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Smart City Challenges: Prioritization Methods

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Abstract: Substantial shifts in our way of life prompt us to consider creating smarter, more sustainable cities. The construction of smart cities has become increasingly popular in both systematic studies and international policies. The research seeks to identify the main barriers to smart cities by reviewing the existing literature and consulting with subject-matter experts. In order to identify the most significant obstacle category and rank certain challenges within the categories to the development of smart cities in Serbia and the surrounding area, this investigation also attempted to prioritize the barriers. The foundation for all planned actions in the administration of the urban environment, including its sectors and infrastructure, is the Fourth Industrial Revolution and digitization. Multi-criteria decision-making (MCDM) has used the following fuzzy logic techniques to identify key indicators that are pertinent preconditions for the creation of a smart city: triangular and trapezoidal fuzzy analytic hierarchy process (FAHP) and triangular and trapezoidal interval type-2 fuzzy sets (IT2FS). The creation 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 have been identified as the prominent indicators based on six groups of criteria and a significant number of sub-criteria.

Keywords: *Smart city, FAHP, IT2FS, MCDM, algorithm ranking*

1 INTRODUCTION

Over the past 20 years, smart city development has gained significant attention in worldwide policies and systematic research [1-3]. According to this study, a smart city is a modern, technologically sophisticated area with a certain level of intelligence that addresses different social, technical, and economic facets of development using smart computing techniques to create better infrastructure components and services [4-6].

Despite being the epicentres of education, research, and culture, cities are more frequently referenced negatively than rural places. They are in the public eye mostly because of the issues with metropolitan settings, such as being the top energy consumers and environmental polluters [7]. A major factor in the concentration of people in cities is the rising demands of modern man in terms of comfort, a high standard of living, and financial stability. This process encourages people to migrate to economically developed areas and from rural to urban areas, even beyond the borders of the country where they previously resided. 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 environmental quality [8]. Strict lifestyle modifications have forced us to think of creative solutions for building a more sustainable civilization that can endure the quick changes in our surroundings. A key component of guaranteeing sustainable progress is qualitative management founded on sustainable strategies, accountability, transparency, public engagement, emissions reduction, energy efficiency, waste management, and mobility [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. All planned actions in managing urban environments, their sectors, and infrastructure require the Fourth Industrial Revolution and digitization. Information-communicative technologies (ICT) are becoming a key tool in developing future technical patents and smart grids due to the quest for solutions that will expedite the monitoring of urban operations, enhance infrastructure systems, and simplify daily activities.

The world has turned into a global marketplace where nations compete with one another in terms of technical product innovation and sustainability, human capital, scientific advancements, and robust businesses. The Smart City model differs from nation to nation based on various economic, social, and political considerations. Many developing countries are still far from having strategies that accurately implement the Smart City concept in future urban development, despite developed nations taking pride in inventions that use sensors and artificial intelligence, require virtually no manual human control, and extensively use available resources [10,11].

The pandemic has altered our perspectives on sustainable future development and our goals for developing sustainable living spaces.

This study looks at the potential applications of artificial intelligence in creating smart cities. It offers a theoretical summary of the most recent scientific findings about creating and using the Smart City concept, fostering a conversation about potential obstacles. Using multi-criteria analysis, the study attempts to pinpoint important 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 selection of barriers was made through literature and inputs received from experts. Prioritizing the barriers is a decision problem involving various 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 6 provides conclusions, limitations, and directions for future research

2 LITERATURE REVIEW

This section illustrates the literature linked to smart cities, and identifies the barriers related to smart cities development.

2.1 Smart City Concept: From Idea to Reality

The idea of a "smart city" was originally introduced in the 1990s to focus on the implications of information and communication technology for better infrastructures and network upgrades. Thanks to the widespread use of information technologies, cities are empowered to develop essential services for safety, health, governance, and delivery [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 links urban ideas with recent scientific and technical advancements to provide fresh answers to current urban issues in response to the mounting challenges of urbanization. The idea 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].

When thinking about a smart sustainable environment, technological developments have pushed the boundaries. The use of innovative solutions has become a good tool for collecting information that would help uncover current urban problems.In 1994, the term "smart" was linked to the city, the center from which sustainability must be derived [17]. The idea has expanded since the EU began utilizing the "smart" label to qualify sustainable urban development projects in 2010 [18].

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

Because the term "smart" is interconnected and utilized in many facets of contemporary life, smart devices, smart apps, smart roads, smart phones, smart lights, and smart buildings have become commonplace. The value of libraries as public institutions has been undermined by internet searches [20]. At the same time, sensors in cell phones provide us with information about weather and weather conditions, free parking applications, public transportation arrival times, and less congested routes [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 [25], 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.

One of the fundamental responsibilities of a smart city is to use cutting-edge technologies to make urban surroundings more sustainable. 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 [26]. Generally accepted [27], "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 [28];

• 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 [29];

• 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 [31,32],

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 challenges in the development of smart cities

Challenges indicators	*Challenges sub-indicators*
Governance (G)	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)
	Insufficient development entrepreneurship and innovation (E_1) Lack of adequate ICT sector development and job opportunities within it (E_2)

Economic (E)	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)
Livability (L)	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)	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)	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)	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 SOLUTION METHODOLOGY

This exploratory study aims to build a theoretical foundation in the context of smart cities.To achieve the goal, AHP gives each variable a numerical priority. However, AHP has its limitations, which are as follows:

- The issue of priority shifts or rank reversals brought on by modifications to variables or options
- The idea is that elements exist independently.
- Subjectivity and human bias in opinions when making pairwise comparisons
- Consensus measure

To overcome the aforementioned drawbacks, our research methodology employed triangular and trapezoidal fuzzy AHP and interval triangular and trapezoidal fuzzy AHP. Fuzzy AHP makes it possible to determine the importance and weight of the barriers associated with smart cities and their categories.

3.1 Triangular and trapezoidal fuzzy numbers and analysis

In addition to the crisp numbers utilized in the Analytic Hierarchy Process (AHP) method [33–35], this study uses triangular and trapezoidal fuzzy numbers when applying the Fuzzy Analytic Hierarchy Process (FAHP) methodology [36, 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 [38].

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

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

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

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: $\left(\left(\bar{M}^U: H_1(\bar{M}^U), H_2(\bar{M}^U)\right), \left(\bar{M}^L; H_1(\bar{M}^L), H_2(\bar{M}^L)\right)\right)$, (Figure 1)

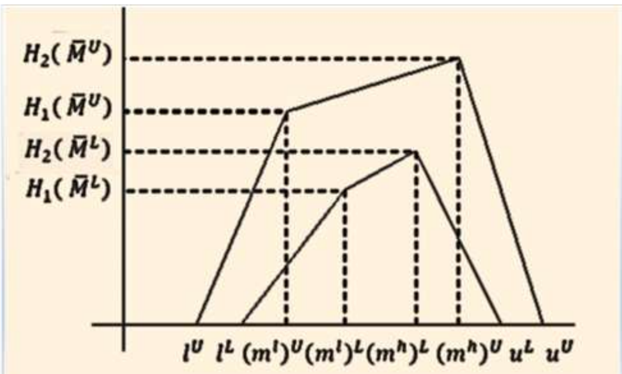

Figure 1 Graphical representation of trapezoidal IT2FS

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,

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

and

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

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	$k\bar{\bar{M}}_1=\left(\left(k\bar{M}_1^U; H_1(\bar{M}_1^U), H_2(\bar{M}_1^U)\right), \left(k\bar{M}_1^L; H_1(\bar{M}_1^L), H_2(\bar{M}_1^L)\right)\right)$
*n*th 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 is introduced in [39], who 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 [40] also presented fuzzy set type-2 (T2FS). More degrees of uncertainty can be conveyed by T2FS, which produces more reliable results and makes it possible to model uncertain environments appropriately. We introduced the interval type-2 fuzzy set IT2FS and the usual T2FS type. This set has a larger degree of uncertainty than T1FS but allows for significant calculation reduction, resulting in more reliable and accurate findings [41,42].

The algorithm as it 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}, $i,j = 1,2,\ldots,n$ 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:

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

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

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

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 DATA ANALYSIS AND RESULTS

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

The ranking results by triangular FAHP (1), trapezoidal FAHP (2), triangular IT2FS (3), and trapezoidal IT2FS (4) fuzzy logic techniques of the most important challenge indicators are shown in Figure 2.

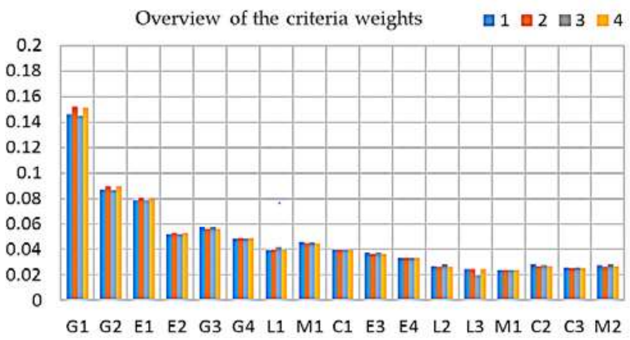

Figure 2 Weights of key indicators of challenges to the development of smart city

The comparative application of FAHP methods, triangular and trapezoidal, and corresponding hybrid IT2FS methods in the field of smart city development highlights the following indicators that are potentially the most significant barriers to change:

- The absence of a platform's strategic and legal framework, as well as collaboration and coordination among the city's operational networks;
- The need for ICT management standardization and an unclear ICT management vision;
- Insufficient development of entrepreneurship and innovation;
- Lack of adequate ICT sector development and job opportunities within it;
- Political instability;
- Lack of trust between the governed and government, Poor private-public participation;
- A greater degree of community awareness;
- Greater personal security;
- Higher funding for design and implementation of local and national smart solutions and initiatives;
- Higher commercialization of innovative technologies assessment.

5 CONCLUSION

In this paper, we explore the possibilities for developing smart city models, considering the obstacles to their development and the possibilities for overcoming them. The theoretical background primarily explains the most important aspects and challenges of smart cities in our country and the surrounding area. In terms of the applied methodology, the contribution lies in the comparative application of triangular and trapezoidal FAHP methods and the corresponding hybrid IT2FS methods in creating a platform of challenges for developing smart cities. In addition to the pandemic, globalization, environmental catastrophes, and general overpopulation require human society to think and live more intelligently. The study identifies important prerequisites for a smart city, including key barrier indicators. 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.Transparent regulatory frameworks and clearly defined objectives can create opportunities for the development of smart cities. Based on findings about the primary indicators, this study may serve as the foundation for future research initiatives.

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6 REFERENCES

[1] Albino, V., Berardi, U. & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*, *22*(1), 3-21.https://doi.org/10.1080/10630732.2014.942092

[2] Koo, C., Ricci, F., Cobanoglu, C. & Okumus, F. (2017). Special issue on smart, connected hospitality and tourism. *Information Systems Frontiers, 19*(4), 699-703https://doi.org/10.1007/s10796-017-9776-9

[3] Mori, K. & Christodoulou, A. (2012). Review of sustainability indices and indicators: Towards a new City Sustainability Index (CSI). *Environmental Impact Assessment Review*, *32*(1), 94-106.https://doi.org/10.1016/j.eiar.2011.06.001

[4] Bakıcı, T., Almirall, E. & Wareham, J. (2013). A smart city initiative: The case of Barcelona. *Journal of the Knowledge Economy*, *4*(2), 135-148.https://doi.org/10.1007/s13132-012-0084-9

[5] Cruz-Jesus, F., Oliveira, T., Bacao, F. & Irani, Z. (2017). Assessing the pattern between economic and digital development of countries. *Information Systems Frontiers*, *19*(4), 835-854.https://doi.org/10.1007/s10796-016-9634-1

[6]Zygiaris, S. (2013). Smart city reference model: Assisting planners to conceptualize the building of smart city innovation ecosystems. *Journal of the Knowledge Economy*, *4*(2), 217-231.https://doi.org/10.1007/s13132-012-0089-4

[7] Moser, C., Wendel, T. & Carabias-Hütter, V. (2014). Scientific & Practical Understandings of Smart Cities. *Proceedings of the Conference REAL CORP,Vienna, Austria, 21–23 May 2014,* 507–514.

[8] Wang, W., Wu, T., Li, Y., Xie, S., Han, B., Zheng, H. & Ouyang, Z. (2020). Urbanization Impacts on Natural Habitat and Ecosystem Services in the Guangdong-Hong Kong-Macao "Megacity". *Sustainability*, *12*(16), 6675. https://doi.org/10.3390/su12166675

[9]Salvioni, D. M., & Almici, A. (2020). Transitioning Toward a Circular Economy: The Impact of Stakeholder Engagement on Sustainability Culture. *Sustainability*, *12*(20), 8641. https://doi.org/10.3390/su12208641

[10] Milošević, M. R., Milošević, D. M., Stević, D. M., & Stanojević, A. D. (2019). Smart City: Modeling Key Indicators in Serbia Using IT2FS. *Sustainability*, *11*(13), 3536.https://doi.org/10.3390/su11133536

[11] Milošević, M., Milošević, D. & Stanojević, A. (2021). Making Opportunities for Developing Smart Cities Using Artificial Intelligence. *Holistic Approach for Decision Making Towards Designing Smart Cities. Future City,Lazaroiu, G.C., Roscia, M., Dancu, V.S., Eds.,Springer, Cham, Switzerland, 18*, 147–173.https://link.springer.com/book/10.1007/978-3-030-85566-6

[12] Saračević, M., Selimi, A., & Plojović, Š. (2019). Some specific examples of attacks on information systems and smart cities applications. *Cybersecurity and Secure Information Systems: Challenges and Solutions in Smart Environments*, 205-226.https://link.springer.com/book/10.1007/978-3-030-16837-7

[13] Perera, C., Zaslavsky, A., Christen, P. & Georgakopoulos, D. (2014). Sensing as a service model for smart cities supported by internet of things. *Transactions on Emerging Telecommunications Technologies, 25*(1), 81-93 https://doi.org/10.1002/ett.2704

[14] Alawadhi, S., Aldama-Nalda, A., Chourabi, H., Gil-García, J., Leung, S., Mellouli, S., Nam, T., Pardo, T. A., Scholl, H. J. & Walker, S. (2012). Building understanding of smart city initiatives. *Electronic Government,* 40-53. https://link.springer.com/chapter/10.1007/978-3-642-33489-4_4

[15] Albino, V., Berardi, U. & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology,* *22*(1), 3-21. https://doi.org/10.1080/10630732.2014.942092

[16] Wey, W.M. & Hsu, J. (2014). New Urbanism and Smart Growth: Toward achieving a smart National Taipei University District. *Habitat Interntational,* *42*, 164–174. https://doi.org/10.1016/j.habitatint.2013.12.001

[17]Dameri, R.P. & Cocchia, A. (2013). Smart City and Digital City: Twenty Years of Terminology Evolution. *Proceedings of the 10th Conference of the Italian Chapter of AIS (ITAIS), 14 December,Universita Commercial Luigi Bocooni, Milan, Italy*, 1–8. https://www.itais.org/proceedings/itais2013/pdf/119.pdf

[18] Susantia, R., Soetomo, S., Buchori, I. & Brotosunaryo, P.M. (2016). Smart Growth, Smart Cities and Density, Search of the Appropriate Indicator for Residential Density in Indonesia,*Procedia Soc. Behav. Sci. 227,* 194–201. https://doi.org/10.1016/j.sbspro.2016.06.062

[19] Djahel, S., Salehie, M., Tal, I. & Jamshidi, P. (2013). Adaptive traffic management for secure and efficient emergency services in smart cities. *2013 IEEE International Conference on Pervasive Computing and Communications Workshops,* 340-343.

[20] Koca-Baltić, I. & Momčilović-Petronijević, A. (2020). Revitalization as protection instrument of cultural heritage of libraris. *Facta Univeristatis, Series: Architecture and Civil Engineering, 18*(1), 1-14. https://doi.org/10.2298/FUACE190911001K

[21] Park, E., Pobil, A.P. & Kwon, S.J. (2018). The Role of Internet of Things (IoT) in Smart Cities: Technology Roadmap-oriented Approaches. *Sustainability,* *10*, 1388. https://doi.org/10.3390/su10051388

[22] Lazaroiu, G. C. & Roscia, M. (2012). Definition methodology for the smart cities model. *Energy,* *47*(1), 326-332. https://doi.org/10.1016/j.energy.2012.09.028

[23] Lee, J. H., Phaal, R. & Lee, S. H. (2013). An integrated service-device-technology roadmap for smart city development. *Technological Forecasting and Social Change, 80*(2), 286-306. https://doi.org/10.1016/j.techfore.2012.09.020

[24] Paskaleva, K. A. (2011). The smart city: A nexus for open innovation? *Intelligent Buildings International, 3*(3), 153-171.

[25]Lee, J. H., Hancock, M. G. & Hu, M. C. (2014). Towards an effective framework for building smart cities: Lessons from Seoul and San Francisco. *Technological Forecasting and Social Change, 89,* 80-99. https://doi.org/10.1016/j.techfore.2013.08.033

[26] Milošević, M. R., Milošević, D. M., Stanojević, A. D., Stević, D. M. & Simjanović, D. J. (2021). Fuzzy and Interval AHP Approaches in Sustainable Management for the Architectural Heritage in Smart Cities. *Mathematics*, *9*(4), 304. https://doi.org/10.3390/math9040304

[27]Li, C.X., Fong, P.S.W., Dai, S. & Li, Y. (2019). Towards sustainable smart cities: An empirical comparative assessment and development pattern optimization in China. *J. Clean. Prod. 215,* 730–743. https://doi.org/10.1016/j.jclepro.2019.01.046

[28]Bibri, S.E. (2019). On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review. *Journal of Big Data 6,* 25. https://doi.org/10.1186/s40537-019-0182-7

[29] Talari, S., Shafie-khah, M., Siano, P., Loia, V., Tommasetti, A., & Catalão, J. P. S. (2017). A Review of Smart Cities Based on the Internet of Things Concept. *Energies*, *10*(4), 421. https://doi.org/10.3390/en10040421

[30]Yadav, G., Mangla, S.K., Luthra, S. & Rai, D.P. (2019). Developing a sustainable smart city frame-work for developing economies: An Indian context. *Sustainable Cities and Society, 47,* 101462. https://doi.org/10.1016/j.scs.2019.101462

[31] Milošević, M., Milošević, D., Stanojević, A. & Simjanović, D. (2020). IAHP kao podrška primeni tehnoloških inovacija u razvoju pametnih gradova, *ECOLOGICA, Naučno-stručno društvo za zaštitu životne sredine Srbije, 99,* 407-413. ISSN 0354-3285.

[32] Milošević, M., Milošević, D. & Stanojević, A. (2021). Managing cultural built heritage in smart cities using fuzzy and interval multi-criteria decision making. *Advances in Intelli-gent Systems and Computing - Proceedings of the INFUS 2020 Conference - Intelligent and Fuzzy Tech-niques: Smart and Innovative Solutions, C. Kahraman, S. C. Onar, B. Oztaysi, I. Ucal Sari, S. Cebi & A. Cagri Tolga (eds.),Turkey, Instanbul,21-23 July 2021,1197,* 599-607. ISBN 978-3-030-51156-2, https://doi.org/10.1007/978-3-030-51156-2

[33] Milošević, M.R., Nikolić, M.M., Milošević, D.M. & Dimić, V. (2022). Managing Resources Based on Influential Indicators for Sustainable Economic Development: A Case Study in Serbia. *Sustainability, 14*, 4795. https://doi.org/10.3390/su14084795

[34] Selimi, A., Milošević, M., & Saračević, M. (2018). AHP–TOPSIS model as a mathematical support in the selection of project from aspect of mobility–case study. *J. Appl. Math. Comput.(JAMC)*, *2*, 257-265. https://www.hillpublisher.com/ArticleDetails/117

[35] Stanojević, A., Jevremović, L.j., Milošević, M., Turnšek, B. & Milošević, D. (2019). Identifying priority indicators for reuse of industrial buildings using AHP method—Case study of Electronic Industry in Nis, Serbia, *Proceedings of the 6th International Academic Conference on Places and Technologies,9–10 May, Pecs, Hungary,* 555–563.

[36] Milošević, D., Milošević, M. & Simjanović, D. (2022). A Comparative Study of FAHP with Type-1 and Interval Type-2 Fuzzy Sets for ICT Implementation in Smart Cities. *Intelligent and Fuzzy Techniques for Emerging Conditions and Digital Transformation. INFUS 2021. Lecture Notes in Networks and Systems, Kahraman, C., Cebi, S., Cevik Onar, S., Oztaysi, B., Tolga, A.C., Sari, I.U. (eds), Springer, Cham.* 308. https://doi.org/10.1007/978-3-030-85577-2_97

[37] Milošević, M. & Dimić, V. (2018). Multi-Criteria Analysis in ICT Implementation for Smart Cities. Eds.: Nikitović, Z. et al., *Successful Implementation of Information Technology,Pub.: Silver & Smith, London, England,* 83-104. http://www.eee-conference.com

[38] Ozkok, B.A. (2019). Finding fuzzy optimal and approximate fuzzy optimal solution of fully fuzzy linear programming problems with trapezoidal fuzzy numbers. *J. Intell. Fuzzy Syst. 36,* 1389–1400 https://content.iospress.com/articles/journal-of-intelligent-and-fuzzy-systems/ifs18016

[39] Zadeh, L.A. (1965). Fuzzy sets. *Inf. Control, 8,* 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

[40] Zadeh, L.A. (1975). The concept of a linguistic variable and its application to approximate reasoning. *Inf. Sci., 8,* 199–249 https://doi.org/10.1109/91.995115

[41]Dereli, T., Baykasoglu, A., Altun, K., Durmusoglu, A. & Turksen, I.B. (2011).Industrial applications of type-2 fuzzy sets and systems: A concise review. *Comput. Ind.*, *62*, 125–137.https://doi.org/10.1016/j.compind.2010.10.006

[42]Celik, E., Gul, M., Aydin, N., Gumus, A.T. & Guneri, A.F. (2015). A comprehensive review of multi criteria decision making approaches based on interval type-2 fuzzy sets. *Knowl.-Based Syst.*, *85*, 329–341https://doi.org/10.1016/j.knosys.2015.06.004

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