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Research Article

PRIORITIZATION OF IOT CHALLENGES IN MULTI-SPECIALIST HOSPITAL: PYTHAGOREAN FUZZY MCDM BASED APPROACH

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Abstract: The Internet of Things (IoT) is a rapidly growing technology that connects devices and enables data exchange, allowing for advanced automation and optimization in hospitals. Despite its potential benefits, IoT adoption faces several challenges that need

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to be addressed. In this context, we reviewed the existing literature on IoT adoption challenges and identified the most critical factors that affect the adoption of IoT. Furthermore, the Analytic Hierarchy Process (AHP) is applied to determine the comparative weight of each challenge. Additionally, a comparative analysis of two novel Multi-Criteria Decision Making (MCDM) techniques, namely Weighted Aggregates Sum Product Assessment (WASPAS) and Combined Compromise Solution (CoCoSo) are applied to evaluate the rank of all the alternatives in the Pythagorean fuzzy environment. Furthermore, the sensitivity analysis was conducted to check the model's suitability and reliability in a scientific manner. The results of the evaluation indicate that the most critical challenges in the adoption of IoT devices in hospitals are privacy and security of patient data, IT infrastructure, top management support, partner collaboration and implementation cost. The findings can help policymakers, industry practitioners and other stakeholders to make informed decisions in their efforts to enhance the adoption and deployment of IoT technology.

Keywords: IoT; Multi-specialist hospital; Pythagorean fuzzy set; Score function; AHP; WASPAS; CoCoSo.

MSC: 68R99, 74P05, 94D05.

1. INTRODUCTION

The rapid growth of telecommunications, internet, microelectronics, and automation techniques creates novel prospects in the healthcare industry [1]. The healthcare management system has been gradually considered as a discipline for information systems for a decade [2]. Smart healthcare systems demand the conjunction of internet technologies with information and communication technology (ICT) to redesign their mode of operations in a more efficient and effective manner [3, 4]. Healthcare sectors are benefiting strategically from a variety of new technologies. In particular, they notice the deliberate advantages of using Artificial Intelligence (AI), robots, Internet of Things (IoT), and connected sensor devices [5, 6]. Even though numerous technology developments enhance the entire healthcare sector, IoT has drastically transformed the traditional healthcare system into a smart and sophisticated healthcare system. The IoT is an emerging platform that primarily consists of an embedded network of advanced sensors and self-directed devices, aimed at increasing the efficiency and effectiveness of healthcare operations and activities using big data analysis [7, 8, 9]. It appears that the IoT's error-free network intends to connect any ”Thing” independent of its overall system [10], which is capable of collecting and exchanging real time healthcare data from the patient to medical teams. Hence, there are wide scope of applications of IoT in the healthcare industry. Particularly, Remote patient monitoring, Patient tracking, and Disease prediction [11, 12, 13, 14, 15].

According to the World Health Organisation (WHO), even well-developed nations are anticipated to have significant issues in adopting IoT despite its steady growth [2]. The reasons for difficulty in the implementation of IoT vary from country to country [16].

Despite the several direct and indirect benefits of IoT implementation, organisations are still working to overcome a number of adoption challenges before a large scale roll out (Ahmetoglu & Cob [17]). These challenges significantly lower the adoption rate and make it more difficult to realise the enormous advantages of IoT (Ahmetoglu & Cob [17] and Nord et al. [18]).

1.1. Research gap

In the recent past, many scholars have proposed and discussed the associated challenges and adoption models for IoT adoption. Various study has been conducted to study different adoption challenges in different scenario (Ahmetoglu & Cob [17]; Mishra et al. [19]; Desingh & Baskaran [20]; Liu & Mishra [21]; Janssen [22]; Cui et al. [23]; Tariq et al. [24]; Oke et al. [25]; Kamble et al. [26]; Luthra et al. [27]; Hsu & Yeh [28]). Some of the studies focus on the evaluation of adoption factors in healthcare (Manal Al-rawashdeh et al. [29]; Aisyah & Dachyar [30]; Alfarisi & Dachyar [31]; Sukma & Dachyar [32]; Huang & Nazir [33]; Radulescu et al. [34]; Dachyar & Azizia [35]). However, a few studies have been done to evaluate IoT adoption challenges using multi-criteria decision making in the hospital industry (Desingh & Baskaran [20]; Tariq et al. [24]). To our knowledge, there is very little evidence of the evaluation of the adoption challenges in hospitals for non-communicable diseases. This has inspired academics to create a new assessment strategy that would aid in the efficient delivery of IoT-based healthcare services.

Additionally, a number of IoT applications in the healthcare industry, such as telehealth, drug management, food management, rehabilitation system, tracking patient information about their glucose level, blood pressure, oxygen saturation, electrocardiogram in an multi-speciality hospital (Bhuiyan et al. [36]), create more complex interrelationship among the adoption challenges (Desingh & Baskaran [20]; Janssen [22]; Kamble et al. [26]). Hence, a medical IoT service provider faces enormous challenges in prioritising these issues to design an appropriate device for specialised hospitals. This paper helps the decision maker prioritise the challenges of IoT adoption and identify areas for improvement. Additionally, it enables hospitals to focus on areas for improvement prior to IoT implementation.

The widespread adoption of IoT is still difficult to achieve in the meantime. Therefore, it is crucial to identify and assess the challenges of medical IoT implementation in the Indian context. In this regard, this paper helps to achieve the following objectives:

RO1: To identify the different challenges associated with the adoption of IoT in hospitals for non-communicable diseases.

RO2: Ranking of these identified challenges.

1.2. Motivation of this study

According to the above introduction and necessity, the motivation of this paper are as follows:

i. Selection of the best IoT for the healthcare sector. Adopting IoT is a challenging and complex task in a multi-specialist hospital.
ii. Different conflicting factors and sub-factors are studied and evaluated for this IoT challenge. Furthermore, various IoT devices are considered as alternatives and prioritised based on their importance.
iii. Hospitality with IoT has a lot of uncertainty and indeterminacy in the decision. For that reason, the Pythagorean fuzzy set is considered for capture and evaluation.
iv. Multiple decision experts, serving as decision makers (DMs), consider the need for unbiased and appropriate data collection.

v. Various MCDM methods are applied to select the best IoT option based on weighted factors.

1.3. Research outline of this research

Based on the above motivation and inspiration, the outline of this study is as follows:

a. We identify various criteria and sub-criteria for choosing the IoT in multi-speciality hospitals. Also, select the alternatives based on requirements and funding with safety and health kept in mind.
b. Decision makers (DMs) are experts in their fields and provide unbiased, transparent opinions on comparative matrices and decision matrices. They provide a view of linguistic terms and are further converted into Pythagorean fuzzy numbers (PFN) for comparison matrices and decision matrices.
c. Find out the weight of the criteria and sub-criteria using fuzzy AHP techniques in the PFN field. Local and global weights are considered to evaluate the ranking of alternatives.
d. Rank the alternatives on the basis of various criteria and sub-criteria on weighted value by two MCDM methods, WASPAS and CoCoSo. Ranking between two MCDM methods gives a comparative study and stability of the results.
e. Sensitivity analysis is conducted to check the consistency of the ranking and assess its robustness.

1.4. Structure of this study

This study contains, in Section 1 the introduction and motivation. The literature review on methodology and application field is covered in Section 2. Section 3 described the preliminaries of mathematics tools and used the MCDM solution techniques covered in Section 4. Model formulation and IoT adoption challenges in a multi-specialist hospital are described in Section 5 and Section 6, respectively. Next, the alternative for the associated model and data collection is described in Section 7 and Section 8, respectively. Furthermore, Section 9 contains results and discussion, followed by sensitivity analysis in Section 10. Research implications discussed in Section 11. Finally, the conclusions are concluded in Section 12.

2. LITERATURE REVIEW

In this section, we study different types of important keywords. We used recent times articles as well as important contributing papers related to the topics. First, we discussed the IoT related articles [37] associated with MCDM methods. After that, we conducted a literature survey on the Pythagorean fuzzy sets [38] and their applications in various fields. Lastly, we performed a literature review on the topic of MCDM methodologies [39, 40, 41] in numerous fields.

2.1. IoT and it's applications with MCDM

In this section, we discussed different IoT adaptation challenges with MCDM methodologies and applications in the hospital sector in detail. First, in Table 1, we focus on a summary of MCDM works related to IoT adoption challenges. Then, in Table 2, a summary of previous work related to the evaluation of IoT in the hospital industry is described.

Table 1: Summary of MCDM works related to IoT adoption challenges

Author	Year	Country	Application	Tools/Techniques
[27] Luthra, L. et al.	2018	India	Evaluation of adoption and diffusion challenges	GRA & AHP
[26] Kamble, S. et al.	2019	India	Investigates the inter-dependences between adoption barriers in food retail supply chains	ISM and DEMATEL
[42] Singh, R. et al.	2019	India	Ranking of adoption barriers in manufacturing industry	DEMATEL-MMDE-ISM
[24] Tariq, M. I. et al.	2020	Pakistan	Evaluation of medical IoT based on adoption challenges	Fuzzy AHP and Fuzzy TOPSIS
[23] Cui, Y. et al.	2021	None	Evaluating different manufacturing organisations based on adoption barriers for circular economy	Pythagorean fuzzy SWARA-CoCoSo
[43] Wang, K. et al.	2021	China	Investigation of causal inter-relationships among adoption challenges, Internet of Things (IoT) and Artificial Intelligence (AI) for smart city	DEMATEL
[19] Mishra, R. et al.	2022	India	Prioritisation and investigation of interrelations among adoption challenges in renewable energy	EFA & Fuzzy-DEMATEL
[44] Narwane, V. et al.	2022	India	Ranking of adoption challenges in agricultural and food supply chain	DEMATEL
[45] Kumar, V. et al.	2024	India	Evaluation of performance and efficiency of implementation of Industry 4.0	AHP & CoCoSo
[46] Al-Zaidawi, M. et al.	2025	Türkiye	Enhancing IoT network tracking to modern deep learning model	AHP & TOPSIS

Table 2: Some recent work on the evaluation of IoT in the hospital industry

Author	Year	Application	Optimization Techniques
[47] Kim, S. et al.	2017	Channel selection for MAC protocols	AHP
[48] Lokshina, I. et al.	2018	Evaluation of IoT-driven eHealth	Theoretical and practical viewpoints
[49] Alsubaei, F. et al.	2019	Evaluating Security	AHP
[35] Dachyar, M. et al.	2019	Hospital unit selection	DEMATEL-ANP and VIKORRUG
[50] Wang, L. et al.	2020	Evaluating Security	AHP-TOPSIS
[30] Aisyah, S. et al.	2021	Internet of Things Technology Selection for Psychotherapy Services	BWM and COPRAS
[31] Alfarisi, M. et al.	2021	IoT Selection for Hospital Laboratory Maintenance	Fuzzy AHP and Additive Ratio Assessment (ARAS)
[51] Kiourtis, A. et al.	2021	Prioritization of IoT Devices Healthcare Data	Attribute Scoring and Metadata Annotation
[52] Xue, D. et al.	2021	Selection and Ranking of Fog Computing-Based IoT	Analytic Network Approach
[53] Waqas, M. et al.	2022	Evaluation of smart city healthcare features	Machine Learning
[54] Gumina, S. et al.	2024	Evaluation of IoT in IT sector	ADDIE
[55] Diwan, S. A.	2025	Improvement on smart hospitality sector	AHP
This study	2026	IoT in multi-specialist hospital	AHP, WASPAS & CoCoSo

2.2. Pythagorean Fuzzy Sets and it's applications

This section covers some recent studies on the Pythagorean fuzzy sets. Table 3 shows a literature review on it and describes its application area and optimisation techniques.

2.3. Literature review on MCDM techniques

Table 4 describes the current work on weighted calculating methods for AHP. This table shows the type of uncertainty, optimisation techniques and application in different previous studies.

Table 3: Different studies on Pythagorean fuzzy set with application

Authors	Year	Application	Optimization techniques
[56] Guleria, A. et al.	2018	Numerical examples	MCDM algorithm with (R, S)-norm entropy
[57] Khan, A. A. et al.	2019	Surface Irrigation Problem	PTULFEWA & PTULFEHA operators
[58] Tang, M. et al.	2019	Green supplier selection	DHPFGWHM operator
[59] Geetha, S. S. et al.	2020	Numerical examples	Parallel moving method
[38] Wan, S. P. et al.	2020	Knowledge measure	MAGDM
[60] Mahanta, J. et al.	2021	Medical diagnosis	Degree of confidence (DoC)
[61] Kirişci, M. et al.	2022	Infectious diseases application	Cardinal score(CSc) method
[62] Pan, L. et al.	2022	Medical diagnosis	Similarity measure
[63] Labassi, F. et al.	2024	Application to visualization technology industry	CPFWA operator with MADM
[64] Hussain, Z. et al.	2024	Applied in clustering	Similarity measure on PFS
This study	2026	IoT in multi-specialist hospital	AHP, WASPAS & CoCoSo

Table 4: Literature survey on AHP method with application field

Authors	Year	Type of uncertainty	Optimization techniques	Number of criteria	Application
[65] Stojić, G. et al.	2018	Fuzzy	AHP & WASPAS	9	Manufacturing PVC carpentry
[66] Ghorui, N. et al.	2020	Fuzzy	AHP & TOPSIS	7	Shopping mall site selection
[39] Wang, L. et al.	2020	Crisp	AHP & TOPSIS	13	Security evaluation and decision in health system
[67] Zarour, M. et al.	2020	Fuzzy	AHP & TOPSIS	6	Block chain on healthcare services
[68] Bharsakade, et al.	2021	Fuzzy	AHP	7	Healthcare management
[69] Lahane, S. et al.	2021	Fuzzy	AHP & CoCoSo	7	Empirical case study of Indian manufacturing organization
[70] Saucedo-Martínez. J. A. et al.	2024	Fuzzy	AHP	8	Supplier selection through supply chain
[71] Momena, A. F.et al.	2025	Fuzzy	AHP	5	Evaluate of electric vehicles (EV) adaptation challenges
This paper	2026	PFN	AHP, WASPAS & CoCoSo	4	IoT in multi-specialist hospital

WASPAS is an MCDM method and Table 5 shows some current work on it, and uncertainty, application field and other details are covered in it.

Table 5: Literature review on recent work on WASPAS method

Authors	Year	Uncertainty	MCDM methods	Application field
[72] Deveci, M. et al.	2018	Fuzzy set	TOPSIS & WASPAS	Selection of a car sharing station
[73] Turskis, Z. et al.	2019	Fuzzy set	AHP, WSM & WASPAS	Determine critical information infrastructures
[74] Baç, U.	2020	Crisp set	SWARA & WASPAS	Evaluate Smart Card Systems for Public Transportation
[75] Simić, V. et al.	2021	Picture fuzzy set	WASPAS	Last-mile delivery
[76] Stanujkić, D. et al.	2021	Crisp set	WASPAS, ARAS, SAW, TOPSIS & CoCoSo	Flotation machine selection
[40] Kavus, B. Y. et al.	2022	Fuzzy set	WASPAS	Parcel locker location selection
[77] Abdullah, S. et al.	2024	Fuzzy set	WASPAS	Evaluation of water filtration
[78] Mukherjee, A. K. et al.	2025	Fuzzy set	WASPAS & CoCoSo	Application on hospital selection and sustainable women empowerment
[79] Naik, M. et al.	2025	Crisp set	WASPAS	Smart agriculture through IoT technology
This paper	2026	PFN	AHP, WASPAS & CoCoSo	IoT in multi-specialist hospital

Some recent work on the CoCoSo method is shown in Table 6. Uncertainty, MCDM methods and application fields are also shown in this table.

Table 6: Literature survey of the CoCoSo method with its application area

Authors	Year	Uncertainty	MCDM methods	Application field
[80] Peng, X. et al.	2020	Orthopair fuzzy set	CRITIC & CoCoSo	Evaluation of financial risk
[81] Peng, X. et al.	2020	Pythagorean fuzzy set	CRITIC & CoCoSo	5G industry evaluation
[69] Lahane, S. et al.	2021	Fuzzy set	AHP & CoCoSo	Empirical case study of Indian manufacturing organization
[76] Stanujkić, D. et al.	2021	Crisp set	WASPAS, ARAS, SAW, TOPSIS & CoCoSo	Flotation machine selection
[82] Mishra, A. et al.	2022	Fermatean fuzzy sets	CoCoSo	Waste management
[83] Wei, D. et al.	2022	Fuzzy set	CoCoSo & Entropy	Selection of green supplier
[84] Nguyen, T. M. et al.	2024	Pythagorean fuzzy set	AHP & CoCoSo	Installation of artificial intelligence technologies
[78] Mukherjee, A. K. et al.	2025	Fuzzy set	WASPAS & CoCoSo	Application on hospital selection and sustainable women empowerment
This paper	2025	PFN	Entropy, WASPAS & CoCoSo	IoT in multi-specialist hospital

3. PRELIMINARIES OF MATHEMATICAL TOOLS

This section briefly discusses the mathematical tools applied in the study. The extension of the fuzzy set, namely the Pythagorean fuzzy set (PFS), is considered and the evaluation, definition, examples, properties and theorems of PFS are discussed here. The fuzzy set is defined as follows:

3.1. Fuzzy Set

In a classical set, every element of the set has a degree of belongingness of 100% always. But in the fuzzy set, every element in the set has a degree of belongingness that differs from standard set theory. This set is an extension of classical set theory. The membership value of a classical set theory is the binary condition; either an element x belongs to the set, or it does not belong to the set. The classical set (bivariate set) is called the crisp set in fuzzy set theory. A fuzzy set is an ordered pair of sets, where the first element is the set itself and the second element is the degree of belongingness of the set. Lotfi A. Zadeh [85] introduced the fuzzy set in 1965. Fuzzy sets are applied in numerous fields, including optimization [46], decision making [86], differential equations [87] and others.

Definition 1. ***Fuzzy Set*** *[85]. If U is universe of discourse with an arbitrary elements t, then the fuzzy set $\tilde{A}$ of U is define as order pairs*

$$\tilde{A} = \{(t, \mu_{\tilde{A}}(t)) : t \in U\} \tag{1}$$

where $\mu_{\tilde{A}}(t)$ is denote the membership function or degree of belongingness of the element $t \in U$ to $\tilde{A}$ define as $\mu_{\tilde{A}}(t) : U \rightarrow [0,1]$.

The belongingness of every element in a fuzzy set depends on its membership value. If the value $\mu_{\tilde{A}}(t)$ more closed to 1 then the element t more belongs to $\tilde{A}$. The belongingness vary 0 to 1, where 0 indicates the element t not in $\tilde{A}$, 1 indicates the elements fully belongs to $\tilde{A}$ and any value between 0 and 1 indicates the proposition of belongingness of t in $\tilde{A}$. The value of the membership function $(\mu_{\tilde{A}})$ is called the degree of membership or degree of belongingness.

3.2. Fuzzy Number

A fuzzy number is a fuzzy set [85] that satisfies additional conditions. Fuzzy number [87] is a set in the real line that satisfies some properties described as follows.

Definition 2. ***Fuzzy Number*** *[87]. A fuzzy number $\tilde{F}$ defined on the universal set $\mathbb{R}$ (set of real numbers) is a fuzzy set that obeys the following properties are*

1. *Fuzzy set $\tilde{F}$ is normalized, i.e.; $\mu_{\tilde{F}}(x) = 1$ hold for at least one $x \in \mathbb{R}$,*
2. *Membership function of $\tilde{F}$ (i.e.; $\mu_{\tilde{F}}(x)$) is piecewise continuous function in $\mathbb{R}$,*
3. *Support of fuzzy set $\tilde{F}$ (i.e.; $S(\tilde{F}) = \{x \in \mathbb{R} : \mu_{\tilde{F}}(x) > 0\}$) is bounded set,*
4. *Fuzzy set $\tilde{F}$ must be convex set, i.e.; for all $x_i, x_j \in \tilde{F}$ satisfy $\min\{\mu_{\tilde{F}}(x_i), \mu_{\tilde{F}}(x_j)\} \leq \mu_{\tilde{F}}(\lambda x_i + (1-\lambda)x_j)$, where $\lambda \in [0,1]$.*

3.3. Intuitionistic Fuzzy Set

K. Atanassov and G. Gargov [88] introduced the intuitionistic fuzzy set concept in the year 1989. In the intuitionistic fuzzy set, there are two membership functions, one is a membership function, like in fuzzy set [85] and the other is a non-membership function. In the non-membership function, describe the assurance of not belonging to the element in the fuzzy set.

Definition 3. ***Intuitionistic Fuzzy Set*** *[89]. Let Σ be the universal set of discourse. Intuitionistic Fuzzy Set (IFS) denoted by $\tilde{Q}$ and define as*

$$\tilde{Q} = \{(\xi, \mu_{\tilde{Q}}(\xi), \nu_{\tilde{Q}}(\xi)) : \xi \in \Sigma\} \tag{2}$$

where $\mu_{\tilde{Q}}(\xi) : \Sigma \to [0,1]$ and $\nu_{\tilde{Q}}(\xi) : \Sigma \to [0,1]$ are membership function and non-membership function of element $\xi \in \Sigma$, respectively and for every element $\forall \xi \in \Sigma : 0 \leq \mu_{\tilde{Q}}(\xi) + \nu_{\tilde{Q}}(\xi)) \leq 1$.

For each IFS $\tilde{Q} \in \Sigma$, the indeterminacy or hesitation of an arbitrary element $\xi \in \Sigma$ is denoted by $\pi_{\tilde{Q}}(\xi)$ and define by $\pi_{\tilde{Q}}(\xi) = 1 - \mu_{\tilde{Q}}(\xi) - \nu_{\tilde{Q}}(\xi)$. The hesitancy edge $\pi_{\tilde{Q}}(\xi)$ of the element $\xi \in \Sigma$ is an indeterminacy of the element which is bounded by $[0,1]$. The more well-known (i.e., the belongingness and non-belongingness) element $\xi \in \Sigma$ of $\tilde{Q}$ is, the less the degree of indeterminacy $\pi_{\tilde{Q}}(\xi)$ becomes.

3.4. Pythagorean Fuzzy Set

Ronald R. Yager [90] presented the Pythagorean fuzzy set in 2013. This type of fuzzy set also has two membership functions like intuitionistic fuzzy set [88], but there is some difference in the boundary of the membership functions [91]. The Pythagorean fuzzy set is defined as follows:

Definition 4. *Consider W to be the universe of discourse. Let τ be an arbitrary element in W, then Pythagorean Fuzzy Set (PFS) [92] $\tilde{\Delta}$ defined by*

$$\tilde{\Delta} = \{(\tau, \mu_{\tilde{\Delta}}(\tau), \nu_{\tilde{\Delta}}(\tau)) : \tau \in W\} \tag{3}$$

where $\mu_{\tilde{\Delta}}(\tau) : W \to [0,1]$ is membership function and $\nu_{\tilde{\Delta}}(\tau) : W \to [0,1]$ is non-membership function with satisfy the condition $0 \leq (\mu_{\tilde{\Delta}}(\tau))^2 + (\nu_{\tilde{\Delta}}(\tau))^2 \leq 1$ for all $\tau \in W$.

The hesitancy or indeterminacy membership function $(\pi_{\tilde{\Delta}})$ of arbitrary element $\tau \in W$ of the set $\tilde{\Delta}$ is $\pi_{\tilde{\Delta}}(\tau) = \sqrt{1-(\mu_{\tilde{\Delta}}(\tau))^2-(\nu_{\tilde{\Delta}}(\tau))^2}$. The indeterminacy bounded by $[0,1]$ for all $\tau \in W$ of $\tilde{\Delta}$. The difference between IFS and PFS are described in Table 7 and Figure 1 represents the membership & non-membership functions of IFS and PFS, respectively.

Table 7: Difference between IFS and PFS

Category	IFS	PFS
Boundary	$0 \leq \mu_{\tilde{\Delta}} + \nu_{\tilde{\Delta}} \leq 1$	$\mu_{\tilde{\Delta}} + \nu_{\tilde{\Delta}} \leq 1$ or $\mu_{\tilde{\Delta}} + \nu_{\tilde{\Delta}} \geq 1$
Linearity	$0 \leq \mu_{\tilde{\Delta}} + \nu_{\tilde{\Delta}} \leq 1$	$0 \leq \mu_{\tilde{\Delta}}^2 + \nu_{\tilde{\Delta}}^2 \leq 1$
Indeterminacy	$\pi_{\tilde{\Delta}} = 1 - \mu_{\tilde{\Delta}} - \nu_{\tilde{\Delta}}$	$\pi_{\tilde{\Delta}} = \sqrt{1-\mu_{\tilde{\Delta}}^2-\nu_{\tilde{\Delta}}^2}$
Summation criteria	$\mu_{\tilde{\Delta}} + \nu_{\tilde{\Delta}} + \pi_{\tilde{\Delta}} = 1$	$\mu_{\tilde{\Delta}}^2 + \nu_{\tilde{\Delta}}^2 + \pi_{\tilde{\Delta}}^2 = 1$
$\mu_{\tilde{\Delta}}$ = membership value, $\nu_{\tilde{\Delta}}$ = non-membership value & $\pi_{\tilde{\Delta}}$ = indeterminacy value		

Remark 5. *The structural difference between the intuitionistic fuzzy set (IFS) and the Pythagorean fuzzy set (PFS) are presented in Table 7. In IFS, summation the membership value $(\mu_{\tilde{\Delta}})$ and non-membership value $(\nu_{\tilde{\Delta}})$ must be bounded by 1 but in PFS, it may exceed the boundary. This unique feature of PFS makes it more realistic and flexible for real-life use.*

Example 6. *Let $U = \{\alpha, \beta, \gamma, \delta, \tau\}$ are universal set of discourse. $\tilde{\Lambda}$ be the Pythagorean fuzzy set defined as:*

$$\tilde{\Lambda} = \left\{ \left(\frac{0.9, 0.2}{\alpha}\right), \left(\frac{0.75, 0.45}{\beta}\right), \left(\frac{0.8, 0.5}{\gamma}\right), \left(\frac{0.6, 0.7}{\delta}\right), \left(\frac{0.5, 0.8}{\tau}\right) \right\}$$

Here, PFS $\tilde{\Lambda}$ has five elements and shows their membership and non-membership value, which are in $[0,1]$. Also satisfy $0 \leq \mu_{\tilde{\Lambda}}^2 + \nu_{\tilde{\Lambda}}^2 \leq 1$. Hesitation measurement of the elements $\alpha, \beta, \gamma, \delta, \tau$ are $\pi_{\tilde{\Lambda}}(\alpha) = 0.387$, $\pi_{\tilde{\Lambda}}(\beta) = 0.485$, $\pi_{\tilde{\Lambda}}(\gamma) = 0.332$, $\pi_{\tilde{\Lambda}}(\delta) = 0.387$ and $\pi_{\tilde{\Lambda}}(\tau) = 0.332$.

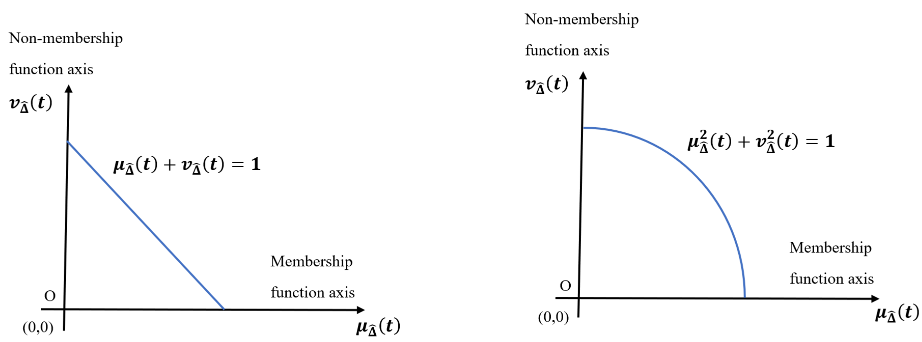

Figure 1: Comparison of membership vs non-membership functions of IFS & PFS

3.5. Pythagorean Fuzzy Number

Pythagorean fuzzy number (PFN) [81] is a spatial type of Pythagorean fuzzy set that satisfies the fuzzy number properties. The PFN can be defined as follows:

Definition 7. *Assume $\mathbb{R}$ is the set of real numbers represented as the universal set of discourse. Then the Pythagorean fuzzy number (PFN) [93] is a Pythagorean fuzzy set (Definition 4), defined on $\mathbb{R}$ and satisfies fuzzy numbers properties (Definition 2), respectively.*

Example 8. *Consider the universal set of discourse $W = \{\xi_1, \xi_2, \xi_3, \xi_4, \xi_5, \xi_6\} \subset \mathbb{R}$. Pythagorean fuzzy number $\tilde{G}$ and $\tilde{H}$ define as*

$$\tilde{G} = \left\{ \left(\frac{0.8, 0.4}{\xi_1}\right), \left(\frac{0.75, 0.55}{\xi_2}\right), \left(\frac{0.6, 0.75}{\xi_4}\right), \left(\frac{0.35, 0.85}{\xi_5}\right), \left(\frac{0.15, 0.95}{\xi_6}\right) \right\}$$

and

$$\tilde{H} = \left\{ \left(\frac{0.6, 0.6}{\xi_2}\right), \left(\frac{0.75, 0.25}{\xi_3}\right), \left(\frac{0.45, 0.85}{\xi_4}\right), \left(\frac{0.95, 0}{\xi_6}\right) \right\}$$

Here, two PFNs $\tilde{G}$ and $\tilde{H}$ are Pythagorean fuzzy sets (PFS) and satisfy all fuzzy numbers properties described in Definition 2.

Two PFNs $\tilde{\Delta}$ & $\tilde{\Gamma}$ are depicted in Figure 2; where X axis represented the real axis ($\mathbb{R}$), μ axis represented the membership axis and non-membership axis represented by μ axis with opposite order from 1.

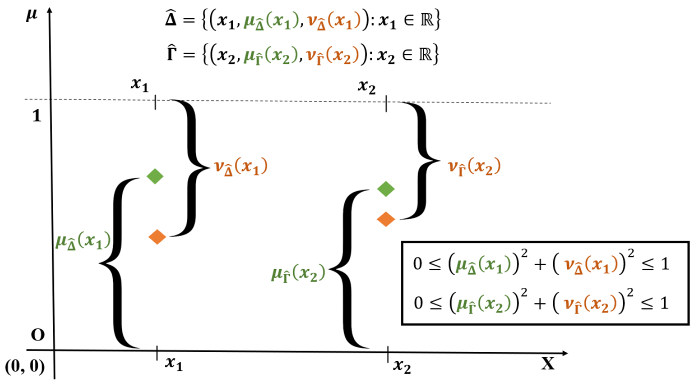

Figure 2: Geometric departure of two Pythagorean fuzzy numbers (PFNs)

3.6. Pythagorean fuzzy sets operations:

The basic set operations on PFS are described in this section, as follows:

Definition 9. ***Equal PFS:*** *Let* $\tilde{\Delta} = \{(\alpha, \mu_{\tilde{\Delta}}(\alpha), \nu_{\tilde{\Delta}}(\alpha)) : \alpha \in U\}$ *and* $\tilde{\Gamma} = \{(\alpha, \mu_{\tilde{\Gamma}}(\alpha), \nu_{\tilde{\Gamma}}(\alpha)) : \alpha \in U\}$ *are two Pythagorean Fuzzy Sets defined on universal set* U*. Then the sets* $\tilde{\Delta}$ *and* $\tilde{\Gamma}$ *are called similar sets (or equal sets), if they satisfy the following:*

$$\mu_{\tilde{\Delta}}(\alpha) = \mu_{\tilde{\Gamma}}(\alpha) \text{ and } \nu_{\tilde{\Delta}}(\alpha) = \nu_{\tilde{\Gamma}}(\alpha) \tag{4}$$

for all $\alpha \in U$*.*

Definition 10. ***Equivalents PFS*** *[94]: Let us consider two Pythagorean fuzzy set* $\tilde{\Delta} = \{(\tau, \mu_{\tilde{\Delta}}(\tau), \nu_{\tilde{\Delta}}(\tau)) : \tau \in U\}$ *and* $\tilde{\Gamma} = \{(\tau, \mu_{\tilde{\Gamma}}(\tau), \nu_{\tilde{\Gamma}}(\tau)) : \tau \in U\}$ *define on universal set of discourse* U*. Then* $\tilde{\Delta}$ *and* $\tilde{\Gamma}$ *are called equivalents sets if the following condition satisfies:*

$$f : \mu_{\tilde{\Delta}}(\tau) \to \mu_{\tilde{\Gamma}}(\tau) \text{ and } g : \nu_{\tilde{\Delta}}(\tau) \to \nu_{\tilde{\Gamma}}(\tau) \tag{5}$$

with all $\tau \in U$*. Also,* f *and* g *are two bijective functions.*

Example 11. *Let* $U = \{\alpha, \beta, \gamma, \delta, \tau\}$ *are universal set of discourse.* $\tilde{\Lambda}$ *and* $\tilde{\Omega}$ *are the Pythagorean fuzzy set define as:*

$$\tilde{\Lambda} = \left\{ \left(\frac{0.8, 0.3}{\alpha}\right), \left(\frac{0.7, 0.4}{\beta}\right), \left(\frac{0.75, 0.5}{\gamma}\right), \left(\frac{0.6, 0.75}{\delta}\right), \left(\frac{0.55, 0.65}{\tau}\right) \right\}$$

and

$$\tilde{\Omega} = \left\{ \left(\frac{0.6, 0.15}{\alpha}\right), \left(\frac{0.5, 0.25}{\beta}\right), \left(\frac{0.55, 0.65}{\gamma}\right), \left(\frac{0.4, 0.6}{\delta}\right), \left(\frac{0.75, 0.5}{\tau}\right) \right\}$$

Here, PFS $\tilde{\Lambda}$ *and* $\tilde{\Omega}$ *are equivalent sets where two equivalent functions are described as: for membership function:* $f(\mu_{\tilde{\Lambda}}) = \mu_{\tilde{\Lambda}} - 0.20 = \mu_{\tilde{\Omega}}$ *and for non-membership function:* $g(\nu_{\tilde{\Lambda}}) = \nu_{\tilde{\Lambda}} - 0.15 = \nu_{\tilde{\Omega}}$*.*

Definition 12. ***Subset or Super set of PFS:*** *Let* $\tilde{\Delta} = \{(\tau, \mu_{\tilde{\Delta}}(\tau), \nu_{\tilde{\Delta}}(\tau)) : \tau \in W\}$ *and* $\tilde{\Gamma} = \{(\tau, \mu_{\tilde{\Gamma}}(\tau), \nu_{\tilde{\Gamma}}(\tau)) : \tau \in W\}$ *are two Pythagorean Fuzzy Sets define on universal set* W*. Then* $\tilde{\Delta}$ *is subset of* $\tilde{\Gamma}$ *as well as* $\tilde{\Gamma}$ *is super set of* $\tilde{\Delta}$ *is denoted by* $\tilde{\Delta} \subseteq \tilde{\Gamma}$ *(i.e.,* $\tilde{\Gamma} \supseteq \tilde{\Delta}$*) and defined as:*

$$\mu_{\tilde{\Delta}}(\tau) \leq \mu_{\tilde{\Gamma}}(\tau) \text{ and } \nu_{\tilde{\Delta}}(\tau) \geq \nu_{\tilde{\Gamma}}(\tau) \tag{6}$$

satisfy $\forall\, \tau \in W$*.*

And $\tilde{\Delta}$ *is proper subset of* $\tilde{\Gamma}$ *is denoted by* $\tilde{\Delta} \subset \tilde{\Gamma}$ *(i.e.,* $\tilde{\Delta} \subseteq \tilde{\Gamma}$ *and* $\tilde{\Delta} \neq \tilde{\Gamma}$*)and defined as:*

$$\mu_{\tilde{\Delta}}(\tau) < \mu_{\tilde{\Gamma}}(\tau) \text{ and } \nu_{\tilde{\Delta}}(\tau) > \nu_{\tilde{\Gamma}}(\tau) \tag{7}$$

satisfies $\forall\, \tau \in U$*.*

Example 13. *In Example 11, shown two Pythagorean fuzzy sets* $\tilde{\Lambda}$ *and* $\tilde{\Omega}$ *where* $\mu_{\tilde{\Omega}} \leq \mu_{\tilde{\Lambda}}$ *and* $\nu_{\tilde{\Omega}} \geq \nu_{\tilde{\Lambda}}$ *for all elements* $x \in U$*. Therefore,* $\tilde{\Omega}$ *is subset of* $\tilde{\Lambda}$ *(i.e.;* $\tilde{\Omega} \subseteq \tilde{\Lambda}$*). Specially,* $\mu_{\tilde{\Omega}} < \mu_{\tilde{\Lambda}}$ *and* $\nu_{\tilde{\Omega}} > \nu_{\tilde{\Lambda}}$ *for all elements* $x \in U$ *then* $\tilde{\Omega}$ *is proper subset of* $\tilde{\Lambda}$ *(i.e.;* $\tilde{\Omega} \subset \tilde{\Lambda}$*).*

Example 14. *Let $W = \{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5\}$ are universal set of discourse. Two Pythagorean fuzzy sets $\tilde{\Lambda}_1$ and $\tilde{\Lambda}_2$ are defined as*

$$\tilde{\Lambda}_1 = \left\{ \left(\frac{0.93, 0.25}{\alpha_1}\right), \left(\frac{0.86, 0.39}{\alpha_2}\right), \left(\frac{0.71, 0.56}{\alpha_3}\right), \left(\frac{0.55, 0.67}{\alpha_4}\right), \left(\frac{0.36, 0.79}{\alpha_5}\right) \right\}$$

and

$$\tilde{\Lambda}_2 = \left\{ \left(\frac{0.87, 0.31}{\alpha_1}\right), \left(\frac{0.74, 0.43}{\alpha_2}\right), \left(\frac{0.68, 0.59}{\alpha_3}\right), \left(\frac{0.51, 0.71}{\alpha_4}\right), \left(\frac{0.29, 0.81}{\alpha_5}\right) \right\}$$

Here see that $\mu_{\tilde{\Lambda}_2} \leq \mu_{\tilde{\Lambda}_1}$ and $\nu_{\tilde{\Lambda}_2} \geq \nu_{\tilde{\Lambda}_1}$ for all elements $\alpha_i \in W$ for $i = 1, 2, \ldots, 5$. Therefore, $\tilde{\Lambda}_2$ is subset of $\tilde{\Lambda}_1$ (i.e.; $\tilde{\Lambda}_2 \subseteq \tilde{\Lambda}_1$). Since $\mu_{\tilde{\Lambda}_2} < \mu_{\tilde{\Lambda}_1}$ and $\nu_{\tilde{\Lambda}_2} > \nu_{\tilde{\Lambda}_1}$ for all elements $\alpha_i \in W$ for $i = 1, 2, \ldots, 5$ then $\tilde{\Lambda}_2$ is proper subset of $\tilde{\Lambda}_1$ (i.e.; $\tilde{\Lambda}_2 \subset \tilde{\Lambda}_1$).

Definition 15. ***Set operation on PFS:***

Let $\tilde{\Delta} = \{(\xi, \mu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Delta}}(\xi)) : \xi \in U\}$ and $\tilde{\Gamma} = \{(\xi, \mu_{\tilde{\Gamma}}(\xi), \nu_{\tilde{\Gamma}}(\xi)) : \xi \in U\}$ are two Pythagorean Fuzzy Sets (PFS) with universal set U. The basic set operations are:

1. ***Union:***

$$\tilde{\Delta} \cup \tilde{\Gamma} = \{(\xi, \max\{\mu_{\tilde{\Delta}}(\xi), \mu_{\tilde{\Gamma}}(\xi)\}, \min\{\nu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Gamma}}(\xi)\}) : \xi \in U\} \tag{8}$$

2. ***Intersection:***

$$\tilde{\Delta} \cap \tilde{\Gamma} = \{(\xi, \min\{\mu_{\tilde{\Delta}}(\xi), \mu_{\tilde{\Gamma}}(\xi)\}, \max\{\nu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Gamma}}(\xi)\}) : \xi \in U\} \tag{9}$$

Example 16. *In Example 8, describe two Pythagorean fuzzy sets $\tilde{G}$ and $\tilde{H}$. Now union $(\tilde{G} \cup \tilde{H})$ and intersection $(\tilde{G} \cap \tilde{H})$ of $\tilde{G}$ and $\tilde{H}$ are follows*

$$\tilde{G} \cup \tilde{H} = \left\{ \left(\frac{0.8, 0.4}{\xi_1}\right), \left(\frac{0.75, 0.55}{\xi_2}\right), \left(\frac{0.75, 0.25}{\xi_3}\right), \left(\frac{0.6, 0.75}{\xi_4}\right), \left(\frac{0.35, 0.85}{\xi_5}\right), \left(\frac{0.95, 0}{\xi_6}\right) \right\}$$

and

$$\tilde{G} \cap \tilde{H} = \left\{ \left(\frac{0.8, 0.4}{\xi_1}\right), \left(\frac{0.6, 0.6}{\xi_2}\right), \left(\frac{0.75, 0.25}{\xi_3}\right), \left(\frac{0.45, 0.85}{\xi_4}\right), \left(\frac{0.35, 0.85}{\xi_5}\right), \left(\frac{0.15, 0.95}{\xi_6}\right) \right\}$$

Definition 17. ***Complement of PFS:***

Let us consider Pythagorean fuzzy set $\tilde{\Delta} = \{(\tau, \mu_{\tilde{\Delta}}(\tau), \nu_{\tilde{\Delta}}(\tau)) : \tau \in U\}$. Then the complement of $\tilde{\Delta}$ is denoted by $\tilde{\Delta}^c$ and defined as

$$\tilde{\Delta}^c = \{(\tau, \nu_{\tilde{\Delta}}(\tau), \mu_{\tilde{\Delta}}(\tau)) : \tau \in U\} \tag{10}$$

with all $\tau \in U$.

Example 18. *Consider in Example 6, Pythagorean fuzzy set $\tilde{\Lambda}$ describe. Now complement of PFS $\tilde{\Lambda}$ denoted as $\tilde{\Lambda}^c$ and describe by*

$$\tilde{\Lambda}^c = \left\{ \left(\frac{0.2, 0.9}{\alpha}\right), \left(\frac{0.45, 0.75}{\beta}\right), \left(\frac{0.5, 0.8}{\gamma}\right), \left(\frac{0.7, 0.6}{\delta}\right), \left(\frac{0.8, 0.5}{\tau}\right) \right\}$$

3.7. Arithmetic Operation on PFN

The arithmetic operations on Pythagorean fuzzy numbers (PFN) are discussed in this section. The addition, multiplication, scalar multiplication, etc., on PFNs are defined here, as follows:

Definition 19. *Let* $\tilde{\Delta} = \{(\xi, \mu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Delta}}(\xi)) : \xi \in W\}$ *and* $\tilde{\Gamma} = \{(\xi, \mu_{\tilde{\Gamma}}(\xi), \nu_{\tilde{\Gamma}}(\xi)) : \xi \in W\}$ *are two Pythagorean Fuzzy Sets with universe of discourse* W*. Further consider,* $\lambda\,(> 0)$ *be a scalar. Then the arithmetic operation on PFNs* $\tilde{\Delta}$ *and* $\tilde{\Gamma}$*, as follows:*

1. ***Addition of two PFNs:***
$$\tilde{\Delta} \oplus \tilde{\Gamma} = \left\{ \left(\xi, \sqrt{(\mu_{\tilde{\Delta}}(\xi))^2 + (\mu_{\tilde{\Gamma}}(\xi))^2 - (\mu_{\tilde{\Delta}}(\xi))^2 (\mu_{\tilde{\Gamma}}(\xi))^2}, (\nu_{\tilde{\Delta}}(\xi))(\nu_{\tilde{\Gamma}}(\xi)) \right) : \xi \in W \right\} \quad (11)$$

2. ***Subtraction of two PFNs:*** *[95]*
$$\tilde{\Delta} \ominus \tilde{\Gamma} = \left\{ \left(\xi, \sqrt{\frac{(\mu_{\tilde{\Delta}}(\xi))^2 - (\mu_{\tilde{\Gamma}}(\xi))^2}{1 - (\mu_{\tilde{\Gamma}}(\xi))^2}}, \frac{\nu_{\tilde{\Delta}}(\xi)}{\nu_{\tilde{\Gamma}}(\xi)} \right) : \xi \in W \right\} \quad (12)$$
if $\mu_{\tilde{\Delta}}(\xi) \geq \mu_{\tilde{\Gamma}}(\xi)$ *and* $\nu_{\tilde{\Delta}}(\xi) \leq \min\left\{ \nu_{\tilde{\Gamma}}(\xi), \frac{\nu_{\tilde{\Gamma}}(\xi) \times \pi_{\tilde{\Delta}}(\xi)}{\pi_{\tilde{\Gamma}}(\xi)} \right\}$ *where* $\pi_{\tilde{D}}(\xi)$ *is indeterminacy of PFN* $\tilde{D}$*.*

3. ***Scalar multiplication of PFN:***
$$\lambda \times \tilde{\Delta} = \left\{ \left(\xi, \sqrt{1 - \left(1 - (\mu_{\tilde{\Delta}}(\xi))^2\right)^{\lambda}}, (\nu_{\tilde{\Delta}}(\xi))^{\lambda} \right) : \xi \in W \right\} \quad (13)$$
when $\lambda > 0$.

4. ***Multiplication of two PFNs:***
$$\tilde{\Delta} \otimes \tilde{\Gamma} = \left\{ \left(\xi, (\mu_{\tilde{\Delta}}(\xi))(\mu_{\tilde{\Gamma}}(\xi)), \sqrt{(\nu_{\tilde{\Delta}}(\xi))^2 + (\nu_{\tilde{\Gamma}}(\xi))^2 - (\nu_{\tilde{\Delta}}(\xi))^2 (\nu_{\tilde{\Gamma}}(\xi))^2} \right) : \xi \in W \right\} \quad (14)$$

5. ***Deviation of PFN by PFN:***
$$\tilde{\Delta} \oslash \tilde{\Gamma} = \frac{\tilde{\Delta}}{\tilde{\Gamma}} = \left\{ \left(\xi, \frac{\mu_{\tilde{\Delta}}(\xi)}{\mu_{\tilde{\Gamma}}(\xi)}, \sqrt{\frac{(\nu_{\tilde{\Delta}}(\xi))^2 - (\nu_{\tilde{\Gamma}}(\xi))^2}{1 - (\nu_{\tilde{\Gamma}}(\xi))^2}} \right) : \xi \in W \right\} \quad (15)$$
if $\mu_{\tilde{\Delta}}(\xi) \leq \min\left\{ \mu_{\tilde{\Gamma}}(\xi), \frac{\mu_{\tilde{\Gamma}}(\xi) \times \pi_{\tilde{\Delta}}(\xi)}{\pi_{\tilde{\Gamma}}(\xi)} \right\}$ *and* $\nu_{\tilde{\Delta}}(\xi) \geq \nu_{\tilde{\Gamma}}(\xi)$ *where* $\pi_{\tilde{P}}(\xi)$ *is indeterminacy of PFN* $\tilde{P}$*.*

6. ***Scalar power of PFN:***
$$\tilde{\Delta}^{\lambda} = \left\{ \left(\xi, (\mu_{\tilde{\Delta}}(\xi))^{\lambda}, \sqrt{1 - \left(1 - (nu_{\tilde{\Delta}}(\xi))^2\right)^{\lambda}} \right) : \xi \in W \right\} \quad (16)$$
when $\lambda > 0$.

Example 20. *Consider two PFN* $\tilde{\Lambda} = \{(\xi, \mu_{\tilde{\Lambda}}(\xi), \nu_{\tilde{\Lambda}}(\xi)) : \xi \in X\} = \{(\xi, 0.9, 0.4)\}$ *and* $\tilde{\Theta} = \{(\xi, \mu_{\tilde{\Theta}}(\xi), \nu_{\tilde{\Theta}}(\xi)) : \xi \in X\} = \{(\xi, 0.8, 0.3)\}$ *and* $\lambda = 0.5$ *be a positive scalar. Then arithmetic operation on two PFNs* $\tilde{\Lambda}$ *&* $\tilde{\Theta}$ *define in Definition 19 and calculated as follows:*

1. *Addition of* $\tilde{\Lambda}$ *&* $\tilde{\Theta}$ *is*

$$\tilde{\Lambda} \oplus \tilde{\Theta} = \{(\xi, 0.9652, 0.08)\}$$

2. *Subtraction of* $\tilde{\Theta}$ *from* $\tilde{\Lambda}$ *is*

$$\tilde{\Lambda} \ominus \tilde{\Theta} = \{(\xi, 0.6872, 0.50)\}$$

since $0.9 \geq 0.8$ $\left(\mu_{\tilde{P}}(\xi) \geq \mu_{\tilde{Q}}(\xi)\right)$ *and* $0.2 \geq 0.3464 = \min\{0.4, 0.3464\}$ $\left(\nu_{\tilde{P}}(\xi) \leq \min\left\{\nu_{\tilde{Q}}(\xi), \frac{\nu_{\tilde{Q}}(\xi)\times\pi_{\tilde{P}}(\xi)}{\pi_{\tilde{Q}}(\xi)}\right\}\right)$ *where* $\pi_{\tilde{I}}(\xi)$ *is indeterminacy of PFN* $\tilde{I}$.

3. *Scalar multiplication of* $\tilde{\Lambda}$ *is (scalar* $\lambda = 0.5$*)*

$$0.5 \times \tilde{\Lambda} = \{(\xi, 0.7511, 0.4472)\}$$

4. *Multiplication of* $\tilde{\Lambda}$ *by* $\tilde{\Theta}$ *is*

$$\tilde{\Lambda} \otimes \tilde{\Theta} = \{(\xi, 0.72, 0.44)\}$$

5. *Scalar power of* $\tilde{\Lambda}$ *is (scalar* $\lambda = 0.5$*)*

$$\tilde{\Lambda}^{0.5} = \{(\xi, 0.9487, 0.4214)\}$$

6. *Division of* $\tilde{\Lambda}$ *by* $\tilde{\Theta}$ *is not define. Since* $0.9 \not\leq 0.6928 = \min\{0.8, 0.6928\}$ $\left(\mu_{\tilde{\Lambda}}(\xi) \leq \min\left\{\mu_{\tilde{\Theta}}(\xi), \frac{\mu_{\tilde{\Theta}}(\xi)\times\pi_{\tilde{\Lambda}}(\xi)}{\pi_{\tilde{\Theta}}(\xi)}\right\}\right)$ *and* $\nu_{\tilde{\Lambda}}(\xi) \geq \nu_{\tilde{\Theta}}(\xi)$ *where* $\pi_{\tilde{I}}(\xi)$ *is indeterminacy of PFN* $\tilde{I}$.
But division of $\tilde{\Theta}$ *by* $\tilde{\Lambda}$ *is define and* $\tilde{\Theta} \oslash \tilde{\Lambda} = \frac{\tilde{\Theta}}{\tilde{\Lambda}}$ *is*

$$\tilde{\Theta} \oslash \tilde{\Lambda} = \frac{\tilde{\Theta}}{\tilde{\Lambda}} = \{(\xi, 0.889, 0.354)\}$$

as $0.8 \leq 0.9$, $\left(\mu_{\tilde{\Theta}}(\xi) \leq \min\left\{\mu_{\tilde{\Lambda}}(\xi), \frac{\mu_{\tilde{\Lambda}}(\xi)\times\pi_{\tilde{\Theta}}(\xi)}{\pi_{\tilde{\Lambda}}(\xi)}\right\}\right)$ *and* $0.4 \geq 0.2$, $(\nu_{\tilde{\Theta}}(\xi) \geq \nu_{\tilde{\Lambda}}(\xi))$.

Example 21. *Let us* $\tilde{\Gamma} = \{(\xi, \mu_{\tilde{\Gamma}}(\xi), \nu_{\tilde{\Gamma}}(\xi)) : \xi \in X\} = \{(\xi, 0.7, 0.6)\}$ *and* $\tilde{\Delta} = \{(\xi, \mu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Delta}}(\xi)) : \xi \in X\} = \{(\xi, 0.9, 0.3)\}$ *be two PFNs. Then* $\tilde{\Gamma}$ *divided by* $\tilde{\Delta}$ *is*

$$\tilde{\Gamma} \oslash \tilde{\Delta} = \frac{\tilde{\Gamma}}{\tilde{\Delta}} = \{(\xi, 0.778, 0.545)\}$$

where $0.7 \leq 0.9$ $\left(\mu_{\tilde{\Gamma}}(\xi) \leq \min\left\{\mu_{\tilde{\Delta}}(\xi), \frac{\mu_{\tilde{\Delta}}(\xi)\times\pi_{\tilde{\Gamma}}(\xi)}{\pi_{\tilde{\Delta}}(\xi)}\right\}\right)$ *and* $0.6 \geq 0.3$ $(\nu_{\tilde{\Gamma}}(\xi) \geq \nu_{\tilde{\Delta}}(\xi))$.

Remark 22. *Division of one PFN by another PFN is possible under two conditions. Consider PFN $\tilde{\Delta}$ divisible by PFN $\tilde{\Gamma}$ with $\mu_{\tilde{\Delta}}$, $\mu_{\tilde{\Gamma}}$, $\nu_{\tilde{\Delta}}$, $\nu_{\tilde{\Gamma}}$, $\pi_{\tilde{\Delta}}$ and $\pi_{\tilde{\Gamma}}$ are the membership, non-membership and indeterminacy functions of PFNs $\tilde{\Delta}$ and $\tilde{\Gamma}$ respectively. The conditions are*

- $\mu_{\tilde{\Delta}}(\xi) \leq \min\left\{\mu_{\tilde{\Gamma}}(\xi), \frac{\mu_{\tilde{\Gamma}}(\xi)\times\pi_{\tilde{\Delta}}(\xi)}{\pi_{\tilde{\Gamma}}(\xi)}\right\}$
- $\nu_{\tilde{\Delta}}(\xi) \geq \nu_{\tilde{\Gamma}}(\xi)$

If either or both conditions are disqualified, then division is not possible.

3.8. Score function and Accuracy function of PFN

The score function is an operation to transform a fuzzy number to a crisp number. Since two fuzzy numbers are not comparable, some rule or process is required to compare those numbers. To compare any two PFNs by corresponding real numbers, there are many processes that exist, such as the du-fuzzification method, score function method, and accuracy function method. In this study, first we use the score function method and when the score function method fails or gives the same value, then we consider the accuracy function.

Let us consider $\tilde{\Lambda}$ be a PFN define as $\tilde{\Lambda} = \{(\xi, \mu_{\tilde{\Lambda}}(\xi), \nu_{\tilde{\Lambda}}(\xi)) : \xi \in X\}$. Then, various score functions in different studies are as follows

1. Score function by Yager, R.R. et al. [96] is

$$S_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 + (\nu_{\tilde{\Lambda}}(\xi))^2 \tag{17}$$

2. Score function by Wei, G. et al. [97] is

$$S_{\tilde{\Lambda}}(\xi) = \frac{1}{2}\left\{1 + (\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2\right\} \tag{18}$$

3. Score function by Liu, P. et al. [98] is

$$S_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2 \tag{19}$$

4. Score function by Peng, X. et al. [99] is

$$S_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2 + \left\{\frac{e^{\left(\mu_{\tilde{\Lambda}}(\xi)\right)^2 - \left(\nu_{\tilde{\Lambda}}(\xi)\right)^2}}{e^{\left(\mu_{\tilde{\Lambda}}(\xi)\right)^2 - \left(\nu_{\tilde{\Lambda}}(\xi)\right)^2} + 1} - \frac{1}{2}\right\}(\pi_{\tilde{\Lambda}}(\xi))^2 \tag{20}$$

5. Score function by Farhadinia, B. et al. [100] is

$$S_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 + \alpha\left\{1 - (\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2\right\} \tag{21}$$

   where $0 \leq \alpha \leq 1$. In general, consider $\alpha = 0.5$.

6. Score function by Peng, X. et al. [101] is

$$S_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2 + \left\{(\mu_{\tilde{\Lambda}}(\xi))^2 - (\nu_{\tilde{\Lambda}}(\xi))^2\right\}(\pi_{\tilde{\Lambda}}(\xi))^2 \tag{22}$$

The accuracy function is another way to measure the crisp value of a fuzzy number. Here we first apply the score function and when the score function fails to differentiate, then we use the accuracy function. Let us consider $\tilde{\Lambda}$ be a PFN define as $\tilde{\Lambda} = \{(\xi, \mu_{\tilde{\Lambda}}(\xi), \nu_{\tilde{\Lambda}}(\xi)) : \xi \in U\}$ where U describe the set of universe. Then several accuracy functions in the previous study are as follows

1. Accuracy function by Wei, G. et al. [97] is

$$A_{\tilde{\Lambda}}(\xi) = \frac{1}{2}\left\{(\mu_{\tilde{\Lambda}}(\xi))^2 + (\nu_{\tilde{\Lambda}}(\xi))^2\right\} \tag{23}$$

2. Accuracy function by Liu, P. et al. [98] is

$$A_{\tilde{\Lambda}}(\xi) = (\mu_{\tilde{\Lambda}}(\xi))^2 + (\nu_{\tilde{\Lambda}}(\xi))^2 \tag{24}$$

Here, above all those study [96, 97, 98, 99, 101] score and accuracy functions conclude that only Liu, P. et al. [98] and Wei, G. et al. [97] define accuracy functions. Because if the score function gives a conclusion, then there is no need for an accuracy function. In our study, we proposed a score function model and an accuracy function model, which are defined below.

Definition 23. ***Proposed Score Function:*** *Let* $\tilde{\Lambda} = \{(\delta, \mu_{\tilde{\Lambda}}(\delta), \nu_{\tilde{\Lambda}}(\delta)) : \delta \in W\}$ *be a PFN. Then the proposed score function* $S_{\tilde{\Lambda}}$ *of PFN define as*

$$S_{\tilde{\Lambda}}(\delta) = (\mu_{\tilde{\Lambda}}(\delta))^2 - (\nu_{\tilde{\Lambda}}(\delta))^2 + \frac{1}{2}\ln\left\{1 + (\pi_{\tilde{\Lambda}}(\delta))^2\right\} \tag{25}$$

where $\pi_{\tilde{\Lambda}}(\delta)$ *is indeterminacy value of PFN* $\tilde{\Lambda}$*, evaluated by* $\pi_{\tilde{\Lambda}}(\delta) = \sqrt{1 - (\mu_{\tilde{\Lambda}}(\delta))^2 - (\nu_{\tilde{\Lambda}}(\delta))^2}$.

Example 24. *Let consider* $\tilde{\Lambda}_1 = \{0.90, 0.40\}$, $\tilde{\Lambda}_2 = \{0.80, 0.50\}$ *and* $\tilde{\Lambda}_3 = \{0.75, 0.55\}$ *are three PFNs. Then the score function* $S_{\tilde{\Lambda}_i}$ *of PFN* $\tilde{\Lambda}_i$ *where* $i = 1, 2, 3$ *are shows in Table 8.*

Table 8: Score function values of different PFN in various scales

PFN	Score function by						
	Yager et al. [96]	**Wei et al.** [97]	**Liu et al.** [98]	**Peng et al.** [99]	**Farhadinia et al.** [100]	**Peng et al.** [101]	**Proposed method**
	Equation (17)	Equation (18)	Equation (19)	Equation (20)	Equation (21)	Equation (22)	Equation (25)
$\tilde{\Lambda}_1$	0.97	0.825	0.65	0.655	0.825	0.67	0.62
$\tilde{\Lambda}_2$	0.89	0.695	0.39	0.401	0.695	0.433	0.286
$\tilde{\Lambda}_3$	0.865	0.63	0.26	0.269	0.63	0.295	0.133

Definition 25. ***Accuracy Function:*** *Let us consider PFN* $\tilde{\Lambda} = \{(\delta, \mu_{\tilde{\Lambda}}(\delta), \nu_{\tilde{\Lambda}}(\delta)) : \delta \in W\}$*. Then the proposed accuracy function* $A_{\tilde{\Lambda}}$ *define as*

$$A_{\tilde{\Lambda}}(\delta) = (\mu_{\tilde{\Lambda}}(\delta))^2 - (\nu_{\tilde{\Lambda}}(\delta))^2 \tag{26}$$

Example 26. *Consider* $\tilde{\Lambda_1} = \{0.90, 0.40\}$, $\tilde{\Lambda_2} = \{0.80, 0.50\}$ *and* $\tilde{\Lambda_3} = \{0.75, 0.55\}$ *are three PFNs. Then the accuracy function* $A_{\tilde{\Lambda}_i}$ *of PFN* $\tilde{\Lambda}_i$ *where* $i = 1, 2, 3$ *are shows in Table 9.*

Table 9: Accuracy function values of PFNs in different scale

PFN	Accuracy function by		
	Wei, G. et al. [97]	**Liu, P. et al.** [98]	**Proposed method**
	Equation (23)	Equation (24)	Equation (26)
$\tilde{\Lambda_1}$	0.485	0.97	0.65
$\tilde{\Lambda_2}$	0.445	0.89	0.39
$\tilde{\Lambda_3}$	0.433	0.865	0.26

Note 27. *The score function and accuracy function are operations to convert PFN to a crisp number. In PFN, there is no ordered pair, i.e., no comparison between two PFNs; is the first one greater, less, or equal to the other one? For that reason, we consider another function on PFN to* $\mathbb{R}$ *(set of real numbers) in which the Euclidean order relation is defined.*

Theorem 28. *Let* $\tilde{\Delta} = \{(\xi, \mu_{\tilde{\Delta}}(\xi), \nu_{\tilde{\Delta}}(\xi)) : \xi \in \mathbb{R}\}$ *and* $\tilde{\Gamma} = \{(\xi, \mu_{\tilde{\Gamma}}(\xi), \nu_{\tilde{\Gamma}}(\xi)) : \xi \in \mathbb{R}\}$ *are two PFNs on* $\mathbb{R}$. *Consider score function and accuracy function denoted by* $S_{\tilde{\Lambda}}$ *and* $A_{\tilde{\Lambda}}$ $(\Lambda = \{\Delta, \Gamma\})$ *respectively, then*

1. *If* $S_{\tilde{\Delta}}(\xi) < S_{\tilde{\Gamma}}(\xi)$ *then* $\tilde{\Delta}(\xi) < \tilde{\Gamma}(\xi)$*; for* $\xi \in \mathbb{R}$,
2. *If* $S_{\tilde{\Delta}}(\xi) > S_{\tilde{\Gamma}}(\xi)$ *then* $\tilde{\Delta}(\xi) > \tilde{\Gamma}(\xi)$*; for* $\xi \in \mathbb{R}$,
3. *If* $S_{\tilde{\Delta}}(\xi) = S_{\tilde{\Gamma}}(\xi)$ *for* $\xi \in \mathbb{R}$ *; then*
   (a) *If* $A_{\tilde{\Delta}}(\xi) < A_{\tilde{\Gamma}}(\xi)$ *then* $\tilde{\Delta}(\xi) < \tilde{\Gamma}(\xi)$ *; for* $\xi \in \mathbb{R}$,
   (b) *If* $A_{\tilde{\Delta}}(\xi) > A_{\tilde{\Gamma}}(\xi)$ *then* $\tilde{\Delta}(\xi) > \tilde{\Gamma}(\xi)$*; for* $\xi \in \mathbb{R}$,
   (c) *If* $A_{\tilde{\Delta}}(\xi) = A_{\tilde{\Gamma}}(\xi)$ *then* $\tilde{\Delta}(\xi) \approx \tilde{\Gamma}(\xi)$*; for* $\xi \in \mathbb{R}$.

Remark 29. *The score and accuracy functions are defined from PFN to* $\mathbb{R}$. *First, consider the score function to evaluate PFNs, but if it fails, then think about the accuracy function (Theorem 28). Various studies introduce score functions and accuracy functions, some of which we mentioned. We proposed the score function in Equation* (25) *and the accuracy function in Equation* (26)*, respectively. Another comparison analysis was conducted on score and accuracy functions in different PFNs to check the stability, shown in Table 8 and Table 9, respectively.*

4. USED MCDM SOLUTION TECHNIQUES

This section discusses the MCDM methodologies [86] in detail. First, we formulate the mathematical procedure of the Analytic Hierarchy Process (AHP) method to check the consistency of the comparison matrix, followed by evaluating the criteria weights. After that, we discussed the procedure for determining sub-criteria weight in the local and global stages. Then represents the ranking based on two MCDM methods to rank alternatives in a scientific way, considering the criteria and sub-criteria weights. Additionally, the pseudo code of the proposed study is drawn here.

4.1. Analytic Hierarchy Process (AHP) Methodologiy

Multi-criteria decision making (MCDM) is the most challenging problem in the real world, and the Analytic Hierarchy Process (AHP) is one of the popular optimisation techniques in MCDM methods. In 1980, Thomas L. Saaty [102] developed the AHP method. This methodology calculates the criteria and sub-criterion's weight and gives relative importance. Previously, AHP has been used in numerous fields like shopping mall site selection [66], IoT in the healthcare field [103, 104, 105, 68], manufacturing organisation [69], manufacturing carpentry [65], so on. This method gives DMs a heuristic, scientific, and well-defined solution to complex real-world problems.

Fuzzy numbers reviewed factors and sub-factors better than crisp numbers; therefore, we applied FAHP instead of AHP. Evaluation of criteria and sub-criterion's weights is essential for selecting the best IoT. AHP deals with different orders, and the comparison matrix is built by DMs subjective opinions based on criteria and sub-criteria. In this study, Fuzzy AHP has been considered instead of AHP to capture various uncertainty and indeterminacy for the DMs ratings. Fuzzy AHP gives a more accurate and appropriate result. The preceding steps of Fuzzy AHP are described as follows:

I. Formulation of comparison matrix in Pythagorean fuzzy number by the DMs:
The criterion's of this study is recognised by a detailed literature study and the experts' opinions. Consider m DMs give ratings on p criterion's. Comparison matrix C_i DMs give their own opinion on their experiences and knowledge in linguistic terms. Linguistic term converted to a Pythagorean fuzzy number by the conversion Table 12.

II. Aggregate m DMs review in a single comparison matrix as follows:
Consider the ith DMs given comparison matrix C_i as

$$C_i = \begin{bmatrix} (\chi_{11})_i & (\chi_{12})_i & \cdots & (\chi_{1p})_i \\ (\chi_{21})_i & (\chi_{22})_i & \cdots & (\chi_{2p})_i \\ \vdots & \vdots & \ddots & \vdots \\ (\chi_{p1})_i & (\chi_{p2})_i & \cdots & (\chi_{pp})_i \end{bmatrix} \tag{27}$$

where $(\chi_{cd})_i = \{t_{cdi}, f_{cdi}\}$ be the rating by ith DM of c criteria to d criteria in PFN and $c, d = 1, 2, \ldots, p$.
Aggregation of m DMs rating in a single comparison matrix as follows

$$C = \begin{bmatrix} (\chi_{11}) & (\chi_{12}) & \cdots & (\chi_{1p}) \\ (\chi_{21}) & (\chi_{22}) & \cdots & (\chi_{2p}) \\ \vdots & \vdots & \ddots & \vdots \\ (\chi_{p1}) & (\chi_{p2}) & \cdots & (\chi_{pp}) \end{bmatrix} \tag{28}$$

and $(\chi_{cd}) = \{t_{cd}, f_{cd}\}$ with

$$\begin{cases} t_{cd} = \min\{t_{cdi}\} \text{ where } i = 1, 2, \ldots, m \\ f_{cd} = \max\{f_{cdi}\} \text{ where } i = 1, 2, \ldots, m \end{cases} \tag{29}$$

III. Score valued of comparison matrix
Find out the score valued comparison matrix C^v by equation (25) of matrix C.

IV. Normalized the score valued comparison matrix
Normalised the comparison matrix by dividing each entry by the corresponding sum of columns.

V. Find out criteria weights

$$w_c = \frac{\left(\prod_{d=1}^{p} \chi_d\right)^{\frac{1}{p}}}{\sum_{c=1}^{p} \left(\prod_{d=1}^{p} \chi_d\right)^{\frac{1}{p}}} \tag{30}$$

VI. Consistency Index (C.I.) of the matrix is evaluated as

$$C.I. = \frac{\lambda_{max} - p}{p-1} \tag{31}$$

where λ_{max} is maximum eigenvalue of the score valued comparison matrix C^v and p is the order of the matrix.

VII. Calculate the Consistency Ratio (C.R.):

$$C.R. = \frac{C.I.}{R.I.} \tag{32}$$

where $R.I.$ denote Random Index. The R.I. value depends on the size of the comparison matrix and is calculated by Saaty, T.L. [102], and is shown in Table 10.

Table 10: Random Index (RI) value for different size of comparison matrix (p)

Matrix size (p)	1	2	3	4	5	6	7	8	9	10	11	12
Random Index (RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

If the C.R. value < 0.1, then the comparison matrix is consistent; otherwise, it is inconsistent. Criterion's weights are obtained from Equation (30) and utilised in later sections.

4.2. Determination the Weight of the Sub-criteria

In this section, we find the sub-criterion's weight and incorporate it with the criterion's weight for determining the global weight. All sub-criterion are compared with their corresponding homogeneous sub-criterion and construct a sub-criteria bases comparison matrix. Sub-criteria weights are found as follows:

A. After recognising all the criteria for the IoT selection problem, we must sort the sub-criteria for each criterion. Let an arbitrary criteria s, their are n_s number of sub-criteria considered, where $s = 1, 2, \ldots, s, \ldots, p$.

B. Then m DMs give their rating by $n_s \times n_s$ comparison square matrix in linguistic terms for each criterion's s.

C. Aggregate m DMs review in a single comparison matrix by step II of the previous Section 4.1.

D. Score value calculated from the aggregated comparison matrix by the Equation (25).

E. Finally, check out sub-criteria weights by

$$C_{k_s} = \frac{\left(\prod_{k_s=1}^{n_s} \chi_{k_s}\right)^{\frac{1}{n_s}}}{\sum_{l_s=1}^{n_s} \left(\prod_{k_s=1}^{n_s} \chi_{k_s}\right)^{\frac{1}{n_s}}} \quad (33)$$

where $k_s, l_s = 1_s, 2_s, \ldots, n_s$ are sub-criterion's of the criteria s.
C_{k_s} denote the kth sub-criteria weight of the criteria s, also denoted by C_{sk} $(= C_{k_s})$ and known as local weight of this sub-criteria.

F. Global weight of the sub-criteria calculated as follows:

$$C_{sk}^{g} = C_s \times C_{sk} \quad (34)$$

where C_s denote the criteria weight of the criteria s getting from the Equation (30).

4.3. The Weighted Aggregates Sum Product Assessment (WASPAS) Method

WASPAS is one of the popular and robust useful determining applications. This technique was developed by Zavadskas, E. K. et al. [106] in 2012. This method [107] is an integrated approach of Weighted Sum Model (WSM) and Weighted Product Model (WPS), which calculates optimum results from additive and multiplicative utility functions [75]. This technique evaluates the solutions of the alternatives in rearranged from best to worst order. Also, use the consistency of the decision matrix at a very high level for estimation and optimising the weighted integrated assignment [106, 108, 109]. Mardani, A. et al. [110] reviewed on the basis of the WASPAS method and showed the importance of this newly developed method.

Similar to the previous section, let p and q be the numbers of criterion's and alternatives, respectively, create a decision matrix D with m number of decision makers. The WASPAS method is processed as following steps:

1. Constrict the decision matrix.
Identification of criteria and alternatives and on the basis of the DMS construct m decision matrices $D_1, D_2, \ldots, D_m$. Every DMs reveals their opinion on their own experiences and knowledge in linguistic terms in a decision matrix form. Convert the linguistic term to a Pythagorean fuzzy number (PFN) in the decision matrix.

2. The decision matrix of ith DMs is

$$D_i = \begin{bmatrix} (\phi_{11})_i & (\phi_{12})_i & \cdots & (\phi_{1p})_i \\ (\phi_{21})_i & (\phi_{22})_i & \cdots & (\phi_{2p})_i \\ \vdots & \vdots & \ddots & \vdots \\ (\phi_{q1})_i & (\phi_{q2})_i & \cdots & (\phi_{qp})_i \end{bmatrix} \quad (35)$$

where $(\phi_{rs})_i = \{t_{rsi}, f_{rsi}\}$ be the rating by ith decision maker of alternative r on criteria s in PFN.

3. Aggregate m DMs viewpoint in a single decision matrix as follows

$$D = \begin{bmatrix} (\phi_{11}) & (\phi_{12}) & \dots & (\phi_{1p}) \\ (\phi_{21}) & (\phi_{22}) & \dots & (\phi_{2p}) \\ \vdots & \vdots & \ddots & \vdots \\ (\phi_{q1}) & (\phi_{q2}) & \dots & (\phi_{qp}) \end{bmatrix} \tag{36}$$

and $(\phi_{rs}) = \{t_{rs}, f_{rs}\}$ with

$$\begin{cases} t_{rs} = \min\{t_{rsi}\} \text{ where } i = 1, 2, \dots, m \\ f_{rs} = \max\{f_{rsi}\} \text{ where } i = 1, 2, \dots, m \end{cases} \tag{37}$$

4. Score valued of decision matrix
Find out the score valued decision matrix D^v by equation (25) of matrix D. A score-valued decision matrix is defined as

$$D^v = \begin{bmatrix} (\phi_{11})^v & (\phi_{12})^v & \dots & (\phi_{1p})^v \\ (\phi_{21})^v & (\phi_{22})^v & \dots & (\phi_{2p})^v \\ \vdots & \vdots & \ddots & \vdots \\ (\phi_{q1})^v & (\phi_{q2})^v & \dots & (\phi_{qp})^v \end{bmatrix} \tag{38}$$

where ϕ_{rs}^v are score value of PFN ϕ_{rs} for all $r = 1, 2, \dots, q$ and $s = 1, 2, \dots, p$.

5. Obtain weight the criteria
Equation (34) gives the weight of the criterion's and sub-criteria. Weights are used to find out weighted sum and weighted product models.

6. Weighted Sum model (WSM)
S_r^+ is the first total relative importance value is calculated by Equation (39) according to the Weighted Sum Model. Here, use score valued decision matrix D^v using Equation (38) and weight of the criterion's C_s and global weight of the sub-criterion's $C_{sk}^g = C_s^g$ using Equation (34).

$$S_r^+ = \sum_{s=1}^{p} \left(C_s^g \times \phi_{rs}^{'} \right) \tag{39}$$

Here s represents the criteria and k represents the sub-criteria defined in Section 4.2.

7. Weighted Product Model (WPM)
S_r^* is the second total relative importance value is calculated by Equation (40) according to the Weighted Product Model. Similar to the previous step, here we also use normalised decision matrix and weights of the criterion's and sub-criterion's.

$$P_r^* = \sum_{s=1}^{p} \left(\phi_{rs}^{'} \right)^{C_s^g} \tag{40}$$

8. The combined optimally value
Finally, the Weighted Aggregated Sum Product Assessment (WASPAS) method, which is a unique combination of WSM and WPM, for ranking alternatives, is calculated as

$$S_r = \lambda S_r^+ + (1-\lambda)P_r^* \tag{41}$$

where $\lambda \in [0,1]$, is the coefficient of combined optimality. If the Weighted Sum Model and Weighted Product Model approaches have equal effect on the combined optimality criteria, λ is equal to 0.5.

On the basis of the S_r value in Equation (41), rank the alternatives. The higher the S_r value, the higher the priority of the first as an alternative.

4.4. The combined compromise solution (CoCoSo) Technique

CoCoSo technique is a newly developed MCDM method developed by Yazdani, M. et al. [111] in 2018. This method [82] is based on simple additive weighting (SAW) and exponentially weighted product model (MEP), known as weighted sum model (WSM) and weighted product model (WPM), respectively. Combining compromise perspectives is the abstract of this model, which deals with various conflicting criterion's and sub-criterion's. The CoCoSo model fully deals with the weight of the criterion's and gives an integrated solution of the WASPAS method. This model is an advanced MCDM technique [112] that depends on WSM, WPM and WASPAS methods. This model gives an overview of a favourable compromise outcome by the decision makers [113] as a solution.

Since the CoCoSo method depends on the WASPAS method, the initial steps are the same as the previous method. There are p and q numbers of criterion's and alternatives, respectively, taken to create the decision matrix D with m number of decision makers. The CoCoSo methods are given as follows:

a. Constrict the decision matrix.
Decision matrix D_i is constructed by Section 4.3.
b. Aggregate m DMs viewpoint in a single decision matrix by Equation (36).
c. Score valued of decision matrix
Obtain score valued decision matrix D^v by Equation (25) of matrix D. Score valued decision matrix formed by Equation (38).
d. Obtain weight the criteria
Equation (34) gives the weight of the criterion's and sub-criteria. Weights are used to find out weighted sum and weighted product models.
e. Weighted Sum model (WSM):
Equation (39) gives the WSM values of each and every alternative.
f. Weighted Product Model (WPM):
WPM values are found out using Equation (40) in Section 4.2.
g. Calculated the values of K_{ra} in Equation (42), K_{rb} in Equation (43) and K_{rc} in Equation (44), with the help of WSM (S_r^+) from the Equation (39) and WPM (P_r^*) from the Equation (40), respectively, as follows:

$$K_{ra} = \frac{(S_r^+ + P_r^*)}{\sum_{r=1}^{q}(S_r^+ + P_r^*)} \tag{42}$$

,

$$K_{rb} = \frac{S_r^+}{\min_{1 \le r \le q} S_r^+} + \frac{P_r^*}{\min_{1 \le r \le q} P_r^*} \tag{43}$$

and

$$K_{rc} = \frac{\lambda S_r^+ + (1-\lambda) P_r^*}{\lambda \max_{1 \le r \le q} S_r^+ + (1-\lambda) \max_{1 \le r \le q} P_r^*} \tag{44}$$

where $\lambda \in [0,1]$. Usually consider, $\lambda = 0.5$.

h. Finally, the ranking of the alternatives is obtained based on the value of K_r and is found by Equation (45), as follows

$$K_r = \{K_{ra} \times K_{rb} \times K_{rc}\}^{\frac{1}{3}} + \frac{K_{ra} + K_{rb} + K_{rc}}{3} \tag{45}$$

Ranking alternatives on the basis of K_r values in increasing order determined in Equation (45).

4.5. Pseudo code depicting of this experimental study

In this study, the framework considered p number of criteria with n_s number of sub-criteria of criteria s. Also, sum up q number of alternatives. All the rating is given by m number of decision makers in the linguistic term. The linguistic term rating is converted to PFN and applied to the MCDM techniques. Calculate the weight and then rank alternatives on the basis of them. The comparison matrix is $p \times p$ order, and the decision matrix is $q \times p$ order.

INPUT: Comparison matrix & Decision matrix
OUTPUT: Ranking the alternatives
COMPUTE: Consistency ratio, weight of the criteria and sub-criteria
INITIALIZE: TPFN
OPERATION: AHP, weight of criteria & sub-criteria, WASPAS and CoCoSo

FOR AHP
    AGGREGATION aggregated the m number of DMs inputs of comparison matrix
    IF comparison matrix is inconsistent (i.e., $CR \geq 0.10$)
        THEN rectify the comparison matrix
    ELSE comparison matrix is consistent (i.e., $CR < 0.10$)
END FOR

COMPUTE criteria & sub-criteria weight
    CONSTRUCT comparison matrix for criteria and sub-criteria by m DMs
    AGGREGATION aggregated the m number of DMs viewpoints
    THEN compute the weighted normalized comparison matrix
FIND calculated the weight of the criteria and sub-criteria

THEN decision matrix given by m DMs $q \times p$ order
    AGGREGATION aggregated the m number of DMs opinion of decision matrix
COMPUTE the weighted normalised decision matrix evaluated

BEGIN WASPAS
  COMPUTE calculation of the ranking of the alternatives using weighted normalized decision matrix
END WASPAS

BEGIN CoCoSo
  COMPUTE calculation of the ranking of the alternatives using weighted normalized decision matrix
END CoSoSo

5. MODEL FORMULATION

The healthcare sector has undergone a paradigm shift due to the Internet of Things (IoT), which is collecting real-time patient data, helping healthcare practitioners to make better decisions and enhance patient outcomes. This emerging technology primarily consists of an embedded network of smart sensors and self-directed devices that can provide accurate, continuous, and real-time patient monitoring. There are broadly four types of medical IoT devices, namely wearable devices, implantable devices, ambient devices and stationary devices [12]. Whereas the last two IoT devices are not attached to the body of the patient. Hence, these two devices are treated as non-wearable devices in this study. Each device has its own benefits and drawbacks [114]. Further, it may encounter different obstacles to adoption based on its unique characteristics. In this context, this study makes an attempt to compare these IoT devices in terms of the above identified challenges. The three alternatives, namely Wearable device (A1), Non-wearable devices (A2) and Implantable devices (A3) are chosen for this study.

Several studies have been conducted to evaluate IoT adoption challenges in the healthcare industry. Particularly, in the hospital of pulmonology unit [115], laboratory maintenance [116], psychotherapy services [117], and overall medical IoT [118]. However, there has not been any research conducted for the multi-speciality hospital. Again, a Multi-speciality hospital demands all types of IoT devices at the same time. Whereas a specialist hospital requires any one or two types of IoT devices at a time. In addition, if a multi-speciality hospital wants to use one of these devices for the first time, it should choose the one with the least obstacles. In this regard, there are four criteria, the identified 25 IoT adoption challenges treated as sub-criteria and three different IoT devices as alternatives shown in Figure 3. The investigator aimed to determine the best alternative by comparing the importance of the sub-criteria's adoption challenges with those of the criteria.

6. IOT ADOPTION CHALLENGES IN A MULTI-SPECIALIST HOSPITAL

Numerous studies on innovation and technology adoption in various IS fields have been conducted. According to Parker and Castleman [119] from 2003 to 2008, at least 128 publications on the adoption and innovation of technology were published in information journals. The aim of these adoption theories in the field of information systems is to comprehend, clarify, or predict how, why, and to what extent individuals or organisations decide to adopt and implement a new technology. Out of which, the Technology Organization Environment (TOE) framework is the most suitable organisation level

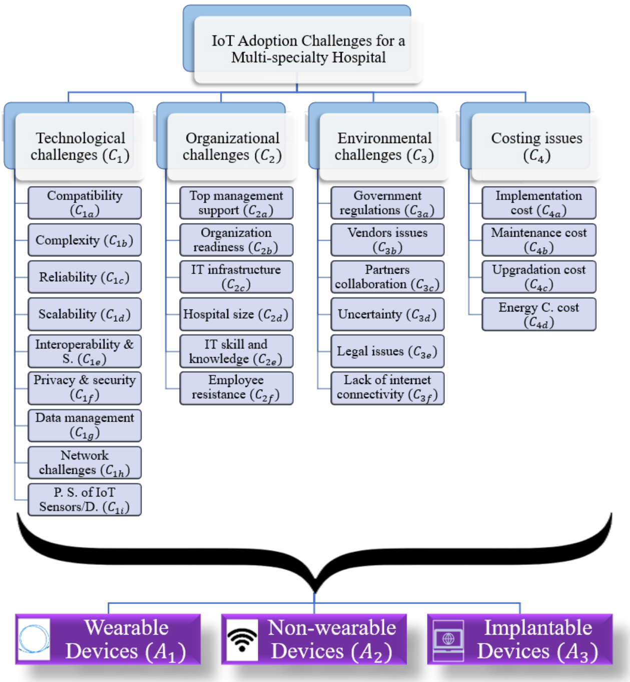

Figure 3: Hierarchical structure of the IoT adoption challenges

adoption theory for the hospital industry (Esfahani et al. [120]; Shahzad et al. [121]). Three organisational dimensions that may operate as drivers or obstacles for the adoption and implementation of new technologies are highlighted by the TOE framework [122], shown in Figure 4. The technological dimension refers to both existing and to be adopted technologies and focuses on how technical aspects influence the adoption process. The organisational dimension provides an explanation of the factors that either support or hinder the adoption of technological innovations. The environment dimension covers the interaction of different stakeholders. All the constructs or factors under this dimension can affect the success or failure of IoT adoption in a hospital. The TOE is too flexible (Riyadh et al. [123]) and lack a predetermined major constructs (Y. M. Wang et al. [124]). So, a researcher can add or remove any construct/factor within each dimension (Gangwar et al. [125]). Therefore, an attempt is made in this study to focus only on those factors/constructs which hinder the adoption of IoT.

Furthermore, cost involvement for adoption of technology is one of the major concerns (Davis et al. [126]) because adoption of medical IoT demands a significant investment in IT infrastructure creation. Especially, when you take into account the up-front expenses of buying and installing the equipment as well as the continuing costs of maintenance and support (Ahmetoglu & Cob [17]). Further, it may be a challenge for smaller healthcare institutions and hospitals with limited budgets (Shahzad et al. [121]). Hence, cost is also included in this study as another dimension. Finally, an attempt has been made to explore the possible IoT adoption challenges with respect to these dimensions.

Figure 4: TOE framework presented by Tornatzky, L. G. et al. [122] in 1990

An initial review of the literature was conducted by searching a combination of keywords like (challenges or barriers or issues), (Internet of Things or IoT), and (medical or healthcare or hospital). Scopus, Web of Science and Google Scholar databases were used for searching the keywords. The inclusion criteria for selection of articles are: (i) Published in the last five years, (ii) Written in English, (iii) Available as full text, (iv) Published in a peer-reviewed journal, Articles and conference papers (v) Articles investigating the IoT adoption challenges of in healthcare. Finally, we included the relevant papers cited by the selected studies by using the forward and backwards snowball approach. A panel of experts from industry and academia analysed all the major IoT adoption challenges found through a literature study in order to clarify any ambiguous facts. These challenges were further grouped into four categories, viz. Technical, Organisational, Environmental, and Cost based on their relevance. The same professionals were consulted throughout the classification of adoption challenges. Discussion about all criteria and sub-criteria are mentioned in Table 11.

Table 11: Evaluation criteria for IoT adoption challenges

Sub-criteria	Description/Implied meaning	Authors	Year
Criteria: Technological challenges (C_1)			
Compatibility (C_{1a})	The implementation of IoT in the medical industry is made more difficult by the presence of cross-functional requirements, legacy system integration, process integration, and obsolete IT infrastructure.	[17] Ahmetoglu, S. et al.	2022
		[30] Aisyah, S. et al.	2021
		[35] Dachyar, M. et al.	2019
		[121] Shahzad, K. et al.	2020
		[31] Alfarisi, M. R. et al.	2021
Complexity (C_{1b})	Medical IoT's requirement for a sizable number of unique devices from various suppliers makes it challenging to configure into a unified standards and protocols.	[17] Ahmetoglu, S. et al.	2022
		[30] Aisyah, S. et al.	2021
		[121] Shahzad, K. et al.	2020
		[22] Janssen, M.	2022
		[20] Desingh, V. et al.	2022
		[127] Ratta, P. et al.	2021
Reliability (C_{1c})	A reliable system is require to continuously tracking and monitoring of remote patients. For this, there must be a minimum loss of data during transmission.	[32] Sukma, A. N. et al.	2021
		[35] Dachyar, M. et al.	2019
		[31] Alfarisi, M. R. et al.	2021
		[22] Janssen, M.	2022
Scalability (C_{1d})	In the near future, the healthcare industry must install a significant number of IoT devices. Instead of requiring a complete system redesign, the system architecture must be created to allow for the upgrade of computational resources alone.	[17] Ahmetoglu, S. et al.	2022
		[121] Shahzad, K. et al.	2020
		[24] Tariq, M. I. et al.	2020
		[22] Janssen, M.	2022

Table 11: *Cont.*

Sub-criteria	Description/Implied meaning	Authors	Year
Criteria: Technological challenges (C_1)			
Interoperability & standardization (C_{1e})	There must be seamless data interchange across several entities, individuals, and systems for smooth function of medical IoT. Furthermore, more system and stakeholder interoperability is needed for IoT applications.	[17] Ahmetoglu, S. et al. [128] Haghparast, et al. [32] Sukma, A. N. et al. [22] Janssen, M. [20] Desingh, V. et al.	2022 2021 2021 2022 2022
Privacy & security (C_{1f})	IoT devices continuously gather a patient's private or sensitive information. It is challenging to protect patient privacy, prevent misuse and hiding of data from unauthorised parties when a variety of IoT health signalling sensors and devices gather significant amounts of data at diversified locations and times.	[128] Haghparast, et al. [50] Wang, L. et al. [33] Huang, X. et al. [30] Aisyah, S. et al. [35] Dachyar, M. et al. [31] Alfarisi, M. R. et al. [127] Ratta, P. et al.	2021 2020 2020 2021 2019 2021 2021
Data management (C_{1g})	The complexity of medical IoT solutions makes it difficult to gather, store, analyse, and visualise massive amounts of heterogeneous data without making errors.	[44] Narwane, V. S. et al. [127] Ratta, P. et al.	2022 2021
Network challenges (C_{1h})	Healthcare IoT systems are highly dependent on network communication issues like with routing, propagation losses, and communication range.	[44] Narwane, V. S. et al.	2022
Physical Security of IoT sensors/devices (C_{1i})	There is a chance that IoT-enabled wearables that are connected to patients for continuous monitoring of health indicators including blood sugar levels, blood pressure, heart rate, and blood oxygen level could be misused or damaged.	[50] Wang, L. et al. [33] Huang, X. et al.	2020 2020
Criteria: Organizational challenges (C_2)			
Top management support (C_{2a})	Top managements' perceptions of IoT include resistance to change, false assumptions about return on investment, and exaggerated expectations about the amount of work required to manage the technological innovations.	[32] Sukma, A. N. et al. [30] Aisyah, S. et al. [35] Dachyar, M. et al. [121] Shahzad, K. et al. [31] Alfarisi, M. R. et al. [22] Janssen, M.	2021 2021 2019 2020 2021 2022
Organization readiness (C_{2b})	Organizations are reluctant to take chances while altering their business models, which can result in unforeseen disruptions and significant shifts in the way they now do business.	[17] Ahmetoglu, S. et al. [30] Aisyah, S. et al. [35] Dachyar, M. et al. [31] Alfarisi, M. R. et al.	2022 2021 2019 2021
IT infrastructure (C_{2c})	The efficiency and adoption of IoT technology in the medical business are substantially impacted by the lack of adequate IT infrastructure and sensor systems.	[35] Dachyar, M. et al. [121] Shahzad, K. et al. [31] Alfarisi, M. R. et al. [22] Janssen, M. [20] Desingh, V. et al.	2019 2020 2021 2022 2022
Hospital size (C_{2d})	A larger hospital demands more resources for IoT adoption than a small one does.	[121] Shahzad, K. et al. [129] Lin, D. et al.	2020 2017
IT skill and knowledge (C_{2e})	One of the main obstacles impacting the adoption of IoT in the healthcare industry is the lack of knowledge and expertise related IoT in addition to the absence of training facilities to educate employees from non-specialized domains.	[17] Ahmetoglu, S. et al. [30] Aisyah, S. et al. [35] Dachyar, M. et al. [31] Alfarisi, M. R. et al. [22] Janssen, M. [20] Desingh, V. et al.	2022 2021 2019 2021 2022 2022
Employee resistance (C_{2f})	The successful implementation of IoT in healthcare is significantly impacted by staff concerns about losing their employment, resistance to learning new technology, and unwillingness to alter their daily routines.	[17] Ahmetoglu, S. et al.	2022

Table 11: *Cont.*

Sub-criteria	Description/Implied meaning	Authors	Year
Criteria: Environmental challenges (C_3)			
Government regulations (C_{3a})	Government support contributes to successful medical IoT adoption by providing conducive environment.	[17] Ahmetoglu, S. et al.	2022
		[32] Sukma, A. N. et al.	2021
		[30] Aisyah, S. et al.	2021
		[35] Dachyar, M. et al.	2019
		[31] Alfarisi, M. R. et al.	2021
Vendors issues (C_{3b})	IoT technologies may be too complex and impractical due to a variety of vendor-specific hardware/software setups, communication protocols, security protocols, and data formats that were implemented to serve healthcare customers.	[17] Ahmetoglu, S. et al.	2022
		[30] Aisyah, S. et al.	2021
		[121] Shahzad, K. et al.	2020
		[31] Alfarisi, M. R. et al.	2021
Partners collaboration (C_{3c})	The many stakeholder interests, as well as their various platforms, practises, and legacy systems, may conflict with those of other stakeholders. They may also have distinct approaches for implementing new technologies and investment policies.	[17] Ahmetoglu, S. et al.	2022
		[32] Sukma, A. N. et al.	2021
		[22] Janssen, M.	2022
Uncertainty (C_{3d})	Both commercial and technical uncertainty are inherent to medical IoT technologies.	[17] Ahmetoglu, S. et al.	2022
		[32] Sukma, A. N. et al.	2021
Legal issues (C_{3e})	Data privacy and security laws should be followed while collecting and sharing patient data, and they should not be infringed.	[24] Tariq, M. I. et al.	2020
		[22] Janssen, M.	2022
		[20] Desingh, V. et al.	2022
		[127] Ratta, P. et al.	2021
Lack of internet connectivity (C_{3f})	A large number of internet-connected sensors are crucial for a successful medical IoT in order to monitor and track patients remotely. However, a lack of internet connectivity from the patients' location is a critical concern.	[44] Narwane, V. S. et al.	2022
		[27] Luthra, S .	2018
		[20] Desingh, V. et al.	2022
Criteria: Costing issues (C_4)			
Implementation cost (C_{4a})	A significant barrier to using IoT in healthcare is the higher initial expenditure required for hardware, software, and staff training.	[17] Ahmetoglu, S. et al.	2022
		[24] Tariq, M. I. et al.	2020
		[35] Dachyar, M. et al.	2019
		[31] Alfarisi, M. R. et al.	2021
		[22] Janssen, M.	2022
Maintenance cost (C_{4b})	Benefits may not always be distributed fairly since the maintenance of sensor/IoT device networks and a secure information-sharing infrastructure needs substantial investment and cooperation between stakeholders.	[24] Tariq, M. I. et al.	2020
		[30] Aisyah, S. et al.	2021
		[35] Dachyar, M. et al.	2019
		[31] Alfarisi, M. R. et al.	2021
		[20] Desingh, V. et al.	2022
Upgradation cost (C_{4c})	The expense of upgrading current IT infrastructure to be compatible with the requirements of medical IoT technologies is one of the obstacles to IoT adoption.	[24] Tariq, M. I. et al.	2020
Energy consumption cost (C_{4d})	One of the main challenges facing medical IoTs is the rising energy requirement driven on by the expanding number of sensors, IoT devices, data centres, and networks.	[17] Ahmetoglu, S. et al.	2022
		[44] Narwane, V. S. et al.	2022
		[20] Desingh, V. et al.	2022
		[127] Ratta, P. et al.	2021

7. ALTERNATIVE FOR ASSOCIATED MODEL

This section discusses the alternatives for these IoT adaptation challenges. There are several studies conducted on this topic. Zikria, Y. B. et al. [130] analysis the next generation IoT in different parameters and Zhang, T. et al. [131] examine the IoT in different parameters like challenges, applications and opportunities. In this study, three alternatives are considered as IoT adaptation in a multi-speciality hospital, which are discussed more elaborately as follows:

7.1. Wearable devices (A_1)

Wearable devices are becoming more and more popular in the healthcare sector because of their ability to gather information and various data in real-time. It allows us to individualise and enterprising healthcare. Wearable devices in health care are used to collect data and information from the body to check the status of various aspects of health. In the health sector, the percentage of wearable devices is rapidly increasing, such as Fitbit, monitoring vital signs, wearable monitors and discovering health conditions. Some frequently used wearable devices in the health sector are:

a. Fitness trackers: This wearable device checks the status and tracks the body's health related data.
b. Smartwatches: To check blood pressure, heart rate and oxygen status, use smartwatches.
c. ECG: Electrocardiogram (ECG) data was collected by these wearable devices. Heart-related various problems are captured using this device.
d. Smart clothing: Smart clothing is a sensor cloth that can collect various data from the body areas for treatment.

In general, wearable devices collect real-time health-related data and have the potential to identify the disease.

7.2. Non-wearable devices (A_2)

Similar to wearable devices, many non-wearable devices are used in the medical sector. In IoT technology, various devices are beneficial for multi-speciality hospitals. These devices are set up with various types of sensors, cameras and connected to other devices like a computer. One of the advantages of non-wearable devices is their capacity to upgrade operational productivity and minimise costs. Some of them are:

i. Smart thermometers: To check body temperature and track the health status of the present smart thermometer is very useful.
ii. Smart inhalers: Smart inhalers are used for asthma and COPD treatment in the present and track the health report. It also reminds them when medicine is required.
iii. Smart bed: Patient's heart rate, respiratory rate, body movement, and other things are tracked by the smart bed and all information is stored for better treatment.
iv. Smart pill dispensers: Smart pill dispensers remind patients when they take medicine and alert them when it's time to take pills. It is helpful in IoT technology in the healthcare sector.

Non-wearable devices in the health sector have strong benefits. It improves the medical service, regains patients' health, and reduces health costs, especially in managing multi-speciality hospitals, which play an important role.

7.3. Implantable devices (A_3)

Implantable devices are another classification of IoT devices that are rapidly increasing in use in the medical sector. These types of devices are usually small, electronically powered and surgically inserted into the patient's body. It is controlled by the monitor and observes the various anatomical activities. It is used for different diseases to improve the health of patients. Some of the most useful devices are:

I. Implantable pacemakers: Pacemaker IoT implantable device used to regulate heart rate and track heart activity. This device can be monitored and programmed remotely by the health expert based on health data.
II. Implantable drug pump: Transfer the medicine directly to the side of the injured or diseased using the implantable drug pump IoT technology.
III. Implantable sensor: Implantable sensors are used in the medical sector to track various physical activities, like blood pressure and oxygen level. It can give real-time data, which helps treat the disease and achieve an early cure.

Overall, implantable devices of Iot technology can bring a revolution in the medical sector and improve the treatment procedures. It can give better health data and reduce medical costs.

8. DATA COLLECTION

Gathering data on IoT adoption challenges across different types of super-speciality hospitals is a time-consuming and delicate task. To ensure data authenticity and obtain more accurate results, we consider multiple decision experts, i.e., the decision maker (DM). They are professional and experienced in their field. All data are given in linguistic terms and converted into a Pythagorean fuzzy number. Hastiness and indeterminacy are detected and quantified by the PFN. Table 12 shows the linguistic term and PFN conversion for the comparison matrix. Table 13 displays the comparison matrix for the four criterion's given by the three DMs. Comparison matrices for sub-criterion's Technological challenges (C_1), Organizational challenges (C_2), Environmental challenges (C_3) and Costing issues (C_4) are shown in Table 14, Table 15, Table 16 and Table 17, respectively.

Note 30. *This study collected all data from three DMs, who are professionals with experience in IoT adoption and the hospitality industry. Experts were selected from three different fields, as follows:*

a) A senior doctor with 10 years' experience from the district hospital is considered a first DM (DM_1).
b) A hospital superintendent with 15 years' experience from a medical college is considered a second DM (DM_2).
c) A government officer working in the Ministry of Health is considered a third DM (DM_3).

Table 12: Linguistic rating & their corresponding Pythagorean fuzzy number

Linguistic Term	Crisp Number	Pythagorean Fuzzy Number (PFN)
Absolutely Important (AI)	9	$(0.96, 0.06)$
Very Important (VI)	7	$(0.92, 0.10)$
Slightly Important (SI)	5	$(0.88, 0.14)$
Important (I)	3	$(0.84, 0.18)$
Moderate (M)	1	$(0.80, 0.22)$
Unimportant (U)	$1/3$	$(0.76, 0.26)$
Slightly Unimportant (SU)	$1/5$	$(0.72, 0.30)$
Very Unimportant (VU)	$1/7$	$(0.68, 0.34)$
Absolutely Unimportant (AU)	$1/9$	$(0.64, 0.38)$

Note 31. *To understand the linguistic term and corresponding PFN, we also mention their comparable crisp value. In Table 12, take crisp value in* $(0,9)$ *scale. It is not the de-fuzzified or score value that is mentioned in the previous section. To better incorporate between the linguistic term and PFN, we consider this. Those crisp numbers are not evaluated in the numerical section.*

Table 13: Comparison matrix in linguistic terms by three DMs

	Criteria	C_1	C_2	C_3	C_4
DM 1	Technological challenges (C_1)	M	SI	AI	SI
	Organizational challenges (C_2)	SU	M	VI	AI
	Environmental challenges (C_3)	AU	VU	M	U
	Costing issues (C_4)	SU	AU	I	M
DM 2	Technological challenges (C_1)	M	I	VI	I
	Organizational challenges (C_2)	U	M	AI	VI
	Environmental challenges (C_3)	VU	AU	M	U
	Costing issues (C_4)	U	VU	I	M
DM 3	Technological challenges (C_1)	M	I	AI	SI
	Organizational challenges (C_2)	U	M	AI	SI
	Environmental challenges (C_3)	AU	AU	M	M
	Costing issues (C_4)	SU	VU	M	M

Table 14: Comparison matrix of sub-criteria of Technological challenges (C_1)

	Alternatives	C_{1a}	C_{1b}	C_{1c}	C_{1d}	C_{1e}	C_{1f}	C_{1g}	C_{1h}	C_{1i}
DM 1	Compatibility (C_{1a})	M	SI	VI	SI	I	SU	SI	AI	AI
	Complexity (C_{1b})	SU	M	SI	SI	I	VU	I	VI	VI
	Reliability (C_{1c})	VU	SU	M	M	SU	VU	SI	SI	VI
	Scalability (C_{1d})	SU	SU	M	M	SU	VU	U	SU	VU
	Interoperability & S. (C_{1e})	U	U	SI	SI	M	VU	I	SI	U
	Privacy & security (C_{1f})	SI	VI	VI	VI	VI	M	AI	AI	VI
	Data management (C_{1g})	SU	U	SU	I	U	AU	M	I	U
	Network challenges (C_{1h})	AU	VU	SU	SI	SU	AU	U	M	U
	Physical S. of IoT (C_{1i})	AU	VU	VI	VI	I	VU	I	I	M
DM 2	Compatibility (C_{1a})	M	I	VI	AI	VI	SU	SI	AI	AI
	Complexity (C_{1b})	U	M	VI	SI	I	SU	I	VI	VI
	Reliability (C_{1c})	VU	VU	M	I	SU	SU	VI	SI	SI
	Scalability (C_{1d})	AU	SU	U	M	SU	VU	SU	SU	SU
	Interoperability & S. (C_{1e})	VU	U	SI	SI	M	VU	M	SI	M
	Privacy & security (C_{1f})	SI	SI	SI	VI	VI	M	AI	AI	AI
	Data management (C_{1g})	SU	U	VU	SI	M	AU	M	SI	SU
	Network challenges (C_{1h})	AU	VU	SU	SI	SU	AU	SU	M	SU
	Physical S. of IoT (C_{1i})	AU	VU	SU	SI	M	AU	SI	SI	M
DM 3	Compatibility (C_{1a})	M	SI	VI	AI	AI	VU	VI	AI	AI
	Complexity (C_{1b})	SU	M	VI	SI	I	VU	I	AI	SI
	Reliability (C_{1c})	VU	VU	M	I	VU	VU	SI	VI	SI
	Scalability (C_{1d})	AU	SU	U	M	U	AU	SU	SU	SU
	Interoperability & S. (C_{1e})	AU	U	VI	I	M	VU	I	SI	SI
	Privacy & security (C_{1f})	VI	VI	VI	AI	VI	M	AI	AI	AI
	Data management (C_{1g})	VU	U	SU	SI	U	AU	M	SI	SU
	Network challenges (C_{1h})	AU	AU	VU	SI	SU	AU	SU	M	SU
	Physical S. of IoT (C_{1i})	AU	SU	SU	SI	SU	AU	SI	SI	M

Table 15: Comparison matrix of sub-criteria of Organizational challenges (C_2)

	Alternatives	C_{2a}	C_{2b}	C_{2c}	C_{2d}	C_{2e}	C_{2f}
DM 1	Top management support (C_{2a})	M	AI	VI	AI	I	VI
	Organization readiness (C_{2b})	AU	M	SU	I	SI	M
	IT infrastructure (C_{2c})	VU	SI	M	AI	I	AI
	Hospital size (C_{2d})	AU	U	AU	M	VU	VU
	IT skill and knowledge (C_{2e})	U	SU	U	VI	M	VI
	Employee resistance (C_{2f})	VU	M	AU	VI	VU	M
DM 2	Top management support (C_{2a})	M	VI	VI	AI	I	VI
	Organization readiness (C_{2b})	VU	M	U	SI	SI	M
	IT infrastructure (C_{2c})	VU	I	M	AI	I	AI
	Hospital size (C_{2d})	AU	SU	AU	M	AU	VU
	IT skill and knowledge (C_{2e})	U	SU	U	AI	M	AI
	Employee resistance (C_{2f})	VU	M	AU	VI	AU	M
DM 3	Top management support (C_{2a})	M	AI	SI	VI	VI	SI
	Organization readiness (C_{2b})	AU	M	SU	I	I	M
	IT infrastructure (C_{2c})	SU	SI	M	AI	I	AI
	Hospital size (C_{2d})	VU	U	AU	M	AU	VU
	IT skill and knowledge (C_{2e})	VU	U	U	AI	M	AI
	Employee resistance (C_{2f})	SU	M	AU	VI	AU	M

Table 16: Comparison matrix of sub-criteria of Environmental challenges (C_3)

	Alternatives	C_{3a}	C_{3b}	C_{3c}	C_{3d}	C_{3e}	C_{3f}
DM 1	Government regulations (C_{3a})	M	SU	VU	I	I	U
	Vendors issues (C_{3b})	SI	M	SU	SI	I	SI
	Partners collaboration (C_{3c})	VI	SI	M	VI	SI	AI
	Uncertainty (C_{3d})	U	SU	VU	M	U	U
	Legal issues (C_{3e})	U	U	SU	I	M	U
	Lack of internet connectivity (C_{3f})	I	SU	AU	I	I	M
DM 2	Government regulations (C_{3a})	M	SU	AU	U	M	M
	Vendors issues (C_{3b})	SI	M	VU	SI	I	SI
	Partners collaboration (C_{3c})	AI	VI	M	AI	VI	AI
	Uncertainty (C_{3d})	I	SU	AU	M	M	M
	Legal issues (C_{3e})	M	U	VU	M	M	I
	Lack of internet connectivity (C_{3f})	M	SU	AU	M	U	M
DM 3	Government regulations (C_{3a})	M	SU	VU	U	M	U
	Vendors issues (C_{3b})	SI	M	SU	VI	SI	I
	Partners collaboration (C_{3c})	VI	SI	M	VI	VI	VI
	Uncertainty (C_{3d})	I	VU	VU	M	U	M
	Legal issues (C_{3e})	M	SU	VU	I	M	I
	Lack of internet connectivity (C_{3f})	I	U	VU	M	U	M

Table 17: Comparison matrix of sub-criteria of Costing issues (C_4)

	Alternatives	C_{4a}	C_{4b}	C_{4c}	C_{4d}
DM 1	Implementation cost (C_{4a})	M	AI	VI	AI
	Maintenance cost (C_{4b})	AU	M	VU	U
	Upgradation cost (C_{4c})	VU	VI	M	AI
	Energy consumption cost (C_{4d})	AU	I	AU	M
DM 2	Implementation cost (C_{4a})	M	AI	AI	AI
	Maintenance cost (C_{4b})	AU	M	SU	U
	Upgradation cost (C_{4c})	AU	SI	M	AI
	Energy consumption cost (C_{4d})	AU	I	AU	M
DM 3	Implementation cost (C_{4a})	M	VI	VI	AI
	Maintenance cost (C_{4b})	VU	M	VU	U
	Upgradation cost (C_{4c})	VU	VI	M	AI
	Energy consumption cost (C_{4d})	AU	I	AU	M

A similar concept is applicable to the data collection of the comparison matrix. Decision makers (DMs) gave their opinion or review in linguistic terms based on their experiences and real data. The conversion chart is shown in Table 18. Decision matrix of criterion's expressed by Technological challenges (C_1) in Table 19, Organizational challenges (C_2) in Table 20, Environmental challenges (C_3) in Table 21 and Costing issues (C_4) in Table 22, respectively.

Table 18: Linguistic rating & their corresponding Pythagorean fuzzy number

Linguistic Term	Crisp Number	Pythagorean Fuzzy Number (PFN)
Extremely Priority (EP)	9	$(0.90, 0.40)$
Very Priority (VP)	7	$(0.80, 0.40)$
Medium Priority (MP)	5	$(0.80, 0.50)$
Below Priority (BP)	3	$(0.70, 0.50)$
Low Priority (LP)	1	$(0.70, 0.60)$

Table 19: Decision matrix in linguistic terms on Technological challenges (C_1)

	Alternatives	C_{1a}	C_{1b}	C_{1c}	C_{1d}	C_{1e}	C_{1f}	C_{1g}	C_{1h}	C_{1i}
DM 1	Wearable devices (A_1)	VP	VP	MP	MP	VP	EP	MP	BP	MP
	Non-wearable devices (A_2)	MP	MP	BP	LP	BP	VP	BP	LP	LP
	Implantable devices (A_3)	EP	EP	MP	EP	VP	EP	VP	BP	LP
DM 2	Wearable devices (A_1)	VP	VP	MP	MP	VP	EP	MP	LP	MP
	Non-wearable devices (A_2)	BP	MP	BP	BP	MP	VP	BP	LP	LP
	Implantable devices (A_3)	EP	EP	MP	EP	EP	EP	VP	LP	LP
DM 3	Wearable devices (A_1)	VP	VP	MP	MP	VP	EP	MP	BP	BP
	Non-wearable devices (A_2)	MP	MP	BP	LP	BP	VP	BP	LP	LP
	Implantable devices (A_3)	EP	EP	VP	VP	EP	EP	MP	BP	LP

Table 20: Decision matrix in linguistic terms on Organizational challenges (C_2)

	Alternatives	C_{2a}	C_{2b}	C_{2c}	C_{2d}	C_{2e}	C_{2f}
DM 1	Wearable devices (A_1)	MP	VP	EP	MP	EP	MP
	Non-wearable devices (A_2)	BP	MP	VP	BP	VP	VP
	Implantable devices (A_3)	VP	EP	EP	LP	EP	BP
DM 2	Wearable devices (A_1)	MP	VP	EP	MP	EP	MP
	Non-wearable devices (A_2)	BP	MP	VP	MP	VP	VP
	Implantable devices (A_3)	VP	EP	EP	LP	EP	BP
DM 3	Wearable devices (A_1)	MP	MP	VP	MP	EP	MP
	Non-wearable devices (A_2)	BP	MP	VP	MP	VP	VP
	Implantable devices (A_3)	VP	VP	EP	LP	EP	BP

Table 21: Decision matrix in linguistic terms on Environmental challenges (C_3)

	Alternatives	C_{3a}	C_{3b}	C_{3c}	C_{3d}	C_{3e}	C_{3f}
DM 1	Wearable devices (A_1)	MP	EP	VP	MP	VP	BP
	Non-wearable devices (A_2)	LP	EP	EP	BP	LP	LP
	Implantable devices (A_3)	EP	MP	BP	EP	EP	BP
DM 2	Wearable devices (A_1)	VP	EP	EP	MP	VP	BP
	Non-wearable devices (A_2)	LP	EP	EP	BP	LP	LP
	Implantable devices (A_3)	VP	MP	LP	EP	EP	LP
DM 3	Wearable devices (A_1)	MP	VP	EP	MP	VP	BP
	Non-wearable devices (A_2)	LP	EP	VP	BP	BP	LP
	Implantable devices (A_3)	EP	MP	BP	EP	EP	LP

Table 22: Decision matrix in linguistic terms on Costing issues (C_4)

	Alternatives	C_{4a}	C_{4b}	C_{4c}	C_{4d}
DM 1	Wearable devices (A_1)	VP	VP	EP	MP
	Non-wearable devices (A_2)	MP	MP	MP	BP
	Implantable devices (A_3)	EP	LP	EP	LP
DM 2	Wearable devices (A_1)	VP	MP	VP	MP
	Non-wearable devices (A_2)	MP	VP	BP	BP
	Implantable devices (A_3)	EP	LP	EP	BP
DM 3	Wearable devices (A_1)	VP	MP	VP	MP
	Non-wearable devices (A_2)	MP	VP	MP	BP
	Implantable devices (A_3)	EP	BP	EP	BP

Note 32. *All ratings given by experts in their professional field, with their experience and on the basis of real data. Decision experts already have knowledge, therefore their opinions are more assured. That means in PFN, the true membership value is more than the false membership value. Since they are more confident about their opinion, the hesitancy/indeterminacy part is always very little.*

9. RESULT AND DISCUSSION

This section represents the results of the proposed model presented in the previous section. First, we calculated the weight of the criteria and sub-criteria, followed by the global weight of the criteria and sub-criteria. After that, we determined the ranking of the alternatives by two ranking-based MCDM methods. All the evaluation results are presented in the section below. Furthermore, all the results are discussed and analysed with our motivation and aim of this study in the later sections.

9.1. Calculate criteria and sub-criteria weight

Table 23 shows the criteria weight of the IoT adaptation challenge. Sub-criteria weight of the criteria in local and global form is shown in a different table. Sub-criteria weight of Technological challenges (C_1) shown in Table 24. Table 25 shows the sub-criteria weight of Organizational challenges (C_2). Sub-criterion's weight of Environmental challenges (C_3) and Costing issues (C_4) are shown in Table 26 and Table 27, respectively.

Table 23: Criteria weight of criterion's using AHP methodology

Criteria	Technological challenges (C_1)	Organizational challenges (C_2)	Environmental challenges (C_3)	Costing issues (C_4)
Weight (C_s^w)	0.2918	0.2810	0.2037	0.2236

Remark 33. *Calculated the criteria weight of IoT adoption challenges for different kinds of super speciality hospitals. Applying the AHP method (Section 4.1) using data from Table 13, we get the criteria weight in crisp values shown in Table 23. Here, the most important criterion is Technological challenges* (C_1) *with* 0.2918 *score value. Then Organizational challenges* (C_2) *and Costing issues* (C_4) *with weight values* 0.2810 *and* 0.2236 *respectively. Finally, the list priorities are Environmental challenges* (C_3) *and the weight is* 0.2037.

Note 34. *Calculated the global weight of the sub-criteria* (C^g_{sr}) *from the criteria weight (in Table 23) and local weight of the sub-criteria (techniques are mentioned in Section 4.2), as follows:*

$$C^g_{sr} = C^w_s \times C^w_{sr} \tag{46}$$

where

$$\begin{cases} for\ s = 1; & then\ r = a, b, \ldots, i \\ for\ s = 2; & then\ r = a, b, \ldots, f \\ for\ s = 3; & then\ r = a, b, \ldots, f \\ for\ s = 4; & then\ r = a, b, \ldots, d \end{cases}$$

Table 24: Local and global weight of sub-criterion Technological challenges (C_1)

Sub-criteria	C_{1a}	C_{1b}	C_{1c}	C_{1d}	C_{1e}	C_{1f}	C_{1g}	C_{1h}	C_{1i}
Local Weight (C^w_{1r})	0.1613	0.1409	0.0998	0.0656	0.1064	0.1967	0.0858	0.0617	0.0817
Global Weight (C^g_{1r})	0.4706	0.0411	0.0291	0.0191	0.0310	0.0574	0.0250	0.0180	0.0238

Table 25: Different weight of the sub-criteria Organizational challenges (C_2)

Sub-criteria	C_{2a}	C_{2b}	C_{2c}	C_{2d}	C_{2e}	C_{2f}
Local Weight (C^w_{2r})	0.2719	0.1511	0.2198	0.0703	0.1783	0.1086
Global Weight (C^g_{2r})	0.0764	0.0425	0.0618	0.0198	0.0501	0.0305

Table 26: Two types of weight of the sub-criteria Environmental challenges (C_3)

Sub-criteria	C_{3a}	C_{3b}	C_{3c}	C_{3d}	C_{3e}	C_{3f}
Local Weight (C^w_{3r})	0.1285	0.2016	0.2767	0.1154	0.1444	0.1334
Global Weight (C^g_{3r})	0.0262	0.0411	0.0564	0.0235	0.0294	0.0272

Table 27: Local and global weight of the sub-criteria Costing issues (C_4)

Sub-criteria	C_{4a}	C_{4b}	C_{4c}	C_{4d}
Local Weight (C^w_{4r})	0.4440	0.1553	0.2564	0.1443
Global Weight (C^g_{4r})	0.0993	0.0347	0.0573	0.0323

Remark 35. *First, calculate the local weight of sub-criteria using Section 4.2. Then, evaluate the global weight of sub-criteria applying Equation* (46)*. For further numerical evaluation, consider the global weight as a sub-factor weight.*

9.2. Finding alternatives ranking

Apply two MCDM methods for ranking alternatives for choosing the best IoT adoption challenges for different kinds of super speciality hospitals. Here, we consider three alternatives for ranking and find the best among them. The weight of the criterion is obtained from the previous four Tables (24, 25, 26 & 27) and evaluated in the next numericals. Firstly, the MCDM technique WASPAS (described in Section 4.3) applies and the corresponding data is shown in Table 28. Also, the ranking of the alternatives is mentioned in this table.

Table 28: Ranking of alternatives & their adjacent data using WASPAS method

Alternative	WSM	WPM	WASPAS	Ranking
Wearable devices (A_1)	0.5172	0.5073	0.5122	**1**
Non-wearable devices (A_2)	0.4200	0.3976	0.4089	**3**
Implantable devices (A_3)	0.5173	0.4720	0.4946	**2**

To check the flexibility of the ranking and verify the decision, use the second MCDM method, namely the CoCoSo method. The methodology is depicted in Section 4.4. The values of K_{ra}, K_{rb}, K_{rc}, K_r and ranking of the alternatives are mentioned in Table 29.

Table 29: Alternatives ranking with associated values using CoCoSo method

Alternative	K_{ra}	K_{rb}	K_{rc}	K_r	Ranking
Wearable devices (A_1)	0.3618	2.5075	0.9999	2.2578	**1**
Non-wearable devices (A_2)	0.2888	2.0000	0.7980	1.8013	**3**
Implantable devices (A_3)	0.3494	2.4189	0.9656	2.1792	**2**

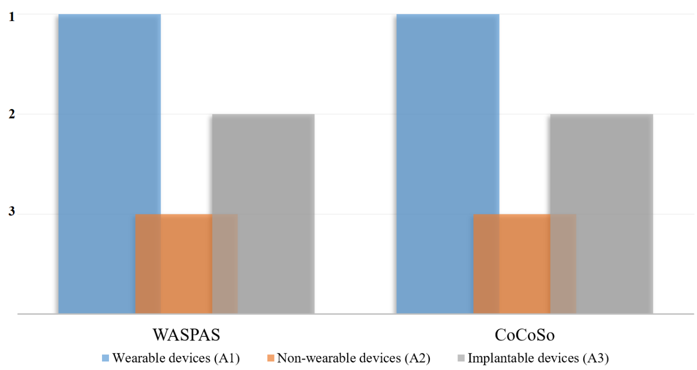

Figure 5: Diagram of alternatives ranking by two MCDM techniques

Remark 36. *By WASPAS and CoCoSo, two MCDM methods calculated alternative rankings, and all data are shown in Table 28 and Table 29, respectively. Figure 5 shows the pictorial ranking of alternatives. From the above ranking, we see that Wearable devices* (A_1) *is the first priority as an IoT adaptation challenge, then Implantable devices* (A_3) *and Non-wearable devices* (A_2) *in order.*

10. SENSITIVITY ANALYSIS

To assess the ranking of the alternatives' robustness and steadiness, we perform a sensitivity analysis across various artificial environments. Decision-making depends on several conflicting factors and sub-factors; that's why we remove some factors or interchange the factors' weights to conduct a sensitivity analysis. This study considers four different cases to check the consistency of the alternatives' ranking. Two different MCDM ranking methods, WASPAS and CoCoSo, provide rankings of the alternatives and calculate the factors' weights in the AHP technique, all in the field of a Pythagorean fuzzy uncertain environment. Ranking of alternatives in MCDM methods is presented in tables and later followed by a graphical representation.

10.1. Removing criteria Organizational challenges (C_2)

Sometimes, there is an experienced organization team that controls the system. This team contains all support systems with professional skills and knowledge. They organised the systems so well that there is no difficulty and in past records, there is no issue. For that reason, we may weigh the value of this criteria take down to zero and calculate the ranking of the alternatives on the basis of other variables.

Table 30: Alternatives ranking by removing criteria Organizational challenges (C_2)

Alternative	WASPAS	CoCoSo
Wearable devices (A_1)	1	1
Non-wearable devices (A_2)	3	3
Implantable devices (A_3)	2	2

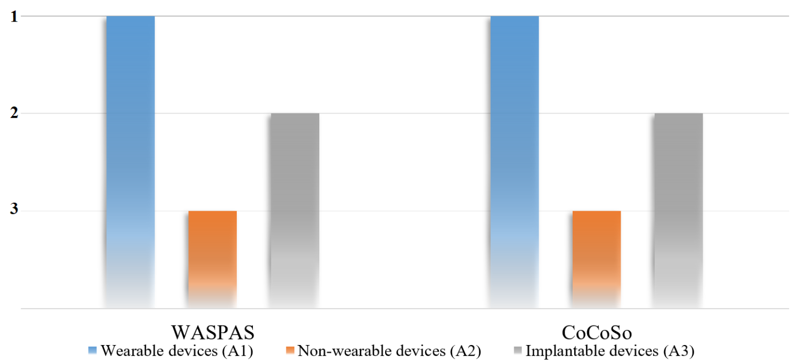

Figure 6: Depiction of alternatives ranking by removing criteria C_2

Remark 37. *Ranking the alternatives by removing the criteria, Organizational challenges (C_2) by two MCDM methods are shown in Table 30 and pictorial ranking displayed in Figure 6. Here, WASPAS and CoCoSo methods give the same ranking. The Wearable devices (A_1) get first priorities. Alternatives Implantable devices (A_3) and Non-wearable devices (A_2) are second and third rank, respectively.*

10.2. Removing criteria Environmental challenges (C_3)

In this section, we may think there are no environmental challenges, like when a governmental body builds super speciality hospitals. In this scenario, all surrounding legal, political, and economic drawbacks can be easily addressed. We then remove this criterion and rank the alternatives based on the remaining criteria.

Table 31: Ranking of alternatives by removing the third criteria C_3

Alternative	WASPAS	CoCoSo
Wearable devices (A_1)	2	2
Non-wearable devices (A_2)	3	3
Implantable devices (A_3)	1	1

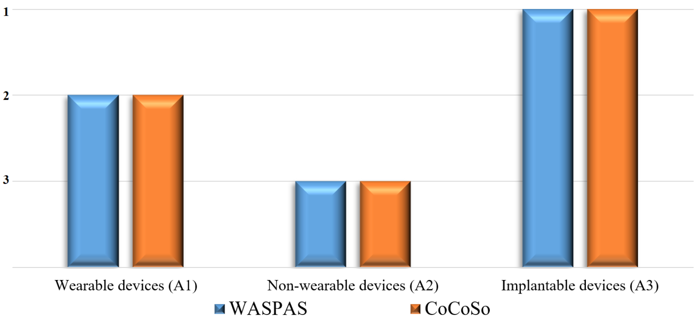

Figure 7: Alternatives ranking by removing Environmental challenges

Remark 38. *Removing the third criterion, Environmental challenges* (C_3)*, and ranking alternatives based on the remaining criterion's depicted in Table 31 and pictured in Figure 7. The same result comes from two MCDM methods, where ranking orders are Implantable devices* (A_3)*, Wearable devices* (A_1)*, then Non-wearable devices* (A_2)*.*

10.3. Removing criteria Costing issues (C_4)

If there is no financial issue, then the weight of this criteria becomes zero. Like, a large company or a governmental body maintains this super speciality hospital. In this case, there are no costing issues for construction and maintenance.

Table 32: Comparison ranking of alternatives by removing Costing issues

Alternative	WASPAS	CoCoSo
Wearable devices (A_1)	1	1
Non-wearable devices (A_2)	3	3
Implantable devices (A_3)	2	2

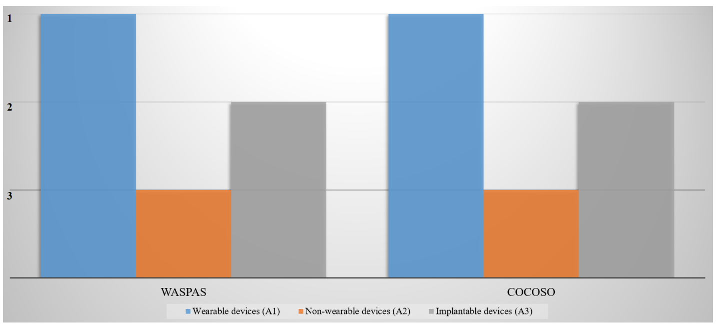

Figure 8: Pictorial of ranking alternatives by removing Costing issues

Remark 39. *Effective on ranking alternatives by removing criteria Costing issues* (C_4) *shown in Table 32 and Figure 8. WASPAS and CoCoSo techniques give the same results. Here Wearable devices* (A_1) *get first priorities then Implantable devices* (A_3) *and Non-wearable devices* (A_2) *respective order.*

10.4. Interchange criterion's weight of Organizational challenges (C_2) and Environmental challenges (C_3)

To check the robustness and stability of our ranking, we may interchange the weight and rating of the criterion's and sub-criterion's between Organizational challenges (C_2) and Environmental challenges (C_3).

Table 33: Comparison ranking of alternatives by interchanging two criterion's

Alternative	WASPAS	CoCoSo
Wearable devices (A_1)	1	1
Non-wearable devices (A_2)	3	3
Implantable devices (A_3)	2	2

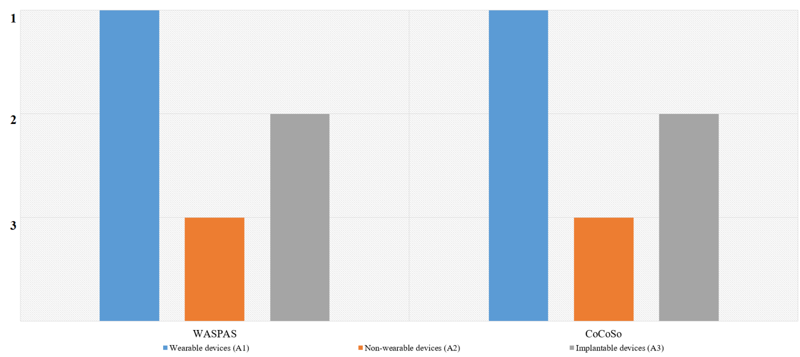

Figure 9: Ranking of alternatives by interchanging two criterion's C_2 and C_3

Remark 40. *Impact on ranking alternatives by interchanging two criterion's Organizational challenges* (C_2) *and Environmental challenges* (C_3)*, displayed in Table 33 and Figure 9. Two different MCDM methods yield similar results. Result of ranking order are Wearable devices* (A_1)*, Implantable devices* (A_3)*, Non-wearable devices* (A_2)*.*

11. RESEARCH IMPLICATION

The research has several implications for various stakeholders, including consumers, device manufacturers, service providers, and policymakers. From a practical viewpoint, this study explores significant challenges to the adoption IoT in Indian hospitals. As a result, the decision-makers must pay close attention to these issues and act to mitigate their impact on the successful adoption of IoT. The practical implications of this study are summarised below: Firstly, the findings of the research can be utilised to raise awareness among patients as well as hospitals about the possible difficulties they might encounter when utilising these IoT devices. Consumers may use this information to decide whether or not to adopt these devices. The research can also be used to develop marketing strategies that address the challenges faced by consumers in adopting IoT devices. For example, marketing campaigns can be designed to educate consumers on the benefits of IoT devices, as well as address any concerns they may have about the privacy and security of patient data. Furthermore, the research can inform the development of new business models for IoT devices. For example, if the research shows that consumers are hesitant to adopt IoT devices due to high upfront costs, manufacturers may consider offering subscription-based models to make their products more affordable. Secondly, the research can inform device manufacturers about the challenges faced by consumers in adopting wearable and non-wearable IoT devices. Device manufacturers can use this information to design devices that are more user-friendly and address the challenges identified in the research. Thirdly, the service providers like Google Fit can use the research findings to design services that are tailored to the needs of consumers who use wearable and implantable IoT devices. This can help service providers improve the user experience and increase the adoption of these devices. Finally, policymakers can use the research findings to develop policies and regulations that address the challenges of IoT adoption, particularly in the areas of privacy and security. Further, different IoT devices may use different protocols or standards, making it difficult to integrate them into existing healthcare systems. Hence, policymakers can also use the research to promote the development of industry standards that ensure interoperability and compatibility between different IoT devices and platforms.

The second part of the implications of this research in terms of the overall ranking of IoT devices would assist decision makers in making well-informed choices if they were interested in introducing any IoT device for the first time in their hospital. Overall, the research on the evaluation of adoption challenges for wearable, non-wearable, and implantable IoT devices can help promote the responsible and sustainable adoption of IoT technology and support its continued growth and development.

12. CONCLUSIONS

The pace of technological development is rising day by day and attracting the attention of all industries. The Internet of Things is one of the emerging technologies and has significant potential for improving the efficiency and effectiveness of any industry. It is gaining popularity in the healthcare industry rapidly in recent times. The healthcare industry is crucial to a nation's development and its citizens' well being; as such, it has to start using IoT as its primary instrument to improve the quality of healthcare for the general public. However, there are several challenges that must be addressed to avail its full potential. In this context, the challenges relevant to IoT adoption were identified through a literature review and consultation with experts. A total of 25 obstacles were considered in this study.

This study introduced a unique MCDM approach to rank, assess, and analyse IoT adoption challenges using AHP in the PFN. In order to assess the research framework, a comparative study of two unique methods known as WASPAS and CoCoSo, under the PF environment, was presented. Valuable inputs from DMs were collected for assessing the importance of each obstacle in IoT adoption in the context of different IoT devices. Based on the analysis and results, out of three alternatives, the IoT device and wearable device face the maximum weightage of challenges to implement in both of the MCDM techniques. Whereas non-wearable IoT devices got a minimum overall weightage of challenges, which favours the chances of installation in any hospital. Additionally, a sensitivity analysis was conducted to check the robustness and steadiness of the ranking for different alternatives in the fuzzy environment.

Furthermore, the most critical challenges in the adoption of IoT devices in hospitals are privacy and security of patients' data, IT infrastructure, top management support, partner collaboration, and implementation cost. Organizations must prioritise security and privacy measures. and resilient data management practices, establish universal standards and protocols to ensure compatibility and interoperability between different devices and platforms, and invest in IT infrastructure to keep up with the rapid development of IoT technologies in order to overcome these challenges. Furthermore, there is a need for increased collaboration and cooperation between the Government and regulatory bodies with industry to establish clear guidelines and regulations to ensure privacy, safety and security. Finally, there are many complex and multifaceted obstacles to IoT adoption. However, by addressing these challenges through collaborative efforts and smart investments, one can fully realise the potential of IoT technology and provide a pathway to a connected and efficient future.

12.1. Limitations and Future Scope

In this study, all the challenges relevant to IoT adoption are identified using a systematic literature review and further verified by consultation with experts from industry and academia in India. However, a few challenges that might have a significant impact on IoT adoption in various national contexts could not have been taken into consideration. The current study is purely subjective and is based on the opinions of academic and industry experts. The future scope of this research expands to include many businesses and cross-country adoption of IoT. At the same time, it is pertinent to note that the challenges outside the scope of cost and the TOE framework have not been considered in this study. Also, the adoption of implanted IoT devices, which is still in its infancy, will face certain unique challenges. Further, the interrelation of each sub-criteria with other sub-criteria within and across other criteria is not captured in this study. Hence, an advanced MCDM technique like Analytic Network Process (ANP) can be applied to capture such interrelationships among challenges in future research work. Finally, researchers can use the findings from this research to design more targeted studies that address specific challenges faced by consumers in adopting wearable and non-wearable IoT devices.

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