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APPLICATION OF FUZZY AHP APPROACH FOR DESIGNING MODEL OF SMART CITY DEVELOPMENT

Mimica Milošević[1]; Dušan Milošević [2];Violeta Dimić[3]

Abstract

Each city represents a unique system where different actors, citizens, administration, and utility companies undertake numerous activities, creating complex interactions and interdependencies. Previous initiatives aimed at creating a platform for a smart sustainable city have proven that there is no one-size-fits-all approach to making a city "smarter" and sustainable. It is critical to develop a methodology that will assist in determining the best route to the end objective, a sustainable and smart city, by thoroughly grasping the unique ecological and social city surroundings, priority activities, history, and distinctive traits. Our research attempts to formulate a plan for the smart city scheme in Serbia. Additionally, we aim to model and optimize the proposed concept based on a systematic evaluation of the various dimensions and corresponding indicators that govern the smart city framework. The paper relies on a ranking system for these dimensions and indicators. The applied methodology is a mathematical method that uses a phased approach to the analytical hierarchical process, FAHP, which hierarchically classifies the whole system through various criteria and sub-criteria with expert opinions.

Keywords: *smart city; Serbia; sustainability; fuzzy AHP, development, MCDM*

Introduction

Smart cities can be considered systems consisting of people, nature, and elements of an artificial environment, using water, energy, materials, services, information, and financial flows to catalyze sustainable development, resilience, and a high quality of life in nature. Smart cities can be considered systems consisting of people, nature, and elements of an artificial environment, using water, energy, materials, services, information, and financial flows to catalyze sustainable development, resilience, and a

[1] Mimica Milošević, 1964, PhD in Mathematics, Full Professor, Faculty of Informatics and Computer Science, University "Union-Nikola Tesla", Cara Dušana 62-64, Belgrade, Serbia, mmilosevic@unionnikolatesla.edu.rs https://orcid.org/0000-0002-9524-9663
[2] Dušan Milošević, 1963, PhD in Mathematics, Full Professor, Department of mathematics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, Niš, Serbia, dusan.milosevic@elfak.ni.ac.rs https://orcid.org/0000-0003-2248-6809
[3] Violeta Dimić, 1964, PhD in Electrical Engineering and Computing, Assistant Professor, Faculty of Information Technology, Alfa BK University, Maršala Tolbuhina 8, Belgrade, Serbia, violeta.dimic@alfa.edu.rs https://orcid.org/0000-0002-0157-436X

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high quality of life in nature. Information and communication infrastructure and services are used to design and manage transparent urban processes, making flows and interactions "smarter". Diverse arrays of stakeholders at various hierarchical levels are involved in the global Smart Cities Initiative.

Currently, over half of the world's population resides in cities, and by 2050, metropolitan areas are expected to house 70% of all people [1,2]. National migration patterns from rural to urban regions and international migrations are the leading causes of urbanization [3]. The infrastructure of cities is significantly strained by rapid urbanization, necessitating creative planning solutions and robust tactics [4]. Urban population growth also points to the rise in environmental and human issues addressed for sustainable development and improved quality of life [5]. Specifically, cities have started aiming for smart targets rather than just sustainability goals in recent years [6]. As a response to the problems brought forth by urbanization, the notion of the smart city was born out of the desire to use cutting-edge information and communication technologies (ICT) to enhance people's lives [7]. The integration of ICT into various urban functions such as transportation, infrastructure, energy, culture, and entertainment has brought increased efficiency in responding to changes and resolving issues [8]. Cities vary in size, climate, demographics, economic development, history, culture, and architecture. As a result, diverse criteria have to be considered while developing solutions for smart cities. Smart cities are prevalent in Western Europe, where there was a shift from secondary to tertiary industrial output (which includes the ICT industry) near the end of the 20th century. Not only are the post-socialist nations of Central and Southeast Europe trailing behind those of Western Europe, but they are also not at the forefront of programs aimed at developing smart cities. It is particularly evident in Serbia and other non-EU Balkan nations, which have failed to establish the necessary planning, legal, and technology frameworks for smart urban development. Opposite to wealthy nations where multimodal decision-making poses a significant obstacle to converting pre-existing metropolitan regions into smart ones, Serbia has lately established the ideal conditions for designing the concept of smart cities. As a result, to provide the opportunity for smart city growth, it is necessary to specify the proper technique and pinpoint the indications or troublesome aspects of the city. This paper aims to present the model of smart city strategy by analyzing the development of these cities in Serbia and optimizing it.

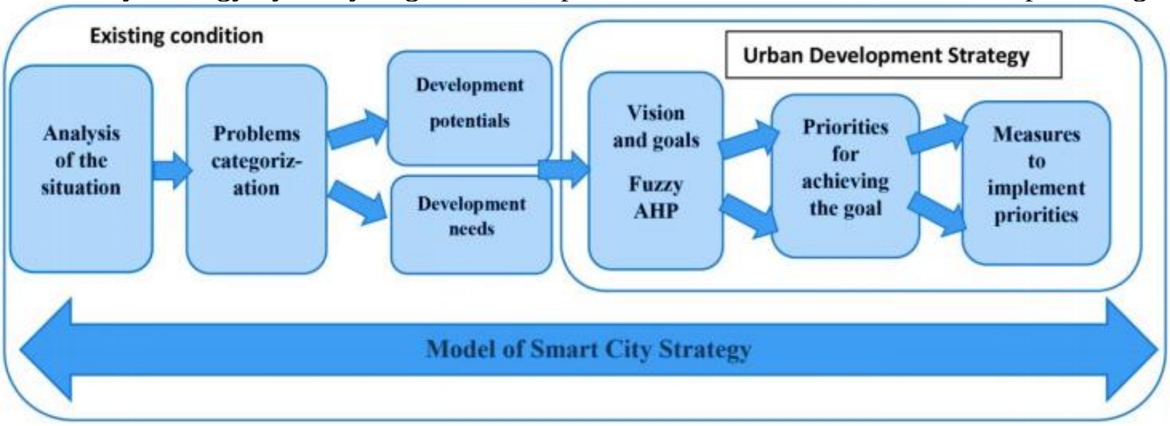

Figure 1: Research model

Towards the smart city concept

A smart city is a city that monitors and integrates the conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, and even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor

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security aspects while maximizing services to its citizens" [9], according to Hall, who provided one of the first widely accepted interpretations of the concept. This definition downplayed the significance of ICT and instead focused on infrastructure systems. After 2005, technology companies began using the term "smart city" to describe the process of ICT systems integration with urban infrastructure systems, coinciding with the expansion of technological development. "A city can be considered as smart when investments in human and social capital, as well as traditional (transport) and modern (ICT) communication infrastructure, fuel sustainable economic growth and a high quality of life, with a wise management of natural resources through participatory governance," is the explanation provided later and is still widely accepted today [10,11]. The term "smart city" is most commonly associated with the use of ICT technologies which enhances urban infrastructure. Real-time information is required to manage resources by installing data sensors. An issue can be viewed from various angles using big data, crowdsourcing, and Internet of Things platforms, and their combination makes it possible to identify the best possible solution. [12,13]. ICT technologies are significant, but local government vision—which puts the needs of the people at the center of strategy formulation—is ultimately responsible for the development of smart cities. The smart city concept means collaborative cooperation between urban planners, architects, electrical engineers, programmers, construction engineers, and social sciences experts. It encompasses many fields in the functioning of a city, from urban planning through energy management, water supply, public transport, and electronic administration to the formation of an attractive urban area [14,15].

Dimensions and indicators of a smart city

Since the Smart City Concept is not unique to the performances of individual system components, different approaches have been used to define the boundaries and domains of the solutions. The study uses components defined in 2007 because it is clear that standardization is necessary, particularly in terms of measurable and transparent management of concept projects. These components determine six criteria of a smart city: governance, citizens, economy, mobility, liveability, and environment [16,17], shown in Figure 2. In contrast to developed nations where multidimensional decision-making poses significant challenges to transform the existing urban areas into smart ones, suitable conditions have recently been established in Serbia to base the concept of smart cities.

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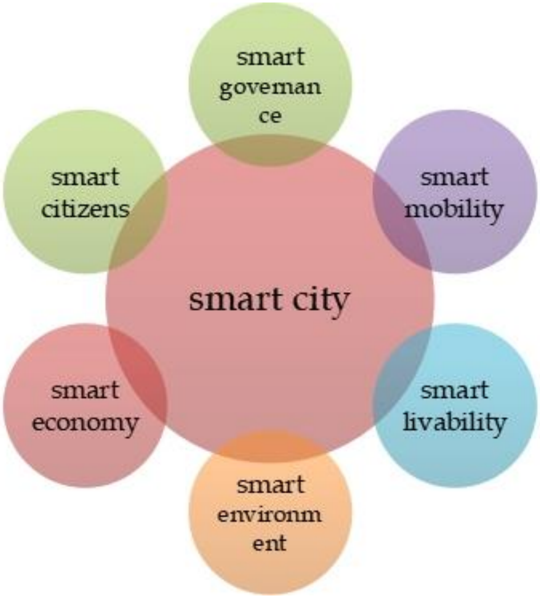

Figure 2: Six dimensions of a smart city

Consequently, to create adequate conditions for the growth of a smart city, it is imperative to specify the proper methodology and pinpoint the indicators or troublesome elements of the city. Table 1 shows the six dimensions of criteria and their sub-criteria that were examined to identify the factors influencing the implementation of the Smart City Concept.

Table 1: Criteria and sub-criteria for Smart City Concept

Governance (G)	**Mobility (M)**
Defining urban development strategies and perspectives (G_1)	Integration of ICT in urban mobility (M_1)
Engaging citizens in decision making (G_2)	Planning for non-motorized transport in urban areas (M_2)
Accessibility of e-Government services (G_3)	Local and worldwide accessibility (M_3)
Enhancing transparency through open government data (G_4)	
Environment (O)	**Economy(E)**
Planning sustainable land management (O_1)	Fostering self-employment and entrepreneurship (E_1)
Environmental pollution control and protection (O_2)	Innovations and strategic investment (E_2)
Using Water Efficiently (O_3)	Economic opportunities (E_3)
Uses of renewable energy sources (RES) (O_4)	Productivity (E_4)
Green buildings and eco-friendly construction (EE) (O_5)	Transformation capacity and market flexibility (E_5)
Management and conservation of natural resources (O_6)	Promoting the economy and market competitiveness (E_6)
Natural beauty of the environment (O_7)	E-business (E_7)

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	Global market integration (E_8)
Citizens (C)	**Livability (L)**
Active participation in the community (C_1)	Individual safety (L_1)
Power citizens' civic consciousness (C_2)	Dwelling conditions (L_2)
High level of education and qualification (C_3)	Utilities, infrastructure equipment (L_3)
Inclination toward e-learning and lifelong learning (C_4)	Healthcare (L_4)
Inventiveness, adaptability, and open-mindedness (C_5)	Education and training (L_5)
Social and ethnic diversity (C_6)	Social integration and recreational activities (L_6)
	Culture and tourism (L_7)

Multi-criteria decision making (MCDM)

The Fuzzy Analytic Hierarchy Process (FAHP), a popular and practical methodology for handling fuzziness and uncertainty in multiple criteria decision-making (MCDM), has seen significant use in recent years. Pairwise comparisons in fuzzy AHP are expressed using language terms like equally important, slightly more important, moderately more important, strongly more important, etc. The linguistic terms are represented by the membership functions, most often of triangular shape. In the paper, Synthetic Triangular Fuzzy Numbers (STFN) will be applied [18]. Theoretical analysis has revealed that this methodology can produce a unique optimal priority vector for any fuzzy pairwise comparison matrix. Matrix theory and fuzzy arithmetic provide the mathematical foundation for the fuzzy AHP approach. A fuzzy number is a special fuzzy set $F = \{(x, \mu_F(x)), x \in R\}$, where $x \in (-\infty, +\infty)$, and $\mu_F(x)$: $(-\infty, +\infty) \rightarrow [0, 1]$ is a continuous function. The notation for a triangular fuzzy number is $M = (l, m, u)$ and the membership function is:

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

Here is $l \leq m \leq u$, l and u stand for the lower and upper values of the support of M respectively, and m is the modal value. It is a "normal" crisp number when $l=m=u$.

Table 2: Main laws for operations for two triangular fuzzy numbers M_1 and M_2

$M_1 \oplus M_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$
$\lambda \cdot M_1 = \lambda \cdot (l_1, m_1, u_1) = (\lambda \cdot l_1, \lambda \cdot m_1, \lambda \cdot u_1), \forall \lambda > 0$
$M_1 \otimes M_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2), l_1, l_2 > 0$
$M_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right).$

For the two triangular fuzzy numbers M_1 and M_2, the following are the primary operating laws in Table 2. Denotations and meanings of the STFNs are: $\tilde{1} = (1,1,3)$ is equal importance; $\tilde{3} = (1,3,5)$ is moderate importance (one element has a slight advantage over the other); $\tilde{5} = (3,5,7)$ strong importance; $\tilde{7} = (5,7,9)$ very strong or demonstrated importance; $\tilde{9} = (7,9,9)$ extreme importance. $\tilde{2} = (1,2,3)$,

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$\tilde{4} = (3,4,5)$, $\tilde{6} = (5,6,)$ and $\tilde{8} = (7,8,9)$ are intermediate values. For the given triangular fuzzy number *M* = (*l*, *m*, *u*), the total integral value is defined as follows [19]:

$$I_\lambda(M) = 0.5(\lambda u + m + (1-\lambda)l), \quad \lambda \in [0,1], \tag{2}$$

where λ represents an optimism index. The smaller value of λ indicates a higher degree of risk (a lower degree of optimism), which reflects the decision maker's attitude toward risk. The decision-makers optimistic, moderate, and pessimistic viewpoints are represented, respectively, by the values 0, 0.5, and 1.
The method is presented through the following steps:
Step 1 Creating the problem hierarchy; defining the primary objective and the criteria and sub-criteria that contribute to it.
Step 2 The fuzzy comparison matrices are obtained. Using a fuzzified evaluation scale, a pairwise comparison has been made. Using triangular fuzzy numbers, we form a comparison matrix $\tilde{C} = (\tilde{c}_{ij})_{n\times n}$ for a fuzzy comparison of criteria by pairs, where $\tilde{c}_{ij}$ is a fuzzy value that expresses the relative importance of one criterion to another. The relative importance of the criterion to itself is expressed by the fuzzy values $\tilde{c}_{ii}$ at the diagonal. Consequently, we set $\tilde{c}_{ii} = (1,1,1)$. The averaging method is used to calculate the aggregate of the opinions of various experts.
Step 3 The consistency of the comparison matrix $\tilde{C}$ is examined. The consistency ratio (*CR*) and consistency index (*CI*) for the matrix $\tilde{C} = (\tilde{c}_{ij})_{n\times n}$ are computed by: $CI = \frac{\lambda_{max} - n}{n-1}$, $CR = \frac{CI}{RI}$, where λ_{max} represents the maximal eigenvalues, and *RI* is an accepted random index of a matrix $\tilde{C}$. If the consistency ratio CR is less than or equal to 0.10, we can consider the assessed fuzzy elements of the matrix; if not, we need to eliminate the factors contributing to the unfavorable high estimations and carry out pairwise comparisons until the consistency level falls within acceptable bounds.
Step 4 The fuzzy synthetic extents determination. The synthetic triangular fuzzy numbers have been calculated, according to total integral values calculated by (2) [20], we compare obtained TFNs: $\tilde{S}_i = (a_i, m_i, b_i)$. By normalization, we obtain the weight vector: $W = (\omega_1, \omega_2, ..., \omega_n)^T$.
The corresponding results are given in the table of final ranks.

Results

Triangular fuzzy numbers for criteria and sub-criteria for Smart City Concept are in Table 3 and Figure 3.

Table 3: Triangular fuzzy numbers for the criteria and sub-criteria

STFN (Main criteria)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.130435, 0.344595, 0.821918)	0.321746	0.327886	0.344007
(0.069565, 0.233108, 0.616438)	0.234321	0.230148	0.21919
(0.059130, 0.138514, 0.410959)	0.151555	0.149231	0.14313
(0.050435, 0.138514, 0.342466)	0.132663	0.133813	0.136833
(0.040000, 0.072635, 0.251142)	0.089304	0.087170	0.081568
(0.031304, 0.072635, 0.182648)	0.070412	0.071752	0.075271
STFN (Governance)	W (λ = 1)	W (λ = ½)	W (λ = 0)

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(0.125000, 0.446281, 1.19318)	0.439856	0.433995	0.418010
(0.104167, 0.272727, 0.681818)	0.256098	0.261377	0.275776
(0.079167, 0.140496, 0.511364)	0.174889	0.171090	0.160729
(0.058333, 0.140496, 0.340909)	0.129157	0.133538	0.145485
STFN (Mobility)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.272727, 0.535032, 1.03053)	0.505146	0.518692	0.547127
(0.127273, 0.343949, 0.801527)	0.369599	0.353330	0.319177
(0.076364, 0.121019, 0.267176)	0.125255	0.127978	0.133695
STFN (Economy)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.107623, 0.264676, 0.607913)	0.248569	0.253604	0.266245
(0.076233, 0.188327, 0.472821)	0.188337	0.188582	0.189197
(0.071749, 0.188327, 0.439048)	0.178716	0.180788	0.18599
(0.039462, 0.125551, 0.337729)	0.131972	0.127994	0.118007
(0.033184, 0.075500, 0.225153)	0.085645	0.083389	0.077724
(0.028700, 0.075500, 0.191380)	0.076024	0.075595	0.074517
(0.022934, 0.041059, 0.135092)	0.050179	0.048921	0.045764
(0.018450, 0.041059, 0.101319)	0.040558	0.041127	0.042557
STFN (Living)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.113703, 0.286396, 0.655589)	0.275601	0.277778	0.283040
(0.090379, 0.201779, 0.486405)	0.201346	0.202906	0.206680
(0.084548, 0.201779, 0.444109)	0.188971	0.192945	0.202555
(0.042566, 0.134519, 0.359517)	0.144543	0.138905	0.125274
(0.034402, 0.083532, 0.218530)	0.088376	0.086929	0.083430
(0.026906, 0.045997, 0.148036)	0.056769	0.055249	0.051573
(0.021075, 0.045997, 0.105740)	0.044394	0.045288	0.047448
STFN (Citizens)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.125348, 0.321464, 0.745974)	0.315765	0.315431	0.314638
(0.118384, 0.237271, 0.497316)	0.217302	0.227107	0.250447
(0.068245, 0.165834, 0.447584)	0.181459	0.176541	0.164835
(0.061281, 0.165834, 0.397853)	0.166747	0.164731	0.159931
(0.028651, 0.078325, 0.215504)	0.086919	0.083491	0.075331
(0.018172, 0.031272, 0.076255)	0.031808	0.032698	0.034818
STFN (Environment)	W (λ = 1)	W (λ = ½)	W (λ = 0)
(0.119617, 0.291853, 0.662680)	0.282884	0.284853	0.289527
(0.098352, 0.215971, 0.473343)	0.204284	0.209289	0.221171
(0.060074, 0.149818, 0.397608)	0.162235	0.157924	0.147689
(0.054758, 0.149818, 0.359740)	0.151012	0.148919	0.143948
(0.048378, 0.100203, 0.233516)	0.098900	0.100574	0.104548

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(0.024531, 0.065570, 0.183026)	0.073674	0.070628	0.063398
(0.015468, 0.026767, 0.064375)	0.027011	0.027813	0.029718

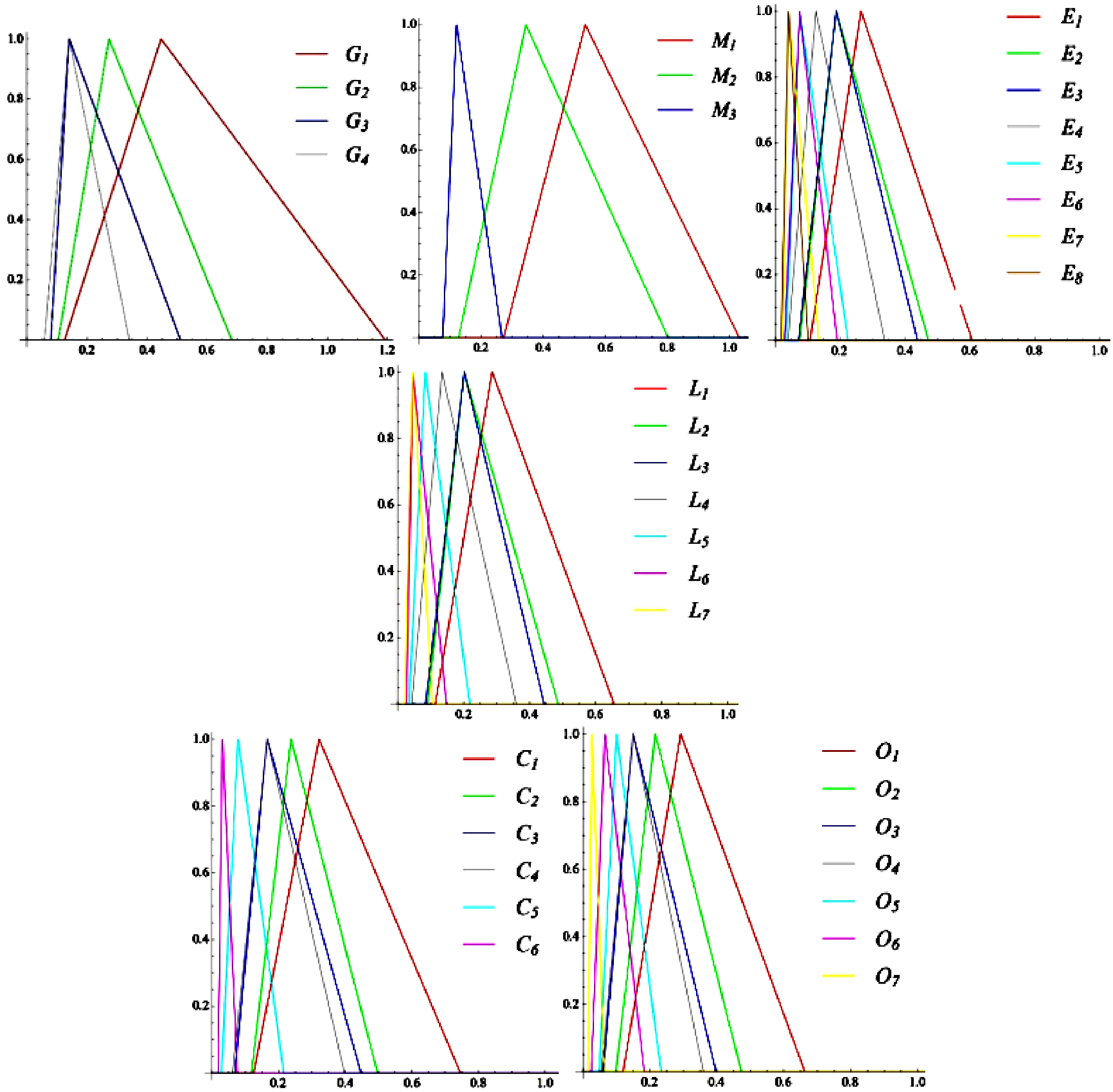

Figure 3: STFNs for governance, mobility, economy, livability, citizens, and environment.

Monitored factors that influence the development of the Smart City Concept and the ranking performance were obtained by the author's developed software, given in Table 4.

Table 4: The final ranking results

Rank of sub-criteria for	λ = 0	λ = 1

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λ = 0 and λ = 1	$I_0(M_1)$	$I_0(M_2)$	$I_0(M)$	$I_1(M_1)$	$I_1(M_2)$	$I_1(M)$
Defining urban development strategies and perspectives - G_1	0.334	0.418	0.139	0.321	0.439	0.141
Engaging citizens in decision making - G_2	0.334	0.275	0.092	0.321	0.256	0.082
Active participation in the community - C_1	0.213	0.314	0.067	0.234	0.315	0.073
Accessibility of e-Government services - G_3	0.334	0.160	0.053	0.321	0.174	0.056
Power citizens' civic consciousness - C_2	0.213	0.250	0.053	0.234	0.217	0.050
Integration of ICT in urban mobility -M_1	0.079	0.547	0.043	0.089	0.505	0.045
High level of education and qualification - C_3	0.213	0.164	0.035	0.234	0.181	0.042
Enhancing transparency through open government data - G_4	0.334	0.145	0.048	0.321	0.129	0.041
Inclination toward e-learning and lifelong learning - C_4	0.213	0.159	0.034	0.234	0.166	0.039
Fostering self-employment and entrepreneurship - E_1	0.167	0.266	0.044	0.151	0.248	0.037
Individual safety - L_1	0.132	0.283	0.037	0.132	0.275	0.036
Planning for non-motorized transport in urban areas - M_2	0.079	0.319	0.025	0.089	0.369	0.033
Innovations and strategic investment - E_2	0.167	0.189	0.031	0.151	0.188	0.028
Economic opportunities- E_3	0.167	0.185	0.031	0.151	0.178	0.027
Dwelling conditions - L_2	0.132	0.206	0.027	0.132	0.201	0.026
Utilities, infrastructure equipment - L_3	0.132	0.202	0.026	0.132	0.188	0.025
Inventiveness, adaptability, and open-mindedness - C_5	0.213	0.075	0.016	0.234	0.086	0.020
Productivity - E_4	0.167	0.118	0.019	0.151	0.131	0.020
Planning sustainable land management - O_1	0.073	0.289	0.021	0.070	0.282	0.019
Healthcare - L_4	0.132	0.125	0.016	0.132	0.144	0.019
Environmental pollution control and protection - O_2	0.073	0.221	0.016	0.070	0.204	0.014
Transformation capacity and market flexibility- E_5	0.167	0.077	0.013	0.151	0.085	0.012
Education and training - L_5	0.132	0.083	0.011	0.132	0.088	0.011
Promoting the economy and market competitiveness - E_6	0.167	0.074	0.012	0.151	0.076	0.011
Using Water Efficiently - O_3	0.073	0.147	0.010	0.070	0.162	0.011
Local and worldwide accessibility - M_3	0.079	0.133	0.010	0.089	0.125	0.011
Use of renewable energy sources (RES) - O_4	0.073	0.143	0.010	0.070	0.151	0.010
E-business - E_7	0.167	0.045	0.007	0.151	0.050	0.007
Social integration and recreational activities - L_6	0.132	0.051	0.006	0.132	0.056	0.007
Social and ethnic diversity - C_6	0.213	0.034	0.007	0.234	0.031	0.007
Green buildings and eco-friendly construction - O_5	0.073	0.104	0.007	0.070	0.098	0.006
Global market integration-E_8	0.167	0.042	0.007	0.151	0.040	0.006
Culture and tourism - L_7	0.132	0.047	0.006	0.132	0.044	0.005
Management and conservation of natural resources - O_6	0.073	0.063	0.004	0.070	0.073	0.005
Natural beauty of the environment - O_7	0.073	0.029	0.002	0.070	0.027	0.001

The final ranking results are given in Figure 4.

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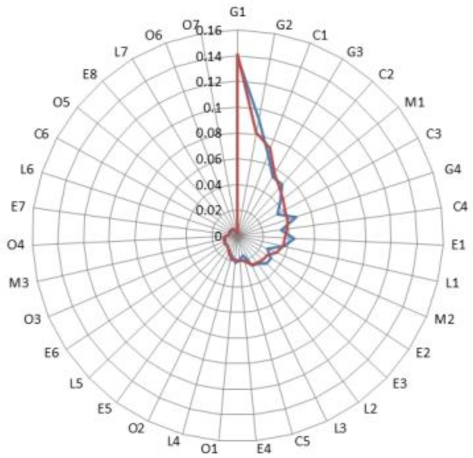

Figure 4: Graphic representation of the final ranking of sub-criteria,
(λ = 0 is blue, λ = 1 is red)

Conclusion

The goal of a smart city is to start a sustainable development process that considers the actual demands of significant stakeholders. The research aims to represent the smart city by developing a technique for determining the best course of action for a sustainable and smart city in Serbia. In this article, we used a fuzzy analytic hierarchy technique to survey the ranking of significant indicators of the smart city idea. The paper considered six groups of criteria and 35 sub-criteria. The main dominant measures are:

- Defining urban development strategies and perspectives,
- Engaging citizens in decision-making and
- Active participation in the community.

The development of an appropriate strategy requires accessible services and e-government development. Raising awareness, educating citizens, and monitoring results should create a smart sustainable city. Entrepreneurship and the promotion of self-employment with the integration of ICT and the satisfaction of citizens with a high degree of qualification and education are additional prerequisites for creating the desired strategy. Alongside transparent management and open data usage, it is imperative to encourage lifelong education. It entails initiating pilot projects, identifying financial mechanisms, and exchanging experiences with other cities, starting from project identification and investment planning. A Smart City Concept development strategy can be designed using well-defined projects that create solid and transparent regulatory frameworks, provide incentives for investment, and set long-term goals for all participants. This paper aims to support such a concept.

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