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# Assessment of Smart Waste Management Systems with Spherical AHP Method

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**Abstract.** The increasing population and resource constraints in the world have made life in cities complex and difficult to manage. Especially the need for energy, water and other resources has become alarming, and the management and disposal of waste materials has also emerged as an important area of risk. Although waste management has been improved over time by methods such as recycling, it cannot fully solve the problems that have occurred. The need for land-fill in cities, health and environmental problems have created the need for a more effective system to solve problems. It has become vital to create a sustainable life in cities that is more efficient, and which consumes less resources and improves the desired quality of life. The increase in these needs and especially developments in information technologies have created the "smart city" concept and applications that bring great innovations and facilities in many areas such as transportation, communication, health, security, energy efficiency, water use and waste management. Smart Waste Management Systems (SWMS) emerging in this context make an important contribution to the sustainability of today's cities and play an important role in carrying human life into the future. In addition, it increases the quality of life with cost optimization, energy efficiency, information management, time saving, improving hygiene, and reduction in traffic, noise, bad odor and carbon emissions. This operation, defined as "smart", also sets an example for the use of artificial intelligence. The levels of the structures, processes and performances of the existing SWMSs show their success and thus the level of providing a sustainable life. The evaluation of these currently developing systems with their components will guide all relevant actors in the improvement of existing systems. Lack of a clear criterion used in the evaluation of SWMS required this assessment to be made with the MCDM (multi-criteria decision making) methods, which makes it possible to evaluate both objective and subjective criteria. As evaluating SWMS problem needs both tangible and intangible data, using fuzzy logic is a useful tool to solve the problem. Therefore, in the application section, the Spherical fuzzy AHP (Analytic Hierarchy Process) method is used to handle determined problem. In the application section, three alternatives are evaluated under four determined criteria. Results show that the problem is handled with Spherical fuzzy AHP method by efficiently and effectively.

**Keywords:** Sustainability, Smart City, Smart Waste Management System, Multi Criteria Decision Making, Fuzzy Sets Theory, Spherical AHP Method.

## 1 Introduction

Today, the effects of smart systems that analyze digital data and reach accurate results are increasing rapidly. The analysis of real-time data with algorithmic techniques and engineering principles and their use in decision making create new and interesting research areas. Smart systems (SSs) include sensing, actuation, and control functions to identify and analyze a situation and make predictive or adaptive decisions based on available data, thereby taking intelligent actions [1]. SSs are software assets that perform a series of intelligent actions on behalf of a user or another program, which will involve making decisions using available data in a predictive or adaptive manner. SSs integrate the human mind with machine operations. They are dynamic and unstable, introducing various applications from health, aviation, logistics and ICT (information and communications technology). The improvement of SSs in many sectors can be associated with the reality that SS will reduce critical global problems such as climate change, health, and waste management. The improvement, downsizing and cheapening of the components used in SSs cause the increase in integration of SSs. Internet connections of the objects used in the SSs and users also create the combination of SSs [2].

Smart cities (SCs) are at the forefront of the areas where the mentioned combination is seen very clearly. A SC is an urban area that uses different types of electronic IoT (internet of things) sensors to collect data and then use the insights from this data to efficiently manage assets, resources, and services. SCs increase the quality of life of people with physical, digital, and human systems compatible with the environment, offering a modern, competitive, functional, and sustainable future. They are cities supported by advanced vital technologies. For a city to be called a SC, it is expected to have the following systems and parameters [3, 4]:

- Sufficient amount of water and energy,
- Effective solid waste management system,
- A sustainable informatics and communication infrastructure,
- An effective public transport and the mobile system of this public transport,
- E-municipal services suitable for the era,
- A successful, planned and programmed environmental management system,
- Age-appropriate crisis and emergency response system.

The concept of "sustainability", which was introduced through the report "Our Common Future" published by the World Commission on Environment and Development in 1987 [5], maintains its importance and even increases day by day, as can be seen with the "17 Sustainable Development Goals" put forward by the UN [6]. The following statement was used in the report: "Humanity; It has the ability to make development sustainable by meeting daily needs without compromising the ability of nature to respond to the needs of future generations." and the spirit of sustainability has been revealed. Although the first thing that comes to mind when it comes to sustainability is the protection of the environment, the concept of sustainability is actually a holistic approach that includes ecological, economic, and social dimensions [7].

Smart waste management system (SWMS) is an energy-efficient, economic, and technology-oriented system that optimizes the containers' and waste collection vehicles' capacities by minimizing the time loss. Thanks to the SWMS, end-to-end system control and citizen satisfaction are ensured, traffic congestion, working hours, fuel consumption and carbon emissions are reduced with waste collection optimization. It digitizes waste management, making it efficient and traceable. On the software side, smart waste audits are performed through online tools that use data analysis to review waste generation data, current waste collection practices and costs, and current onsite recycling levels. The SWMS includes decision support systems and performs process management and optimization, waste collection optimization, internet-based solutions, and data analysis. SWMS has a data management center; this center integrates garbage trucks, garbage containers, sensors, and their maps in a network. SWMS is designed to solve the current complex and costly process of inefficient routes served by a fleet of trucks at arbitrary and unconnected schedules [8, 9].

SWMSs draw attention in the transformation of cities into a sustainable living space. Through the implementation of IOT (internet of things), digitalization, and ICT (information and communication technology), achieving sustainability in waste management is becoming more possible, reliable, transparent, efficient, and optimum in the industrial revolution 4.0 era. IOT and ICT applications can help reduce the time and resources required to provide better performance of waste management toward sustainable and SSs [10]. Industrial Revolution 4.0 has brought significant changes in global waste management and value changes [11]. SWMS's framework consists of five aspects, including governance, economy, social, environmental, and technological [12].

The choices of the users determine the development direction and future features of SWMS, which causes the decisions about SWMS to emerge as a multi criteria decision making (MCDM) problem. Evaluation of SWMSs may contain conflicting criteria and therefore requires expert evaluations through linguistic variables. For this purpose, Spherical AHP Method, which is a newly introduced method as an extension of fuzzy sets, is used.

Spherical fuzzy sets (SFSs) are suggested by Kutlu Gündoğdu and Kahraman [13]. SFSs are based on the spherical fuzzy distances and satisfy the condition as follows  $0 \leq \mu_{(x)}^2 + \nu_{(x)}^2 + \pi_{(x)}^2 \leq 1$ . The hesitancy degree is represented by  $\pi_{(x)}$  and hesitancy degree can be determined in the spherical representation based on the given membership and non-membership values. So, a decision maker's hesitancy may be specified independently of membership degrees and non-membership degrees.

In this study, we used a hybrid model including SFSs and AHP method. The method, named Spherical Fuzzy AHP, is utilized to solve SWMS selection decision making problem. The criteria are determined to evaluate SWMS selection problem, and steps of the algorithm are applied to the problem.

In the literature with related studies, it is possible to see the [waste management and](#) some important applications of SWMS. Kayakutlu et al. evaluated the regional scenarios in the conversion of waste-to-energy with Bayesian network analysis [14] and used Value Stream Map in the detection and optimization of waste [15]. [Yalçınkaya studied on a spatial modeling approach in organic waste management](#) [16]. [An IoT architecture was proposed for a proactive waste management by Aytaç and Korçak](#) [17]. Kamm et al. presented a case study that represent a smart device implementation in smart waste collection processes [18]. Nizetic et al. focused on smart technologies in their study for promotion of energy efficiency, utilization of sustainable resources and waste management [19]. A mobile application using IoT in the waste collection system proposed by Kang et al., in this system it is aimed to dispose of the e-wastes generated at home by the users [20]. Rabbani et.al proposed a model which combine the decision-making techniques and location routing model for industrial waste management [21]. Sarkar and Sarkar [22] presented a study on the reduction of consumed energy and waste in a sustainable biofuel system. Marques et al. [23] presented a model on a multi-level IoT-based smart city infrastructure management architecture and evaluated the performance of this model with a real waste management problem. Sharma et al. [24] presented a study on the major IoT barriers faced in realizing smart city waste management. In this study, they revealed that internet connection problems, lack of standardization, policy norms, guidelines and regulations are the issues that prevent smart cities from showing better development, especially in terms of waste management. Aazam et al. proposed a cloud-based SWM mechanism in their study [25]. Zhang et al, listed the barriers of SWM in China and prioritized them with fuzzy DEMATEL (Decision-Making Trial and Evaluation Laboratory) [26]. Murugesan et al. proposed a theoretical model of SWMS that uses WSN (Wireless Sensor Network) and IoT [27]. Abdallah et.al. presented a systematic research review that provides comprehensive analysis of the different AI models and techniques applied in SWM [10]. Sohag and Podder studied on an article where an IoT-based SWMS for sustainable urban life was presented [28]. Lu et al. presented an ICT based smart waste classification and collection system that is abstracted as a biobjective mathematical programming model to optimize the waste collection problem [29]. Esmailian et al. presented a review and concept paper about the future of waste management in smart and sustainable cities [30].

The rest of the paper is presented as follows: Steps of Spherical AHP are presented in Section 2, an application is given in Section 3, and Sensitivity Analysis is given in Section 4. Finally, conclusions are presented in Section 5.

## 2 Spherical AHP

This section covers the steps of the Spherical fuzzy AHP method.

### Step 1. Build the hierarchical structure

**Mis en forme :** Police par défaut, Couleur de police : Automatique

**Mis en forme :** Police par défaut, Police :12 pt, Couleur de police : Automatique

This step includes establishing a hierarchical structure. The hierarchical structure includes at least 3 levels; aim, which is at the top, attributes identified in the middle and alternatives at the bottom.

**Step 2.** Establish pairwise comparisons using spherical fuzzy judgment matrices.

Table 1 represents the linguistic terms with spherical numbers. After establishing the pairwise comparisons matrices, matrices need to be checked for consistency. For this purpose, linguistic terms are converted to their corresponding score indices, as seen in Table 1. After constructing pairwise comparison matrices, consistency formula, developed by Saaty [31], is applied.

**Table 1. Linguistic Scale**

Linguistic Expression	$(\mu, \nu, \pi)$	Score Index (SI)
Extremely preferred (ExP)	(0.9,0.1,0.0)	9
Very strongly preferred (VSP)	(0.8,0.2,0.1)	7
Strongly preferred (SP)	(0.7,0.3,0.2)	5
Moderately preferred (MP)	(0.6,0.4,0.3)	3
Equally preferred (EP)	(0.5,0.4,0.4)	1
Moderately low preferred (MLP)	(0.4,0.6,0.3)	1/3
Low preferred (LP)	(0.3,0.7,0.2)	1/5
Very low preferred (VLP)	(0.2,0.8,0.1)	1/7
Extremely low preferred (ELP)	(0.1,0.9,0.0)	1/9

**Step 3.** Compute the criteria and alternatives' local weights including spherical information.

In this step, Equation (1) is utilized to get local weight of each alternative.

$$SWAM_w(A_{S1}, \dots, A_{Sn}) = w_1 A_{S1} + w_2 A_{S2} + \dots + w_n A_{Sn} = \left( \frac{[1 - \prod_{i=1}^n (1 - \mu_{A_{S_i}}^2)^{w_i}]^{\frac{1}{2}}, \prod_{i=1}^n \nu_{A_{S_i}}^{w_i}, [\prod_{i=1}^n (1 - \mu_{A_{S_i}}^2)^{w_i} - \prod_{i=1}^n (1 - \mu_{A_{S_i}}^2 - \pi_{A_{S_i}}^2)^{w_i}]^{\frac{1}{2}}}{2} \right) \quad (1)$$

where  $w = 1/n$ .

**Step 4.** Calculate the spherical global weights.

In this step, Equation (2) is utilized to get Spherical fuzzy global weights.

$$\prod_{j=1}^n \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \otimes \tilde{A}_{S_{i2}} \dots \otimes \tilde{A}_{S_{in}} \quad \forall i$$

$$i. e. \tilde{A}_{S_{11}} \otimes \tilde{A}_{S_{12}} = \left( \mu_{\tilde{A}_{S_{11}}} \mu_{\tilde{A}_{S_{12}}}, \left( v_{\tilde{A}_{S_{11}}}^2 + v_{\tilde{A}_{S_{12}}}^2 - v_{\tilde{A}_{S_{11}}}^2 v_{\tilde{A}_{S_{12}}}^2 \right)^{1/2}, \left( \left( 1 - v_{\tilde{A}_{S_{12}}}^2 \right) \pi_{\tilde{A}_{S_{11}}}^2 + \left( 1 - v_{\tilde{A}_{S_{11}}}^2 \right) \pi_{\tilde{A}_{S_{12}}}^2 - \pi_{\tilde{A}_{S_{11}}}^2 \pi_{\tilde{A}_{S_{12}}}^2 \right)^{1/2} \right) \quad (2)$$

Then, the final score of each alternative is determined via Equation (3).

$$\begin{aligned} \tilde{F} &= \sum_{j=1}^n \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \oplus \tilde{A}_{S_{i2}} \dots \oplus \tilde{A}_{S_{in}} \quad \forall i \\ i. e. \tilde{A}_{S_{11}} \oplus \tilde{A}_{S_{12}} &= \left( \left( \mu_{\tilde{A}_{S_{11}}}^2 + \mu_{\tilde{A}_{S_{12}}}^2 - \mu_{\tilde{A}_{S_{11}}}^2 \mu_{\tilde{A}_{S_{12}}}^2 \right)^{1/2}, v_{\tilde{A}_{S_{11}}} v_{\tilde{A}_{S_{12}}}, \left( \left( 1 - \mu_{\tilde{A}_{S_{12}}}^2 \right) \pi_{\tilde{A}_{S_{11}}}^2 + \left( 1 - \mu_{\tilde{A}_{S_{11}}}^2 \right) \pi_{\tilde{A}_{S_{12}}}^2 - \pi_{\tilde{A}_{S_{11}}}^2 \pi_{\tilde{A}_{S_{12}}}^2 \right)^{1/2} \right) \quad (3) \end{aligned}$$

**Step 5.** The final score of each alternative is defuzzified by using the score function by Equation (4).

$$S(\tilde{W}_i^s) = \sqrt{100 * \left[ \left( 3\mu_{\tilde{A}_s} - \frac{\pi_{\tilde{A}_s}}{2} \right)^2 - \left( \pi_{\tilde{A}_s} - \frac{v_{\tilde{A}_s}}{2} \right)^2 \right]} \quad (4)$$

**Step 6.** At the last step, the alternatives are ordered according to their defuzzified final scores in descending order.

### 3 Application

In this part of the paper, the SWMS selection problem is handled by spherical AHP method. To the this aim, first four different alternatives are determined as follows; A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub>. After a literature review, four criteria have been determined. Criteria are Governance (C<sub>1</sub>), Social (C<sub>2</sub>), Environmental (C<sub>3</sub>), and Technological (C<sub>4</sub>). Pairwise comparison matrices are fulfilled by us after gathering data from different SWMS users' experience.

**Step 1.** The hierarchical structure is established as seen in Figure 1.



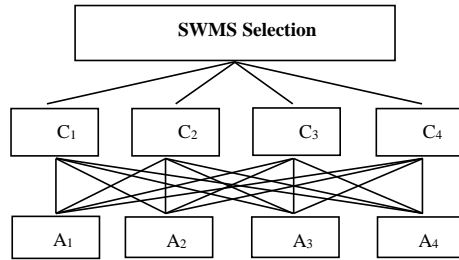


Figure 1. The hierarchical structure

**Step 2.** Pairwise comparisons are established as seen in Tables 2-6. Tables 2-6 also includes spherical weights ( $\tilde{w}^s$ ) and crisp weights ( $\bar{w}^s$ ), and consistency ratios (CR).

Table 2. Pairwise comparison of criteria

Criteria	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>
C <sub>1</sub>	EP	SP	VSP	SP
C <sub>2</sub>	LP	EP	MP	EP
C <sub>3</sub>	VLP	MLP	EP	MLP
C <sub>4</sub>	LP	EI	MP	EP
	$\tilde{w}^s$		$\bar{w}^s$	CR
C <sub>1</sub>	(0.70, 0.29, 0.22)		0.352	0.027
C <sub>2</sub>	(0.49, 0.46, 0.34)		0.232	
C <sub>3</sub>	(0.39, 0.58, 0.30)		0.184	
C <sub>4</sub>	(0.49, 0.46, 0.34)		0.232	

Table 3. Pairwise comparison of alternatives according to C1

C <sub>1</sub>	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
A <sub>1</sub>	EP	SP	MP	MP
A <sub>2</sub>	LP	EP	MLP	MLP
A <sub>3</sub>	MLP	MP	EP	LP
A <sub>4</sub>	MLP	MP	PP	EP
	$\tilde{w}^s$		$\bar{w}^s$	CR
A <sub>1</sub>	(0.61, 0.37, 0.30)		0.298	0.029
A <sub>2</sub>	(0.41, 0.56, 0.31)		0.190	
A <sub>3</sub>	(0.51, 0.44, 0.35)		0.239	
A <sub>4</sub>	(0.51, 0.44, 0.35)		0.239	

**Table 4. Pairwise comparison of alternatives according to C2**

$C_2$	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
A <sub>1</sub>	EP	MP	VSP	SP
A <sub>2</sub>	MLP	EP	MP	MP
A <sub>3</sub>	VLP	MLP	EP	MLP
A <sub>4</sub>	LP	MLP	MP	EP
	$\tilde{w}^s$		$\tilde{w}^s$	CR
A <sub>1</sub>	(0.67, 0.31, 0.25)		0.338	0.052
A <sub>2</sub>	(0.57, 0.41, 0.30)		0.278	
A <sub>3</sub>	(0.39, 0.58, 0.30)		0.184	
A <sub>4</sub>	(0.45, 0.53, 0.30)		0.216	

**Table 5. Pairwise comparison of alternatives according to C3**

$C_3$	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
A <sub>1</sub>	EP	MP	VLP	MLP
A <sub>2</sub>	MLP	EP	ELP	LP
A <sub>3</sub>	VSP	ExP	EP	MP
A <sub>4</sub>	MP	SP	MLP	EP
	$\tilde{w}^s$		$\tilde{w}^s$	CR
A <sub>1</sub>	(0.46, 0.53, 0.30)		0.218	0.033
A <sub>2</sub>	(0.36, 0.62, 0.28)		0.169	
A <sub>3</sub>	(0.76, 0.24, 0.20)		0.387	
A <sub>4</sub>	(0.57, 0.41, 0.30)		0.278	

**Table 6. Pairwise comparison of alternatives according to C4**

$C_4$	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
A <sub>1</sub>	EP	MP	SP	EP
A <sub>2</sub>	MLP	EP	MP	LP
A <sub>3</sub>	LP	MLP	EP	LP
A <sub>4</sub>	EP	SP	SP	EP
	$\tilde{w}^s$		$\tilde{w}^s$	CR
A <sub>1</sub>	(0.59, 0.37, 0.32)		0.284	0.043
A <sub>2</sub>	(0.47, 0.51, 0.31)		0.223	
A <sub>3</sub>	(0.39, 0.59, 0.29)		0.181	
A <sub>4</sub>	(0.62, 0.35, 0.30)		0.302	

**Step 3.** Spherical fuzzy local weights of alternatives are calculated as seen Table 7

**Table 7. Spherical fuzzy weighted matrix**

Alternatives	C <sub>1</sub>	C <sub>2</sub>
A <sub>1</sub>	(0.42, 0.46, 0.35)	(0.37, 0.51, 0.37)
A <sub>2</sub>	(0.28, 0.61, 0.35)	(0.28, 0.59, 0.40)
A <sub>3</sub>	(0.35, 0.51, 0.39)	(0.19, 0.70, 0.37)
A <sub>4</sub>	(0.35, 0.51, 0.39)	(0.22, 0.67, 0.37)
	C <sub>3</sub>	C <sub>4</sub>
A <sub>1</sub>	(0.19, 0.71, 0.36)	(0.33, 0.54, 0.39)
A <sub>2</sub>	(0.15, 0.76, 0.33)	(0.22, 0.66, 0.38)
A <sub>3</sub>	(0.27, 0.64, 0.35)	(0.18, 0.71, 0.36)
A <sub>4</sub>	(0.23, 0.67, 0.36)	(0.30, 0.57, 0.39)

**Step 4 and Step 5.** Spherical fuzzy global preference weights and defuzzified values of final scores of each alternative can be seen in Table 8.

**Table 8. Defuzzified final score values and ranking of alternatives**

	Total	Total	Ranking
A <sub>1</sub>	(0.63, 0.09, 0.54)	9.679	1
A <sub>2</sub>	(0.46, 0.18, 0.60)	6.128	4
A <sub>3</sub>	(0.49, 0.16, 0.59)	6.759	3
A <sub>4</sub>	(0.53, 0.13, 0.59)	7.408	2

**Step 6.** Alternatives are ranked in descending order according to the defuzzified final scores.

Alternative 1 > Alternative 4 > Alternative 3 > Alternative 2

“Alternative 1” is chosen the best according to the ranking scores.

#### 4 Sensitivity Analysis

In this section, a sensitivity analysis is performed. Different weights are assigned to criteria and are analyzed to observe how much it would influence the final scores of alternatives. In the first case, the criteria weights are 0.352, 0.232, 0.184, and 0.232 respectively and the final scores are obtained as 9.679, 6.128, 6.759, 7.408 respectively.

In the second case, the criteria weights are 0.10, 0.70, 0.10, and 0.70 respectively and the final scores are obtained as 6.345, 5.254, 7.009, 7.408 respectively. Therefore, the fourth alternative is selected best alternative, and the third alternative is chosen the second alternative. As a result, we can say that the second criterion has big impact on third and fourth alternative.

In the third case, the criteria weights are 0.70, 0.10, 0.10, and 0.70 respectively and the final scores are obtained as 12.345, 5.254, 6.009, 2.208 respectively. Therefore, the first alternative is selected best alternative. Briefly, we can say that the first criterion has a big impact on first alternative.

In the fourth case, the criteria weights are 0.10, 0.10, 0.70, and 0.70 respectively and the final scores are obtained as 6.345, 4.254, 12.009, 7.208 respectively. Therefore, the third alternative is selected best alternative. Briefly, we can say that the third criterion has a big impact on third alternative.

In the last case, the criteria weights are 0.10, 0.10, 0.10, and 0.70 respectively and the final scores are obtained as 10.345, 8.254, 8.009, 13.208 respectively. Therefore, the fourth alternative is selected best alternative. Briefly, we can say that the fourth criterion has a big impact on fourth alternative.

According to the sensitivity analysis results we can say that the best alternative decision is sensitive to the changes in the criteria weights. Figure 2 illustrates the results of sensitivity analysis.

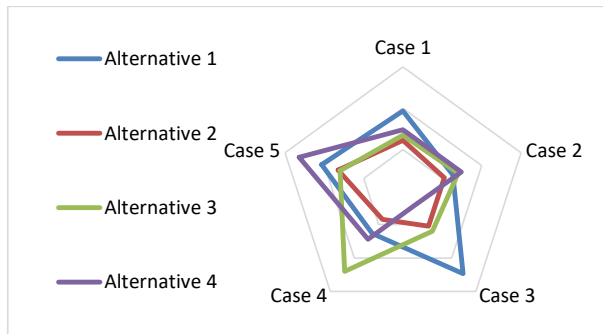


Figure 2. The results of sensitivity analysis.

## 5 Conclusion

With the development of ICT, IoT applications and artificial intelligence, smart systems have become widespread in all areas of life. The transformation of cities, which are one of the basic platforms of life, into smart cities is progressing and smart applications about cities are getting preferable. In this process, SWMS stands out as one of the systems that continue to develop in the city and affect human life in a significant way.

The development of SWMS still goes on, this formation is guided by the development of information technologies and especially by the preferences of the users. User preferences determine the future features of SWMS, which continues to evolve. Evaluation of SWMSs may involve different conflicting criteria. Since SWMS assessment is considered as an MCDM problem, there is a need for this assessment to be obtained through linguistic variables and experts' assessments. In this study, a newly developed method, spherical AHP method, as an extension of fuzzy set, is used to get the opinions of experts.

In the application section, we evaluated different smart waste management systems. Therefore, we determined four different alternatives and four different criteria. We used newly developed method named spherical fuzzy AHP to determine the best alternative. Finally, we ranked the alternatives in descending order according to the used methods result.

In future, the smart waste management system evaluation problem can be solved by different extension of fuzzy set such as intuitionistic fuzzy TOPSIS, Pythagorean fuzzy TOPSIS, hesitant fuzzy TOPSIS, etc.

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