IoT BASED SMART CITIES EVALUATION BY CIRCULAR INTUITIONISTIC FUZZY ANALYTIC HIERARCHY PROCESS

Esra Çakır

Department of Industrial Engineering, Galatasaray University,
Ortakoy/Istanbul 34349, Turkey
ecakir@gsu.edu.tr

ABSTRACT

With the involvement of IoT in urban planning, smart cities increase the quality of life and contribute to the sustainable environment in issues such as waste management, air quality, transportation integration and healthy living. Thus, it is also important for people to evaluate smart cities that will increase their living standards. This study evaluates smart cities by integrating circular intuitionistic fuzzy sets (C-IFS), which is newly introduced to the literature, into the Analytic Hierarchy Process (AHP) approach. Alternative cities to smart waste management, air pollution control, transportation integration and smart energy consumption systems are ranked within the scope of smart cities.

Keywords: Circular Intuitionistic Fuzzy Sets, Analytic Hierarchy Process, IoT BASED SMART CITIES , Fuzzy Multi Criteria Decision Making.

1. Introduction

With the increase in urbanization, the communication of each unit in crowded societies increases the quality of life. The Internet of things (IoT) has an important place in providing communication from the control of small household appliances to the communication of large buildings in the city (Hammi et al., 2018). The remote control of the goods and the ability to transmit instant information accelerated the successive events. Thus, by using smart solutions in cities, it is ensured that the society can communicate quickly and take action in many large areas such as transportation, air quality and waste management (Alam, 2021). Smart cities are developing day by day for a sustainable environment and healthy life. The fact that cities increase the quality of life along with the importance they give to smart solutions also affects their preferability (Bellini, 2021).

In this study, a new fuzzy AHP approach is applied in the evaluation of smart cities in line with the linguistic expressions of the experts. Extending Zadeh's concept of fuzzy numbers (Zadeh, 1965) as Intuitionistic fuzzy numbers (IF) (Atanassov, 1986), Atanassov proposed a new fuzzy number for the use of IF numbers. Circular intuitionistic fuzzy set (Atanassov, 2020) is the extension of the IFS and differs from IFS by including a circle of the number consisting of membership and non-membership degrees (Kahraman & Alkan, 2021). Since the C-IFS concept is relatively new, there are few applications containing

C-IFS and MCDM methods in the literature. Applications of C-IFS MCDM methodologies include supplier selection (Otay & Kahraman, 2022), site selection (Kahraman & Otay, 2021; Çakır et al., 2021), health tourism center appraisement (Çakır & Taş, 2021), and industrial symbiosis evaluation (Çakır et al., 2022).

This paper contributes to the literature by recommending the use of C-IFS on the AHP procedure. C-IFS is in a format suitable for combining viewpoints in group decision making. In addition to the applications of AHP, which is a multi-criteria decision-making technique, in fuzzy environments, a new integration has been carried out. Alternatives are evaluated using the decision makers' fuzzy linguistic IFS decisions and the C-IFS structure. The proposed approach is used in a ranking of several cities to assess their IoT feature to be smart.

2. Methodology

The circular intuitionistic fuzzy AHP (C-IFS AHP) methodology is given step by step as follows:

Step 1: Define the case, determine the decision makers "$D = \{D_1, D_2, ..., D_k\}$" and construct the hierarchical structure by determining the levels. For a three-level hierarchy, Level 1 is the best option for the problem according to the score. Level 2 consists of sub-criteria by defining the set "$C = \{C_1, C_2, ..., C_n\}$" for any criterion C. In the Level 3, alternatives are placed at the bottom of the hierarchy by defining the set "$A = \{A_1, A_2, ..., A_m\}$".

For each level repeat from Step 2 to Step 6 to obtain weights.

Step 2: Construct intuitionistic fuzzy decision matrix $||DM||$ from decision-makers using linguistic scales in Table 1 (Efe & Efe, 2018).

Table 1. Intuitionistic fuzzy linguistic terms

Linguistic Terms	Code	IFS	Linguistic Terms	Code	IFS
Very Low	VL	<0.05,0.95>	Medium	M	<0.5,0.4>
Low	L	<0.25,0.65>	High	H	<0.75,0.15>
Equal	E	<0.5,0.5>	Very High	VH	<0.95,0.05>

Step 3: Check the consistency of IFS decision matrix by experts. The consistency test of IFS judgements is carried out according to the Algoirthm I on the study (Xu & Liao, 2013) exist in the literature. The threshold of consistency is 0.1. If this threshold is exceeded, experts should reconsider their decisions based on Algorithm II on the study (Xu & Liao, 2013).

Step 4: Obtain the aggregated IF decision matrix $||DM_{aggr}||$ using IFWA operator Eq. (1). These values are also the center of each aggregated decision.

$$C_i = IFWA_{W_i}\left(< m_{i,1}, n_{i,1} >, < m_{i,2}, n_{i,2} >, ...\right) =< 1 - \prod_{j=1}^{n}\left(1 - m_{i,j}\right)^{w_{i,j}}, \prod_{j=1}^{n} n_{i,j}^{\ w_{i,j}} > \quad (1)$$

Step 5: Calculate the maximum radius lengths of each aggregated decision $||DM_{aggr}||$ by Eq. (2) from IF decision matrix $||DM||$ and revise the aggregated decision $||DM||$ with radius (C-IFS).

$$r_i = \max_{1 \le j \le k_i} \sqrt{\left(u_C\left(C_i\right) - m_{i,j}\right)^2 + \left(v_C\left(C_i\right) - n_{i,j}\right)^2} \quad (2)$$

Step 6: The priority vector "$w = \{w_1, w_2, ..., w_k\}$" of each C-IFS preference relation by Eq.(3) as follows:

$$w_i = \left(\frac{\sum_{k=1}^{n} \mu_{ik}}{\sum_{i=1}^{n}\sum_{k=1}^{n} \left(1-v_{ik}\right)}, \frac{\sum_{k=1}^{n} \left(1-v_{ik}\right)}{\sum_{i=1}^{n}\sum_{k=1}^{n} \mu_{ik}}; max(r_{ik}) \right) \tag{3}$$

The idea using the $max(r_{ik})$ in calculation of weight comes from a C-IF number of circles of radius *r* has at least one element around it, and its radius must not be smaller to take this decision into account.

Step 7: Combine the calculated weights at all levels of the hierarchy from Level n to Level 1. The final matrix consists entirely of C-IFS numbers. First, defuzzify only the criterion weights by score function. The revised IFWA operator for C-IFS (called C-IFWA) is used as in Eq. (4) to obtain values for alternative order.

$$C - IFWA_{W_i}\left(< m_{i,1}, n_{i,1} >, < m_{i,2}, n_{i,2} >, ...\right) = < 1 - \prod_{j=1}^{n} \left(1 - m_{i,j}\right)^{w_{i,j}}, \prod_{j=1}^{n} n_{i,j}^{\ w_{i,j}}; max(r_i) > \tag{4}$$

Scores of these values is obtain by $S(w_i) = \frac{u_c - v_c + \sqrt{2}r + 3}{6}$ where $W_{C_i} \in [0, 1]$ and then normalize. (We recommend here to set $\lambda = 0.5$ unless you have a special point of view on Eq.(5-6))

$$S_{C-IFS}(c) = \frac{u_c - v_c + \sqrt{2}r(2\lambda - 1)}{3} \quad \text{where } S_{C-IFS}(c) \in [-1, 1] \tag{5}$$

$$H_{C-IFS}(c) = u_c + v_c \quad \text{where } H_{C-IFS}(c) \in [0, 1] \tag{6}$$

Step 8: Rank the score of alternatives and the alternative with the highest score is the best option.

3. Case Study

The C-IFS AHP method proposed in this study was used to evaluate adaptation to smart systems for four cities in Turkey. A1,A2,A3 and A4 cities are evaluated according to the criteria C1: Smart waste management, C2: Air pollution control, C3: Transportation integration, C4: Smart energy consumption system. The hierarchical structure of the case is shown in Figure 1.

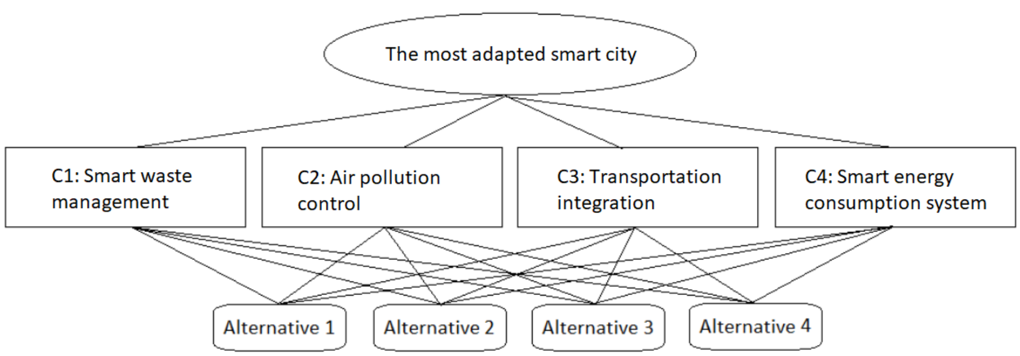

Fig. 1. The hierarchy process of the case study.

Table 2. Final Matrix of combined weights of levels

	C1 SwC1=0.235	C2 SwC2=0.272	C3 SwC3=0.250	C4 SwC4=0.243	Ranking Value	Score	Norm. Score
A1	<0.297,0.342;0.218>	<0.203,0.243;0.365>	<0.295,0.341;0.410>	<0.240,0.281;0.467>	<0.258,0.297;0.467>	0.649	0.233
A2	<0.229,0.262;0.144>	<0.305,0.349;0.431>	<0.247,0.293;0.406>	<0.203,0.250;0.532>	<0.255,0.288;0.532>	0.672	0.241
A3	<0.147,0.185;0.254>	<0.205,0.255;0.221>	<0.215,0.255;0.467>	<0.210,0.249;0.631>	<0.197,0.235;0.631>	0.704	0.252
A4	<0.254,0.291;0.280>	<0.205,0.242;0.431>	<0.162,0.199;0.436>	<0.267,0.307;0.810>	<0.223,0.255;0.810>	0.765	0.274

4. Limitations

The missing aspect of this method is that there may be different approaches in the aggregation expression of the newly developed circular intuitionistic fuzzy number. C-IFS consists of intuitionistic numbers, it does not give the exact equivalent of linguistic expression. Therefore, fuzzy linguistic expressions should be expressed as intuitionistic numbers, and these expression sets should be grouped. While creating a circular intuitionistic number, different methods should be tried to determine the center and radius. Likewise, new suggestions and comparisons can be made for the defuzzification/score function.

5. Conclusions

This study evaluated IoT-based smart cities, which have been extensively researched in recent years, with the proposed C-IFS AHP approach. As an alternative to group decision making approaches, C-IFS developed by Atanassov is used in the expression of IF group decisions. The evaluations given by each of the decision makers to the criterion (or alternative) pair form the group decision for that pair. Thus, IF decisions become C-IFS. Subsequently, this paper contributes to the literature by proposing new formulas and algorithm for C-IFS to implement the necessary steps for the AHP procedure. The proposed model was successfully implemented, and as a result of the three-stage hierarchical structure used in the IoT-based smart city evaluation, the city a3 was evaluated as the city with the best score on the basis of criteria.

6. Key References

Hammi, B., Khatoun, R., Zeadally, S., Fayad A. & Khoukhi, L. (2018). IoT technologies for smart cities, *IET Networks*, vol. 7, no. 1, 1-13.

Alam, T. (2021). Cloud-based IoT applications and their roles in smart cities. *Smart Cities*, *4*(3), 1196-1219.

Bellini, P., Nesi, P., & Pantaleo, G. (2022). IoT-enabled smart cities: A review of concepts, frameworks and key technologies. *Applied Sciences*, *12*(3), 1607.

Zadeh, L. A.: Fuzzy Sets. Information Control, 8(3), 338-353 (1965).

Atanassov, K.: Intuitionistic fuzzy sets. Fuzzy Sets System, 20 (1), 87–96 (1986).

Atanassov, K.: Circular intuitionistic fuzzy sets. Journal of Intelligent and Fuzzy Systems, 39(5), 5981–5986 (2020).

Kahraman, C. & Alkan, N. (2021). Circular intuitionistic fuzzy TOPSIS method with vague membership functions: Supplier selection application context. *Notes Intuitionistic Fuzzy Sets, 27(1)*, 24-52.

Otay, İ. & Kahraman, C. (2022) A novel circular intuitionistic fuzzy AHP&VIKOR methodology: An application to a multi-expert supplier evaluation problem. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 28(1),* 194-207.

Kahraman, C. & Otay, I. (2021) Extension of VIKOR method using circular intuitionistic fuzzy sets. *International Conference on Intelligent and Fuzzy Systems*, *Springer, Cham,* 48-57.

Çakır, E., Taş, M. A. & Ulukan, Z. (2021). A New Circular Intuitionistic Fuzzy MCDM: A Case of Covid-19 Medical Waste Landfill Site Evaluation. *2021 IEEE 21st International Symposium on Computational Intelligence and Informatics (CINTI)* 143-148.

Çakır, E. & Taş, M.: (2021) Circular Intuitionistic Fuzzy Multi-Criteria Decision Making Methodology. *Avrupa Bilim ve Teknoloji Dergisi, (28)*, 900-905.

Çakır E., Taş M.A. & Ulukan Z. (2022). Circular Intuitionistic Fuzzy Sets in Multi Criteria Decision Making. *ICSCCW 2021. Lecture Notes in Networks and Systems, 362, Springer, Cham,* 34-42.

Efe, B. & Efe, Ö. F. (2018). Intuitionistic fuzzy number based group decision making approach for personnel selection. *Uludağ University Journal of The Faculty of Engineering, 23(3),* 11-26.

Xu, Z. & Liao, H. (2013). Intuitionistic fuzzy analytic hierarchy process. *IEEE transactions on fuzzy systems, 22(4),* 749-761.

.