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A Hybrid Fuzzy MCDM Approach for Identifying and Prioritizing Barriers to Smart City Development

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Abstract: Significant changes in our lifestyles prompt us to consider building more intelligent and sustainable cities. In both systematic research and international policy, the development of smart cities has gained popularity. Through a review of the literature and consultation with subject-matter experts, the study aims to identify the primary obstacles to achieving smart cities. Additionally, this study aimed to prioritize the challenges to the development of smart cities in the Western Balkans by identifying the most significant obstacle category and ranking specific issues within each category. The Fourth Industrial Revolution and digitization serve as the cornerstones for all planned initiatives in urban environment management, encompassing its various sectors and infrastructure. Fuzzy logic techniques, such as the triangular and trapezoidal fuzzy analytic hierarchy process (FAHP) and triangular and trapezoidal interval type-2 fuzzy sets (IT2FS), have been employed in multi-criteria decision-making (MCDM) to identify important indicators relevant to the development of a smart city. Six categories of criteria and a large number of sub-criteria have been used to determine the key indicators, which include the development of a legislative and strategic framework for the Smart City platform, its implementation in the post-COVID-19 era, and the standardization of ICT and ICT management. The findings identify key obstacles and strategic priorities that can inform the shift to smarter and more sustainable urban environments, providing policymakers and urban planners with valuable insights.

Keywords: Smart city, Fuzzy Analytic Hierarchy Process (FAHP), Interval Type-2 Fuzzy Sets (IT2FS), Multi-Criteria Decision Making (MCDM), algorithm ranking, descriptive statistics

1 INTRODUCTION

The events of recent years have caused changes in all aspects of modern human life [1]. Smart city development has garnered significant attention in global policy and systematic studies over the last 20 years [2,3]. This study defines a smart city as a contemporary, technologically advanced region with a certain degree of intelligence that utilizes smart computing techniques to enhance infrastructure components and services while addressing various social, technical, and economic aspects of development [4-6].

Cities are more often mentioned unfavourably than rural areas, even though they are the centers of culture, education, and research. Their prominence in the public eye is primarily due to the problems associated with urban environments, such as their status as the largest energy consumers and environmental polluters [7]. The growing expectations of modern man for comfort, a high standard of living, and financial stability play a fundamental role in the concentration of people in cities. Among the issues that metropolitan regions face are the effects of the ongoing urbanization process, disregard for environmental preservation, and irrational resource usage, some of which jeopardize ecological quality [8]. Strict lifestyle changes have compelled us to devise innovative ways to create a more resilient society that can withstand the rapid environmental changes. Qualitative management based on sustainable strategies, accountability, transparency, public participation, carbon reduction, energy efficiency, waste management, and mobility is essential to ensuring sustainable progress [9]. One step in that direction is the Smart City concept. As one of the non-exclusive layers in contemporary social policy conduction, circular economy, and urban development, smart cities are a topic of interest to both scientific academics and modern society. The Fourth Industrial Revolution and digitization are necessary for all planned actions in managing urban environments, their sectors, and infrastructure. Due to the need for solutions that improve infrastructure systems, streamline daily tasks, and speed up the monitoring of urban operations, information and communication technologies (ICT) are emerging as a crucial tool in the development of future technical patents and smart grids. The globe has become a global marketplace where countries compete with each other in terms of human capital, technological developments, sustainable product innovation, and strong enterprises. The Smart City model varies from country to country due to several political, social, and economic factors. Even though developed nations take pride in inventions that utilize sensors and artificial intelligence, require almost no manual human control, and extensively use available resources, many developing countries still lack strategies that accurately implement the Smart City concept in future urban development [10,11].

Our aspirations for creating sustainable living spaces and our thoughts on sustainable future development have evolved as a result of the pandemic.

This study examines the potential applications of artificial intelligence in the development of smart cities. It provides a theoretical overview of the most recent scientific findings on creating and utilizing the Smart City concept, promoting a discussion about potential challenges. Using multi-criteria analysis, the study aims to identify key indicators as essential preconditions for the development of smart cities. We decided to use triangular FAHP, triangular IT2FS, trapezoidal FAHP, and trapezoidal IT2FS as fuzzy logic techniques because of the problem's multidimensionality and complexity.

The barriers were identified through a review of the literature and consultation with experts. Prioritizing these obstacles is a decision-making task that involves multiple criteria and sub-criteria.

The remaining sections of the paper are structured as follows: Section 2 presents the related literature on smart cities and highlights the barriers to smart city development. Section 3 discusses the solution methodology along with the research framework. Section 4 illustrates the data analysis and results. Section 5 provides conclusions.

2 LITERATURE REVIEW

This section highlights the obstacles to the development of smart cities and provides examples of relevant literature.

2.1 From Conceptualization to Implementation of Smart Cities

The idea of a "smart city" was first proposed in the 1990s to emphasize the implications of information and communication technology for enhanced infrastructure and network upgrades. The extensive use of information technologies has enabled cities to provide vital services for governance, delivery, safety, and health [12,13].

The California Institute for Smart Communities investigated how to turn a city into a smart city and the degree of information technology used in smart cities to help policymakers design smart city networks [14,15].

The Smart City movement was initially raised in relation to "growing cities in a smart way" and advocating for the "compact city" model to avoid the agglomeration of metropolitan areas and foster environmental consciousness [16]. Technological advancements have stretched the frontiers of a smart, sustainable ecosystem. Using creative solutions has emerged as a useful method for gathering data that can reveal contemporary urban issues. The city, from which sustainability must be formed, was associated with the term "smart" as early as 1994 [17]. Since the EU began leveraging the "smart" label in 2010 to qualify sustainable urban development projects, the idea has expanded [18].

The European Commission launched plans for smart cities in 2010 as a significant and logical initiative. These plans support four aspects of cities: construction, power, heating and cooling systems, and transportation [19].

Smart devices, apps, roads, phones, lighting, and buildings are just a few of the many facets of contemporary life that are increasingly being incorporated into the term "smart." Traditional public institutions, such as libraries, are becoming less important as more people utilize the Internet [20]. At the same time, sensors in mobile phones provide users with data on weather, traffic, parking, and public transportation, facilitating informed movement in urban environments [21].

The European Commission has also supported proposals for "smart cities" to increase community energy efficiency and green transportation [22]. In [23], six essential components for a smart city were proposed. These include economics, mobility, environment, people, living, and governance.

According to the Pan-European research project Intel Cities (2009) [24], the development of smart cities depends on efficient governance. According to an analysis of various definitions and practices of smart cities worldwide, the majority of smart cities heavily rely on mobile infrastructure and services. Given Serbia's growing urban population and rising service quality, scholars and decision-makers must have a solid grasp of smart cities and the associated challenges.

Utilizing state-of-the-art technologies to create more sustainable urban environments is one of a smart city's primary duties. The term "smart city" is interpreted differently in the literature; it no longer refers to entities that are entirely reliant on contemporary technologies but rather to a type of sustainable city with a well-defined planning strategy, excellent management, effective citizen-government communication, and an "intelligent" approach to resilience and self-improvement [25]. Generally accepted [26], "the city can be considered smart" "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources through participatory governance."

Several writers and researchers define a smart city as:

- a worldwide movement that emerged concurrently with the Fourth Industrial Revolution and was mostly represented in the scientific domain of spatial planning and urbanism [27];
- a city, usually of medium size (100-500k inhabitants) [22], created by various actors: government, public-private partnership, investors, IT and other types of companies, scientists, but also the citizens themselves;
- a sustainable system that enhances the quality of life in the areas of infrastructure management, transportation, energy, urban water, and building [28];
- a product of the Internet of Things (IoT) platform, which enhances current urban environments through the use of big data, artificial intelligence platforms, sensors, and applications [30];
- a livable urban environment resistant to changes [10].

The following categories can be used to organize technological advancements in the creation of a Smart City across several facets of daily life [30,31],

2.2 Barriers of smart cities development

Based on earlier research, this study identified 35 major barriers to the development of smart cities. With experts' consultation, it categorised these barriers into six key categories. The various categories and associated barriers are represented in Table 2.

Table 1 Identifying indicators of barriers in the development of smart cities

Barriers indicators	*Barriers sub-indicators*
Governance (G) encompasses the institutional and managerial aspects of smart city development, including the legislative framework, inter-sector coordination, and decision-making transparency. This category is essential for identifying obstacles that may impede the effective implementation and long-term sustainability of Smart City initiatives..	Lack of a legislative and strategic framework of platform and cooperation and coordination between the city's operational networks (G_1) Unclear ICT management vision, the need for standardization of ICT management (G_2) Political instability (G_3) Lack of trust between the governed and government, Poor private-public participation (G_4)
Economic (E) encompasses the financial and economic factors of smart city development, including funding, cost-effectiveness, and resource allocation. This category is important for identifying obstacles that could limit the implementation and sustainability of Smart City initiatives..	Insufficient development entrepreneurship and innovation (E_1) Lack of adequate ICT sector development and job opportunities within it (E_2) Higher funding for design and implementation of local and national smart solutions and initiatives (E_3) Higher commercialization of innovative technologies assessment (E_4) Higher technology competition on the national and international market (E_5) Higher external funding for the Smart City platforms (E_6) Lack of competitiveness (E_7) Higher operational and maintenance costs (E_8)
Liveability (L), which includes social inclusivity, safety, environmental quality, and service accessibility, refers to the standard of living and overall well-being of residents in a smart city. This field is essential for identifying obstacles that can compromise the general comfort, well-being, and living conditions of urban dwellers.	Greater personal security (L_1) More affordable housing (L_2) Accessible utilities, resource availability and infrastructure equipment (L_3) Job opportunities for all (L_4); Improvement of health, education, tourism and culture sectors (L_5) Geographical diversification problems (L_6) Social integration (L_7)
Citizens (C) focuses on the needs, involvement, and engagement of citizens in the creation of smart cities, including responsiveness to citizen feedback, public involvement, and digital literacy. This category is crucial for identifying potential obstacles to active citizen participation and the successful co-creation of Smart City projects.	A greater degree of community awareness (C_1) A high level of education and qualification (C_2) A readiness to try new things (C_3) Demonstrated flexibility, creativity, and public confidence in modern solutions (C_4) Greater civic engagement (C_5) Increased awareness of ethnic and social diversity (C_6)
Mobility (M) focuses on transportation and movement within smart cities, including public transit, traffic management, and sustainable mobility. This category is important for identifying obstacles that may hinder efficient, safe, and eco-friendly urban mobility.	Insufficiently integrated ICT infrastructure (M_1), Innovative transport scheme that prioritizes non-motorized vehicles (M_2), Domestic and international accessibility (M_3)
Surroundings (Environment) (S) encompasses the environmental and spatial aspects of smart city development, including air quality, green spaces, waste management, and sustainable urban planning. This category is essential for identifying obstacles that may affect environmental sustainability and the overall quality of urban living.	More consideration of sustainability (S_1) Monitoring quality and protecting the environment continuously (S_2) Recycling in urban areas (S_3) Higher renewable energy source utilization (S_4) Construction of energy-efficient and smart facilities (S_5) Not enough the reduction in energy usage linked to the development of new technologies (S_6) Not enough natural resource protection and management (S_7)

3 METHODOLOGICAL FRAMEWORK

This exploratory study aims to establish a solid theoretical foundation for understanding the development of smart cities. To achieve this goal, the Analytic Hierarchy Process (AHP) is used to assign numerical priorities to each variable. However, there are several well-known drawbacks to the traditional AHP technique. The potential for rank reversals—where priority rankings shift when criteria or alternatives are altered—is one of the primary problems. Furthermore, AHP makes the frequently impractical assumption that every component is mutually independent in complex socio-technical systems, such as smart cities. In pairwise comparisons, the method is vulnerable to human bias because it depends on the subjective opinions of experts.

Furthermore, the consistency and dependability of the results may be impacted by the lack of a systematic method for gauging decision-makers' agreement. To address these shortcomings, this research employs triangular and trapezoidal Fuzzy Analytic Hierarchy Process (FAHP) and their interval type-2 fuzzy extensions (IT2FS-FAHP).

3.1 Triangular and trapezoidal fuzzy numbers and analysis

In addition to the precise numbers used in the AHP method [32–34], this study uses triangular and trapezoidal phase numbers [35, 36]. Building on previous applications of advanced phase AHP methods [37].

A unique fuzzy set $F = \{(x, \mu_F(x)), x \in \mathbb{R}\}$, is a fuzzy number, and $\mu_F(x)$: $\mathbb{R} \rightarrow [0, 1]$ is a continuous function.

$\tilde{T} = (l, m, u)$ is the notation for the triangular fuzzy number (TFN), and its membership function is:

$$\mu_F(x) = \begin{cases} \frac{x-l}{m-l}, & x \in (l, m) \\ \frac{u-x}{u-m}, & x \in (m, u) \\ 0, & otherwise. \end{cases} \quad (1)$$

Trapezoidal fuzzy numbers (TrFN), represented by $\bar{M} = (l, m^l, m^h, u)$, are employed in the trapezoidal FAHP method.

$$\mu_F(x) = \begin{cases} \frac{x-l}{m^l-l}, & x \in (l, m^l) \\ 1, & x \in (m^l, m^h) \\ \frac{u-x}{u-m^h}, & x \in (m^h, u) \\ 0, & otherwise. \end{cases} \quad (2)$$

If $m^l = m^h$, the trapezoidal fuzzy number $\bar{M}$ is reduced to the triangular fuzzy number $\tilde{M}$.

The triangular fuzzy number $\tilde{M}$ is obtained by reducing the trapezoidal fuzzy number $\bar{M}$ to $m^l = m^h$.

Table 2. The laws for operations for an arbitrary two trapezoidal fuzzy numbers

Operation	Expression
$\bar{M}_1 \oplus \bar{M}_2$	$(l_1 + l_2, m_1^l + m_2^l, m_1^h + m_2^h, u_1 + u_2)$
$\bar{M}_1 \ominus \bar{M}_2$	$(l_1 - u_2, m_1^l - m_2^h, m_1^h - m_2^l, u_1 - l_2)$
$\bar{M}_1 \odot \bar{M}_2$	$(l_1 \cdot l_2, m_1^l \cdot m_2^l, m_1^h \cdot m_2^h, u_1 \cdot u_2)$
$\bar{M}_1 \oslash \bar{M}_2$	$(l_1/u_2, m_1^l/m_2^h, m_1^h/m_2^l, u_1/l_2)$
$k\bar{M}_1$	$(kl_1, km_1^l, km_1^h, ku_1)$
$\sqrt[n]{\bar{M}_1}$	$\left(\sqrt[n]{l_1}, \sqrt[n]{m_1^l}, \sqrt[n]{m_1^h}, \sqrt[n]{u_1}\right)$

Similar definitions apply to the operations for triangular fuzzy numbers. The fuzzy set

$$G = \{((x, u), \mu_G(x, u)) \; \forall x \in X, \forall u \in I_x \in [0,1], \; 0 \le \mu_G(x, u) \le 1\}$$

is the definition of a type-2 fuzzy number (T2FN), where I_x represents an interval in [0,1]. When $\mu_G(x, u) = 1$ is the membership function, interval type-2 fuzzy numbers (IT2FN) are a particular case of T2FN. The trapezoidal IT2FN number $\bar{\bar{M}}$ is represented with: $\left((\bar{M}^U: H_1(\bar{M}^U), H_2(\bar{M}^U)), (\bar{M}^L; H_1(\bar{M}^L), H_2(\bar{M}^L))\right)$, (Figure 1)

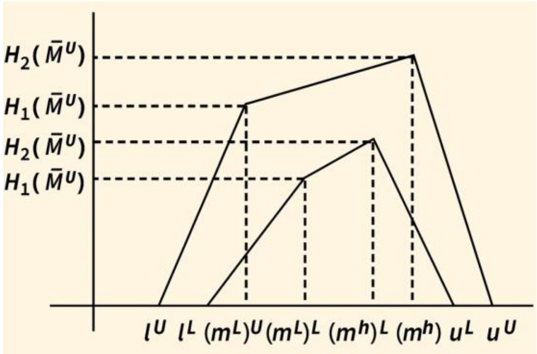

Figure 1 Graphical representation of trapezoidal IT2FS

where $\bar{M}^U = (l^U, (m^l)^U, (m^h)^U, u^U)$ and $\bar{M}^L = (l^L, (m^l)^L, (m^h)^L, u^L)$ are TrFNs, while $H_1(\bar{M}^U)$, $H_2(\bar{M}^U)$, $H_1(\bar{M}^L)$ and $H_2(\bar{M}^L)$ represent the middle left and right vertex heights of the upper and the lower trapeze, respectively. Heights $H_1(\bar{M}^U)$, $H_2(\bar{M}^U)$, $H_1(\bar{M}^L)$ and $H_2(\bar{M}^L)$ belong to the interval [0,1].

For two trapezoidal IT2FNs,

$$\bar{\bar{M}}_1 = \left((\bar{M}_1^U; H_1(\bar{M}_1^U), H_2(\bar{M}_1^U)), (\bar{M}_1^L; H_1(\bar{M}_1^L), H_2(\bar{M}_1^L))\right)$$

and

$$\bar{\bar{M}}_2 = \left((\bar{M}_2^U; H_1(\bar{M}_2^U), H_2(\bar{M}_2^U)), (\bar{M}_2^L; H_1(\bar{M}_2^L), H_2(\bar{M}_2^L))\right)$$

arithmetic operations are given in Table 3.

Table 4 provides the linguistic descriptions of triangular and trapezoidal IT2FN fuzzy numbers.

Table 3. The laws for operations for an arbitrary two interval trapezoidal fuzzy numbers

Addition	$\bar{\bar{M}}_1 \oplus \bar{\bar{M}}_2 = \begin{pmatrix} \left(\bar{M}_1^U \oplus \bar{M}_2^U; \min\left(H_1(\bar{M}_1^U), H_1(\bar{M}_2^U)\right), \min\left(H_2(\bar{M}_1^U), H_2(\bar{M}_2^U)\right)\right), \\ \left(\bar{M}_1^L \oplus \bar{M}_2^L; \min\left(H_1(\bar{M}_1^L), H_1(\bar{M}_2^L)\right), \min\left(H_2(\bar{M}_1^L), H_2(\bar{M}_2^L)\right)\right) \end{pmatrix}$
Subtraction	$\bar{\bar{M}}_1 \ominus \bar{\bar{M}}_2 = \begin{pmatrix} \left(\bar{M}_1^U \ominus \bar{M}_2^U; \min\left(H_1(\bar{M}_1^U), H_1(\bar{M}_2^U)\right), \min\left(H_2(\bar{M}_1^U), H_2(\bar{M}_2^U)\right)\right), \\ \left(\bar{M}_1^L \ominus \bar{M}_2^L; \min\left(H_1(\bar{M}_1^L), H_1(\bar{M}_2^L)\right), \min\left(H_2(\bar{M}_1^L), H_2(\bar{M}_2^L)\right)\right) \end{pmatrix}$
Multiplication	$\bar{\bar{M}}_1 \odot \bar{\bar{M}}_2 = \begin{pmatrix} \left(\bar{M}_1^U \odot \bar{M}_2^U; \min\left(H_1(\bar{M}_1^U), H_1(\bar{M}_2^U)\right), \min\left(H_2(\bar{M}_1^U), H_2(\bar{M}_2^U)\right)\right), \\ \left(\bar{M}_1^L \odot \bar{M}_2^L; \min\left(H_1(\bar{M}_1^L), H_1(\bar{M}_2^L)\right), \min\left(H_2(\bar{M}_1^L), H_2(\bar{M}_2^L)\right)\right) \end{pmatrix}$
Division	$\bar{\bar{M}}_1 \oslash \bar{\bar{M}}_2 = \begin{pmatrix} \left(\bar{M}_1^U \oslash \bar{M}_2^U; \min\left(H_1(\bar{M}_1^U), H_1(\bar{M}_2^U)\right), \min\left(H_2(\bar{M}_1^U), H_2(\bar{M}_2^U)\right)\right), \\ \left(\bar{M}_1^L \oslash \bar{M}_2^L; \min\left(H_1(\bar{M}_1^L), H_1(\bar{M}_2^L)\right), \min\left(H_2(\bar{M}_1^L), H_2(\bar{M}_2^L)\right)\right) \end{pmatrix}$
Scalar multiplication	$k\bar{\bar{M}}_1 = \left((k\bar{M}_1^U; H_1(\bar{M}_1^U), H_2(\bar{M}_1^U)), (k\bar{M}_1^L; H_1(\bar{M}_1^L), H_2(\bar{M}_1^L))\right)$
nth root	$\sqrt[n]{\bar{\bar{M}}_1} = \left(\left(\sqrt[n]{\bar{M}_1^U}; H_1(\bar{M}_1^U), H_2(\bar{M}_1^U)\right), \left(\sqrt[n]{\bar{M}_1^L}; H_1(\bar{M}_1^L), H_2(\bar{M}_1^L)\right)\right)$

Table 4 TFN, TrFN and interval type-2 fuzzy scale for the triangular and trapezoidal IT2FN with linguistic variables

Crisp	*TFN*	*Upper TFN with high*	*Lower TFN with high*	*TrFN*	*Upper TrFN with highs*	*Lower TrFN with highs*	*Linguistic variables*
1	(1,1,3)	(1,1,3;1)	(1,1,2;0.9)	(1,1,1,3)	(1,1,1,3;1,1)	(1,1,1,2;0.9,0.9)	Equally important (E)
2	(1,2,3)	(1,2,3;1)	(1.5,2,2.5;0.9)	(1,1.5,2.5)	(1,1.5,2.5,3;1,1)	(1.5,1.75,2.25,2.5;0.9,0.9)	Intermediate value (I_1)
3	(1,3,5)	(1,3,5;1)	(2,3,4;0.9)	(1,2,4,5)	(1,2,4,5;1,1)	(2,2.5,3.5,4;0.9,0.9)	Weakly important (W)
4	(3,4,5)	(3,4,5;1)	(3.5,4.4,5;0.9)	(3,3.5,4.5,5)	(3,3.5,4.5,5;1,1)	(3.5,3.75,4.25,4.5;0.9,0.9)	Intermediate value (I_2)
5	(3,5,7)	(3,5,7;1)	(4,5,6;0.9)	(3,4,6,7)	(3,4,6,7;1,1)	(4,4.5,5.5,6;0.9,0.9)	Fairly important (F)
6	(5,6,7)	(5,6,7;1)	(5.5,6,6.5;0.9)	(5,5.5,6.5,7)	(5,5.5,6.5,7;1,1)	(5.5,5.75,6.25,6.5;0.9,0.9)	Intermediate value (I_3)
7	(5,7,9)	(5,7,9;1)	(6,7,8;0.9)	(5,6,8,9)	(5,6,8,9;1,1)	(6,6.5,7.5,8;0.9,0.9)	Strongly important (S)
8	(7,8,9)	(7,8,9;1)	(7.5,8,8.5;0.9)	(7,7.5,8.5,9)	(7,7.5,8.5,9;1,1)	(7.5,7.75,8.25,8.5;0.9,0.9)	Intermediate value (I_4)
9	(7,9,9)	(7,9,9;1)	(8,9,9;0.9)	(7,9,9,9)	(7,9,9,9;1,1)	(8,9,9,9;0.9,0.9)	Absolutely important (A)

3.2 Fuzzy Hybrid Model

The theory of fuzzy sets was introduced in [38], which also discusses the imprecision and ambiguity of human language and thought. A fuzzy set, also called a type-1 fuzzy set (T1FS), represents a class of objects on a continuum of membership grades. It is distinguished by a membership function that allocates a membership grade between 0 and 1 to every object. As an expansion of T1FS, Zadeh [39] also presented fuzzy set type-2 (T2FS). More degrees of uncertainty can be conveyed by T2FS, which produces more reliable results and enables the modelling of uncertain environments more accurately. We introduced the interval type-2 fuzzy set (IT2FS) and the standard type-2 fuzzy set (T2FS). This set has a larger degree of uncertainty than T1FS but allows for significant calculation reduction resulting in more reliable and accurate findings [40].

The algorithm is explained below:

Step 1: Create the fuzzy evaluation matrices A (formula (3) in the manner described below for each preference criterion that is taken into consideration:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \quad (3)$$

$a_{ij},\ i,j = 1,2,\dots,n$ is a crisp number in the AHP method or corresponding triangular fuzzy number, trapezoidal fuzzy number, triangular IT2FN and trapezoidal IT2FN in fuzzy AHP.

Step 2: Use the method to investigate the consistency of fuzzy evaluation matrices. The *CI* for matrix consistency is $CI = \frac{\lambda_{max}-n}{n-1}$, consistency ratio $CR = \frac{CI}{RI}$. The value λ_{max} represents the maximal eigenvalue of the comparison crisp matrix A. The matrix's dimension is n, and *RI* is the known random index. The comparison matrix is consistent if CR is less than 0.1 and the estimates of the criteria's relative importance are deemed acceptable.

Step 3: Use the following formula to determine each row's geometric mean:

$$r = [a_{11} \odot a_{12} \odot \dots \odot a_{1n}]^{\frac{1}{n}},\ i = \overline{1,n} \quad (4)$$

Step 4: Determine the fuzzy weights assigned to each criterion.

$$w_j = r \odot [r_1 \oplus r_2 \oplus \dots \oplus r_n]^{-1},\ j = \overline{1,n}. \quad (5)$$

Step 5: The defuzzified values in the FAHP procedures are obtained using the center area approach. In the case of triangular fuzzy number, the defuzzified value is $\frac{1}{4}(l + 2m + u)$. When a trapezoidal fuzzy number, the defuzzified value is $\frac{1}{4}(l + m^l + m^h + u)$. For the triangular IT2FN, , the defuzzified value is $\frac{1}{8}\left(l^U + u^U + l^L + u^L + 2H(\tilde{T}^U)m^U + 2H(\tilde{T}^L)m^L\right)$ and for the trapezoidal IT2FN, the defuzzified value is $\frac{1}{8}\left(l^U + u^U + l^L + u^L + H(\widetilde{M}^U)((m^l)^U + (m^r)^U) + H(\widetilde{M}^L)((m^l)^L + (m^r)^L)\right)$.

4 RESULTS AND DISCUSSION

The techniques described in Section 3 will be used in this section. The linguistic expressions presented in Table 2 are used to assess the importance of each criterion and sub-criterion. Expert-derived fuzzy matrices of comparison of criteria and sub-criteria are provided in Tables 5 through Table 11. Based on the obtained value of CR < 0.1, one can conclude that all comparison matrices are consistent

Table 5 Comparison matrix of criteria

	G	E	C	L	M	S
G	E	I_1	W	W	I_2	I_2
E	1/I_1	E	I_1	I_1	W	W
C	1/W	1/I_1	E	I_1	I_1	I_1
L	1/W	1/I_1	1/E	E	I_1	I_1
M	1/I_2	1/W	1/I_1	1/I_1	E	E
S	1/I_2	1/W	1/I_1	1/I_1	1/E	E

Table 6 Comparison matrix of sub-criterion G

	G_1	G_2	G_3	G_4
G_1	EI	I_1	W	W
G_2	1/I_1	EI	I_1	I_1
G_3	1/W	1/I_1	E	I_1
G_4	1/ W	1/I_1	1/E	E

Table 7 Comparison matrix of sub-criterion E

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8
E_1	EI	I_1	I_1	W	I_2	I_2	F	F
E_2	1/I_1	E	E	I_1	W	W	I_2	I_2
E_3	1/I_1	1/E	E	I_1	I_1	W	I_2	I_2
E_4	1/W	1/I_1	1/ I_1	E	I_1	I_1	W	W
E_5	1/I_2	1/W	1/W	1/I_1	E	E	I_1	I_1
E_6	1/I_2	1/W	1/W	1/I_1	1/E	E	I_1	I_1

E_7	1/F	$1/I_2$	$1/I_2$	1/W	$1/I_1$	$1/I_1$	E	E
E_8	1/F	$1/I_2$	$1/I_2$	1/W	$1/I_1$	$1/I_1$	1/E	E

Table 8 Comparison matrix of sub-criterion L

	L_1	L_2	L_3	L_4	L_5	L_6	L_7
L_1	E	I_1	I_1	W	I_2	F	F
L_2	$1/I_1$	E	E	I_1	W	I_2	I_2
L_3	$1/I_1$	1/E	E	I_1	I_1	I_2	I_2
L_4	1/W	$1/I_1$	$1/ I_1$	E	I_1	W	W
L_5	$1/I_2$	1/W	1/W	$1/I_1$	E	I_1	I_1
L_6	1/F	$1/I_2$	$1/I_2$	1/W	$1/I_1$	E	E
L_7	1/F	$1/I_2$	$1/I_2$	1/W	$1/I_1$	1/E	E

Table 9 Comparison matrix of sub-criterion C

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	E	I_1	W	W	F	S	E
C_2	$1/ I_1$	E	I_1	I_1	I_2	I_3	$1/ I_1$
C_3	1/W	$1/I_1$	E	E	W	F	1/W
C_4	1/W	$1/I_1$	1/E	E	W	F	1/W
C_5	1/F	$1/I_2$	1/W	1/W	E	W	1/F
C_6	1/S	$1/I_3$	1/ F	1/F	1/W	E	1/S
C_7	E	I_1	W	W	F	S	E

Table 10 Comparison matrix of sub-criterion M

	M_1	M_2	M_3
M_1	E	I_1	I_2
M_2	$1/I_1$	E	W
M_3	$1/I_2$	1/W	E

Table 11 Comparison matrix of sub-criterion S

	S_1	S_2	S_3	S_4	S_5	S_6	S_7
S_1	E	I_1	W	W	I_2	F	S
S_2	$1/I_1$	E	I_1	I_1	W	I_2	I_3
S_3	1/W	$1/I_1$	E	E	I_1	I_2	F
S_4	1/W	$1/I_1$	1/E	1/E	I_1	W	F
S_5	$1/I_2$	1/W	$1/I_1$	$1/I_1$	E	I_1	I_2
S_6	1/F	$1/I_2$	1/W	1/W	$1/I_1$	E	W
S_7	1/S	$1/I_3$	1/F	1/F	$1/I_2$	1/E	E

Based on the results of the fuzzy MCDM evaluation, the relative importance of each challenge category was determined by aggregating the weights of the criteria and sub-criteria. The ranking results by triangular FAHP (1), trapezoidal FAHP (2), triangular IT2FS (3), and trapezoidal IT2FS (4) fuzzy logic techniques of the most important barriers indicators are shown in Figure 2.

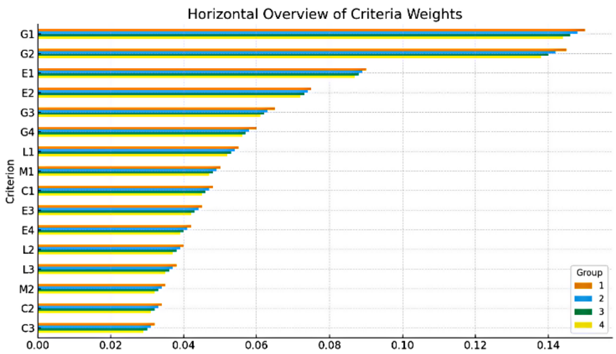

Figure 2 Weights of key indicators of barriers to the development of smart city

The analysis shows consistent results across all four models, confirming the reliability of the applied approach. Governance (G) has the highest weighted set of criteria, suggesting that institutional and strategic factors are the main obstacles to the development of smart cities in the area. The most influential sub-criteria within this group are the lack of a legislative and strategic framework, as well as the absence of coordination among operational city networks (G1–G2). These findings confirm that the creation of an integrated policy framework and stronger inter-sectoral cooperation represent a prerequisite for the successful establishment of Smart City platforms.

The growth of smart cities in the Western Balkans depends on enhancing economic innovation, promoting public participation, and strengthening governance. Even if the variables of liveability, citizens, mobility, and environment have smaller numerical weights, they are nevertheless very important for long-term sustainability, as they emphasize the value of environmental modernization, social involvement, and transportation that is integrated with ICT. The shift to resilient, cutting-edge, and sustainable urban settings can be accelerated by removing these obstacles through legislative reform, strategic investment, and participatory planning.

Descriptive statistics of the results are given in the Table 12.

Table 12 Descriptive statistics

Statistical measure	Value
Number of criteria (N)	16
Minimum weight	0.035 (C3)
Maximum weight	0.145 (G1)
Range (max–min)	0.110
Mean	≈ 0.0629
Median	≈ 0.053
Standard deviation	≈ 0.033
coefficient of variation (CV)	≈ 52%

Interpretation of results:

1. Dominant criteria:

G_1 and G_2 have significantly higher average weights than the others (0.145 and 0.137), indicating that they are key factors in the decision. Their values are about 2.3 times higher than the average weight of all criteria.

2. Medium important criteria:

E_1, E_2, and G_3 form the next group of significant criteria (0.07–0.10). These criteria have a moderate impact on the final decision.

3. Less important criteria:

From G_4 to C_3, the values are between 0.035 and 0.065. These criteria represent a stable but secondary contribution to the evaluation.

4. Value distribution:

o The distribution is asymmetric to the left (positive skewness) – a few high values (G_1, G_2) pull the average up. The mean value between 0.05 and 0.06 is the focal point of most of the criteria. The criteria's relevance is uneven, according to the coefficient of variance (52%).

5. Visual conclusion (Figure 2):

Weight reduction after three separate indicators.

To evaluate the reliability of the collected data, a stability analysis (also known as robustness analysis) was performed. The purpose of this study was to investigate how minor adjustments to expert views or fuzzy weight parameters impact the final ranking of criteria and sub-criteria. Since these changes had no appreciable effect on the ranking order, the results highlight the stability and robustness of the fuzzy decision-making framework. Thus, the results of the triangular FAHP and IT2FS models are trustworthy and consistent in supporting strategic decisions for the creation of smart cities.

The comparative application of FAHP methods, including triangular and trapezoidal methods, and corresponding hybrid IT2FS methods in the field of smart city development highlights the following key barriers, as presented in Figure 3.

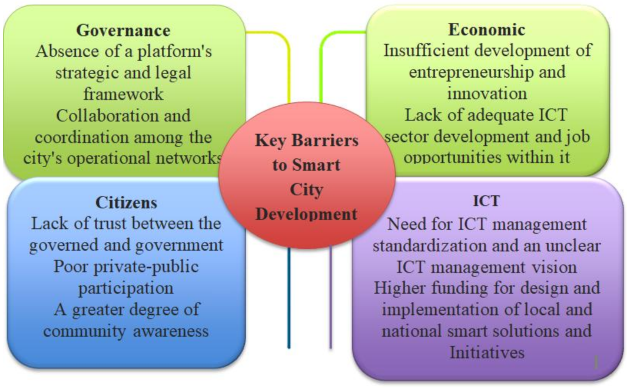

Figure 3 The key barriers to smart city development

The decision model is highly hierarchical: a few criteria have a key weight (G_1, G_2, E_1), while most others have a similar but smaller contribution. This structure suggests that decision optimization could focus on improving performance precisely in the most influential criteria, because they have the greatest impact on the overall result.

5 CONCLUSION

This study examines the potential for creating smart city models, as well as the obstacles to their adoption and strategies for overcoming them. In terms of the applied methodology, the contribution lies in the comparative application of triangular and trapezoidal FAHP methods, as well as the corresponding hybrid IT2FS methods, in creating a platform for developing smart cities. The study identifies important prerequisites for a smart city, including key indicators that serve as barriers to its development. The primary dominant indicators, derived from many sub-criteria and six groups of criteria, were the lack of cooperation and coordination between the city's operational networks and a platform's legal and strategic framework; the necessity of standardizing ICT management and the lack of clarity in its vision; inadequate growth in innovation and entrepreneurship; inadequate job opportunities and development in the ICT sector; and a state of political instability. Clear objectives and transparent regulatory frameworks can open doors for the growth of smart cities. Ultimately, the insights gained from this study can guide decision-makers in designing more resilient, inclusive, and sustainable smart cities in the future.

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