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A Multi-Criteria Decision-Making Framework for Blockchain Technology Adoption in Smart Healthcare

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Abstract
Blockchain technology holds significant potential to revolutionize electronic medical records, owing to its core features of decentralization, transparency, and immutability. However, the suitability of different types of blockchain varies, each presenting unique benefits and limitations within the healthcare settings. Hence, selecting the most appropriate blockchain platform remains a complex decision, influenced by various conflicting criteria. This study presents a software engineering-driven decision-support framework to evaluate blockchain platforms for healthcare applications, using the Intuitionistic Fuzzy TOPSIS (IFS-TOPSIS) method. Through a literature review and expert consultations, we identified eight criteria for objective assessment. Among the three blockchain platforms evaluated, the results indicate that permissioned blockchain technology is the most suitable for the healthcare sector, primarily due to its strengths in regulatory compliance, data privacy, and system integration. The study's findings would help practitioners identify and choose the best blockchain platform, thus contributing to a transition in the healthcare industry called "Smart Healthcare 5.0".

Keywords- Industry 5.0, Smart healthcare 5.0, Blockchain technology, Software engineering, Multi-criteria decision-making, Fuzzy approach.

1. Introduction

The healthcare sector is experiencing a significant transition driven by the digital revolution. This sector has already been advancing toward Industry 4.0 which focuses on economic value, and now it is ready to enter the next transitional phase, which is Industry 5.0, where the focus is on societal value (Jamwal et al., 2022; Liu et al., 2024). In short, the transition is now from welfare to well-being (Wang et al., 2023). Industry 5.0 uses novel technologies, like big data, blockchain, and the Internet of Everything, to continuously manage and secure healthcare records (Sabuncu & Bilgehan, 2024).

Blockchain technology (BT), a decentralized record database, stores and shares information through a secure and transparent method for conducting transactions and tracking data (Bali et al., 2023a; Zarour et al., 2020). A blockchain's decentralized structure allows multiple participants to validate and authenticate transactions without central authority. This makes it more efficient and secure than traditional, centralized databases (Hannan et al., 2023). Satoshi Nakamoto introduced this technology to conduct online payments using electronic cash. It transfers money between the two parties without involving third party (Nakamoto & Bitcoin, 2008). A transaction can be operated in a decentralized way using BT. It has the competence to significantly lower expenses and improve efficiency (Zarour et al., 2020; Zheng et al., 2018). Every block in BT holds the record of multiple transactions; after adding data to a block, it cannot be changed (Bali et al., 2023a). Blockchain is approachable for all participants, and every participant can access information uniformly. This ensures a secure and immutable record of all transactions on the network (Alshamsi et al., 2024). Many leading Organizations have identified the revolutionary capability of BT. Many e-commerce firms, such as Alibaba, Amazon, Walmart, etc., are investigating the potential of BT to reduce transactional costs and secure the company's expansive databases and transactions. The agriculture (Giganti et al., 2024), education (Chen et al., 2018), infrastructure (Roustaei et al., 2024) and supply chain management sectors (Kafeel et al., 2023), are also considering the integration of BT into their operations.

IBM reported that many healthcare organizations will upgrade the healthcare management system by establishing a decentralized architecture for the interchange of electronic healthcare information. This transition has been accelerated due to the emergence of COVID-19, which has significantly impacted the healthcare system (Bali et al., 2023a). Healthcare is a critical sector within the IT industry, significantly advancing through the widespread adoption of electronic health records (Hussien et al., 2019; Zaidan et al., 2015). A vital challenge accompanying recent technological developments in healthcare data management is ensuring enhanced security, privacy, transparency, confidentiality, and decentralization (Kumar et al., 2020). Blockchain technology, characterized by a decentralized database managed by multiple stakeholders, provides a robust solution, offering greater security, transparency, and efficiency than traditional centralized databases. This decentralized, peer-to-peer approach disrupts conventional healthcare data management systems by improving interoperability, ensuring data integrity, and empowering patients through direct control over their medical data (Ar et al., 2020; Yu et al., 2020). Furthermore, blockchain integration into healthcare promises significant economic, environmental, and social benefits by enabling secure telemedicine, automating claims processing, facilitating transparent clinical trials, and enhancing supply chain traceability (Kshetri, 2017). Consequently, leveraging blockchain technology holds transformative potential for sustainable advancement and improved patient care within the healthcare sector.

The successful adoption of blockchain in healthcare depends upon applying rigorous software engineering (SE) practices, which provide the foundational methodologies and frameworks necessary to develop secure, scalable, and efficient blockchain-based solutions (Farooq et al., 2022). Unlike traditional centralized software applications, blockchain-based systems demand a paradigm shift in SE practices. SE helps decision-makers assess platforms based on architectural design, maintainability, process optimization, integration, and lifecycle support - factors vital in critical domains like healthcare.

After examining extant literature, the study identifies four critical research gaps where further investigation is needed. First, this study addresses the problem of blockchain selection. Most of the investigations conducted in the past focused on enablers and barriers of blockchain technology adoption (Bali et al., 2023a; Chen et al., 2024; Dhingra et al., 2024; Samad et al., 2023) however a handful of the work is done in the area of BT selection aligned with SE practices (Nanayakkara et al., 2021; Zarour et al., 2020). Second, the emergence of the pandemic, which has severely affected the healthcare system, has attracted the attention of academicians and practitioners toward blockchain technology selection and implementation. Therefore, this research seeks to address the existing gap by adding to the extant studies through its concentration on various types of BT and identifying the most suitable option for the healthcare industry. Next, the most prevailing technique for BT selection in the existent literature includes the Simple Multi-Attribute Rating Technique (SMART) (Nanayakkara et al., 2021) and fuzzy ANP (Zarour et al., 2020). As far as the authors know, none of the prior studies have applied an intuitionistic fuzzy set (IFS) with the TOPSIS method to select the BT platform. This analytical method introduced by Atanassov (1986) is an extension of the classical fuzzy set theory use to measure the uncertainties of the decision-makers. Lastly, while prior studies have primarily focused on evaluation criteria such as scalability, security, interoperability, efficiency, and performance, this research extends the framework by incorporating often-overlooked but essential dimensions: sustainability, which accesses the long-term environmental and economic impact of blockchain solutions; regulatory compliance, which evaluates adherence to healthcare laws and data protection standards; and usability, which considers ease of implementation, user adoption, and operational integration. The study aims to provide a more comprehensive and practical decision-support model for healthcare stakeholders considering blockchain adoption by embedding these critical yet unexplored criteria within SE practices.

Based on gaps, the study endeavors to propose the following research questions:
***RQ*1:** What are the key criteria for selecting blockchain platform in the healthcare sector?
***RQ*2:** Which analytical technique can be applied to select the appropriate BT platform for healthcare sector?
***RQ*3:** Which is the best BT platform for healthcare sector?

This study endeavors to find answers for the above RQs through a systematic process as indicated. In Section 2, a detailed literature review, comprising BT and healthcare along with the criteria for BT selection is argued. Section 3 outlines the methodology and extensively describes the proposed IFS-TOPSIS method. Results and discussions on the findings are discussed in Sections 4 and 5 respectively. The study's implications are deliberated in Section 6. Finally, the end section put forward the conclusions derived from the findings of the proposed framework.

2. Literature Review
This section examines and assesses extant literature regarding blockchain in the healthcare sector. The review is subdivided into two subsections.

2.1 Blockchain Technology and Healthcare
Nowadays, BT is the noteworthy development and progressive innovation of the software industry (Hannan et al., 2023). This novel technology occupies a significant place in the ongoing digital age, and by now, it has made a remarkable difference in humankind (Sabuncu & Bilgehan, 2024). BT is utilized in a wide range of applications, for example, tracking the electronic healthcare records (Bali et al., 2023a; Shahnaz et al., 2019), ownership of assets, government administration (Lykidis et al., 2021; Sahoo & Halder, 2021),

agricultural development (Kamilaris et al., 2019; Mukherjee et al., 2022), e-commerce (Treiblmaier & Sillaber, 2021), conducting supply chain audits (Antipova, 2018; Castka et al., 2020; Jiang et al., 2023), to increase the security of Industrial (IoT) systems (Hasan & Chaudhary, 2024), enabling secure voting systems and several other sectors (Li et al., 2020; Shahnaz et al., 2019). In banking, BT examines challenges in the credit business, aiming to enhance the effectiveness of financial services and operations by leveraging blockchain's advancements in the banking sector (Xu et al., 2024; Yan & Li, 2023). Electronic healthcare records contain information that is confidential for the treatment of patients. These data are more sensitive and valuable information sources in healthcare intelligence. Sharing health information is crucial and highly sensitive, playing a key role in making the healthcare system more intelligent and efficient. (Xiang et al., 2024; Yue et al., 2016). Electronic health care records contain information about a patient's history in the form of a digital model, and they are stored by multiple hospitals, health insurance providers, pharmacists, and laboratories. However, specific issues exist about the security of records, user data ownership, and data integrity (Liu et al., 2024; Shahnaz et al., 2019; Xu et al., 2022). The solution to these issues is a novel technology, i.e., Blockchain. With the help of BT, healthcare systems can exchange information, providing a model by making EHR more secure and trustable. Therefore, we can say that the blockchain emerges as a comprehensive digital platform, securing patient data, preserving privacy, and streamlining the payment process (Mahdi et al., 2024). The emergence of BT and healthcare 5.0 trends has the competence to revolutionize the healthcare industry by introducing a smart healthcare 5.0 system refer to **Figure 1**.

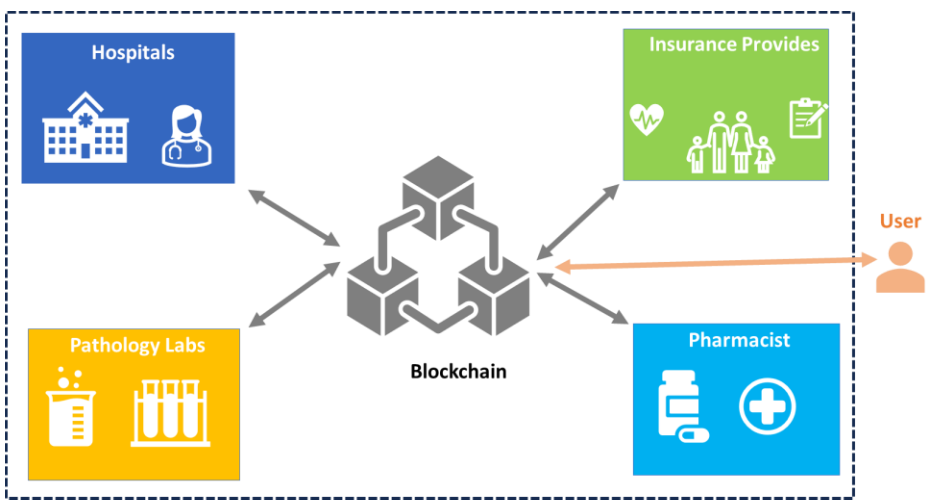

Figure 1. Smart healthcare 5.0 system using BT (authors' own creation).

2.2 Blockchain Selection

Different types of BT platforms are available in the software market, however, the task of selecting the right platform that meets the industry's requirements is a complicated task. The different types of blockchain platforms vary significantly in terms of access control, transparency, and governance, thus influencing their suitability for healthcare applications:

Permissioned blockchain: Also known as consortium blockchain, permissioned blockchains limit participation to specific, pre-authorized entities, providing controlled transparency, enhanced security, and regulatory compliance. This type of blockchain is well-suited for healthcare applications where multiple trusted entities such as hospitals, insurers, and regulatory agencies are involved to facilitate secure, interoperable data sharing (Kaleido, 2023).

Public blockchain: Public blockchains, also known as open blockchains offer complete transparency, decentralization, and immutability. In this type of blockchain, the transactions are publicly visible but encrypted, ensuring user anonymity. Ethereum is currently one of the most prominent and widely used blockchain, particularly notable for its large-scale adoption and extensive developer community (Wood, 2014; Zhao et al., 2021).

Hybrid blockchain: It is a combination of permissioned as well as public blockchain that enables selective transparency and flexibility (Haleem et al., 2021). Sensitive data can be securely managed in a restricted permissioned environment, while non-sensitive data or transactions requiring greater transparency can utilize the public layer. This adaptability makes hybrid blockchains attractive for complex healthcare scenarios, where balancing patient privacy with transparent data sharing among diverse stakeholders is critical. Example of hybrid blockchain are IBM, Swiss Coin (Cui et al., 2020; Marar & Marar, 2020).

Table 1. The criteria list.

No.	Criteria	Explanation	Key SE domains
A1	Security	The blockchain system have strong security measure in place to protect data and ensure that it is only accessible to authorized parties.	Security architecture, Protocol design
A2	Scalability	The system will be capable to handle a large volume of transaction, as the healthcare industry generates a significant amount of data.	Architectural design, Node software engineering
A3	Interoperability	The system is capable to interoperate with other healthcare system and database, making the seamless exchange of information amongst different healthcare providers and authorized parties.	System integration, API development
A4	Sustainability	The system will be designed to be sustainable and able to satisfy the long terms need of healthcare industry.	Sustainability engineering, Evaluation & maintenance
A5	Efficiency	By streamlining data management and reducing the need for intermediaries, blockchain technology potentially help to enhance the efficiency of healthcare system and lower costs.	Requirements engineering, Process optimization, Smart contract development
A6	Performance	The blockchain system should be able to process transaction and access data quickly to meet the needs of healthcare provider and patients.	Performance engineering, Testing & validation
A7	Regulatory compliance	The system will comply with relevant regulations and industry standards, by ABDM in India.	Requirements engineering, Regulatory analysis
A8	Usability	The system will be easy to use for all stakeholders, healthcare providers, pharmacist, insurance providers and patients, with a user-friendly interface and straightforward process for accessing and updating records.	User-centered design, Front-end/ back-end development

Proven software engineering practices play a pivotal role in bridging the gap between the conceptual promise of blockchain technology and its practical implementation in the healthcare sector (Dubey et al., 2024). As blockchain is fundamentally a software system driven by cryptographic protocols, decentralized architectures, and consensus mechanisms, SE ensures the systematic design, development, and maintenance of reliable and secure solutions (Bhatt, 2023). Key SE domains such as protocol design, smart contract development, node software engineering, and security architecture directly support critical blockchain selection criteria like security, scalability, interoperability, and performance – all vital in sensitive healthcare environments. Furthermore, requirements engineering and user-centred design help align blockchain implementations with regulatory compliance, usability, and efficiency, ensuring that healthcare professionals and patients can adopt and benefit from the technology seamlessly (Farooq et al., 2022). These aligned with key software engineering domains, provide a comprehensive foundation for evaluating and implementing blockchain solutions effectively in the healthcare sector. **Table 1** presents mapping of blockchain technology selection criteria with descriptions and key SE domains.

Further, **Table 2** presents a comparative analysis of different criteria explored in the extant literature in the domain of healthcare.

Table 2. Comparative state-of-the-art analysis of different criteria discussed in the extant literature.

Sr. No.	Author & Year	Journal	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*E*7	*E*8
1.	Gordon & Catalini (2018)	Computational and structural biotechnology journal	✓	×	✓	×	×	×	✓	×
2.	Zheng et al. (2018)	International journal of web and grid services	✓	✓	×	×	✓	✓	×	×
3.	Shahnaz et al. (2019)	IEEE access	✓	✓	✓	×	×	✓	×	×
4.	Dhagarra et al. (2019)	Business process management journal	✓	×	✓	×	×	×	×	×
5.	Hussien et al. (2019)	Journal of medical system	✓	×	×	×	×	×	×	×
6.	Ar et al. (2020)	Expert system with applications	✓	✓	✓	×	×	×	×	×
7.	Houtan et al. (2020)	IEEE access	✓	×	✓	×	×	✓	×	×
8.	Kumar et al. (2020)	IEEE access	✓	×	×	✓	×	✓	×	×
9.	Palas & Bunduchi (2020)	Information technology and people	✓	×	✓	×	✓	✓	×	×
10.	Tandon et al. (2020)	Computers in industry	✓	✓	✓	×	✓	×	✓	×
11.	Zarour et al. (2020)	IEEE Access	✓	×	×	×	×	✓	×	×
12.	Haleem et al. (2021)	International journal of intelligent networks	✓	×	✓	×	✓	✓	×	×
13.	Akbar et al. (2022)	Journal of software – evolution and process	✓	✓	×	×	×	✓	×	✓
14.	Han et al. (2022)	International journal of environmental research and public health	✓	×	×	×	✓	✓	×	×
15.	Xu et al. (2022)	Enterprise information systems	✓	×	✓	×	✓	✓	×	✓
16.	Dhingra et al. (2024)	Journal of modelling in management	✓	×	✓	×	✓	×	✓	✓
17.	Xiang et al. (2024)	Decision support system	✓	✓	×	×	✓	×	×	×
18.	Alshamsi et al. (2024)	Technology in society	✓	✓	×	✓	✓	✓	✓	×
19.	Liu et al. (2024)	Journal of cleaner production	✓	✓	✓	×	✓	✓	✓	✓
20.	Sabuncu & Bilgehan (2024)	Technology in society	✓	×	×	✓	✓	✓	×	×
21.	This paper		✓	✓	✓	✓	✓	✓	✓	✓

**E*1- *Security, E*2- *Scalability, E*3- *Interoperability, E*4 - *Sustainability, E*5 - *Efficiency, E*6 - *Performance, E*7- *Regulatory compliance,* *E*8 – *Usability*

In conclusion, decision-makers in healthcare face several challenges in evaluating blockchain technologies, including regulatory compliance, system integration, scalability, and data security. Selecting the most appropriate blockchain platform remains a complex decision, influenced by various often conflicting criteria. While prior studies have addressed technical aspects, limited attention has been given to linking BT selection criteria with structured SE practices. Therefore, this study offers a practical and systematic decision support framework to ensure informed decision-making in healthcare blockchain adoption.

3. Material and Methods

The research employs a structured methodology to objectively select the most suitable blockchain technology for healthcare applications using an MCDM framework, specifically IFS-TOPSIS. The various stages are illustrated in **Figure 2** and discussed below:

***Stage* 1:** Reviewing the Extant Literature

A comprehensive review of the extant literature focused on BT implementation within the healthcare sector was conducted. The primary objective was identifying previously applied evaluation criteria, selection, and SE methodologies relevant to BT adoption. Scholarly databases - Scopus and Google Scholar were searched using the keywords "Blockchain" OR "Blockchain Technology" OR "BT" AND "healthcare" OR "health sector" OR "Hospitals". From this search, fifty articles were selected for further examination. All the articles were thoroughly read, and articles related to adopting Blockchain technology were shortlisted to meet the selection criteria. At this stage, twenty articles were finally shortlisted to construct a preliminary set of criteria (refer **Table 2**).

***Stage* 2:** Identifying Potential BT Platforms for Healthcare Industry
In this stage, potential BT platforms suitable for health applications were identified through a structured process. Initially, different platforms were considered based on insights gained from a comprehensive literature review in stage 1. This initial pool of candidates was narrowed down through expert consultation by considering application relevance in the healthcare sector. Experts from healthcare IT professionals and blockchain technology practitioners were involved in shortlisting the platforms. As a result, three BT platforms - permissioned, public, and hybrid blockchain emerged as the most promising alternatives for detailed evaluation using selected criteria.

***Stage* 3:** Finalization of Criteria for Assessment
Following the initial identification of selection criteria in stage 1, the list was refined and validated using expert consultation. A panel comprising of healthcare IT professionals and blockchain technology practitioners was convened. The Delphi method was utilized, involving iterative rounds of expert feedback & controlled discussions to reach a consensus on the most critical & contextually relevant criteria. This iterative approach ensured the elimination of less relevant criteria and the inclusion of essential dimensions, resulting in the final list of eight criteria (refer to **Table 1**). All selected criteria were treated with equal importance. The criteria were explicitly aligned with the software engineering to facilitate objective & systematic evaluations in subsequent stages.

***Stage* 4:** Applying IFS-TOPSIS for the Selection of BT platform
The blockchain selection is considered as an MCDM problem. This section briefly explains the IFS-TOPSIS technique.

Utilizing Intuitionistic fuzzy sets, proposed by Atanassov (1986), is suitable for addressing ambiguity and is implemented in various decision-making scenarios within an uncertain environment. Hwang & Yoon (1981) proposed TOPSIS method, the authors suggested that this method is a widely utilized decision-making approach for prioritizing complicated problems. In this, criteria are rated from best to worst (Gupta & Barua, 2017) for selection of blockchain platform. Therefore, for the proposed MCDM blockchain selection problem the authors employed the IFS-TOPSIS method. Additionally, to aggregate all individual DMs judgments for ranking alternatives, an intuitionistic fuzzy weighted averaging (IFWA) operator suggested by Xu (2007) is applied. The suggested method seeks to provide a comprehensive resolution for selection issues that arise in the actual world.

Let $A = \{a_1, a_2, \ldots\ldots a_n\}$ be a non-empty finite set in an intuitionistic fuzzy set X. Then X can be defined as

$$X = \{a_j, \mu_x(a_j), \nu_x(a_j) \; \forall \; a_j \in A\} \tag{1}$$

Here $\mu_x(a_j), \nu_x(a_j)$ both are subset of [0,1] denotes the degree of membership and non-membership function respectively such that $0 \leq \mu_x(a_j) + \nu_x(a_j) \leq 1$. An intuitionistic index $\pi_x(a_j)$ in IFS X is the degree of hesitation, where,

$$\pi_x(a_j) = 1 - \mu_x(a_j) - \nu_x(a_j) \quad (2)$$

represent the level of uncertainty of a_j to set X with the condition that for every $a_j \in A$, $0 \leq \pi_x(a_j) \leq 1$. It is obvious that $\mu_x(a_j) = 1 - \nu_x(a_j)$ for every element, ordinary fuzzy concepts is captured (Shu et al., 2006).

Figure 2. Research methodology (authors' creation).

Let X & Y are the IFS of set A, then multiplication operator is defined as (Atanassov, 1986):

$$X \oplus Y = \{\mu_x(a_j) \times \mu_y(a_j), \nu_x(a_j) + \nu_y(a_j) - \nu_x(a_j) \times \nu_y(a_j) : a_j \in A\} \quad (3)$$

Intuitionistic Fuzzy TOPSIS Method: A model based on IFS-TOPSIS given by (Rouyendegh, 2015) for assessment of alternatives, is presented in this section.

Let $X = \{X_1, X_2, X_3, \ldots\ldots, X_m\}$ & $A = \{A_1, A_2, A_3 \ldots\ldots, A_n\}$ denotes the set of alternatives & criteria, whereas $U = \{u_1, u_2, u_3, \ldots\ldots, u_p\}$ is set of decision maker.

The seven step procedure for the given IFS- TOPSIS model is shown as follows:

Step 1. Find out weight of DMs.
Every decision-maker importance can be measured in linguistic terms, refer **Table 3** is expressed as intuitionistic fuzzy numbers (IFNs). Let $D_k = (\mu_k, \nu_k, \pi_k)$ is the IFN for k^{th} DM ranking. Then weight of K^{th} decision-maker is obtained as follows:

$$\lambda_k = \frac{\left[\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right]}{\sum_{k=1}^{p}\left[\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right]} \quad (4)$$

where, $\lambda_k \in [0,1]$ & $\sum_{k=1}^{p} \lambda_k = 1$.

Table 3. Linguistic terms to rate the importance of criteria and the DMs.

Linguistic terms	Notations	IFNs
Very important	VI	(0.90, 0.10, 0.00)
Important	I	(0.75, 0.20, 0.05)
Medium	M	(0.50, 0.45, 0.05)
Unimportant	UI	(0.35, 0.60, 0.05)
Very unimportant	VU	(0.10, 0.90, 0.00)

(Source: Boran et al., 2009)

Step 2. Determine aggregated intuitionistic fuzzy decision-matrix (AIFDM).
The AIFDM for the weights of decision matrix is attained by IFWA operator (Xu, 2007). To find the distinct opinion calculated from a team of DMs can be obtained by putting an individual opinion for AIFDM model. Let $T^{(k)} = \left(t_{ij}^{(k)}\right)_{m\times n}$ is an IFDM for each DM and their respective weight is considered as $\lambda = \{\lambda_1, \lambda_2, \lambda_3, \ldots\ldots, \lambda_n\}$. In a collective decision-making scenario, it is fundamental to consolidate the opinions of DM into a unified group perspective. This is achieved by forming an AIFDM.

Let $T = \left(t_{ij}\right)_{m\times n}$.

where, $t_{ij} = IFWA_\lambda(t_{ij}^{(1)}, t_{ij}^{(2)} \ldots\ldots t_{ij}^{(p)})$

$$= \lambda_1 t_{ij}^{(1)} \oplus \lambda_2 t_{ij}^{(2)} \oplus \lambda_3 t_{ij}^{(3)} \oplus \ldots\ldots \oplus \lambda_l t_{ij}^{(l)}$$

$$= \left[1 - \prod_{k=1}^{p}\left(1 - \mu_{ij}^{(k)}\right), \prod_{k=1}^{p}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{p}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{p}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}\right] \tag{5}$$

Hence, $t_{ij} = \left(\mu_{X_i}(A_j), \nu_{X_i}(A_j), \pi_{X_i}(A_j)\right)$.

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

The AIFDM is described as

$$T = \begin{bmatrix} (\mu_{X_1}(A_1), \nu_{X_1}(A_1), \pi_{X_1}(A_1)) & (\mu_{X_1}(A_2), \nu_{X_1}(A_2), \pi_{X_1}(A_2)) & \cdots & (\mu_{X_1}(A_n), \nu_{X_1}(A_n), \pi_{X_1}(A_n)) \\ (\mu_{X_2}(A_1), \nu_{X_2}(A_1), \pi_{X_2}(A_1)) & (\mu_{X_2}(A_2), \nu_{X_2}(A_2), \pi_{X_2}(A_2)) & \cdots & (\mu_{X_2}(A_n), \nu_{X_2}(A_n), \pi_{X_2}(A_n)) \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ (\mu_{X_m}(A_1), \nu_{X_m}(A_1), \pi_{X_m}(A_1)) & (\mu_{X_m}(A_2), \nu_{X_m}(A_2), \pi_{X_m}(A_2)) & \cdots & (\mu_{X_m}(A_n), \nu_{X_m}(A_n), \pi_{X_m}(A_n)) \end{bmatrix}$$

$$T = \begin{bmatrix} t_{11} & t_{12} & t_{13} & \cdots & \cdots & t_{1n} \\ t_{21} & t_{22} & t_{23} & \cdots & \cdots & t_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{m1} & t_{m2} & t_{m3} & \cdots & \cdots & t_{mn} \end{bmatrix} \tag{6}$$

Step 3. Determine criteria weights on the basis of linguistic term.
As we have already discussed that all criteria may or may not be equally important. Define S as a set of importance grades calculated by using IFWA operator. Consider $S_j^{(k)} = \left[\mu_j^{(k)}, \nu_j^{(k)}, \pi_j^{(k)}\right]$ be an IFN for A_j by k^{th} DM. Hence, the weight of the criteria is given below:

$$S_j = IFWA_\lambda\left(s_j^{(1)}, s_j^{(2)}, \ldots.. s_j^{(p)}\right)$$
$$= \lambda_1 s_j^{(1)} \oplus \lambda_2 s_j^{(2)} \oplus \lambda_3 s_j^{(3)} \oplus \ldots \ldots \oplus \lambda_p s_j^{(p)}$$
$$= \left[1 - \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k}, \ \prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}, \ \prod_{k=1}^{l}\left(1-\mu_j^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}\right] \quad (7)$$
$$S = [s_1, s_2, s_{3,} \ldots.., s_j].$$

Here $s_j = (\mu_j, \ \nu_{j,} \ \pi_j)$,
where, j = 1, ……... n.

Step 4. Construct aggregated weighted intuitionistic fuzzy decision matrix (AWIFDM).
To calculate AWIFDM, the criteria weights with respect to IFDM (T) can be expressed as:
$T' = T \otimes S$.

$$T \otimes S = (\mu'_{X_i}, \nu'_{X_i})$$
$$= \left\{\left(A, \mu_{X_i}(A) \times \mu_S(A), \nu_{X_i}(A) + \nu_S(A) - \nu_{X_i}(A) \times \nu_S(A)\right)\right\} \quad (8)$$

Then the AWIFDM ‘T’ can be defined as

$$T = \begin{bmatrix} (\mu_{X_1S}(A_1), \nu_{X_1S}(A_1), \pi_{X_1S}(A_1)) & (\mu_{X_1S}(A_2), \nu_{X_1S}(A_2), \pi_{X_1S}(A_2)) & \ldots & (\mu_{X_1S}(A_n), \nu_{X_1S}(A_n), \pi_{X_1S}(A_n)) \\ (\mu_{X_2S}(A_1), \nu_{X_2S}(A_1), \pi_{X_2S}(A_1)) & (\mu_{X_2S}(A_2), \nu_{X_2S}(A_2), \pi_{X_2S}(A_2)) & \ldots & (\mu_{X_2S}(A_n), \nu_{X_2S}(A_n), \pi_{X_2S}(A_n)) \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ (\mu_{X_mS}(A_1), \nu_{X_mS}(A_1), \pi_{X_mS}(A_1)) & (\mu_{X_mS}(A_2), \nu_{X_mS}(A_2), \pi_{X_mS}(A_2)) & \ldots & (\mu_{X_mS}(A_n), \nu_{X_mS}(A_n), \pi_{X_mS}(A_n)) \end{bmatrix},$$

$$T' = \begin{bmatrix} t'_{11} & t'_{12} & \ldots & \ldots & \ldots & t'_{1j} \\ t'_{21} & t'_{22} & \ldots & \ldots & \ldots & t'_{2j} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ t'_{i1} & t'_{i2} & \ldots & \ldots & \ldots & t'_{ij} \end{bmatrix} \quad (9)$$

Table 4. Linguistic terms to rate alternatives.

Linguistic terms	Abbreviations	IFNs[a]
Extremely high	EH	(1.00, 0.00, 0.00)
Very very high	VVH	(0.90, 0.10, 0.00)
Very high	VH	(0.80, 0.10, 0.10)
High	H	(0.70, 0.20, 0.10)
Medium high	MH	(0.60, 0.30, 0.10)
Medium	M	(0.50, 0.40, 0.10)
Medium low	ML	(0.40, 0.50, 0.10)
Low	L	(0.25, 0.60, 0.15)
Very low	VL	(0.10, 0.75, 0.15)
Very very low	VVL	(0.10, 0.90, 0.00)

(Source: Boran et al., 2009)

Step 5. Determine intuitionistic fuzzy positive-ideal solution (IFPIS) and fuzzy negative-ideal solution (IFNIS).

Let M_1 & M_2 be 'benefit' and 'cost' criteria, respectively. X^* denotes IFPIS and X^- is IFNIS. Then X^* and X^- are obtained as:

$$X^* = \left(\mu_{X^*S}(A_j), \left(\nu_{X^*S}(A_j)\right)\right) \tag{10}$$

$$X^- = \left(\mu_{X^-S}(A_j), \left(\nu_{X^-S}(A_j)\right)\right) \tag{11}$$

where,

$$\mu_{X^*S}(A_j) = \left(\left(\max_i \mu_{X_iS}(A_j): j\epsilon M_1\right), \min_i \mu_{X_iS}(A_j): j\epsilon M_2\right) \tag{12}$$

$$\nu_{X^*S}(A_j) = \left(\left(\min_i \nu_{X_iS}(A_j): j\epsilon M_1\right), \max_i \nu_{X_iS}(A_j): j\epsilon M_2\right) \tag{13}$$

$$\mu_{X^-S}(A_j) = \left(\left(\min_i \mu_{X_iS}(A_j): j\epsilon M_1\right), \max_i \mu_{X_iS}(A_j): j\epsilon M_2\right) \tag{14}$$

$$\nu_{X^-S}(A_j) = \left(\left(\max_i \nu_{X_iS}(A_j): j\epsilon M_1\right), \min_i \nu_{X_iS}(A_j): j\epsilon M_2\right) \tag{15}$$

Step 6. Calculation separation measure.
To determine the separation measures among the alternatives on IFS, the existing literature offers distance measures given by Atanassov (1999), Grzegorzewski (2004), and Szmidt & Kacprzyk (2000) based on the different methods. We have used normalized Euclidean distance (Szmidt & Kacprzyk, 2000) to calculate the separation measures, j_i^* and j_i^-, for each alternative from IFPIS and IFNIS.

$$j^* = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{X_iS}(A_j) - \mu_{X^*S}(A_j)\right)^2 + \left(\nu_{X_iS}(A_j) - \nu_{X^*S}(A_j)\right)^2 + \left(\pi_{X_iS}(A_j) - \pi_{X^*S}(A_j)\right)^2\right]} \tag{16}$$

$$j^- = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{X_iS}(A_j) - \mu_{X^-S}(A_j)\right)^2 + \left(\nu_{X_iS}(A_j) - \nu_{X^-S}(A_j)\right)^2 + \left(\pi_{X_iS}(A_j) - \pi_{X^-S}(A_j)\right)^2\right]} \tag{17}$$

Step 7. Ranks the alternatives.
The relative closeness coefficient ($\mathrm{C_i}$) of an alternative X_i with respect to IFPIS, X^* is expressed below:

$$\mathrm{C_i} = \frac{j_i^-}{j_i^- + j_i^*} \tag{18}$$

where, $0 \leq \mathrm{C_i} \leq 1$.

Then $\mathrm{C_i}$ values were arranged in the decreasing order. The highest value indicates the first rank and will be the best choice of alternative for decision-making.

Stage 5: Selecting the best BT platform.
In the final stage of methodology, the best blockchain platform is selected based on the IFS-TOPSIS method and is presented in the next section.

4. Results & Findings

Blockchain has the potential to revolutionize the healthcare industry by providing a comprehensive, secure, and transparent framework for storing, sharing, and using patient information while ensuring both accuracy and confidentiality. A network of hospitals, insurance companies, pathology labs, and pharmacists can adopt blockchain technology and request the patients' healthcare records. In developing this type of intelligent healthcare system (see **Figure 1**), choosing the right blockchain platform is a crucial task. This section outlines the findings of the suggested methodology.

4.1 Findings

To select a blockchain platform, a committee comprised of three DMs was formed. The decision-makers were a software industry expert in blockchain technology (12 years of experience), IT heads of two hospitals who have knowledge of BT and its implementation in healthcare sector (18 & 25 years of experience respectively). In India, the implementation of blockchain technology is at a very nascent stage, therefore, finding experts in the domain of blockchain and healthcare was a challenge. Looking at the objective of the study, the authors aimed to approach experts who are experts in implementing novel I5.0 technology into healthcare operation. Following the proposed methodology, first we calculate the weights of DMs using Equation (4) & **Table 3**. Final weights obtained are given in **Table 5**.

Table 5. Importance of DMs with their respective weights.

Decision maker	**DM1**	**DM2**	**DM3**
Linguistic terms	VI	I	M
Weight	0.406	0.356	0.237

The researchers hold a series of meetings with the DMs to gather the final criteria list which will be considered for the selection. Finally, eight criteria were considered for the selection given in **Table 1**. After pre-evaluation, and decision-makers' recommendations, three different types of blockchain platforms were considered as alternatives for evaluation. They are public, hybrid and permissioned blockchain respectively. Then in the next step the alternatives ratings using linguistic terms (refer **Table 4**) from each decision-maker were collected and given in **Table 6**.

Table 6. Ratings of the alternatives.

Criteria	**Type of blockchain**	**DM1**	**DM2**	**DM3**
Security	X_1	MH	M	EH
	X_2	H	H	EH
	X_3	VH	VVH	EH
Scalability	X_1	M	M	VH
	X_2	H	H	VH
	X_3	VVH	EH	VVH
Interoperability	X_1	M	MH	VH
	X_2	VH	VH	VH
	X_3	ML	M	VH
Sustainability	X_1	M	M	H
	X_2	MH	MH	H
	X_3	VH	H	H
Efficiency	X_1	VH	H	EH
	X_2	H	H	EH
	X_3	VH	VH	EH
Performance	X_1	M	MH	VVH
	X_2	H	H	VVH
	X_3	H	VH	EH
Regulation compliance	X_1	M	ML	VH
	X_2	MH	MH	VH
	X_3	VVH	EH	EH
Usability	X_1	H	VH	VH
	X_2	H	VH	VH
	X_3	H	VH	EH

where, X_1 denotes 'public blockchain', X_2 denotes 'hybrid blockchain', X_3 denotes 'permissioned blockchain'.

Further, using **Table 4**, the importance criteria weight was then gathered from the DMs, their judgements are presented in **Table 7**.

Table 7. The importance weight of the criteria.

Criteria	DM1	DM2	DM3
Security	VI	VI	VI
Scalability	VI	VI	VI
Interoperability	VI	VI	VI
Sustainability	I	I	M
Efficiency	I	I	I
Performance	VI	VI	I
Regulatory compliance	I	I	I
Usability	I	VI	I

Following all the steps of IFS-TOPSIS method, **Table 8** presents the result which indicates the ranks assigned to the different blockchain technologies considered in the study.

Table 8. Separation measures and the relative closeness coefficient of each alternative.

Alternatives	N^*	N^-	C_i	Rank
X_1	0.23762	0.182	0.4337	3
X_2	0.17291	0.177	0.5058	2
X_3	0.15274	0.303	0.6650	1

According to the above results, permissioned blockchain (X_3) is the most suitable blockchain for the healthcare systems as it has got the highest ranking.

4.2 Sensitivity Analysis

Sensitivity analysis helps researchers assess whether any potential bias from a specific expert has notably influenced the results (Vaid et al., 2022). It also assists in evaluating the strength and applicability of the results across different scenarios (Biswas & Gupta, 2019). A sensitivity analysis compares the rankings produced by the proposed methodology and examines the relative closeness coefficients and the rankings of the alternatives (Kumar & Channi, 2022). Initially, decision maker one was selected, and during each sensitivity analysis run, the linguistic importance assigned to this expert (as shown in **Table 3**) was varied. In contrast, the weights for the other two experts were kept constant. This process was repeated for decision makers 2 and 3, as detailed in **Table 9**. **Table 10** displays the rankings of the selection of blockchain across fourteen sensitivity analysis runs. It is observed that in all 14 runs; the ranking remains unchanged.

Table 9. The linguistic importance assigned to the experts during sensitivity analysis.

Decision maker	DM1	DM2	DM3
Original run	VI	I	M
RUN 1	I	I	M
RUN 2	M	I	M
RUN 3	U	I	M
RUN 4	VU	I	M
RUN 5	VI	VI	M
RUN 6	VI	I	M
RUN 7	VI	M	M
RUN 8	VI	U	M
RUN 9	VI	VU	M
RUN 10	VI	I	VI
RUN 11	VI	I	I
RUN 12	VI	I	M
RUN 13	VI	I	U
RUN 14	VI	I	VU

Table 10. Ranking of blockchain for the fourteen-sensitivity analysis runs.

Alternatives	OR	C_{OR}	R1	C_1	R2	C_2	R3	C_3
X_1	3	0.4337	3	0.4330	3	0.4311	3	0.4298
X_2	2	0.5058	2	0.5035	2	0.4970	2	0.4923
X_3	1	0.6650	1	0.6660	1	0.6688	1	0.6710
Alternatives	**R4**	C_4	**R5**	C_5	**R6**	C_6	**R7**	C_7
X_1	3	0.4269	3	0.4332	3	0.4337	3	0.4350
X_2	2	0.4822	2	0.5070	2	0.5058	2	0.5023
X_3	1	0.6758	1	0.6650	1	0.6650	1	0.6650
Alternatives	**R8**	C_8	**R9**	C_9	**R10**	C_{10}	**R11**	C_{11}
X_1	3	0.4359	3	0.4377	3	0.4327	3	0.4330
X_2	2	0.4998	2	0.4946	2	0.4897	2	0.4939
X_3	1	0.6650	1	0.6653	1	0.6698	1	0.6685
Alternatives	**R12**	C_{12}	**R13**	C_{13}	**R14**	C_{14}		
X_1	3	0.4337	3	0.4342	3	0.4355		
X_2	2	0.5058	2	0.5147	2	0.5342		
X_3	1	0.6650	1	0.6627	1	0.6588		

Therefore, we can conclude that the ranks obtained in the original run and the Fourteen-sensitivity analysis runs are the same. Permissioned blockchain consistently ranks at the top across all fourteen runs.

5. Discussions

Within this section, the authors discuss the results of utilizing the proposed IFS-TOPSIS method to address the RQs initially stated in the introduction section. To accomplish this, we will commence by showcasing the ranking of alternatives within the Blockchain context. Three options were ranked in decreasing order after finding the relative closeness coefficients (refer to **Table 8**). The alternatives' ranks are as follows: the order is $X_3 > X_2 > X_1$, that is, permissioned > hybrid > public blockchain (refer to **Figure 3**). Permissioned blockchain was selected as an appropriate blockchain platform for the healthcare sector.

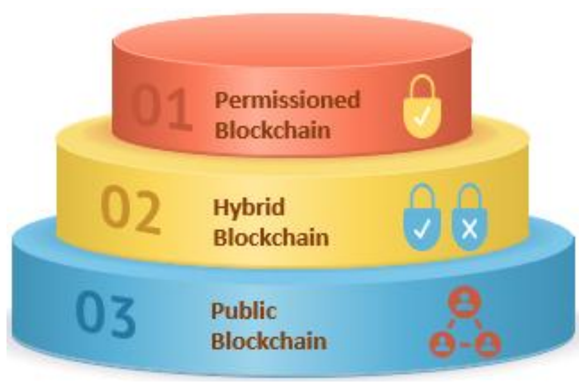

Figure 3. Result of proposed model (authors' own creation).

A permissioned blockchain is a distributed ledger that requires permission to participate in a network with varying capacities. The use of permissioned blockchain offers several advantages. Firstly, these blockchains provide a more secure and reliable platform by restricting the participants and clearly defining their roles, thus enhancing security and trust (Haleem et al., 2021). Secondly, permissioned blockchains improve scalability and performance, as they can manage higher transaction volumes more efficiently than public blockchains. This is due to the restricted number of nodes and optimized consensus mechanisms, which results in better overall performance. Lastly, permissioned blockchains are more capable of meeting regulatory requirements, allowing greater control over data and transactions (Kaleido, 2023). This is especially important for highly regulated industries like finance and healthcare. Our result also indicated that the healthcare sector should consider permissioned blockchain for adoption as it manages patients' records with a high level of security, enhances data interoperability & usability, facilitates research collaborations, and ensures regulatory compliance.

The investigation findings assist practitioners in choosing the best blockchain platform, thus contributing towards significant progress in the healthcare industry. According to the results obtained, permissioned blockchain technology was acknowledged to be the highest-ranked alternative amongst all alternatives to be selected for adoption in the healthcare sector. A study to evaluate the impact of BT implementation for secured and trustworthy EHR records by Zarour et al. (2020) obtained results closer to our findings. It ranked private blockchains in the first position. A similar study by Nanayakkara et al. (2021) applied the MCDM method to select BT for developing an enterprise system. Their findings revealed that an open-source permissioned blockchain, Hyperledger Fabric, was the most suitable platform for creating a BT-based complex enterprise system. Hyperledger Fabric, developed by the Linux Foundation, is designed for use in enterprise contexts where performance, scalability, and security are crucial. Hyperledger is a popular choice among practitioners and researchers in the domain of healthcare (Arora et al., 2024). Corda is another choice for many businesses; it promotes security & efficiency in transactions within a regulated environment (Kaleido, 2023). Lastly, Quorum, a permissioned blockchain derived from Ethereum, is another platform that offers enhanced security and performance capabilities.

6. Study Implications

The integration of permissioned BT in electronic healthcare holds several significant implications for healthcare practitioners, researchers and managers.

6.1 Managerial Implications

The results of the study present important implications for healthcare managers and practitioners. First, the study's findings suggest that permissioned blockchain technology emerges as the most appropriate platform for the healthcare system. This allows healthcare professionals to make informed decisions about technology investments, assuring that they meet essential criteria like regulatory compliance, security, and interoperability. The outlined criteria are consistent with established software engineering practices. For instance, regulatory compliance is in alignment with requirement engineering and regulatory analysis, ensuring that blockchain technology adheres to healthcare laws, including HIPAA and GDPR. Therefore, the second implication of the study is that aligning blockchain adoption with software engineering domains, such as user-centred design and architectural evaluation improves stakeholders' acceptance and promotes integration within healthcare processes. Third, the MCDM framework outlined in this study provides managers with a solid foundation for effective technology adoption and risk management by directly addressing uncertainties and ambiguities in expert judgment. This study presents sustainability as a novel and essential criteria for assessing blockchain platforms in healthcare, a dimension frequently overlooked in earlier studies. Hence, the study helps policymakers to establish standardize guidelines to promote sustained digital transformation by implementing permissioned blockchain technology. For instance, implementing BT in conjunction with reusable smart contracts for electronic health records promotes sustainability. These contracts improve modularity, scalability, and system reusability, while also promoting energy efficiency, regulatory compliance, and maintainability. By emphasizing sustainability, healthcare organizations can achieve responsible innovation that aligns with operational requirements and environmental factors.

6.2 Research Implications

The study suggests notable contributions to the healthcare field and provides direction for potential research for future scholars. First, the study proposed a novel framework for selecting appropriate blockchain technology based on eight essential criteria. These criteria were chosen after a comprehensive review of extant literature, which was then presented to the domain experts to check their relevance to the study context. With this, it was easy to understand the critical contextual criteria, which were also considered the best practices for BT adoption in the healthcare sector. Future studies may consider adding more criteria to benefit the healthcare sector's transition at lightning speed. Second, the study employed the IFS-TOPSIS approach; scholars can apply other MCDM methods, like Fuzzy AHP, DEMATEL, etc., to confirm the model results. Thirdly, our framework can be extended by incorporating Generative AI into blockchain technology. This innovative integration could revolutionize the provision of efficient healthcare services, paving the way for more patient-centric solutions. This presents an exciting avenue for future research to explore. Fourth, very few research papers discuss the integration of healthcare 5.0 and BT adoption, leaving a potential for future researchers to explore this domain. Lastly, the study focused only on the healthcare sector of developing nations; a similar framework of BT adoption can be designed for the other industry sectors, such as the textile, travel, and hospitality sectors of both developing and developed nations.

7. Conclusion

7.1 Contributions of the Research

The paper offers a framework for choosing the best BT platform for healthcare systems driven by software engineering practices. The selection of the most suitable blockchain technology goes beyond just technical considerations; it is a strategic decision that necessitates a blend of analytical methods and methodological rigor. Consequently, the authors provide an in-depth evaluation of the appropriateness of public, hybrid, and permissioned blockchain for effective healthcare 5.0, utilizing the IFS-TOPSIS methodology. The proposed framework assesses the three blockchain technologies based on eight criteria: security, scalability, interoperability, sustainability, efficiency, performance, regulatory compliance, and usability. The criteria were established through an extensive review of existing literature and confirmed by experts in the field, ensuring alignment with relevant software engineering domains. The findings indicated that permissioned blockchain stands out as the most appropriate platform for healthcare due to its capability to tackle data privacy, interoperability, and compliance issues while facilitating efficient and scalable system integration. The study introduces sustainability as a new evaluation criterion, highlighting the importance of long-term viability and responsible innovation within healthcare systems. The proposed framework presents a strategic approach for integrating blockchain technologies into healthcare, ensuring sustainability and readiness for future developments in a scholarly context.

7.2 Limitations and Future Scope

The study findings are based on the limited number of participants, as BT adoption in the healthcare sector is nascent in India. The study aimed to engage participants with experience in the blockchain field and a background in the healthcare sector. In the future, the penetration of technology will increase in the healthcare sector; this will provide more extensive and more varied participants who will better understand the impact of BT implementation. Secondly, it's crucial to note that permissioned blockchains are an emerging technology, and the performance, scalability, and regulatory compliances are constantly evolving with time, which may change significantly in the coming times, providing scope for future work in this area. The study examined eight essential criteria for selecting the blockchain platform for the healthcare industry. As technology continues to evolve, more criteria may emerge for further research. Future researchers could extend the study by incorporating another MCDM technique, such as AHP for prioritizing criteria and DEMATEL, to discover the interrelationships between the criteria. Additionally, alternative methods can be employed to ensure the robustness of the results when selecting blockchain technology for adoption. Further research could also explore the adoption and impact of blockchain across a broader range of industries beyond healthcare, such as manufacturing and government, to acquire a more comprehensive understanding of technology's adaptability and potential.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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