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Research Article

Evaluation of the Challenges in the Internet of Medical Things with Multicriteria Decision Making (AHP and TOPSIS) to Overcome Its Obstruction under Fuzzy Environment

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The exponential speed of advancement of innovation has expanded the needs of all users to avail all their information on the Internet 24/7. The Internet of things (IoT) enables smart objects to develop a significant building block in the development of the pervasive framework. The messaging between objects with one another means the least work and least expense for the enterprise. The industry that intends to implement the Internet of medical things (IoMT) in its organizations is still facing difficulties. Recognition and solving of these challenges are a time-consuming task and also need significant expenses if not adequately evaluated and prioritized. The application of the Internet of things is covered in almost every area, including medical/healthcare. In this research, the authors investigated the factors dealing with the Internet of medical things. The outcome of this study is to prioritize the level of significance of the elements causing these challenges, evaluated through fuzzy logic and multicriteria decision-making (MCDM) techniques like Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP). It would be beneficial for enterprises to save time and revenue. The main criteria, as well as subcriteria, were determined after due consultation with the Internet of medical things experts. In this study, our goals are to figure out which criteria/factors create hurdles in the adoption of the Internet of medical things. Through the investigation, we figured out 20 criteria ought to be given more importance/preference by the industry that is in the transition phase of the Internet of medical things adoption. The enterprise, with the help of this study, will be enabled to accelerate that adoption by limiting time and fiscal misfortune.

1. Introduction

Internet of things (IoT) is probably the most sizzling innovation in the period of digital transformation, connecting and ensuring the availability of every device over the Internet. It is the most significant innovation behind smart homes, driving vehicles, smart utility billing, and intelligent urban communities [1]. Be that as it may, there are so many fundamental challenges for the eventual fate of the IoT. The adaptability of IoT devices is quickly expanding in the course of the most recent couple of years [2]. As indicated by the survey organization, namely, Gartner, there will be more than 26 billion connected IoT devices around the globe by 2020. While IoT devices made possible viable communication between devices, computerized things, and also ensured saving of time and cost, it also has various advantages [3–5].

Numerous organizations are sorting out themselves to concentrate on integrating IoT and the availability of their future items and services. For the IoT business to flourish, there are three classifications of difficulties to survive, and this is valid for any new pattern in innovation, not just IoT: innovation, business, and society [6].

The effect of IoT has been reformed in all areas of life; however, its impact on the medical system has been substantial because of its front-line transition. The job of IoT turns out to be increasingly prevailing when it is bolstered by the highlights of mobile computing [7]. This thing broadens the usefulness of IoT in the medical environment by getting tremendous help in the type of mobile health [8].

The unexpected ascent in the populace has given rise to numerous challenges in medical administrations and services, and eventually, it has led to a shortage of clinical assets [2, 9]. The medical organization does not have the expertise to resolve medical technology-related issues and challenges and provide an effective solution keeping in view the available resources [10]. IoT and mobile communication offer excellent solutions to the healthcare industry due to its less cost and easy to use features. The central theme of the medical IoT is to provide luxurious services to the users with very minimum price and best quality of service [11].

The main goal of the IoT is to give network services to the available healthcare resources and trustable, efficient, and medical services to the old patient. The IoT enabled medical and healthcare facilities, which consist of sensors, wireless networks for transferring data to a server, and also cloud computing to forward the same data over the Internet [12]. Furthermore, the Internet of medical things system also focuses on providing patient monitoring, treatment suggestions, and many more.

It is an undeniable fact that soon many Internet of things applications will be introduced in the market and many new smart objects will be available to connect with each other. The selection of Internet of medical things challenges depends upon various factors like specifications of the smart objects, cost, legal, and security issues; thus, it is required to compare a large number of criteria and subcriteria to alternatives, which need massive efforts and time. Second, the Internet of things firms and suppliers also write up their white and technical papers to inform the IoT users about the Internet of medical things challenges. Third, many blog writers who write up their survey reports on the Internet of medical things challenges also ranked these challenges without considering exact criteria and subcriteria or applying any mathematical model to prioritize the Internet of medical things challenges. Finally, many factors are required to be taken into consideration during the decision process. In the light of above, prioritization and evaluation of Internet of medical things challenges are complex multicriteria decision-making (MCDM) problems [13, 14]. It is pertinent to add here that due to a large number of Internet of medical things challenges, high complexity and computational power are required to be reduced.

To evaluate and choose the most challenging position for the Internet of medical things, the recommendations of the experts are the most appropriate solutions. In this study, the authors formulated an efficient and effective expert opinion system using MCDM methodology to evaluate and prioritize the Internet of medical things challenges. To simplify the proposed solution and to reduce the complexities in the existing solutions, the authors proposed a hybrid multicriteria decision-making approach incorporating TOPSIS and AHP. The AHP is used to develop local and global weights of the criteria and subcriteria, and the TOSPSIS is used to prioritize the alternatives. The authors, after a systematic literature review, claimed that this study is the first approach that they used to evaluate the Internet of medical things challenges. We properly designed and proposed hybrid AHP and TOPSIS model-based expert's opinion systems in the context of the Internet of medical things. This study is also the first to study existing criteria and develop its approaches after considering the pros and cons of the existing methods. After validation of the proposed framework with existing frameworks, the results proved that the proposed framework is better to rank the challenges of the Internet of Medical Things (IoMT).

The rest of the article is organized as follows. Section 2 is regarding literature review on the Internet of medical things challenges, MCDM techniques, and the most critical Internet of medical things challenges that the medical industry is currently facing. Section 3 describes identifying the main criteria methods, subcriteria, and alternatives, whereas Section 4 discusses the proposed research methodology used in this paper to resolve the problem. Section 5 is related to the simulation of the proposed methodology and results. In Section 6, a comparison of the proposed technique with existing technique is presented, and finally, Section 7 concludes the article.

2. Literature Review

The idea of IoT has a wide range of definitions in innovative dimensions. This is because analysts and industry have given significant importance to the IoT, keeping in view their requirements and business interests. Generally, the idea of IoT depends upon three methodologies: the Internet-based methods, the significance-based approach, and the object-based method. Internet of things is penetrating in our lives in the shape of intelligent objects like applications that can communicate on the system, have single IP addresses, are based on relevant communication protocols and procedures, and can sense changes in the environment like heat and radiations. A network connected with interrelated devices and internet, receive sensor's data as input, process on it, and send information to the desired nodes without human interaction known as the Internet of Things.

During the literature review, the authors of [6, 15, 16] gave information on benefits and challenges in the IoT and also informed the many issues like security and cost. Dizdarević et al. [17], Conti et al. [18], Farahani et al. [19], and Stojkoska and Trivodaliev [20] also discussed the various types of the IoT challenges like security, privacy, vendor lock-in, malicious insider, complexity in integration, competing standards, ubiquitous connectivity, law and regulations, business policies and procedures, the volume of data, and data analysis.

The Internet of things also connected with other technologies like cloud computing [21] and deep learning [22].

During a systematic literature review, it is observed that security and privacy are still a big challenge for the Internet of medical things. Several studies were already conducted in the near past to deal with the Internet of medical things security challenges [23–26] and as well as to deal with security challenges of cloud computing [27–32].

The IoT is the complex network developed through smart devices that are connected in different ways, producing data and information for communication and exchanging information within the network. The IoT is formulated with objects, tools, sensors, computers, desktop computers, and handheld devices, and it also helps the system to artificially think, feel, and speak.

Although there are several global definitions of the IoT, the core idea of this concept is the connectivity of different smart objects, which are automatically able to produce, communicate, and use information with very little human intervention to achieve common goals. Many studies were conducted regarding the challenges of the IoT, benefits or opportunities, and prioritization of the IoT challenges, but none of the studies were conducted till now for the prioritization of the Internet of medical things challenges. Ullah et al. [33] using fuzzy ANP conducted a study to prioritize the IoT challenges in the context of Iran. Uslu et al. studied the challenges of the IoT and prioritized these challenges by using AHP and ANP methodologies of the MCDM [34]. Mashal et al. examined the selection of the best application of IoT through MCDM and AHP [31].

Similarly, Mashal et al. [35] used the fuzzy analytic hierarchy process model for the analysis of the IoT. Kao et al. [36] evaluated the problems of the IoT in manufacturing industries using multicriteria decision making. Liu et al. [37] used hybrid MCDM tools to notice consumer adoption for mobile healthcare services. Abdel-Basset et al. [38] used MCDM to develop a medical decision support system. Shin et al. [39] conducted their study on the sustainability of the Internet of medical things and its integrated acceptance. A thorough investigation and research were carried out by Alsubaei et al. on the security and privacy of the Internet of medical things, and they also conducted risk assessment [40]. The selection of a stable IoT platform is also a challenge for the industry, and it is also solved through MCDM [41]. Another study was carried out by using MCDM for the zone head selection of the IoT-based WSN [42]. The authors used the fuzzy analytic hierarchy process and TOPSIS for the evaluation and ranking of ISO/IEC 27001:2013 information security controls [43].

However, after searching and investigating, the authors could not find a single study on the prioritization of the Internet of medical things challenges, especially using a combination of AHP and TOPSIS. It is pertinent to add here that such prioritization will help the industry to address critical challenges first to save time and reduce costs.

It would be practically difficult to cover the broad scope of the Internet of medical things challenges in a single article. Therefore, after critically reviewing the literature, Internet of medical things-related problems were dug out from high impact factor scientific papers. The authors, after intensive review, prepared the list of the Internet of medical things challenges and, after due consultations with the Internet of medical things experts, categorized the challenges into five distinct categories and also presented the hierarchical structure. It is worthwhile to mention here that the experts confirmed the adequacy of the difficulties, and the validity of the criteria was verified.

2.1. Multicriteria Decision Making. Multicriteria decision making refers to discover the best option among the different alternatives having different characteristics, usually conflicting and based on decision matrix. It addresses and helps in the decision-making process when there are complex decision criteria. MCDM defines specific criteria and subcriteria, evaluates, selects, and prioritizes the alternatives. Many MCDM methods have been studied during the literature review. It is a very sophisticated and easy decision-making tool that provides quantitative and qualitative factors.

Multicriteria decision making has various methods, as shown in Figure 1. Many of these methods are already used for solving problem IoT-related problems like Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), TOPSIS, Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Grey Relational Analysis (GRA), Goal Programming (GP), Value Analysis (VA), Value Engineering (VE), ELimination Et Choix Traduisant la REalité (ELECTRE), and Simple Additive Weighting (SAW).

In this article, the authors selected a combination of AHP and TOPSIS to evaluate the Internet of medical things challenges, develop criteria and subcriteria, formulate a comparison matrix, calculate local weights of the criteria and global weights of the subcriteria, and finally develop a decision matrix to rank the alternatives.

2.2. Analytical Hierarchy Process (AHP). Renowned mathematician Thomas Saaty formulated AHP to complicated decisions [44] and facilitated all kinds of industries to decide their priorities in all areas among different alternatives [43, 45, 46]. It is a powerful technique to solve unstructured, complex, and complicated problems. In AHP, the complex problem is always breakdown into small problems and organized into hierarchical levels. Each level of the hierarchical structure represents several criteria, subcriteria, and alternatives [47]. Each alternative is synthesized to finally rank/prioritize them to get the best solution. The AHP is a multicriteria analysis methodology based on the weighting process, and each criterion represents its importance. AHP is applied in various areas like education, engineering, healthcare, and especially in the financial areas. In AHP, initially, the importance of each criterion is set through pairwise comparison in which each criterion is compared with the rest of the criteria by assigning values. The first version of the AHP has various shortcomings [48]. Mr. Chen and Yang while highlighting deficiencies in AHP, pointed out that it is only used for crisp information, an unbalanced scale is used for judgment, it also not able to handle the uncertainty associated with human opinions, generate imprecise ranking, and final

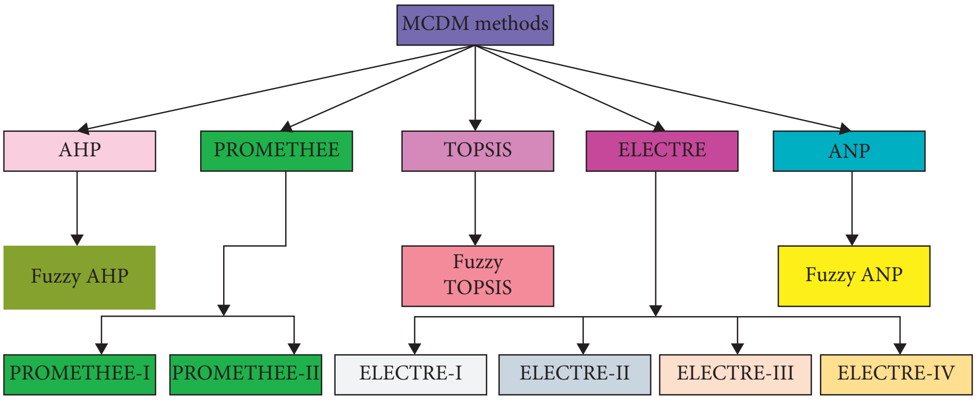

Figure 1: Multicriteria decision-making methods.

selection of alternatives are only based on experts' opinion. To remove the discrepancies in the AHP, various researchers integrated AHP with fuzzy set theory. In the year 1987, Buckley used fuzzy trapezoidal numbers to calculate the weights [49]. After applying the fuzzy analytic hierarchy process, the biasness of the evaluators can also be minimized, reliability can be increased, and it also becomes more validated [50].

2.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The TOPSIS technique was initially formulated in the year 1981 by Yoon and Hwang [51]. The main aim of the method is to evaluate the alternatives based on specific criteria, get opinions of the experts/decision makers to develop decision matrix, and select an alternative that has the shortest distance from the positive ideal solution and an alternative that has the farthest distance from the negative ideal solution. In a positive ideal solution, we give more weightage to the benefit criteria and less weightage to the cost criteria, whereas on the other hand, in a negative ideal solution, the cost criteria have more weightage and benefit criteria have less weightage. The upshot is the positive ideal solution provides the best values based on the criteria and vice versa. The reader who is more interested in studying the TOPSIS may read a broad survey [52]. According to Chen's method [53], the technique of fuzzy TOPSIS is like classical TOPSIS. Various studies have already been conducted by using fuzzy logic with TOPSIS for the IoT [54, 55].

3. Identifying the Criteria, Subcriteria, and Alternatives

In the AHP, the purpose of the criteria is to help in the selection problem. All the alternatives have to satisfy an independent set of criteria. The authors developed the criteria and their subcriteria based on the opinions of the Internet of medical things experts and proposed five criteria: (C1) security and privacy criterion, which represents the most influential factors regarding security and privacy; (C2) data criterion, which represents the Internet of medical things challenges related to data; (C3) technology criterion, which represents the technology-related Internet of medical things challenges; (C4) legal criterion, which is used to highlight the legal issues of the IoMT; and (C5) cost criterion, which identifies the cost related to Internet of medical things challenges. The proposed framework is about the evolution of the Internet of medical things challenges as criteria, and three medial IoT scenarios, as alternatives, were developed and organized into four main layers, as shown in Figure 2. The first layer of the framework is to define the goal of the study, and the second layer consists of five significant forces, namely, security and privacy, data, technology, legal, and cost. In the third layer, twenty subcriteria are placed against each significant force. Every subcriterion is adequately connected with its relevant criteria. The fourth layer of Figure 2 is about alternatives, and we placed three alternatives for prioritization purposes based on criteria and subcriteria.

The analytic hieratical process deliberated many assessment criteria and helped to select the best alternative [45, 56, 57]. Figure 2 shows a hierarchy structure based on the AHP method for the evaluation of the Internet of medical things challenges.

Figure 2 explains the methods of AHP, criteria, subcriteria, and alternatives in a graphical view. In the AHP, the first stage is to establish the goals of the study that is to evaluate and select the most critical Internet of medical things challenges. After formulating goals, criteria for evaluation and prioritization are required to be developed with the consultations of the experts/decision makers. In Figure 2, the authors defined five criteria and twenty subcriteria with the discussion of experts. Every criterion has been assigned a weight that designates the position of the criteria. The planned criteria are applied to alternatives to choose the best alternative, among other ambiguous alternatives, and also rank the alternatives. Figure 2 shows three Internet of medical things challenges as alternatives. The most critical Internet of medical things challenge and ranking of the IoMT challenges should be done according to 20 subcriteria.

4. Fuzzy Analytic Hierarchy Process and Fuzzy TOPSIS Methodology

In this study, the Internet of medical things- (IoMT-) related challenges in the medium-sized industry in Pakistan were assessed. The investigation's point was to decide

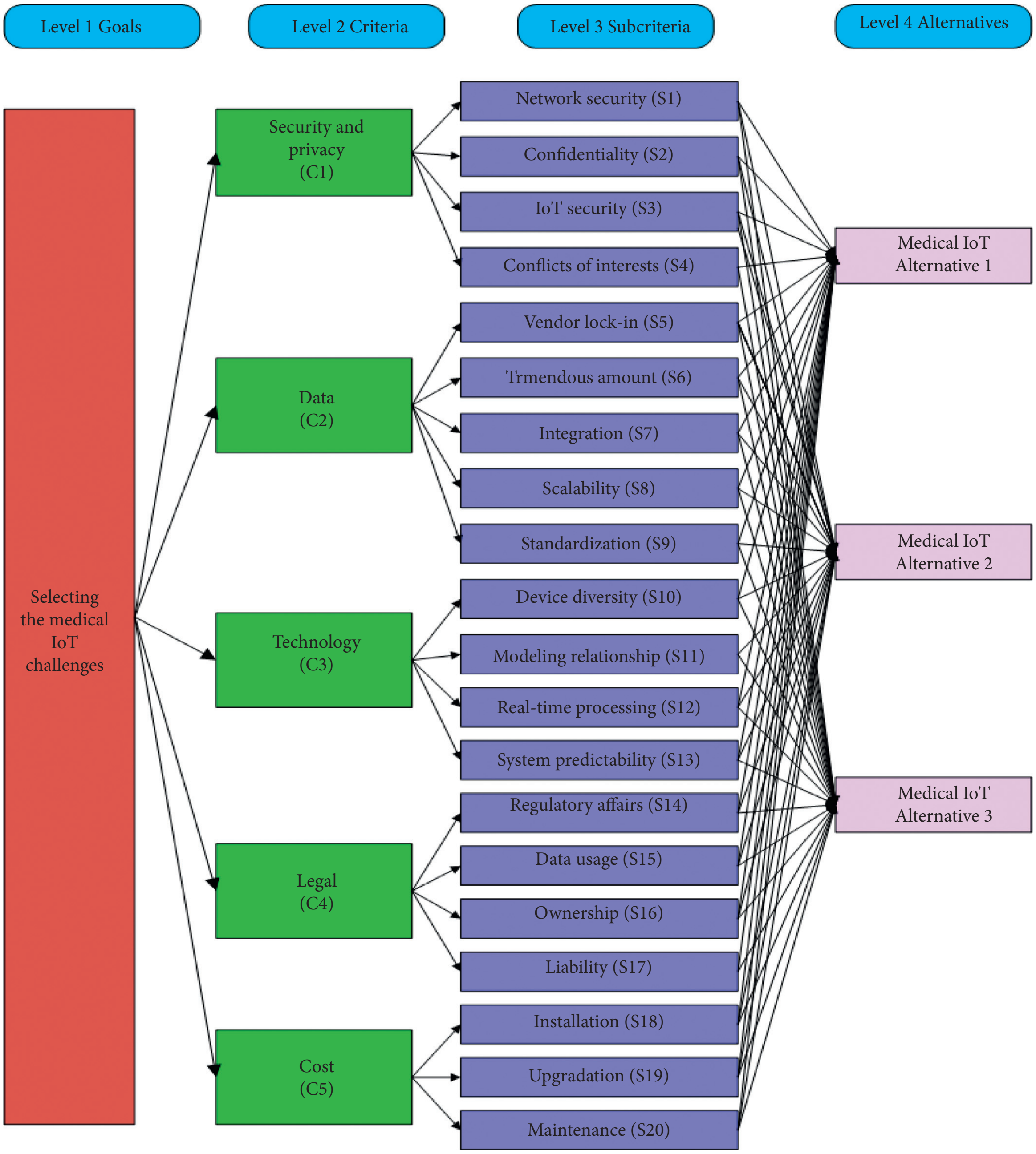

Figure 2: Hierarchy structure of AHP.

the Internet of medical things challenges in the adoption and deployment by studying and developing the importance of criteria. The criteria that ought to get specific consideration were underlined. Criteria were developed based on consultations with IoMT experts and relevant industry stakeholders. In this study, we considered small and medium-sized enterprises (SMEs) that are willing to adopt IoMT services as a case study. To evaluate the criteria, specialists were consulted for their expert opinion. As per the resources of the organization, three decision makers were asked. These decision makers were individuals who researched on the Internet of medical things. The Decision Makers have also studied the literature related to IoMT and also have experience to deal with such challenges.

The limited number of decision makers is the obstruction of this study. To cater to this prompting lacking assessments, the authors of this article get the help from the literature review to authenticate the accuracy of the evaluation. Three decision makers used fuzzy-based AHP and TOPSIS techniques for the assessment in the area of Internet of medical things. Fuzzy-based pairwise comparison matrices were assessed independently by the decision makers. These evaluations were then aggregated by using fuzzy aggregation equations.

The proposed hybrid methodology consists of four phases, as shown in Figure 3. Each stage consists of the next stage to get the outcome. Based on Figure 3, the following steps were taken to evaluate and rank the IoMT challenges:

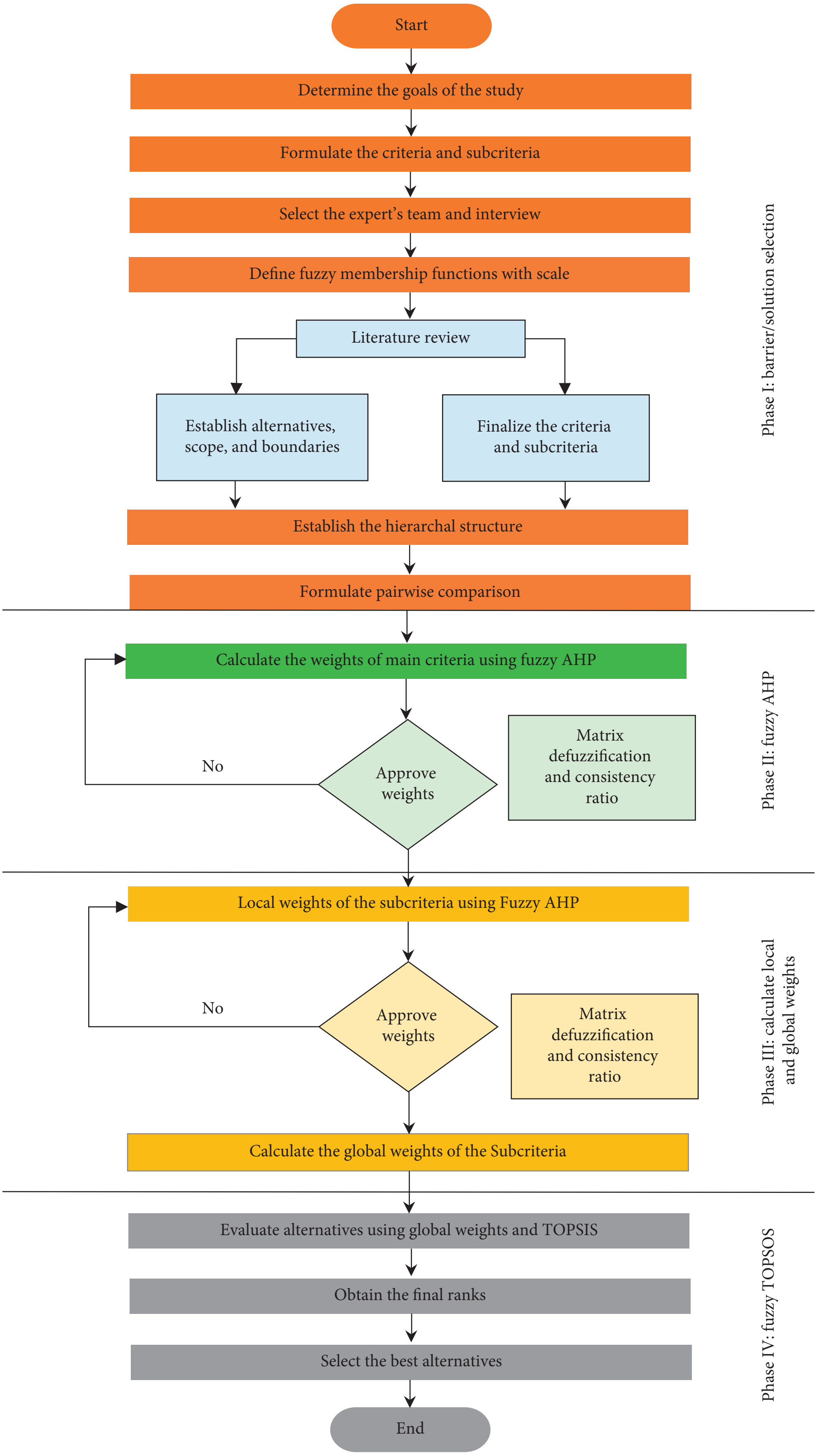

FIGURE 3: Fuzzy analytic hierarchy process and TOPSIS methodology.

(1) Define the goals and objective of the study.
(2) Contact decision makers/experts and hold a meeting with them to formulate criteria and subcriteria and select alternative.
(3) For pairwise comparison, the express scale consists of fuzzy membership functions.
(4) Conduct systematic literature review (SLR).
(5) Finalize criteria, subcriteria, and alternatives with the Internet of medical things experts.
(6) Define scope and boundaries of the Internet of medical things.
(7) Prepare matrix based on hierarchal structure.
(8) Establish a pairwise comparison matrix.
(9) Initiate the fuzzy defuzzification process and check the CR. If $CR < 0.1$ and weights of the criteria are according to pairwise comparison, then move forward; otherwise, go back to Step 7.
(10) Compute the weight of criteria using the fuzzy analytic hierarchy process technique.
(11) Formulate the pairwise comparison matrix of each subcriterion based on the opinions of decision makers. Check the consistency ratio of the subcriteria matrix and move forward to calculate the local weights of the subcriteria; otherwise, repeat previous steps to rectify the error.
(12) Calculate the local weights of the subcriteria using fuzzy analytic hierarchy process.
(13) Calculate the global weights of the subcriteria by multiplying weights of the criteria with local weights of the subcriteria.
(14) Develop decision matrices using fuzzy TOPSIS.
(15) Aggregate the options of the decision makers by applying fuzzy aggregation equations.
(16) Normalize the decision matrix and assign the global weights to the decision matrix.
(17) Compute final ranks through fuzzy-based TOPSIS techniques.
(18) Select the best alternative/Internet of medical things challenges.

Figure 3 reflects the proposed methodology for the prioritization of the Internet of medical things challenges. The core advantages of this integrated and hybrid methodology are that the limitation of the AHP is covered with the introduction of the fuzzy logic for the weighting of criteria and the best-ranking technique, i.e., TOPSIS is used along with fuzzy logic to evaluate and prioritize the best alternative.

4.1. Phase I: Identification of Medical IoT Challenge.

A detailed systematic literature review was conducted on the Internet of medical things and examined. We also investigated the same nature of the problem addressed in the literature review; the methodology used by the author of the study, criteria, and method adopted by the authors were also determined. During the systematic literature review, we observed that each area of science has its importance which is still under development. Although the idea of IoT is not new, it has dynamic characteristics due to rapid change in growth, especially in the area of healthcare. Initially, we conducted this study in collaboration with small and medium-sized enterprises. The criteria and subcriteria of the Internet of medical things were developed by the authors of this article and duly examined and evaluated by the Internet of medical things experts having industry experience, and the fuzzy analytic hierarchy process and fuzzy TOPSIS methods were introduced. The decision makers/experts before evaluation first examined the organizational structure. The decision makers, thereafter, studied the concepts of the literature review of this article and the Internet of medical things. The experts, keeping in view the existing study on the related topics, prepared the goals of the survey and amended and finalized their own proposed criteria and subcriteria of the Internet of medical things challenges. The validity and authenticity of the criteria were discussed in detail with experts and industry stakeholders, and finally, the evaluation process was initiated. The goals of the study, main criteria, subcriteria, and alternatives are shown in Figure 2.

The next step is the formulation of the pairwise comparison matrix and transformation of the real numbers into fuzzy numbers. To accomplish this, triangular fuzzy numbers (TFNs) are used, as shown in Figure 4.

Although there are many other methods like trapezoidal fuzzy numbers (TrFNs), due to full acceptance of the TFNs, we used this in AHP and TOPSIS. Equation (1) is used to formulate FTMF, and (l, m, u) are used for notation.

$$\mu\left(\overline{M}\right) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & x > u. \end{cases} \tag{1}$$

Use equation (2) to construct the pairwise comparison matrix, which has comparison in pairs, and select the appropriate linguistic values for alternatives regarding criteria. The goal is to define relative priorities for each element. The value a_{ij} demonstrates the relative significance of criterion i (c_i) in comparison with criterion j (c_j) in Saaty's scale.

$$A = [a_{ij}] = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_n \end{array}\begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \end{array} \tag{2}$$

Let $X = \{x_1, x_2, x_3, \ldots, x_n\}$ be an object set and $G = \{g_1, g_2, g_3, \ldots, g_n\}$ be the goal setting. Therefore, we can calculate m extent analysis value for every object using the following equation:

$$M_{gi}^{1}, M_{gi}^{2}, \ldots, M_{gi}^{m}, \quad i = 1, 2, 3, \ldots, n. \tag{3}$$

4.2. Phase II: Fuzzy Analytic Hierarchy Process.

To calculate the weights of the criteria, first, we have to figure the fuzzy synthetic extent concerning ith object by using the following equation:

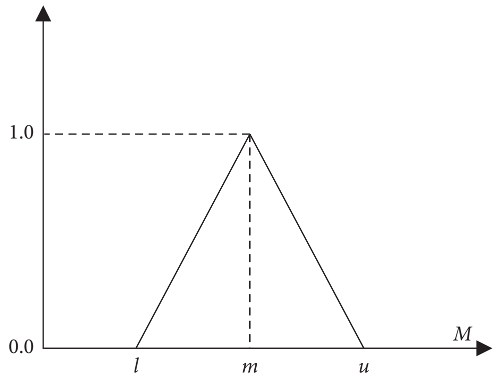

Figure 4: Fuzzy triangular number.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \oplus \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}. \tag{4}$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, the fuzzy adding formula will be applied to m extent analysis through the following equation:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_i \right). \tag{5}$$

To obtain $[\sum_{i=1}^{n} X_i \sum_{j=1}^{m} M_{gi}^{j}]^{-1}$, fuzzy logic-based addition function set in equation (6) will be applied, and we also compute the inverse of equation (6) by using equation (7).

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_i \right), \tag{6}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{j=1}^{n} u_i} \frac{1}{\sum_{j=1}^{n} m_i} \frac{1}{\sum_{j=1}^{n} l_i} \right). \tag{7}$$

Calculate degree to the possibility in a situation where $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$, and it is defined as equations (8) to (10).

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y) \right) \right], \tag{8}$$

$$V(M_2 \geq M_1) = hgt\ (M_1 \cap M_2) = \mu_{M2}(d), \tag{9}$$

$$V(M_2 \geq M_1) = hgt\ (M_1 \cap M_2) = \frac{(l_1 - u_2)}{(m_2 - u\_2)} - (m_1 - l_1), \tag{10}$$

where (d) is an ordinate linked with intersection point (D), and the highest intersection point between TFNs is shown in Figure 5.

To calculate the lowest degree of possibility $M_2 \geq M_1$, fuzzy values $M_i = (1, 2, \ldots, k)$ are required to be computed as shown in the following equation:

$$V\ (M \geq M_1, M_2, \ldots, M_k) = \min V\ (M \geq M_i), \quad (i = 1, 2, \ldots, k). \tag{11}$$

Assuming that $d'(A_i) = \min V\ (S_i \geq S_k)$ for $K = 1, 2, \ldots, n$, finally weights of main criteria shall be computed using the following equation:

$$W' = (d'(A_1), d'(A_2), \ \ldots, d'(A_n)), \tag{12}$$

where $A_i = (i = 1, 2, \ldots, n)$ and n are elements.

It is imperative to normalize the matrix; W' represents priority weights and is calculated using the following equation:.

$$W = (d(A_i), d(A_2), \ldots, d(A_n))^T, \tag{13}$$

where W is not a fuzzy number.

AHP calculates the consistency index (CI) to validate the results of the comparison matrix. Equation (14) helps to calculate inconsistency in the decisions of experts, whereas $\lambda_{\max}$ is the principal eigenvalue of the decision matrix.

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{14}$$

Equation (15) assists in calculating the consistency ratio (CR) to authenticate the final weights.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \tag{15}$$

The values of the random index (RI) are available in [58].

4.3. Phase III: Calculating Local and Global Weights.

After calculating the weights of the criteria, the next step is to calculate the local weights of the subcriteria. For each subcriterion, the pairwise comparison matrix will be

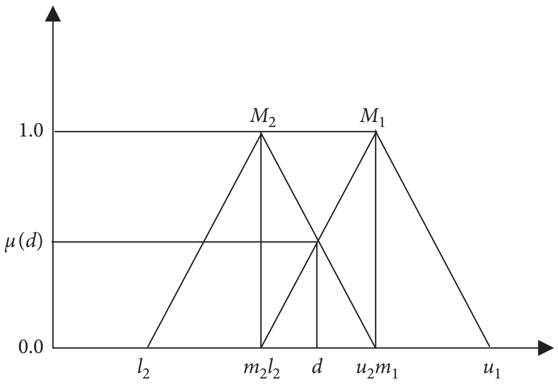

Figure 5: The intersection between M_1 and M_2.

developed, and equation (1) to equation (15) will be used to compute the local weights of the subcriteria. The numerical example is shown in all steps in Section 5.

Global weights of the criteria are also required to be calculated by multiplying the values of the weights with local weights of the subcriteria.

The complete steps using the fuzzy analytic hierarchy process to calculate the weights, local weights, and global weights of the criteria are explained in Figure 6.

4.4. Phase IV: Fuzzy TOPSIS. The fourth stage of the study is to introduce a fuzzy TOPIS technique to evaluate the alternatives based on the weights of the criteria determined through the fuzzy analytic hierarchy process.

Equation (16) is used to develop a decision matrix of the TOPSIS method. Linguistic variables are used in this process.

$$\mathrm{E} = [e_{ij}]_{n\times m} = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} e_{11} & \cdots & e_{1n} \\ \vdots & \ddots & \vdots \\ e_{m1} & \cdots & e_{mn} \end{bmatrix}_{m\times n} \tag{16}$$

Thereafter, the linguistic variables are required to be converted into TFNs so that related fuzzy operations may be applied.

In TOPSIS, we have taken the expert opinion of three decision makers individually. Equations (17) to (20) are related to the aggregation of experts' preference values.

$$\widetilde{X}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right), \tag{17}$$

$$a_{ij} = \min_K \left\{a_{ij}^k\right\}, \tag{18}$$

$$b_{ij} = \frac{1}{k}\sum_{k=1}^{k} b_{ij}^k, \tag{19}$$

$$c_{ij} = \max_K \left\{a_{ij}^k\right\}. \tag{20}$$

Normalize the fuzzy decision matrix using equation (21), and it is denoted as $\widetilde{B}$:

$$\widetilde{B} = \left[r_{ij}\right]_{m\times n}. \tag{21}$$

In order to compute beneficial criteria, equation (22) is used.

$$\begin{aligned} \widetilde{r}_{ij} &= \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \\ c_j^* &= \max\left\{c_{ij}\right\}. \end{aligned} \tag{22}$$

To compute non-bifacial criteria/criteria, equation (23) is used.

$$\begin{aligned} \widetilde{r}_{ij} &= \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \\ c_j^* &= \min\left\{a_{ij}\right\}. \end{aligned} \tag{23}$$

Equation (24) is used to compute weighted normalized fuzzy decision matrix:

$$\widetilde{v}_{ij} = \widetilde{r}_{ij} \times w_j. \tag{24}$$

Equation (25) is related to calculating fuzzy positive ideal solution (FPIS), and equation (26) is associated with fuzzy negative ideal solution (FNIS).

$$V_i^+ = \left\{\max_{1\le i\le n}\right\}\left(\left\{v_{ij}\right\}_{i=1}^n\right) \mid j \in J^+, \min_{1\le i\le n}\left(\left\{v_{ij}\right\}_{i=1}^n\right) \mid j \in J_- = \left\{v_{ij} \mid j = 1, 2, \ldots, n\right\}, \tag{25}$$

$$V_i^- = \left\{\min_{1\le i\le n}\right\}\left(\left\{v_{ij}\right\}_{i=1}^n\right) \mid j \in J^+, \max_{1\le i\le n}\left(\left\{v_{ij}\right\}_{i=1}^n\right) \mid j \in J_- = \left\{v_{ij} \mid j = 1, 2, \ldots, n\right\}. \tag{26}$$

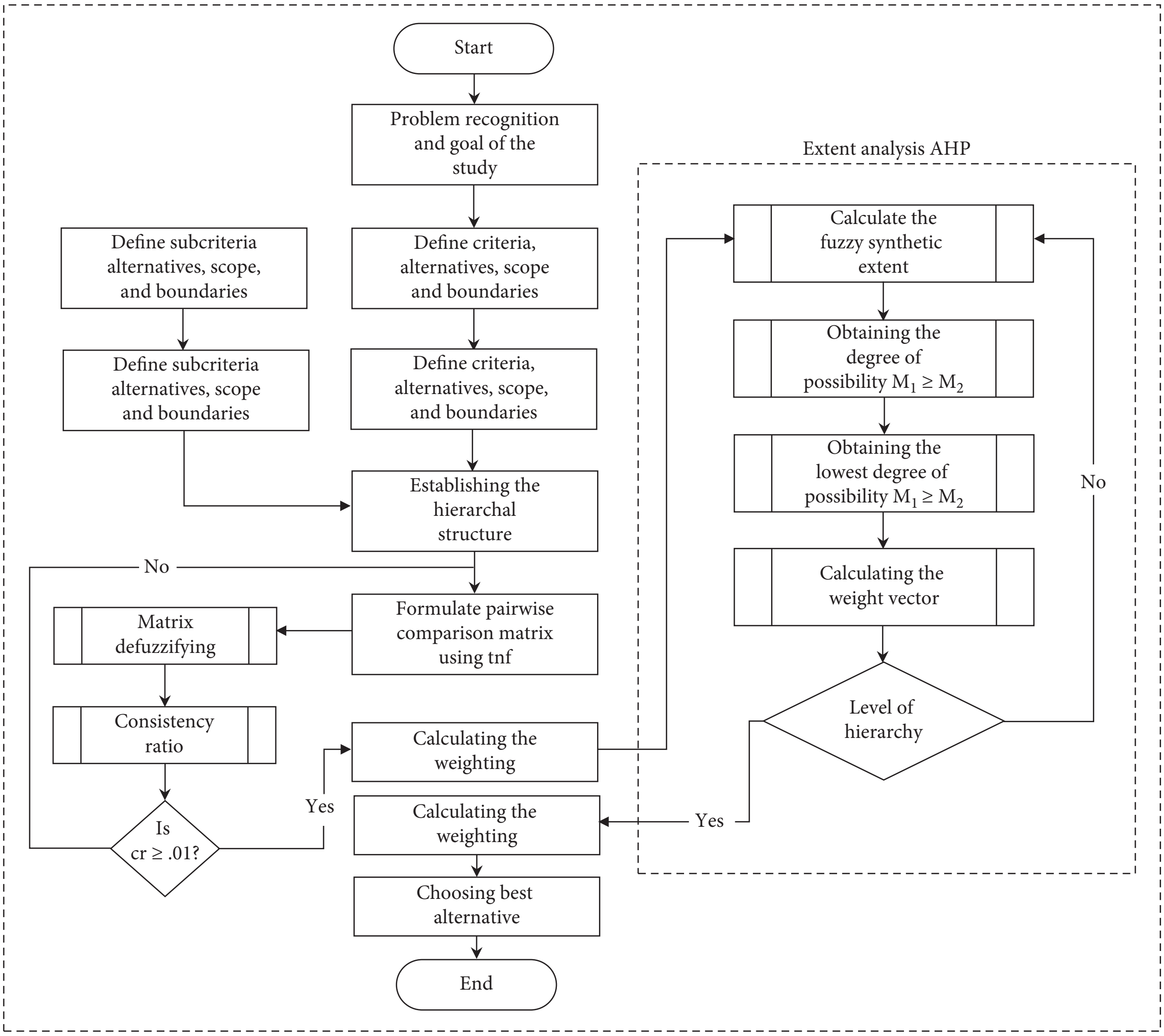

Figure 6: Fuzzy analytic hierarchy process methodology.

Calculate the distance of alternatives from fuzzy positive ideal solution using equation (27) and fuzzy negative ideal solution through equation (28).

$$d_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_i^+\right)^2}, \tag{27}$$

where $(i = 1, 2, \ldots, n)$.

$$d_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_i^-\right)^2}, \tag{28}$$

where $(i = 1, 2, \ldots, n)$.

The final relative proximity P_i is calculated using the following equation:

$$P_i = \frac{d_i^-}{d_i^+ + d_i^-}. \tag{29}$$

5. Results and Discussion

The organization deploying the Internet of medical things may use the proposed methodology for the evaluation of real-world Internet of medical things-related challenges. In this Internet of medical things challenge problem, there are five criteria, twenty subcriteria, and four alternatives. The hierarchical structure to choose the most critical Internet of medical things challenge is shown in Figure 2. The proposed organization size is a small and medium-sized enterprise. In this study, detailed interviews were conducted with three Internet of medical things experts and one industry stakeholder to identify weight coefficients. Before gathering data from the experts, we defined the linguistic scale based on the fuzzy triangular numbers and discussed the same scale with the experts. The authors contacted many IoMT experts, but the majority of the experts refused to assist the authors due to their personal and official limitations. After the approval of the linguistic scale, we also discussed the criteria and subcriteria with the experts.

It is pertinent to mention here that due to personal access to the IoMT experts, one of the authors of this article visited each expert and discussed the aforementioned things. It is also paramount to add here that to protect their privacy, the name of the experts and their organizations are not mentioned in this article. After finalizing the proposed criteria and linguistic scale, the experts were given both things with the guideline to insert their input in the pairwise matrix. After the development of the pairwise matrix, the authors applied the proposed fuzzy analytic hierarchy process methodology, and the results are shown in Table 1. The authors then identified the four alternatives as a sample to evaluate and prioritize them. The experts then gave their opinion on each alternative by considering the TOPSIS parameters and ranked each alternative. The aggregated matrix is shown in Table 2.

Fuzzy analytic hierarchy process and fuzzy TOPSIS techniques were integrated to obtain the best results and to rectify the shortcomings in both methodologies. The step by step numerical example of the proposed method for the Internet of medical things challenges is given as follows.

Step 1. The first step is to define the objectives and goals of the study. Here in this example, the purposes of the research are to evaluate and prioritize the Internet of medical things challenges and find the most critical problems to save cost and take measures in due course of time.

Step 2. The most important and critical stage of this study is to finalize the criteria to evaluate and rank the alternatives. We already explained the details about the formulation of the criteria in the previous section.

Step 3. During the literature review, we studied many linguistic scales for the evaluation of alternatives, and these scales were developed, keeping in view the nature of the problem. In this study, we agreed to use TFNs and Saaty's scale [59], as shown in Table 3. The range of the scale is 0 to 11. Figure 7 represents the fuzzy analytic hierarchy process scale opted for evaluation, and Table 3 expresses the scale for pairwise comparison matrix.

Step 4. In the next level, prepare a comparison matrix table using given above linguistic scale, as shown in Table 4.

Step 5. By using equations (2) and (3), develop a fuzzy pairwise comparison matrix based on the decision maker's opinion and linguistic scale, as shown in Table 5.

Step 6. Use equation (4) to calculate the weights of the main criteria by synthesizing values.

$S_{C1} = (7.00, 13.00, 19.00) * (0.017, 0.023, 0.035) = (0.116, 0.301, 0.666)$.

$S_{C2} = (6.14, 10.20, 14.33) * (0.017, 0.023, 0.035) = (0.102, 0.236, 0.502)$.

$S_{C3} = (6.68, 8.87, 11.67) * (0.017, 0.023, 0.035) = (0.111, 0.205, 0.409)$.

$S_{C4} = (2.51, 4.81, 8.20) * (0.017, 0.023, 0.035) = (0.042, 0.111, 0.287)$.

$S_{C5} = (6.20, 6.33, 7) * (0.017, 0.023, 0.035) = (0.103, 0.147, 0.245)$.

Step 7. Equations (9) and (10) were used to calculate the degree of possibility.

$V\,(S_{C1} \geq S_{C2}) = 1$, $V\,(S_{C1} \geq S_{C3}) = 1$, $V\,(S_{C1} \geq S_{C4}) = 1$, $V\,(S_{C1} \geq S_{C5}) = 1$.

$V\,(S_{C2} \geq S_{C1}) = 0.856$, $V\,(S_{C2} \geq S_{C3}) = 1$, $V\,(S_{C2} \geq S_{C4}) = 1$, $V\,(S_{C2} \geq S_{C5}) = 1$.

$V\,(S_{C3} \geq S_{C1}) = 0.754$, $V\,(S_{C3} \geq S_{C2}) = 0.909$, $V\,(S_{C3} \geq S_{C4}) = 1$, $V\,(S_{C3} \geq S_{C5}) = 1$.

$V\,(S_{C4} \geq S_{C1}) = 0.474$, $V\,(S_{C4} \geq S_{C2}) = 0.598$, $V\,(S_{C4} \geq S_{C3}) = 0.653$, $V\,(S_{C4} \geq S_{C5}) = 0.839$.

$V\,(S_{C5} \geq S_{C1}) = 0.456$, $V\,(S_{C5} \geq S_{C2}) = 0.616$, $V\,(S_{C5} \geq S_{C3}) = 0.696$, $V\,(S_{C5} \geq S_{C4}) = 1$.

Step 8. To compute priority weights, equation (11) was considered.

$d'\,(C_1) = \min\,(1, 1, 1, 1, 1) = 1$.

$d'\,(C_2) = \min\,(0.856, 1, 1, 1, 1, 1) = 0.856$.

$d'\,(C_3) = \min\,(0.754, 0.909, 1, 1) = 0.754$.

$d'\,(C_4) = \min\,(0.474, 0.598, 0.653, 0.839) = 0.474$.

$d'\,(C_5) = \min\,(0.456, 0.616, 0.696, 1) = 0.456$.

The priority weights are $W' = (1, 0.856, 0.754, 0.474, 0.456)$.

Step 9. Equations (12) and (13) were used to normalize the priority weights of the criteria. The weights of each criterion are shown in Table 1. The contribution of the main criteria for the evaluation of the Internet of medical things challenges is shown in Figure 8.

Step 10. Compute the value of $\lambda_{\max} = 7.629$ and then calculate the consistency index (CI) using equation (14) to validate the methodology, and 0.105 means the comparison matrix and expert's opinions are well. Similarly, equation (15) was used to calculate consistency ratio (CR), and it was 0.094, which was less than 0.1.

Step 11. The local weights of the subcriteria were calculated by using the fuzzy analytic hierarchy process equations (1) to (13). The local weights are shown in Table 6.

Step 12. The values of the consistency index (CI) and consistency ratio (CR) of each subcriterion were again calculated using equations (14) and (15), and the same is reflected in Table 7.

Step 13. The global weights of the main criteria are calculated by multiplying the weights of the criteria with the local weights of the subcriteria. The values of the global weights of

Table 1: Weights of each criteria.

(C1)	(C2)	(C3)	(C4)	(C5)
0.282	0.242	0.213	0.134	0.129

Table 2: Aggregated fuzzy-based decision matrix.

Subcriteria alternative	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Alternative 1	(5, 7, 9)	(3, 7, 9)	(3, 5, 7)	(3, 6, 9)	(1, 6, 9)	(1, 5, 9)	(3, 7, 9)	(3, 7, 9)	(3, 5, 7)	(3, 5, 7)
Alternative 2	(1, 6, 9)	(1, 6, 9)	(5, 7, 9)	(1, 6, 9)	(1, 4, 9)	(1, 3, 7)	(1, 6, 9)	(1, 6, 9)	(5, 7, 9)	(1, 6, 9)
Alternative 3	(5, 8, 9)	(1, 6, 9)	(5, 8, 9)	(5, 7, 9)	(5, 7, 9)	(1, 6, 9)	(3, 6, 9)	(5, 8, 9)	(5, 8, 9)	(5, 8, 9)
Alternative 4	(5, 8, 9)	(3, 5, 7)	(1, 2, 5)	(1, 4, 7)	(1, 6, 9)	(3, 6, 9)	(1, 5, 9)	(3, 5, 7)	(1, 2, 7)	(1, 3, 5)
Subcriteria alternative	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Alternative 1	(3, 8, 9)	(1, 6, 9)	(1, 5, 9)	(5, 7, 9)	(1, 5, 9)	(3, 7, 9)	(3, 6, 9)	(3, 6, 9)	(3, 6, 7)	(3, 6, 9)
Alternative 2	(1, 4, 9)	(1, 4, 9)	(1, 4, 9)	(1, 5, 9)	(1, 4, 9)	(1, 6, 9)	(5, 7, 9)	(1, 5, 9)	(1, 6, 9)	(5, 7, 9)
Alternative 3	(5, 7, 9)	(1, 6, 9)	(3, 6, 9)	(1, 6, 9)	(3, 6, 9)	(3, 7, 9)	(5, 8, 9)	(5, 7, 9)	(5, 8, 9)	(5, 8, 9)
Alternative 4	(1, 4, 7)	(3, 6, 9)	(1, 6, 9)	(1, 4, 7)	(1, 6, 9)	(1, 4, 7)	(1, 4, 7)	(1, 3, 7)	(1, 4, 7)	(1, 4, 7)

Table 3: Fuzzy scale and numbers.

Scale (0–11)	Evaluation	Fuzzy scale	Reciprocal
1	Equally important (EI)	(1, 1, 1)	(1, 1, 1)
3	Moderately important (MI)	(1, 3, 5)	(1/5, 1/3, 1)
5	Strongly important (SI)	(3, 5, 7)	(1/7, 1/5, 1/3)
7	Very strongly important (VSI)	(5, 7, 9)	(1/9, 1/7, 1/5)
9	Extremely important (EI)	(7, 9, 11)	(1/11, 1/9, 1/7)

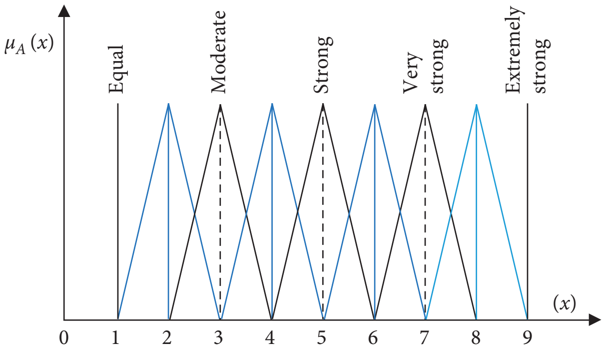

Figure 7: Linguistic scale based on triangular numbers.

Table 4: Comparison matrix based on linguistic scale.

Criteria	Security and privacy (C1)	Data (C2)	Technology (C3)	Legal (C4)	Cost (C5)
Security and privacy (C1)	1	5	3	3	1
Data (C2)	1/5	1	5	3	1
Technology (C3)	1/3	1/5	1	7	1/3
Legal (C4)	1/3	1/3	1/7	1	3
Cost (C5)	1	1	3	1/3	1

Table 5: Fuzzy-based pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5
C1	(1, 1, 1)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 1, 1)
C2	(1/7, 1/5, 1/3)	(1, 1, 1)	(3, 5, 7)	(1, 3, 5)	(1, 1, 1)
C3	(1/5, 1/3, 1)	(1/7, 1/5, 1/3)	(1, 1, 1)	(5, 7, 9)	(1/3, 1/3, 1/3)
C4	(1/5, 1/3, 1)	(1/5, 1/3, 1)	(1/9, 1/7, 1/5)	(1, 1, 1)	(1, 3, 5)
C5	(1, 1, 1)	(1, 1, 1)	(3, 3, 3)	(1/5, 1/3, 1)	(1, 1, 1)

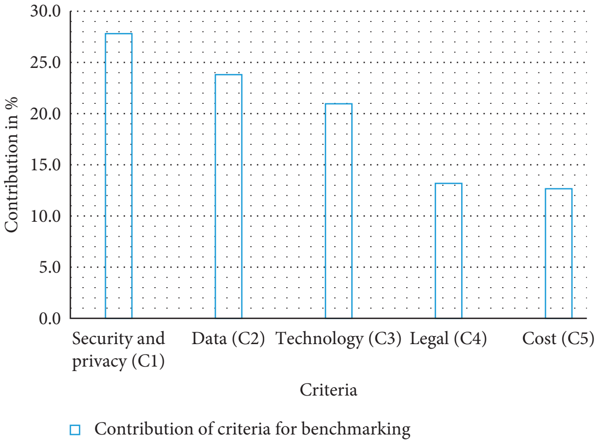

Figure 8: Contribution of the criteria for benchmarking Internet of medical things challenges.

Table 6: Local weights of the subcriteria.

Criteria	Subcriteria	Local weights of subcriteria
Security and privacy (C1)	Network security (S1)	0.2115
	Confidentiality (S2)	0.3786
	IoT security (S3)	0.2438
	Conflicts of interest (S4)	0.1661
Data (C2)	Vendor lock-in (S5)	0.2097
	Tremendous amount (S6)	0.2902
	Integration (S7)	0.2616
	Scalability (S8)	0.1746
	Standardization (S9)	0.0638
Technology (C3)	Device diversity (S10)	0.1718
	Modelling relationship (S11)	0.2405
	Real-time processing (S12)	0.3790
	System predictability (S13)	0.2088
Legal (C4)	Regulatory affairs (S14)	0.3769
	Data usage (S15)	0.3114
	Ownership (S16)	0.1895
	Liability (S17)	0.1221
Cost (C5)	Installation (S18)	0.4770
	Maintenance (S19)	0.3458
	Upgradation (S20)	0.1771

Table 7: Consistency index and consistency ratio of subcriteria.

Criteria	DM-1		DM-2		DM-3		DM-4		DM-5	
	CI	CR	CI	CR	CI	CR	CI	CR	CI	CR
Security and privacy	0.044	0.049	0.063	0.070	0.054	0.059	0.054	0.060	0.054	0.059
Data	0.089	0.079	0.034	0.031	0.054	0.048	0.078	0.070	0.056	0.050
Technology	0.067	0.074	0.054	0.060	0.051	0.057	0.044	0.049	0.054	0.059
Legal	0.088	0.098	0.066	0.074	0.023	0.025	0.031	0.034	0.017	0.019
Cost	0.002	0.004	0.038	0.066	0.029	0.050	0.038	0.066	0.029	0.050

the criteria are given in Table 8. The contribution of the global weights for benchmarking the Internet of medical things challenges is shown in Figure 9.

The criteria and weights were finalized, and these weights were used as weights of the TOPSIS decision matrix.

The robust features of fuzzy TOPSIS were used to evaluate and rank the alternatives.

Step 14. Formulate linguistic variables for the decision matrix. The authors developed the triangular fuzzy

Table 8: Global weights of the main criteria.

Criteria	Weights of the criteria	Subcriteria	Local weights of subcriteria	Global weights of the criteria
Security and privacy (C1)	0.282	Network security (S1)	0.2115	0.060
		Confidentiality (S2)	0.3786	0.107
		IoT security (S3)	0.2438	0.069
		Conflicts of interest (S4)	0.1661	0.047
Data (C2)	0.242	Vendor lock-in (S5)	0.2097	0.051
		Tremendous amount (S6)	0.2902	0.070
		Integration (S7)	0.2616	0.063
		Scalability (S8)	0.1746	0.042
		Standardization (S9)	0.0638	0.015
Technology (C3)	0.213	Device diversity (S10)	0.1718	0.037
		Modelling relationship (S11)	0.2405	0.051
		Real-time processing (S12)	0.3790	0.081
		System predictability (S13)	0.2088	0.044
Legal (C4)	0.34	Regulatory affairs (S14)	0.3769	0.128
		Data usage (S15)	0.3114	0.106
		Ownership (S16)	0.1895	0.064
		Liability (S17)	0.1221	0.042
Cost (C5)	0.129	Installation (S18)	0.4770	0.062
		Maintenance (S19)	0.3458	0.045
		Upgradation (S20)	0.1771	0.023

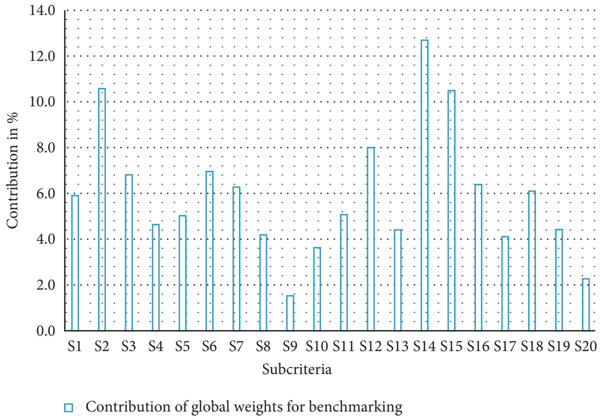

Figure 9: Contribution of the global weights for benchmarking Internet of medical things challenges.

number- (TFN-) based linguistic scale, as shown in Table 9.

Step 15. Establish a decision matrix in the light of the decision maker's rating. In this study, three decision makers participated who already gave their opinions in the fuzzy analytic hierarchy. For demonstration purposes, the authors selected 4 medical IoT challenges for the ranking/prioritization purpose. Equations (17) to (20) were used to aggregate the decisions. The aggregated decision matrix is shown in Table 2.

Step 16. Use equations (21) to (23) to normalize the decision matrix, as shown in Table 10. It is worthwhile and pertinent to add here that installation cost (S18), maintenance cost (S19), and upgradation cost (S20) are the nonbeneficial subcriteria and the remaining subcriteria are beneficial in said matrix.

Table 9: Linguistic variable ratings.

Linguistic variables	Assigned TFN
Very low	(1, 1, 3)
Low	(1, 3, 5)
Average	(3, 5, 7)
High	(5, 7, 9)
Very high	(7, 9, 9)

Step 17. Compute weighted normalized matrix through equation (24). The output of $(\tilde{v}_{ij})$ is shown in Table 11.

Step 18. Use equation (25) to compute (V_i^+) and equation (26) for (V_i^-); the results are shown in Table 12.

Table 10: Normalized fuzzy decision matrix.

Subcriteria alternative	S1	S2	S3	S4	S5
Alternative 1	(0.56, 0.78, 1)	(0.33, 0.78, 1)	(0.33, 0.56, 0.78)	(0.33, 0.70, 1)	(0.11, 0.63, 1)
Alternative 2	0.11, 0.63, 1)	(0.11, 0.63, 1)	(0.56, 0.78, 1)	(0.11, 0.63, 1)	(0.11, 0.48, 0.78)
Alternative 3	(0.56, 0.86, 1)	(0.11, 0.70, 1)	(0.56, 0.86, 1)	(0.56, 0.78, 1)	(0.56, 0.78, 1)
Alternative 4	(0.56, 0.92, 1)	(0.33, 0.56, 0.78)	(0.11, 0.26, 0.56)	(0.11, 0.41, 0.78)	(0.11, 0.63, 1)
Subcriteria alternative	S6	S7	S8	S9	S10
Alternative 1	(0.11, 0.56, 1)	(0.33, 0.78, 1)	(0.33, 0.78, 1)	(0.33, 0.56, 0.78)	(0.33, 0.56, 0.78)
Alternative 2	(0.11, 0.33, 0.78)	(0.11, 0.63, 1)	(0.11, 0.63, 1)	(0.56, 0.78, 1)	(0.11, 0.63, 1)
Alternative 3	(0.11, 0.63, 1)	(0.33, 0.70, 1)	(0.56, 0.92, 1)	(0.56, 0.86, 1)	(0.56, 0.86, 1)
Alternative 4	(0.33, 0.63, 1)	(0.11, 0.56, 0.78)	(0.33, 0.56, 0.78)	(0.11, 0.26, 0.78)	(0.11, 0.33, 0.56)
Subcriteria alternative	S11	S12	S13	S14	S15
Alternative 1	(0.33, 0.86, 1)	(0.11, 0.63, 1)	(0.11, 0.56, 1)	(0.56, 0.78, 1)	(0.11, 0.56, 1)
Alternative 2	(0.11, 0.48, 1)	(0.11, 0.48, 1)	(0.11, 0.41, 1)	(0.11, 0.56, 1)	(0.11, 0.41, 1)
Alternative 3	(0.56, 0.78, 1)	(0.11, 0.70, 1)	(0.33, 0.70, 1)	(0.11, 0.63, 1)	(0.33, 0.70, 1)
Alternative 4	(0.11, 0.48, 0.78)	(0.33, 0.70, 1)	(0.11, 0.70, 1)	(0.11, 0.48, 0.78)	(0.11, 0.70, 1)
Subcriteria alternative	S16	S17	S18	S19	S20
Alternative 1	(0.33, 0.78, 1)	(0.33, 0.63, 1)	(0.11, 0.16, 0.33)	(0.11, 0.16, 0.33)	(0.11, 0.18, 0.33)
Alternative 2	(0.11, 0.70, 1)	(0.56, 0.78, 1)	(0.11, 0.20, 1)	(0.11, 0.16, 1)	(0.11, 0.14, 0.20)
Alternative 3	(0.33, 0.78, 1)	(0.56, 0.92, 1)	(0.33, 0.14, 0.20)	(0.11, 0.13, 0.20)	(0.11, 0.12, 0.20)
Alternative 4	(0.11, 0.48, 0.78)	(0.11, 0.41, 0.78)	(0.14, 0.33, 1.00)	(0.14, 0.23, 1)	(0.14, 0.27, 1)

Table 11: Weighted normalized fuzzy decision matrix.

Subcriteria alternative	S1	S2	S3	S4	S5
W_j	0.060	0.107	0.069	0.047	0.051
Alternative 1	(0.03, 0.05, 0.06)	(0.04, 0.08, 0.11)	(0.02, 0.04, 0.05)	(0.02, 0.03, 0.05)	(0.01, 0.05, 0.06)
Alternative 2	(0.01, 0.04, 0.06)	(0.01, 0.07, 0.11)	(0.04, 0.05, 0.07)	(0.01, 0.03, 0.05)	(0.01, 0.04, 0.06)
Alternative 3	(0.03, 0.05, 0.06)	(0.01, 0.07, 0.11)	(0.04, 0.06, 0.07)	(0.03, 0.04, 0.05)	(0.01, 0.04, 0.06)
Alternative 4	(0.03, 0.05, 0.06)	(0.04, 0.06, 0.08)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.04)	(0.02, 0.04, 0.06)
Subcriteria alternative	S6	S7	S8	S9	S10
W_j	0.070	0.063	0.042	0.015	0.037
Alternative 1	(0.01, 0.04, 0.07)	(0.02, 0.05, 0.06)	(0.02, 0.05, 0.06)	(0.02, 0.04, 0.05)	(0.02, 0.04, 0.05)
Alternative 2	(0.01, 0.02, 0.05)	(0.01, 0.04, 0.06)	(0.01, 0.04, 0.06)	(0.04, 0.05, 0.06)	(0.01, 0.04, 0.06)
Alternative 3	(0.01, 0.04, 0.07)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.06)	(0.04, 0.05, 0.06)	(0.04, 0.05, 0.06)
Alternative 4	(0.02, 0.04, 0.07)	(0.01, 0.04, 0.06)	(0.02, 0.04, 0.05)	(0.01, 0.02, 0.05)	(0.01, 0.02, 0.04)
Subcriteria alternative	S11	S12	S13	S14	S15
W_j	0.051	0.81	0.044	0.128	0.106
Alternative 1	(0.02, 0.05, 0.06)	(0.01, 0.04, 0.06)	(0.01, 0.04, 0.06)	(0.04, 0.05, 0.06)	(0.01, 0.04, 0.06)
Alternative 2	(0.01, 0.03, 0.06)	(0.01, 0.03, 0.06)	(0.01, 0.03, 0.06)	(0.01, 0.04, 0.06)	(0.01, 0.03, 0.06)
Alternative 3	(0.04, 0.05, 0.06)	(0.01, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.01, 0.04, 0.06)	(0.02, 0.04, 0.06)
Alternative 4	(0.01, 0.03, 0.05)	(0.02, 0.04, 0.06)	(0.01, 0.04, 0.06)	(0.01, 0.03, 0.05)	(0.01, 0.04, 0.06)
Subcriteria alternative	S16	S17	S18	S19	S20
W_j	0.064	0.042	0.062	0.045	0.023
Alternative 1	(0.02, 0.05, 0.06)	(0.02, 0.04, 0.06)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)
Alternative 2	(0.01, 0.04, 0.06)	(0.04, 0.05, 0.06)	(0.01, 0.01, 0.06)	(0.01, 0.01, 0.06)	(0.01, 0.01, 0.01)
Alternative 3	(0.02, 0.05, 0.06)	(0.04, 0.06, 0.06)	(0.01, 0.01, 0.01)	(0.01, 0.01, 0.01)	(0.01, 0.01, 0.01)
Alternative 4	(0.01, 0.03, 0.05)	(0.01, 0.03, 0.05)	(0.01, 0.02, 0.06)	(0.01, 0.01, 0.06)	(0.01, 0.02, 0.06)

Step 19. Use equation (27) to calculate the distance of every alternative from a positive ideal solution (d_i^+) and negative ideal solution (d_i^-) by using equation (28). The value to relative proximity (P_i) is computed through equation (29), as shown in Table 13.

The fuzzy analytical hierarchy process and TOPSIS results indicate that security and privacy with a score of 0.282 (28.2%) and data with a score of 0.242 (24.2%) are the most influential factors in the decision-making process of the IoMT challenges. The authors proposed 20 subcriteria of the five criteria. If we consider the local weights of the criteria and subcriteria given in Table 6 and also consider global weights of the subcriteria shown in Table 8, respectively, the first criterion, confidentiality, has the most weightage with the score of (0.3786, 0.107), followed by IoT security (0.2438, 0.069), network security (0.2115, 0.060), and conflicts of interest (0.1661, 0.047). The second criterion titled data has five subcriteria, and among these criteria, tremendous

Table 12: The fuzzy positive ideal solution and fuzzy negative ideal solution.

Subcriteria	S1	S2	S3	S4	S5
(V_i^+)	(0.03, 0.05, 0.06)	(0.04, 0.08, 0.11)	(0.04, 0.06, 0.07)	(0.03, 0.04, 0.05)	(0.03, 0.04, 0.05)
(V_i^-)	(0.01, 0.04, 0.06)	(0.01, 0.0, 06.08)	(0.01, 0.0, 02.04)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.05)
Subcriteria	S6	S7	S8	S9	S10
(V_i^+)	(0.02, 0.04, 0.07)	(0.02, 0.05, 0.06)	(0.04, 0.06, 0.06)	(0.04, 0.05, 0.06)	(0.04, 0.05, 0.06)
(V_i^-)	(0.01, 0.02, 0.05)	(0.01, 0.04, 0.06)	(0.01, 0.04, 0.05)	(0.01, 0.02, 0.05)	(0.01, 0.02, 0.04)
Subcriteria	S11	S12	S13	S14	S15
(V_i^+)	(0.04, 0.05, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.05, 0.06)	(0.02, 0.04, 0.06)
(V_i^-)	(0.01, 0.03, 0.05)	(0.01, 0.03, 0.06)	(0.01, 0.03, 0.06)	(0.01, 0.03, 0.05)	(0.01, 0.03, 0.06)
Subcriteria	S16	S17	S18	S19	S20
(V_i^+)	(0.02, 0.05, 0.06)	(0.04, 0.06, 0.06)	(0.01, 0.02, 0.06)	(0.01, 0.01, 0.06)	(0.01, 0.02, 0.06)
(V_i^-)	(0.01, 0.03, 0.05)	(0.01, 0.03, 0.05)	(0.01, 0.01, 0.01)	(0.01, 0.01, 0.01)	(0.01, 0.01, 0.01)

Table 13: Relative proximity and a final rank.

Alternative	d_i^+	d_i^-	P_i	Rank
Alternative 1	0.217	0.240	0.5249	2
Alternative 2	0.263	0.223	0.4591	3
Alternative 3	0.146	0.314	0.6825	1
Alternative 4	0.274	0.184	0.4021	4

Table 14: Comparison of fuzzy AHP and TOPSIS with other methodologies for IoMT challenges.

Criteria	[34]	[60]	[61]	[63]	[62]	Fuzzy AHP and TOPSIS technique of this article
Fuzzy logic	No	Yes	No	No	No	Yes
Pairwise comparison	No	No	Yes	Yes	No	Yes
Weighting of criteria	No	No	No	Yes	No	Yes
Complexity	Moderate	Moderate	Low	Moderate	Low	High
Consistency	No	No	Yes	No	No	Yes
Independence	No	Yes	Yes	Yes	Yes	Yes
Computational requirement	High	High	Low	Moderate	Low	High
Probability and possibility	No	No	Yes	No	No	Yes

amount (0.2902, 0.070) is the most influential factor in this category, followed by integration (0.2616, 0.063), vendor lock-in (0.2097, 0.051), scalability (0.1746, 0.042), and standardization (0.0638, 0.015). The most interesting criterion that every researcher used in their studies is technology, and it also has four subcriteria. The real-time processing subcriterion has taken the lead by scoring (0.3790, 0.081), followed by modelling relationship (0.2405, 0.051), system predictability (0.2088, 0.044), and device diversity (0.1718, 0.037). Legal is the fourth criterion that is also used by many authors as described in the introduction section; regulatory affairs has the highest score (0.3769, 0.128), followed by data usage (0.3114, 0.106), ownership (0.1895, 0.064), and liability (0.1221, 0.042). The last proposed criterion is cost, and it has only 3 subcriteria. Installation has greater score (0.4770, 0.062) among other scores ((0.3458, 0.045) and (0.1771, 0.023)).

In regard to subcriteria, the two most influential criteria are regulatory affairs, which has 0.128 (12.8%) value, and confidentiality, which has 0.107 (10.7%) value. In the light of final scores, we can say that Alternative 3 is the most challenging factor for the IoMT followed by Alternative 1; on the other hand, Alternative 4 demonstrates the least challenge in the light of the expert decision.

6. Comparison of Fuzzy AHP and TOPSIS Techniques with Other Existing Techniques

The authors of this article studied and examined many criteria developed by different authors to rank the challenges of IoT, but none of the authors ranked the IoMT challenges by using hybrid techniques known as fuzzy logic and AHP TOPSIS. The authors who used multicriteria decision-making tools to evaluate the IoT challenges neither used the features of fuzzy logic nor used core functions of AHP and TOPSIS. Many authors used a general criterion to evaluate IoT challenges and still could not find proper criteria. In this study, the authors developed 5 criteria after studying highly cited papers on IoMT challenges and also developed 20 subcriteria after studying high impact factor journal papers.

The authors also critically studied each criterion and subcriteria that cover all the tasks and meet the characteristics of a good methodology. After a thorough examination of the task that covers all approaches, we formulated a single methodology that covers all requirements.

The authors formulated simple criteria to evaluate the Internet of medical things challenges, and the same criteria have been implemented by using the proposed methodology in Section 5 just to show that the proposed methodology is producing better results as compared to other methodologies that were used in the past for the IoT challenges. The comparison of the IoT methodologies with the proposed methodology is given in Table 14.

Table 14 depicts many existing methodologies opted by different researchers to compare and prioritize IoT and select the most critical challenge. We compared the existing techniques to prove that the fuzzy AHP and TOPSIS technique is the most efficient technique to evaluate and prioritize the Internet of medical things challenges as it confronts ambiguity. This permits the formulation of criteria, associates subcriteria, establishes a pairwise comparison, normalizes the decision matrix, calculates local and global weights, and validates the results using the consistency index and consistency ratio.

7. Conclusions

Nowadays, smart objects communicate and interact with each other and play a significant role in human life. Industry stakeholders think that more usage of the Internet and interaction between smart objects will increase the number of opportunities and increase the level of competition. Healthcare enterprises that have the aim to introduce the Internet of things should know the current challenges, the significance of these challenges, and the methods to encounter these challenges with less effort, cost, and hardship.

Internet of medical things challenge selection decision became an essential operational and technical decision in a complex network environment. In this article, for the first time, a hybrid fuzzy multicriteria decision-making approach based on fuzzy logic, AHP, and TOPSIS is proposed for dealing with the Internet of medical things. Using fuzzy set theory with AHP to obtain the weights of the criteria of TOPSIS can minimize the ambiguities and doubts that are still roadblock in decision making about IoT challenges, especially for healthcare. We proposed a triangular fuzzy number-based methodology with AHP and computed weights of the criteria, local weights of the subcriteria, and global weight values used for TOPSIS. We also used linguistic variables and expert's opinion for pairwise comparison and decision matrix which made the final decision-making process easy, reliable, and realistic. The proposed methodology consists of four phases; each phase is independent and transforms its output to next step. In this study, small and medium-sized enterprises located in Pakistan were explored, focusing on challenges related to the Internet of medical things. The Internet of medical things challenges were identified as criteria, and experts of this field evaluated these challenges. The study comprises five criteria: security and privacy, data, technology, legal, and cost, which affected the challenges related to the Internet of medical things. There were twenty subcriteria and four alternatives. The significance of the criteria was computed by using the fuzzy analytic hierarchy process and fuzzy TOPSIS methods. In light of the results, it was observed that the industry which was going to adopt the Internet of medical things should pay attention to security and privacy, data, technology, legal, and cost. When the global weights of the criteria were calculated through the fuzzy analytic hierarchy process as weights of the criteria of TOPSIS, the top four criteria are regulatory affairs with 12.8%, confidentiality with 10.7%, and data usage with 10.6%, followed by real-time processing with 8.1%.

For the further extension of this work, we will consider other decision-making methods for the selection of Internet of medical things challenges that can be employed. The comparison of current and previous studies is suggested. Furthermore, we will also consider other weight calculation methods used with TOPSIS like the entropy method, and least square programming methods can be applied. Moreover, different scenarios and criteria can be considered for future work.

Data Availability

The Expert's opinion data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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