Neural Computing and Applications (2024) 36:7343–7357
https://doi.org/10.1007/s00521-024-09463-x

ORIGINAL ARTICLE

Alternative prioritization for mitigating urban transportation challenges using a Fermatean fuzzy-based intelligent decision support model

Mouhamed Bayane Bouraima[1,2,3] · Ertugrul Ayyildiz[4] · Gokhan Ozcelik[4] · Nyamatari Anselem Tengecha[5] · Željko Stević[6]

Received: 5 June 2023 / Accepted: 14 January 2024 / Published online: 19 February 2024

Abstract
Practitioners and decision-makers often face difficulties in selecting and prioritizing effective strategies to address challenges to sustainable urban transportation development. Although there has been considerable research conducted on the subject, the Tanzanian context, which is greatly affected by social and environmental problems, has received inadequate attention. Therefore, this study intends to bridge this gap by pinpointing the obstacles to sustainable urban transportation and proposing the most appropriate strategies to tackle them. The study proposes seven strategies and determines five criteria to prioritize them. To accomplish this, the study proposes a novel Fermatean fuzzy-based intelligent decision support model to assess the criteria weights and prioritizes strategies based on the weighted criteria. The study validates the proposed methodology by conducting a sensitivity analysis, which indicates that restricting car use (A5), improving sector coordination (A1), and conducting extensive research on transportation issues (A7) are the top three strategies for promoting sustainable urban transportation. The study's findings hold significant value in providing urban transportation planners with helpful guidance to develop optimization techniques that can improve transportation systems.

Keywords Urban transportation · Fermatean fuzzy number · SWARA · CODAS

1 Introduction

Urban transportation is a major challenge in all countries due to its close connections with almost all aspects of the urban environment. A World Bank study has identified economic transition, globalization, fiscal decentralization, and urbanization as key factors linked to the challenges of urban transportation. As urban populations continue to grow and the density of buildings increase, traffic issues have become increasingly problematic. This has led to

✉ Ertugrul Ayyildiz
ertugrulayyildiz@ktu.edu.tr

Mouhamed Bayane Bouraima
mouba121286@yahoo.fr

Gokhan Ozcelik
gozcelik@ktu.edu.tr

Nyamatari Anselem Tengecha
transresearch.africa2022@gmail.com

Željko Stević
zeljko.stevic@vilniustech.lt

1 Sichuan College of Architectural Technology, Deyang Campus: No. 4, West Jialingjiang Road, Deyang, Sichuan 618000, China

2 School of Civil Engineering, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

3 Highway Engineering Key Laboratory of Sichuan Province, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

4 Department of Industrial Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey

5 Trans Research Africa Limited, P.O. Box 12105, Dar es Salaam, Tanzania

6 Department of Mobile Machinery and Railway Transport, Vilnius Gediminas Technical University, Vilnius, Lithuania

chronic congestion, severe air pollution, high accident rates, and lengthy travel time to work [1]. As cities expand in size, there is a proportional increase in transportation demand, especially as services and workplaces become more dispersed over greater distances. It is noteworthy that a rise in residents' income can influence transportation systems, often leading to a higher dependency on automobiles. As indicated in the report [2], transportation stakeholders, government policymakers, and urban planners have been extensively discussing the underlying causes of urban transportation issues. The debate has centered on identifying when and under what circumstances issues may be solved through the implementation of original, successful, and authentic approaches and procedures.

In recent years, Tanzania's cities have experienced a significant increase in population, which has created various challenges that are difficult to manage. On the positive side, the surge in population has led to the growth of industries and businesses, providing economic opportunities for rural migrants. However, managing transportation systems has become more challenging due to congestion and delays that make it harder for passengers and freight to access markets. Additionally, the high population density has increased fatalities, with road traffic accidents in urban areas causing an average of 3,400 deaths and 20,000 severe injuries annually [3]. Of particular concern, more than half of the fatalities related to car use in major Tanzanian cities occur before reaching the hospital or within the first four hours of admission, primarily due to transportation issues. Mrema [4] noted that the rise in population density has also contributed to increased fatalities. The estimated daily loss of around 4 billion Tanzanian Shillings by the Dar es Salaam Rapid Transit (DART) system further highlights the significant impact of transportation challenges in the city.

Although stakeholders, policymakers, and transportation managers have made efforts to tackle the challenges of urban transportation in growing cities, the situation remains problematic. As such, it is crucial to have a thorough understanding of the situation and implement effective strategies to mitigate it. In doing so, diverse paradoxical criteria should be examined. Traditional decision-making methods based on a single criterion are insufficient to handle such complex issues. As a solution, multi-criteria decision-making (MCDM) approaches have been developed, which have shown great potential in providing policymakers and managers with complementary tools that allow for greater flexibility [5–9]. These approaches use pre-established criteria to categorize and select one or more components from a group of options [10–16]. The selected parameters are then evaluated based on how well they fulfill their functions and determine the eligibility of alternatives [17]. Unfortunately, at present, there is no comprehensive study available that focuses on alternative prioritization for mitigating urban transportation problems, using Tanzania as a case study.

1.1 Objectives

This study assesses the urban transportation challenges across Tanzanian cities and suggests effective strategies to alleviate them using a new integrated MCDM approach. The effectiveness of the strategies is evaluated using five criteria that are relevant to the major challenges faced in urban transportation. Based on these criteria, the research puts forward seven strategies to address these challenges. In addition, the study presents a novel integrated methodology that can be utilized for resolving other urban transportation challenges, thereby facilitating more comprehensive and pragmatic solutions. The study also outlines a guideline to help select the most appropriate strategies to improve urban transportation in cities across Tanzania. This framework may serve as a model for other cities in various countries that are confronted with similar challenges.

1.2 The motive behind the application of Fermatean fuzzy sets

Senapati and Yager [18] introduced Fermatean fuzzy sets (FFS) as a way to handle uncertainty, building upon the concepts of intuitionistic fuzzy sets (IFS) and Pythagorean fuzzy sets (PFS). Compared to IFS and PFS, the FFS theory is a more advanced approach for managing imprecise and uncertain data. Moreover, when faced with conflicting decision-making scenarios, IFS and PFS are limited. The FFS theory is an impressive approach for expressing complex human preferences in decision-making. When dealing with practical problems in the real world, it is common for the available information to be incomplete and vague. These types of problems can often be more accurately modeled using FFS rather than IFS or PFS. In this study, a new integrated Fermatean fuzzy MCDM model is introduced to solve the urban transportation issue in Tanzania.

1.3 The motive behind the application of the SWARA method

The stepwise weight assessment ratio analysis (SWARA) method evaluates the weights of the subjective criteria [19]. In the SWARA method, experts can express their thoughts freely since they are not constrained by predetermined scales. By evaluating weights, this method settles arguments and makes logical judgments based on expert evaluations. This method can be utilized in any situation as a decision support system to resolve practical and scientific disagreements between competing aims. The SWARA technique has a greater level of stability, less calculation complication, and simple operations. Thanks to its numerous advantages, this method finds application in determining criteria weights in an FF environment.

1.4 The motive behind the application of the CODAS method

The combinative distance-based assessment method is a way to assess alternative solutions in MCDM [20] by utilizing both Euclidean and Taxicab measurements. In cases where two alternatives are considered incomparable based on Euclidean distance (i.e., they are equally close to the negative ideal), the secondary measure, Taxicab distance, is used to determine the best alternative. The approach is appealing for its straightforward and methodical computation process, which is logically consistent with the principles of real-world decision-making issues. Compared to other MCDM methods, CODAS offers several advantages that have not been previously considered. One significant advantage is that the method is based on two distinct types of distances, leading to more accurate ranking results in the assessment process. Thanks to its numerous advantages, this method finds application in ranking the alternative strategies for overcoming the challenges of urban transportation in an FF environment.

1.5 The structure of the study

After the introductive section, a review of the literature is provided in Sect. 2, followed by the problem definition in Sect. 3. Sections 4 and 5 present the methodology and its application, respectively, while the sensitivity analysis along with the discussion is shown in Sects. 6 and 7. Finally, the conclusion is elucidated in Sect. 8.

2 Literature review

Three sub-sections have characterized this section.

2.1 Decision-making approaches related to urban transportation

The emphasis of recent studies has been on urban transportation systems, with the majority of them delving into the challenges associated with these systems. For instance, Anin, Annan [21] investigated the challenges facing the transportation system in the Kumasi Metropolis. Kant, Quak [22] identified key lessons determined in the domains of technology, policy, and logistics in urban freight transportation. Ogunbodede [23] explored and discussed the challenges related to the Nigerian road transportation system. Schünemann, Finke [24] evaluated the environmental impact of an electric cargo bike used in Ghana. Solanke [25] proposed a collaborative approach among academia, transport practitioners, and policymakers at different levels of government to address urban transportation challenges in Nigeria. Thomas [26] conducted a study that presented an overview of how the South African government has provided public transportation services since the end of apartheid. Table 1 shows the related studies regarding the topic under discussion.

2.2 Multi-criteria approach usage in urban transportation studies

Various domains within urban transportation have made use of multi-criteria techniques [27]. For instance, Donais, Abi-Zeid [28] assessed the potential for redesigning streets to increase sustainability. Romero-Ania, Rivero Gutiérrez [29] identified appropriate urban vehicles based on a recommended feasible threshold. Büyüközkan, Feyzioğlu [30] evaluated different sustainable transportation alternatives and found that interdependencies of criteria play a critical role in rankings. Hajduk [31] examined seven criteria and 44 alternatives related to urban and public transportation systems. Deveci [32] prioritized the sustainable transportation system in Metaverse. Simic, Gokasar [33] selected sustainable policies for reducing the impacts of climate change on urban transportation. Görçün [34] proposed an MCDM approach to determine the most appropriate trams and metro vehicles for maximum benefits in public transit systems. Table 2 indicates the application of MCDM methods on urban transportation systems.

2.3 Research gaps

The research gaps are as follows: a) Tanzania's efforts toward sustainable urban transportation face several challenges that have not been adequately examined or addressed to date. To address this gap, this study is conducted, which is the first of its kind to focus on this issue. The study identifies the challenges impeding sustainable urban transportation development and proposes effective strategies to overcome them, as summarized in Table 1; b) a comprehensive framework that integrates the SWARA and CODAS methods using Fermatean fuzzy logic to identify and categorize the challenges associated with sustainable urban transportation development, as well as propose effective strategies to overcome them, is currently unavailable.

Table 1 Decision-making approaches related to urban transportation

Authors	Goal	GDM	SA	Approaches	Location
Anin, Annan [21]	Urban transportation problems evaluation	No	No	Questionnaire	Ghana
Kant, Quak [22]	Urban transportation challenges and successes assessment	No	No	Market research reports, stakeholder's views, literature	Global
Ogunbodede [23]	Discussion of related problems of the road transportation system	No	No	Exploratory method	Nigeria
Schünemann, Finke [24]	Environment impact assessment of urban freight transportation	No	No	Life cycle assessment method	Ghana
Solanke [25]	Urban transportation challenges identification	No	No	Narratives	Nigeria
Thomas [26]	Problems and benefits assessment of public transportation	No	No	Narratives based on historical sources	South Africa
Our study	Alternative Prioritization for mitigating urban transport challenges	Yes	Yes	FF, SWARA, CODAS	Tanzania

GDM: Group decision-making; SA: Sensitivity analysis

Table 2 Applications of MCDM Methods on urban transportation

Authors	Goal	Approaches	Location
Donais, Abi-Zeid [28]	Street identification and rank	MACBETH, GIS	Canada
Romero-Ania, Rivero Gutiérrez [29]	Urban public transportation examination	ELECTRE, Delphi	Spain
Büyüközkan, Feyzioğlu [30]	Choice of alternative in urban transport	IFCI	Turkey
Hajduk [31]	Choice of smart city	TOPSIS, Entropy	–
Deveci [32]	Evaluation of urban transport	DN, SWARA, DN, MEREC	–
Simic, Gokasar [33]	Urban transport impact on climate change	MEREC, MARCOS	–
Görçün [34]	Choice of urban railway vehicle	EDAS, CRITIC	Turkey
Our study	Alternative Prioritization for mitigating urban transportation challenges	FF, SWARA, CODAS	Tanzania

CRITIC: CRiteria Importance Through Intercriteria Correlation; DN: Double Normalization; EDAS: Evaluation based on Distance from Average Solution; ELECTRE: Elimination and choice translating reality; IFCI: Intuitionistic Fuzzy Choquet Integral; GIS: Geographic Information System; MACBETH: Measuring Attractiveness by a Categorical Based Evaluation Technique; MARCOS: Measurement of alternatives and ranking according to COmpromise solution; MEREC: MEthod based on the Removal Effects of Criteria

3 Problem definition

The sustainable development of urban transportation is a critical issue that requires urgent attention due to the challenges it presents. An effective framework and its proper implementation can significantly contribute to promoting sustainable urban transportation. To address these challenges, several strategies have been proposed to mitigate issues related to sustainable development. This study emphasizes the importance of engaging experts to thoroughly analyze these alternative strategies and provide recommendations for improving the current state of urban transportation in Tanzania.

3.1 Alternatives characterization

This section presents the alternatives that have been found based on the literature review and the expert's point of view.

A1: Improve sector coordination: Establishing a single authority with a clear mandate and sufficient power is necessary for the effective coordination of the transportation modes in cities. The transport authority of Dar es Salaam City (DUTA) is currently the only organization being considered for this role. However, stakeholders have raised concerns about the lack of clarity regarding DUTA's structure and function.

A2: Construction, improvement, and periodic maintenance of drainage systems: When drains are inadequate or blocked, roads can become flooded during rainy seasons, leading to traffic disruptions and reduced road lifespan due to potholes. In most urban areas of Tanzania, drainage systems are often ineffective during rainy seasons, making this a common problem. To combat this issue and support the long-term sustainability of roads, it is essential to prioritize the construction, improvement, and periodic maintenance of drainage systems to mitigate problems caused by poor drainage.

A3: Provision of off-street parking facilities according to the design of the city: Insufficient off-street parking availability can cause vehicles to park on the street, leading to narrowed roads and obstructed traffic flows. To prevent these issues, off-street parking spaces should be given in areas of high activity concentration along the road.

A4: Distribution of the traffic light at main intersections across the cities: During peak hours, there is a noticeable surge in traffic on the major roads in Tanzanian cities. To regulate traffic, "STOP" signs should be placed at suitable intersections, and traffic wardens should manage other intersections. Furthermore, it is advisable to install road signs on all roads within Tanzanian cities where they are currently absent.

A5: Restricted car use (expert opinion): There is no need to completely proscribe the selling of cars or prevent citizens from getting them. Rather, the focus is on promoting the judicious use of cars, limiting their usage to situations where they are strictly necessary, and encouraging people to use alternative modes of transportation like public transit, cycling, and walking for most of their trips.

A6: Regular maintenance of roads in cities (expert opinion): Adequate funding must be provided to road maintenance agencies to enable them to carry out their duties effectively. During the rehabilitation of major roads, the government should exercise caution and pay close attention to the process. Furthermore, in locations where there is a high concentration of pedestrians, it is recommended to promote the complete separation of vehicles and pedestrians to prevent conflicts and enhance pedestrian safety in urban areas.

A7: Intensive studies of transportation problems (expert opinion): Many urban centers in Tanzania lack a comprehensive transportation study, resulting in an incomplete understanding of traffic volumes along various urban routes. To aid city planners in future transportation planning, it is crucial to implement this strategy.

3.2 Criteria characterization

This section presents the criteria that have been found based on the literature review and the expert's point of view.

C1: Vehicular growth: The national vehicle registration department has released statistical data revealing a concerning trend in the growth rates of vehicles. Specifically, the data shows that the quantity of vehicles at the national level is not the primary issue [3]. Instead, the problem lies in the concentrated distribution of vehicles in a few select urban areas, which is contributing to a range of issues. One significant issue is the insufficient and ineffective public transport system, which has failed to meet the increasing travel demand.

C2: Parking difficulties: One of the factors contributing to traffic congestion in Tanzania is the prevalence of roadside and illegal parking, which is a common issue in the central business district. This often leaves drivers with no choice but to park on the roadside, causing the already narrow roads to become even more congested. Adding to the problem is the unsuccessful parking law, which has only worsened the situation.

C3: High rate of accidents in urban centers: The environment across the cities is particularly vulnerable to motor accidents. This is partly due to the high concentration of vehicles in these areas, which often leads to traffic mix and flow conflicts. However, a significant contributing factor is the impatience and aggressive nature of road users, which frequently results in accidents [3].

C4: Environmental and noise pollution (expert opinion): Tanzania's carbon footprint has recently increased significantly, with vehicular traffic being one of the primary sources of such pollution, which generates both noise and toxic substances, jeopardizing the urban population's health and well-being.

C5: Poor existing infrastructures (expert opinion): The road infrastructure in Tanzania faces significant challenges, as there is insufficient space for the increasing number of vehicles and pedestrians. Many main roads and intersections are congested with parked vehicles and vendors on the roadside, which limits the available space for moving vehicles. Additionally, poor road conditions further exacerbate the situation.

4 Proposed methodology

A Fermatean Fuzzy MCDM-based methodology is presented for sustainable urban transportation development. For that, in this section, after the preliminaries regarding Fermatean fuzzy sets (FFS) are given, FF-SWARA and FF-CODAS methods employing Fermatean fuzzy numbers (FFN) are expressed. Figure 1 presents the proposed methodology as a flowchart.

4.1 Preliminaries

Fermatean fuzzy sets (FFS) can be described as a novel framework for representing uncertain information under a fuzzy environment [35]. The graphical visualization regarding the interrelations between IFS, PFS, and FFS is presented in Fig. 2.

Definition 1 An FF number in fixed set X is presented as $\widetilde{F}$ in Eq. 1:

$$\widetilde{F} \cong \left\{x, \mu_{\widetilde{F}}(x), v_{\widetilde{F}}(x); x \in X\right\} \tag{1}$$

$\mu_{\widetilde{F}}(x): X \mapsto [0,1]$ and $v_{\widetilde{F}}(x): X \mapsto [0,1]$ characterize the membership and non-membership degrees of the constituent $x \in X$ to $\widetilde{F}$.

where

$$0 \le \mu_{\widetilde{F}}(x)^3 + v_{\widetilde{F}}(x)^3 \le 1 \tag{2}$$

The calculation of the hesitancy degree is as follows:

$$\pi_{\widetilde{p}}(x) = \sqrt[3]{1 - \left(\mu_{\widetilde{F}}(x)\right)^3 + \left(v_{\widetilde{F}}(x)^3\right)} \tag{3}$$

Definition 2 Multiplication by a scalar $(\lambda \ge 0)$ of an FFN $\widetilde{\alpha} = \left(\mu_{\widetilde{\alpha}}, v_{\widetilde{\alpha}}\right)$:

$$\lambda\widetilde{\alpha} = \left(\sqrt[3]{1 - \left(1 - \mu_{\widetilde{\alpha}}^3\right)^{\lambda}}, v_{\widetilde{\alpha}}^{\lambda}\right) \tag{4}$$

Definition 3: The power $(\lambda \ge 0)$ of an FF Number $\widetilde{\alpha} = \left(\mu_{\widetilde{\alpha}}, v_{\widetilde{\alpha}}\right)$.

$$\widetilde{\alpha}^{\lambda} = \left(\mu_{\widetilde{\alpha}}^{\lambda}, \sqrt[3]{1 - \left(1 - v_{\widetilde{\alpha}}^3\right)^{\lambda}}\right) \tag{5}$$

Definition 4: The score function of an FF Number $\widetilde{\alpha} = \left(\mu_{\widetilde{\alpha}}, v_{\widetilde{\alpha}}\right)$.

$$\mathrm{S}(\widetilde{\alpha}) = \mu_{\widetilde{\alpha}}^3 - v_{\widetilde{\alpha}}^3 \tag{6}$$

Definition 5: The positive score function of an FF Number $\widetilde{\alpha} = \left(\mu_{\widetilde{\alpha}}, v_{\widetilde{\alpha}}\right)$.

$$\mathrm{S}^{+}(\widetilde{\alpha}) = 1 + \mathrm{S}(\widetilde{\alpha}) = 1 + \mu_{\widetilde{\alpha}}^3 - v_{\widetilde{\alpha}}^3 \tag{7}$$

Definition 6: Summation and multiplication of two FF numbers $\widetilde{\alpha} = (\mu_{\widetilde{\alpha}}, v_{\widetilde{\alpha}})$ and $\widetilde{\beta} = (\mu_{\widetilde{\beta}}, v_{\widetilde{\beta}})$ are given:

$$\widetilde{\alpha} \oplus \widetilde{\beta} = \left(\sqrt[3]{\mu_{\widetilde{\alpha}}^3 + \mu_{\widetilde{\beta}}^3 - \mu_{\widetilde{\alpha}}^3\mu_{\widetilde{\beta}}^3}, v_{\widetilde{\alpha}}v_{\widetilde{\beta}}\right) \tag{8}$$

$$\widetilde{\alpha} \otimes \widetilde{\beta} = \left(\mu_{\widetilde{\alpha}}\mu_{\widetilde{\beta}}, \sqrt[3]{v_{\widetilde{\alpha}}^3 + v_{\widetilde{\beta}}^3 - v_{\widetilde{\alpha}}^3 v_{\widetilde{\beta}}^3}\right) \tag{9}$$

4.2 FF-SWARA method

The SWARA approach has proven to be a useful decision-making instrument in numerous fields. In this study, FF-SWARA is expressed step by step as follows [36]:

Step 1: A decision matrix is established by using the expert's point of view related to criteria using Table 3. The assessment of criterion i by expert t is $A_{it} = (\mu_{it}, v_{it})$. The conversion to FFN is done using the scale from Table 3.

Step 2: The FF decision matrix is established through the aggregation of the expert's point of view. The expert's weight (ψ_t) is considered when performing the aggregation.

$$z_i = Y(\mu_i, v_i) = \left(\prod_{t=1}^{d} (\mu_{it})^{\psi_t}, \sqrt[3]{1 - \prod_{t=1}^{d}\left(1 - (v_{it})^3\right)^{\psi_t}}\right), i = 1, \ldots, n. \tag{10}$$

where z_i-aggregated assessment for criterion i, n-criteria number.

Step 3: Computation of criterion positive score S^{+} (i) through Eq. 11.

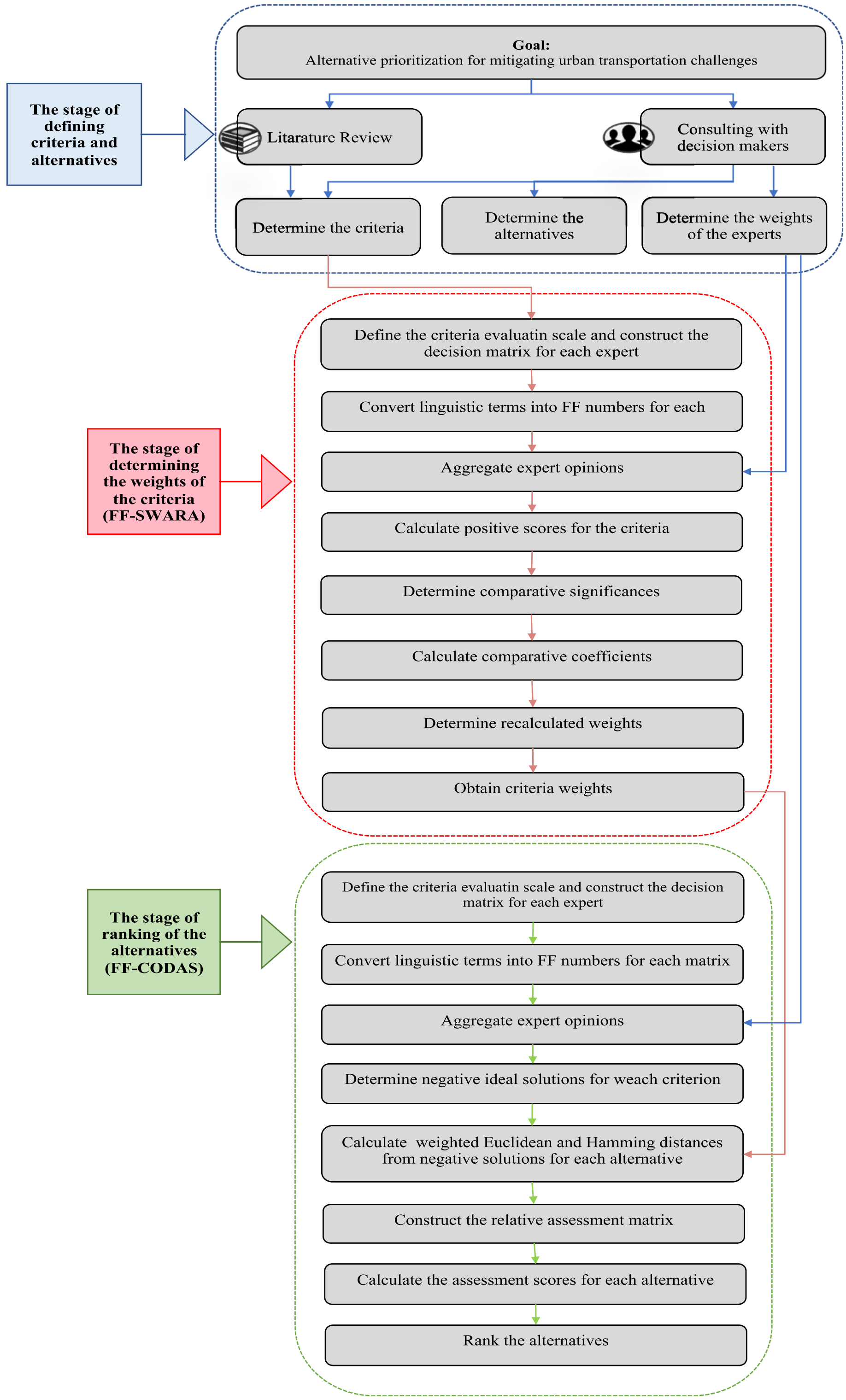
$$S^{+}(i) = 1 + \mu_i^3 - v_i^3 \tag{11}$$

Step 4: Rank criteria based on the scores of their positive values.

Step 5: Determination of comparative importance (c_i) for each criterion.

Step 6: Calculation of comparative coefficient (k_i) for each criterion

Fig. 1 Fermatean Fuzzy MCDM-based methodology flowchart



$$k_i = \begin{cases} 1, & i = 1 \\ S^{+}(i) + 1, & i > 1 \end{cases} \tag{12}$$

Step 7: Estimation of recomputed weights (q_i)

$$q_i = \begin{cases} 1, & i = 1 \\ \dfrac{q_{(i-1)}}{k_i}, & i > 1 \end{cases} \tag{13}$$

Step 8: Final criteria weights are determined by using Eq. (14):

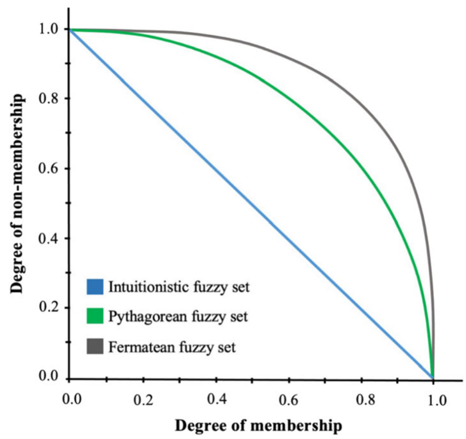


Fig. 2 Interrelations between IFS, PFS, and FFS (Simic, Gokassar, et al., 2022)

Table 3 Evaluation of criteria using linguistic terms [37]

Linguistic term	μ	v
Extremely important-E	0.975	0.10
Very important-V	0.85	0.20
Important-I	0.70	0.35
Moderately important-M	0.55	0.50
Slightly important-S	0.35	0.70
Not important-N	0.20	0.85
Extremely unimportant-U	0.10	0.975

$$w_i = \frac{q_i}{\sum_{i=1}^{n} q_i} \tag{14}$$

where n denotes the number of criteria.

4.3 FF-CODAS method

After being introduced by Keshavarz Ghorabaee, Zavadskas [20], various studies have applied this approach. In this section, FF-CODAS is expressed step by step as follows [33]:

Step 1: A decision matrix is established by using the expert's point of view related to criteria using Table 4. The assessment of alternative i regarding criterion j by expert t is $A_{ij}^t = \left(\mu_{ij}^t, v_{ij}^t\right)$. And n and m are the criteria and alternative numbers, respectively.

Step 2: Establishment of a decision matrix through the aggregation of the expert's point of view using Eq. (16).

$$Z = \begin{bmatrix} (\mu_{11}, v_{11}) & (\mu_{12}, v_{12}) & \cdots & (\mu_{1n}, v_{1n}) \\ (\mu_{21}, v_{21}) & \ddots & \ddots & (\mu_{2n}, v_{2n}) \\ \vdots & \ddots & \ddots & \vdots \\ (\mu_{m1}, v_{m1}) & \cdots & \cdots & (\mu_{mn}, v_{mn}) \end{bmatrix} \tag{15}$$

$$z_{ij} = Z\left(\mu_{ij}, v_{ij}\right) = \left(\sqrt[3]{1 - \prod_{t=1}^{d}\left(1 - \left(\mu_{ij}^t\right)^3\right)^{\psi^t}}, \prod_{t=1}^{d}\left(v_{ij}^t\right)^{\psi^t}\right) \tag{16}$$

Step 3: Determination of FF-NIS for criteria according to the decision matrix aggregated (Z). Namely, the minimum (k_j^-) values of k_{ij} are determined for each criterion by using Eq. (18).

$$k_j^- = \min_i k_{ij} \tag{17}$$

$$k_{ij} = S^+\left(z_{ij}\right) = 1 + S\left(z_{ij}\right) = 1 + \mu_{ij}^3 - v_{ij}^3 \tag{18}$$

Step 4: Computation of weighted distances from FF-NIS for each alternative:

$$E\left(S_i, k_j^-\right) = \sum_{j=1}^{n} w_j \sqrt{0.5\left[\left(\mu_{ij}^3 - \left(\mu_j^-\right)^3\right)^2 + \left(v_{ij}^3 - \left(v_j^-\right)^3\right)^2 + \left(\pi_{ij}^3 - \left(\pi_j^-\right)^3\right)^2\right]} \tag{19}$$

$$H\left(S_i, k_j^-\right) = \sum_{j=1}^{n} w_j \sqrt{0.5\left[\left|\mu_{ij}^3 - \left(\mu_j^-\right)^3\right| + \left|v_{ij}^3 - \left(v_j^-\right)^3\right| + \left|\pi_{ij}^3 - \left(\pi_j^-\right)^3\right|\right]} \tag{20}$$

Step 5: The relative assessment $P = \left[P_{ij}\right]_{n \times n}$ matrix is constructed by Eq. (21).

Table 4 Alternatives assessment using linguistic terms

Linguistic terms	FF numbers	
	μ	v
Extremely low-EL	0.1	0.9
Very low-VL	0.1	0.75
Low-L	0.25	0.6
Medium low-ML	0.4	0.5
Medium-M	0.5	0.4
Medium high-MH	0.6	0.3
High-H	0.7	0.2
Very high-VH	0.8	0.1
Extremely high-EH	0.9	0.1

$$P_{ij} = \left[E(S_i, S^-) - E(S_j, S^-)\right] + \left(\Phi\left[E(S_i, S^-) - E(S_j, S^-)\right]x\left[\mathcal{H}(S_i, S^-) - \mathcal{H}(S_j, S^-)\right]\right) \quad (21)$$

Here, Φ is a threshold function, given in Eq. (22), for the determination of the equality of the weighted Euclidean distance of two alternatives:

$$\Phi_{ij}\left(E(S_i, S^-) - E(S_j, S^-)\right) = \begin{cases} 1|\phi \geq \left|E(S_i, S^-) - E(S_j, S^-)\right| \\ 0|\phi < \left|E(S_i, S^-) - E(S_j, S^-)\right| \end{cases} \quad (22)$$

ϕ is the threshold parameter, Keshavarz Ghorabaee, Zavadskas [20] suggest setting this parameter between 0.01 and 0.05 value. In our case, the threshold parameter value is chosen as 0.2.

Step 6: Calculate the assessment scores by using Eq. (23) and rank the alternatives.

$$B_i = \sum_{j=1}^{n} P_{ij}, i = 1, \ldots, n \quad (23)$$

5 Application

In our study, five criteria characterizing the challenges to sustainable urban transportation along with the associated alternatives are explained in detail in Sect. 3. Obtaining expert judgments is a critical step in assessing decision-making issues, examining current issues, and finding absolute solutions. Experts may possess various demographic characteristics, including graduation, experience, skills, and age. However, the number of experts involved in the evaluation procedure should be carefully considered, as exceeding seven experts may lead to deviations in the general assessment results [27]. Some studies have even relied on evaluations from only three experts [5, 12, 36]. To ensure the logic and reliability of the evaluation procedure, the authors of this study call for senior executives who manage urban transport systems in the growing cities of Tanzania and experts from Dar es Salaam University involved in urban transportation to serve as members of the expert board. To identify suitable board members, the researchers established specific criteria that had to be met. These included being senior executives in the urban transport sector of rapidly growing cities in Tanzania, as well as having at least a decade of experience in urban transportation, including experience in academia. After inviting six experts who met these requirements, four of them responded affirmatively. The researchers then held personal online meetings with these four highly experienced professionals and subsequently decided to work with them as board members. Our study values all experts equally and comprises two academicians and two industry professionals, each possessing a minimum of a Master's degree and more than a decade of experience.

5.1 Application of FF-SWARA for the criteria weights

At first, the opinions of the experts are collected and translated into a decision matrix using scales from Table 3. To accomplish this, the criteria are assessed by experts using their experience and knowledge. The compilation of their assessment is presented in Table 5.

FFN is obtained through the conversion of linguistic terms. Experts' evaluations have been aggregated by Eq. 18 as shown in Table 6.

Score values of the criteria have been calculated by Eq. 19 using aggregated criteria evaluations given in Table 7. The classification of criteria is done based on the values they scored. The criteria' weights are found and shown in Table 7 using other steps of FF-SWARA.

In Table 7, it was revealed that the foremost challenge in Tanzania's urban areas is environmental and noise pollution, which experts considered to be of great concern. The second to fifth positions were held by vehicular growth, parking difficulties, poor existing infrastructure, and a high rate of accidents, respectively.

5.2 Application of FF-CODAS for ranking strategies

The assessment of alternatives is made based on the weights of the criteria. As shown in Table 8, the decision matrix is established in step 1 to evaluate options based on linguistic terms.

After the decision matrix is established, the computation of the weighted matrix is made. The identification of NIS for the criteria is first done, and using Definition 13, the computation of distances between NIS and each location is made. Both distances are indicated in Table 9.

Table 5 Criteria evaluations by each expert

Main criteria	E1	E2	E3	E4
C1	I	I	I	I
C2	I	I	I	M
C3	S	M	M	I
C4	V	V	V	E
C5	S	V	V	E

Table 6 Aggregated criteria evaluations

Main criteria	μ	ν
C1	0.771	0.350
C2	0.726	0.400
C3	0.619	0.551
C4	0.918	0.184
C5	0.735	0.470

Table 9 Distances from ideal solutions

	A1	A2	A3	A4	A5	A6	A7
Euclidean	0.378	0.148	0.216	0.086	0.431	0.185	0.277
Hamming	0.648	0.327	0.426	0.217	0.676	0.437	0.533

Table 7 Results of the FF-SWARA application

Main criteria	Scores	c_j	k_j	q_j	Weights
C4	1.766		1	1	0.277
C1	1.416	0.351	1.351	0.740	0.205
C2	1.319	0.097	1.097	0.675	0.187
C5	1.294	0.025	1.025	0.658	0.182
C3	1.070	0.224	1.224	0.538	0.149

Table 9 is then used to generate the relative matrix which is indicated in Table 10. The threshold number (ϕ) is equal to 0.2 at this stage.

Then, Eq. (23) is used to calculate the final assessment scores. At last, the most appropriate alternative is found to be the one that has the location with the greatest value, as indicated in Fig. 3.

As presented in Fig. 3, the most appropriate strategy for a sustainable urban transportation development is "*restricted car use- (A5)*" with a final score of 2,441, whereas the least appropriate strategy is "*distribution of the traffic lights at main intersections across the cities -(A4)*" with a final score of -1.822. The rank of other alternatives is as A1 > A7 > A3 > A6 > A2.

6 Sensitivity

A sensitivity analysis was conducted to exhibit the effectiveness of our methodology. To demonstrate the resilience of the alternative selection decision, the threshold number (ϕ) was increased by 0.1 from 0 to 0.5 until the results no longer changed. The results of the proposed methodology were then discussed based on the sensitivity analysis. By increasing the threshold number and observing the results, the analysis showed the resilience of the alternative selection decision. The eventual results of alternatives based on this analysis are presented in Fig. 4 and Table 11.

The sensitivity analysis conducted on the proposed methodology has shown that altering the value of the threshold number can have an impact on the final results, as anticipated. This is likely because the alternatives have varying values for both Euclidean and Hamming distances. Despite the changes in the final scores of the alternatives, their rankings remain constant. The sensitivity analysis of the suggested approach has revealed that the optimal

Table 8 Alternative evaluation matrix

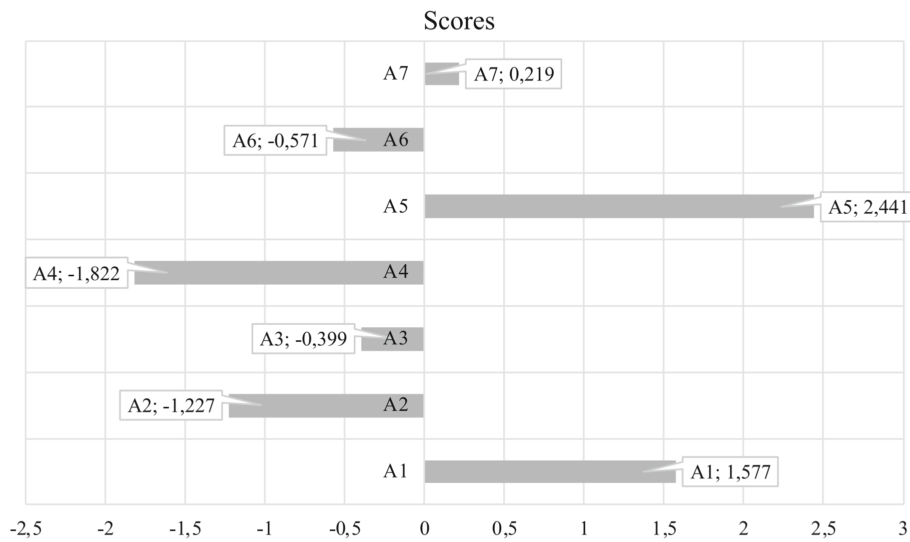
Experts	Alternatives	Criteria										Experts
		C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	
E1	A1	H	MH	MH	MH	M	VH	VH	H	H	VH	E3
	A2	L	M	H	M	H	EL	ML	MH	VL	VH	
	A3	ML	VH	H	MH	VH	L	VH	MH	L	EL	
	A4	L	L	H	L	ML	L	L	VH	EL	EL	
	A5	VH	VH	VH	VH	L	VH	VH	VH	EH	L	
	A6	L	M	VH	L	VH	L	M	H	L	VH	
	A7	M	VH	VH	MH	M	MH	MH	H	MH	H	
	A1	H	VH	VH	H	H	EH	EH	EH	EH	EH	E4
	A2	VL	VH	H	ML	EH	L	M	VH	L	VH	
	A3	M	EH	MH	L	EL	ML	EH	MH	L	ML	
E2	A4	ML	VL	H	EL	EL	M	ML	VH	M	M	
	A5	EH	EH	EH	VH	L	EH	EH	EH	VH	M	
	A6	L	M	VH	VL	VH	L	ML	VH	MH	VH	
	A7	MH	EH	VH	M	H	M	ML	EH	M	H	

E-expert

Table 10 Relative assessment matrix

	A1	A2	A3	A4	A5	A6	A7
A1	0	0.551	0.162	0.724	− 0.053	0.193	0.101
A2	− 0.551	0	− 0.068	0.062	− 0.633	− 0.037	− 0.129
A3	− 0.162	0.068	0	0.130	− 0.465	0.030	− 0.061
A4	− 0.724	− 0.062	− 0.130	0	− 0.805	− 0.100	− 0.192
A5	0.053	0.633	0.465	0.805	0	0.485	0.154
A6	− 0.193	0.037	− 0.030	0.100	− 0.485	0	− 0.092
A7	− 0.101	0.129	0.061	0.192	− 0.154	0.092	0

Fig. 3 Final scores of alternatives



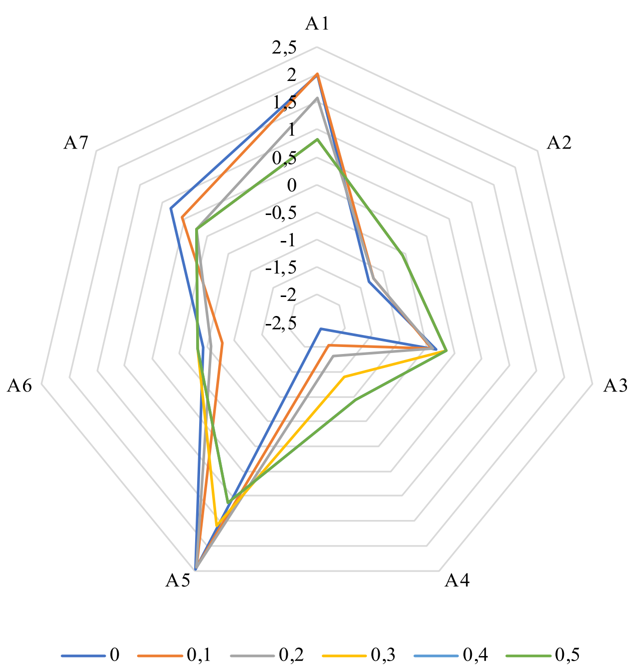


Fig. 4 The visualization of the results concerning different ϕ values

alternative option remains consistent, regardless of variations in the threshold number value. Specifically, A5 consistently emerges as the top choice, followed by A1 and A7, which always rank among the top three alternatives.

Table 11 Results of sensitivity analysis

∅	0	0.1	0.2	0.3	0.4	0.5
A1	1.981	2.009	1.577	0.825	0.825	0.825
A2	− 1.326	− 1.227	− 1.227	− 0.556	− 0.556	− 0.556
A3	− 0.323	− 0.411	− 0.399	− 0.149	− 0.149	− 0.149
A4	− 2.362	− 2.031	− 1.822	− 1.391	− 0.931	− 0.931
A5	2.470	2.441	2.441	1.602	1.143	1.143
A6	− 0.439	− 0.781	− 0.571	− 0.332	− 0.332	− 0.332
A7	0.805	0.563	0.219	0.219	0.219	0.219

7 Discussion

In this section, the study's main findings are disclosed, accompanied by their corresponding theoretical, managerial, and policy-based implications.

7.1 Findings

After examining the literature and gathering opinions from experts, it has become apparent that numerous challenges have hindered the transportation system across Tanzanian cities. From this analysis, five potential challenges have been identified that may contribute to the unsustainable development of urban transportation. The FF-SWARA methodology was utilized in this study to determine the weights of the criteria. According to the results, the most critical challenge identified by the experts was environmental and noise pollution, with a weight of 0.2324, while the high rate of accidents in the urban areas received the least attention, with a weight of 0.1753. The experts' prioritization of environmental and noise pollution aligns with previous research by Farooqi, Sabir [38], which highlighted its detrimental impact on the quality of life worldwide, with noise pollution levels reaching alarming levels due to the rapid expansion of urban transport systems. Furthermore, vehicular growth is the second most critical challenge in Tanzania's urban areas after environmental and noise pollution. This finding aligns with the research conducted by Kinyaga [39], which indicated a 15 percent increase in vehicle growth rates in 2016, particularly in the capital city. Over the last two decades, the capital city experienced a growth rate of 8% in terms of vehicles, while other urban areas have only grown at a rate of 2%. Approximately 1.5 million vehicles are estimated to exist at the national level, with the majority of them being located in urban areas [39]. As a result, there is a necessity to explore alternative modes of transportation, such as electric bike-sharing services or electric vehicles, to decrease the current vehicular growth and curb the severity of pollution caused by old and reconditioned vehicles in Tanzania. Furthermore, providing high-quality public transportation services that are accessible to all could encourage people to opt for buses or trains over personal vehicles. Discouraging the use of personal cars by increasing their cost, decreasing their convenience, or making them slower could also be effective in reducing car use.

The findings of the FF-SWARA-CODAS framework suggest that restricting car use (A5) is the most appropriate strategy for achieving sustainable urban transportation development in Tanzania. To accomplish this, it is recommended to implement national transport policies that limit personal vehicle usage. One effective policy recommended by the framework is the implementation of a vehicle quota system, which can manage car ownership levels by controlling the number of new cars purchased. Actions targeted at reducing road congestion can also have an impact on car ownership, as they make it less appealing for people to own and use cars in congested areas. Additionally, the implementation of parking policies can serve as an effective method to promote sustainable urban mobilities. Parking policies are implemented globally and can aid in addressing adverse effects like traffic congestion, pollutants, and environmental change. The second most appropriate strategy for dealing with urban transportation challenges is to enhance sector coordination (A1). This entails creating authority with the power and mandate to coordinate urban transport systems. To keep stakeholders informed, the authority's function and form must be well-defined, specifying whether it will control road and traffic infrastructures, how it will be financed, and how it will interact with other sectors with responsibilities in this area. Given the country's diverse geography, multiple authorities may be required to effectively address the issues facing urban transportation. The establishment of these authorities should be expedited to make progress swiftly. While stakeholders agree that an authority coordinating urban transport systems is essential to overcoming transportation challenges, the speed of its establishment is vital. As a result, it is critical to make a consensus among stakeholders and create a platform for development. Urban transportation problems in Tanzania lack comprehensive studies, and thus, an intensive investigation (A7) is the third most appropriate strategy. Insufficient awareness about the flow of traffic in urban areas highlights the necessity of obtaining longitudinal data on various aspects of urban transportation. These data can support city planners in their future transport planning efforts. Monitoring the traffic flow on major roads regularly is imperative to avoid surpassing the predetermined capacity limits. To enhance transportation on a national scale, it is recommended to incorporate established "Best Practices". These encompass the implementation of clean fuels, improvement of public transportation, reinforcement of traffic laws, adjustment of current infrastructure, and construction of new infrastructure. In addition, addressing the challenges associated with urban transportation necessitates the promotion of motorless means of transportation, the incorporation of transportation and land use systems, an increase in user education, and regular monitoring of transportation issues by stakeholders and planners.

7.2 Theoretical contributions

This study presents a new integrated mathematical model that aims to identify challenges to sustainable urban transportation. The proposed model extends the SWARA method by incorporating the Fermatean fuzzy environment and utilizes the FF-CODAS approach to rank potential strategies. By merging the strengths of SWARA and CODAS and enhancing the model with FFS, the proposed method is capable of addressing complex uncertainties and solving difficult decision-making issues in diverse areas. Moreover, our methodology demonstrates robustness and effectiveness in addressing complex problems. The study also provides the following theoretical contributions.

- With the integration of Fermatean fuzzy number sets (FFNS), the proposed model has been fortified to effectively capture and process intricate uncertainties. As a result, the Fermatean fuzzy number (FFN) model can be implemented by decision-makers and practitioners to effectively address complicated decision-making challenges that are prevalent across diverse industries, not just limited to urban transportation.
- The FF-SWARA model is a mathematical framework that extends the SWARA method based on FFNS and facilitates the identification of decision-making criteria. This model allows for the use of a mathematical tool to determine the factors that influence the decision-making process, thereby minimizing the impact of subjective and intuition-based evaluations by experts.
- The study proposes FF-SWARA-CODAS as a dependable decision-making model to prioritize solutions for urban transportation issues. The model's resilience was confirmed through a thorough sensitivity analysis in the preceding section, attesting to its consistency and stability in the face of significant modifications. Consequently, the model provides decision-makers with dependable and precise results.

7.3 Managerial implications

The following managerial implications can be derived from the findings of this study.

- Planners can evaluate current urban transportation systems by taking into account the results and conclusions presented in this study. The study provides practical implications regarding the relative importance and impact of strategies that can be implemented to promote sustainable urban transportation development. It can also help identify which strategies are suitable for financial aid.
- Beneficial perspectives are presented for individuals who are in charge of Tanzania's urban transportation. By using these perspectives to re-examine the design and planning of their cities, as well as to re-coordinate transportation systems and reduce reliance on cars, decision-makers can make progress toward sustainable development. Practitioners can also benefit from the paper's implications, which provide practical guidance for implementing effective strategies in urban transportation.

7.4 Policy implications

The paper endeavors to address significant gaps in the literature by first evaluating available strategies for the sustainable development of urban transportation and presenting the most appropriate strategies. It aims to provide a useful guide for city planners and practitioners to develop optimal techniques for enhancing transportation systems. The second issue addressed in the paper is the absence of a commonly accepted set of criteria for evaluating strategies to implement sustainable urban transportation systems. This problem is exacerbated by the lack of literature on alternative prioritization for mitigating urban transportation challenges in Tanzania. To address this issue, the study combines two classical approaches: identifying criteria used in previous studies through literature review and collecting experts' opinions about influential factors. By providing a comprehensive set of criteria, the study aims to assist policymakers and city officials in selecting appropriate strategies for sustainable urban transportation development at the city or national level. The third key point in the paper is that the proposed approach offers a way to reduce the impact of subjective opinions from experts and allows for the identification of influential challenges through a mathematical model. This approach prioritizes empirical evidence over personal biases, helping decision-makers make informed decisions that are based on objective data.

8 Conclusion

This study examines various approaches for tackling urban transportation issues in Tanzania and their potential to promote sustainable development. Notably, there is a significant research gap in this area, as no previous studies have investigated this research question. To bridge this gap, the study proposes FF-SWARA-CODAS, a practical decision-making tool that streamlines complex decision-making processes. The weights of criteria and ranking of alternatives are found based on FF-SWARA and FF-CODAS methods in a Fermatean fuzzy environment, respectively. It has been revealed that environmental and noise pollution and vehicular growth are the top two critical challenges. Meanwhile, limiting car use, improving sector coordination, and conducting extensive research on transportation issues are the top three strategies for promoting sustainable urban transportation.

The study has two significant contributions that can be viewed from various perspectives. Firstly, it provides a framework for sustainable urban transportation development in Tanzania. This framework outlines appropriate strategies to be implemented rationally and systematically, making it a professional contribution. Secondly, the study makes a scientific contribution by utilizing integrated SWARA and CODAS methods in a Fermatean fuzzy environment to achieve sustainable development of urban transportation in Tanzania. This approach has not been previously explored in the literature.

Although the study made valuable contributions, it is important to acknowledge its limitations. Firstly, our methodology is not compared to other existing fuzzy-based multi-criteria procedures for addressing the issue at hand. This creates a significant opportunity for future research. Another limitation is that the study did not consider the criteria under the three sustainability dimensions. To obtain a more holistic understanding of the criteria (challenges), future research could examine the issue from a multidimensional perspective, which could help in identifying key areas that require more attention. Moreover, the study's findings may not be generalizable to other African countries due to the varying conditions and circumstances in each country. Therefore, it is crucial to replicate the research framework used in this study in other African countries and compare the results obtained. Lastly, the data collection process involved only a limited number of experts, and this could have affected the generalizability of the findings. Therefore, future research should involve more experts and the consideration of the risk attitudes of experts. Furthermore, future studies could examine how the models/approaches studied are affected by noisy/sparse data [40, 41].

Author Contributions MBB contributed to conceptualization, project administration, formal analysis, visualization, writing—original draft, and writing—review and editing; EA involved in methodology, software, formal analysis, visualization, writing—original draft, and writing—review and editing; GO involved in methodology, software, formal analysis, visualization, writing—original draft, and writing—review and editing; NAT involved in visualization and writing—review and editing; ZS involved in visualization and writing—review and editing.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Data availability The data are available upon request to the first author and corresponding author (*).

Declarations

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

References

1. Drakakis-Smith D (2003) Third World Cities: Introduction to Development Series. Routledge, New York
2. Bank W. (2002) Cities on the move: A World Bank urban transport strategy review: The World Bank.
3. Msigwa RE (2013) Challenges facing urban transportation in Tanzania. Math Theory Model 3:18–26
4. Mrema G. (2011) Traffic congestion in Tanzanian major cities: causes, impact and suggested mitigations to the problem. In: Proceedings of 26th National conference on challenges in addressing traffic congestion and enhancing road safety for national development, Arusha, Tanzania.
5. Bouraima MB, Tengecha NA, Stević Ž, Simić V, Qiu Y. (2023) An integrated fuzzy MCDM model for prioritizing strategies for successful implementation and operation of the bus rapid transit system. Annals of Operations Research.
6. Bouraima MB, Saha A, Stević Ž, Antucheviciene J, Qiu Y, Marton P (2023) Assessment actions for improving railway sector performance using intuitionistic fuzzy-rough Multi-Criteria Decision-Making model. Appl Soft Comput 148:110900
7. Bouraima MB, Qiu Y, Stević Ž, Simić V (2023) Assessment of alternative railway systems for sustainable transportation using an integrated IRN SWARA and IRN CoCoSo model. Socioecon Plann Sci 86:101475
8. Moslem S (2024) A novel parsimonious spherical fuzzy analytic hierarchy process for sustainable urban transport solutions. Eng Appl Artif Intell 128:107447
9. Ayyildiz E, Taskin GA (2021) A novel distance learning ergonomics checklist and risk evaluation methodology: a case of Covid-19 pandemic. Human Factors Ergon Manuf Serv Indust 31:397–411
10. Bouraima MB, Qiu Y, Ayyildiz E, Yildiz A (2023) Prioritization of strategies for a sustainable regional transportation infrastructure by hybrid spherical fuzzy group decision-making approach. Neural Comput Appl 35:1–20
11. Bouraima MB, Gore A, Ayyildiz E, Yalcin S, Badi I, Kiptum CK et al (2023) Assessing of causes of accidents based on a novel integrated interval-valued Fermatean fuzzy methodology: towards a sustainable construction site. Neural Comput Appl 35(29):21725–21750
12. Bouraima MB, Qiu Y, Stević Ž, Marinković D, Deveci M (2023) Integrated intelligent decision support model for ranking regional transport infrastructure programmes based on performance assessment. Expert Syst Appl 222:119852
13. Bouraima MB, Ayyıldız E, Badi I, Özçelik G, Yeni FB, Pamucar D (2024) An integrated intelligent decision support framework for the development of photovoltaic solar power. Eng Appl Artif Intell 127:107253
14. Bouraima MB, Oyaro J, Ayyildiz E, Erdogan M, Maraka NK. An integrated decision support model for effective institutional

coordination framework in planning for public transportation. Soft Computing. 2023.
15. Pamucar D, Deveci M, Gokasar I, Tavana M, Koppen M (2022) A metaverse assessment model for sustainable transportation using ordinal priority approach and Aczel-Alsina norms. Technol Forecasting Social Change. 182:121778
16. Ayyildiz E, Yildiz A, Taskin Gumus A, Ozkan C (2021) An integrated methodology using extended swara and dea for the performance analysis of wastewater treatment plants: Turkey case. Environ Manage 67:449–467
17. Kavus BY, Tas PG, Ayyildiz E, Taskin A (2022) A three-level framework to evaluate airline service quality based on interval valued neutrosophic AHP considering the new dimensions. J Air Transp Manag 99:102179
18. Senapati T, Yager RR (2019) Fermatean fuzzy weighted averaging/geometric operators and its application in multi-criteria decision-making methods. Eng Appl Artif Intell 85:112–121
19. Keršuliene V, Zavadskas EK, Turskis Z (2010) Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA). J Bus Econ Manag 11:243–258
20. Keshavarz Ghorabaee M, Zavadskas EK, Turskis Z, Antucheviciene J (2016) A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. Econom Comput Econom Cybernet Stud Res 50:25–44
21. Anin E, Annan J, Alexander O (2013) Assessing the causes of urban transportation challenges in the Kumasi Metropolis of Ghana. Am Res J 2:1–12
22. Kant G, Quak H, Peeters R, van Woensel T. (2016) Urban freight transportation: challenges, failures and successes: Springer.
23. Ogunbodede E (2008) Urban road transportation in Nigeria from 1960 To 2006: problems, prospects and challenges. Ethiopian J Environ Stud Manag 1:7–18
24. Schünemann J, Finke S, Severengiz S, Schelte N, Gandhi S (2022) Life cycle assessment on electric cargo bikes for the use-case of urban freight transportation in Ghana. Procedia CIRP 105:721–726
25. Solanke M (2013) Challenges of urban transportation in Nigeria. Int J Dev Sci 2:891–901
26. Thomas DP. Public transportation in South Africa: Challenges and opportunities. World. 2016;3.
27. Ecer F, Küçükönder H, Kayapınar Kaya S, Faruk GÖ (2023) Sustainability performance analysis of micro-mobility solutions in urban transportation with a novel IVFNN-Delphi-LOPCOW-CoCoSo framework. Transp Res Part A: Policy Pract 172:103667
28. Donais FM, Abi-Zeid I, Waygood EOD, Lavoie R (2019) Assessing and ranking the potential of a street to be redesigned as a Complete Street: a multi-criteria decision aiding approach. Transp Res Part A: Policy and Pract 124:1–19
29. Romero-Ania A, Rivero Gutiérrez L, De Vicente Oliva MA (2021) Multiple criteria decision analysis of sustainable urban public transport systems. Mathematics 9:1844
30. Büyüközkan G, Feyzioğlu O, Göçer F (2018) Selection of sustainable urban transportation alternatives using an integrated intuitionistic fuzzy Choquet integral approach. Transp Res Part D: Transp Environ 58:186–207
31. Hajduk S (2021) Multi-criteria analysis in the decision-making approach for the linear ordering of urban transport based on TOPSIS technique. Energies 15:274
32. Deveci M (2022) A decision support system for assessing and prioritizing sustainable urban transportation in metaverse. IEEE Trans Fuzzy Syst 11(8):397
33. Simic V, Gokasar I, Deveci M, Švadlenka L (2022) Mitigating Climate change effects of urban transportation using a type-2 neutrosophic MEREC-MARCOS model. IEEE Trans Eng Manag 71:3233–3249
34. Görçün ÖF (2021) Evaluation of the selection of proper metro and tram vehicle for urban transportation by using a novel integrated MCDM approach. Sci Prog 104:0036850420950120
35. Garg H, Shahzadi G, Akram M (2020) Decision-making analysis based on Fermatean fuzzy Yager aggregation operators with application in COVID-19 testing facility. Math Probl Eng 2020:1–16
36. Ayyildiz E (2022) Fermatean fuzzy step-wise Weight Assessment Ratio Analysis (SWARA) and its application to prioritizing indicators to achieve sustainable development goal-7. Renew Energy 193:136–148
37. Simic V, Karagoz S, Deveci M, Aydin N (2021) Picture fuzzy extension of the CODAS method for multi-criteria vehicle shredding facility location. Expert Syst Appl 175:114644
38. Farooqi ZUR, Sabir M, Zeeshan N, Murtaza G, Hussain MM, Ghani MU. Vehicular noise pollution: its environmental implications and strategic control. Autonomous Vehicle and Smart Traffic: IntechOpen; 2020.
39. Kinyaga B (2021) Chaos and disruptions as the challenge to urban transportation in Tanzania. J Traffic Transp Eng 9:73–80
40. Poulinakis K, Drikakis D, Kokkinakis IW, Spottswood SM (2023) Machine-learning methods on noisy and sparse data. Mathematics 11(1):236
41. Christakis N, Drikakis D (2023) Reducing uncertainty and increasing confidence in unsupervised learning. Mathematics 11(14):3063