



# Improving the performance of Fog-assisted Internet of Things Networks using Bipolar Trapezoidal Neutrosophic sets

Abedallah abualkishik<sup>1\*</sup>, Rasha Almajed<sup>2</sup>, Watson Thompson<sup>3</sup>

<sup>1</sup>American University in the Emirates, Dubai, UAE

<sup>2</sup>American University in the Emirates, Dubai, UAE

<sup>3</sup>Towson University, Towson University, Maryland's University, USA

Email: [abedallah.abualkishik@ae.ae](mailto:abedallah.abualkishik@ae.ae) ; [rasha.almajed@ae.ae](mailto:rasha.almajed@ae.ae) ; [wvthompson@towson.edu](mailto:wvthompson@towson.edu)

## Abstract

Large numbers of devices with varying hardware capabilities and data traffic patterns make up what we call the Internet of Things (IoT). Furthermore, various IoT services, like knowledge economy, e-health, e-business, parking management, etc., display dynamically varying QoS (Quality of Service) needs inside the IoT network. As a consequence of the inconsistency in service delivery, it is difficult to attain spectrum efficiency in the Internet of Things (IoT). There will be a shortage of spectrum for critical IoT services as a result. In this study, we suggest using a Multi-Criteria Decision Making (MCDM) technique to coordinate spectrum sharing across IoT devices. To ensure that the capacity and quality-of-service requirements of IoT devices are met, this framework prioritizes the accessible spectrum bands based on their numerous spectral properties. When all relevant information for reaching a choice is supplied by decision-makers, as is the case in both the trapezoidal and bipolar neutrosophic environments, this research presents a novel, effective approach to tackling these challenges. Conceptually related, the bipolar trapezoidal neutrosophic set's governing principles and rules of operation are laid forth. We cover several important accumulation operations for accumulating bipolar trapezoidal neutrosophic data. The ARAS technique is combined with the bipolar trapezoidal neutrosophic sets to compute the weights of principles and rank the substitutions.

**Keywords:** Fog; IoT networks; MCDM; ARAS; Neutrosophic sets

## 1. Introduction

The Internet of Things (IoT) denotes a network of organized physical substances that may be either wireless or hardwired. The rapid growth of the Internet of Things devices has been seen in the market in recent years. By 2020, it's predicted that there will be over 50 billion connected gadgets.

As the amount of physical nodes in an IoT network grows, so does the volume of IoT data, necessitating the introduction of cloud storage. However, you can't completely rely on the cloud server. Thus, it is imperative that the IoT data be encrypted prior to being sent to a cloud server. A data search service that protects user anonymity must be made available if an authorized user needs to access the information. Many searchable encryption techniques have been developed by researchers to suit this need[1]–[3].

User roles in a functional IoT system are constantly shifting. In a business or organization, for instance, data search privileges may be granted to newly hired employees and revoked from departing ones when

personnel changes occur[4]–[6]. Thus, the customers' search permissions are post-activation, including research right permission and revocation, which may be performed by key generation or data index update inaccessible encryption techniques. In prior research, users had the option of being granted full or partial search rights, making the administration of these privileges user-centric[7], [8].

The search system for IoT data, however, requires more nuanced search right management. For instance, if a person within the same organization switches between projects, his or her manager may revoke access to the old project's data search and provide access to the new one. A worker, for instance, may transfer from Workbench A to Workshop B in an industrial production facility. The worker should now be granted access to search IoT data in workplace B once the permission to search IoT data in workplace A has been revoked. Such searching right administration is not addressed in the prior systems. Therefore, searching right cancellation at the data level should be established[9], [10].

Many qualitative factors are often used to evaluate fog IoT implementations. It is really difficult for DEs to assign precise numerical numbers to these criteria. Zadeh developed the fuzzy set (FS) theory, whereby a degree of belongingness is used to express a collection of values, to deal with such issues (BD). Many researchers from many fields have poured time and energy into studying the many facets of the FS concept. In the literature, both the intuitionistic fuzzy set (IFS) and the Pythagorean fuzzy set (PFS) have been presented as generalizations of FS. The neutrosophic sets are generalized to address the shortcomings of IFS and PFS.

Invented by Zavadskas and Turskis, the ARAS technique is a cutting-edge strategy predicated on the idea that complicated domains with contradicting qualities may be proved via the use of simple comparative examples[11]–[13]. Specifically, the method ranks solutions based on the idea of optimality degree[14]–[16]. The main benefits of the ARAS strategy are that (i) it has a direct and measurable connection with criterion weights; (ii) it can deal with immensely complicated troubles; and (iii) it is comprised of straightforward and straightforward processes that produce satisfactory, realistic, and pretty accurate results in analyzing and prioritizing different alternatives. Much recent research has explored how the traditional ARAS framework might be broadened[17]–[20].

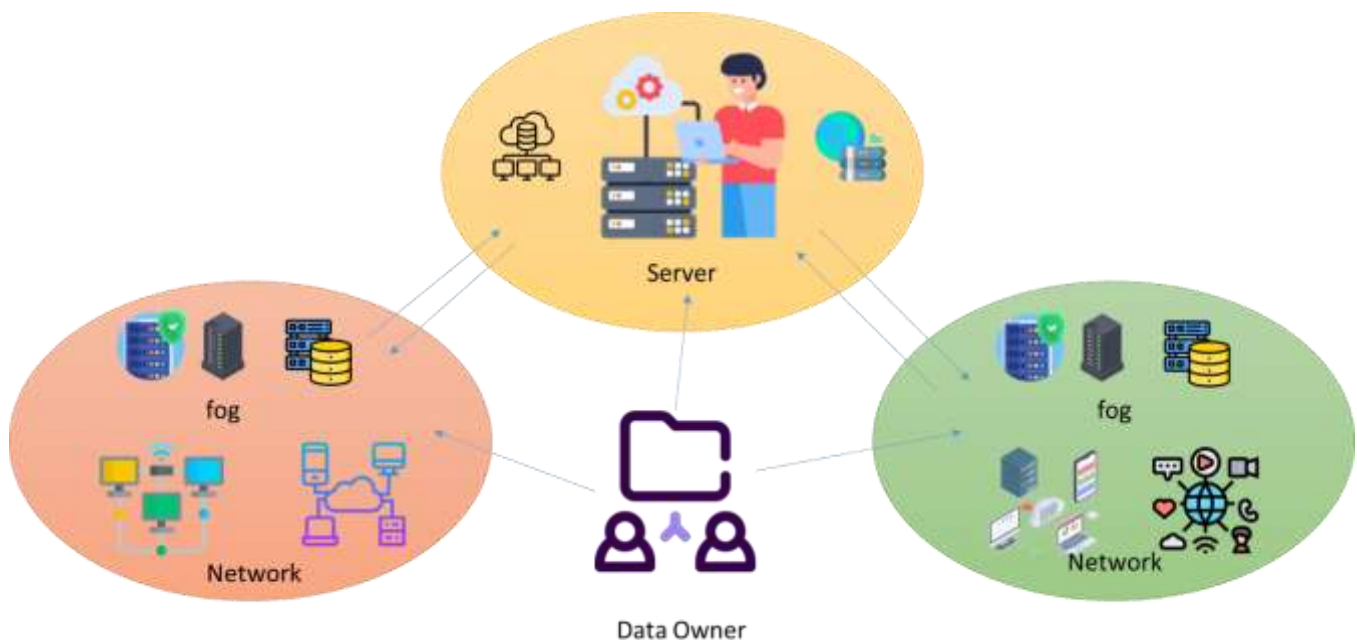


Figure 1: Fog assisted IoT

## 2. Fog Computing and IoT

The Internet of Things (IoT) requires the development of a robust fog-assisted search functionality with variable search right guidance at the document level to ensure the security and confidentiality of IoT data. To achieve this goal, as seen in Figure 1, a fog-assisted private information IoT query processing model was designed. In this architecture, data from all IoT devices is gathered by a fog node, saved in a predetermined document, and then dispatched to the cloud.

Responsible party for the data. The right to do a search on the owner's IoT data is managed by the data owner. For authorised users, he generates searches keys and saves these on the fog layer at the user end, while for IoT nodes, he uses the fog network to keep the index generating key.

Connected device hubs. The data collected by the IoT nodes is encrypted, along with any associated keywords, before being sent to the fog devices for IoT. Most nodes in the Internet of Things are limited in some way by their limited resources.

Dense patches of fog. In order to lessen the burden on the Iot networks and the user endpoints, two distinct types of trustworthy fog nodes are established in the corporate network. The IoT fog node collects data and ideas from IoT nodes, then computes phrase indexes and sends them off to a remote server. The user-facing fog node is responsible for storing newly generated search credentials from of the data controller and collecting users' encrypted keyword input to use in creating search garage doors. After that, it transfers the query backdoors to the remote server and delivers the cloud customer's search results to the relevant users in a honest fashion.

Remote server. Storage and retrieval of IoT data is handled by a server in the cloud. It is expected that the cloud server would be both trustworthy and inquisitive, answering users' inquiries truthfully and without maliciously altering their data while yet maintaining an interest in their right to search in private. Plus, it doesn't work with others to try to figure out what people are searching for based on the data in the indexes and searches.

Users. An entered by the user rights come straight from the data's creator. In order to conduct a search, users encrypt their terms before sending them towards the fog layer for client endpoints.

There are four criteria, which be evaluated in this work

Bit Failure Rate (BER) through the connection to reach the frequency band is what this term refers to.

It is the smallest amount of time during which a spectrum is usable.

Transfer Rate

It represents the very minimal of capacity that may be offered to serve requests.

A Powerful Plan

It's the maximum allowable output in terms of neighbouring channel utilisation or neighbouring channel external interference.

## 2. Mathematical Model

Definition 1[20]–[22]:

A set  $O$  is bipolar trapezoidal neutrosophic set (BTNS) if

$$O = \left\langle \begin{array}{l} \eta^+ o(q), \\ \theta^+ o(q), \\ \vartheta^+ o(q), \\ \eta^- o(q), \\ \theta^- o(q), \\ \vartheta^- o(q) \end{array} \right\rangle; q \in R$$

Definition 2[23]–[25]:

$$O_1 = \langle (a_1^+(q), b_1^+(q), c_1^+(q), d_q^{+1}), (e_1^+(q), f_1^+(q), g_1^+(q), h_1^+(q)), (l_1^+(q), m_1^+(q), n_1^+(q), o_1^+(q)), (a_1^-(q), b_1^-(q), c_1^-(q), d_1^-(q)), (e_1^-(q), f_1^-(q), g_1^-(q), h_1^-(q)), (l_1^-(q), m_1^-(q), n_1^-(q), o_1^-(q)) \rangle : q \in R$$

$$O_2 = \langle (a_2^+(q), b_2^+(q), c_2^+(q), d_2^{+1}), (e_2^+(q), f_2^+(q), g_2^+(q), h_2^+(q)), (l_2^+(q), m_2^+(q), n_2^+(q), o_2^+(q)), (a_2^-(q), b_2^-(q), c_2^-(q), d_2^-(q)), (e_2^-(q), f_2^-(q), g_2^-(q), h_2^-(q)), (l_2^-(q), m_2^-(q), n_2^-(q), o_2^-(q)) \rangle : q \in R$$

Definition 3[26]–[28]:

(BTN subset)  $o_1^{\wedge} \subseteq o_2^{\wedge}$  if

$$\langle \begin{aligned} & a_1^+(r) \leq a_2^+(r), b_1^+(r) \leq b_2^+(r), c_1^+(r) \leq c_2^+(r), d_1^+(r) \leq d_2^+(r), e_1^+(r) \geq e_2^+(r), f_1^+(r) \geq h + 2(r), l + 1(r) \geq c \\ & \geq f^{\wedge} + 2(r), g + 1(r) \geq g + 2(r), h + 1(r) \geq l + 2(r), m + 1(r) \geq m + 2(r), n + 1(r) \geq n^{\wedge} + 2(r), p + 1(r) \geq p + 2(r), a - 1(r) \geq a - 2(r), b - 1(r) \geq b - 2(r), c - 1(r) \\ & - 2(r), d - 1(r) \geq d - 2(r), e - 1(r) \leq e - 2(r), f - 1(r) \leq f - 2(r), g - 1(r) \leq g - 2(r), h - 1(r) \leq h - 2(r), l - 1(r) \\ & \leq l - 2(r), m - 1(r) \leq m_2^-(r), n_1^-(r) \leq n_2^-(r), p_1^-(r) \leq p - 2(r) \end{aligned} \rangle$$

Definition 4:

(BTN union)  $o^1 \cup o^2 =$

$$\begin{aligned}
 & (\max\{a_1^+(q), a_2^+(q)\}, \max\{b_1^+(q), b_2^+(q)\}, \max\{c_1^+(q), c_2^+(q)\}, \\
 & \quad \max\{d_1^+(q), d_2^+(q)\}, (\min\{e_1^+(q), e_2^+(q)\}, \\
 & \quad \min\{f_1^+(q), f_2^+(q)\}, \min\{f_1^+(q), f_2^+(q)\} \\
 & \quad , \min\{h_1^+(q), h_2^+(q)\}), (\min\{l_1^+(q), l_2^+(q)\}, \\
 & \quad \min\{m_1^+(q), m_2^+(q)\}, \min\{n_1^+(q), n_2^+(q)\}, \\
 & \quad \min\{o_1^+(q), o_2^+(q)\} \\
 & \langle (\min\{a_1^-(q), a_2^-(q)\}, \min\{b_1^-(q), b_2^-(q)\}, \min\{c_1^-(q), c_2^-(q)\}, \\
 & \quad \min\{d_1^-(q), d_2^-(q)\}), (\max\{e_1^-(q), e_2^-(q)\}, \\
 & \quad \max\{f_1^-(q), f_2^-(q)\}, \max\{f_1^-(q), f_2^-(q)\} \\
 & \quad , \max\{h_1^-(q), h_2^-(q)\}), (\max\{l_1^-(q), l_2^-(q)\}, \\
 & \quad \max\{m_1^-(q), m_2^-(q)\}, \max\{n_1^-(q), n_2^-(q)\}, \\
 & \quad \max\{o_1^-(q), o_2^-(q)\} \\
 & \quad q \in R) \\
 & \quad ) \\
 & \quad )
 \end{aligned}$$

### 3. The ARAS method

Step 1: Build the decision matrix

Let experts assess the standards and options, which are collected from the previous studies. Then calculate the weights of factors by the mean method.

Step 2: Compute the positive and negative criteria

$$x_{ij} = \max_i x_{ij} \text{ for profit criteria}$$

$$x_{ij} = \min_i x_{ij} \text{ for cost criteria}$$

Step 3: Normalize the decision matrix

$$Nx_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}} \text{ for maximum criteria}$$

$$Nx_{ij} = \frac{\sum_{i=1}^m x_{ij}}{x_{ij}} \text{ for minimum factors}$$

Step 4: Calculate the weighted normalized decision matrix

$$WNx_{ij} = W_j * Nx_{ij}$$

Step 5: Calculate the value of the optimality

$$S_i = \sum_{j=1}^n WNx_{ij}$$

Step 6: Compute the value of the utility

$$K_i = \frac{S_i}{S_0}$$

Step 7: Rank the alternatives

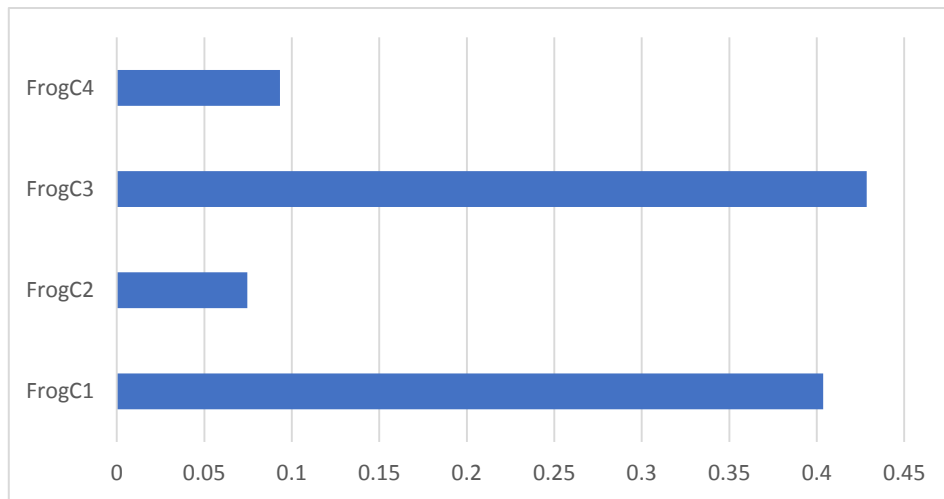


Figure 2: The weights of the criteria

#### 4. An Illustration Example

Step 1: Build the decision matrix

There are four criteria such as type1,2,3,4 and three alternatives. Let experts evaluate the criteria and alternatives and compute the weights of criteria as shown in figure 2. Experts evaluate the criteria and the alternatives to build the decision matrix by the bipolar trapezoidal neutrosophic numbers. Criterion 3 is the uppermost weight and criterion 2 is the lowermost weight.

Step 2: Compute the positive and negative criteria

Step 3: Normalize the judgment background

Table 1. shows the normalization judgment background.

Table 1: The normalization matrix

	FrogC1	FrogC2	FrogC3	FrogC4
FrogA1	0.628571	0.092199	0.117647	0.175676
FrogA2	0.238095	0.255319	0.168067	0.297297
FrogA3	0.133333	0.652482	0.714286	0.527027

Step 4: Compute the weighted normalized judgment background

Table 2: demonstrates the weighted normalized judgment background

	FrogC1	FrogC2	FrogC3	FrogC4
FrogA1	0.049905	0.004534	0.005204	0.009934
FrogA2	0.018903	0.012555	0.007434	0.016811
FrogA3	0.010586	0.032086	0.031594	0.029801

Step 5: Calculate the value of the optimality

Step 6: Calculate the value of the utility

Step 7: Rank the alternatives

Figure 3 shows the rank of alternatives. Alternative 3 is the best alternative and alternative 1 is the worst alternative.

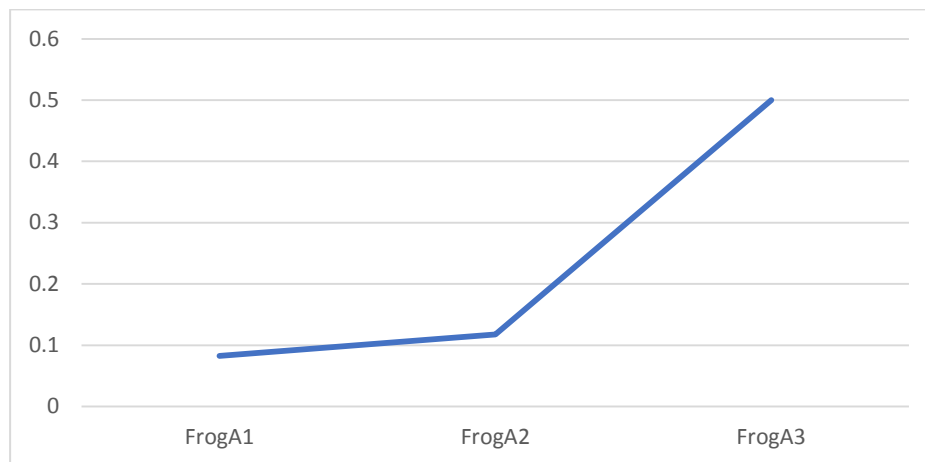


Figure 3: The rank of alternatives.

## 5. Conclusion

When making decisions based on several criteria, neutrosophic sets and their information aggregation operatives follow a crucial criterion. Using Dombi norms and conorms, we addressed the bipolar trapezoidal neutrosophic set, its extended version, and the information aggregation operators that operate inside it. We also introduced ARAS algorithms to address a wide range of challenges encountered in bipolar trapezoidal neutrosophic MCDM procedures. An innovative approach to spectrum management is offered to meet the Quality of Service needs of IoT networks. There is a moderator in the spectrum management framework that keeps track of the spectrum bands available in its geographic area and recommends the best ones to use for each kind of Internet of Things service. The suggested Service-based ARAS method models efficient spectrum selection as an MCDM issue.

## References

- [1] R. Zhou, X. Zhang, X. Wang, G. Yang, H. Wang, and Y. Wu, "Privacy-preserving data search with fine-grained dynamic search right management in fog-assisted Internet of Things," *Information Sciences*, vol. 491, pp. 251–264, 2019.
- [2] J. Zhang, J. Ma, Y. Yang, X. Liu, and N. N. Xiong, "Revocable and Privacy-Preserving Decentralized Data Sharing Framework for Fog-Assisted Internet of Things," *IEEE Internet of Things Journal*, 2021.
- [3] A. K. Junejo, N. Komninos, and J. A. McCann, "A Secure Integrated Framework for Fog-Assisted Internet-of-Things Systems," *IEEE Internet of Things Journal*, vol. 8, no. 8, pp. 6840–6852, 2020.
- [4] A. Manocha, R. Singh, and P. Verma, "An internet of things fog-assisted sleep-deprivation prediction framework for spinal cord injury patients," *Computer*, vol. 53, no. 2, pp. 46–56, 2020.
- [5] R. K. Barik *et al.*, "Fog assisted cloud computing in the era of big data and internet-of-things: systems, architectures, and applications," in *Cloud computing for optimization: foundations, applications, and challenges*, Springer, 2018, pp. 367–394.
- [6] U. Verma and D. Bhardwaj, "A secure lightweight anonymous elliptic curve cryptography-based authentication and key agreement scheme for fog assisted-Internet of Things enabled networks," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 23, p. e7172, 2022.
- [7] A. Anzanpour, H. Rashid, A. M. Rahmani, A. Jantsch, N. Dutt, and P. Liljeberg, "Energy-efficient and reliable wearable Internet-of-Things through fog-assisted dynamic goal management," *Procedia Computer Science*, vol. 151, pp. 493–500, 2019.
- [8] J. I. Z. Chen and S. Smys, "Interoperability improvement in internet of things using fog assisted semantic frame work," *Journal of trends in Computer Science and Smart technology (TCSST)*, vol. 2, no. 01, pp. 56–68, 2020.

- [9] U. Verma, M. Sohani, S. Borah, K. K. Nagwanshi, and S. Pathak, "Role of Fog-Assisted Internet of Things-Enabled System for Managing the Impact of COVID-19," in *Advances in Data Science and Management*, Springer, 2022, pp. 397–406.
- [10] S. P. Eswaran, S. Sripurushottama, and M. Jain, "Multi criteria decision making (mcdm) based spectrum moderator for fog-assisted internet of things," *Procedia computer science*, vol. 134, pp. 399–406, 2018.
- [11] N. Liu and Z. Xu, "An overview of ARAS method: Theory development, application extension, and future challenge," *International Journal of Intelligent Systems*, vol. 36, no. 7, pp. 3524–3565, 2021.
- [12] V. Sihombing *et al.*, "Additive Ratio Assessment (ARAS) Method for Selecting English Course Branch Locations," in *Journal of Physics: Conference Series*, 2021, vol. 1933, no. 1, p. 12070.
- [13] A. Raj Mishra, G. Sisodia, K. Raj Pardasani, and K. Sharma, "Multi-criteria IT personnel selection on intuitionistic fuzzy information measures and ARAS methodology," *Iranian Journal of Fuzzy Systems*, vol. 17, no. 4, pp. 55–68, 2020.
- [14] A. R. Mishra and P. Rani, "A q-rung orthopair fuzzy ARAS method based on entropy and discrimination measures: An application of sustainable recycling partner selection," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–22, 2021.
- [15] C. Ghenai, M. Albawab, and M. Bettayeb, "Sustainability indicators for renewable energy systems using multi-criteria decision-making model and extended SWARA/ARAS hybrid method," *Renewable Energy*, vol. 146, pp. 580–597, 2020.
- [16] S. Jovcic, V. Simic, P. Prusa, and M. Dobrodolac, "Picture Fuzzy ARAS Method for Freight Distribution Concept Selection.," *Symmetry*, vol. 12, no. 7, p. 1062, 2020.
- [17] S. Jovčić, V. Simić, P. Průša, and M. Dobrodolac, "Picture fuzzy ARAS method for freight distribution concept selection," *Symmetry*, vol. 12, no. 7, p. 1062, 2020.
- [18] Y. Dorfeshan, S. M. Mousavi, E. K. Zavadskas, and J. Antucheviciene, "A new enhanced ARAS method for critical path selection of engineering projects with interval type-2 fuzzy sets," *International Journal of Information Technology & Decision Making*, vol. 20, no. 01, pp. 37–65, 2021.
- [19] S. Goswami and S. Mitra, "Selecting the best mobile model by applying AHP-COPRAS and AHP-ARAS decision making methodology," *International Journal of Data and Network Science*, vol. 4, no. 1, pp. 27–42, 2020.
- [20] G. Büyüközkan and F. Göçer, "An extension of ARAS methodology under interval valued intuitionistic fuzzy environment for digital supply chain," *Applied Soft Computing*, vol. 69, pp. 634–654, 2018.
- [21] I. Deli, "Operators on single valued trapezoidal neutrosophic numbers and SVTN-group decision making," *Neutrosophic Sets and Systems*, vol. 22, pp. 131–150, 2018.
- [22] B. C. Giri, M. U. Molla, and P. Biswas, "TOPSIS method for MADM based on interval trapezoidal neutrosophic number," *Neutrosophic Sets and Systems*, vol. 22, pp. 151–167, 2018.
- [23] K. Khatter, "Interval valued trapezoidal neutrosophic set: multi-attribute decision making for prioritization of non-functional requirements," *Journal of Ambient Intelligence and Humanized Computing*, vol. 12, no. 1, pp. 1039–1055, 2021.
- [24] A. Chakraborty, S. P. Mondal, A. Mahata, and S. Alam, "Different linear and non-linear form of trapezoidal neutrosophic numbers, de-neutrosophication techniques and its application in time-cost optimization technique, sequencing problem," *RAIRO-Operations Research*, vol. 55, pp. S97–S118, 2021.
- [25] H. Kamacı, H. Garg, and S. Petchimuthu, "Bipolar trapezoidal neutrosophic sets and their Dombi operators with applications in multicriteria decision making," *Soft Computing*, vol. 25, no. 13, pp. 8417–8440, 2021.
- [26] I. R. Sumathi and C. Antony Crispin Sweety, "New approach on differential equation via trapezoidal neutrosophic number," *Complex & Intelligent Systems*, vol. 5, no. 4, pp. 417–424, 2019.
- [27] C. Jana, M. Pal, F. Karaaslan, and J. Q. Wang, "Trapezoidal neutrosophic aggregation operators and their application to the multi-attribute decision-making process," *Scientia Iranica. Transaction E, Industrial Engineering*, vol. 27, no. 3, pp. 1655–1673, 2020.
- [28] S. Pramanik and R. Mallick, "VIKOR based MAGDM strategy with trapezoidal neutrosophic numbers," *Neutrosophic Sets and Systems*, vol. 22, pp. 118–129, 2018.