus on creative traffic planning solutions among policymakers. Solutions to the problems of traffic congestion, slow travel times, and pollution and carbon emissions have emerged in the form of intelligent transportation systems. This work stands out because it looks to the future to find solutions to transportation problems in the metaverse. The metaverse is marketed as a promising platform for evaluating potential answers to multi-faceted environmental, social, and economic problems by means of capabilities such as digital twins and extended reality.

TABLE 17. The influence of the parameter Λ on the outcome of the decision.

Λ	$\mathfrak{AT}_1$	$\mathfrak{AT}_2$	$\mathfrak{AT}_3$	Ranking	
$\Lambda = 0.1$	0.4418	0.7349	0.6875	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.2$	0.4593	0.5916	0.4855	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.3$	0.3433	0.5510	0.3608	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.4$	0.3033	0.5510	0.3608	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.5$	0.3141	0.4579	0.3536	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.6$	0.2049	0.3789	0.3064	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.7$	0.2955	0.3878	0.3399	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
$\Lambda = 0.8$	0.3125	0.4765	0.3889	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$

TABLE 18. Comparison with some exiting.

PyFWA (Peng and Yuan [12])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
PyFWOG (Rahman *et al.* [14])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
PyFWG (Rahman *et al.* [14])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
A-PyFIWG (Wang & Garg [15])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
GPyFWA (Peng and Yuan [12])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
A-PyFIWA (Wang & Garg [15])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
PyFPWA (Wei & Lu [54])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
CPyFWG (Garg [56])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_1 \succ \mathfrak{AT}_3$	$\mathfrak{AT}_2$
PyFHWG (Wu & Wei [55])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
WSC method (Shekhovtsov [57])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
RANCOM (Więckowski *et al.* [58])	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$
PyFPG$_d$ (Proposed)	$\mathfrak{AT}_2 \succ \mathfrak{AT}_3 \succ \mathfrak{AT}_1$	$\mathfrak{AT}_2$

Thanks to heavy investment in this dynamic field, the article alludes to the hope of revolutionary solutions throughout the metaverse's formative years. The literature study deftly pulls together previous research, highlighting the well-established link between the transportation sector and the metaverse. We thank earlier research for suggesting models and outlining possible advantages and disadvantages. But the study spots a hole in the literature, and that is the absence of studies that compare different methods of implementation. Introducing a multi-criteria decision-making model optimized for PyF sets, this research fills this knowledge gap and offers a systematic way to examine the complex procedure of establishing transportation networks in the metaverse. The inclusion of the CRITIC-AROMAN model within the PyF framework is a notable contribution to the article. This model provides a more thorough evaluation of the analysis by providing a high-tech instrument for comparing and contrasting the efficacy of various methods for implementing transportation systems. Following this, a thorough case study comparing three different methods along dimensions such as management, safety, user experience, and urban mobility puts this concept into action inside the PyF framework. Finally, the article concludes that the CRITIC-AROMAN model should be used in the PyF setting. It sheds light on the complexities and potential benefits of smart transportation systems' incorporation into the metaverse. In this cutting-edge technical environment, the decision-making model provides a detailed comprehension of the many facets of transportation system implementation when used inside the PyFS framework. Practical implications for scholars and practitioners in the area are offered by this debate, which adds depth to the continuing topic on intelligent transportation systems and their convergence with the metaverse.

1) MANAGERIAL IMPLICATIONS

The outcomes of the PyF with CRITIC-AROMAN model have significant repercussions for the managers who are accountable for supervising the inclusion of the Metaverse into their information technology systems. By offering a solid foundation for strategic decision-making and a detailed review of the many different implementation alternatives, this technique assists managers in locating the most effective solutions. As a result of the approach's capacity to emphasise the relative relevance of a number of different elements, investments are given priority in areas that have the greatest potential for return or effect. This plays a role in the distribution of resources. As a result of the model's ability to handle complicated interactions between criteria and ambiguity, it improves risk management and assists managers in anticipating and planning for challenges that are connected to integration. The vast research and empirical data that the model provides may be of use to policymakers in the process of formulating rules and policies that encourage the efficient and long-term utilisation of Metaverse technology. Because of its impartiality, the CRITIC-AROMAN technique also makes it easier to communicate openly and honestly with stakeholders. This is an excellent way to create trust and collaborate with others. When it comes to the smart transportation systems industry, organisations have the ability to keep their competitive advantage by using this cutting-edge evaluation method. Because of this, they are able to make consistent adjustments to their plans in response to new facts and ideas, which ultimately leads to continuous progress.

VII. CONCLUSION

In conclusion, this research has been effective in examining the intricate interaction that exists between information and communication technologies (ICTs) and the metaverse. It has shed light on the revolutionary potential that these technologies provide for enhancing sustainability and modifying the dynamics of urban transportation. By conducting a thorough investigation of the situation, we have proved how vitally crucial intelligent transportation systems are for addressing contemporary issues that are brought about by urban areas. Throughout this entire process, we have positioned the metaverse as a potential new frontier, offering a digital environment in which innovative concepts for more environmentally friendly modes of transportation may be demonstrated and evaluated. Through the incorporation of the CRITIC-AROMAN model into the PyFS framework, we have been able to enhance the analytical approach and get a more comprehensive understanding of the intricate aspects that are involved in the implementation of transportation systems. An enhancement that has been made is that the decision-making process now includes a comprehensive evaluation of factors that span the management, safety, user experience, and urban mobility dimensions. In the future, academics working in this area should conduct more in-depth investigations into the ever-evolving metaverse, exploring for applications in the real world and potential disruptions connected to transportation. The enhancements and expansions that are made to decision-making models, particularly in the context of PyFS, provide interesting new avenues for research. The major objectives should be to ensure that these models are universally applicable and flexible enough to accommodate a variety of transportation scenarios, while also taking into consideration the preferences and constraints of individual users. In essence, this study marks a turning point in our knowledge and management of urban mobility. It lays the groundwork for future research and ushers in a new era of revolutionary change. In other words, it creates the framework for future research. When intelligent transportation systems and the metaverse collaborate, we may anticipate the emergence of novel concepts that have the potential to transform our urban areas and pave the way for a transportation future that is both more environmentally friendly and more efficient.

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