yönetim ve ekonomi araştırmaları dergisi
journal of management and economics research
Cilt/Volume: 23 Sayı/Issue: 2 Haziran/June 2025 ss. /pp. 125-161
E. Mukul, G. Büyüközkan, http://dx.doi.org/10.11611/yead.1623687

PRIORITIZING SMART CITIES USING HESITANT FUZZY LINGUISTIC MULTI-CRITERIA DECISION-MAKING FRAMEWORK

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ABSTRACT

Smart cities represent contemporary urbanization paradigms aimed at enhancing efficiency, sustainability, and livability through technology and data-driven solutions. Positioned as a cornerstone for a more equitable and sustainable future, smart cities address the pressing challenges of growing urban populations with innovative approaches. However, evaluating their performance requires comprehensive analytical methodologies capable of managing uncertainty and conflicting priorities. This study proposes an integrated hesitant fuzzy linguistic (HFL) multi-criteria decision-making framework to address this need. The methodology combines the HFL Analytic Hierarchy Process (AHP) for determining the relative importance of evaluation criteria and the HFL Evaluation Based on Distance from Average Solution (EDAS) for ranking smart cities. By embracing the flexibility and hesitancy in decision-makers' judgments, this framework ensures robust and reliable results even under uncertain conditions. The proposed approach is applied to assess and rank smart cities, with Aalborg, Denmark, emerging as the top-performing city. Aalborg's exemplary achievements in sustainable and safe transport systems, pollution control, and environmental protection underscore its leadership in smart city initiatives. This study contributes to the field by providing a scalable and adaptable decision-support tool for policymakers and urban planners, paving the way for more effective smart city performance evaluation.

Keywords: *Hesitant Fuzzy Linguistic Term Set, Analytic Hierarchy Process (AHP), Evaluation Based on Distance from Average Solution (EDAS), Multi-Criteria Decision-Making, Smart City, Performance Evaluation.*

JEL Codes: *C63, L90, Q56.*

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Makale Geçmişi/Article History

Başvuru Tarihi / Date of Application	: 20 Ocak / January 2025
Düzeltme Tarihi / Revision Date	: 26 Mayıs / May 2025
Kabul Tarihi / Acceptance Date	: 2 Temmuz/ July 2025

Araştırma Makalesi/Research Article

1. INTRODUCTION

Rapid population growth and migration from rural regions to cities have a significant influence on urban challenges. These issues endanger not just urban economic and social life, but also the environment. It also has a negative impact on the quality of life in cities. Smart cities, as a novel idea, have risen to the forefront of policy debates seeking a rational answer to urban issues.

Smart city is an urban development concept that represents the integration of urban assets and resources using information technologies. Smart cities are built on the notion of self-management of mobility, networks, and infrastructure, and they consist of several elements. Work on smart cities has expanded in recent years, with the goal of increasing social prosperity in a complicated network of living areas (Hollands, 2008; Cocchia, 2014; Alghamdi, 2023; Goumiri et al., 2023).

Citizens' needs shall be addressed in the best way in the renewed world with developing technologies. To provide the best service while meeting these needs, one can determine how smart cities are and draw road maps accordingly. The motivation of this paper is to assess the smartness levels of cities with the presented model and compare the results obtained with the analytical methods given in the reports. Thus, with the evaluation of smart cities, road maps are prepared according to the smartness levels of the cities, it is determined which digital technology is suitable for the infrastructure of cities, the integration process is accelerated and citizens' needs are met more easily. Simultaneously, the issue of smart cities is important in the digital transformation process.

Decision-making is described as choosing between two or more possibilities. When several decision possibilities are available, not all of them are always the best. There is a better choice that cannot be conceived, or actual knowledge that is unavailable at the time. The assessment of smart cities is seen in this paper as a multi-criteria decision-making (MCDM) problem (Hwang and Yoon, 1981). Realistic decision problems are excessively complex and poorly organized. A one-dimensional method is an oversimplification of the real features of the issue and can easily lead to unrealistic choices. MCDM is a sophisticated operations research area that focuses on the improvement of MCDM techniques to go up against complex decision issues. It allows decision-makers (DMs) to reach decisions when there are multiple and usually contradictory criteria. Such methods are quite popular methods in the literature (Barba Romero and Pomerol, 2000).

Evaluating and comparing smart cities is not straightforward and involves several contradicting parameters. However, when information is ambiguous, selecting and ranking smart cities is tough. DMs typically struggle to communicate their views in numbers since these quantitative notions are foreign to them. Furthermore, rather of employing clear statistics, DMs may communicate their ideas more boldly using words. The hesitant fuzzy linguistic term set (HFLTS) (Torra, 2010) addresses the uncertainty of this MCDM problem.

Hesitant fuzzy sets (HFS) are widely used in the literature for MCDM problems. To illustrate a methodology for computing with terms, HFLTS with a fuzzy envelope was presented by Liu and Rodriguez (2014). A comprehensive and ordered introduction to the theory of HFS is given by Xu (2014). He introduced expanded hesitant fuzzy preference relationship and calculation techniques, HFS aggregation techniques, and hesitant fuzzy MCDM approaches.

1.1. Motivations

The motivation for this study is to ensure that cities can compete in a globally interconnected economy and sustainably ensure the well-being of their residents. This motivation reveals the need to address city solutions holistically and systematically, and the smart city approach is the solution to meet this need.

In this context, this study presents a methodology for evaluating smart cities with all their components. The HFL MCDM approach is presented to obtain realistic results from the smart city evaluation problem.

The advantages of the HFLTS are as follows (Torra, 2010; Rodriguez et al., 2012; Büyüközkan et al., 2021; Krishankumar et al., 2021; Krishankumar et al., 2022a):

- The use of HFLTS provides ease of expression for DMs. In this decision model, DMs can express their opinions in linguistic expressions instead of numerical expressions.
- The flexibility of linguistic phrases allows for the adaptation of expressions to diverse criteria based on their nature. At this time, HFLTS is beneficial in resolving the issue.
- There are several elements to consider while determining the best choice in an evaluation problem. MCDM based on HFLTS was employed to provide a more realistic outcome for DM evaluation.

An integrated Evaluation Based on Distance from Average Solution (EDAS) - Analytic Hierarchy Process (AHP) methodology based on HFLTS with a fuzzy envelope is proposed for the smart city concept.

In the first step of the study, the HFL AHP approach is implemented for computing the weights of smart city selection criteria. In the second step, the HFL EDAS method is used to rate and evaluate smart cities in terms of importance and benefit ratings. The AHP method includes an easy data framework and talent to overcome complicated MCDM problems (Saaty, 1980). Several potential values can be employed in HFL AHP to explain the hesitancy of the DMs' evaluations (Zhu and Xu, 2014). The EDAS method is a distance-based method first developed by Ghorabaee et al. (2015). It pursues the average solution for comparing alternatives.

The advantages of combining AHP and EDAS methods are as follows (Ecer, 2018; Stević et al., 2019; Büyüközkan and Güler, 2021; Mi, 2023):

- The capacity of the AHP method to establish a hierarchical structure from main criteria to sub-criteria
- The flexibility and adeptness of AHP to extensively compare
- EDAS is relatively new in the MCDM domain and is particularly useful when the preferred average value of attribute evaluations is known.
- EDAS is an additive MCDM method with no criteria interdependencies.

1.2. Research Gap and Main Contributions

The research gap is the lack of a study examining the evaluation models presented in the smart city literature with advanced fuz zy MCDM methods.

This paper's contributions can be presented as follows:

- It is the first paper using the combined methods of HFL AHP and HFL EDAS with a fuzzy envelope approach.
- It illustrates how verbal knowledge is efficient for MCDM and how HFL approaches, a rare approach in the literature, result in the case of hesitancy. The proposed HFL approach offers reliable findings as it takes the hesitancy of DMs into account and creates a wider and more flexible evaluation space. In addition, a comparative study is performed to verify the feasibility of the proposed technique.
- It contributes to the literature on smart cities by implementing a new comprehensive HFL MCDM-based methodology.

The structure of the study is outlined as follows: Section 2 provides a literature review on the concept of smart cities. Section 3 introduces the proposed methodology. Section 4 presents an application for smart city evaluation to illustrate the practicality and effectiveness of the methodology. Section 5 discusses the findings of the study. Finally, the study concludes with the final section.

2. LITERATURE SURVEY

2.1. Literature Survey of Smart City Evaluation Models

Cities are growing more congested, and technology is evolving into a vital part of our daily life. During this process, citizens' demands grow and expectations become more complex. Our lives are changing as a result of technology, and municipal governments must consider the future more than ever before. To achieve the best possible integration process in cities, a robust model must be established. Planning and applications are made easier with a complete smart city model. As a result, several smart city models are promoted in the literature (Ivaldi et al., 2020).

A smart city is a comprehensive concept that encompasses not only integrating advanced information technology infrastructure, but also the ability to effectively manage resources and data to improve the quality of life of its residents. It enables real-time monitoring, control and communication with various urban services such as transportation, environmental management, public safety, energy distribution and emergency response. By facilitating such services, information systems allow cities to optimize their resources, streamline services and respond more efficiently to citizens' needs (Kollarova et al., 2023).

Table 1 lists the smart city models and their many aspects as stated in the literature. Different dimensions are associated with distinct components. Some research use a theoretical approach, while others are more applied.

Lee and Lin (2008) suggested a case framework for smart city analysis using a six-dimensional smart city model, which they applied to San Francisco and Seoul. Hsieh et al. (2011) proposed a model that covers aspects such as smart transportation, environment, economics, and lifestyle for smart city development strategies. Lazaroiu and Roscia (2012) described a framework and applied it for ten smart cities. Bruni et al. (2017) established a methodology for quantifying smartness using metrics applicable to small and medium-sized cities. A comparison of Chinese smart city evaluation frameworks is present by Shi et al. (2017). A conceptual smart city model for the Vienna is proposed Fernandez-Anez et al. (2018). Sharma and Tayal (2019) provided an analytic-based Indian smart city ranking algorithm. Ezugwu et al. (2021) proposed a smart city framework for machine learning applications. Abu-Rayash and Dincer (2022) provide a unique integrated strategy to smart cities based on fresh technical and socioeconomic transformations. Da Silva (2023) presents the rules for a smart city plan that would handle Amazon's urban environmental challenges. Kollarova et al. (2023) offered a detailed assessment of a variety of major security and privacy issues pertinent to the development of smart cities in Slovakia. Singh et al. (2024) developed a set of enablers to promote smart city development through business participation and socially responsible conduct.

Table 2 shows the smart city models and their proportions, as stated in industry studies. It demonstrates that the models are largely distinct from one another, however there are some similarities.

The Deloitte Report (2015) presents the major features of the smart city concept, including aims and obstacles. The research emphasizes that smart city models emerge from clever solutions developed in response to obstacles. The Ministry of Housing and Urban Affairs of the Government of India (2015) has developed a smart city initiative to address issues posed by an expanding population. This model includes adequate sanitation, including efficient public transport, solid waste management, robust IT accessibility and digitalization, affordable housing, a sustainable environment, citizens' protection and security, good governance, health, and education. The model presented in the report published by KAIA (2023), unlike the reports of previous years, includes more human-related dimensions such as smart living, people, governance, and environment.

In this study, the evaluation model proposed by Giffinger and Pichler-Milanović (2007) is used. This model is highly developed, applicable, and can be integrated with analytical methods. They presented a smart city approach for rating Europe's medium-sized cities. This concept identifies six major dimensions of a smart city. These are the smart governance, economy, mobility, living, people, and environment. This model has been used in many different studies in the literature. Shen et al. (2018) used this smart city model to assess the performance of cities in China. An MCDM approach is proposed for the evaluation of this smart city model (Escolar et al., 2019). Also, this model is evaluated by using exploratory factor analysis and a fuzzy approach (Vasuaninchita et al., 2020). Tarig et al. (2020) presented the ranking of Australian cities by using this smart city model. In this context, this model is presented with integrated HFL MCDM methods to rank cities.

Table 1. Smart City Models Developed by Academics

		Dimensions										
Year	**Source**	**Smart environment**	**Smart transportation**	**Smart living**	**Smart economy**	**Smart governance**	**Smart people**	**Smart energy**	**Smart infrastructure**	**Smart healthcare**	**Theoric/ Application**	**Application Area**
2011	Hsieh et al.	X	X	X	X						Application	Chung Hsing, Taiwan
2012	Lombardi et al.	X		X	X	X					Theoric	-
2012	Lazaroiu and Roscia	X	X	X	X	X	X				Application	Rome, Rieti, Naples, Foggia, Milan, Pavia, Bergamo, Como, Salerno, Cremona
2012	Chourabi et al.	X			X	X	X		X		Theoric	-
2013	Cohen	X	X	X	X	X	X				Theoric	-
2014	Lee et al.		X	X		X	X		X		Application	San Francisco - Seoul
2014	Neirotti et al.		X	X	X	X	X	X	X		Theoric	-
2015	Mattoni et al.	X	X		X		X	X			Theoric	-
2017	Bruni et al.	X	X	X	X	X	X	X			Application	Northern Italy
2017	Varol	X	X	X		X					Application	Ankara, Turkey
2017	Uçar et al.	X	X	X	X	X	X				Application	Amsterdam

2017	Rondini et al.	X	X	X	X	X	X				Application	Bergamo, Italy
2018	Fernandez-Anez et al.	X	X	X	X	X	X				Application	Vienna
2018	Shi et al.			X	X	X	X		X		Application	China
2018	Alabdulatif et al.	X	X	X	X		X	X		X	Theoric	-
2019	Sharma and Tayal	X			X	X	X		X		Application	India
2019	Andrade and Yoo	X	X	X	X	X	X				Theoric	-
2020	Rădulescu et al.	X	X	X	X				X	X	Theoric	-
2020	Lafioune and St-Jacques	X	X			X		X	X		Theoric	-
2021	Lom and Pribyl	X				X		X			Theoric	-
2021	Ezugwu et al.			X		X	X		X	X	Theoric	-
2022	Baran et al.	X	X	X	X	X	X				Application	Poland
2022	Kumar et al.	X	X	X				X			Application	-
2023	Abu-Rayash and Dincer	X	X		X	X	X	X	X	X	Application	20 different cities
2023	da Silva	X	X	X	X	X	X				Theoric	-
2023	Kociuba et al.	X	X		X	X			X		Application	Lublin, Eastern Poland
2023	Pereira et al.	X	X		X	X	X				Theoric	-
2023	Kollarova et al.	X	X	X	X	X			X	X	Application	Slovakia
2024	Singh et al.		X				X	X		X	Theoric	-

Table 2. Smart City Models Developed by Practitioners

			Dimensions									
Year	**Institution/Source**	**Model Name**	**Smart environment**	**Smart transportation**	**Smart living**	**Smart economy**	**Smart governance**	**Smart people**	**Smart energy**	**Smart safety**	**Smart education**	**Smart healthcare**
2007	Giffinger and Pichler-Milanović	Characteristics of a smart city	X	X	X	X	X	X				
2010	Forrester	Smart City Blueprint		X	X		X			X	X	X
2015	Deloitte	Smart Cities		X	X	X	X		X	X	X	X
2016	IESE Cities in Motion Index	Smart City Indicators	X	X	X	X	X	X				
2016	UN Commission on Science and Technology	Smart City Key Themes	X	X	X	X	X	X				
2016	Ministry of Urban Affairs India	Smart City Mission	X	X			X	X	X			X
2016	Public Technology Platform	Smart City Model	X	X	X	X	X	X				
2017	EasyPark Group	Smart Cities Index	X	X	X	X	X	X				
2017	Urban-Hub	Smart City Model		X	X			X		X		
2017	ASCIMER	Smart City Project Actions	X	X	X	X	X	X				
2019	Ministry of Land, Infrastructure and Transport of Korea	Smart City Model	X	X	X	X			X	X		
2020	OECD	Smart City Model	X	X	X	X	X	X				
2021	KPMG	Smart City Model	X	X	X	X	X	X		X		
2023	Korea Agency for Infrastructure Technology Advancement	Smart City Model	X		X		X	X				

2.2. Literature Survey of Smart City Concept with MCDM Methods

Smart cities are built on the concept of rearranging cities to improve efficiency for all stakeholders. Smart cities are created with a people-cantered, strategic, and ecologically friendly management plan, service areas, and living standards in mind. These structures are constructed on imaginative and sustainable techniques to generating new, resource-efficient living environments and strategically utilized, environmentally friendly, pleasant, healthy, and citizen-focused (Hollands, 2008).

Smart cities that are integrated with technologies provide several benefits. These advantages include: safety, healthcare, energy, retail and logistics, people, tourism and leisure, mobility, government, and environment (Giffinger and Pichler-Milanović, 2007; Deloitte Report, 2015; Vlahogianni et., 2016; El Hamdani et al., 2020).

- For tourism and leisure, it enables visitors to travel more freely by studying tourist movements in real time.
- For retail and logistics, it allows the peer-to-peer exchange of products and services.
- For governance, identifying policies based on data gives quantitative proof of efficacy. Co-production in MCDM processes introduces new concepts of digital governance and participatory management.
- For people, dynamic citizen groups are created, enabling citizens to organize and cooperate effectively in line.
- For mobility, the effective utilization of transportation infrastructure leads to decreased levels of congestion and pollution.
- For healthcare, in large amounts of patient data, artificial intelligence allows for more accurate diagnosis and individualized therapy. People in need of assistance can enjoy longer lives at home owing to better warning systems and healthcare robotics.
- For safety, it responds promptly to public safety issues by evaluating sensor and camera data in real-time.
- For energy and environment, energy savings are obtained by conducting real-time energy use checks and combining them with ideas. The garbage containers' sensors gather waste more effectively. The analysis of sensor data in the water supply network enables leak detection and prompt repair.

The literature on smart cities mainly focuses on smart city definitions and methods. The number of studies on smart cities and their applications is on the rise. In this study, smart cities are combined with analytical methodologies. Table 3 shows studies that apply smart cities and MCDM methodologies.

Table 3. Studies Conducting Smart City and MCDM Methods

Year	Source	Aim of the Study	MCDM Methods	Application Area
2012	Lombardi et al.	to suggest a deep analysis of relations between smart city elements	ANP	-
2015	Anthopoulos and Fitsilis	to identify social networks in smart cities	ELECTRE I - ELECTRE TRI	-
2016	Shinde and Kiran	to review different auction methods considered for the cloud market	AHP	-
2016	Anthopoulos and Giannakidis	to present the task-based approach and standardization of processes for smart cities	PROMETHEE	Trikala, Greece
2017	Anand et al.	to determine how important different criteria are for sustainability smart cities	Fuzzy AHP - DEA	India
2017	Giang et al.	to present an optimal method for modeling of a procedure in smart city projects	Fuzzy cognitive map	-
2017	Carli et al.	to present an MCDM method for energy efficiency of street illumination in a smart city	TOPSIS	Bari, Italy
2017	Jain et al.	to offer an IoT based-sensor network approach for smart cities	TOPSIS	-
2018	Manupati et al.	to come up with an urban renewal approach for developing cities in India	ANP	Southern India
2019	Nabeeh et al.	to present a methodology for IoT-based enterprises	Neutrosophic AHP	Egypt, U.K., China
2019	Milošević et al.	to determine key indicators for the smart city	Interval type-2 fuzzy sets	Serbia
2019	Zhu et al.	to rate the durability of smart cities in China	AHP-TOPSIS	China
2019	Xu et al.	to present IoT service placement for smart cities	TOPSIS	-
2020	Ogrodnik	to analyze the largest Polish cities	PROMETHEE	Poland
2021	Milošević et al.	to examine the architectural heritage management in smart cities	Fuzzy and Interval AHP	-
2021	Hanine et al.	to present the evaluation of the smart city development for developing countries	Intuitionistic fuzzy AHP-DEMATEL	-
2022b	Krishankumar et al.	to assess renewable energy sources for smart cities	CRITIC	Tamil Nadu
2022	Ye et al.	to present models for smart city ranking	WSM-TOPSIS-VIKOR	China
2023	Shao et al.	to propose a sustainable evaluation framework for smart cities	Z-fuzzy DEMATEL-TOPSIS	Xiamen
2023	Bagheri et al.	to identify and evaluate smart city dimensions	Fuzzy DEMATEL	-
2023	Yenkar and Sawarkar	to present a complaints' ranking	AHP-TOPSIS	-
2024	Ibrahim et al.	to present a simulation tools' evaluation for smart cities	Interval-valued fermatean fuzzy rough WZIC	-
2024	Rani and Potika	to introduce a wildfire prediction model that ranks cities based on risk leveraging MCDM	Fuzzy TOPSIS	California
2024	Makki and Alqahtani	to evaluate the main barriers hindering the progress of smart cities	DEMATEL	-

According to the table, the smart city idea is commonly utilized in conjunction with a variety of MCDM approaches, including TOPSIS, AHP, ANP, ELECTRE, PROMETHEE, and DEMATEL. Its use to sophisticated MCDM approaches such as fuzzy is quite restricted. Anand et al. (2017) estimated the relevance of several sustainability criteria in a smart city using the fuzzy AHP-DEA approach. Milošević et al. (2019) explore key indicators in the concept of the smart city, and assess the activities with interval type-2 fuzzy sets. Hanine et al. (2021) evaluated the development of smart cities with intuitionistic fuzzy AHP-DEMATEL methods. In 2024, the evaluation of simulation tools in smart cities is presented by Ibrahim et al. (2024). This subject will be utilized in combination with the HFL MCDM, a gap in the literature.

3. THE PROPOSED METHODOLOGY

Decision problems encountered in actual life are often intertwined with uncertainty and complexity. Linguistic information can help to represent such uncertainty. DMs usually intend to make decisions by combining different information. This is not always a straightforward process. It might be difficult to decide when there are many criteria and insufficient information. For this reason, this paper proposes an MCDM approach based on HFLTS to utilize information where data providers are hesitant to express certain opinions.

HFS is strongly useful in registering existing hesitations when DMs evaluate alternatives. This also constitutes a big research field (Torra, 2010; Rodriguez et al., 2011). Torra (2010) proposed the HFS to address this challenge. Liu and Rodriguez (2014) present an MCDM model in which DMs state their opinions linguistically. This approach proposes these assessments by representing HFLTS.

In this study, there are three basic steps of the methodology:

Step 1. Identification of the smart city criteria and alternatives.

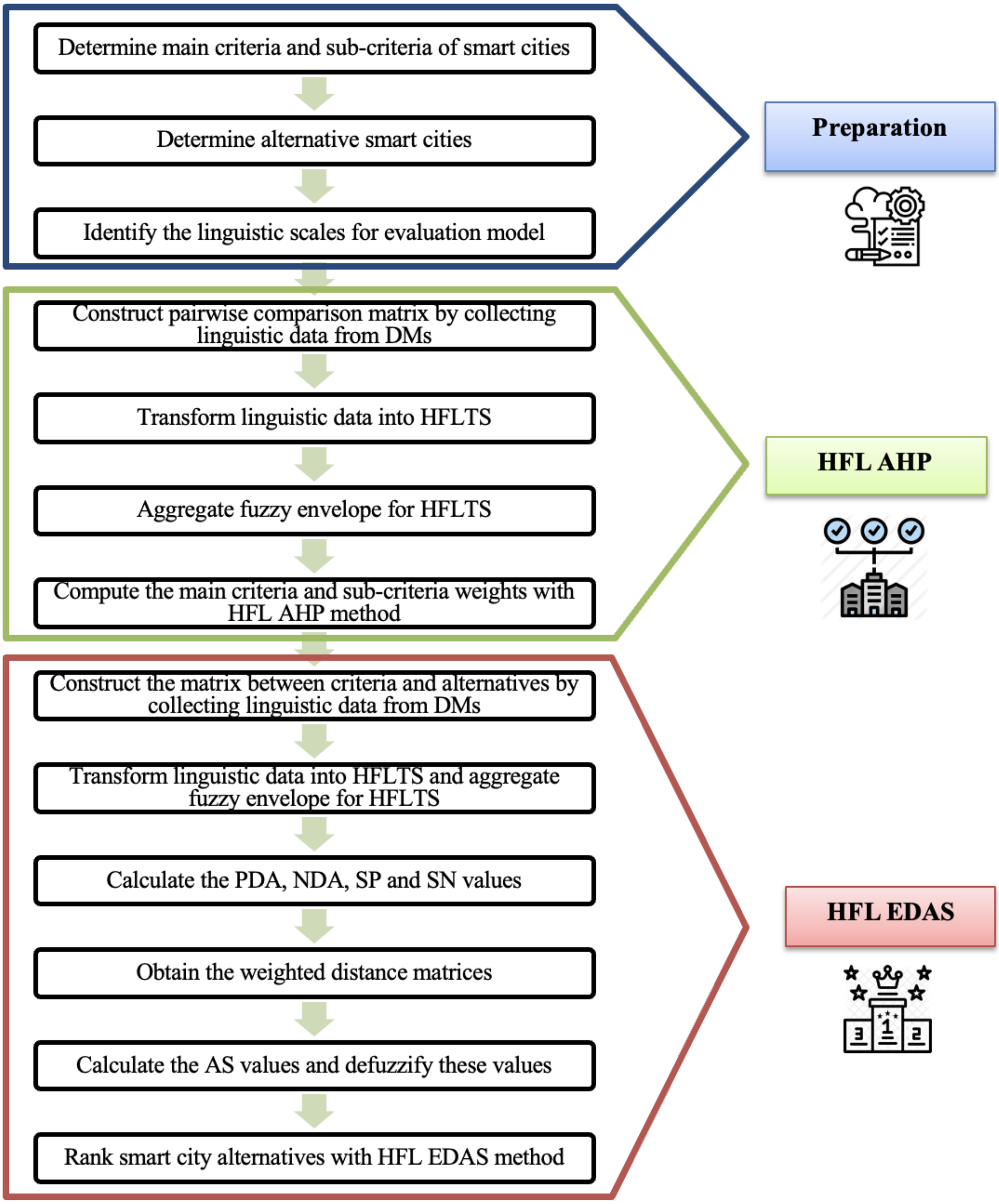
Step 2. Calculation of the weights of the criteria using HFL AHP method.

Step 3. Ranking smart cities with the HFL EDAS method using the criteria.

For determining the final relative weights of criteria, the HFL AHP approach is used. It is focused on pairwise comparisons with hesitant choices and provides state management capabilities to managers. It is a method that helps administrators in a dynamic world to categorize priorities and paths.

HFL EDAS is an MCDM approach for evaluating options in linguistic expressions in a hesitant scenario, determining their distances from the ideal answer, and selecting the best choice. Figure 1 depicts the flowchart for this technique.

Figure 1. Flowchart of the Proposed Methodology



3.1. HFL AHP Method for Weighting Criteria

One of the most implemented techniques in MCDM is the AHP method, developed by Saaty (1980). A powerful and clear decision-making tool is the rating of several criteria. In the MCDM process, hesitancy is a common phenomenon and if the MCDM process is in an uncertain environment, AHP is used based on hesitancy (Zhu et al., 2016).

In literature, Mousavi et al. (2014) proposed the hesitant AHP method for bridge construction. The hesitant AHP method with group decision-making (GDM) is introduced by Zhu and Xu (2014) for water conservancy in China. Onar et al. (2016) used the QFD approach with HFS-based AHP and TOPSIS. In another study, AHP based on HFLTS for performance evaluation in the cargo sector is proposed by Tüysüz and Şimşek (2017). In used-car management, Mi et al. (2018) introduced a hesitant AHP approach to consistency checking. In the industrial maintenance management field, the classical, fuzzy, hesitant, and intuitionistic AHP was compared by Ohta (2020). HFL-based AHP is used also recently by Colak and Kaya (2020) to prioritize the energy storage technologies' evaluation criteria. Kumar et al. (2020) presented the hesitant AHP- TOPSIS methods for evaluating the security and durability of web applications. The solar energy plant project selection with HFL AHP is provided by Coban (2020). Ayağ and Samanlioglu (2021) introduced the HFL AHP-TOPSIS methodology to evaluate ERP software packages. Büyüközkan et al. (2021) presented the HFL AHP-MABAC approach for health tourism strategy selection. The evaluation of CAD software packages is proposed with hesitant fuzzy by Ayağ (2022). Yilanci et al. (2023) identified the roles of energy and economic factors with the hesitant fuzzy AHP method.

The preliminaries of HFLTS are presented in the literature. The importance degree of criteria is computed by HFL AHP (Onar et al., 2016) with the following steps:

Step 1. DMs created pairwise matrices with obtained assessments with HFLTS, which are obtained with linguistic expressions in Table 4.

Table 4. Scale for HFL AHP

Linguistic terms	si	Abb.	Triangular fuzzy number
Absolutely high importance	s10	(AHI)	(7,9,9)
Very high importance	s9	(VHI)	(5,7,9)
Essentially high importance	s8	(ESHI)	(3,5,7)
Weakly high importance	s7	(WHI)	(1,3,5)
Equally high importance	s6	(EHI)	(1,1,3)
Exactly equal	s5	(EE)	(1,1,1)
Equally low importance	s4	(ELI)	(0.33,1,1)
Weakly low importance	s3	(WLI)	(0.2,0.33,1)
Essentially low importance	s2	(ESLI)	(0.14,0.2,0.33)
Very low importance	s1	(VLI)	(0.11,0.14,0.2)
Absolutely low importance	s0	(ALI)	(0.11,0.11,0.14)

Step 2. HFLTS' fuzzy envelope is built with the OWA operator (Liu and Rodriguez, 2014). With this operator, a trapezoidal fuzzy number (TrFN) is obtained.

$A = \{a_1, a_2, \dots, a_n\}$ is a set of elements to be aggregated. The OWA operator F is calculated as

$$F(a_1, a_2, \dots, a_n) = wb^T = \sum_{i=1}^{n} w_i b_i, \tag{1}$$

where the weighing vector $w = (w_1, w_2, \dots, w_n)^T$ is composed of $w_i \in [0, 1]$ and $\sum_{i=1}^{n} w_i = 1$; and b is the related ordered value vector. Here, $b_i \in$ b is A's i^{th} largest value.

Assume the evaluations of the DMs vary between s_i and s_j. Then $s_0 \leq s_i < s_j \leq s_g$. The TrFN membership function A = (α,β,γ,δ) are computed as:

$$\alpha = \min \{a_L^i, a_M^i, a_M^{i+1}, \dots, a_M^j, a_R^j\} = a_L^i \tag{2}$$

$$\delta = \max \{a_L^i, a_M^i, a_M^{i+1}, \dots, a_M^j, a_R^j\} = a_R^i \tag{3}$$

$$\beta = \begin{cases} a_M^i & if\ i+1=j \\ OWA_{w^2}\left(a_M^i, \dots, a_M^{\frac{i+j}{2}}\right) & if\ i+j\ is\ even \\ OWA_{w^2}\left(a_M^i, \dots, a_M^{\frac{i+j-1}{2}}\right) & if\ i+j\ is\ odd \end{cases} \tag{4}$$

$$\gamma = \begin{cases} a_M^{i+1} & if\ i+1=j \\ OWA_{w^1}\left(a_M^j, a_M^{j-1}, \dots, a_M^{\frac{i+j}{2}}\right) & if\ i+j\ is\ even \\ OWA_{w^1}\left(a_M^j, a_M^{j-1}, \dots, a_M^{\frac{i+j+1}{2}}\right) & if\ i+j\ is\ odd \end{cases} \tag{5}$$

OWA operator necessitates weight vectors. 1st and 2nd type weights are determined with the parameter in the interval [0, 1] (Liu and Rodriguez, 2014).

Step 3. The pairwise comparison matrix ($\tilde{C}$) includes the aggregated TrFN. It is generated in Step 2 where $\widetilde{c_{ij}} = (c_{ijl}, c_{ijm1}, c_{ijm2}, c_{iju})$ is acquired. The reciprocal values are computed as:

$$\widetilde{c_{ij}} = \left(\frac{1}{\mathrm{ciju}}, \frac{1}{\mathrm{cijm2}}, \frac{1}{\mathrm{cijm1}}, \frac{1}{\mathrm{cijl}}\right) \tag{6}$$

Step 4. It is controlled whether each matrix $(\tilde{C})$ is sufficiently consistent based on the de-fuzzification of these matrices (Tüysüz and Şimşek, 2017).

$A = (l, m_1, m_2, u)$ is turned to a crisp number with (7).

$$\mu_d = \frac{l+m_1+m_2+u}{6} \tag{7}$$

After the de-fuzzification step, the CR (consistency ratio) is obtained using (8) and (9).

$$CI = \frac{\lambda_{max}-n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

where CI is the consistency index, λ_{max} refers to the largest eigenvector, n is the number of criteria and the random index is RI.

Step 5. The fuzzy geometric mean is determined with (10) for each row ($\tilde{r}_i$).

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \ldots \otimes \tilde{c}_{in})^{1/n} \tag{10}$$

Step 6. Each criterion's fuzzy weight ($\tilde{w}_i^{CR}$) is determined with ($\tilde{r}_i$) values as:

$$\tilde{w}_i^{CR} = \tilde{r}_i \otimes (\tilde{r}_1 \otimes \tilde{r}_2 \ldots \otimes \tilde{r}_n)^{-1} \tag{11}$$

Step 7. Sub-criteria global weights are calculated where $\tilde{w}_{ij}^G$ the global weight of sub-criteria.

$$\tilde{w}_{ij}^G = \tilde{w}_i^{CR} \times \tilde{w}_j^{CR} \tag{12}$$

Step 8. TrFN $\tilde{w}_{ij}^G$ are de-fuzzified with (13). These de-fuzzified values are normalized with (14).

$$w_{ij}^G = \frac{\alpha+2\beta+2\gamma+\delta}{6} \tag{13}$$

$$w_{ij}^N = \frac{w_{ij}^G}{\sum_i \sum_j w_{ij}^G} \tag{14}$$

3.2. HFL EDAS Method for Evaluating Alternatives

Ghorabaee et al. (2016) introduce the EDAS approach with fuzzy logic for the supplier selection problem for the first time in the literature. The EDAS approach was furthermore integrated with the neutrosophic sets (Peng and Liu, 2017; Karaşan and Kahraman, 2018; Wang et al., 2019). Some authors have developed an intuitionistic fuzzy EDAS method. This method has been used in the assessment of landfills (Kahraman et al., 2017). An interval type-2 fuzzy EDAS methodology is developed for selecting suppliers (Ghorabaee et al., 2017).

In the literature, EDAS is combined with sophisticated fuzzy approaches. Kutlu Gündoğdu et al. (2018) offer a hesitant fuzzy EDAS for hospital selection, using various aggregation operators with and without de-fuzzification. Feng et al. (2018) describe an expanded HFL EDAS technique. Liu et al. (2023) proposed using hesitant fuzzy numbers in the EDAS technique for selecting energy projects. However, the EDAS approach based on HFLTS with the envelope will be used for the first time in this study.

Using this method, alternatives are compared to each other with HFLTS. The steps of HFL EDAS are presented next (Ghorabaee et al., 2016):

Step 1: The matrix between criteria and alternatives is structured with the linguistic scale shown in Table 5, which is converted to fuzzy numbers with fuzzy envelope, as shown in (2)-(5).

Step 2: The criteria weights are determined as $\tilde{w}_j$.

Step 3: The positive (PDA) and negative (NDA) hesitant fuzzy L_1 distances to the ideal fuzzy solution are found by avoiding non-prospective assessments:

$$\widetilde{pda}_{ij} = \psi(L_1(\tilde{x}_{ij}, \widetilde{av}_j) \tag{15}$$

$$\widetilde{nda}_{ij} = \psi(L_1(\widetilde{av}_j, \tilde{x}_{ij}) \tag{16}$$

$$\text{with } \psi(\tilde{A}) = \begin{cases} \tilde{A} & if\ k(\tilde{A}) > 0 \\ \tilde{0} & if\ k(\tilde{A}) \leq 0 \end{cases} \tag{17}$$

$$k(\tilde{A}) = \frac{a_1+a_4}{2} + (a_2 - a_1 - a_4 + a_3) \tag{18}$$

where $\widetilde{av}_j$ represents the average solutions matrix and $\kappa(\widetilde{av}_j)$ represents a de-fuzzified number.

Table 5. Linguistic scale for HFL EDAS

Linguistic term	S_i	Abb.	Fuzzy Numbers
None	s_{-3}	N	(0,0,0.17)
Very Low	s_{-2}	VL	(0,0.17,0.33)
Low	s_{-1}	L	(0.17,0.33,0.5)
Medium	s_0	M	(0.33,0.5,0.67)
High	s_1	H	(0.5,0.67,0.83)
Very High	s_2	VH	(0.67,0.83,1)
Perfect	s_3	P	(0.83,1,1)

In this study, different L_1 distances are integrated into this method. Here, $a = (a_1, a_2, \ldots a_m)$ and $b = (b_1, b_2, \ldots b_m)$ are two separate points in an m-dimensional vector space.

Manhattan distance: It is the sum of absolute differences of their coordinate:

$$d_{Man} = \sum_{i=1}^{m} |a_i - b_i| \tag{19}$$

Step 4: It computes the weighted sum of the PDA and NDA.

$$\widetilde{sp}_i = \oplus_{j=1}^{m} (\tilde{w}_j \otimes \widetilde{pda}_{ij}) \tag{20}$$

$$\widetilde{sn}_i = \oplus_{j=1}^{m} (\tilde{w}_j \otimes \widetilde{nda}_{ij}) \tag{21}$$

Step 5: The values for all alternatives are normalized using (22).

$$\widetilde{nsp}_i = \frac{\widetilde{sp}_i}{\max_i(\kappa(\widetilde{sp}_i))} \tag{22}$$

$$\widetilde{nsn}_i = 1 - \frac{\widetilde{sn}_i}{\max_i(\kappa(\widetilde{sn}_i))} \tag{23}$$

Step 6: Compute the appraisal score ($\widetilde{as}_i$) of each alternative.

$$\widetilde{as}_i = \frac{1}{2} (\widetilde{nsp}_i \oplus \widetilde{nsn}_i) \tag{24}$$

Step 7: The alternatives based on their final values are ranked.

4. APPLICATION

The smart city strategy to addressing the difficulties of an increasing population includes several components. Studies on smart city models have lately been expedited to help enhance the degree of social prosperity in living areas that have become a complicated network, allowing them to expand and manage growth in a sustainable manner. These studies show a variety of smart city models. It is important to examine the current state of cities and establish their ranking while migrating to a new configuration.

Smart cities are one of the most popular subjects on the government agenda. It is a concept for urban space development that represents the integration of urban assets and resources via the safe use of information technology (Public Technology Platform Report, 2016). According to the report, the following notions emerge when describing a smart city:

- Developing urban apps suitable with technology,
- Linking apps and platforms,
- Governance – administering the city with the citizen,
- Making efficient use of energy resources,
- Making good use of water resources,
- Nature and harmony with citizen,
- Intelligent transportation, infrastructure, and buildings,
- Managing assets sustainably,
- More rapid adaptability to changing situations.

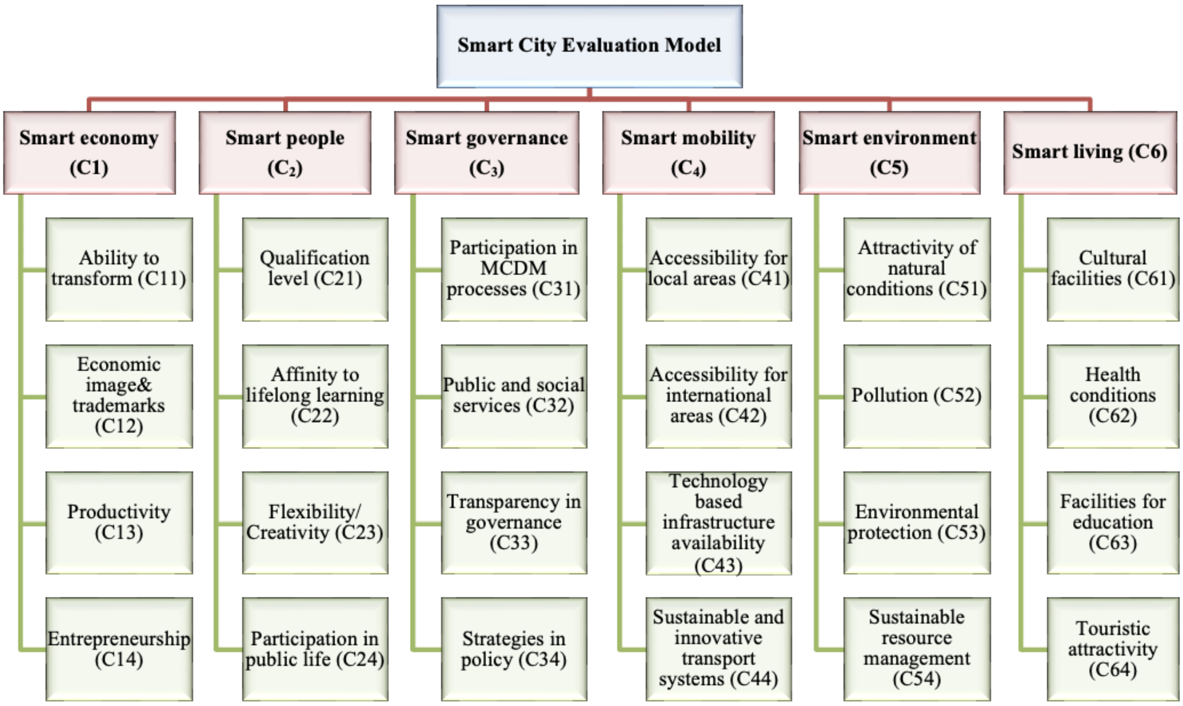
Smart city components are characteristic features of cities that aim to improve their socio-economic, logistical, competitive and ecological performance and to have a long-term sustainable performance.

In this study, the proposed model's application is demonstrated in an application to validate its usefulness. A technology firm named 'ABC' plans to invest in the field of digital technologies for cities. However, there are many cities in the world. ABC wants to invest by evaluating the level of "smartness" of cities. The smart city evaluation model is assessed by industrial experts. Two experts work in the department of smart city technologies projects in İSBAK IT and Smart City Technologies Inc. Two other experts work in a consulting firm working on sustainability issues. The fifth expert works at the academy in the field of smart cities and technologies. Each of the experts has sufficient knowledge and experience in smart cities.

4.1. Evaluation Criteria and Alternatives for Smart Cities

There are many academic and industrial studies on this subject. The criteria of our smart city model are identified based on a literature review and the professional opinions of industrial experts. These criteria are illustrated in Figure 2 and are mainly based on the model of Giffinger and Pichler-Milanović (2007). Six 'smart' criteria are determined accordingly: living, economy, people, governance, environment, and mobility. These criteria are regarded as the relevant group characterizing a smart city. Furthermore, under these 6 main criteria, there are 24 sub-criteria that represent the most significant aspects of each smart characteristic.

Figure 2. The Smart City Evaluation Model



To examine the ranking in the reports, smart cities are evaluated with analytical methods. Giffinger and Pichler-Milanović (2007) consider medium-sized cities and their development perspectives, not Europe's leading metropolises, when evaluating smart cities. The 6 cities determined in this context are as follows: A1 is Aalborg in Denmark, A2 is Tampere in Finland, A3 is Luxembourg, A4 is Aarhus in Denmark, A5 is Odense in Denmark and A6 is Turku in Finland. The main criteria are the following:

Smart economy: Cities often serve as the foundation for national economies. Each city should assess its own strengths and shortcomings when developing its economic models and determining future prospects. Cities must be prepared for the future. City economic movements must be inventive, entrepreneurial, productive, labor-market adaptable, and globally efficient (Deloitte Report, 2015). Smart economic movements incorporate the ideals of smart, sustainable, and inclusive growth. The new smart economy model restores idle resources to the economy while also ensuring individual savings (Hollands, 2008).

Smart people: A smart city needs smart citizens to succeed in all activities. The presence of citizens who are ready to take action in smart urban life will present new arrangements that enable creativity, innovation, and variety (ASCIMER, 2017).

Smart governance: Smart governments utilize accessible technologies to arrange the exercises carried out by different districts, accomplish cooperative energies through collaborations with different partners, and connect citizens' needs to improve trust in the general population organizations (Di Bella et al., 2015; Public Technology Platform, 2016). Citizens' engagement in the planning and management processes of the public and commercial sectors, local governments, non-governmental organizations, and universities is critical to the success of smart city applications (Giang et al., 2017).

Smart mobility: Smart mobility aims to present an effective, clean, and sustainable transport system for individuals and businesses. It uses accessible technologies to give data to clients, organizers, and transport administrators, to upgrade multimodality by enhancing the coordination and combination of various transportation modes (Deloitte Report, 2015). It helps to diminish the traffic and manage the simple moving of products or travel for individuals. Furthermore, it additionally helps to avoid traffic jams, reducing pollution and advancing a more advantageous life.

Smart environment: Smart environment gathers and processes information from different networks, users, and city resources to provide useful inputs to city infrastructure planning for achieving a more efficient and sustainable urban environment (Urban Hub, 2017). Smart energy helps in structuring and executing different methodologies to cut down power consumption. Integration of the Internet of Things (IoT) helps urban areas optimize power creation, enhance the network of executives, and effectively distribute energy production (ASCIMER, 2017).

Smart living: Smart buildings incorporate distinctive physical frameworks in buildings, such as systems for building automation, energy management, lighting control, fire and life safety control, and intelligent parking guidance. All the distinctive frameworks in a building demonstration are together for optimization and productivity. Smart building frameworks can enhance energy efficiency in buildings, diminish waste, and ensure ideal utilization of water with operational effectiveness and inhabitant satisfaction (Deloitte Report, 2015; Public Technology Platform, 2016).

4.2. Weighting Criteria using HFL AHP Method

DMs use the linguistic scale in Table 4 to assess the criteria. For the main criteria, supplied by the DMs using the linguistic scale, Table 6 lists these pairwise comparisons. The sub-criteria are formed as in Table 6.

Table 6. Pairwise Comparisons of the Main Criteria

	C1	C2	C3	C4	C5	C6
C1	EE	btw. ESHI and AHI	btw. EHI and WHI	btw. ESLI and ELI	btw. ESLI and ELI	btw. ELI and EHI
C2		EE	btw. WHI and ESHI	btw. ELI and EHI	btw. ELI and EHI	btw. ESLI and ELI
C3			EE	btw. ALI and VLI	btw. ESLI and ELI	btw. ELI and EHI
C4				EE	btw. ELI and EHI	btw. EHI and WHI
C5					EE	btw. EHI and WHI
C6						EE

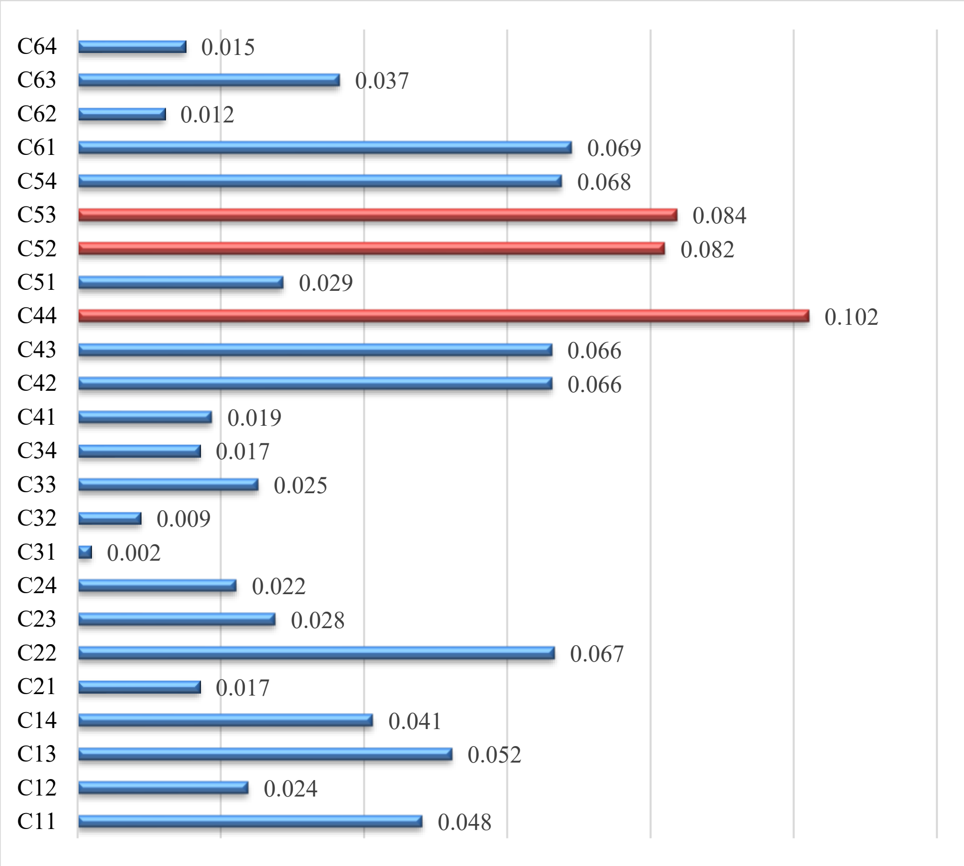
With the aid of the OWA operator and Eqs. (1)-(5), these linguistic expressions in Table 6 are converted into TrFN with a fuzzy envelope for the main criteria. By using equations, geometric means and weights of each criterion are determined. The normalized weights of the main criteria as seen in Table 7.

Table 7. Pairwise Comparison Values and Main Criteria's Normalized Weights

	C1	C2	C3	C4	C5	C6	Normalized Weights
C1	(1,1,1,1)	(3,6.78,7.22,9)	(1,1,3,5)	(0.14,0.32,0.34,1)	(0.14,0.32,0.34,1)	(0.3,1,1,3)	(0.036,0.126,0.196,0.735)
C2	(0.11,0.14,0.14,0.33)	(1,1,1,1)	(1,3,5,7)	(0.3,1,1,3)	(0.3,1,1,3)	(0.14,0.32,0.34,1)	(0.024,0.096,0.132,0.538)
C3	(0.2,0.33,1,1)	(0.14,0.2,0.33,1)	(1,1,1,1)	(0.11,0.11,0.14,0.2)	(0.14,0.32,0.34,1)	(0.3,1,1,3)	(0.016,0.049,0.084,0.297)
C4	(1,3,3,7)	(0.33,1,1,3)	(5,7,9,9)	(1,1,1,1)	(0.3,1,1,3)	(1,1,3,5)	(0.063,0.223,0.350,1.222)
C5	(1,3,3,7)	(0.33,1,1,3)	(1,3,3,7)	(0.33,1,1,3)	(1,1,1,1)	(1,1,3,5)	(0.049,0.193,0.291,1.172)
C6	(0.33,1,1,3)	(1,3,3,7)	(0.33,1,1,3)	(0.2,0.33,1,1)	(0.2,0.33,1,1)	(1,1,1,1)	(0.028,0.111,0.202,0.647)

The CR is determined for six main criteria in order to verify the consistency, and DMs' evaluations are found to be strongly reliable according to the results of the consistency. For the sub-criteria, these steps are replicated and, finally, criteria weights are determined by using Eqs. (10)-(14) and Figure 3 shows the normalized criteria weights.

Figure 3. Weights of Criteria



The HFL AHP approach concludes with the calculation of the criterion weights. The most important criteria are "Sustainable, innovative and safe transport systems (C44)" the 2nd most important criterion is "Pollution (C52)" and the 3rd one is "Environmental protection (C53)".

4.3. Evaluating Smart Cities using HFL EDAS Method

As seen in Table 8, the decision matrix connecting criteria and alternatives is developed with respect to the assessment of DMs by using linguistic expressions in Table 5. Using the OWA operator and the equations (1)-(5), the linguistic words mentioned in Table 8 are converted into TrFN with a fuzzy envelope.

Table 8. Evaluation Matrix for Smart Cities

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	at least H	at most L	at least VH	at least H	btw. L and H	at least VH	btw. M and VH	btw. L and H	btw. M and VH	btw. L and H	btw. M and VH	btw. M and VH
A2	at least H	btw. L and H	at least VH	btw. L and H	at least H	at most VL	at least H	btw. L and H	at most L	at least VH	btw. L and H	at least VH
A3	btw. M and VH	btw. M and VH	btw. L and H	btw. VL and M	btw. VL and M	btw. L and H	btw. L and H	btw. L and H	btw. L and H	btw. L and H	btw. L and H	btw. L and H
A4	btw. M and VH	at least H	btw. M and VH	btw. M and VH	btw. M and VH	at most L	btw. L and H	btw. VL and M	btw. VL and H	at least H	at least H	at least H
A5	btw. M and VH	btw. L and H	btw. M and VH	at least H	btw. L and H	at least VH	btw. L and H	at least H	at most VL	at least H	btw. L and H	at most L
A6	btw. L and H	btw. L and H	btw. L and H	btw. L and H	btw. M and VH	btw. L and H	btw. VL and M	btw. L and H	btw. L and H	btw. L and H	btw. L and H	at most L

	C41	C42	C43	C44	C51	C52	C53	C54	C61	C62	C63	C64
A1	at most L	at least VH	at least H	btw. L and H	btw. M and VH	btw. L and H	btw. M and VH	at most L	at least VH	at least H	btw. L and H	btw. M and VH
A2	btw. L and H	at least VH	btw. L and H	btw. L and H	at most L	at least VH	btw. L and H	btw. L and H	at least VH	btw. L and H	at least VH	btw. L and H
A3	btw. M and VH	btw. L and H	btw. VL and M	btw. L and H	btw. L and H	btw. L and H	btw. L and H	btw. M and VH	btw. L and H	btw. VL and M	btw. L and H	btw. L and H
A4	at least H	btw. M and VH	btw. M and VH	btw. VL and M	btw. VL and M	at least H	at least H	at least H	btw. M and VH	btw. M and VH	at least H	at least H
A5	at least VH	btw. L and H	at least VH	btw. L and H	btw. M and VH	btw. L and H	btw. M and VH	at least H	btw. M and VH	btw. M and VH	btw. L and H	btw. M and VH
A6	btw. M and VH	btw. L and H	btw. M and VH	at least VH	btw. M and VH	btw. L and H	btw. M and VH	btw. L and H	btw. M and VH	btw. M and VH	at most L	at least VH

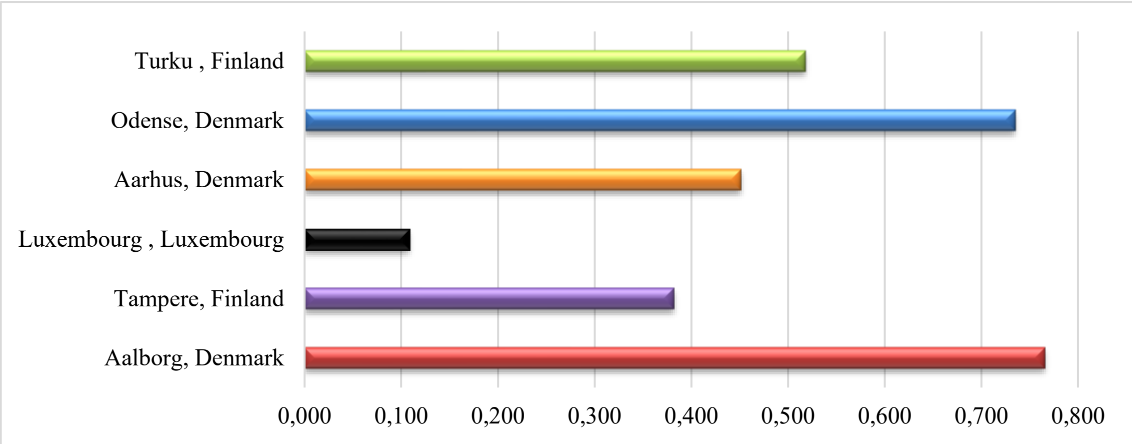
The average value of each criterion is calculated. PDA, NDA, SP, and SN values are computed with equations (15)-(21). The weighted matrix is normalized by using equations (22) and (23). Evaluations' average of positive and negative distances to the ideal solution (AS) is computed and these values are de-fuzzified. Table 9 shows the results.

Table 9. Evaluation Results for Smart City Alternatives

Alternatives	NSP	NSN	AS	Ranking
A1	0.884	0.648	0.766	1
A2	0.665	0.100	0.382	5
A3	0.217	0.000	0.109	6
A4	0.592	0.311	0.452	4
A5	1.000	0.471	0.735	2
A6	0.658	0.379	0.518	3

As a result, Aalborg (A1) has become the best smart city among six alternatives with the final value. The other cities are ranked as Odense (A5), Turku (A6), Aarhus (A4), Tampere (A2), and Luxembourg (A3), respectively (Figure 4).

Figure 4. Ranking of the Smart Cities



5. MANAGERIAL IMPLICATIONS AND DISCUSSIONS

Cities have begun to evaluate new technologies and innovative approaches to compete in an interconnected economy and sustainably ensure the well-being of the citizens. As a result of this evaluation, the smart city approach, which meets the expectations and problems of interoperable systems based on data and expertise, developed in cooperation with stakeholders, is a solution.

The objectives of the smart city concept are:

- making the current and future aspirations of the city a driving force in all systems,
- to be able to carry out physical, social and digital planning together,
- to anticipate, identify and solve emerging problems in a systematic, agile and sustainable manner,
- developing innovative solutions by facilitating the interaction between institutional systems in the city.

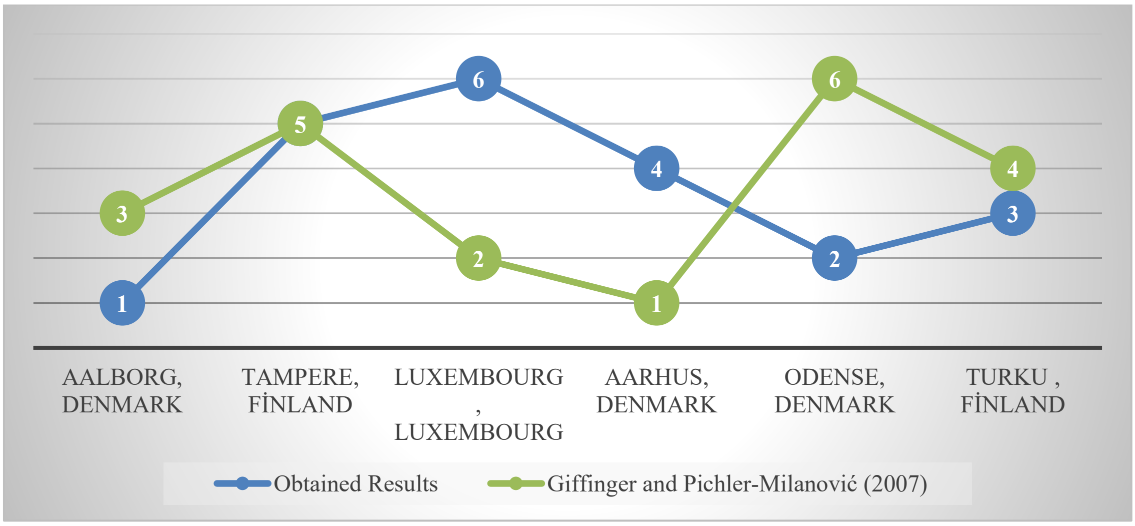
In this context, the smart city concept is handled by supporting with HFL MCDM approach. The weights of smart city selection criteria are calculated with HFL AHP. According to the obtained results, the three most appropriate criteria were ranked as “Sustainable, innovative and safe transport systems (C44)”, “Pollution (C52)” and “Environmental protection (C53)”. The HFL EDAS method is used for the ranking of smart cities. According to the obtained results, the smartest city is Aalborg (A1). A similar ranking is obtained with the HFL MABAC, HFL COPRAS, and HFL TOPSIS methods.

With a population of 130,000 and an urban area of 139 km², Aalborg is an industrial and university city in the north of Denmark. Today, it is strategically situated in Northern Jutland County and serves as the county's city center. With a population of 161,000, Aalborg is Denmark's fourth-largest city (Giffinger and Pichler-Milanović, 2007).

Aalborg is characterized by a high level of entrepreneurship and local solutions. As part of smart urban development, ubiquitous IT and technology, networks are an important part of the Aalborg infrastructure. The potential of the city to be "smart" comes from here. This city manages the dynamics, decision, and implementation processes of the multi-stakeholder and dimensional ecosystem with effective, sustainable, and smart solutions. With advanced technologies such as IoT software applications, the integration of estimated maintenance and service, smart inventory, connected device analysis, sensors, and business data are provided. In this city, automatic counting is done with the sensors placed at the intersections and the transition advantage to be given to the road where the vehicle is more is determined automatically. Thus, unnecessary waiting is prevented in the transitions with a high number of vehicles, the traffic density is reduced, and the greenhouse gas emission rate of vehicles in the city is minimized.

The ranking of smart cities by obtained results in this study and Giffinger and Pichler-Milanović (2007) is shown in Figure 5. The results show that the ranking of cities varies. Giffinger and Pichler-Milanović (2007) use statistical methods to make this evaluation. Nevertheless, to get reasonable results, it is necessary to provide good coverage of all cities. For this reason, an evaluation covering all cities is presented through the use of MCDM methods. To obtain more realistic results, a hesitant fuzzy approach is used to enable DMs to express their opinions with linguistic expressions. Thus, they make evaluations of all cities in a more flexible environment.

Figure 5. Ranking of the Smart Cities by Obtained Results and Giffinger and Pichler-Milanović (2007)



This systematic assessment approach will help planners and analysts evaluate and make better-informed decisions about the value of the smart city concept. This research should be used by management as a policy support framework method to make initial investment decisions for smart cities.

6. CONCLUSION

The rapid growth of urban populations creates problems in the distribution of cities' limited resources. To tackle these problems effectively, governments must have access to adequate resources. The smart city concept offers important approaches to make cities more liveable. By incorporating ICTs into smart city strategies, more efficient and practical solutions are provided for a range of urban problems. The integration of digital technologies into smart city frameworks not only improves city governance, but also increases its resilience to future challenges.

To solve problems, MCDM approaches have been developed since judgment difficulties with a wide range of criteria and alternatives are complicated. In real-life MCDM problems, determining when there are not enough requirements and appropriate details is a difficulty. Many separate and conflicting parameters require the complicated structure of the problem. DMs also have difficulty voicing their feelings in numbers since these quantitative values are far from their way of thought in real life. In addition, instead of crisp numbers, DMs can choose to express their thoughts more easily with words. The uncertainty of this MCDM problem is resolved by the HFLTS.

In this paper, the evaluation of smart cities was taken as a problem that can be addressed with integrated HFL MCDM methods. MCDM methods are available for the solution of the problems caused by the complexity of a large number of criteria and alternatives. The mixed structure of smart city evaluation involves various criteria. However, it is difficult to decide on smart cities, and the HFL MCDM approach overcomes this problem. First, the HFL AHP method was applied to obtain criteria weights. Once this was accomplished, selected smart cities were compared to each other using the HFL EDAS technique. The proposed method’s usability was tested on an application. The results of this application suggest that Aalborg (A1) was the smartest city among its peers.

In light of the applied methods and the obtained results, the contributions of this article are as follows:

- This article proposes for the first time in the literature the combination of HFL AHP and HFL EDAS methods with the fuzzy envelope, which are found in the literature but not used in an integrated way.
- This article presents how verbal expression can be used effectively for MCDM and how HFL approaches can overcome uncertainty.

• Finally, this article contributes to the analytically lacking smart city literature by presenting a new and comprehensive HFL MCDM methodology.

For future research, the hesitant fuzzy aggregation operators can be used to aggregate DMs' evaluations. Also, the proposed model and methodology can be used to rank other cities.

ACKNOWLEDGEMENT

The authors kindly thank the industrial experts for their feedback and support. The Scientific Research Projects Commission of Galatasaray University has financed this study (FBA-2024-1255).

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Hakem Değerlendirmesi: Dış bağımsız.

Çıkar Çatışması: Yazar çıkar çatışması bildirmemiştir.

Finansal Destek: Yazar bu çalışma için finansal destek almadığını beyan etmiştir.

Teşekkür: -

Peer-review: Externally peer-reviewed.

Conflict of Interest: The author has no conflict of interest to declare.

Grant Support: The author declared that this study has received no financial support.

Acknowledgement: -