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Research Article

Comparative Ranking Preferences Decision Analysis through a Novel Fuzzy TOPSIS Technique for Vehicle Selection

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Acquiring a vehicle or financing its purchase is often considered a luxury, particularly for middle-class households. In addition to their primary concern, consumers prioritize distinguishing elements such as vehicle type, size, capacity, engine power, fuel efficiency, safety features, and life-cycle costs. Furthermore, the choice of vehicle has multiple factors and is contingent upon the financial prosperity of the household, allowing for precise expression. The decision-making process is complex and entails selecting the most appropriate alternatives. This study proposes a novel fuzzy technique for order of preference by similarity to the ideal solution (FTOPSIS) method to solve vehicle selection multi-criteria decision-making (MCDM) problems. Decision-makers express their opinions on each alternative and criterion in linguistic terms, in terms of generalized interval type-2 trapezoidal fuzzy numbers (GIT2TrFNs). The FTOPSIS process involved utilizing the defuzzification of GIT2TrFNs to acquire the normalization matrix. Finally, the proposed approach prioritizes the options and chooses the best vehicle when faced with conflicting criteria, as illustrated through a numerical illustration.

1. Introduction

The automotive industry is a significant contributor to India's GDP. Between 2010 and 2022, there was a substantial increase in passenger vehicle sales. Today, engine performance is not the only factor when purchasing a vehicle. Consumers look for additional distinguishing features to help them make informed decisions and compare various brands. Customer preferences have become increasingly intricate and dynamic due to the availability of diverse information sources. Therefore, the automotive sector must consider customer preferences to ensure its sustainability. Achieving customer satisfaction is crucial for its prosperity. According to existing research, the purchase decision process consists of five stages: problem identification, information acquisition, alternative assessment, purchase selection, and post-purchase behaviour. This study focuses on the third phase of the decision-making process, which involves examining options through the mathematical technique.

The evaluation stage of alternatives involves choosing the best among the available alternatives, which can be a complex process. There are many characteristics and options to consider, and it is not easy to articulate these precisely in an uncertain environment. Mathematical methods often assume that model parameters accurately describe the characteristics of the real-world decision-making problem. However, it needs to ensure a perfect method to deal with uncertain data through a suitable mathematical model. Also, the future state of a system may be unknown and uncertain. In such cases, fuzzy set theory can provide a better approach. It can help to better understand the criteria and alternatives in uncertain or imprecise situations by assigning membership values to quantities. In 1965, Zadeh [1] introduced the concept of fuzzy sets. These sets use a fuzzy number to represent ambiguity, imprecision, and haziness. The fuzzy-based model is suitable for making decisions in complex scenarios where the data is imprecise or vague. Fuzzy sets offer a deep investigation of imprecise stochastic uncertainty based on a strict mathematical framework. Choosing an alternative involves conflicting criteria, which makes it an MCDM problem. When dealing with fuzziness and conflicting criteria, a particular situation becomes a fuzzy MCDM problem. Many researchers have used MCDM ([2–5]) techniques and multi-attribute group decision-making (MAGDM) ([6, 7]to solve real-life decision-making problems. In day-to-day reality, people often consider numerous variables implicitly and may be content with making judgments based solely on intuition [8].

Although there are several approaches for solving MCDM and multi-attribute decision-making (MADM) problems, TOPSIS [2] is the most effective and traditional method for solving MCDM, MCGDM, and MAGDM in real-life application problems. The traditional TOPSIS approach has been expanded into the fuzzy TOPSIS [9] method, which is used to solve MCDM problems in which the criteria or alternatives are placed in an uncertain environment. Several authors extended their research in FTOPSIS, such as Chen [9] extended TOPSIS under fuzziness, interval-valued fuzzy number ([10, 11]), Boran et al. [12] extended Chen's methods [10, 11] to intuitionistic fuzzy number, and Park et al. [13] extended Boran et al. [12] methods to interval-valued intuitionistic fuzzy number. Moreover, Chen and Lee [14] developed an interval type-2 [15] and its extension proposed by Dymova et al. [16], which is the same approach utilised by Deveci et al. [5]. Roszkowska and Kacprzak [17] extended the aforementioned fuzzy TOPSIS methods based on ordered fuzzy numbers. Lourenzutti and Krohling [6] explored a generalised TOPSIS technique for group decision-making with the heterogeneous input. Abootalebi et al. [18] proposed a MAGDM using modified TOPSIS techniques with interval information to overcome the shortcomings of the aforementioned fuzzy TOPSIS method. Furthermore, Salih et al. [19] surveyed the developments in fuzzy TOPSIS on FMCDM between 2007 and 2017. This extended fuzzy TOPSIS approach deals with real-world application problems in a variety of fields, such as river valley water quality management [20], aircraft ([21, 22]), supplier selection ([23, 24]), project risk [25], supply chain management in food industries [26], automobile industry [27, 28], and transition supply chain [29] via different decision-making methods.

The techniques mentioned above offer a range of benefits. However, using only numerical values may not always be sufficient to represent real-world scenarios accurately. When faced with subjective human judgements, such as when there are competing criteria, it needs to consider the situation carefully. Under these circumstances, decision-makers ought to take vague or imprecise information into account. Instead of using exact numbers, a more sensible strategy may include using GIT2TrFNs for the proposed MCDM problem. It would mean considering the potential use of GIT2TrFNs to evaluate the ratings of attributes under consideration. The primary objective of this study is to present a novel FTOPSIS method that integrates interval data to tackle the issues associated with MCDM. Two types of proposed ranking methods evaluate FTOPSIS: defuzzification and comparison of preference relations. Defuzzification involves generating a crisp value from the aggregated output of a fuzzy set, which removes the inherent uncertainty. On the other hand, a fuzzy pairwise comparison is difficult and time-consuming, but it preserves the inherent uncertainty. This work offers a defuzzification of GIT2TrFNs for the MCDM-FTOPSIS technique.

Section 1 of, this study uses a literature review to illustrate the importance of MCDM issues and the development of FTOPSIS. Section 2 explains the essential concepts and preliminaries of GIT2TrFNs. The proposed novel FTOPSIS method for determining the ranking preference of MCDM problems is explained in Section 3. The proposed ranking system is applied numerically in Section 4. Finally, comparison studies of the proposed method and the conclusion are discussed in Sections 5 and 6. This study conducts a comprehensive review of existing models and decision-making methodologies based on the FTOPSIS method under various fuzzy numbers and environments from 2000 to 2022. Table 1 shows a wide literature survey on FTOPSIS.

To support the recognition of the relevance of the selection of the proposed study, Figure 1 shows the significant number of publications that fall into different fuzzy categories (TFN, TrFN, IVFN, and IT2FNs) and reveals that the fuzzy TOPSIS is the method that has been utilized the most frequently for performing the decision-making of various applications.

1.1. Highlights. The highlights of this study are as follows:

(1) Development of FTOPSIS
(2) A wide literature survey on FTOPSIS for solving MCDM/MADM/MAGDM problem
(3) The novel FTOPSIS techniques introduced
(4) A real-life application of vehicle selection problem discussed
(5) Comparison of ranking preferences of the proposed method with existing methods

Table 1: Literature survey on decision-making approaches using TOPSIS under fuzziness.

Authors	Year	Methods fuzziness	Type of decision-making	Applicability
Chen [30]	2000	TFN	MCDM	Selection of system analysis engineer
Chu [31]	2002	TFN	MCDM	Selecting plant location
Wang and Elhag [32]	2006	TFN	MCDM	Bridge risk assessment
Wang and Lee [33]	2007	TFN	FMCGDM	Airport operation performance
Chen and Tsao [10]	2008	IVFSs	MADM	Different distance measures
Chu and Lin [34]	2009	IA-TFN	MCDM	A hypothetical facility site selection
Wang and Lee [35]	2009	TFN	MCDM	Selection software problem
Tao et al. [36]	2010	TFN	MADM	Construction project selection
Chen and Lee [14]	2010	IT2FS	MAGDM	Selection of cars
Gligoric et al. [37]	2010	TFN	MCDM	Shaft location selection
Liu [38]	2011	GIVTrFNs	FMADM	Selection of a company manager
Park et al. [13]	2011	IVIFN	MAGDM	Planning to build a municipal library
Krohling and Campanharo [39]	2011	TFN	MCDM	Accidents with oil spill in the sea
Yue [40]	2012	IVFS	MAGDM	Project in road construction
Dymova et al. [41]	2013	TFN	MCDM	Different distance measures
Chen and Hong [42]	2014	IT2FS	MAGDM	Selection of system analysis engineer
Ilieva [43]	2016	IT2FNs	MCDM	Selection of business intelligence platform
Walczak and Rutkowska [44]	2017	TFN	MCDM	Project rankings for participatory budget
Kacprzak [45]	2018	TrFN	MCDM	Construction company plans to recruit a secretary
Husin et al. [25]	2019	TFN	MCDM	Project risk variable ranking
Gan et al. [23]	2019	TFN	MCDM	Select the best resilient supply chain partner
Yang et al. [46]	2020	TrIT2FN	FMCDM	Selecting the best investment option
Carmen [47]	2021	TFN	MCDA	Selection of suitable gamification application
Abootalebi et al. [48]	2022	M-TOPSIS	MADM	Traffic congestion
This study	2023	GIT2TrFNs	MCDM	Vehicle selection

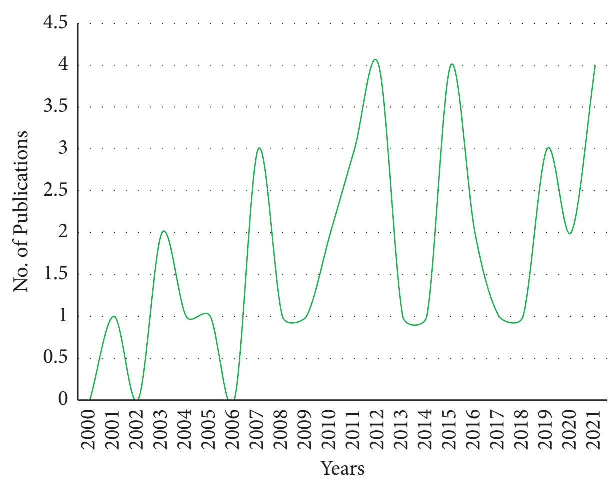

Figure 1: Publication on fuzzy TOPSIS using TFN, TrFN, IVFN, and IT2FNs during 2000–2021.

1.2. Research Questions. The research questions are as follows:

(1) What is the importance of defuzzification of fuzzy number?

(2) What role does invest in vehicle selection play in simplifying complicated criteria?

(3) What are the positive impacts and efficiency gains associated with the utilisation of multicriteria methodologies in the assessment and selection of vehicle investment projects, considering of uncertainties?

2. Preliminaries

This section provides a brief overview of the fundamental concepts related to interval type-2 fuzzy numbers (IT2TrFNs), GIT2TrFNs, and the process of defuzzification for GIT2TrFNs.

Definition 1. Let $\widetilde{U} = (\underline{U}, \overline{U}) = ((\underline{u}_1, \underline{u}_2, \underline{u}_3, \underline{u}_4), (\overline{u}_1, \overline{u}_2, \overline{u}_3, \overline{u}_4))$ be a IT2TrFN with an upper membership function $\mu_{\overline{U}}(x)$ and a lower membership function $\mu_{\underline{U}}(x)$ [49] (where $\underline{u}_1, \underline{u}_2, \underline{u}_3, \underline{u}_4$ and $\overline{u}_1, \overline{u}_2, \overline{u}_3, \overline{u}_4$ are the lower and upper trapezoidal elements, respectively, and $\underline{\omega}$ and $\overline{\omega}$

are the lower and upper membership notations of trapezoidal fuzzy number, respectively), then

$$\mu_{\overline{U}}(x)=\begin{cases}\dfrac{x-\overline{u}_1}{\overline{u}_2-\overline{u}_1}, & \text{for } \overline{u}_1\le x\le \overline{u}_2,\\ \overline{\omega}, & \text{for } \overline{u}_2< x< \overline{u}_3,\\ \dfrac{x-\overline{u}_3}{\overline{u}_4-\overline{u}_3}, & \text{for } \overline{u}_3\le x\le \overline{u}_4,\end{cases} \quad (1)$$

and

$$\mu_{\underline{U}}(x)=\begin{cases}\dfrac{x-\underline{u}_1}{\underline{u}_2-\underline{u}_1}, & \text{for } \underline{u}_1\le x\le \underline{u}_2,\\ \underline{\omega}, & \text{for } \underline{u}_2< x< \underline{u}_3,\\ \dfrac{x-\underline{u}_3}{\underline{u}_4-\underline{u}_3}, & \text{for } \underline{u}_3\le x\le \underline{u}_4.\end{cases} \quad (2)$$

Here, $\underline{U}$ and $\overline{U}$ are two TrFNs with the membership functions $\overline{\mu}_{\tilde{U}}(x)$ and $\underline{\mu}_{\tilde{U}}(x)$, respectively.

Definition 2. A T2FS ([50, 51]) represented by $\tilde{U}$ is characterized by a type-2 membership function $\mu_{\tilde{U}}(x,u)$, where $x\in X$ and $u\in J_x\subseteq[0,1]$.

$$\tilde{U}=\left\{\left((x,u),\mu_{\tilde{U}}(x,u)\right)\middle|\forall x\in X,\text{and } u\in J_x\subseteq[0,1],\right. \quad (3)$$

where $0\le\mu_{\tilde{U}}(x,u)\le 1$ (Figure 2), J_x is the primary membership of x, and $\mu_{\tilde{U}}(x,u)$ is the secondary grade or secondary membership for $x\in X$, $u\in J_x$.

Note: If the elements of $\tilde{U}$ are continuous, then it represents by

$$\begin{aligned}\tilde{U}&=\int_{x\in X}\int_{u\in J_x}\frac{\mu_{\tilde{U}}(x,u)}{(x,u)}\\ &=\int_{x\in X}\frac{\int_{u\in J_x}\mu_{\tilde{U}}(x,u)/u}{\text{x}},J_x\subseteq[0,1],\end{aligned} \quad (4)$$

where $\iint$ denotes union over all admissible x and u. Furthermore, $\int$ is replaced by $\sum$ for the discrete universe of discourse. In (3), when $\mu_{\tilde{U}}(x,u)=1$, $\forall\ x\in X$, and $u\in J_x\subseteq[0,1]$, then $\tilde{U}$ is called IT2FS and it has type-1 interval set membership function.

Definition 3 (see [52]). On the interval $[\overline{u}_1,\overline{u}_2]$, a GIT2TrFN $\tilde{U}$ is defined with its lower membership function taking values equal to ω_1, $\omega_2\in[0,1]$ in the points $\underline{u}_2$ and $\underline{u}_3$, respectively, and its upper membership function taking values equal to $\overline{\omega}_1$, $\overline{\omega}_2\in[0,1]$ in the points u_2 and u_3, respectively.

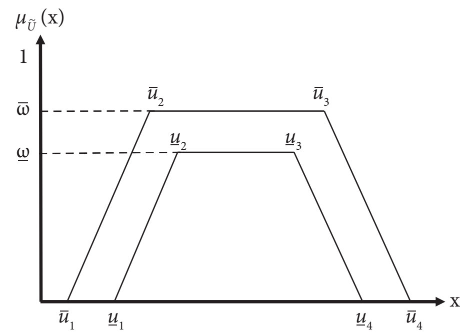

Figure 2: Diagram of IT2FS.

The GIT2TrFN denoted is by $\tilde{U}=(\underline{U},\overline{U})=((\underline{u}_1,\underline{u}_2,\underline{u}_3,\underline{u}_4),(\overline{u}_1,\overline{u}_2,\overline{u}_3,\overline{u}_4))$ and its membership functions are shown in Figure 3 (where $\underline{u}_1,\underline{u}_2,\underline{u}_3,\underline{u}_4$ and u_1,u_2,u_3,u_4 are the lower and upper trapezoidal elements, respectively, and ω_1, ω_2 and ω_1, ω_2 are the lower and upper memberships notations of GIT2TrFN, respectively).

$$\mu_{\underline{U}}(x)=\begin{cases}\mu_{\underline{U}_1}(x)=\underline{\omega}_1\dfrac{x-\underline{u}_1}{\underline{u}_2-\underline{u}_1}, & \text{for } \underline{u}_1\le x\le\underline{u}_2,\\ \mu_{\underline{U}_2}(x)=(\underline{\omega}_2-\underline{\omega}_1)\dfrac{x-\underline{u}_2}{\underline{u}_3-\underline{u}_2}+\underline{\omega}_1, & \text{for } \underline{u}_2\le x\le\underline{u}_3,\\ \mu_{\underline{U}_3}(x)=\underline{\omega}_2\dfrac{\underline{u}_4-x}{\underline{u}_4-\underline{u}_3}, & \text{for } \underline{u}_3\le x\le\underline{u}_4,\\ \mu_{\underline{U}_4}(x)=0, & \text{for } x\le\underline{u}_1, x\ge\underline{u}_4,\end{cases} \quad (5)$$

and

$$\mu_{\overline{U}}(x)=\begin{cases}\mu_{\overline{U}_1}(x)=\overline{\omega}_1\dfrac{x-\overline{u}_1}{\overline{u}_2-\overline{u}_1}, & \text{for } \overline{u}_1\le x\le\overline{u}_2,\\ \mu_{\overline{U}_2}(x)=(\overline{\omega}_2-\overline{\omega}_1)\dfrac{x-\overline{u}_2}{\overline{u}_3-\overline{u}_2}+\overline{\omega}_1, & \text{for } \overline{u}_2\le x\le\overline{u}_3,\\ \mu_{\overline{U}_3}(x)=\overline{\omega}_2\dfrac{\overline{u}_4-x}{\overline{u}_4-\overline{u}_3}, & \text{for } \overline{u}_3\le x\le\overline{u}_4,\\ \mu_{U_4}(x)=0, & \text{for } x\le\overline{u}_1, x\ge\overline{u}_4.\end{cases} \quad (6)$$

In special cases, if $\underline{\omega}_1=\underline{\omega}_2=\omega=\overline{\omega}_1=\overline{\omega}_2=1$, then by Definition 3, a GIT2TrFN is called as interval type-2 flat trapezoidal fuzzy number [52].

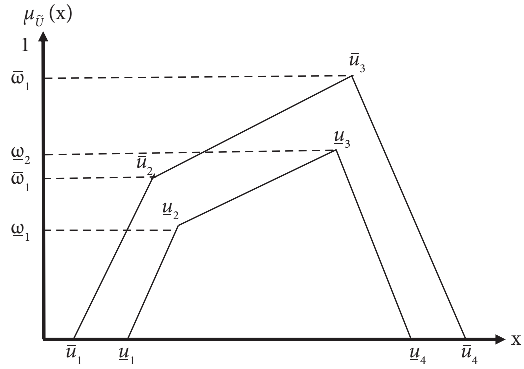

Figure 3: Diagram of GIT2TrFN.

Definition 4 (see [53]). A trapezoidal general interval type-2 fuzzy number's defuzzified value is defined as follows:

$$\mathrm{Def}\,(\widetilde{U}) = \frac{\underline{u}_1 + (1+\underline{\omega}_1)\underline{u}_2 + (1+\ \underline{\omega}_2) + \underline{u}_4}{2(4+\underline{\omega}_1+\underline{\omega}_2)} + \frac{\overline{u}_1 + (1+\overline{\omega}_1)\overline{u}_2 + (1+\overline{\omega}_2) + \overline{u}_4}{2(4+\overline{\omega}_1+\overline{\omega}_2)}. \tag{7}$$

Example 1. Let $\widetilde{U} = ((0.2, 0.5, 1, 1.4; 0.3, 0.4), (0.1, 0.32, 1.4, 1.8; 0.62, 0.72))$ be GIT2TrFNs, then $\mathrm{Def}\,(\widetilde{U})$ is 0.8402 (using Definition 4).

3. The Proposed Novel FTOPSIS Method

The TOPSIS approach for analysing real-valued data was initially proposed by Hwang and Yoon [54]. Subsequently, Chen [30] expanded upon the approach by using T1FSs to account for the inherent uncertainty in the fuzzy environment. Chen et al. [55] enhanced the approach by IT2FSs. There has been a notable focus in current academic research on the topic of fuzzy TOPSIS, but comparatively less attention has been given to the study of IT2FSs [16]. The TOPSIS approach has been employed in this study. The authors Rashid et al. [56] have expanded the original PIS and NIS, which were initially designed for IVFSs, to encompass IT2FSs. The extended vertex approach is employed to ascertain the disparity between viable alternatives and optimal solutions. Its design idea has been changed to include a fuzzy notion with the concept of fuzziness in weight vector of attributes. Let us consider an MCDM problem which is composed of "m" alternatives P_i for $i = 1, \ldots, m$, and "n" criteria C_j for $j = 1, \ldots, n$. The decision matrix $D = [d_{ij}]_{m\times n}$ is formed with all the attributes and the alternatives. The weight vector of attributes is $W = [w_1, w_2, \ldots, w_n]^T$ and $\sum_{j=1}^{n} w_j = 1,\ 0 \le w_j \le 1$.

Steps for the FTOPSIS process are as follows:

(1) Create the decision matrix and assign a weight to each criterion. Let $X = [x_{ij}]_{m\times n}$ be a decision matrix and the weight to each criterion is assigned through $W = [w_1, w_2, \ldots, w_n]^T$ which is known as a weight vector

(2) Compute defuzzified matrix $D_f = [x_{\mathrm{ij}}]_{m\times n}$

(3) Compute the normalized decision matrix $[\eta_{ij}]_{m\times n}$, where

$$\eta_{\mathrm{ij}} = \frac{D_{f\,ij}}{\sqrt{\sum_{j=1}^{n} D_{f\,ij}^{\ 2}}}. \tag{8}$$

(4) Compute the normalized weighted decision matrix

$$\begin{aligned} V &= [v_{\mathrm{ij}}]_{m\times n} \\ &= \mathrm{w_j} * \eta_{\mathrm{ij}}, \quad i = 1, \cdots, m;\ j = 1, \cdots, n. \end{aligned} \tag{9}$$

(5) Obtain the ideal solutions, both positive and negative.

The positive ideal solution (PIS) P^+ has the following form:

$$P^+ = (v_1^{\ +}, v_2^{\ +}, \ldots, v_n^{\ +}) = \left(\max v_{\mathrm{ij}} \middle| j \in I_b; \left(\min v_{\mathrm{ij}} \middle| j \in j_c\right)\right.. \tag{10}$$

The negative ideal solution (NIS) P^- has the following form:

$$P^- = (v_1^{\ -}, v_2^{\ -}, \ldots, v_n^{\ -}) = \left(\left(\min v_{\mathrm{ij}} \middle| j \in I_b; \left(\max v_{\mathrm{ij}} \middle| j \in j_c\right);\right.\right., \tag{11}$$

where I_b denote the benefit criteria (more is better) and J_c denote the cost criteria (less is better); $i = 1, \ldots, m, \mathrm{j} = 1, \ldots, n$.

(6) Calculate the distance measures $d_i^{\ +}$ and $d_i^{\ -}$ of the alternatives far from PIS and NIS. The most utilized conventional n-dimensional Euclidean distance is applied for this purpose.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \tag{12}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}. \tag{13}$$

(7) Compute the relative closeness coefficient (RCC) to the ideal alternatives.

$$\mathrm{RCC}_i = \frac{d_i^-}{d_i^- + d_i^+}, \tag{14}$$

where $0 \le \mathrm{RCC}_i \le 1$, $i = 1, 2, \ldots, m$.

(8) Rank the alternatives based on RCC to the ideal alternatives. On the basis of RCC_i rank, the alternatives are in the descending order.

The concise nature of the fuzzy method of TOPSIS described can engage the reader effectively. Figure 4 showcases the proposed flowchart for TOPSIS approaches, utilizing a fuzzy-based approach.

3.1. Linguistic Terms for the Proposed FTOPSIS Method. In solving the MCDM problem within fuzzy contexts, a novel FTOPSIS approach proves to be highly effective. By representing the criteria weights and scores as linguistic variables, this method employs GIT2TrFN to assign values to these variables, expressed in linguistic terms. This approach is valuable when grappling with real-world situations that are too intricate or ambiguous to be satisfactorily conveyed via quantitative expressions. Table 2 shows the linguistic terms in the form of GIT2TrFNs as an example of the proposed application for vehicle selection.

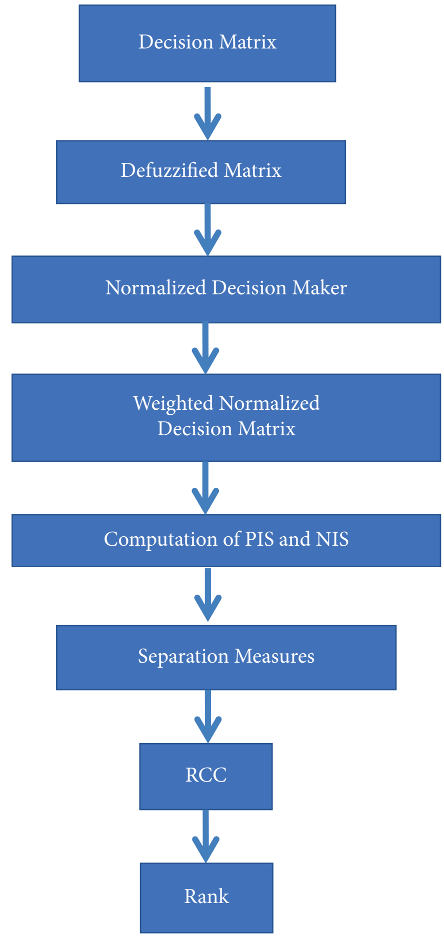

FIGURE 4: Flow diagram for the proposed weighted decision matrix-based TOPSIS under fuzziness.

4. Numerical Example

This section explains the proposed TOPSIS method by solving a numerical example problem. Buying or investing in a vehicle (alternative) is often considered a luxury, especially for middle-class households. On the other hand, lower-income groups tend to compare different vehicle models and brands based on their needs and budgets. People consider various criteria, such as the type, size, capacity, engine power, fuel efficiency, safety features, and life-cycle cost. These criteria are numerous, and people search for the best alternatives to fulfil their needs. This situation falls under the MCDM problem, and it encompasses ambiguous information, which is crucial to articulate with expertise and understanding rather than rigid limitations. The following example focuses on selecting the best alternative when faced with competing criteria such as cost, comfort, service, maintenance, and other factors. These are some of the essential factors to consider when buying a vehicle. Interestingly, the least expensive, most comfortable, and safest alternative is preferable.

This example shows how to use the proposed MCDM model to choose a vehicle. Assume a customer wishes to purchase a vehicle, and the person has to pick out the best one among the five alternatives (vehicle) with specific criteria. Let P_1, P_2, P_3, P_4, and P_5 denote the variety of vehicles as alternatives (P_i) available. These vehicles are distinct in their own way and the stakeholder (decision-maker) is to select the best alternative available with the set $C = \{$style (C_1), reliability (C_2), fuel-economy (C_3), cost $(C_4)\}$ of certain criterion (C_j). The alternatives are to be ranked according to the given criteria. Since the criteria are not defined in sharp boundaries, it is appropriate to represent them using GIT2TrFN. From the expert opinion, each of these criteria is given some weights, and this is represented by the weight vector $W = (0.25, 0.25, 0.25, 0.25)^T$. Figure 5 shows the procedures for computing critical features for the MCDM, which will assist in selecting a vehicle.

Table 2: Linguistic terms in the form of general interval type-2 fuzzy sets.

Linguistic terms	Corresponding general IT2FS
Absolutely low (AL)	((0.00, 0.00, 0.01, 0.11; 0.70, 0.80), (0.0, 0.0, 0.12, 0.15; 0.9, 1))
Very low (VL)	((0.23, 0.28, 0.30, 0.32; 0.70, 0.80), (0.04, 0.13, 0.35, 0.38; 0.9, 1))
Low (L)	((0.31, 0.33, 0.35, 0.40; 0.70, 0.80), (0.19, 0.28, 0.48, 0.50; 0.9, 1))
Medium low (ML)	((0.57, 0.61, 0.63, 0.66; 0.70, 0.80), (0.42, 0.46, 0.67, 0.75; 0.9, 1))
Medium (M)	((0.68, 0.7, 0.71, 0.75; 0.70, 0.80), (0.50, 0.55, 0.72, 0.77; 0.9, 1))
Medium high (MH)	((0.70, 0.72, 0.74, 0.76; 0.70, 0.80), (0.65, 0.68, 0.75, 0.78; 0.9, 1))
High (H)	((0.80, 0.85, 0.88, 0.90; 0.70, 0.80), (0.75, 0.82, 0.90, 0.92; 0.9, 1))
Very high (VH)	((0.92, 0.94, 0.96, 0.98; 0.70, 0.80), (0.89, 0.90, 0.97, 0.99; 0.9, 1))
Absolutely high (AH)	((1, 1, 1, 1; 0.7, 0.8), (1, 1, 1, 1; 1, 1))

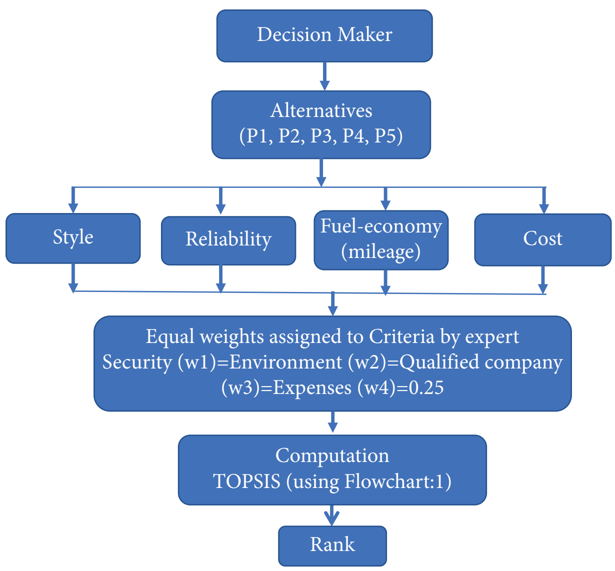

Figure 5: Computational steps of numerical solution of vehicle selection.

4.1. Steps for the Numerical Solution of Vehicle Selection Example

4.1.1. Construction of a Decision Matrix. Table 3 of the decision matrix $D = [x_{ij}]_{m\times n}$ $(i = 1, \ldots, 5;\ j = 1, \ldots, 4)$ is formed using the linguistic terms presented in Table 2. The different criteria that consumers consider are represented by fuzzy numbers of type-2 interval values. They are assigned membership values based on subjective judgements which are illustrated in Table 2. The essence of this decision matrix is to portray the different alternatives that are displayed against attributes that consumers may consider when buying a vehicle. In Table 3, P_i' s represents the variety of vehicles available to consumers. They would choose their vehicle from amongst these alternatives, of course, subject to the different criteria which are represented by GIT2TrFNs. However, these fuzzy quantities are transformed back into crisp numbers for further calculations. This is represented in Table 3. Also, since all the criteria may not be of equal importance, some weights are assigned to these criteria, and with these weights in place, a weighted decision matrix is calculated as shown in Table 4. The rest of the steps that follow in TOPSIS are shown in Tables 3–8.

Table 3: Decision matrix $D = [x_{ij}]_{m\times n}$.

Alternatives	C_1	C_2	C_3	C_4
P_1	H	MH	ML	MH
P_2	VH	M	AL	ML
P_3	ML	H	VL	AL
P_4	ML	M	MH	H
P_5	VH	VL	L	AL

Table 4: The weighted normalized decision matrix.

Alternatives	C_1	C_2	C_3	C_4
P_1	0.1192	0.1211	0.1438	0.1423
P_2	0.1314	0.1127	0.0064	0.1174
P_3	0.0830	0.1434	0.0623	0.0052
P_4	0.0830	0.1127	0.1745	0.1686
P_5	0.1314	0.0433	0.0863	0.0052

Table 5: Defuzzified matrix.

Alternatives	C_1	C_2	C_3	C_4
P_1	0.8560	0.7229	0.5960	0.7229
P_2	0.9437	0.6726	0.0264	0.5960
P_3	0.5960	0.8560	0.2582	0.0264
P_4	0.5960	0.6726	0.7229	0.8560
P_5	0.9437	0.2582	0.3577	0.0264

Table 6: Normalized decision matrix.

Alternatives	C_1	C_2	C_3	C_4
P_1	0.4767	0.4844	0.5753	0.5694
P_2	0.5256	0.4507	0.0255	0.4694
P_3	0.3319	0.5736	0.2493	0.0208
P_4	0.3319	0.4507	0.6978	0.6742
P_5	0.5256	0.1730	0.3453	0.0208

Table 7: Distance measures d_i^+ and d_i^-.

Alternatives	d_i^+	d_i^-
P_1	0.1428	0.1642
P_2	0.2044	0.0989
P_3	0.1221	0.1996
P_4	0.1731	0.1819
P_5	0.1334	0.1882

Table 8: RCC to the ideal solutions.

Alternatives	$RCC_i = d_i^- / d_i^- + d_i^+$	Rank
P_1	0.5348	3
P_2	0.3261	5
P_3	0.6204	1
P_4	0.5123	4
P_5	0.5852	2

4.1.2. Defuzzification. Table 5 gives defuzzified values to the decision matrix D in the form of $D_f = [x_{ij}]_{m\times n}$ (see Definition 4). Defuzzification is ensured to convert the fuzzy values to crisp numbers, and the next step is normalising the achieved defuzzified values.

4.1.3. Normalization. Table 6 gives the normalized decision matrix using (9).

4.1.4. Computing Weighted Matrix. Table 4 shows the weights assigned to the criteria by the expert (decision-maker). The criteria are security (w_1), environment (w_2), qualified company (w_3), and expenses (w_4), with the equal weight $w = [w_1, w_2, w_3, w_4]^T = [0.25, 0.25, 0.25, 0.25]^T$ by $V = [v_{ij}]_{m\times n} = w_j * \eta_{ij} = 1, \ldots, 5; j = 1, \ldots, 4$.

4.1.5. Computation of PIS and NIS. Using (10) and (11), the PIS and NIS are calculated as follows:

(i) The PIS is $P_{ij}^{+} = (0.1314, 0.1434, 0.1745, 0.0052)$

(ii) The NIS is $P_{ij}^{-} = (0.0830, 0.0433, 0.0064, 0.1686)$

4.1.6. Distance Measures. The separation measures were calculated from the PIS and the NIS using (12) and (13), which is shown in Table 7.

4.1.7. Relative Closeness Coefficient (RCC). The RCC to the ideal solutions (RCC) are calculated using (14).

4.1.8. Ranking Preference. The ranking preference given here is the justification of $P_2 \prec P_4 \prec P_1 \prec P_5 \prec P_3$ based on RCC's values. The alternative P_3 has a higher value of the relative closeness among the other alternatives. As a result, based on the abovementioned evaluation criteria, the alternative P_3 is the best automotive vehicle among the five alternatives.

4.2. Sensitivity Analysis. In this sensitivity analysis, this study examines the effect of different scenarios on purchasing a vehicle. The decision-maker evaluated five alternatives based on various criteria. Table 9 shows the performance of the fuzzy TOPSIS method, and alternatives are ranked equally for different membership values. As shown in Figure 6, the proposed FTOPSIS method is less affected by changes in the membership values of GIT2TrFN but more affected by changes in the weights of the criteria. If a particular criterion adds more weight, it will alter the order of the alternatives. Moreover, the FTOPSIS technique can accurately distinguish between different variations. This capability of the FTOPSIS method can prove particularly advantageous for decision-makers when dealing with highly subjective criteria and complex judgements.

5. Comparison of Ranking Preferences with Existing Methods

The FTOPSIS approaches were evaluated and compared to existing methods across various TOPSIS outcomes. Several researchers have investigated the FTOPSIS methodology in diverse practical contexts inside fuzzy settings, employing triangular fuzzy numbers to explore the inherent fuzziness. To conduct a comparative analysis between the proposed technique and current methods, we have found scholarly works that have employed the FTOPSIS method and those that have focused on TrFNs and IT2FNs in Table 1. For a quick view of the real-world application, Table 10 shows the results of the existing approaches relating to the RCC for ranking preference. Chu [57] proposed FTOPSIS by developing the membership function of two TrFNs. In addition to this, there is a drawback associated with arranging the generalised and interval-valued trapezoidal fuzzy numbers [59] in inconsistent order. On the other hand, Ashtiani et al. [60] tackled the FMADA problem using interval-valued triangular fuzzy numbers. The decision-making method proposed by [60] utilised the lower and upper limits of interval-valued triangular fuzzy numbers to compute the relative closeness coefficient using the TOPSIS method. However, this approach must only consider the holistic nature of interval-valued triangular fuzzy numbers. Dymova et al. [16] used an IT2FV α-cut representation for the type-2 interval fuzzy extension of the FTOPSIS method to overcome the limitations and drawbacks of earlier techniques. Many uncertainties cannot be dealt with using a type-1 interval fuzzy set. Celik et al. [61] reviewed many articles based on fuzzy sets of type-2 intervals to identify uncertainty in solving MCDM problems, despite shortcomings in addressing the generalised interval type-2 fuzzy sets in solving MCDM problems. To address the deficiency mentioned earlier, Ilieva [43] proposed a modified TOPSIS based on IT2FNs with drawbacks on the defuzzification of GIT2TrFN. To overcome all the abovementioned limitations and disadvantages, Meniz [62] compared defuzzications ([53, 63, 64]) and contributed the new idea of fuzzy metric for obtaining the optimum solution to the MCDM problems. The extensions of the fuzzy TOPSIS approach, created by various authors, possess certain limits and drawbacks. However, it is important to note that these extensions are particularly advantageous in tackling problems related to MCDM/MADM, MCGDM, and other comparable issues. This study introduces GIT2TrFN as a proposed method for extending FTOPSIS, along with its corresponding defuzzification technique. Table 10 presents a comparison between existing methods and the proposed novel FTOPSIS outcomes using different methodologies.

Table 9: Performance of TOPSIS under various linguistic values and distinct membership values of GIT2TrFN

GIT2TrFNs membership values	P_i	Normalization matrix				Weighted matrix $W = (0.25, 0.25, 0.25, 0.25)$				Positive and negative ideal solution PIS and NIS	Separation measures		$RCC_i = d_i^- / d_i^- + d_i^+$	Rank
		C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4		d_i^+	d_i^-		
$\omega = 0.1$	P_1	0.4757	0.4847	0.5761	0.5697	0.1189	0.1212	0.1440	0.1424	PIS	0.1418	0.1633	0.5352	3
$\bar{\omega}^1 = 0.2$	P_2	0.5257	0.4514	0.0308	0.4703	0.1314	0.1128	0.0077	0.1176	(0.1314, 0.1432, 0.1475, 0.0063)	0.2028	0.0989	0.3280	5
$\overline{\overline{\omega}}_1^2 = 0.3$	P_3	0.3324	0.5727	0.2475	0.0252	0.0831	0.1432	0.0619	0.0063	NIS	0.1225	0.1980	0.6178	1
$\overline{\omega}_2 = 0.4$	P_4	0.3324	0.4514	0.6979	0.6731	0.0831	0.1128	0.1745	0.1683	(0.0831, 0.0430, 0.0077, 0.1683)	0.1717	0.1808	0.5128	4
	P_5	0.5257	0.1719	0.3448	0.0252	0.1314	0.0430	0.0862	0.0063		0.1335	0.1864	0.5826	2
$\omega = 0.3$	P_1	0.4762	0.4846	0.5756	0.5695	0.1191	0.1211	0.1439	0.1424	PIS	0.1423	0.1637	0.5350	3
$\bar{\omega}^1 = 0.4$	P_2	0.5257	0.4511	0.0283	0.4698	0.1314	0.1128	0.0071	0.1174	(0.1313, 0.1433, 0.1744, 0.0053)	0.2041	0.0989	0.3263	5
$\overline{\overline{\omega}}_1^2 = 0.6$	P_3	0.3321	0.5732	0.2484	0.0231	0.0830	0.1433	0.0621	0.0058	NIS	0.1222	0.1994	0.6200	1
$\overline{\omega}_2 = 0.7$	P_4	0.3321	0.4511	0.6979	0.6737	0.0830	0.1128	0.1745	0.1648	(0.0829, 0.0432, 0.0065, 0.1685)	0.1729	0.1817	0.5122	4
	P_5	0.5257	0.1725	0.3452	0.0231	0.1314	0.0431	0.0863	0.0058		0.1334	0.1879	0.5848	2
$\omega = 0.6$	P_1	0.4766	0.4845	0.5754	0.5694	0.1191	0.1211	0.1439	0.1424	PIS	0.1426	0.1640	0.5348	3
$\bar{\omega}^1 = 0.7$	P_2	0.5256	0.4508	0.0262	0.4695	0.1314	0.1127	0.0065	0.1174	(0.1313, 0.1433, 0.1744, 0.0053)	0.2041	0.0989	0.3263	5
$\overline{\overline{\omega}}_1^2 = 0.8$	P_3	0.3320	0.5735	0.2490	0.0214	0.0830	0.1434	0.0623	0.0053	NIS	0.1222	0.1994	0.6200	1
$\overline{\omega}_2 = 0.9$	P_4	0.3320	0.4508	0.6978	0.6741	0.0830	0.1127	0.1745	0.1685	(0.0829, 0.0432, 0.0065, 0.1685)	0.1729	0.1817	0.5122	4
	P_5	0.5256	0.1728	0.3453	0.0214	0.1314	0.0432	0.0863	0.0053		0.1334	0.1879	0.5848	2
$\omega = 0.7$	P_1	0.4767	0.4844	0.5753	0.5694	0.1192	0.1211	0.1438	0.1423	PIS	0.1428	0.1641	0.5347	3
$\bar{\omega}^1 = 0.8$	P_2	0.5256	0.4507	0.0255	0.4694	0.1314	0.1127	0.0064	0.1174	(0.1313, 0.1434, 0.1744, 0.0051)	0.2043	0.1989	0.3261	5
$\overline{\overline{\omega}}_1^2 = 0.9$	P_3	0.3319	0.5736	0.2493	0.0208	0.0830	0.1434	0.0623	0.0052	NIS	0.1221	0.1996	0.6203	1
$\overline{\omega}_2 = 1.0$	P_4	0.3319	0.4507	0.6978	0.6742	0.0830	0.1127	0.1745	0.1686	(0.0829, 0.0432, 0.0063, 0.1685)	0.1731	0.1818	0.5122	4
	P_5	0.5256	0.1730	0.3453	0.0208	0.1314	0.0433	0.0863	0.0052		0.1334	0.1882	0.5852	2

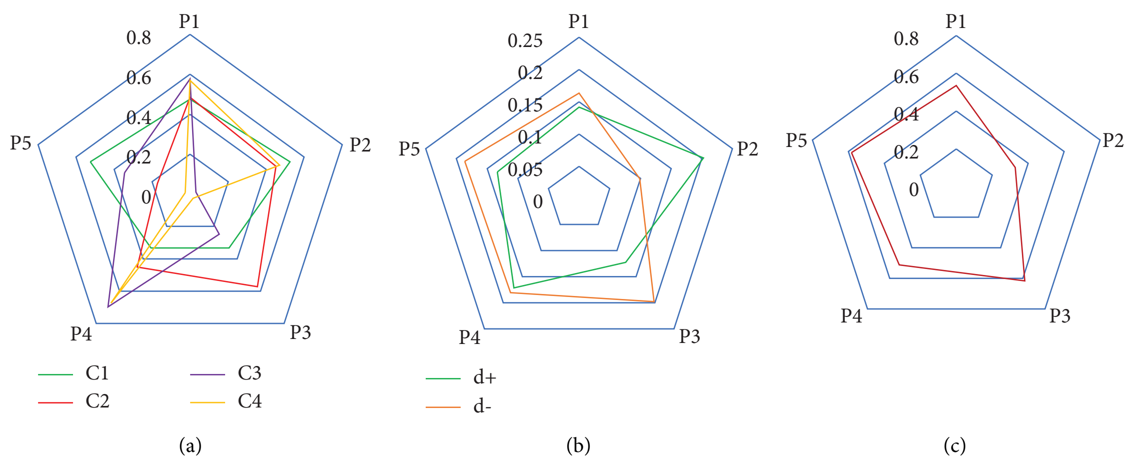

FIGURE 6: Sensitivity analysis of the proposed TOPSIS method: (a) normalization, (b) separation measures, and (c) RCC.

TABLE 10: Comparison of ranking preferences of different methods.

Authors	Fuzziness	Technique	No. of decision-makers	No. of criteria	P_i	d_i^+	d_i^-	RCC	Rank	Ranking preference
Chu [57]	TrFN	MCDM	3	4	P_1	0.5780	1.1307	0.6617	1	$P_1 \succ P_2 \succ P_3 \succ P_4$
					P_2	0.5884	1.1218	0.6197	2	
					P_3	1.5219	1.5119	0.4983	3	
					P_4	0.2678	0.2461	0.4788	4	
Liu [38]	GIVTrFNs	MAGDM	3	5	P_1	0.1040	0.2112	0.6700	2	$P_2 \succ P_4 \succ P_1 \succ P_3$
					P_2	0.2140	0.2142	0.5002	4	
					P_3	0.0607	0.2163	0.7808	1	
					P_4	0.0281	0.0291	0.5087	3	
Rashid et al. [56]	GITFN	MCDM	3	6	P_1	0.6891	0.2972	0.3013	3	$P_3 \succ P_2 \succ P_1$
					P_2	0.1181	0.4508	0.7924	2	
					P_3	0.1238	0.5951	0.8277	1	
Dymova et al. [16]	IT2FV	MCDM	DMs	5	P_1	0.0129	0.0093	0.4189	1	$P_1 \succ P_3 \succ P_2$
					P_2	0.0029	0.0014	0.3256	3	
					P_3	0.0039	0.0020	0.3360	2	
Sharaf [58]	IT2FS	MAGDM	3	2	P_1	0.5654	0.0708	0.1136	4	$P_4 \succ P_2 \succ P_3 \succ P_1$
					P_2	0.2895	0.1832	0.3875	2	
					P_3	0.4149	0.2331	0.3597	3	
					P_4	0.3969	0.3954	0.4990	1	
Yang et al. [46]	IT2FS	FMCDM	DMs	4	P_1	0.4352	0.3011	0.4088	5	$P_5 \succ P_4 \succ P_1 \succ P_2 \succ P_3$
					P_2	0.2961	0.3984	0.5736	4	
					P_3	0.1988	0.4939	0.7130	1	
					P_4	0.2605	0.5159	0.6644	2	
					P_5	0.2786	0.4041	0.5919	3	
This paper	GIT2TrFN	MCDM	DMs	4	P_1	0.1428	0.1642	0.5348	3	$P_3 \succ P_5 \succ P_1 \succ P_4 \succ P_2$
					P_2	0.2044	0.0989	0.3261	5	
					P_3	0.1221	0.1996	0.6204	1	
					P_4	0.1731	0.1819	0.5123	4	
					P_5	0.1334	0.1882	0.5852	2	

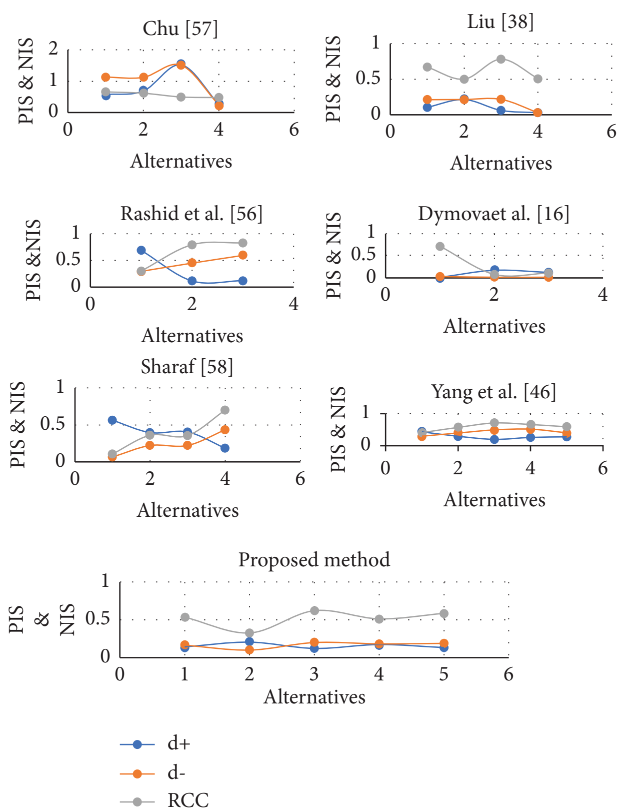

Figure 7: Performance of PIS and NIS with existing methods.

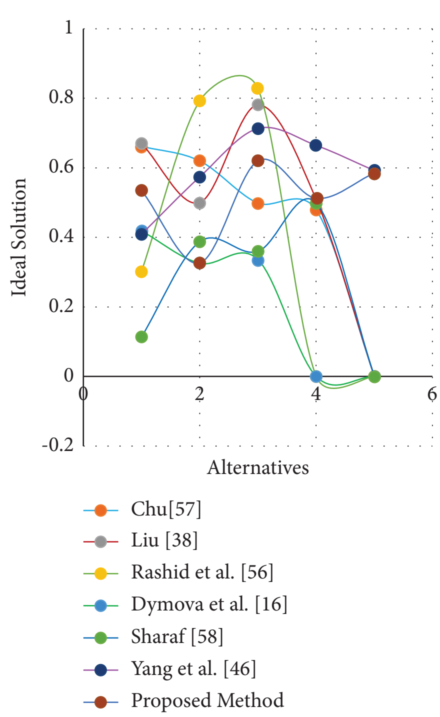

Figure 8: RCC performance of the proposed method with existing methods.

6. Conclusion

This study investigates the novel FTOPSIS technique for selecting the best vehicle from an individual's perspective. Using GIT2TrFN instead of traditional fuzzy sets simplifies and allows more ambiguity inputs in MCDM problems, improving the strategy's resilience and intelligence. Furthermore, the vehicle selection MCDM problem demonstrates the novel FTOPSIS technique's high effectiveness when using GIT2TrFN to address real-world uncertain scenarios. This study helps to determine the existence of contradictory criteria when we use fuzzy linguistic terms using GIT2TrFN rather than exact numbers. The presented sensitivity analysis gives more information about the reasonable study of the proposed method. Figures 7 and 8 provide more details about the proposed FTOPSIS and the existing methods. The performance of the PIS and NIS of the proposed alternatives is nearly the same as that of the Liu [38] methods (Figure 7). In Figure 8, the proposed FTOPSIS method shows that the RCC of alternative performance is neutral compared to the existing method. The proposed FTOPSIS technique evaluates alternatives in scenarios, including contradictory criteria . Also, it gives better ranking results for the numerical example of the vehicle selection problem. As a result, the decision-maker may choose a vehicle P_3 as the best option among the five alternatives. The practical scenario involved the application of the proposed methodology, where an automotive company chooses the most suitable vehicle for its manufacturing development. The proposed decision process holds considerable managerial significance, as it offers potential assistance to top-level management in effectively managing proposed projects by optimizing resource allocations and improving productivity. Given our inclination towards employing more realistic mathematical abstractions to depict human decision-making, it is evident that further investigation on this specialized subject is warranted.

6.1. Limitations.

This study is unsuitable for determining the weights of the best and worst alternatives, as it focuses solely on the ideal and anti-ideal options through the FTOPSIS methodology.

6.2. Future Recommendations.

This study holds promise for future growth and deals with many real-life decision-making problems in exploring the wide range of mathematical frameworks using extended fuzzy numbers, Fermatean fuzzy numbers, q-rung fuzzy sets, and neutrosophic fuzzy numbers.

Abbreviations

AHP: Analytic hierarchy process
COPRAS: Complex proportional assessment

GIVTrFNs: Generalized interval-valued trapezoidal fuzzy numbers
IF: Intuitionistic fuzzy
IT2FSs: Interval type-2 fuzzy sets
IT2FNs: Interval type-2 fuzzy numbers
IVIFN: Interval-valued intuitionistic fuzzy number
IVFN: Interval-valued fuzzy number
IVFSs: Interval-valued fuzzy sets
IVIFN: Interval-valued intuitionistic fuzzy number
SAW: Simple additive weighting
T1FSs: Type-1 fuzzy sets
TFN: Triangular fuzzy number
TrIT2FN: Trapezoidal interval type-2 fuzzy number
TrFNs: Trapezoidal fuzzy numbers.

Data Availability

Data sharing is not applicable to this article, as no datasets were generated or analysed during the current study.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

The study's conception and design were a collaborative effort among all the authors. Marimuthu Dharmalingam was responsible for developing the conceptualization and methodology, while he and Mahuya Deb assessed the numerical example using MATLAB. Marimuthu Dharmalingam, Ghanshaym Singha Mahapatra, and Fasika Bete Georgise performed validation, review writing, and editing. Marimuthu Dharmalingam penned the initial manuscript, which underwent review by all the authors.

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