Granular Computing (2024)9:56
https://doi.org/10.1007/s41066-024-00480-8

ORIGINAL PAPER

Multicriteria group decision making for prioritizing IoT risk factors with linear diophantine fuzzy sets and MARCOS method

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Received: 27 February 2024 / Accepted: 24 March 2024

Abstract

In a dynamic world of technological advances, the Internet of Things (IoT) is a transformational and widespread force that has revolutionized the way we communicate with our surroundings and regulate our environments. It offers several advantages but also introduces inherent risks. In this study, we provide a comprehensive analysis of the risks associated with IoT and employ the effectiveness of a Linear Diophantine Fuzzy Set to rank the risk factors. Because of the significant uncertainties frequently present in IoT contexts, the use of a fuzzy framework is invaluable in discerning and addressing these risks. The primary contribution is to employ the Measurement of Alternatives and Ranking according to the Compromise Solution (MARCOS) method and linear diophantine fuzzy sets to propose a multi-criteria group decision-making method (MCGDM) for ranking attributes to facilitate risk prioritization, enabling consumers to determine the crucial hazards in their IoT systems. Furthermore, we implement a comparative study and a sensitivity analysis to demonstrate the robustness of our proposed methodology. The insights obtained from our research not only improve the awareness of IoT hazards but also enable organizations and individuals to make informed decisions when navigating IoT fields. By proactively addressing these risks, we endorse the development and secure deployment of IoT technology.

Keywords Linear diophantine fuzzy set · MARCOS · IoT · Risk factors

1 Introduction

The Internet of Things (IoT) is a pervasive and transformational force in the dynamic terrain of modern technology that has changed how we connect with our surroundings and manage our environments. IoT, a term that has become increasingly popular in recent years, refers to the networking of a wide range of physical objects, devices, and systems that are all equipped with the ability to gather, share, and process data to form an intelligent, interconnected system 1.

IoT is fundamentally an expression of the interconnected society envisioned by the digital age, in which commonplace items and industrial gear are active players in the digital ecosystem rather than being passive objects.

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The possibilities are endless because of this interconnection, which can optimize supply chains, healthcare systems, and agriculture in addition to enabling smart homes and cities. It gives organizations, authorities, and people the ability to fully utilize the promise of data-driven decision-making, increased productivity, and cutting-edge services that were previously only seen in science fiction. The ubiquitous nature of IoT, which crosses industry borders and permeates a wide range of sectors, is one of its distinguishing features. IoT devices are used in healthcare to track vital signs of patients and provide medical personnel with real-time data. Automation and smart sensors can improve crop management and reduce agricultural waste. IoT helps create intelligent transportation networks in urban planning, which reduces traffic and environmental effects. These are only a few instances of the enormous possibilities that the IoT offers.

Enabling these items to interact, communicate, and make intelligent decisions without direct human interaction is the main premise underlying the IoT. Important IoT components include:

1. Devices or Things: These actual physical items or entities with communication interfaces, actuators, and sensors installed in them. These sensors can collect information regarding location, temperature, humidity, and other factors.
2. Connectivity: To connect to the Internet and other devices, Internet of Things (IoT) devices use a variety of communication protocols, including Wi-Fi, Bluetooth, cellular networks, and Low power wide area network.
3. Analytics and Data Processing: For processing and analysis, the gathered data are transferred to edge computing systems or the cloud. Advanced analytics, machine learning, and artificial intelligence algorithms are frequently used to obtain valuable insights from data.
4. User Interface: IoT systems generally feature user interfaces that allows users to view and manage linked devices from a distance. These interfaces can be online or mobile.
5. Automobile gadgets: IoT devices frequently can act or control other devices in addition to gathering data, depending on the algorithms in place and the data they receive. A smart thermostat, for instance, can change the temperature in response to sensor data and user preferences.

IoT has the potential to provide several advantages, including increased safety, cost savings, efficiency gains, and improved decision-making. It also introduces up issues with data management, security, privacy, and the possibility of IoT data misuse. As a result, solving these issues is crucial as IoT develops and grows. There are numerous uses of IoT in many different industries, such as:

1. Smart home: Remotely controlled appliances, lights, security cameras, and thermostats for energy efficiency and convenience.
2. Industrial IoT (IIoT): supply chain management in production, predictive maintenance of equipment, and monitoring and optimization of industrial processes.
3. Healthcare: Connectivity between medical devices, wearable fitness trackers, and remote patient monitoring to enhance healthcare delivery.
4. Smart cities: Putting IoT technologies into practice for trash management, traffic control, environmental monitoring, and energy saving in metropolitan regions.
5. Transportation: Smart traffic management systems, driverless cars, and connected vehicles for safer and more effective transportation.

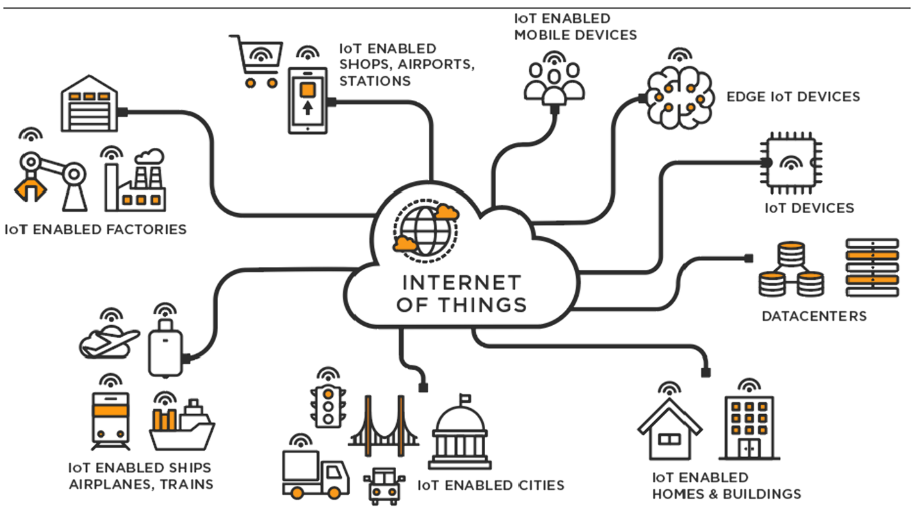

Fig. 1 IoT devices

6. Agriculture: Precision farming methods that maximize crop management, irrigation, and animal monitoring using IoT.
7. Retail: IoT-based inventory control, customer tracking, and customized shopping experience.

Functions of IoT devices: IoT devices are essential for many applications, ranging from increasing productivity and safety in transportation and industry to boosting convenience in smart homes. Depending on the technology they use and their intended use, their functionality and capabilities can differ greatly 2. Typically, IoT devices operate by performing the following:

1. Collection of data: The gadgets gather information pertinent to their functions through sensors. For instance, a smart thermostat gathers information on humidity and temperature.
2. Data processing: Depending on the capabilities of the device, some processing of the gathered data may occur. More sophisticated processing may occur at the edge or in the cloud,.
3. Data transmission: To communicate the gathered data to a central server, cloud platform, or user' device, IoT devices use a variety of communication protocols, such as Wi-Fi, Bluetooth, cellular networks, or LPWAN.
4. Data analysis and Storage: Users can access the data through apps or dashboards, or it can be analyzed for insights using a central database or cloud platform.
5. Supervision and supply: IoT devices may occasionally be able to receive updates or orders from user devices or the cloud, thereby enabling remote control or configuration modifications.

A large and growing body of literature has investigated IoT. Some of the markable research on the IoT is presented in table 1.

1.1 Comprehensive review

In this section, we explore the foundations for the development and conceptualization of our innovative approach.

1.1.1 Linear Diophantine Fuzzy Set

The concept of fuzzy sets (FS) was initially articulated by Zadeh (1965). FS has a wide range of applications in various fields(Chen and Lee (2010); Chen and Jian (2017); Chen et al. (2019); Al-Zibaree and Konur (2023)). Consequently, citeifs introduced the Intuitionistic Fuzzy Set (IFS), a non-membership grade that was added to the fuzzy set. Following various limitations of the two IFS memberships(Rajareega and Vimala (2021); Chen and Randyanto (2013); Zou et al. (2020); Chen et al. (2016)), Yager (2014) created a Pythagorean fuzzy set (PFS). Given the complexity of the problems and progress made in PFS theory, Yager (2017) provided another extensive description of the q-Rung Orthopair Fuzzy Set (q-ROFS). By adding neutral membership, spherical fuzzy set was introduced by and Mahmood et al. (2018). The arbitrary property of the reference parameters was also employed to show that the space of this set is larger than that of FS, IFS, PFS, and q-ROFS(Pethaperumal et al. 2023).

Riaz and Hashmi (2019) suggested using linear diophantine fuzzy control parameters to remove the limits because they stated that these set ideas have limitations

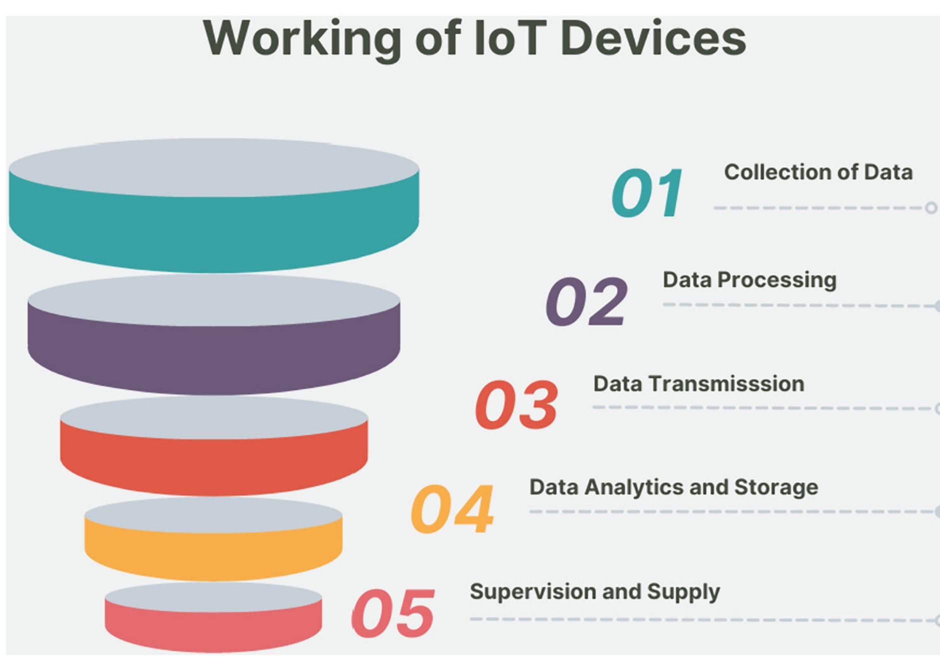

Fig. 2 Functions of IoT devices

Table 1 Literature review on IoT related research

Article	Discussion
Ullah et al. (2019)	Discussed deep learning method for identifying cybersecurity risks in the internet of things
Nurse et al. (2017)	Evaluated the security risk in IoT systems
Kuzlu et al. (2021)	Studied the function of artificial intelligence in cybersecurity for the IoT
Mahmoud et al. (2015)	Investigated the challenges and prospective measures of IoT
Tweneboah-Koduah et al. (2017)	Analyzed risks of IoT service domains and its applications
Boudko and Abie (2019)	Researched the framework of healthcare IoT
Zhao et al. (2020)	Evaluated internet of things powered by computational intelligence
Abdullah et al. (2019)	Reviewed IoT security
Rizvi et al. (2018)	Studied security taxonomy for IoT
Tawalbeh et al. (2020)	Discussed the challenges and solution of IoT privacy and security
Abomhara and Kien (2015)	Studied on vulnerability and threads of IoT
Islam and Aktheruzzaman (2020)	Analysed cybersecurity attacks against IoT
Lopez-Vargas et al. (2020)	Investigated challenges and opportunities of IoT
Andrade et al. (2020)	Examined the IoT security in smart cities
Xiaojian et al. (2021)	Designed zero trust approach for IoT security protection
Kulik et al. (2018)	Prepared a structure for threat-driven IoT system cybersecurity verification
Toapanta et al. (2020)	Analysed the impact of IoT security for public organizations in Latin America
Toapanta et al. (2020)	Examined the layered approach to assess risk and threats of IoT
Aydos et al. (2019)	Researched a reference model for IoT risk management strategy
Mu and Antwi-Afari (2024)	The applications of IoT in industrial management
Machine learning techniques for iot security (2024)	Machine learning techniques for IoT security
Sarker et al. (2022)	IoT security intelligence

about membership and non-membership grades. In LDFS, Riaz and Hashmi employed the reference parameter approach, which is gaining popularity as a precise and thorough method for evaluating choices. This prompted us to contemplate the necessity of demanding and comprehensive LDFS observations. In soft computing, optimization, and uncertain decision-making analysis, the LDFS is a modern approach for tackling real-world problems. A different utilization of the reference parameters is used as a weight vector whose cumulative is less than 1. These characteristics help handle unclear information about the objects under examination by classifying the physical properties of an object.

Due to the practicality of LDFS, they have attracted the attention of several academics from other systematic fields, leading to the writing of several important works. Iampan et al. (2021) covered the LDFS for MCDM issues using a variety of Einstein aggregation approaches. Subsequently, by making decisions, Ayub et al. (2021) created LDF relationship and related algebraic properties. Kamacı (2021) built algebraic structures using an LDF. The LDFS was expanded by Riaz et al. (2020), who included the concept of soft rough sets for material handling equipment. The application of modeling uncertainty in spherical linear Diophantine fuzzy sets to MCDM was discussed in Hashmi et al. (2021). Riaz et al. (2021) developed prioritized AOs for linear Diophantine fuzzy numbers (LDFNs), which were then used to choose third-party logistics suppliers. The applications of Einstein's prioritized linear Diophantine fuzzy AOs were proposed by Farid et al. (2022). Furthermore, Frank AOs for interval-valued linear Diophantine fuzzy numbers were recently constructed by Riaz et al. (2022). The goal of Petchimuthu et al. (2022) was to identify methods for selecting suppliers using IVLDF data and its AOs. Similarity metrics for LDFS have been introduced and applied to pattern recognition to overcome the COVID-19 issue Mohammad et al. (2022). Subsequently, some LDFS extensions have been presented and used in the fields of medical diagnosis (Vimala et al. 2023), agri-drones(Jayakumar et al. 2023), tender selection(KANNAN and JAYAKUMAR 2023), climate crisis(Kannan et al. 2024) and digital transformations(Jeevitha et al. 2023). Also, the correlation coefficient for LDFS was introduced by Kannan et al. (2024).

1.1.2 MARCOS technique

The theoretical basis for a new approach to problem-solving called MARCOS (Measurement of Alternative and Ranking According to the Compromise Solution), was laid by Popescu et al. (2021) MARCOS solves a variety of issues, that expedites the decision-making process in the literature. The utility functions of the alternatives are determined, and an adaptive ranking of the options is obtained by defining the relationship between the options and the ideal and counter-ideal degrees as reference points. When comparing the MARCOS method to another multi-criteria decision making(MCDM) methods such as WASPAS(Radomska-Zalas 2023), DEMATEL(?), SWARA-MOORA (Ghoushchi and Sarvi 2023), VIKOR (Dağıstanlı 2024), SAW(Aliyeva et al. 2023), and TOPSIS(Vimala et al. 2023), some of its advantages include higher efficiency, ease of structuring and optimization of the decision process, more accurate determination of the degree of desirability concerning the reference point, better stability and robustness of the results in terms of changing measurement scales, and no problem of ranking inversion(Stević et al. 2020).

The MARCOS method has been applied in several fields. ? employed a technique to sort drivers based on five criteria to assess the transportation system of an international transportation company. Subsequently, a sensitivity analysis was conducted between the MARCOS methods and other methods, demonstrating the superiority of the MARCOS method and the dependability of the ranking. To select a suitable provider, Chattopadhyay et al. (2020) used a modified version of the Marcos technique with the application of D numbers. Ecer and Pamucar (2021) ranked insurance companies in healthcare services by using the MARCOS technique in an intuitionistic fuzzy environment.

Supplier selection using the hybrid grey theory Marcos technique, as proposed by Badi and Pamucar (2020). Moreover, the picture fuzzy MARCOS approach was developed by Simić et al. (2020) to score railway infrastructures. Geographic information systems (GIS), the best-worst method (BWM), and MAROCS techniques are integrated by Torkayesh et al. (2021) to address sustainable landfill placement selection issues for medical waste. The authors employed this terminology when selecting a sustainable provider Subsequently, Stanković et al. (2020) presented an implementation of the MARCOS approach in a fuzzy version. Puška et al. (2020) used the MARCOS approach to address the problem of evaluating project management software. By offering its applications in many disciplines, researchers further expanded the MARCOS approach Using the MARCOS technique in an IF setting, Kang et al. (2022) evaluated the performance of insurance firms during the COVID-19 pandemic. Ali (2021) created a score function and improved the MARCOS approach in the q-ROF scenario.

1.2 Contribution of this research

The contribution of this study comprises of:

1. Demonstrating the MARCOS in LDF framework, a revolutionary approach to IoT risk assessments.
2. Offering a thorough method for ranking risks in an environment of uncertainty.
3. Providing knowledgeable decision-making instruments to stakeholders to manage risks.
4. Raising awareness and encouraging the safe application of IoT technology.
5. Verifying via sensitivity analysis and comparative studies the robustness of the suggested methodology.

1.3 Motivation and objective of this research

The Internet of Things (IoT) has a widespread influence on how we interact with our surroundings in a rapidly changing world of technological breakthroughs. Despite its many advantages, there are risks associated with the Internet of Things. The urgent necessity to thoroughly examine these hazards in light of the ever-changing nature of IoT technology is what has spurred this study. Through the application of the Linear Diophantine Fuzzy Set to handle uncertainties and the MARCOS approach to prioritize risks, our research aims to increase awareness so that people and organizations can make educated decisions when navigating the complex IoT environment. The ultimate objective is to contribute to the safe development and application of IoT technology.

1. **Dynamic nature of IoT:**
   - (i) Discuss the ever-changing field of technological innovation.
   - (ii) Recognize and assess the revolutionary effects of IoT on environmental regulation and communication.
   - (iii) Comprehensive investigation focusing on vulnerabilities inherent in IoT technologies.
   - (iv) Explain the uncertainty of IoT, highlighting the necessity of flexible analytical models.
2. **LDF-MARCOS technique:**
   - (i) To prioritize and comprehend IoT risk variables in the face of ambiguity, we use the Linear Diophantine Fuzzy Set.
   - (ii) Benefits of using a fuzzy framework to identify and manage risks in an ever-changing IoT environment.
   - (iii) Make use of the MARCOS technique to prioritize risks efficiently and help users identify critical risks in their IoT systems.
   - (iv) Conduct sensitivity analysis and comparative research to demonstrate the strength of the proposed methodology.
3. **Proactive risk addressing:**
   - (i) Boost knowledge and awareness of the dangers posed by IoT technologies.
   - (ii) Give people and organizations the tools they need to navigate the complex IoT environment and make wise decisions.
   - (iii) Encourage the creation and safe application of IoT technology by taking proactive measures to mitigate the hazards discovered.

In summary, our research is motivated by the need to fully comprehend and manage the dangers related to the ever-changing and revolutionary nature of IoT technology. The objective is to support safe development and well-informed decision-making in the IoT space.

1.4 Flow of the research

The background definitions for this study are provided in Section 2. In Section 3, the multicriteria group decision (MCGDM) method based on the LDF-MARCOS methodology is described. In Section 4, an IoT risk factors case study is presented. The section labeled "Result and Discussion" comprises a sensitivity analysis and comparative evaluation of the suggested methodology. The research discussed throughout the study and forthcoming initiatives are included in the concluding section.

2 Preliminaries

Definition 1 Zadeh (1965) The fuzzy set $\mathbb{F}$ defined on the set $\aleph$ is characterized by a mapping μ: $\aleph \rightarrow [0,1]$, where $\mu(\mathfrak{g})$ indicates the extent to which elements in $\aleph$ exhibit membership in the set, and the set is represented as

$$\mathbb{F} = \{(\mathfrak{g}, \mu(\mathfrak{g})) : \mathfrak{g} \in \aleph\}$$

Definition 2 Riaz and Hashmi (2019) The object of the form:

$$\mathbb{L} = \{(\mathfrak{g}, \langle \mu_{\mathbb{L}}(\mathfrak{g}), \nu_{\mathbb{L}}(\mathfrak{g})\rangle, \langle \tau_{\mathbb{L}}(\mathfrak{g}), \eta_{\mathbb{L}}(\mathfrak{g})\rangle) : \mathfrak{g} \in \aleph\}$$

Here, $\mu_{\mathbb{L}}(\mathfrak{g}), \nu_{\mathbb{L}}(\mathfrak{g}), \tau_{\mathbb{L}}(\mathfrak{g}), \eta_{\mathbb{L}}(\mathfrak{g}) \in [0,1]$ are the membership, non-membership and reference parameters respectively. These are restricted by the constraints

$$0 \leq \tau_{\mathbb{L}}(\mathfrak{g})\mu_{\mathbb{L}}(\mathfrak{g}) + \eta_{\mathbb{L}}(\mathfrak{g})\nu_{\mathbb{L}}(\mathfrak{g}) \leq 1$$

and

$$0 \leq \tau_{\mathbb{L}}(\mathfrak{g}) + \eta_{\mathbb{L}}(\mathfrak{g}) \leq 1$$

for all $\mathfrak{g} \in \aleph$

Definition 3 Riaz and Hashmi (2019) Consider two LDFS $\mathfrak{C}_1 = (\mathfrak{g}, \langle \mu_{\mathfrak{C}_1}, \nu_{\mathfrak{C}_1}\rangle, \langle \alpha_{\mathfrak{C}_1}, \beta_{\mathfrak{C}_1}\rangle) : \mathfrak{g} \in \aleph$ and $\mathfrak{C}_2 = (\mathfrak{g}, \langle \mu_{\mathfrak{C}_2}, \nu_{\mathfrak{C}_2}\rangle, \langle \tau_{\mathfrak{C}_2}, \eta_{\mathfrak{C}_2}\rangle) : \mathfrak{g} \in \aleph$. The arithmetic operations between $\mathfrak{C}_1$ and $\mathfrak{C}_2$ are summarized as follows:

1. $\mathfrak{C}_1 \cup \mathfrak{C}_2 = \big(\langle max\{\mu_{\mathfrak{C}_1}, \mu_{\mathfrak{C}_2}\}, min\{\nu_{\mathfrak{C}_1}, \nu_{\mathfrak{C}_2}\}\rangle, \langle max\{\tau_{\mathfrak{C}_1}, \tau_{\mathfrak{C}_2}\}, min\{\eta_{\mathfrak{C}_1}, \eta_{\mathfrak{C}_2}\rangle\big)$
2. $\mathfrak{C}_1 \cap \mathfrak{C}_2 = (\langle min\{\mu_{\mathfrak{C}_1}, \mu_{\mathfrak{C}_2}\}, max\{\nu_{\mathfrak{C}_1}, \nu_{\mathfrak{C}_2}\}\rangle, \langle min\{\tau_{\mathfrak{C}_1}, \tau_{\mathfrak{C}_2}\}, max\{\eta_{\mathfrak{C}_1}, \eta_{\mathfrak{C}_2}\rangle)$.
3. $\mathfrak{C}_1^c = \big(\langle \nu_{\mathfrak{C}_1}, \mu_{\mathfrak{C}_1}\rangle, \langle \eta_{\mathfrak{C}_1}, \tau_{\mathfrak{C}_1}\rangle\big)$
4. $\mathfrak{C}_1 \oplus \mathfrak{C}_2 = (\langle \mu_{\mathfrak{C}_1} + \mu_{\mathfrak{C}_2} - \mu_{\mathfrak{C}_1}\mu_{\mathfrak{H}}, \nu_{\mathfrak{C}_1}\nu_{\mathfrak{C}_2}\rangle, \langle \tau_{\mathfrak{C}_1} + \tau_{\mathfrak{C}_2} - \tau_{\mathfrak{C}_1}\tau_{\mathfrak{H}}, \eta_{\mathfrak{C}_1}\eta_{\mathfrak{C}_2}\rangle)$
5. $\mathfrak{C}_1 \otimes \mathfrak{C}_2 = (\langle \mu_{\mathfrak{C}_1}\mu_{\mathfrak{C}_2}\rangle, \nu_{\mathfrak{C}_1} + \nu_{\mathfrak{C}_2} - \nu_{\mathfrak{C}_1}\nu_{\mathfrak{C}_2}, \langle \tau_{\mathfrak{C}_1}\tau_{\mathfrak{C}_2}, \eta_{\mathfrak{C}_1} + \eta_{\mathfrak{C}_2} - \eta_{\mathfrak{C}_1}\eta_{\mathfrak{C}_2}\rangle)$
6. $\sigma\mathfrak{C}_1 = (\langle 1 - (1 - \mu_{\mathfrak{C}_1}^{\sigma}), (\nu_{\mathfrak{C}_1})^{\sigma}\rangle, \langle 1 - (1 - \tau_{\mathfrak{C}_1})^{\sigma}, (\eta_{\mathfrak{C}_1})^{\sigma}\rangle)$, where σ is non-zero positive real number.
7. $\mathfrak{C}_1^{\sigma} = (\langle (\mu_{\mathfrak{C}_1})^{\sigma}, 1 - (1 - \nu_{\mathfrak{C}_1})^{\sigma}\rangle, \langle (\tau_{\mathfrak{C}_1})^{\sigma}, 1 - (1 - \eta_{\mathfrak{C}_1})^{\sigma}\rangle)$

3 The proposed MCGDM method based on linear diophantine fuzzy sets and the MARCOS method

Step 1: Organize the LDF decision matrices given by m experts for r alternatives based on n criteria.

$$\mathfrak{A}^p = [\xi_{ij}^{(p)}] = \begin{bmatrix} \xi_{11}^{(p)} & \xi_{12}^{(p)} & \dots & \xi_{1n}^{(p)} \\ \xi_{21}^{(p)} & \xi_{22}^{(p)} & \dots & \xi_{2n}^{(p)} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{r1}^{(p)} & \xi_{m2}^{(p)} & \dots & \xi_{rn}^{(p)} \end{bmatrix}$$

where $\xi_{ij}^{(p)} = \langle \mu_{\xi_{ij}}^{(p)}, v_{\xi_{ij}}^{(p)} \rangle, \langle \alpha_{\xi_{ij}}^{(p)}, \beta_{\xi_{ij}}^{(p)} \rangle$ are the LDF value given by expert p (p= 1,2,...,m) for alternative i (i=1,2...r) based on criteria j (j=1,2,...n) **Step 2:** Aggregate the m LDF decision matrix $\mathfrak{A} = [\xi_{ij}]$ by utilizing the formula

$$\xi_{ij} = (\langle 1 - \prod_{p=1}^{m} (1 - \mu_{\xi_{ij}}^{(p)})_p^{\mathfrak{u}}, \prod_{p=1}^{m} (v_{\xi_{ij}}^{(p)})_p^{\mathfrak{u}} \rangle, \langle 1 - \prod_{p=1}^{m} (1 - \alpha_{\xi_{ij}}^{(p)})_p^{\mathfrak{u}}, \prod_{p=1}^{m} (\beta_{\xi_{ij}}^{(p)})_p^{\mathfrak{u}} \rangle) \tag{1}$$

where $\mathfrak{u}_p$ be the weight of decision makers. **Step 3:** Utilizing the two equations below, compute the positive and negative distance measures ψ_{ij}^{+} and ψ_{ij}^{-} respectively.

$$\psi_{ij}^{+} = \frac{\sqrt{(\mu_{ij} - 1)^2 + (v_{ij} - 0)^2 + (\alpha_{ij} - 1)^2 + (\beta_{ij} - 0)^2}}{4} \tag{2}$$

$$\psi_{ij}^{-} = \frac{\sqrt{(\mu_{ij} - 0)^2 + (v_{ij} - 1)^2 + (\alpha_{ij} - 0)^2 + (\beta_{ij} - 1)^2}}{4} \tag{3}$$

Step 4: Use the positive and negative distance measures to determine the closeness coefficient as follows:

$$\mathfrak{E}_{ij} = \frac{\psi_{ij}^{-}}{\psi_{ij}^{-} + \psi_{ij}^{+}} \tag{4}$$

Step 5: Construct the extended LDF matrix as:

$$\mathfrak{G} = \begin{bmatrix} \mathfrak{E}_{11} & \mathfrak{E}_{12} & \dots & \mathfrak{E}_{1n} \\ \mathfrak{E}_{21} & \mathfrak{E}_{22} & \dots & \mathfrak{E}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathfrak{E}_{r1} & \mathfrak{E}_{m2} & \dots & \mathfrak{E}_{rn} \\ \mathfrak{E}_{ai1} & \mathfrak{E}_{ai2} & \dots & \mathfrak{E}_{ain} \\ \mathfrak{E}_{di1} & \mathfrak{E}_{di2} & \dots & \mathfrak{E}_{din} \end{bmatrix}$$

where $\mathfrak{E}_{aij}$ = min $\mathfrak{E}_{ij}$ if j ∈ Benefit type or max $\mathfrak{E}_{ij}$ if j ∈ Cost type

$\mathfrak{E}_{dij}$ = max $\mathfrak{E}_{ij}$ if j ∈ Benefit type or min $\mathfrak{E}_{ij}$ if j ∈ Cost type

Step 6: Determine the weight $\mathfrak{w}_j (j = 1, 2, ..., n)$ of each criteria.

- 6.1 Construct a LDF matrix(n×m) for n criteria provided by m decision makers.
- 6.2 Making use of steps 2, 3, and 4, find the closeness coefficient.
- 6.3 After the normalization, determine the weight of each criterion.

Step 7: Normalize the extended LDF matrix.

$$\breve{\mathfrak{G}} = \bar{\mathfrak{E}_{ij}} = \begin{cases} \frac{\mathfrak{E}_{ij}}{\mathfrak{E}_{dij}} & j \in \text{ Benifit type} \\ \frac{\mathfrak{E}_{dij}}{\mathfrak{E}_{ij}} & j \in \text{ Cost type} \end{cases}$$

Step 8: Build the weighted LDF matrix $\mathfrak{P} = [\mathfrak{W}_{ij}]$

$$\mathfrak{W}_{ij} = \mathfrak{w}_j \mathfrak{E}_{ij} \tag{5}$$

Step 9: Create the matrix S_i such that

$$S_i = \sum_{j=1} n \mathfrak{W}_{ij} \tag{6}$$

Step 10: Determine the Utility degrees for each alternative by using the formula

$$\mathfrak{y}_i^{-} = \frac{S_i}{S_a i}, \mathfrak{y}_i^{+} = \frac{S_i}{S_d i} \tag{7}$$

Step 11: Compute the utility function of alternatives as follows:

$$\mathfrak{f}(\mathfrak{y}_i) = \frac{\mathfrak{y}_i^{-} + \mathfrak{y}_i^{+}}{1 + \frac{1 - \mathfrak{f}(\mathfrak{y}_i^{-})}{\mathfrak{y}_i^{-}} + \frac{1 - \mathfrak{f}(\mathfrak{y}_i^{+})}{\mathfrak{y}_i^{+}}} \tag{8}$$

where $\mathfrak{f}(\mathfrak{y}_i^{-})$ and $\mathfrak{f}(\mathfrak{y}_i^{+})$ are anti-ideal and ideal computed by the formula:

$$\mathfrak{f}(\mathfrak{y}_i^{-}) = \frac{\mathfrak{y}_i^{+}}{\mathfrak{y}_i^{-} + \mathfrak{y}_i^{+}} \tag{9}$$

$$\mathfrak{f}(\mathfrak{y}_i^{+}) = \frac{\mathfrak{y}_i^{-}}{\mathfrak{y}_i^{-} + \mathfrak{y}_i^{+}} \tag{10}$$

Step 12: Sort the alternatives based on utility function values. An alternative with a higher value is more desirable. A Schematic of the LDF-MARCOS methodology is shown in Fig. 3

4 Prioritizing IoT risk factors: an analysis with LDF-MARCOS

This section examined the risk factors related to IoT and assessed the LDF-MARCOS technique to identify the level of risk in risk factors.

4.1 Case study: IoT risk factors

The IoT is the cornerstone of a smarter and, more connected future in this age of rapid technological innovation. It is a driving force behind innovation, productivity, and advancement that highlights the indisputable reality that the world is growing increasingly intelligent, connected, and dependent on the Internet of Things every day. To create a more connected, data-driven, and efficient world in the future, this article examines many facets of the IoT, including its applications, difficulties, and potential.

4.1.1 Risk factors of IoT

The internet of things (IoT) has brought about numerous benefits: however, it also introduces several risk factors and challenges. Some of the key risk factors associated with IoT are as follows:

1. **Interoperability challenges:** Seamless integration may be hampered by IoT devices from various manufacturers being unable to readily connect with one another owing to disparate communication protocols and standards.
2. **Reliability and availability:** IoT devices depend on network connectivity, and any outages in that connectivity may cause interruptions in services. The actual IoT devices may malfunction or break down, which can cause problems in vital applications.
3. **Scalability and management:** Managing and servicing IoT devices becomes more difficult as their quantity increases. It can be difficult to guarantee that IoT devices receive security upgrades on time, and if updates are not applied regularly, devices may become vulnerable.
4. **Regulatory and compliance issues:** IoT installations are more complicated to implement because they must abide by data protection rules, which differ depending on the location.
5. **Physical security:** Physical tampering with IoT devices can lead to security or functionality breaches. Sensitive data may be exposed if the theft involves expensive IoT equipment.
6. **Environmental factors:** Extreme environments (such as industrial settings or isolated places) may cause wear and tear on IoT devices more quickly.
7. **Privacy issues:**IoT devices frequently gather information about their usage and surroundings, which gives rise to concerns regarding data ownership and privacy. IoT devices can gather and use user data without their knowledge, which could result in privacy violations.
8. **Security concerns:** Owing to their weak security protocols, many IoT devices are open to hacking and illegal access. Sensitive information, such as private company or personal information, may become public knowledge if an IoT device is compromised. IoT devices may be enlisted in botnets for various activities, such as distributing denial-of-service (DDoS) assaults.

4.1.2 Criteria for risk analysis

Impact: Taking into account the possible outcomes of the risk, such as monetary losses, business interruptions, harm to one's reputation, or safety risks. Risks with large potential consequences were frequently chosen.

Likelihood: Determines the likelihood that risk will materialize. In general, risks that have a higher chance of occurrence are considered more serious.

Relevance: Assess the applicability of risk to a particular project, procedure, or circumstance. Risks should be aligned with the goals and circumstances of the assessment.

Severity: Consider the risk of possible injury or damage when determining the severity of injury. Hazards that may have disastrous effects require additional caution.

Risk tolerance: This takes into account the risk appetite and tolerance of the project or organization. The risk culture of an organization may make some hazards more tolerable than others.

Legal and regulatory compliance: Recognize the dangers associated with non-compliance with rules, as breaking the law may have legal repercussions. Let us consider the risk factors $\{\mathfrak{R}_1, \mathfrak{R}_2, \mathfrak{R}_3, \mathfrak{R}_4, \mathfrak{R}_5, \mathfrak{R}_6, \mathfrak{R}_7, \mathfrak{R}_8\}$ as a collection of alternatives. The criteria for the risk analysis were taken as parameter sets $\{\mathfrak{S}_1, \mathfrak{S}_2, \mathfrak{S}_3, \mathfrak{S}_4, \mathfrak{S}_5, \mathfrak{S}_6\}$. Let $\{\mathfrak{A}^1, \mathfrak{A}^2, \mathfrak{A}^3, \mathfrak{A}^4\}$ be the

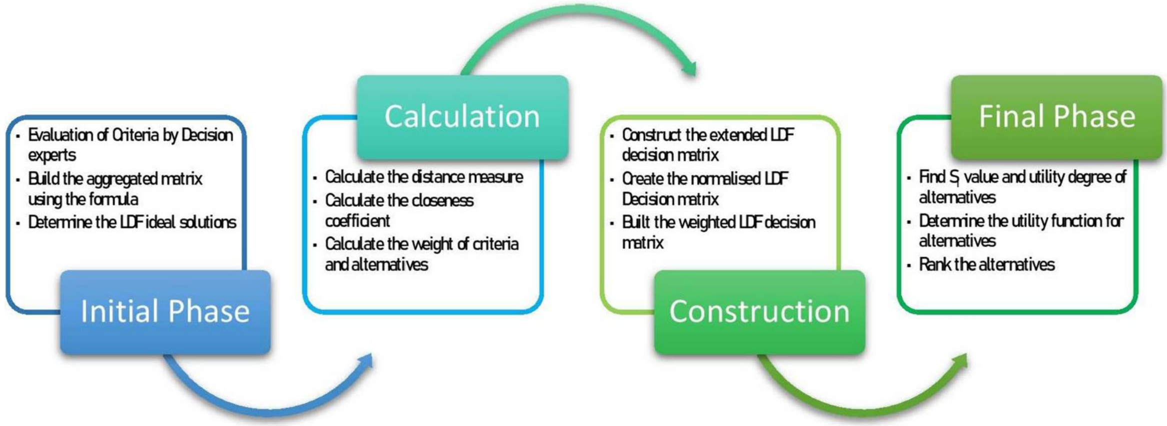

Fig. 3 Graphical depiction of LDF-MARCOS Workflow

Table 2 Determination of weights for criteria

Aggregated value	ψ^+	ψ^-	Weight	Normalised weight
$\langle 0.7877, 0.5107\rangle, \langle 0.8126, 0.1292\rangle$	0.29905	0.75475	0.7162	0.155
$\langle 0.6511, 0.4220\rangle, \langle 0.7312, 0.2311\rangle$	0.32615	0.68625	0.6778	0.147
$\langle 0.7982, 0.2726\rangle, \langle 0.8341, 0.1433\rangle$	0.2019	0.8056	0.7996	0.174
$\langle 0.9067, 0.1468\rangle, \langle 0.9357, 0.0500\rangle$	0.09605	0.91215	0.9047	0.196
$\langle 0.6643, 0.3794\rangle, \langle 0.7896, 0.1751\rangle$	0.2879	0.7298	0.7171	0.156
$\langle 0.7554, 0.2630\rangle, \langle 0.8382, 0.1423\rangle$	0.2094	0.79875	0.7923	0.172

four experts taken in consideration. The weight of decision makers are $\mathfrak{u}_1 = 0.25$, $\mathfrak{u}_2 = 0.15$, $\mathfrak{u}_3 = 0.40$, $\mathfrak{u}_4 = 0.20$.

4.2 LDF-MARCOS approach

Determination of weights for criteria: The LDF-matrix $\mathfrak{M}$ for criteria given by the four experts is considered as follows:

Using formulas 1, 2, 3, 4 the closeness coefficient of each criterion was determined. After normalization, we determined the weight of each criterion, and the values are listed in Table 2.

* Step 1: The LDF decision matrices given by four experts are computed in the matrix $\mathfrak{A}^1_{ij}, \mathfrak{A}^2_{ij}, \mathfrak{A}^3_{ij}, \mathfrak{A}^4_{ij}$.

$$\mathfrak{M} = \begin{bmatrix} \langle 0.72,0.34\rangle,\langle 0.80,0.17\rangle & \langle 0.84,0.17\rangle,\langle 0.80,0.14\rangle & \langle 0.79,0.29\rangle,\langle 0.81,0.12\rangle & \langle 0.81,0.20\rangle,\langle 0.84,0.10\rangle \\ \langle 0.64,0.42\rangle,\langle 0.75,0.21\rangle & \langle 0.56,0.51\rangle,\langle 0.70,0.24\rangle & \langle 0.65,0.40\rangle,\langle 0.72,0.26\rangle & \langle 0.72,0.41\rangle,\langle 0.75,0.20\rangle \\ \langle 0.82,0.26\rangle,\langle 0.84,0.15\rangle & \langle 0.79,0.30\rangle,\langle 0.82,0.17\rangle & \langle 0.80,0.25\rangle,\langle 0.85,0.12\rangle & \langle 0.77,0.32\rangle,\langle 0.80,0.17\rangle \\ \langle 0.94,0.10\rangle,\langle 0.95,0.02\rangle & \langle 0.91,0.20\rangle,\langle 0.94,0.06\rangle & \langle 0.89,0.13\rangle,\langle 0.92,0.07\rangle & \langle 0.88,0.24\rangle,\langle 0.94,0.07\rangle \\ \langle 0.69,0.35\rangle,\langle 0.73,0.21\rangle & \langle 0.72,0.42\rangle,\langle 0.84,0.15\rangle & \langle 0.63,0.40\rangle,\langle 0.79,0.20\rangle & \langle 0.65,0.35\rangle,\langle 0.81,0.12\rangle \\ \langle 0.83,0.21\rangle,\langle 0.85,0.15\rangle & \langle 0.74,0.31\rangle,\langle 0.80,0.13\rangle & \langle 0.65,0.39\rangle,\langle 0.81,0.17\rangle & \langle 0.82,0.14\rangle,\langle 0.89,0.10\rangle \end{bmatrix}$$

$\mathfrak{A}_{ij}^1 =$

	$\mathfrak{S}_1$	$\mathfrak{S}_2$	$\mathfrak{S}_3$	$\mathfrak{S}_4$	$\mathfrak{S}_5$	$\mathfrak{S}_6$
$\mathfrak{R}_1$	$\langle 0.81, 0.23\rangle, \langle 0.85, 0.11\rangle$	$\langle 0.74, 0.31\rangle, \langle 0.80, 0.15\rangle$	$\langle 0.73, 0.40\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.59, 0.31\rangle, \langle 0.78, 0.16\rangle$	$\langle 0.74, 0.18\rangle, \langle 0.79, 0.14\rangle$	$\langle 0.69, 0.36\rangle, \langle 0.88, 0.10\rangle$
$\mathfrak{R}_2$	$\langle 0.47, 0.64\rangle, \langle 0.53, 0.41\rangle$	$\langle 0.55, 0.44\rangle, \langle 0.68, 0.32\rangle$	$\langle 0.83, 0.41\rangle, \langle 0.85, 0.09\rangle$	$\langle 0.65, 0.42\rangle, \langle 0.74, 0.19\rangle$	$\langle 0.43, 0.51\rangle, \langle 0.74, 0.14\rangle$	$\langle 0.46, 0.62\rangle, \langle 0.76, 0.74\rangle$
$\mathfrak{R}_3$	$\langle 0.42, 0.61\rangle, \langle 0.54, 0.40\rangle$	$\langle 0.54, 0.45\rangle, \langle 0.65, 0.32\rangle$	$\langle 0.48, 0.61\rangle, \langle 0.56, 0.42\rangle$	$\langle 0.63, 0.34\rangle, \langle 0.74, 0.13\rangle$	$\langle 0.55, 0.45\rangle, \langle 0.60, 0.32\rangle$	$\langle 0.56, 0.49\rangle, \langle 0.81, 0.17\rangle$
$\mathfrak{R}_4$	$\langle 0.71, 0.34\rangle, \langle 0.82, 0.17\rangle$	$\langle 0.65, 0.42\rangle, \langle 0.72, 0.18\rangle$	$\langle 0.74, 0.31\rangle, \langle 0.80, 0.18\rangle$	$\langle 0.46, 0.48\rangle, \langle 0.56, 0.41\rangle$	$\langle 0.62, 0.42\rangle, \langle 0.74, 0.22\rangle$	$\langle 0.68, 0.31\rangle, \langle 0.72, 0.26\rangle$
$\mathfrak{R}_5$	$\langle 0.64, 0.50\rangle, \langle 0.71, 0.24\rangle$	$\langle 0.72, 0.35\rangle, \langle 0.84, 0.10\rangle$	$\langle 0.52, 0.49\rangle, \langle 0.67, 0.30\rangle$	$\langle 0.42, 0.60\rangle, \langle 0.69, 0.28\rangle$	$\langle 0.64, 0.36\rangle, \langle 0.71, 0.26\rangle$	$\langle 0.47, 0.53\rangle, \langle 0.56, 0.38\rangle$
$\mathfrak{R}_6$	$\langle 0.23, 0.64\rangle, \langle 0.80, 0.18\rangle$	$\langle 0.36, 0.70\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.41, 0.60\rangle, \langle 0.75, 0.22\rangle$	$\langle 0.48, 0.55\rangle, \langle 0.68, 0.31\rangle$	$\langle 0.39, 0.65\rangle, \langle 0.72, 0.26\rangle$	$\langle 0.26, 0.73\rangle, \langle 0.70, 0.26\rangle$
$\mathfrak{R}_7$	$\langle 0.82, 0.20\rangle, \langle 0.90, 0.09\rangle$	$\langle 0.81, 0.16\rangle, \langle 0.85, 0.12\rangle$	$\langle 0.79, 0.29\rangle, \langle 0.89, 0.10\rangle$	$\langle 0.72, 0.39\rangle, \langle 0.80, 0.19\rangle$	$\langle 0.63, 0.40\rangle, \langle 0.81, 0.14\rangle$	$\langle 0.69, 0.42\rangle, \langle 0.79, 0.20\rangle$
$\mathfrak{R}_8$	$\langle 0.76, 0.29\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.86, 0.24\rangle, \langle 0.91, 0.07\rangle$	$\langle 0.81, 0.25\rangle, \langle 0.94, 0.05\rangle$	$\langle 0.76, 0.39\rangle, \langle 0.91, 0.08\rangle$	$\langle 0.82, 0.26\rangle, \langle 0.91, 0.06\rangle$	$\langle 0.81, 0.27\rangle, \langle 0.89, 0.09\rangle$

$\mathfrak{A}_{ij}^2 =$

	$\mathfrak{S}_1$	$\mathfrak{S}_2$	$\mathfrak{S}_3$	$\mathfrak{S}_4$	$\mathfrak{S}_5$	$\mathfrak{S}_6$
$\mathfrak{R}_1$	$\langle 0.74, 0.14\rangle, \langle 0.82, 0.09\rangle$	$\langle 0.86, 0.17\rangle, \langle 0.82, 0.15\rangle$	$\langle 0.71, 0.42\rangle, \langle 0.85, 0.12\rangle$	$\langle 0.58, 0.48\rangle, \langle 0.71, 0.23\rangle$	$\langle 0.75, 0.23\rangle, \langle 0.80, 0.14\rangle$	$\langle 0.70, 0.32\rangle, \langle 0.86, 0.15\rangle$
$\mathfrak{R}_2$	$\langle 0.36, 0.73\rangle, \langle 0.74, 0.15\rangle$	$\langle 0.44, 0.47\rangle, \langle 0.70, 0.28\rangle$	$\langle 0.52, 0.65\rangle, \langle 0.76, 0.12\rangle$	$\langle 0.43, 0.54\rangle, \langle 0.82, 0.15\rangle$	$\langle 0.62, 0.38\rangle, \langle 0.80, 0.13\rangle$	$\langle 0.51, 0.56\rangle, \langle 0.79, 0.20\rangle$
$\mathfrak{R}_3$	$\langle 0.56, 0.39\rangle, \langle 0.62, 0.28\rangle$	$\langle 0.42, 0.58\rangle, \langle 0.53, 0.41\rangle$	$\langle 0.53, 0.44\rangle, \langle 0.62, 0.34\rangle$	$\langle 0.66, 0.39\rangle, \langle 0.72, 0.13\rangle$	$\langle 0.73, 0.32\rangle, \langle 0.78, 0.12\rangle$	$\langle 0.52, 0.60\rangle, \langle 0.73, 0.21\rangle$
$\mathfrak{R}_4$	$\langle 0.75, 0.39\rangle, \langle 0.81, 0.15\rangle$	$\langle 0.60, 0.45\rangle, \langle 0.75, 0.19\rangle$	$\langle 0.76, 0.30\rangle, \langle 0.82, 0.17\rangle$	$\langle 0.47, 0.51\rangle, \langle 0.52, 0.40\rangle$	$\langle 0.70, 0.34\rangle, \langle 0.76, 0.14\rangle$	$\langle 0.65, 0.46\rangle, \langle 0.70, 0.26\rangle$
$\mathfrak{R}_5$	$\langle 0.61, 0.46\rangle, \langle 0.80, 0.16\rangle$	$\langle 0.76, 0.40\rangle, \langle 0.86, 0.11\rangle$	$\langle 0.56, 0.51\rangle, \langle 0.62, 0.31\rangle$	$\langle 0.46, 0.50\rangle, \langle 0.78, 0.12\rangle$	$\langle 0.67, 0.46\rangle, \langle 0.70, 0.24\rangle$	$\langle 0.59, 0.62\rangle, \langle 0.64, 0.23\rangle$
$\mathfrak{R}_6$	$\langle 0.42, 0.70\rangle, \langle 0.76, 0.21\rangle$	$\langle 0.40, 0.69\rangle, \langle 0.76, 0.21\rangle$	$\langle 0.37, 0.70\rangle, \langle 0.70, 0.29\rangle$	$\langle 0.32, 0.70\rangle, \langle 0.70, 0.29\rangle$	$\langle 0.40, 0.59\rangle, \langle 0.70, 0.28\rangle$	$\langle 0.31, 0.63\rangle, \langle 0.73, 0.22\rangle$
$\mathfrak{R}_7$	$\langle 0.76, 0.30\rangle, \langle 0.92, 0.06\rangle$	$\langle 0.80, 0.19\rangle, \langle 0.82, 0.09\rangle$	$\langle 0.76, 0.26\rangle, \langle 0.85, 0.13\rangle$	$\langle 0.79, 0.30\rangle, \langle 0.82, 0.12\rangle$	$\langle 0.65, 0.50\rangle, \langle 0.82, 0.12\rangle$	$\langle 0.64, 0.39\rangle, \langle 0.86, 0.10\rangle$
$\mathfrak{R}_8$	$\langle 0.82, 0.24\rangle, \langle 0.90, 0.06\rangle$	$\langle 0.87, 0.32\rangle, \langle 0.92, 0.06\rangle$	$\langle 0.86, 0.19\rangle, \langle 0.92, 0.06\rangle$	$\langle 0.75, 0.40\rangle, \langle 0.91, 0.07\rangle$	$\langle 0.86, 0.24\rangle, \langle 0.93, 0.03\rangle$	$\langle 0.79, 0.33\rangle, \langle 0.91, 0.06\rangle$

$\mathfrak{A}_{ij}^3 =$

	$\mathfrak{S}_1$	$\mathfrak{S}_2$	$\mathfrak{S}_3$	$\mathfrak{S}_4$	$\mathfrak{S}_5$	$\mathfrak{S}_6$
$\mathfrak{R}_1$	$\langle 0.68, 0.40\rangle, \langle 0.70, 0.24\rangle$	$\langle 0.74, 0.26\rangle, \langle 0.82, 0.17\rangle$	$\langle 0.57, 0.48\rangle, \langle 0.78, 0.21\rangle$	$\langle 0.64, 0.38\rangle, \langle 0.81, 0.16\rangle$	$\langle 0.76, 0.15\rangle, \langle 0.80, 0.18\rangle$	$\langle 0.72, 0.36\rangle, \langle 0.85, 0.17\rangle$
$\mathfrak{R}_2$	$\langle 0.73, 0.35\rangle, \langle 0.82, 0.17\rangle$	$\langle 0.57, 0.45\rangle, \langle 0.72, 0.18\rangle$	$\langle 0.65, 0.41\rangle, \langle 0.74, 0.17\rangle$	$\langle 0.51, 0.46\rangle, \langle 0.75, 0.19\rangle$	$\langle 0.74, 0.23\rangle, \langle 0.80, 0.15\rangle$	$\langle 0.50, 0.47\rangle, \langle 0.80, 0.17\rangle$
$\mathfrak{R}_3$	$\langle 0.45, 0.53\rangle, \langle 0.62, 0.24\rangle$	$\langle 0.49, 0.54\rangle, \langle 0.55, 0.41\rangle$	$\langle 0.52, 0.47\rangle, \langle 0.64, 0.31\rangle$	$\langle 0.47, 0.38\rangle, \langle 0.54, 0.36\rangle$	$\langle 0.52, 0.63\rangle, \langle 0.65, 0.31\rangle$	$\langle 0.49, 0.56\rangle, \langle 0.76, 0.22\rangle$
$\mathfrak{R}_4$	$\langle 0.74, 0.32\rangle, \langle 0.80, 0.17\rangle$	$\langle 0.54, 0.51\rangle, \langle 0.68, 0.30\rangle$	$\langle 0.74, 0.24\rangle, \langle 0.85, 0.10\rangle$	$\langle 0.50, 0.47\rangle, \langle 0.58, 0.32\rangle$	$\langle 0.65, 0.39\rangle, \langle 0.70, 0.26\rangle$	$\langle 0.71, 0.24\rangle, \langle 0.75, 0.19\rangle$
$\mathfrak{R}_5$	$\langle 0.64, 0.32\rangle, \langle 0.75, 0.21\rangle$	$\langle 0.69, 0.43\rangle, \langle 0.80, 0.19\rangle$	$\langle 0.61, 0.46\rangle, \langle 0.70, 0.26\rangle$	$\langle 0.50, 0.62\rangle, \langle 0.65, 0.34\rangle$	$\langle 0.60, 0.41\rangle, \langle 0.73, 0.26\rangle$	$\langle 0.62, 0.36\rangle, \langle 0.46, 0.51\rangle$
$\mathfrak{R}_6$	$\langle 0.40, 0.67\rangle, \langle 0.75, 0.19\rangle$	$\langle 0.37, 0.65\rangle, \langle 0.72, 0.26\rangle$	$\langle 0.33, 0.65\rangle, \langle 0.77, 0.19\rangle$	$\langle 0.38, 0.69\rangle, \langle 0.72, 0.26\rangle$	$\langle 0.32, 0.71\rangle, \langle 0.76, 0.12\rangle$	$\langle 0.24, 0.74\rangle, \langle 0.80, 0.16\rangle$
$\mathfrak{R}_7$	$\langle 0.79, 0.24\rangle, \langle 0.89, 0.10\rangle$	$\langle 0.75, 0.31\rangle, \langle 0.80, 0.16\rangle$	$\langle 0.74, 0.30\rangle, \langle 0.87, 0.10\rangle$	$\langle 0.82, 0.24\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.61, 0.49\rangle, \langle 0.84, 0.13\rangle$	$\langle 0.68, 0.36\rangle, \langle 0.83, 0.12\rangle$
$\mathfrak{R}_8$	$\langle 0.79, 0.30\rangle, \langle 0.84, 0.11\rangle$	$\langle 0.89, 0.23\rangle, \langle 0.90, 0.06\rangle$	$\langle 0.79, 0.22\rangle, \langle 0.90, 0.09\rangle$	$\langle 0.81, 0.26\rangle, \langle 0.92, 0.06\rangle$	$\langle 0.79, 0.32\rangle, \langle 0.92, 0.06\rangle$	$\langle 0.86, 0.30\rangle, \langle 0.88, 0.09\rangle$

$\mathfrak{A}_{ij}^4 =$

	$\mathfrak{S}_1$	$\mathfrak{S}_2$	$\mathfrak{S}_3$	$\mathfrak{S}_4$	$\mathfrak{S}_5$	$\mathfrak{S}_6$
$\mathfrak{R}_1$	$\langle 0.72, 0.34\rangle, \langle 0.77, 0.14\rangle$	$\langle 0.82, 0.14\rangle, \langle 0.91, 0.06\rangle$	$\langle 0.57, 0.31\rangle, \langle 0.68, 0.31\rangle$	$\langle 0.42, 0.73\rangle, \langle 0.63, 0.24\rangle$	$\langle 0.81, 0.14\rangle, \langle 0.89, 0.10\rangle$	$\langle 0.75, 0.31\rangle, \langle 0.81, 0.14\rangle$
$\mathfrak{R}_2$	$\langle 0.86, 0.17\rangle, \langle 0.90, 0.02\rangle$	$\langle 0.84, 0.34\rangle, \langle 0.90, 0.12\rangle$	$\langle 0.75, 0.31\rangle, \langle 0.85, 0.12\rangle$	$\langle 0.72, 0.23\rangle, \langle 0.80, 0.13\rangle$	$\langle 0.70, 0.34\rangle, \langle 0.79, 0.20\rangle$	$\langle 0.47, 0.61\rangle, \langle 0.82, 0.12\rangle$
$\mathfrak{R}_3$	$\langle 0.53, 0.48\rangle, \langle 0.61, 0.32\rangle$	$\langle 0.63, 0.34\rangle, \langle 0.65, 0.32\rangle$	$\langle 0.56, 0.45\rangle, \langle 0.60, 0.35\rangle$	$\langle 0.61, 0.34\rangle, \langle 0.69, 0.26\rangle$	$\langle 0.63, 0.45\rangle, \langle 0.65, 0.32\rangle$	$\langle 0.62, 0.40\rangle, \langle 0.82, 0.12\rangle$
$\mathfrak{R}_4$	$\langle 0.78, 0.36\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.65, 0.40\rangle, \langle 0.75, 0.18\rangle$	$\langle 0.79, 0.26\rangle, \langle 0.80, 0.12\rangle$	$\langle 0.54, 0.46\rangle, \langle 0.61, 0.39\rangle$	$\langle 0.61, 0.42\rangle, \langle 0.69, 0.24\rangle$	$\langle 0.69, 0.34\rangle, \langle 0.71, 0.26\rangle$
$\mathfrak{R}_5$	$\langle 0.66, 0.41\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.80, 0.24\rangle, \langle 0.82, 0.15\rangle$	$\langle 0.48, 0.60\rangle, \langle 0.59, 0.40\rangle$	$\langle 0.54, 0.56\rangle, \langle 0.70, 0.26\rangle$	$\langle 0.65, 0.39\rangle, \langle 0.75, 0.14\rangle$	$\langle 0.45, 0.59\rangle, \langle 0.53, 0.42\rangle$
$\mathfrak{R}_6$	$\langle 0.45, 0.62\rangle, \langle 0.69, 0.28\rangle$	$\langle 0.31, 0.72\rangle, \langle 0.79, 0.16\rangle$	$\langle 0.46, 0.60\rangle, \langle 0.69, 0.36\rangle$	$\langle 0.42, 0.56\rangle, \langle 0.64, 0.31\rangle$	$\langle 0.38, 0.69\rangle, \langle 0.82, 0.12\rangle$	$\langle 0.35, 0.70\rangle, \langle 0.75, 0.21\rangle$
$\mathfrak{R}_7$	$\langle 0.81, 0.16\rangle, \langle 0.85, 0.13\rangle$	$\langle 0.71, 0.36\rangle, \langle 0.82, 0.16\rangle$	$\langle 0.75, 0.31\rangle, \langle 0.85, 0.12\rangle$	$\langle 0.75, 0.30\rangle, \langle 0.79, 0.20\rangle$	$\langle 0.60, 0.39\rangle, \langle 0.81, 0.10\rangle$	$\langle 0.70, 0.31\rangle, \langle 0.81, 0.18\rangle$
$\mathfrak{R}_8$	$\langle 0.75, 0.35\rangle, \langle 0.87, 0.10\rangle$	$\langle 0.82, 0.24\rangle, \langle 0.91, 0.07\rangle$	$\langle 0.84, 0.26\rangle, \langle 0.91, 0.05\rangle$	$\langle 0.79, 0.32\rangle, \langle 0.94, 0.07\rangle$	$\langle 0.83, 0.19\rangle, \langle 0.96, 0.03\rangle$	$\langle 0.73, 0.36\rangle, \langle 0.92, 0.04\rangle$

* Step 2: The Aggregated matrix is computed by ultilizing the formula 1.

$$
\mathfrak{A}_{i}j = \begin{bmatrix}
 & \mathfrak{S}_1 & \mathfrak{S}_2 & \mathfrak{S}_3 & \mathfrak{S}_4 & \mathfrak{S}_5 & \mathfrak{S}_6 \\
\mathfrak{R}_1 & \langle 0.7349, 0.2881\rangle & \langle 0.7799, 0.2252\rangle & \langle 0.6392, 0.4119\rangle & \langle 0.5813, 0.4262\rangle & \langle 0.7649, 0.1963\rangle & \langle 0.7163, 0.3433\rangle \\
 & \langle 0.7844, 0.1530\rangle & \langle 0.8391, 0.1313\rangle & \langle 0.7871, 0.1950\rangle & \langle 0.7601, 0.1832\rangle & \langle 0.8204, 0.1331\rangle & \langle 0.8528, 0.1405\rangle \\
\mathfrak{R}_2 & \langle 0.6810, 0.3933\rangle & \langle 0.6287, 0.4259\rangle & \langle 0.7136, 0.4155\rangle & \langle 0.5880, 0.4010\rangle & \langle 0.6554, 0.3272\rangle & \langle 0.4859, 0.5448\rangle \\
 & \langle 0.7850, 0.1355\rangle & \langle 0.7619, 0.2048\rangle & \langle 0.7994, 0.1284\rangle & \langle 0.7702, 0.1700\rangle & \langle 0.7843, 0.1529\rangle & \langle 0.7935, 0.1548\rangle \\
\mathfrak{R}_3 & \langle 0.4776, 0.5140\rangle & \langle 0.5248, 0.4754\rangle & \langle 0.5543, 0.4924\rangle & \langle 0.5737, 0.3639\rangle & \langle 0.5887, 0.4892\rangle & \langle 0.5408, 0.5116\rangle \\
 & \langle 0.5993, 0.2956\rangle & \langle 0.5955, 0.3667\rangle & \langle 0.6103, 0.3475\rangle & \langle 0.6579, 0.2244\rangle & \langle 0.6625, 0.2727\rangle & \langle 0.7825, 0.1814\rangle \\
\mathfrak{R}_4 & \langle 0.7431, 0.3426\rangle & \langle 0.6017, 0.4542\rangle & \langle 0.7538, 0.2688\rangle & \langle 0.4943, 0.4763\rangle & \langle 0.6433, 0.3950\rangle & \langle 0.6902, 0.3024\rangle \\
 & \langle 0.8107, 0.1648\rangle & \langle 0.7161, 0.2226\rangle & \langle 0.8245, 0.1301\rangle & \langle 0.5729, 0.3785\rangle & \langle 0.7182, 0.2236\rangle & \langle 0.7277, 0.2293\rangle \\
\mathfrak{R}_5 & \langle 0.6398, 0.3970\rangle & \langle 0.7336, 0.3595\rangle & \langle 0.5569, 0.5005\rangle & \langle 0.4838, 0.5834\rangle & \langle 0.6315, 0.3998\rangle & \langle 0.5502, 0.4749\rangle \\
 & \langle 0.7650, 0.1974\rangle & \langle 0.8244, 0.1422\rangle & \langle 0.6612, 0.3016\rangle & \langle 0.6929, 0.2626\rangle & \langle 0.7250, 0.2270\rangle & \langle 0.5304, 0.4045\rangle \\
\mathfrak{R}_6 & \langle 0.3756, 0.6565\rangle & \langle 0.3606, 0.6819\rangle & \langle 0.3814, 0.6340\rangle & \langle 0.4064, 0.6267\rangle & \langle 0.3624, 0.6716\rangle & \langle 0.2788, 0.7119\rangle \\
 & \langle 0.7547, 0.2056\rangle & \langle 0.7687, 0.2024\rangle & \langle 0.7406, 0.2386\rangle & \langle 0.6924, 0.2861\rangle & \langle 0.7565, 0.1653\rangle & \langle 0.7579, 0.2001\rangle \\
\mathfrak{R}_7 & \langle 0.7979, 0.2186\rangle & \langle 0.7675, 0.2516\rangle & \langle 0.7584, 0.2931\rangle & \langle 0.7803, 0.2930\rangle & \langle 0.6194, 0.4463\rangle & \langle 0.6810, 0.3675\rangle \\
 & \langle 0.8910, 0.0950\rangle & \langle 0.8206, 0.1366\rangle & \langle 0.8689, 0.1079\rangle & \langle 0.8094, 0.1673\rangle & \langle 0.8241, 0.1242\rangle & \langle 0.8220, 0.1439\rangle \\
\mathfrak{R}_8 & \langle 0.7803, 0.2967\rangle & \langle 0.8678, 0.2464\rangle & \langle 0.8175, 0.2298\rangle & \langle 0.7859, 0.3200\rangle & \langle 0.8177, 0.2622\rangle & \langle 0.8169, 0.3074\rangle \\
 & \langle 0.8527, 0.1082\rangle & \langle 0.9078, 0.0643\rangle & \langle 0.9167, 0.0650\rangle & \langle 0.9208, 0.0680\rangle & \langle 0.9297, 0.0471\rangle & \langle 0.8963, 0.0720\rangle
\end{bmatrix}
$$

$$
\mathfrak{A}_{ij} = \begin{bmatrix}
llllll & \mathfrak{S}_1 & \mathfrak{S}_2 & \mathfrak{S}_3 & \mathfrak{S}_4 & \mathfrak{S}_5 & \mathfrak{S}_6 \\
\mathfrak{R}_1 & \langle 0.7349, 0.2881\rangle & \langle 0.7799, 0.2252\rangle & \langle 0.6392, 0.4119\rangle & \langle 0.5813, 0.4262\rangle & \langle 0.7649, 0.1963\rangle & \langle 0.7163, 0.3433\rangle \\
 & \langle 0.7844, 0.1530\rangle & \langle 0.8391, 0.1313\rangle & \langle 0.7871, 0.1950\rangle & \langle 0.7601, 0.1832\rangle & \langle 0.8204, 0.1331\rangle & \langle 0.8528, 0.1405\rangle \\
\mathfrak{R}_2 & \langle 0.6810, 0.3933\rangle & \langle 0.6287, 0.4259\rangle & \langle 0.7136, 0.4155\rangle & \langle 0.5880, 0.4010\rangle & \langle 0.6554, 0.3272\rangle & \langle 0.4859, 0.5448\rangle \\
 & \langle 0.7850, 0.1355\rangle & \langle 0.7619, 0.2048\rangle & \langle 0.7994, 0.1284\rangle & \langle 0.7702, 0.1700\rangle & \langle 0.7843, 0.1529\rangle & \langle 0.7935, 0.1548\rangle \\
\mathfrak{R}_3 & \langle 0.4776, 0.5140\rangle & \langle 0.5248, 0.4754\rangle & \langle 0.5543, 0.4924\rangle & \langle 0.5737, 0.3639\rangle & \langle 0.5887, 0.4892\rangle & \langle 0.5408, 0.5116\rangle \\
 & \langle 0.5993, 0.2956\rangle & \langle 0.5955, 0.3667\rangle & \langle 0.6103, 0.3475\rangle & \langle 0.6579, 0.2244\rangle & \langle 0.6625, 0.2727\rangle & \langle 0.7825, 0.1814\rangle \\
\mathfrak{R}_4 & \langle 0.7431, 0.3426\rangle & \langle 0.6017, 0.4542\rangle & \langle 0.7538, 0.2688\rangle & \langle 0.4943, 0.4763\rangle & \langle 0.6433, 0.3950\rangle & \langle 0.6902, 0.3024\rangle \\
 & \langle 0.8107, 0.1648\rangle & \langle 0.7161, 0.2226\rangle & \langle 0.8245, 0.1301\rangle & \langle 0.5729, 0.3785\rangle & \langle 0.7182, 0.2236\rangle & \langle 0.7277, 0.2293\rangle \\
\mathfrak{R}_5 & \langle 0.6398, 0.3970\rangle & \langle 0.7336, 0.3595\rangle & \langle 0.5569, 0.5005\rangle & \langle 0.4838, 0.5834\rangle & \langle 0.6315, 0.3998\rangle & \langle 0.5502, 0.4749\rangle \\
 & \langle 0.7650, 0.1974\rangle & \langle 0.8244, 0.1422\rangle & \langle 0.6612, 0.3016\rangle & \langle 0.6929, 0.2626\rangle & \langle 0.7250, 0.2270\rangle & \langle 0.5304, 0.4045\rangle \\
\mathfrak{R}_6 & \langle 0.3756, 0.6565\rangle & \langle 0.3606, 0.6819\rangle & \langle 0.3814, 0.6340\rangle & \langle 0.4064, 0.6267\rangle & \langle 0.3624, 0.6716\rangle & \langle 0.2788, 0.7119\rangle \\
 & \langle 0.7547, 0.2056\rangle & \langle 0.7687, 0.2024\rangle & \langle 0.7406, 0.2386\rangle & \langle 0.6924, 0.2861\rangle & \langle 0.7565, 0.1653\rangle & \langle 0.7579, 0.2001\rangle \\
\mathfrak{R}_7 & \langle 0.7979, 0.2186\rangle & \langle 0.7675, 0.2516\rangle & \langle 0.7584, 0.2931\rangle & \langle 0.7803, 0.2930\rangle & \langle 0.6194, 0.4463\rangle & \langle 0.6810, 0.3675\rangle \\
 & \langle 0.8910, 0.0950\rangle & \langle 0.8206, 0.1366\rangle & \langle 0.8689, 0.1079\rangle & \langle 0.8094, 0.1673\rangle & \langle 0.8241, 0.1242\rangle & \langle 0.8220, 0.1439\rangle \\
\mathfrak{R}_8 & \langle 0.7803, 0.2967\rangle & \langle 0.8678, 0.2464\rangle & \langle 0.8175, 0.2298\rangle & \langle 0.7859, 0.3200\rangle & \langle 0.8177, 0.2622\rangle & \langle 0.8169, 0.3074\rangle \\
 & \langle 0.8527, 0.1082\rangle & \langle 0.9078, 0.0643\rangle & \langle 0.9167, 0.0650\rangle & \langle 0.9208, 0.0680\rangle & \langle 0.9297, 0.0471\rangle & \langle 0.8963, 0.0720\rangle
\end{bmatrix}
$$

Table 3 Closeness Coefficient of Alternatives

	$\mathfrak{S}_1$			$\mathfrak{S}_2$			$\mathfrak{S}_3$		
Alt	ψ^+	ψ^-	$\mathfrak{E}$	ψ^+	ψ^-	$\mathfrak{E}$	ψ^+	ψ^-	$\mathfrak{E}$
$\mathfrak{R}_1$	0.2362	0.7713	0.7656	0.1886	0.8166	0.8124	0.3095	0.7100	0.6967
$\mathfrak{R}_2$	0.2832	0.7408	0.7234	0.3232	0.6960	0.6829	0.2790	0.7499	0.7288
$\mathfrak{R}_3$	0.4430	0.5744	0.5646	0.4330	0.5715	0.5689	0.4224	0.5838	0.5802
$\mathfrak{R}_4$	0.2482	0.7647	0.7550	0.3518	0.6665	0.6545	0.2125	0.7968	0.7895
$\mathfrak{R}_5$	0.3088	0.7075	0.6962	0.2506	0.7687	0.7541	0.4039	0.6092	0.6013
$\mathfrak{R}_6$	0.4804	0.6041	0.5570	0.4920	0.6038	0.5510	0.4758	0.5937	0.5551
$\mathfrak{R}_7$	0.1655	0.8456	0.8363	0.2051	0.8012	0.7962	0.2080	0.8102	0.7957
$\mathfrak{R}_8$	0.2060	0.8102	0.7973	0.1507	0.8682	0.8521	0.1559	0.8626	0.8469

	$\mathfrak{S}_4$			$\mathfrak{S}_5$			$\mathfrak{S}_6$		
Alt	ψ^+	ψ^-	$\mathfrak{E}$	ψ^+	ψ^-	$\mathfrak{E}$	ψ^+	ψ^-	$\mathfrak{E}$
$\mathfrak{R}_1$	0.3347	0.6914	0.6738	0.1896	0.8034	0.8091	0.2448	0.7763	0.7603
$\mathfrak{R}_2$	0.3210	0.7047	0.6870	0.2719	0.7441	0.7324	0.3961	0.6685	0.6279
$\mathfrak{R}_3$	0.3467	0.6651	0.6573	0.3862	0.6276	0.6191	0.3718	0.6733	0.6442
$\mathfrak{R}_4$	0.4495	0.5552	0.5526	0.3212	0.6889	0.6820	0.2802	0.7222	0.7205
$\mathfrak{R}_5$	0.4388	0.5982	0.5769	0.3251	0.6859	0.6784	0.4506	0.5510	0.5501
$\mathfrak{R}_6$	0.4800	0.5687	0.5423	0.4858	0.6140	0.5583	0.5305	0.5863	0.5249
$\mathfrak{R}_7$	0.2227	0.7838	0.7787	0.3124	0.7308	0.7005	0.2689	0.7537	0.7370
$\mathfrak{R}_8$	0.1995	0.8361	0.8074	0.1651	0.8639	0.8396	0.1897	0.8384	0.8155

* Step 3: Using the formula 2, 3, 4 the closeness coefficient of each alternative is calculated, as given in Table 3.
* Step 4: Utilizing the values in Table 3 and the formula in Step 5, the extended LDF-matrix $\mathfrak{G}$ is constructed.

$$\mathfrak{G} = \begin{bmatrix} 0.7656 & 0.8124 & 0.6967 & 0.6738 & 0.8091 & 0.7603 \\ 0.7234 & 0.6829 & 0.7288 & 0.6870 & 0.7324 & 0.6279 \\ 0.5646 & 0.5689 & 0.5802 & 0.6573 & 0.6191 & 0.6442 \\ 0.7550 & 0.6545 & 0.7895 & 0.5526 & 0.6820 & 0.7205 \\ 0.6962 & 0.7541 & 0.6013 & 0.5769 & 0.6784 & 0.5501 \\ 0.5570 & 0.5510 & 0.5551 & 0.5423 & 0.5583 & 0.5249 \\ 0.8363 & 0.7962 & 0.7951 & 0.7787 & 0.7005 & 0.7370 \\ 0.7973 & 0.8521 & 0.8469 & 0.8074 & 0.8396 & 0.8155 \\ 0.8363 & 0.8521 & 0.8469 & 0.8074 & 0.5583 & 0.8155 \\ 0.5570 & 0.5510 & 0.5551 & 0.5423 & 0.5396 & 0.5249 \end{bmatrix}$$

* Step 5: Normalized LDF-matrix is computed as $\breve{\mathfrak{G}}$.

Table 4 Utility Function and Ranking of Alternatives

S_i	$\mathfrak{y}_i^-$	$\mathfrak{y}_i^+$	$\mathfrak{fy}_i^-$	$\mathfrak{fy}_i^+$	$\mathfrak{fy}_i$	Rank
0.8567	1.0872	1.4484	0.4288	0.5712	0.8225	3
0.8197	1.0402	1.3858	0.4288	0.5712	0.7869	5
0.7581	0.9621	1.2816	0.4288	0.5712	0.7278	6
0.8288	1.0518	1.4012	0.4288	0.5712	0.7957	4
0.767	0.9734	1.267	0.4288	0.5712	0.7267	7
0.7107	0.9019	1.2015	0.4288	0.5712	0.6823	8
0.8732	1.1081	1.4762	0.4288	0.5712	0.8383	2
0.9405	1.1935	1.5900	0.4288	0.5712	0.9029	1

$$\breve{\mathfrak{G}} = \begin{bmatrix} 0.9155 & 0.9534 & 0.8226 & 0.8345 & 0.6900 & 0.9323 \\ 0.8650 & 0.8014 & 0.8606 & 0.8509 & 0.7623 & 0.7700 \\ 0.6751 & 0.6676 & 0.6851 & 0.8141 & 0.9018 & 0.7899 \\ 0.9028 & 0.7681 & 0.9322 & 0.6844 & 0.8186 & 0.8835 \\ 0.8325 & 0.8850 & 0.7100 & 0.7145 & 0.8230 & 0.6746 \\ 0.6660 & 0.6466 & 0.6554 & 0.6717 & 1 & 0.6437 \\ 1 & 0.9344 & 0.9388 & 0.9645 & 0.7246 & 0.9037 \\ 0.9534 & 1 & 1 & 1 & 0.6650 & 1 \\ 0.8363 & 0.8521 & 0.8469 & 0.8074 & 0.5583 & 0.8155 \\ 0.5570 & 0.5510 & 0.5551 & 0.5423 & 0.5396 & 0.5249 \end{bmatrix}$$

* Step 6: The weighted LDF-matrix is computed as $\mathfrak{P}$ with the weights $\mathfrak{w}_j (j = 1, 2, 3, 4, 5, 6)$ estimated in the earlier steps.

$$
\mathfrak{P} = \begin{bmatrix}
0.1419 & 0.1401 & 0.1431 & 0.1636 & 0.1076 & 0.1604 \\
0.1341 & 0.1178 & 0.1497 & 0.1668 & 0.1189 & 0.1324 \\
0.1046 & 0.0981 & 0.1192 & 0.1596 & 0.1407 & 0.1359 \\
0.1399 & 0.1129 & 0.1622 & 0.1341 & 0.1277 & 0.1520 \\
0.1290 & 0.1301 & 0.1235 & 0.1400 & 0.1284 & 0.1160 \\
0.1032 & 0.0951 & 0.1140 & 0.1317 & 0.1560 & 0.1107 \\
0.155 & 0.1374 & 0.1634 & 1890 & 0.1130 & 0.1154 \\
0.1478 & 0.147 & 0.174 & 0.196 & 0.1037 & 0.172 \\
0.1296 & 0.1253 & 0.1474 & 0.1583 & 0.0871 & 0.1403 \\
0.0863 & 0.0810 & 0.0966 & 0.1063 & 0.1310 & 0.0903
\end{bmatrix}
$$

* Step 7: The utility function of each alternative is computed in Table 4 using the formula 6, 7, 8, 9, 10.
* Step 8: From the table, the ranking of alternatives is $\Re_8 > \Re_7 > \Re_1 > \Re_4 > \Re_2 > \Re_3 > \Re_5 > \Re_6$.

5 Results and discussion

In this section, the comparative and sensitivity analyses of our proposed methodology are addressed. Also, the limitations and practical implications of our proposed method are discussed.

5.1 Comparative study

Table 5 provides a comparison of the suggested technique with a few other techniques.

The capacity of the Fuzzy MARCOS approach to more skillfully manage the ambiguity and uncertainties present in decision-making processes is a significant benefit over the classic MARCOS method. LDF MARCOS provides a more accurate and subtle way to determine the degree of utility, enabling a more accurate depiction of decision-maker preferences in complex and unpredictable contexts. It does this by combining fuzzy reference points and utility functions. Due to this improvement, LDF MARCOS outperforms traditional MARCOS when optimizing several goals under uncertain situations, producing more reasonable and consistent outcomes, especially when processing big datasets and dynamic contexts.

5.2 Sensitivity analysis

In this study, a sensitivity analysis was carried out on the weight given to the four decision-makers. In the proposed approach, the weights of the experts were given in the order of $\mathfrak{A}_3 > \mathfrak{A}_1 > \mathfrak{A}_4 > \mathfrak{A}_2$. Here, we consider two cases with a change in the order.

Case 1: $\mathfrak{u}_1 = 0.40$, $\mathfrak{u}_2 = 0.25$, $\mathfrak{u}_3 = 0.20$, $\mathfrak{u}_4 = 0.15$.

1. The weights for the criteria are determined in the table 6.

$$
\mathfrak{G} = \begin{bmatrix}
0.7814 & 0.8365 & 0.7047 & 0.6321 & 0.8277 & 0.7654 \\
0.7539 & 0.7168 & 0.7425 & 0.7173 & 0.7159 & 0.6198 \\
0.5696 & 0.5949 & 0.5677 & 0.6817 & 0.6440 & 0.6659 \\
0.7423 & 0.6764 & 0.7862 & 0.5542 & 0.6822 & 0.7031 \\
0.6949 & 0.7765 & 0.5732 & 0.5919 & 0.6885 & 0.5380 \\
0.5564 & 0.5516 & 0.5517 & 0.5434 & 0.5492 & 0.5277 \\
0.8402 & 0.7964 & 0.7947 & 0.7672 & 0.7060 & 0.7381 \\
0.7935 & 0.8468 & 0.8498 & 0.7984 & 0.8548 & 0.8064 \\
0.8402 & 0.8468 & 0.8498 & 0.7984 & 0.5492 & 0.8064 \\
0.5564 & 0.5516 & 0.5517 & 0.5542 & 0.8548 & 0.5277
\end{bmatrix}
$$

$$
\breve{\mathfrak{G}} = \begin{bmatrix}
0.9300 & 0.9878 & 0.8293 & 0.7917 & 0.6635 & 0.9492 \\
0.8973 & 0.8465 & 0.8737 & 0.8984 & 0.7671 & 0.7686 \\
0.6779 & 0.7025 & 0.6680 & 0.8538 & 0.8528 & 0.8258 \\
0.8835 & 0.7988 & 0.9252 & 0.6941 & 0.8050 & 0.8719 \\
0.8271 & 0.9170 & 0.6745 & 0.7414 & 0.7977 & 0.6672 \\
0.6622 & 0.6514 & 0.6492 & 0.6806 & 1 & 0.6544 \\
1 & 0.9405 & 0.9352 & 0.9609 & 0.7779 & 0.9153 \\
0.9444 & 1 & 1 & 1 & 0.6425 & 1
\end{bmatrix}
$$

$$
\mathfrak{P} = \begin{bmatrix}
0.1572 & 0.1413 & 0.1410 & 0.1536 & 0.1022 & 0.1614 \\
0.1516 & 0.1210 & 0.1485 & 0.1743 & 0.1181 & 0.1307 \\
0.1146 & 0.1005 & 0.1136 & 0.1656 & 0.1313 & 0.1404 \\
0.1493 & 0.1142 & 0.1573 & 0.1347 & 0.1240 & 0.1482 \\
0.1398 & 0.1311 & 0.1147 & 0.1438 & 0.1228 & 0.1134 \\
0.1119 & 0.0932 & 0.1104 & 0.1320 & 0.1540 & 0.1112 \\
0.1690 & 0.1345 & 0.1590 & 0.1864 & 0.1198 & 0.1556 \\
0.1596 & 0.1430 & 0.1700 & 0.1940 & 0.0990 & 0.1700 \\
0.1420 & 0.1211 & 0.1445 & 0.1549 & 0.0846 & 0.1371 \\
0.0940 & 0.0789 & 0.0938 & 0.1075 & 0.1316 & 0.0897
\end{bmatrix}
$$

2. The utility function of each alternative is computed in Table 7 using the formula.

Case:2 $\mathfrak{u}_1 = 0.40$, $\mathfrak{u}_2 = 0.25$, $\mathfrak{u}_3 = 0.20$, $\mathfrak{u}_4 = 0.15$.

1. The weights for the criteria are determined in the table 8.
2. The extended LDF-matrix $\mathfrak{G}$, normalized LDF-matrix $\breve{\mathfrak{G}}$ and weighted LDF-matrix $\mathfrak{P}$ were computed.

$$\mathfrak{G} = \begin{bmatrix} 0.7814 & 0.8365 & 0.7047 & 0.6321 & 0.8277 & 0.7654 \\ 0.7539 & 0.7168 & 0.7425 & 0.7173 & 0.7159 & 0.6198 \\ 0.5696 & 0.5949 & 0.5677 & 0.6817 & 0.6440 & 0.6659 \\ 0.7423 & 0.6764 & 0.7862 & 0.5542 & 0.6822 & 0.7031 \\ 0.6949 & 0.7765 & 0.5732 & 0.5919 & 0.6885 & 0.5380 \\ 0.5564 & 0.5516 & 0.5517 & 0.5434 & 0.5492 & 0.5277 \\ 0.8402 & 0.7964 & 0.7947 & 0.7672 & 0.7060 & 0.7381 \\ 0.7935 & 0.8468 & 0.8498 & 0.7984 & 0.8548 & 0.8064 \\ 0.8402 & 0.8468 & 0.8498 & 0.7984 & 0.5492 & 0.8064 \\ 0.5564 & 0.5516 & 0.5517 & 0.5434 & 0.8548 & 0.5277 \end{bmatrix}$$

$$\breve{\mathfrak{G}} = \begin{bmatrix} 0.9300 & 0.9878 & 0.8293 & 0.7917 & 0.6635 & 0.9492 \\ 0.8973 & 0.8465 & 0.8737 & 0.8984 & 0.7671 & 0.7686 \\ 0.6779 & 0.7025 & 0.6680 & 0.8538 & 0.8528 & 0.8258 \\ 0.8835 & 0.7988 & 0.9252 & 0.6941 & 0.8050 & 0.8719 \\ 0.8271 & 0.9170 & 0.6745 & 0.7414 & 0.7977 & 0.6672 \\ 0.6622 & 0.6514 & 0.6492 & 0.6806 & 1 & 0.6544 \\ 1 & 0.9405 & 0.9352 & 0.9609 & 0.7779 & 0.9153 \\ 0.9444 & 1 & 1 & 1 & 0.6425 & 1 \end{bmatrix}$$

$$\mathfrak{P} = \begin{bmatrix} 0.1693 & 0.1413 & 0.1360 & 0.1480 & 0.1009 & 0.1633 \\ 0.1633 & 0.1210 & 0.1433 & 0.1680 & 0.1166 & 0.1322 \\ 0.1234 & 0.1005 & 0.1096 & 0.1597 & 0.1296 & 0.1420 \\ 0.1608 & 0.1142 & 0.1517 & 0.1298 & 0.1224 & 0.1500 \\ 0.1505 & 0.1311 & 0.1106 & 0.1386 & 0.1213 & 0.1148 \\ 0.1205 & 0.0932 & 0.1065 & 0.1273 & 0.1520 & 0.1126 \\ 0.182 & 0.1345 & 0.1534 & 0.1797 & 0.1182 & 0.1574 \\ 0.1719 & 0.143 & 0.164 & 0.1870 & 0.0977 & 0.172 \\ 0.1529 & 0.1211 & 0.1394 & 0.1493 & 0.0835 & 0.1387 \\ 0.1013 & 0.0789 & 0.0905 & 0.1016 & 0.1299 & 0.0908 \end{bmatrix}$$

3. The utility function of each alternative is computed in Table 9 using the formula.

Based on these studies and the comparative analysis, we conclude that the results calculated using the suggested technique are conservative because they are compatible with the current research. The main advantage of the proposed technique over the current methods for decision-making is that it uses a large amount of data to interpret ambiguities in the data. Because it communicates object information more accurately and objectively under an LDFS, it is a useful tool for dealing with ambiguous and imprecise information throughout the decision-making process. The primary advantage of this suggested approach is the inclusion of the MARCOS method, which provides a more precise weighting of qualities.

The uniqueness of the results obtained from the comparative and sensitivity analyses demonstrates the robustness of the proposed method. From the results, the risk factor " Security concerns" is considered a high risk in IoT devices.

Table 5 Comparative Assessment with existing methodologies

Methods	Score values	Ranking
LDWGO(Riaz and Hashmi 2019)	$\Re_1 = 0.5054; \Re_2 = 0.4101; \Re_3 = 0.22; \Re_4 = 0.3748; \Re_5 = 0.2722; \Re_6 = 0.1090; \Re_7 = 0.5617; \Re_8 = 0.6833$	$\Re_8 > \Re_7 > \Re_1 > \Re_2 > \Re_4 > \Re_5 > \Re_3 > \Re_6$
LDWAO(Riaz and Hashmi 2019)	$\Re_1 = 0.5236; \Re_2 = 0.4216; \Re_3 = 0.2349; \Re_4 = 0.4088; \Re_5 = 0.3036; \Re_6 = 0.1150; \Re_7 = 0.5756; \Re_8 = 0.6887;$	$\Re_8 > \Re_7 > \Re_1 > \Re_4 > \Re_2 > \Re_5 > \Re_3 > \Re_6$
Einstein AO(Iampan et al. 2021)	$\Re_1 = 0.5215; \Re_2 = 0.4201; \Re_3 = 0.2329; \Re_4 = 0.4048; \Re_5 = 0.2998; \Re_6 = 0.1142; \Re_7 = 0.5741; \Re_8 = 0.6945;$	$\Re_8 > \Re_7 > \Re_1 > \Re_2 > \Re_4 > \Re_5 > \Re_3 > \Re_6$
LDFPAO(Riaz et al. 2021)	$\Re_1 = 0.539; \Re_2 = 0.4262; \Re_3 = 0.2355; \Re_4 = 0.4290; \Re_5 = 0.3339; \Re_6 = 0.1175; \Re_7 = 0.5815; \Re_8 = 0.6897;$	$\Re_8 > \Re_7 > \Re_1 > \Re_4 > \Re_2 > \Re_5 > \Re_3 > \Re_6$
LDFPGO(Riaz et al. 2021)	$\Re_1 = 0.5206; \Re_2 = 0.4152; \Re_3 = 0.2192; \Re_4 = 0.4011; \Re_5 = 0.3012; \Re_6 = 0.1108; \Re_7 = 0.5661; \Re_8 = 0.6829;$	$\Re_8 > \Re_7 > \Re_1 > \Re_2 > \Re_4 > \Re_5 > \Re_3 > \Re_6$
Einstein PAO(Farid et al. 2022)	$\Re_1 = 0.5372; \Re_2 = 0.4589; \Re_3 = 0.2336; \Re_4 = 0.4255; \Re_5 = 0.3302; \Re_6 = 0.1169; \Re_7 = 0.5802; \Re_8 = 0.6894;$	$\Re_8 > \Re_7 > \Re_1 > \Re_2 > \Re_4 > \Re_5 > \Re_3 > \Re_6$
Einstein (Farid et al. 2022)	$\Re_1 = 0.5236; \Re_2 = 0.4171; \Re_3 = 0.2214; \Re_4 = 0.406; \Re_5 = 0.3064; \Re_6 = 0.1134; \Re_7 = 0.5685; \Re_8 = 0.6835;$	$\Re_8 > \Re_7 > \Re_1 > \Re_2 > \Re_4 > \Re_5 > \Re_3 > \Re_6$

Table 6 Weights of criteria for case:1

Aggregated value	ψ^+	ψ^-	Weight	Normalised weight
$\langle 0.7832, 0.2558\rangle, \langle 0.8086, 0.1395\rangle$	0.2053	0.8002	0.7958	0.1691
$\langle 0.6375, 0.4353\rangle, \langle 0.7323, 0.2250\rangle$	0.3329	0.6823	0.6721	0.1428
$\langle 0.8018, 0.2758\rangle, \langle 0.8318, 0.1508\rangle$	0.2039	0.8032	0.7975	0.1695
$\langle 0.9168, 0.1429\rangle, \langle 0.9409, 0.0408\rangle$	0.0901	0.9193	0.9107	0.1935
$\langle 0.6812, 0.3630\rangle, \langle 0.7863, 0.1758\rangle$	0.2784	0.7361	0.7256	0.1542
$\langle 0.7797, 0.2465\rangle, \langle 0.8387, 0.1396\rangle$	0.1967	0.8092	0.8092	0.1709

Table 7 Case 1: utility function and rank

S_i	$\mathfrak{y}_i^-$	$\mathfrak{y}_i^+$	$\mathfrak{f}(\mathfrak{y}_i^-)$	$\mathfrak{f}(\mathfrak{y}_i^+)$	$\mathfrak{f}(\mathfrak{y}_i)$	Rank
0.8567	1.0924	1.4386	0.4316	0.5684	0.8227	3
0.8442	1.0765	1.4176	0.4316	0.5684	0.8107	4
0.766	0.9768	1.2863	0.4316	0.5684	0.7357	6
0.8277	1.055	1.3899	0.4316	0.5684	0.7949	5
0.7656	0.9763	1.2856	0.4316	0.5684	0.7353	7
0.7127	0.9088	1.1968	0.4316	0.5684	0.6845	8
0.9344	1.1915	1.5691	0.4316	0.5684	0.8974	2
0.9356	1.1931	1.5711	0.4316	0.5684	0.8985	1

5.3 Limitations of this study

1. There is a chance that some new threats or vulnerabilities pertinent to particular IoT applications or contexts will be left out of the study, which may not cover all possible IoT dangers.
2. Our suggested approach has a computational cost that makes manual calculation impracticable, especially when working with huge datasets. Although it can produce precise results, the large number of algorithmic stages makes manual computing difficult, emphasizing the need for software tools in implementation.

Table 9 Case 2: Utility function and Rank

S_i	$\mathfrak{y}_i^-$	$\mathfrak{y}_i^+$	$\mathfrak{f}(\mathfrak{y}_i^-)$	$\mathfrak{f}(\mathfrak{y}_i^+)$	$\mathfrak{f}(\mathfrak{y}_i)$	Rank
0.8588	1.4482	1.0942	0.4304	0.5696	0.8257	3
0.8444	1.4239	1.0758	0.4304	0.5696	0.8119	4
0.7648	1.2897	0.9744	0.4304	0.5696	0.7353	7
0.8289	1.3978	1.0561	0.4304	0.5696	0.7970	5
0.7669	1.2933	0.9771	0.4304	0.5696	0.7374	6
0.7121	1.2008	0.9072	0.4304	0.5696	0.6846	8
0.9252	1.5602	1.1787	0.4304	0.5696	0.8895	2
0.9356	1.5771	1.1915	0.4304	0.5696	0.8992	1

5.4 Practical implications

We will improve the discussion portion of our study to emphasize the following topics in order to make clear the practical consequences of our suggested methodology:

1. Decision Support for Stakeholders: By offering a systematic framework for ranking IoT hazards, our technique helps stakeholders decide on risk management tactics and resource allocation. Organizations may improve the security and resilience of their IoT systems by detecting and mitigating significant hazards.

Table 8 Weights of criteria for case:2

Aggregated value	ψ^+	ψ^-	Weight	Normalised weight
$\langle 0.7947, 0.2337\rangle, \langle 0.8185, 0.1255\rangle$	0.1907	0.8145	0.8703	0.1816
$\langle 0.6625, 0.4293\rangle, \langle 0.7563, 0.2184\rangle$	0.3183	0.6978	0.6867	0.1433
$\langle 0.7920, 0.2890\rangle, \langle 0.8226, 0.1564\rangle$	0.2137	0.7939	0.7879	0.1644
$\langle 0.9060, 0.1696\rangle, \langle 0.9401, 0.0496\rangle$	0.1045	0.9079	0.8968	0.1871
$\langle 0.6726, 0.3703\rangle, \langle 0.7965, 0.1558\rangle$	0.2784	0.7409	0.7269	0.1517
$\langle 0.7890, 0.2118\rangle, \langle 0.8546, 0.1263\rangle$	0.1778	0.8231	0.8231	0.1718

2. Integration into Risk Management Processes: We will focus on the doable steps involved in incorporating our methodology into the processes that organizations now use for risk management. This entails developing procedures for gathering, analyzing, and making decisions based on data and instructing staff members on how to apply the suggested methodology.
3. We will emphasize the iterative nature of risk management in the context of the Internet of Things, emphasizing the necessity for continual improvement and adaption of risk assessment approaches. Through the adoption of a proactive risk mitigation strategy and the utilization of input from industry experts and stakeholders, organizations can augment their capacity to successfully tackle dynamic risks.

6 Conclusion

This study delves into the complex world of Internet of Things (IoT) technologies, acknowledging how they revolutionize environmental control and communication. We have focused on the dynamic character of these technologies and the requirement for flexible analytical frameworks through a thorough examination of the inherent risks connected to the Internet of Things.

We have been able to rank and comprehend the multitude of dangers in IoT scenarios by applying the Linear Diophantine Fuzzy Set, which has helped us address the enormous uncertainties that frequently characterize this rapidly developing field. Our methodology is made more practical by applying the MARCOS method for risk prioritization. This gives users a useful tool for recognizing and managing critical dangers in IoT systems.

Our results now include a practical component in addition to the validation of the robustness of our suggested technique with the addition of a comparison study and sensitivity analysis. Our goal is to demonstrate the efficacy of our method and offer stakeholders a solid framework for decision-making in a dynamic IoT space. The primary contribution is that the inclusion of MARCOS in the LDF framework improves IoT risk assessments by giving users a way to prioritize hazards in the face of uncertainty and support well-informed decision-making. Through thorough risk assessment and strong technique validation, this strategy promotes awareness and the safe use of IoT technologies.

This study advances the overarching objective of safeguarding the advancement and implementation of IoT technology by raising awareness of IoT hazards and offering useful tools for risk mitigation. The knowledge gathered from this study enables people and organizations to proactively manage risks by traversing the unknowns of the technological future, promoting safer and more sustainable development of IoT technology.

Acknowledgements The article has been written with the joint financial support of RUSA-Phase 2.0 grant sanctioned vide letter No.F 24-51/2014-U, Policy (TN Multi-Gen), Dept. of Edn. Govt. of India, Dt. 09.10.2018, DST-PURSE 2nd Phase Programme vide letter no. SR/PURSE Phase 2/38 (G) Dt. 21.02.2017 and DST (FIST - level I) 657876570 vide letter No.SR/FIST/MS-I/2018/17 Dt. 20.12.2018.

Author contributions Conceptualization, methodology, writing - JK; review, editing, and investigation - VJ, NK, MD, XW.

Funding No funds, grants, or other support was received.

Data availability All data generated are analysed during this study are included in this article.

Code availability NA.

Declarations

Conflict of interest The authors declare no conflict of interest regarding this paper.

Ethical approval NA.

Consent to participate NA.

Consent for publication NA.

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