INDUSTRY 4.0 TRANSFORMATION: PRIORITIZING CHALLENGES TO BLOCKCHAIN ADOPTION IN SUPPLY CHAIN USING BEST-WORST METHOD

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by

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CANDIDATE'S DECLARATION

I Vatan Singh (2K22/IEM/13) hereby certify that the work which is being presented in the thesis entitled "Industry 4.0 Transformation: Prioritizing Challenges to Blockchain Adoption in Supply Chain using Best-Worst Method" in partial fulfillment of the requirements for the award of the Degree of Master of Technology, submitted in the Department of Mechanical Engineering , Delhi Technological University is an authentic record of my own work carried out during the period from January, 2024 to May 2024 under the supervision of Dr. Mohd Shuaib.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Candidate's Signature

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CERTIFICATE BY THE SUPERVISOR

Certified that Vatan Singh (2K22/IEM/13) has carried out their research work presented in this thesis entitled "Industry 4.0 Transformation: Prioritizing Challenges to Blockchain Adoption in Supply Chain using Best-Worst Method" for the award of Master of Technology from Department of Mechanical Engineering, Delhi Technological University, Delhi, under my supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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Industry 4.0 Transformation: Prioritizing Challenges to Blockchain Adoption in Supply Chain Using Best-Worst Method

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ABSTRACT

The advent of Industry 4.0 has resulted in the evolution of technologies such as blockchain, artificial intelligence (AI), Internet of Things (IOT) and smart warehouses that operate via digital methods. The supply chain of any firm comprises a number of parties, including suppliers, distributors, manufacturers, and end users. Due to increased global competition, there is a greater need than ever for businesses to use these technologies to obtain a competitive edge. Furthermore, a company's supply chain can be greatly impacted by the implementation of blockchain technology (BCT), which decentralises, tracks, and monitors the delivery of goods to ultimate customers, hence speeding up procedures. The objective of this study is to pinpoint the primary barriers, particularly within the Indian context, that must be addressed in order to effectively integrate Blockchain Technology in a supply chain. After conducting an extensive examination of existing literature and seeking advice from specialists, this study identified 20 barriers that impede the mainstream use of blockchain technology in supply chain. The BWM method was used to rank those barriers. A total of five analyses were done: Four Sub-criteria analyses and one for the main-criteria and global weights of the barriers were calculated to rank them. Then AHP was used to validate and compare the results which were found by BWM. The results revealed that the most important barriers are the Unfamiliarity with Blockchain Technology, Incompatibility (between various blockchains, current technology, and legacy systems), Lack of Blockchain standardization and insufficiently skilled blockchain developers. This study emphasises the necessity for companies to completely consider the possible advantages and disadvantages of implementing blockchain technology from an industrial standpoint. It also emphasises how critical it is to remove the obstacles to adoption in order to guarantee an effective deployment. Businesses can increase their competitiveness overall and improve supply chain management by doing this.

Keywords: Blockchain Barriers, Supply Chain, BWM, Blockchain Technology

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List of Symbols, Abbreviations and Nomenclature

Abbreviations	Meaning
SCM	Supply Chain Management
SC	Supply Chain
BCT	Blockchain Technology
MCDM	Multi Criteria Decision Making
BWM	Best-Worst Method
BC	Blockchain
IOT	Internet of Things
CC	Cloud Computing
SME	Small and Medium Enterprises
IP	Intellectual Property
TIB	Technological and Infrastructure Barriers
OB	Organizational Barriers
FSB	Financial and Security Barriers
EEB	External Environment Barriers
IT	Information Technology
C	Criteria
AHP	Analytic Hierarchy process
CI	Consistency Index
CR	Consistency Ratio
RI	Random Index

Chapter 1

Introduction

Effective and successful supply chain management (SCM) is the foundation of modern-day businesses. Almost half of the industrial added value comes through supply chains as discussed by Chakraborty et al. (2023). With the goal to improve business performance throughout any sector, including the supply chain, technological disruptions are crucial. The emergence of digital technologies, including the Internet of Things, smart sensors, blockchain technology (BCT), autonomous guided vehicles, and drones has greatly influenced corporate operations, leading to the emergence of industry 4.0. Blockchain technology (BCT) is one of these digital technologies that has the ability to completely transform the supply chain. Blockchain is a modern-day technology that provides better clarity and transparency in transactions among members of supply chain (SC) according to Sheel and Nath (2019). Blockchain allows members to share transactional data by storing it in blocks. These pieces can be combined to create a chain by adding them in a chronological order. Blockchain has the potential to significantly improve transactions, making it helpful for supply chain members as explained by Sheel and Nath (2019). In terms of environmental, social and economic factors, Sustainability in the supply chain can be attained through the effective use of blockchain technology. Businesses can use it to track every step of the supply chain procedures in real time, which will allow participants in the chain to must work together and exchange knowledge in order to make the best choices and manufacture, transport, and get back from customers sustainable products. The benefits of blockchain, the technology that is underpinning bitcoins, have received increased attention. Blockchain's primary benefits are its ledger that is distributed, decentralisation, data openness and transparency, unbreakable architecture, and transparency as discussed by Ibrahim and Samrat (2021). But the adoption of blockchain technology is beset with substantial obstacles. Thus, the aim of this study piece is to evaluate the barriers to the implementation of blockchain technology in supply chain management and rank them by using the BWM and validate the results using AHP. This study intends to give a thorough assessment of the obstacles to blockchain deployment in supply chain and to pinpoint the most important obstacles that require attention by utilising Best Worst Method. The function of these technologies in attaining sustainable manufacturing and delivery as well as supply chain sustainability has been extensively researched in the past. But as far as we are aware, no research has been done that has outlined and pinpointed the fundamental obstacles to the effective execution of blockchain technology (BCT) in supply chains, particularly in the Indian context.

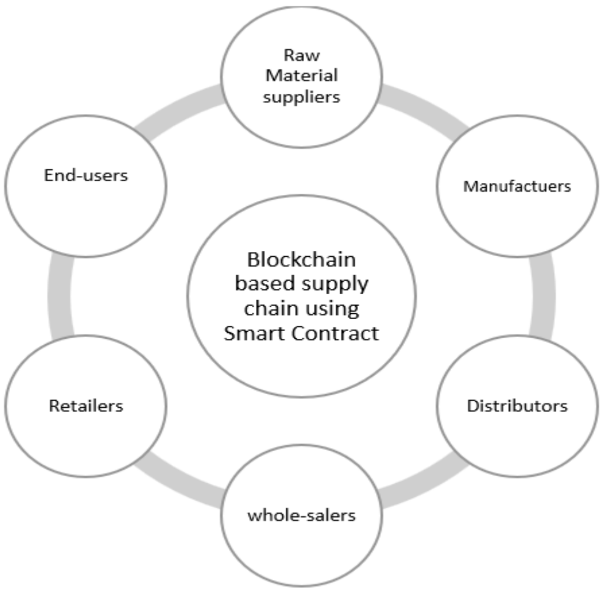

Fig.1.1 Supply chain transformation through blockchain technology by Anand et al. (2022)

Fig.1.1 shows how supply chain can be transformed through blockchain technology. Blockchain based supply chain using smart contracts. This would help all supply chain stakeholders from raw material suppliers to end customers.

1.1 Blockchain technology:

Blockchain is a dynamic technology that is anticipated to enhance competitive advantages through inventive platform-oriented company models according to Alazab et al. (2021). Blockchain, the technology utilised in the cryptocurrency Bitcoin, is thought to possess the capacity to tackle the issue of achieving comprehensive transparency from start to finish. This technology, which is progressively gaining more popularity, functions as a networking tool to streamline company processes by utilising a peer-to-peer (P2P) network for the purpose of verifying and exchanging data. Blockchain technology employs public key encryption to authenticate payments on the Internet and safeguard against cybersecurity vulnerabilities such as ransomware, malware, worms, rootkits and botnets. It represents a collective transaction system where all entries are recorded in public or private ledgers that are accessible to users. Supply chain applications that utilise blockchain technology encompass many functionalities like as smart contracts, traceability of products, enforcement monitoring, management of stocks, payment and agreement, and data immutability. These factors have contributed to the improvement of market, financial, and ecological sustainability via the expansion of partnerships.

1.2 Research Gap and Contribution:

1.2.1 Research Gap:

a. Recently, there has been a strong and enthusiastic interest in the use of blockchain technology (BCT) in supply chains. The literature on barriers is still scarce related to supply chain in general, despite this growing interest.

b. There are various papers regarding barriers to Blockchain Technology (BCT) implementation in various supply chain such as Humanitarian Supply Chain (SC), Food supply chain (SC) etc. But there is no comprehensive paper listing all the barriers to application of BCT in supply chain. People/Organizations who want to integrate BCT into their supply chains face difficulties because of this knowledge gap, especially when it comes to emerging nations like India.

1.2.2 Research Questions:

1. What are the barriers which organizations face while implementing Blockchain technology in a supply chain?
2. Which are the barriers an organization should focus on for effective implementation of BCT in supply chain?

1.2.3 Research Objectives:

1. By identifying and prioritising the major obstacles of integrating BCT in the supply chain, primarily in the Indian context, this study seeks to further enrich the collection of literature. To rank the hurdles, the study used a multi-criteria decision-making (MCDM) process, namely the Best-Worst Method (BWM) approach and validated the results using AHP.

2. The primary significance of this study is in its ability to assess and identify crucial barriers to the use of blockchain technology (BCT) in the supply chain, particularly within the Indian context. The research underscores the utmost need for decision-makers to consider the possible costs and advantages of blockchain adoption as well as the technological and infrastructure barriers.

Chapter 2

Literature Review

2.1 Role of Blockchain Technology (BCT) in Supply Chain:

All supply chain operations can be integrated using blockchain technology (BCT). BCT can create digital ledgers that all parties involved can reliably execute, access, and share. Blockchain is useful for managing inventories, forecasting demand accurately, providing a backup in case of demand interruption, and other tasks as found by Sheel and Nath (2019). The two fundamental components of blockchain technology, which is a disruptive new technology, are cryptographic tools and distributed ledger systems. Without the use of middlemen auditing authority, partners' transactions are verified via the distributed ledger system. Data security and safety are integrated into databases with the use of cryptographic techniques. Blockchain makes it possible for businesses, vendors, clients, and other stakeholders and partners to communicate in real time via a shared platform as found out by Prasad et al. (2022).

Blockchain technology is mostly used in supply chains to track goods transactions over their whole life cycle. Better transparency and visibility are provided by tracing products and processes, from raw materials from suppliers to customers, including locations, manufacture, and data. This improves operational efficiency and control. Transforming the old supply chain into a digital supply chain is necessary in order to eliminate manual and cumbersome procedures, improve traceability, transparency and lower IT transaction costs. Blockchain technology has far-reaching ramifications for supply chain operations, not just for manufacturing enterprises but also for the healthcare, retail, banking, fintech, media and entertainment, agricultural, legal, and notably, government. Other features of blockchain that are utilised to improve the agility of supply chain processes include inventories management, forecasting demand, observing assets, and storing intellectual property which are discussed by Gohil and Thakker (2021). BC is a type of Distributed Ledger Technology that enables information to be kept across multiple computers around the world, utilising a Peer-to-Peer topology. Transparency is ensured because this data is virtually instantly exposed to everyone on the network.

In the digital realm, blockchain's primary benefits given by Johny and Priyadharsini (2021) are:

1. Secure: By adding a digital signature to transactions to prevent fraud, blockchain offers a higher level of security even though it cannot be considered hacker resistant.
2. Decentralisation: All network users participate in the consensus, which speeds up and secures the transaction.
3. Pre-programmed: Blockchain can be set up to react to events by programming it to do certain things.

Blockchain is a sequential collection of blocks, similar to a public ledger, each containing a complete list of transactions. All of the blockchain's records and history are accessible to every node, allowing them to independently validate transactions without the need for middlemen. This system is safe and unchangeable due to its blockchain architecture. A peer-to-peer network called blockchain consists of numerous interconnected nodes. Every node has a local copy of the blockchain (BC), or ledger, and the system's job is to make sure that every copy matches the global ledger as discussed by Ashok and Mishra (2019). The use of blockchain technology extends beyond cryptocurrencies and finance; one category where it is most likely to have an important impact is supply chain operations. Because of its speed, transparency, immutability, and efficient performance and outcome monitoring, blockchain technology can count the problems that traditional supply chain management (SCM) faces. In its early stages, BCT is beginning to transform the way businesses operate. If it lives up to its promises of supply-chain traceability and transparency, it will be an excellent tool for ensuring that businesses are acting ethically. Certainly, one of the most important uses of blockchain technology (BCT) is the traceability of items as they move within the supply chain according to Awwad et al. (2018). Because BCT can establish activity records, it assists businesses in managing resources efficiently, reducing inventory carrying costs, and producing accurate demand projections. In contrast to traditional supply chains, which build large inventories, extra capacity, and 3rd party backup sources in case of disruptions, this aids supply networks in risk mitigation at a lesser cost as found out by Kamble et al. (2019). As per the 2019 Market Watch research, it is estimated that the world market size for supply chains empowered by blockchain technology is going to reach around $9.8 billion by end of 2025. By 2023, blockchain's global contribution to the supply chain market is expected to increase by 424 million dollars according to Alazab et al. (2021).

Existing supply chain traceability systems have issues with establishing trustworthy provenance and avoiding fraud and counterfeiting, which are either difficult to fix with present technologies or not achievable at all. Systems for traceability that are now in use either have a distributed or centralised architecture. The risk associated with centralised architectures is that they are overseen by a powerful outside organisation.

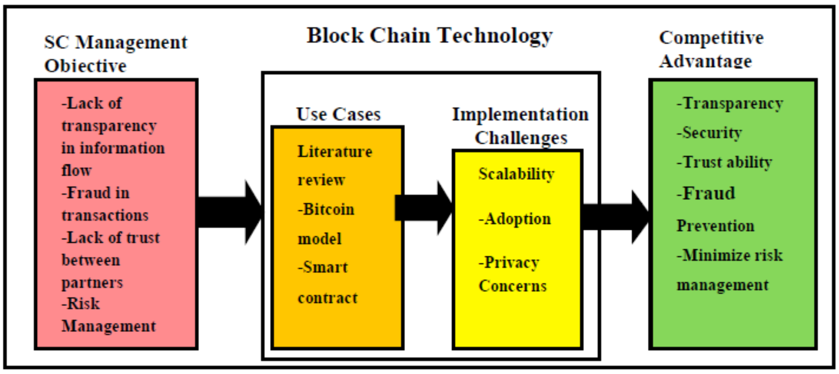

Fig.2.1 Theoretical Framework of Blockchain in SC by Ghode et al. (2020)

Fig.2.1 gives a theoretical framework of blockchain technology in Supply chain indicating objectives, challenges & advantages of blockchain in SC.

Scalability is made possible by distributed design where transparency event data about physical and digital objects can be easily created and shared inside and between organisations. BCT is being employed in several supply chain scenarios, mainly in the manufacturing and finance industries, to increase efficiency in other areas and make processes optimal. Its disruptive nature combined with the Internet of Things (IOT) has made Blockchain one of the most exciting new technological breakthroughs in recent years. By combining these technologies, businesses are able to draw in new clients and improve ties with their primary business stakeholders, particularly those that are already in place according to Jabbar et al. (2021). With the availability of dependable and timely info, blockchain is emphasised as a means of achieving end to end transparency and traceability in supply chain processes, hence eliminating one step forward and one step back practices. Transmitted data can assist in the auditable and permanent system's dynamic cargo movement monitoring, recall interventions, and product provenance tracking. Blockchain registers can be used to assess suppliers' reputations, and when blockchain is applied in conjunction with smart technologies like cloud computing (CC), big data, and the IOT, it offers a safe, fast, responsive, and knowledge-based method that works with logistics, manufacturing industry, and even product recovery procedures as discussed by Risso et al. (2023). Because modern supply chains are more difficult to maintain, blockchain technology (BCT) has the capability to improve effectiveness and dependability of processes. Blockchain keeps the system transparent, which is beneficial for making purchases. Smart contracts built on blockchain technology can automatically confirm agreed terms and conditions and supplier payments after they are made according to Sheel and Nath (2020). The logistics network can be disrupted due to several reasons, including transportation delays, theft, cyberattacks, environmental rules, economic uncertainties such as BREXIT, and quality-related difficulties. These factors might result in short-term costs and new obstacles according to Kadadevaramth et al. (2020).

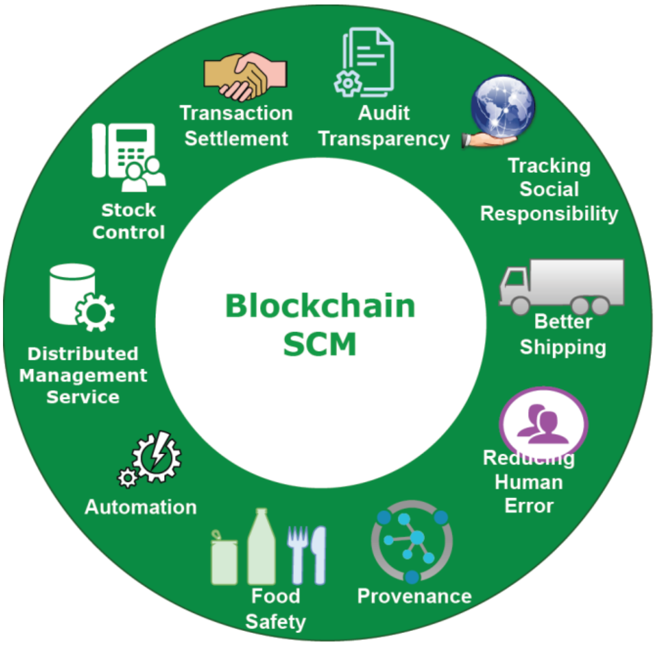

Fig.2.2 Blockchain SCM by Uddin et al. (2023)

Fig.2.2 shows the various benefits of Blockchain Supply chain management. The primary benefits that blockchain technology (BCT) provides to improve supply chain system coordination and integration are numerous and include the basic features of openness, verification, automation, and tokenization according to Uddin et al. (2023). An increasing number of research has shown how important BCT is for tackling supply chain resilience and cyber-security concerns. Even though research on blockchain technology have proliferated, there isn't much room for us to have a thorough understanding of BCT and how it relates to cyber security and supply chain resilience because the literature that is now available tends to focus on certain aspects of blockchain applications according to Kumar Singh et al. (2023). The supply chain (SC) system benefits from including Blockchain (BC) by many means, such as the supply chain's coordination and integration need to be made for robust. This will promote the sharing of information on product maintenance, assembly, manufacturing, supplier and distribution across all parties involved in the SC. By letting customers know where an order or shipment is at any given time, the supply chain might be more open and reliable using BC. It is easier to understand and more accurate to monitor continuously (facilitating origin tracking). The decentralised and cryptographically secured nature of BCT may provide more protection against manipulation or hacking in the areas of data transfer, possession, and ownership. Increasing product visibility and compliancy with international standards to increase trust between the maker and the buyer Agarwal et al. (2022). A smart contract can carry out a change of ownership in the BC based supply chain (SC) model without the need for human interaction. After the ownership transfer is finished, entities known as certifiers and registrars have the ability to modify records that are based on BCT. This way, there is no possibility of anything being tampered with throughout the tracking of all the records from the point of origin to the end of the supply chain as said by Anand et al. (2022). Due to their complex nature, unpredictable market conditions, and consumer expectations for quick product delivery, the interconnected fields of SCM and operations management face a number of challenges today. By facilitating information sharing, transaction transparency, and security, BCT has the ability to improve collaboration inside the SC, making it a valuable tool in combating these threats and issues. These characteristics have an impact on SC operations as well as their organisation and design according to Lohmer et al. (2022).

An inherent benefit of BCT is its ability to facilitate the restructuring of every component within the SC. In addition, blockchain has the capacity to be seamlessly incorporated with other cutting-edge technologies, such as the Internet of Things (IoT) and cyber-physical systems, and big data analytics as discussed by Queiroz & Fosso Wamba, (2019). Many use cases will arise as a result of BCT's ongoing improvements, and organisations in all industries will have to deal with intricate dependencies and challenges—especially given the general lack of knowledge of BCT and its uses. Studies in the past have noted that because of their existing systems' lack of expertise and familiarity with BCT systems, they are not technologically mature or ready for BCT according to Samad et al. (2023). This type of structure and operational plan may offer advantages due to the lack of centralised authority and middlemen in a supply chain setting, along with a stronger foundation of trust. As a result, activity logs, permissions, and asset ownership could all be recorded via blockchain. This allows for more prompt tracking of products and services by strengthening the traceability of data, currency, and process flows. Private, public, and consortium (or federated) blockchains are the numerous types of blockchain that may be applied in different settings for additional advantages and efficacy according to Chang and Chen, (2020).

As a conclusion, these primary avenues have been identified the following as the for future research by Patil et al. (2021):

1. Blockchain development for supply chain management using IoT and smart contracts
2. Supporting additional blockchain features in supply chains that prioritise resilience, sustainability, dependability, and flexibility, among other factors.
3. Using cutting-edge machine learning and soft computing methods in SCM based on the blockchain concept, such as the red deer algorithm and social engineering optimizer.

2.2 Barriers in application of Blockchain Technology (BCT) in a Supply Chain (SC):

After a thorough literature review, these factors were found out from previous research from various research papers. This is given in Table 2.1.

Table 2.1 Barries in application of Blockchain Technology (BCT) in SC

Barriers	References
1. Data privacy, ownership, and safety issues. 2. Scalability and Compatibility 3. Funding and cost challenges 4. Social issues, lawful, and regulations framework 5. Interoperability, cooperation, and cross-pollination among humanitarian organizations 6. Stakeholder awareness and lack of understanding 7. Lack of important consent and engagement 8. Technological difficulty- readiness, immaturity, and appropriateness 9. Risk of media reaction 10. Interorganizational complexities and size imbalance of humanitarian organisations 11. Limited managerial support 12. Operating constraints 13. Value proposition ambiguity. 14. Infrastructure issues: internet and power	Patil et al. (2021)
1. Small and medium-sized enterprises lack enough technology infrastructure. 2. Limited ability to scale and speed of blockchain systems. 3. Inadequate compatibility among blockchains, pre-existing technologies, and legacy systems. 4. Insufficient automation for Invoice and payment settlement operations in SMEs. 5. Lack of standardising. 6. Inadequate infrastructure suppliers. 7. Resistance to adopting new systems. 8. Limited expertise in Blockchain technology among the workforce. 9. Challenges with supply chain cooperation, communication, and coordination.	Kaur et al. (2022)

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Table 2.1 (continued)

Barriers	References
10. Lack of information sharing policies among supply chain (SC) stakeholders. 11. Lack of participation in developing a consortium blockchain. 12. Market competition and uncertainties around BCT. 13. Judicial and Regulations Challenges 14. Shortage of competent blockchain developers. 15. Inadequate ecosystem coordination with blockchain. 16. Inadequate knowledge about blockchain 17. Inadequate grasp of costs 18. ROI and Economic Losses 19. Blockchain architecture choice. 20. Concerns about data protection and privacy. 21. Data Security Problems 22. Data integrity problems. 23. Significant initial investment in infrastructure and energy resources. 24. Limited resources for finance 25. Complex tax consequences for digital assets. 26. Auditing Concerns	Kaur et al. (2022)
1. Complexity of the Blockchain Adoption Framework 2. Scaling issue 3. Inefficient organisational policies 4. Interaction disparity among SC partners 5. Data safety protocol 6. Data safety and privacy 7. High capital cost 8. Trust management problems 9. Online infrastructure cost 10. Inadequate data sharing 11. Inadequate technological resources 12. Inadequate enhanced technologies 13. Inadequate Blockchain knowledge	Khan et al. (2023)
1. Absence of willingness of business owners 2. Inexperience with the technologies 3. Information privacy/security problems 4. Regulation uncertainty 5. Technical feasibility 6. Complicated setup/use 7. Uncertain advantages. 8. Reliance upon blockchain operators 9. Inadequate collaboration among SC partners	Mathivathanan et al. (2021)

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Table 2.1 (continued)

Barriers	References
1. Privacy and security issues. 2. Weak technical infrastructure 3. Complexities 4. Lack of blockchain tools 5. Complexity of involved parties 6. High level managerial support 7. High capital costs 8. Inadequate organisational tactics and Human resources. 9. Stakeholder opposition to blockchain culture 10. Public distrust of supply chain technology 11. Lacking expertise and knowledge 12. Insufficient involvement of key supply chain members 13. High costs for sustainability 14. Lack of engagement from external stakeholders. 15. Inadequate government policies and financial support 16. Market uncertainty and competition	Naseem et al. (2023)
1. Uncertainty in government regulation and regularity 2. High resource and capital requirements 3. Privacy and security concerns 4. Limited standardization and interoperability 5. Limited collaboration for consortia formation 6. Absence of trust among agri-stakeholders or public image. 7. Limited scalability and system performance. 8. Low agri-stakeholder awareness and ease of usage. 9. Complicatedness of blockchain network design 10. Resistance to blockchain culture among agri-stakeholders	Yadav et al. (2020)
1. Security problem. 2. Accessibility to technology 3. Technical backlash 4. Agreement mechanisms 5. Technology immaturity 6. Financial restrictions 7. Unsupportive and disinterested management	Al Amin et al. (2023)

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Table 2.1 (continued)

Barriers	References
8. Lack of BT policies. 9. Difficulties in modifying organisational procedures. 10. Lack of resources for BCT adaptation 11. Lack of consumer awareness 12. Lack of cooperation, coordination, and communication 13. Difficulty exchanging information across SC parties 14. Difficulties combining BCT and sustainability through SCM 15. Cultural gaps between SC partners 16. Absence of legal structure. 17. Inefficient regulatory norms 18. Legality of Smart Contracts 19. Jurisdictional and legal Concerns 20. Intellectual Property (IP) Laws. 21. Market competition and unpredictability. 22. Lack of engagement from outside stakeholders. 23. Lack of incentives and rewards. 24. Inadequate industry support for blockchain use.	Al Amin et al. (2023)
1. Inexperience with technology 2. High capital costs 3. Absence of privacy 4. Absence of regulations and laws 5. Inadequate coordination and cooperation 6. Interoperability 7. Immutability 8. Ability to scale 9. Lack of technological feasibility.	Vern et al. (2023)
1. Scalability problems. 2. Lacking standardization 3. Difficulty in establishing 4. Regulation uncertainty 5. Lacking knowledge/employee training 6. Market-related risks 7. Technology hazards 8. Expensive sustainability expenses 9. Privacy risks 10. Cyber-attack risks 11. Legal risks	Singh et al. (2023)

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Table 2.1 (continued)

Barriers	References
1. Lacking blockchain (BC) standardization. 2. Incompatibilities with current information technologies. 3. Technical immaturity. 4. Absence of trade partner readiness. 5. Lack of government regulations. 6. Lack of market pressure. 7. Small company size (low turnover) 8. Limited economic resources 9. Lack of managerial support.	Agrawal et al. (2022)
1. Ability to scale 2. Interoperability 3. Substantial cost 4. Limited expertise 5. Laws	Mohammed et al. (2023)

These 143 barriers were studied and then mapped into four groups:

1. Technological and infrastructure barriers (TIB)
2. Organisational Barriers (OB)
3. Financial and Security Barriers (FSB)
4. External Environment Barriers (EEB)

These 143 barriers were studied and found which were the most common barriers from previous literature. The barriers were also divided into four groups: TIB, OB, FSB and EEB. Table 2.2 shows the barriers which are common to various research papers. The barriers which were most common were finally selected for the purpose of this study.

Table 2.2 Selection of final barriers for study

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Technological and infrastructure barriers (TIB)	Privacy, ownership, and security concerns with data	☑							☑			
	Scalability and compatibility	☑	☑	☑		☑	☑				☑	☑
	Complexity of technology: preparedness, immaturity, and suitability	☑		☑	☑				☑	☑		☑
	Infrastructure problems: energy and the internet	☑	☑									
	SMEs' deficiency in technology infrastructure	☑	☑									
	Inadequate speed and scalability of blockchain system	☑	☑	☑		☑	☑				☑	☑
	Inadequate speed and scalability of BC system	☑	☑	☑		☑	☑				☑	☑
	Incompatibility (between legacy systems, current technology, and various blockchains)		☑			☑	☑				☑	

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Technological and infrastructure barriers (TIB)	SMEs' inability to automate their payment and invoicing processes		☑									
	Inadequate standardisation		☑				☑			☑		☑
	Insufficient infrastructure suppliers	☑	☑									
	Lack of understanding of blockchain		☑	☑	☑							
	Complexity of the blockchain adoption framework	☑		☑	☑							
	Scalability problem	☑	☑	☑		☑	☑				☑	☑
	Insufficient technical resources			☑								
	Lack of modernised technology			☑								
	Inadequate understanding of blockchain		☑	☑	☑				☑		☑	
	Lack of Experience with Technology		☑	☑	☑				☑		☑	
	Technology not being feasible				☑							
	Difficulty in setup/operation	☑		☑	☑				☑	☑		☑
	Scalability	☑	☑	☑		☑	☑				☑	☑
	Interoperability		☑			☑	☑				☑	

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Technological and infrastructure barriers (TIB)	Inadequate compatibility and standardization		☑			☑	☑			☑		☑
	Inadequate Scalability and System Performance	☑	☑	☑		☑	☑				☑	☑
	Technology accessibility							☑				
	The intricacy of designing a blockchain-based system						☑					
	Reaction against technology							☑				
	Mechanisms of consensus							☑				
	The infancy of technology	☑		☑	☑			☑	☑	☑		☑
	Lack of resources to adapt to BT							☑				
	Difficulties in utilising SCM to integrate BCT and sustainability							☑				
	Privacy and security issues	☑							☑			
	Restricted technological infrastructure	☑		☑	☑			☑	☑	☑		☑
	Complexity								☑			

continued on page 20

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Technological and infrastructure barriers (TIB)	Lack of blockchain tools								☑			
	Lack of standardisation in blockchain			☑				☑		☑		☑
	Insufficient knowledge and experience		☑	☑	☑				☑		☑	
	Lack of standardisation in blockchain			☑				☑		☑		☑
	Improper integration with current information technologies									☑		
	Immaturity in technology	☑		☑	☑			☑	☑	☑		☑
	Lack of experience with technology		☑	☑	☑				☑		☑	
	Scalability	☑	☑	☑		☑	☑				☑	☑
	Interoperability		☑			☑	☑				☑	
	Technological impracticability										☑	
	Immutability										☑	
	Scaling issues	☑	☑	☑		☑	☑				☑	☑
	A lack of standardized procedures		☑				☑			☑		☑
	Complexity of establishing	☑		☑	☑				☑	☑		☑

continued on page 21

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Organisational Barriers (OB)	Interoperability, cooperation, and cross-pollination across humanitarian organizations (HOs)	☑										
	Inadequate knowledge and comprehension between stakeholders	☑	☑	☑	☑							
	A lack of real consent and involvement	☑										
	Interorganizational complicatedness and size imbalance of humanitarian organizations (HOs)	☑										
	Inadequate managerial support	☑						☑	☑	☑		
	Operational constraints	☑										
	Resistance to adopting new technologies		☑						☑			

continued on page 22

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Organisational Barriers (OB)	Inadequate people skilled in blockchain technology (BCT)		☑									☑
	Problems with cooperation, communication, and coordination in the supply chain (SC)		☑		☑		☑	☑			☑	
	Inefficient information disclosure policies among supply chain associates	☑	☑	☑	☑							
	Limited coordination in developing consortium blockchain		☑		☑		☑	☑			☑	
	Blockchain configuration choice		☑									
	Inefficient organizational policies			☑				☑	☑			
	Trust management problems			☑								

continued on page 23

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Organisational Barriers (OB)	Communication gap between Supply Chain (SC) partners	☑	☑	☑	☑							
	Inadequate knowledge sharing			☑				☑				
	Lack of cooperation between SC partners	☑	☑	☑	☑		☑	☑			☑	
	Limited cooperation for consortium formation		☑		☑		☑	☑			☑	
	Limited trust among agricultural stakeholders or public perception						☑					
	Unsupportive and disinterested management	☑						☑	☑	☑		
	Difficulties in altering organizational procedures.			☑				☑	☑			
	Lack of three Cs (cooperation, coordination, and communication)	☑	☑	☑	☑		☑	☑			☑	

continued on page 24

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Organisational Barriers (OB)	Difficulty in sharing data among SC parties			☑				☑				
	Cultural disparities among SC partners							☑				
	Complexity of those involved								☑			
	High-level managerial support	☑						☑	☑	☑		
	High investment expenses								☑			
	'Lack of suitable organizational techniques and human resources'			☑				☑	☑			
	Stakeholder Resistant to Blockchain Culture		☑						☑			
	Insufficient participation by important supply chain participants								☑			
	Small size of the company (turnover)									☑		
	Insufficient financial resources									☑		
	Limited leadership support	☑						☑	☑	☑		
	Limited coordination and teamwork	☑	☑	☑	☑		☑	☑			☑	

continued on page 25

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
OB	Lack of experts and employee training		☑									☑
Financial and Security Barriers (FSB)	Data protection and privacy problems		☑	☑	☑	☑						
	Data security		☑	☑								
	Data integrity problems		☑									
	Information Security Protocol		☑	☑								
	Data Safety and Privacy		☑	☑	☑		☑					
	Data security and confidentiality concerns		☑	☑	☑		☑					
	Privacy and security concerns		☑	☑	☑		☑					
	Security Risks							☑				☑
	Insufficient privacy										☑	☑
	Risks of Confidentiality										☑	☑
	Danger of cyber-attacks							☑				☑
	Legal Risk											☑
	Market-related risks											☑
	Technological hazards											☑
	Funding concerns and cost complications	☑	☑									

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
Financial and Security Barriers (FSB)	Value proposition ambiguity	☑										
	ROI and Monetary Loss		☑									
	Limited knowledge of costs	☑	☑									
	High initial capital expenditure in infrastructures and energy resources		☑	☑		☑	☑				☑	
	Lack of finances	☑	☑									
	Auditing concerns		☑									
	Complex tax consequences for digital assets		☑									
	High costs for investments		☑	☑		☑	☑				☑	
	Platform online cost			☑								
	Substantial cost		☑	☑		☑	☑				☑	
	Large resource (energy, infrastructure) and early capital requirements		☑	☑		☑	☑				☑	
	Financial restrictions							☑				
	Large sustainability cost								☑			☑
	Substantial investment costs		☑	☑		☑	☑				☑	

continued on page 27

Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
External Environment Barriers (EEB)	Risk of media reaction	☑										
	Market competitiveness and uncertainty about the use of blockchain technology (BCT)		☑					☑	☑			
	Legal and regulatory problems		☑									
	Inadequate competent blockchain developers		☑		☑	☑						
	Limited Ecosystem Cooperation with Blockchain		☑									
	Business Owner's reluctance				☑							
	Uncertain advantages				☑							
	Dependence on Blockchain operators		☑		☑	☑						
	Lack in expertise.		☑		☑	☑						
	Agro-stakeholder opposition to blockchain culture						☑					
	Limited rewards and benefits							☑				

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
External Environment Barriers (EEB)	Limited agri-stakeholder awareness and ease of use						☑					
	Market competition and unpredictability		☑					☑	☑			
	Limited participation from external partners							☑	☑			
	Limited industry involvement in the acquiring of blockchain technology							☑	☑			
	Absence of BT standards							☑	☑			
	Lack of customer knowledge							☑				
	Lack pf interaction from external parties							☑	☑			
	A lack of government policy and financial assistance							☑	☑			
	Market Competitiveness and Uncertainty		☑					☑	☑			
	Public Fear and Uncertainty of Supply Chain (SC) Technology								☑			

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
External Environment Barriers (EEB)	Limited competitive pressure									☑		
	Lack of preparedness among trading partners									☑		
	Social, legal, and regulatory structures	☑				☑						
	Uncertainty regarding regulations				☑		☑					☑
	Regulations	☑				☑						
	Inadequate government regulation and ambiguity				☑		☑	☑		☑	☑	☑
	A lack of legal framework							☑				
	Limited regulatory norms						☑	☑		☑	☑	
	Smart agreements and legal validity							☑				
	Jurisdictional problems							☑				
	Intellectual Property (IP) Laws							☑				

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Table 2.2 (continued)

Barrier Group	Barrier	References										
		Patil et al. (2021)	Kaur et al. (2022)	Khan et al. (2023)	Mathivathanan et al. (2021)	Mohammed et al. (2023)	Yadav et al. (2020)	Al Amin et al. (2023)	Naseem et al. (2023)	Agrawal et al. (2022)	Vern et al. (2023)	Singh et al. (2023)
EEB	Lack of government regulations						☑	☑		☑		
	Lack of Rules						☑	☑		☑	☑	
	Uncertainty regarding regulations				☑		☑					☑

A total of 20 barriers were finally selected based on how these were common in various research papers. Six barriers were related to technology and infrastructure, five to organizational, four to financial and security and five to external environment. Table 2.3 gives a description of the barriers which are finally selected for ranking.

Table 2.3 Description of final selected barriers

Barrier Group	Barriers	Description	References
TIB	Technological complexity–readiness and immaturity (TIB1)	BCT's technical complexity renders it unintelligible to non-experts and leads to resistance.	Patil et al. (2021) Khan et al. (2023) Mathivathanan et al. (2021) Singh et al. (2023) Agrawal et al. (2022) Naseem et al. (2023)
	Inadequate expandability and speed of the blockchain network (TIB2)	Because of its limited scalability, blockchain technology performs transactions much worse than existing systems.	Patil et al. (2021) Kaur et al. (2022) Khan et al. (2023) Mohammed et al. (2023) Yadav et al. (2020) Vern et al. (2023) Singh et al. (2023)
	Incompatibility (between various blockchains, current technology, and legacy systems) (TIB3)	The capacity to function and conduct transactions on several systems is known as interoperability.	Kaur et al. (2022) Mohammed et al. (2023) Yadav et al. (2020) Vern et al. (2023)
	Unfamiliarity with Blockchain Technology (TIB4)	Ignorance and infancy with technology	Kaur et al. (2022) Khan et al. (2023) Mathivathanan et al. (2021) Vern et al. (2023) Naseem et al. (2023)
	Lack of blockchain standardization (TIB5)	One of the biggest drawbacks of BCT is its lack of standards. Standards are a recognised and established method of doing business.	Khan et al. (2023) al Amin et al. (2023) Singh et al. (2023) Agrawal et al. (2022)
	Complexity of establishing/Set up (TIB6)	Significant financial outlay, need for a shared software platform, and commitment from the initiators	Patil et al. (2021) Khan et al. (2023) Mathivathanan et al. (2021) Singh et al. (2023) Agrawal et al. (2022) Naseem et al. (2023)

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Table 2.3 (continued)

Barrier Group	Barriers	Description	References
OB	Absence of consciousness and comprehension among stakeholders (OB1)	The stakeholders' knowledge of the benefits and uses of BCT is restricted. This stops BCT from being developed and implemented.	Patil et al. (2021) Kaur et al. (2022) Khan et al. (2023) Mathivathanan et al. (2021)
	Lack of cooperation, coordination and communication among Supply Chain partners (OB2)	The inability of SC partners to coordinate, communicate, and work together hinders performance.	Patil et al. (2021) Kaur et al. (2022) Khan et al. (2023) Mathivathanan et al. (2021) Yadav et al. (2020) Vern et al. (2023) al Amin et al. (2023)
	Lack of management support (OB3)	SCM is hampered by management's limited commitment to eco-friendly and disruptive technology.	Patil et al. (2021) al Amin et al. (2023) Agrawal et al. (2022) Naseem et al. (2023)
	Challenges in Adapting Organisational Procedures (OB4)	Adoption of blockchain introduces new work norms that change the culture of organisations.	al Amin et al. (2023) Khan et al. (2023) Naseem et al. (2023)
	Lack of effective organizational policies/strategies and human resources (OB5)	Establishing new organisational norms to account for evolving roles, responsibilities, and expertise is crucial while implementing BT.	al Amin et al. (2023) Khan et al. (2023) Naseem et al. (2023)
FSB	Data Security and privacy (FSB1)	The issues linked to data are the most commonly mentioned concern with BCT.	Kaur et al. (2022) Khan et al. (2023) Mathivathanan et al. (2021) Yadav et al. (2020)
	Risk of cyber attacks (FSB2)	Cyberattacks could lead to sensitive data being accessed without authorization and shared widely.	al Amin et al. (2023) Singh et al. (2023)

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Table 2.3 (continued)

Barrier Group	Barriers	Description	References
FSB	Significant initial financial outlay for energy resources and infrastructure (FSB3)	Blockchain necessitates a significant financial outlay by organisations and their network of supply chain partners for the acquisition of new hardware and software.	Kaur et al. (2022) Khan et al. (2023) Mohammed et al. (2023) Yadav et al. (2020) Vern et al. (2023)
	High sustainability costs (FSB4)	Much electricity is needed for the intricate computations and digging networks needed to extract the blockchain.	Singh et al. (2023) Naseem et al. (2023)
EEB	Market rivalry and scepticism on the application of blockchain technology (EEB1)	Adoption of BCT and sustainability may introduce uncertainties and affect market competitiveness.	Naseem et al. (2023) al Amin et al. (2023) Kaur et al. (2022)
	Insufficiently skilled blockchain developers (EEB2)	Globally, there is a shortage of skilled blockchain developers.	Kaur et al. (2022) Mathivathanan et al. (2021) Mohammed et al. (2023)
	Absence of BCT policies and lack of industry participation in blockchain adoption (EEB3)	Insufficient support for sustainable blockchain activities from governmental bodies or associations.	Naseem et al. (2023) al Amin et al. (2023)
	Lack of Government regulations (EEB4)	Government entities may exhibit hesitancy in endorsing blockchain technology and promoting sustainability by regulatory standards formation.	Mathivathanan et al. (2021) Yadav et al. (2020) Vern et al. (2023) al Amin et al. (2023) Singh et al. (2023) Agrawal et al. (2022)
	Regulations Uncertainty (EEB5)	With the introduction of BCT, a pertinent legal framework has been built more and more.	Mathivathanan et al. (2021) Yadav et al. (2020) Singh et al. (2023)

2.3 Technological and Infrastructure Barriers:

A total of 6 barriers were finally selected under group TIB. These were the most common barriers in the previous literature and are the most important barriers. These barriers are related to the technology and infrastructure of BCT like lack of technology, technological complexity etc. These are described below.

Technological complexity– readiness and immaturity:

BCT's technical complexity renders it unintelligible to non-experts and leads to resistance. Moreover, there are a number of false beliefs and misconceptions about cryptocurrencies that prevent the advancement of applications. One other technological constraint is the human creation of code, which might include mistakes and carry the developer's legacy.

Inadequate expandability and speed of the blockchain network:

Because of BCT's limited scalability, blockchain technology performs transactions much worse than existing systems. The rate at which transactions process, and latency of data transfer, which results in sluggish transaction speed, are factors that determine the scalability constraints of blockchain technology.

Incompatibility (between various blockchains, current technology, and legacy systems):

The capacity to function and conduct transactions on several systems is known as interoperability. For blockchain to be extensively used, it is essential to integrate blockchain platforms with commonly used legacy systems and mainstream IT applications.

Unfamiliarity with Blockchain Technology:

This is ignorance and infancy with technology. There is still some unfamiliarity with Blockchain Technology and this is among the most important barriers.

Lack of blockchain standardization:

One of the biggest drawbacks of blockchain technology is its lack of standards. Standards are a recognised and established method of doing business. There is a lack of standards when it comes to blockchain technology.

Complexity of establishing/Set up:

There is significant financial outlay, a need for a shared software platform, and commitment from the initiators that makes is challenging to implement Blockchain. There is a huge investment that is needed for adoption of Blockchain Technology.

2.4 Organizational Barriers:

A total of 5 barriers were finally selected under group OB. These were the second most common barriers in the previous literature and are among the most important barriers. These are the barriers which are related to an organization capacity and to human resources.

Absence of consciousness and comprehension among stakeholders:

The stakeholders' knowledge of the benefits and uses of BCT is restricted. This stops BCT from being developed and implemented very well in various organizations.

Lack of cooperation, coordination and communication among Supply Chain partners:

The inability of SC partners to coordinate, communicate, and work together hinders performance in the BCT. So there is a need to cooperate, coordinate and communicate to improve the performance of BCT.

Lack of management support:

SCM is hampered by management's limited commitment to eco-friendly and disruptive technology. There is a lack of high management support that hinders the adoption of BCT.

Challenges in Adapting Organisational Procedures:

Adoption of blockchain introduces new work norms that change the culture of organisations and organizations face challenges in adapting new procedures and it takes significant planning and people to implement these changes.

Lack of effective organizational policies/strategies and human resources:

Establishing new organisational norms to account for evolving roles, responsibilities, and expertise is crucial while implementing BCT and there are ineffective organizational policies and strategies.

2.5 Financial and Security Barriers:

A total of 4 barriers were finally selected under group FSB. Financial and security concerns are very important for any organization or an entity. A detailed description is given below.

Data Security and privacy:

The issues linked to data are the most commonly mentioned concern with BCT. In situations when there is a high concentration of engagement with the vulnerable population, there is a serious risk of data abuse and related risks.

Risk of cyber-attacks:

Cyberattacks could lead to sensitive data being accessed without authorization and shared widely and this could lead to cyber-attacks and that remains a concern for BCT adoption.

Significant initial financial outlay for energy resources and infrastructure:

Blockchain necessitates a significant financial outlay by organisations and their supply chain network partners for new hardware and software. Furthermore, after they are put into place, these devices use a significant amount of energy, raising the organisations' overall costs.

High sustainability costs:

Much electricity is needed for the intricate computations and digging networks needed to extract the blockchain. Blockchain apps running on powerful computers can be used for mining, but at a greater power usage. With the usage of personal computers, miners' ability to extract blockchains in comparable circumstances is constrained.

2.6 External Environment Barriers:

A total of 5 barriers were selected among the external and environmental barriers. These are the barriers which are in the macro environment of an organization and affect the working of an organization.

Market rivalry and scepticism on the application of blockchain technology:

Adoption of blockchain technology and sustainability may introduce uncertainties and affect market competitiveness so there is scepticism on application of BCT.

Insufficiently skilled blockchain developers:

Globally, there is a shortage of skilled blockchain developers. While the technical skills needed for blockchain applications are quite comparable to those of popular programming languages like Python and Java, there are significantly less blockchain developers worldwide than there are Java engineers.

Absence of BCT policies and lack of industry participation in blockchain adoption:

Insufficient support for sustainable blockchain activities from governmental bodies or associations hinders the application and adoption of BCT in supply chains.

Lack of Government regulations:

Governments may be reluctant to support blockchain technology and sustainability by establishing guidelines so a lack of government regulations affect the adoption of BCT.

Regulations Uncertainty:

With the introduction of BCT, a pertinent legal framework has been built more and more in spite of the disruptive technology. In the 2018 Global Blockchain Survey conducted by Deloitte, 39% of participants named "regulatory items" as the main obstacle to blockchain investments.

Chapter 3

Formulation of the problem and solution approach

3.1 Method Selection:

For defining criteria weight coefficients and generating multi-criteria decisions, the Best Worst Method (BWM) is a potent method. The BWM has already been applied to many real-world issues during the last five years, including those pertaining to energy, manufacturing, SCM, transportation, education, investments, performance evaluation, aviation industry, communication, healthcare, finance, technology and travel industry. Furthermore, a great deal of research has been done using the BWM approach alone (singleton integration), as well as articles that combine it with other methods (multiple integrations) according to Pamučar et al. (2020). The best worst method (BWM) selects comparisons carefully in order to address decisions with numerous criteria. BWM concentrates on the most significant aspect (the "best" Criteria) and the least important one (the "worst") rather than overwhelming you with a comparison of every Criteria against every other Criteria. Critical information is gathered by BWM by comparing the relative relevance of the "best" Criteria to all the others and how much more significant it is than the "worst". It assists in allocating weights to each Criteria, indicating their impact on the choice made at the end, by examining these comparisons. The effectiveness of this approach is its main advantage. Compared to other approaches, BWM requires less input from the decision-maker by carefully selecting comparisons. This makes it appropriate for a range of scenarios where it can be advantageous to streamline the decision-making process, such as when picking the best investment opportunity or a new supplier.

3.2 Best Worst Method:

The next stage after decision makers have approved the criteria is to evaluate the weights assigned to each of them. According to Grisi (2010), Hsi (2007), and Kuo (2012), there are several multi-criteria decision-making approaches for determining the weights of the criteria and ranking the alternatives. These methodologies include AHP, TOPSIS, VIKOR, DEMATEL, ANP, and others. Dr. Jafar Rezaei created the BWM, a multi-criteria decision-making technique, in 2015. When compared to the current multi-criteria decision-making methods, BWM yields more consistent comparisons, more dependable outcomes, and uses less comparison data.

The application of BWM has been extensive in several studies to rank barriers and find subjective weights of the criteria. Table 3.1 shows the application of BWM in various previous studies.

Table 3.1 Application of BWM in various studies

Application	References
Evaluation of the societal sustainability of supply chains	Ahmadi et al. (2017)
Application of the BWM in evaluating the effectiveness of a medical tourism development plan	Abadi et al. (2018)
An assessment of the issues posed by Industry 4.0 using BWM	Wankhede and Vinodh (2021)
Assessing the Research & Development performance of companies using BWM	Salimi and Rezaei (2018)
Ranking sustainable manufacturing obstacles using BWM	Malek and Desai (2019)
Bioethanol factory location selection using BWM	Kheybari et al. (2019)
Development of a framework to analyse the factors that contribute to sustainability and the external impacts of Industry 4.0 technologies, using BWM	Baz et al. (2022)
Utilising the BWM method to identify and rank the aspects that contribute to the service experience in the banking industry.	Yadollahi et al. (2018)
BWM for Modelling Mobility Choice after COVID-19	Moslem et al. (2020)
Identifying the most efficient strategy for managing municipal solid waste using BWM	Li et al. (2021)

The BWM is a technique used for multi-criteria decision-making (MCDM) that involves assessing options according to predetermined criteria. This section provides a description of the Barrier Weighting Method (BWM) used to determine the weights of barriers in the implementation of Blockchain Technology (BCT) in supply chains, as outlined by Rezaei (2015). Below is the algorithm, accompanied by mathematical expressions:

3.2.1 BWM Algorithm:

1. Define a set of criteria (C): Identify all relevant/important criteria for your study/decision (C = {c_1, c_2, ..., c_n}).
2. Find the best and worst criteria: Select the most important criteria (best) and the least important criteria (worst) based on your preference/decision maker preference.
3. Perform the pairwise comparisons:
   - Best-to-Others (BO): Compare the best criteria (b) with all other criteria (c_i) using a scale (e.g., 1-9) representing your preference for b over c_i. This creates a vector BO = (b over c_1, b over c_2, ..., b over c_n).
   - Worst-to-Others (WO): Compare all criteria (c_i) with the worst criteria (w) using the scale, indicating your preference for c_i over w. This creates a vector WO = (c_1 over w, c_2 over w, ..., c_n over w).
4. Calculate the weights:

   1. Define a weighting vector (w) where each element (w_i) represents the weight of a criteria (c_i).
   2. Formulate an optimization problem/statement in order to minimise the greatest absolute value difference between the calculated preference values and the values you provided in BO and WO vectors.

Mathematically:

minimise ξ

subjected to:

$|A * w - BO| \leq \xi$ $|w - WO| \leq \xi$

w sum = 1 (weights total sum = 1)

$w_i \geq 0$ (all weights are non-negative)

where:

1. ξ is a slack variable representing the maximum deviation.
2. A is a comparison matrix where each element (a_{ij}) represents the comparative assessment of criteria (i and j). A is diagonally filled with 1s and populated based on BO and WO vectors.

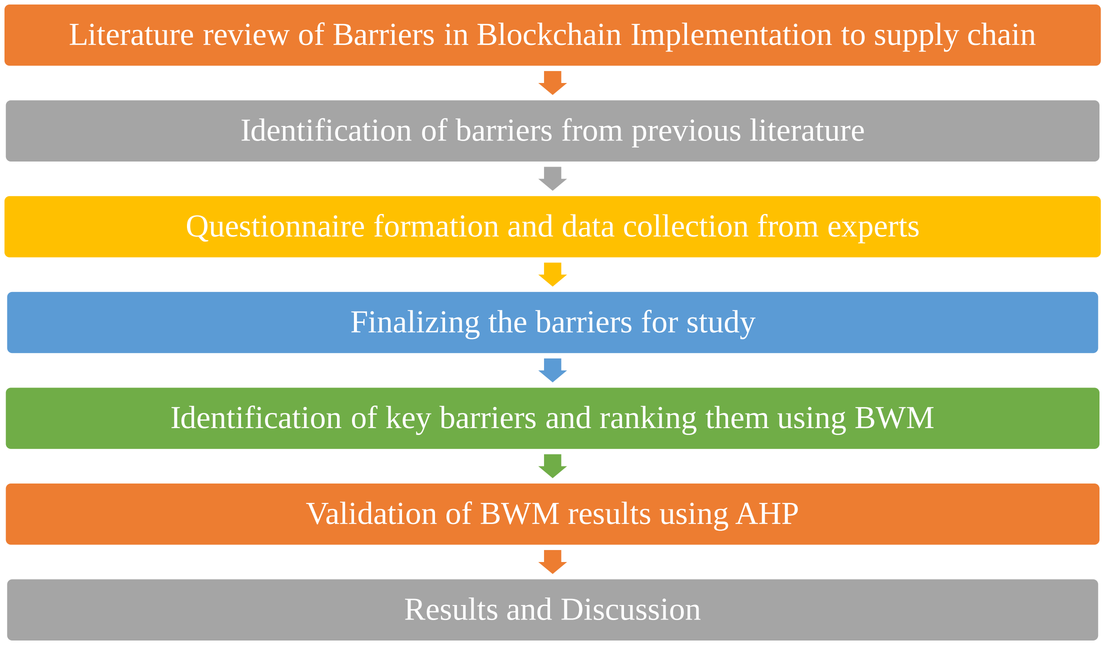
5. Employ linear programming techniques to solve the optimisation issue and get the weight vector (w). The weights indicate the proportional importance of each criterion in the decision-making process.
6. Evaluate alternatives (optional): If there are many choices to consider, assign a score to each option based on certain criteria using a predetermined scale. Compute the product of these scores with the associated criteria weights (obtained from step 5) and calculate the sum for each choice. The alternative with the greatest score is regarded as the optimal choice, taking into account the weighted criteria.
7. CR is calculated with the help of CI and ξ.

$CR = \xi/CI$

Table 3.2 The consistency index for BWM

n	1	2	3	4	5	6	7	8	9
CI	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

3.3 Research Flowchart:



Initially, a thorough literature review was done to find out barriers from previous literature and a total of 143 barriers were studied. Then these barriers were mapped to four groups and finally 20 barriers were selected based on how common they were in previous literature. A questionnaire was formed and data was collected from 18 industry experts which gave us the matrix for pairwise comparison. This data was used to calculate ranking of barriers using BWM. AHP was used to validate the results of BWM since the convenience, adaptability, and wide applicability of AHP make it a superior technique compared to rival approaches like TOPSIS and Entropy method. This methodology has been utilised several times in academic literature to assess and give priority to the factors and obstacles that affect firms' adoption of new software solutions and these results were finally discussed.

3.4 AHP:

Researchers have implemented many approaches for the relative ranking of barriers using Multi Criteria Decision Methods (MCDMs). According to Lee et al. (2014), AHP is recommended as a better approach than other methods due to its usability, versatility, and wide applicability as compared to alternative methods, such as TOPSIS and Entropy method. This technique has been employed a number of times in the literature to rank and prioritize the factors and barriers while evaluating the factors influencing companies' implementation of new software solutions according to Lee et al. (2014). The Analytical Hierarchy Process (AHP) model created by Saaty (1990) is one of the important and generic models. This approach finds the comparative importance of the aspects by statistical analysis of survey responses from Experts/Decision makers. The Analytic Hierarchy Process (AHP) is a model specifically developed for subjective decision-making in a hierarchical organisation. It is particularly useful in addressing intricate problems that require consideration of human perceptions and decisions, as stated by James and James (2020).

3.4.1 AHP Algorithm:

1. Define the problem: Identify the goal, criteria ($C = \{c_1, c_2, ..., c_n\}$), and a set of alternatives ($A = \{a_1, a_2, ..., a_m\}$).
2. Construct pairwise comparison matrices:

    a. Criteria comparisons: Construct a square matrix of size n x n, where each entry (a_{ij}) denotes the relative significance of criterion i compared to criterion j. Use a scale (e.g., 1-9) where value of 1 represents equal priority, whereas higher values show a larger preference for the row criterion compared to the column criterion. The matrix should be reciprocal ($a_{ij} = 1/a_{ji}$ for all $i \neq j$).
    b. Alternative comparisons: For each criterion, create a comparison matrix where each element (a^{ik_j1}) represents the relative performance

of alternative k against alternative l for criterion i. Use the same scale as for criteria comparisons.

3. Calculate weights:

   a. Criteria weights: To determine the eigenvector associated with the biggest eigenvalue (λ_{max}) in the criterion comparison matrix, do the necessary calculations. Standardise the eigenvector elements in order to calculate the weights (w) for each criterion. Consistency check: Calculate the Consistency Index (CI) using λ_{max} and the matrix size (n). Next, the Consistency Ratio (CR) is computed. A coefficient of reliability (CR) below 0.1 signifies that the consistency in judgements is deemed satisfactory. If not, revise your comparisons.

Mathematical Expressions:

- A = Criteria comparison matrix
- λ_{max} = Largest eigenvalue of A
- w = Normalized eigenvector corresponding to λ_{max}
- CI = (λ_{max} - n) / (n - 1)
- CR = CI/RI

Table 3.3 Values of RI corresponding to various values of n

n	1	2	3	4	5	6	7	8	9	10
Random Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.5 Application of the Best-Worst method for Ranking of Barries to Blockchain application in Supply Chain:

The initial weights, best and worst criteria, and best to others and worst to others were decided after taking an expert opinion from 18 experts using a survey. These values were then put into the BWM excel solver and weights were calculated. A total of 5 analysis were done which consisted of four analyses for sub criteria and one analysis for main criteria. The best to others and others to worst vectors used for calculation of weights are shown in Table 3.4 to Table 3.8.

The meaning of the numbers 1-9 when comparing best to others and others to worst is:

1: Equally significant

2: Positioned between the concepts of equality and moderation.

3: Slightly more significance than

4: A level that falls between moderately and strongly.

5: Significantly more important than

6: Moderately strong

7: Significantly more significant than

8: Somewhere between highly potent and exceedingly potent.

9: Absolute superiority over

Table 3.4 Vectors of Pairwise comparison for Main Criteria, ranging from the best to the others and from the others to the worst

Number of Criteria (C) = 4	C -1	C - 2	C - 3	C - 4
Name of Criteria	TIB	OB	FSB	EEB
Best Criteria	TIB			
Worst Criteria	FSB			
Best to the Others	TIB	OB	FSB	EEB
TIB	1	5	8	5
Others to the Worst	FSB			
TIB	8			
OB	3			
FSB	1			
EEB	3			

Table 3.5 Vectors of Pairwise comparison for Sub Criteria TIB, comparing the best to the others and the others to the worst

Number of Criteria (C) = 6	C - 1	C - 2	C - 3	C - 4	C - 5	C - 6
Names of Criteria	TIB1	TIB2	TIB3	TIB4	TIB5	TIB6
Best Criteria	TIB4					
Worst Criteria	TIB2					
Best to the Others	TIB1	TIB2	TIB3	TIB4	TIB5	TIB6
TIB4	3	7	3	1	3	6
Others to the Worst	TIB2					
TIB1	4					
TIB2	1					
TIB3	5					
TIB4	7					
TIB5	4					
TIB6	2					

Table 3.6 Vectors of Pairwise comparison for Sub Criteria OB, comparing the best to the others and the others to the worst

Number of Criteria (C) = 5	C - 1	C - 2	C - 3	C - 4	C - 5
Names of Criteria	OB1	OB2	OB3	OB4	OB5
Best Criteria	OB4				
Worst Criteria	OB5				
Best to the Others	OB1	OB2	OB3	OB4	OB5
OB4	2	5	3	1	7
Others to the Worst	OB5				
OB1	6				
OB2	2				
OB3	4				
OB4	7				
OB5	1				

Table 3.7 Vectors of Pairwise comparison for Sub Criteria FSB, comparing the best to the others and the others to the worst

Number of Criteria (C) = 4	C - 1	C - 2	C - 3	C - 4
Names of Criteria	FSB1	FSB2	FSB3	FSB4
Best Criteria	FSB2			
Worst Criteria	FSB3			
Best to the Others	FSB1	FSB2	FSB3	FSB4
FSB2	2	1	7	5
Others to the Worst	FSB3			
FSB1	6			
FSB2	7			
FSB3	1			
FSB4	2			

Table 3.8 Vectors of Pairwise comparison for Sub Criteria EEB, comparing the best to the others and the others to the worst

Number of Criteria = 5	C - 1	C - 2	C - 3	C - 4	C - 5
Names of Criteria	EEB1	EEB2	EEB3	EEB4	EEB5
Best Criteria	EEB2				
Worst Criteria	EEB3				
Best to the Others	EEB1	EEB2	EEB3	EEB4	EEB5
EEB2	2	1	7	3	4
Others to the Worst	EEB3				
EEB1	6				
EEB2	7				
EEB3	1				
EEB4	4				
EEB5	3				

Using the above data vectors, Best Worst Method was applied and ranking of the various barriers was calculated which is shown in Table 4.1. These were then validated by using AHP to find the ranks of the barriers. Consistency ratio was found to show that the results are consistent and then compared with the results from BWM.

Chapter 4

Results, Validation and Discussion

4.1 Results:

BWM method gave weights of the barriers. Table 4.1 give the values of the local weights; they pertain to both the major criteria and the sub criteria. The global weights were determined by multiplying the weight coefficient of the major criteria with the weight coefficient of the sub criteria. These sub criteria were then ranked using these global weights.

Table 4.1 The optimal values of the weight coefficients of the main criteria/sub-criteria and rank of barriers using BWM

Main Criteria/Sub Criteria	Code	Local Weights	Global Weights	Rank
Technological and Infrastructure Barriers	TIB	0.6429	-	1
Technological complexity– readiness and immaturity	TIB1	0.1581	0.1017	3
Inadequate expandability and speed of the blockchain network	TIB2	0.0465	0.0299	11
Incompatibility (between various blockchains, current technology, and legacy systems)	TIB3	0.1581	0.1017	4
Unfamiliarity with Blockchain Technology	TIB4	0.4000	0.2571	1

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Table 4.1 (continued)

Main Criteria/Sub Criteria	Code	Local Weights	Global Weights	Rank
Lack of blockchain standardization	TIB5	0.1581	0.1017	2
Complexity of establishing/Set up	TIB6	0.0791	0.0508	7
Organisational Barriers	OB	0.1429	-	2
Absence of consciousness and comprehension among stakeholders	OB1	0.2491	0.0356	9
Lack of cooperation, coordination and communication among Supply Chain partners	OB2	0.0997	0.0142	16
Lack of management support	OB3	0.1661	0.0237	12
Challenges in Adapting Organisational Procedures	OB4	0.4327	0.0618	5
Lack of effective organizational policies/strategies and human resources	OB5	0.0524	0.0075	18
Financial and Security Barriers	FSB	0.0714	-	3
Data Security and privacy	FSB1	0.2987	0.0213	14
Risk of cyber attacks	FSB2	0.5189	0.0371	8
Significant initial financial outlay for energy resources and infrastructure	FSB3	0.0629	0.0045	20
High sustainability costs	FSB4	0.1195	0.0085	17

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Table 4.1 (continued)

Main Criteria/Sub Criteria	Code	Local Weights	Global Weights	Rank
External Environment barriers	EEB	0.1429	-	2
Market rivalry and scepticism on the application of blockchain technology	EEB1	0.2431	0.0347	10
Insufficiently skilled blockchain developers	EEB2	0.4222	0.0603	6
Absence of BCT policies and lack of industry participation in blockchain adoption	EEB3	0.0512	0.0073	19
Lack of Government regulations	EEB4	0.1620	0.0231	13
Regulations Uncertainty	EEB5	0.1215	0.0174	15

Table 4.1 gives the ranking, local and global weights of the barriers and main criteria when found using BWM. TIB is the most important barrier group followed by OB and EEB. FSB is the least important barrier group in this study. Unfamiliarity with BCT is the most important barrier followed by lack of blockchain standardization at second rank followed by Technological complexity– readiness and immaturity.

Fig.4.1 to Fig.4.5 gives the bar graph of the weights of the considered barriers which was calculated using BWM method.

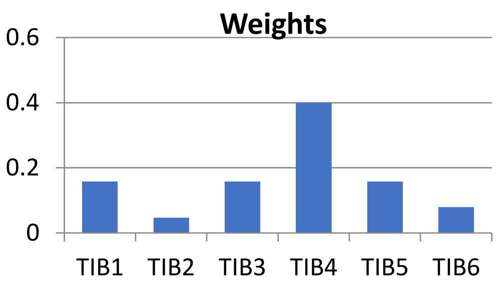

Fig.4.1 The weight of each sub-criteria of the TIB according to considered barriers

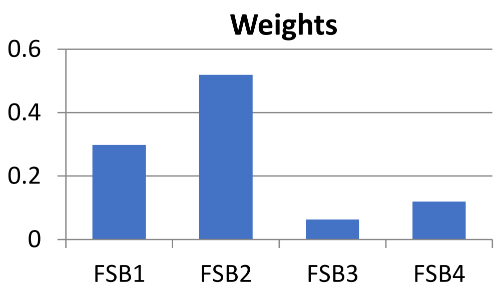

Fig4.2 The weight of each sub-criteria of the FSB according to considered barriers

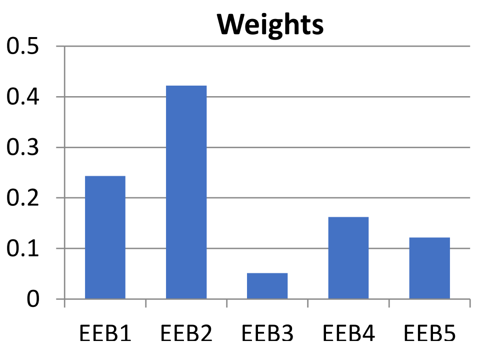

Fig.4.3 Each sub-criteria's weight in EEB according to considered barriers

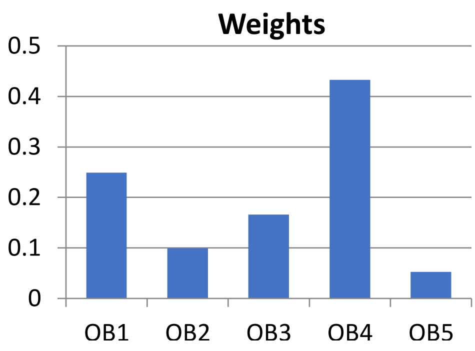

Fig.4.4 Each sub-criteria's weight in OB according to considered barriers

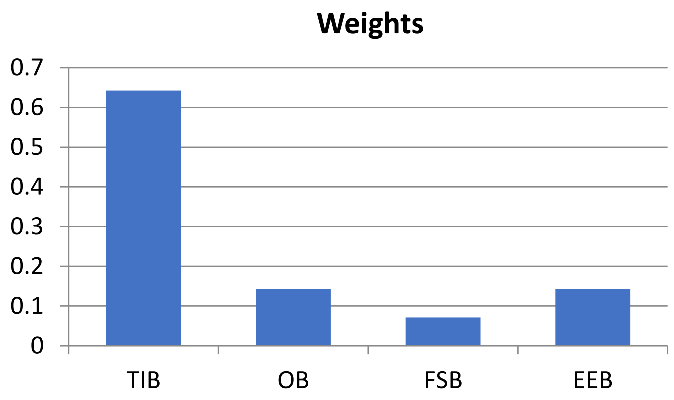

Fig.4.5 The weight of each main criteria according to considered barriers

Fig.4.1 shows that TIB4 is the most important barrier among the technological and infrastructure group. Fig.4.2 shows that FSB2 is the most important barrier among the financial and security group. Fig.4.3 shows that EEB2 is the most important barrier among the external environment barrier group. Fig.4.4 shows that OB4 is the most important barrier among the organizational group. Fig.4.1 shows that TIB4 is the most important barrier among the technological and infrastructure group.

Table 4.2 CR values for various criteria

Criteria	ξ Value	CR = ξ/CI
Main Criteria	0.0714	0.0438
Sub criteria TIB	0.0744	0.0248
Sub criteria OB	0.0655	0.0282
Sub criteria FSB	0.0786	0.0482
Sub criteria EEB	0.0639	0.0277

Table 4.2 gives the CR value for various criteria after the application of BWM. A value closer to zero signifies a better consistency in pairwise comparison whereas a value closer to 1 shows poor consistency. The value should be as close to zero as possible.

4.2 Application of the AHP for validation of results of BWM:

Barrier modelling for the integration of BCT in supply chains necessitates a thorough consideration of barriers influencing implementation and their mutual interrelationships and interdependencies in order to give relative ranks or weights. According to Sharma et al. (2017), ranking the barriers that influence the adoption of new technology according to experts' preferences is a more effective way to determine which barriers are more important when making an adoption decision and to help organizations better understand the adoption scenario. To determine the weights (Wi), the Analytic Hierarchy Process (AHP) procedure, as introduced by Saaty (1990), is used. AHP is a model designed for subjective decision-making within a hierarchical system, proving valuable when dealing with complex issues that involve human perceptions and decisions according to James and James (2020). Thus, the AHP methodology is employed in assigning weights to the smart healthcare implementation barriers of hospital emergency departments. This paper applies this methodology to develop a two-tier hierarchy diagram, where the higher level represents the main technological and infrastructural, organizational, financial and security and environmental barriers, and lower represent the sub barriers respectively. Fig 4.6 gives the hierarchical structure for AHP application.

AHP has been one of the most comprehensive MCDM tool. It was used to find the ranking of Barriers and then compare with results from BWM to validate them. The matrix for pairwise comparison was formed after taking an expert opinion from 18 experts using a survey. Then a normalised matrix was formed and criteria weights were calculated. Consistency matrix was formed and consistency ratio was calculated to find that the results are consistent. Fig.4.6 gives a two-level hierarchical structure for AHP. The main criteria’s which are Technological and infrastructure, Organizational, Financial and security and External environment barriers are at level 1. Level 2 has individual barriers or sub criteria. Level 0 is our objective. Concept of global and local weight was used since this is a two-level hierarchy.

This research utilises the nine-point Saaty scale (1990) to convert a single judgement phrase into a numerical measure for comparison. The scale ranges from 1/9, which represents "extremely less important over another," to 9, which represents "extremely more important over another." Intermediate values between adjacent scale values are represented by 1/2, 1/4, 1/6, 1/8, 2, 4, 6, and 8. An expert opinion was obtained using a subjective questionnaire using the provided alternatives in a Google form. Subsequent computations were then performed based on the collected primary data.

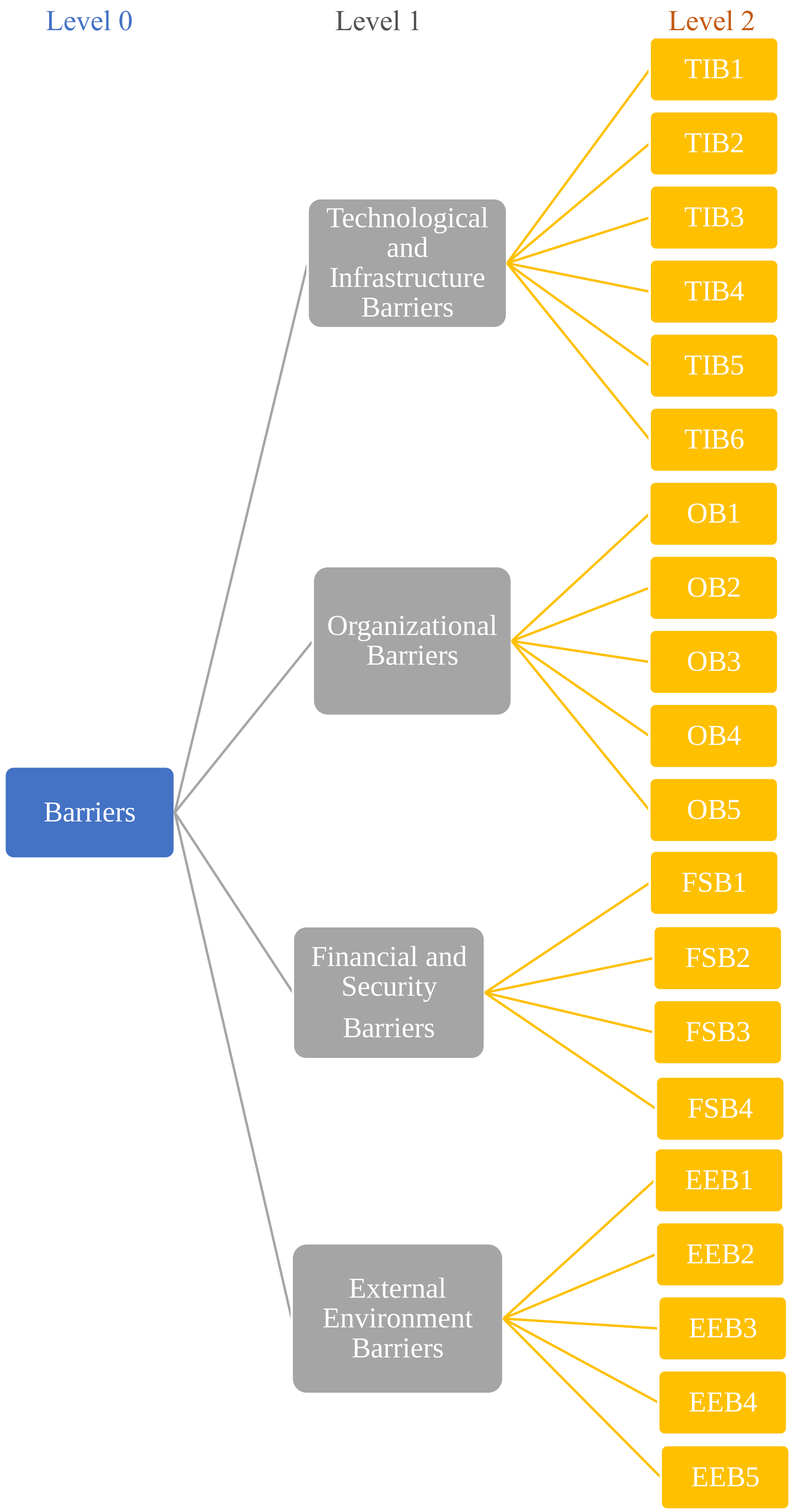

Fig.4.6 Hierarchical Structure for AHP

Initially a matrix for pairwise comparison is formed for all the sub-criteria and main criteria. This matrix was formed on the basis of data collection from experts. Table 4.2 to Table 4.7 gives the matrix for pairwise comparison.

Table 4.3 Matrix for pairwise comparison for Sub- Criteria TIB

	TIB1	TIB2	TIB3	TIB4	TIB5	TIB6
TIB1	1.00	6.00	0.50	0.20	1.00	2.00
TIB2	0.17	1.00	0.14	0.11	0.17	0.25
TIB3	2.00	7.00	1.00	0.25	2.00	3.00
TIB4	5.00	9.00	4.00	1.00	5.00	7.00
TIB5	1.00	6.00	0.50	0.20	1.00	2.00
TIB6	0.50	4.00	0.33	0.14	0.50	1.00

Table 4.3 gives a matrix of pairwise comparison for the sub criteria TIB. This compares the various barriers namely TIB1 to TIB6 in a pair with each other.

Table 4.4 Matrix for pairwise comparison for Sub- Criteria OB

	OB1	OB2	OB3	OB4	OB5
OB1	1.00	5.00	2.00	2.00	6.00
OB2	0.20	1.00	0.33	0.17	2.00
OB3	0.50	3.00	1.00	0.33	4.00
OB4	0.50	6.00	3.00	1.00	7.00
OB5	0.17	0.50	0.25	0.14	1.00

Table 4.4 gives a matrix of pairwise comparison for the sub criteria OB. This compares the various barriers namely OB1 to OB5 in a pair with each other.

Table 4.5 Matrix for pairwise comparison for Sub- Criteria FSB

	FSB1	FSB2	FSB3	FSB4
FSB1	1.00	0.50	9.00	7.00
FSB2	2.00	1.00	9.00	9.00
FSB3	0.11	0.11	1.00	0.33
FSB4	0.14	0.11	3.00	1.00

Table 4.5 gives a matrix of pairwise comparison for the sub criteria FSB. This compares the various barriers namely FSB1 to FSB4 in a pair with each other.

Table 4.6 Matrix for pairwise comparison for Sub- Criteria EEB

	EEB1	EEB2	EEB3	EEB4	EEB5
EEB1	1.00	0.50	8.00	2.00	3.00
EEB2	2.00	1.00	9.00	4.00	5.00
EEB3	0.13	0.11	1.00	0.17	0.20
EEB4	0.50	0.25	6.00	1.00	2.00
EEB5	0.33	0.20	5.00	0.50	1.00

Table 4.6 gives a matrix of pairwise comparison for the sub criteria TIB. This compares the various barriers namely EEB1 to EEB5 in a pair with each other.

Table 4.7 Matrix for pairwise comparison for Main Criteria

	TIB	OB	FSB	EEB
TIB	1.00	6.00	9.00	6.00
OB	0.17	1.00	4.00	1.00
FSB	0.11	0.25	1.00	0.25
EEB	0.17	1.00	4.00	1.00

Table 4.7 gives a matrix of pairwise comparison for the main criterion. This compares the various barriers namely TIB, FSB, OB and EEB in a pair with each other.

After the formation of matrix for pairwise comparison, matrix for normalised comparison was formed and criteria weights were calculated. Table 4.7 to Table 4.11 gives the matrix for normalised comparison.

Table 4.8 Matrix for normalised comparison and Weights for Sub criteria TIB

	TIB1	TIB2	TIB3	TIB4	TIB5	TIB6	Weights
TIB1	0.1034	0.1818	0.0772	0.1050	0.1034	0.1311	0.1170
TIB2	0.0172	0.0303	0.0220	0.0583	0.0172	0.0163	0.0269
TIB3	0.2068	0.2121	0.1544	0.1313	0.2068	0.1967	0.1847
TIB4	0.5172	0.2727	0.6176	0.5252	0.5172	0.4590	0.4848
TIB5	0.1034	0.1818	0.0772	0.1050	0.1034	0.1311	0.1170
TIB6	0.0517	0.1212	0.0514	0.0750	0.0517	0.0655	0.0694

Table 4.8 gives a matrix for normalised comparison and weights of sub criteria TIB from TIB1 to TIB6. TIB4 is the most important criteria among Technological and Infrastructure group.

Table 4.9 Matrix for normalised comparison and Weights for Sub criteria OB

	OB1	OB2	OB3	OB4	OB5	Weights
OB1	0.422535	0.322581	0.303797	0.54902	0.3	0.379587
OB2	0.084507	0.064516	0.050633	0.045752	0.1	0.069082
OB3	0.211268	0.193548	0.151899	0.091503	0.2	0.169644
OB4	0.211268	0.387097	0.455696	0.27451	0.35	0.335714
OB5	0.070423	0.032258	0.037975	0.039216	0.05	0.045974

Table 4.9 gives a matrix for normalised comparison and weights of sub criteria OB from OB1 to OB5. OB1 is the most important criteria among organizational group.

Table 4.10 Matrix for normalised comparison and Weights for Sub criteria FSB

	FSB1	FSB2	FSB3	FSB4	Weights
FSB1	0.307317	0.290323	0.409091	0.403846	0.352644
FSB2	0.614634	0.580645	0.409091	0.519231	0.5309
FSB3	0.034146	0.064516	0.045455	0.019231	0.040837
FSB4	0.043902	0.064516	0.136364	0.057692	0.075619

Table 4.10 gives a matrix for normalised comparison and weights of sub criteria FSB from FSB1 to FSB4. FSB2 is the most important criteria among Financial and security group.

Table 4.11 Matrix for normalised comparison and Weights for Sub criteria EEB

	EEB1	EEB2	EEB3	EEB4	EEB5	Weights
EEB1	0.252632	0.242588	0.275862	0.26087	0.267857	0.259962
EEB2	0.505263	0.485175	0.310345	0.521739	0.446429	0.45379
EEB3	0.031579	0.053908	0.034483	0.021739	0.017857	0.031913
EEB4	0.126316	0.121294	0.206897	0.130435	0.178571	0.152702
EEB5	0.084211	0.097035	0.172414	0.065217	0.089286	0.101632

Table 4.11 gives a matrix for normalised comparison and weights of sub criteria EEB from EEB1 to EEB5. EEB2 is the most important criteria among External Environment group.

Table 4.12 Matrix for normalised comparison and Weights for Main criteria

	TIB	OB	FSB	EEB	Weights
TIB	0.692308	0.727273	0.5	0.727273	0.661713
OB	0.115385	0.121212	0.222222	0.121212	0.145008
FSB	0.076923	0.030303	0.055556	0.030303	0.048271
EEB	0.115385	0.121212	0.222222	0.121212	0.145008

Table 4.12 gives a matrix for normalised comparison and weights of main criteria TIB, OB, FSB and EEB. TIB is the most important criteria whereas OB and EEB are equally important. After matrix for normalised comparison, consistency ratio was calculated to find the consistency of the results. Table 4.13 gives the consistency ratio of main criteria and sub criteria for AHP.

Table 4.13 Consistency Ratio of AHP

Criteria	Consistency Ratio
Main Criteria	0.046
Sub criteria TIB	0.036
Sub criteria OB	0.036
Sub criteria FSB	0.063
Sub criteria EEB	0.032

Since the consistency ratios are for all the criteria are below 0.1, this shows that our matrix was consistent and results are consistent.

Table 4.14 gives us values of local weights of main criteria and sub criteria using AHP. Global weights were calculated by multiplying the weight coefficient of main criteria with weight coefficient of sub criteria. These sub criteria were then ranked using these global weights.

Table 4.14 The optimal values of the weight coefficients of the main criteria/sub-criteria and rank of barriers using AHP

Main Criteria/Sub Criteria	Code	Local Weights	Global Weights	Rank
Technological and Infrastructure Barriers	TIB	0.6617	-	1
Technological complexity– readiness and immaturity	TIB1	0.117	0.0774	3
Inadequate expandability and speed of the blockchain network	TIB2	0.0269	0.0178	13
Incompatibility (between various blockchains, current technology, and legacy systems)	TIB3	0.1847	0.1222	2
Unfamiliarity with Blockchain Technology	TIB4	0.4848	0.3208	1
Lack of blockchain standardization	TIB5	0.117	0.0774	3
Complexity of establishing/Set up	TIB6	0.0695	0.046	8
Organisational Barriers	OB	0.1450	-	2
Absence of consciousness and comprehension among stakeholders	OB1	0.3796	0.055	6
Lack of cooperation, coordination and communication among Supply Chain partners	OB2	0.0691	0.01	16

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Table 4.13 (continued)

Main Criteria/Sub Criteria	**Code**	**Local Weights**	**Global Weights**	**Rank**
Lack of management support	OB3	0.1696	0.0246	11
Challenges in Adapting Organisational Procedures	OB4	0.3357	0.0486	7
Lack of effective organizational policies/strategies and human resources	OB5	0.046	0.0067	17
Financial and Security Barriers	FSB	0.0482	-	3
Data Security and privacy	FSB1	0.3526	0.017	14
Risk of cyber attacks	FSB2	0.5309	0.0256	10
Significant initial financial outlay for energy resources and infrastructure	FSB3	0.0408	0.002	20
High sustainability costs	FSB4	0.0756	0.0037	19
External Environment barriers	EEB	0.1450	-	2
Market rivalry and scepticism on the application of blockchain technology	EEB1	0.26	0.0377	9
Insufficiently skilled blockchain developers	EEB2	0.4538	0.0658	5
Absence of BCT policies and lack of industry participation in blockchain adoption	EEB3	0.0319	0.0046	18
Lack of Government regulations	EEB4	0.1527	0.0221	12
Regulations Uncertainty	EEB5	0.1016	0.0147	15

4.3 Discussion:

After conducting a thorough literature analysis and consulting with experts, this study has determined twenty obstacles to blockchain adoption. These obstacles have been divided into four primary groups. It is difficult to assess how much of an impact these obstacles will have on the application of blockchain in the supply chain (SC). Blockchain adoption in supply chains, however, can have a number of advantages, including better information sharing, streamlined e-contract procedures, improved tracking of reverse logistics flow and return management, improved traceability, and effective warranty claims management. This study employed BWM method to rank the important barriers to blockchain implementation in supply chain mainly in Indian scenario and then used AHP to validate them since AHP is a very well-known MCDM too. The study also emphasises how important it is to remove the obstacles that have been found in order to guarantee that blockchain technology is successfully implemented in a supply chain. By removing these obstacles, companies can improve supply chain operations, their ability to compete, and eventually profit from blockchain technology. Table 4.1 shows the local weights and global weights of sub criteria and main criteria. Based on the table, the ranking order for the primary barriers to application of blockchain is TIB > OB = EEB > FSB, indicating that technological and infrastructure barriers are the most critical, followed by organizational barriers which is equally critical as external environment barriers and then there is financial and security barriers. This was validated by AHP since that gave the same ranks for main criteria. Among the sub criteria, Unfamiliarity with Blockchain Technology is the sub criteria which is most critical to the adoption of Blockchain implementation in supply chain according to both BWM and AHP method. Therefore, it is very important for organizations to have adequate knowledge about BCT and invest in improving the information about BCT. The next most important barrier identified from this study is Lack of blockchain standardization which is again a technological related barrier since there is less standardization between various existing technologies. Next to that barrier is Technological complexity– readiness and immaturity, which can be explained by the fact that BCT is relatively a new technology and haven’t matured yet. So, organizations need to focus on improving their readiness for successful implementation of BCT. The next ranked barrier globally is the Insufficiently skilled blockchain developers. Blockchain developers are not that easily available as java developers or other developers. This is very critical to the implementation of BCT in supply chain to the advantage of an organization. The next barrier is Complexity of establishing/set up which means that there is significant financial outlay, need for a shared software platform, and commitment from the initiators which is why this is a very critical barrier. Table 4.1 and Table 4.14 gives the overall ranking of all the twenty barriers using both BWM and AHP respectively.

The study's conclusions have a number of management and practical applications. Initially, companies involved in the Indian e-commerce supply chain need to concentrate on educating supply chain participants about blockchain technology. Second, for blockchain adoption to be effective, fostering trust among supply chain participants is essential. Third, companies should spend money on infrastructure and technological know-how to encourage the use of blockchain technology. Fourth, in order to promote blockchain implementation in the reverse supply chain of e-commerce, legislators and government organisations need to offer incentives and support. The implementation of blockchain technology is essential to attaining supply chain sustainability because it can result in increased competitiveness, decreased costs, and enhanced efficiency when the stated impediments are addressed.

Chapter 5

Conclusion, Future Scope and Social Impact

5.1 Conclusion:

The industry 4.0 has seen the emergence of digital technologies like blockchain (BC), which have the ability to completely transform supply chain operations. Recognising and removing the barriers impeding blockchain technology's wider acceptance is essential to its successful application in supply chains. Following a thorough literature review and discussions with experts, this paper identified 20 barriers to the use of blockchain technology (BCT) in the supply chain in Indian context. These barriers are divided into four groups: Technological and Infrastructure Barriers (TIB), Organizational Barriers (OB), Financial and Security barriers (FSB) and External Environment Barriers (EEB).

To rank the identified barriers, Best-Worst Method was used. The results show that the most significant barriers are the Unfamiliarity with Blockchain Technology, Incompatibility (between various blockchains, current technologies, and legacy systems), Lack of Blockchain standardization, Technological complexity and lack of qualified blockchain developers. This study provides insightful viewpoints on the main barriers to blockchain adoption in India's reverse supply chain for e-commerce. Additionally, it provides relevant data that helps government agencies, officials, supply chain managers, and lawmakers make educated decisions. Companies can fully use blockchain technology and create a sustainable supply chain by removing these barriers, which will increase customer satisfaction, reduce costs, increase productivity, and bolster their competitiveness.

5.2 Limitations, Future Scope and Social Impact:

This study has some shortcomings, despite its usefulness in outlining the obstacles to blockchain adoption in the context of India's supply chain business. First off, the fact that this study was limited to the Indian supply chain may limit the applicability of the findings to other nations and sectors of the economy. Secondly, the study's expert opinions may not accurately represent the views of experts in other nations because they were restricted to individuals who are acquainted with India's diverse supply chains. Third, no additional research was done to ascertain how the obstacles interact with one another; instead, the barriers were simply rated according to their significance. Future investigations could look at the obstacles to blockchain adoption in different sectors and nations in order to solve the limitations of this study. Future research may also look into the relationships between the hurdles that have been found and how to address them all at once.

Blockchain technology has the potential to enhance the economic sustainability of the supply chain by enabling effective traceability, improved visibility through information sharing, transparent processes, and decentralisation. Additionally, it can contribute to social and environmental sustainability by promoting resource efficiency, responsibility, the use of smart contracts, trust development, and avoidance of fraud.

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List of Publications and their proofs

Title	Conference
Industry 4.0 Transformation: Prioritizing Challenges to Blockchain Adoption in Supply Chain Using Best-Worst Method	22nd ISME International conference on "Recent Advances in Mechanical Engineering for Sustainable Development"

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Decision for Manuscript ID ISME2024_303 submitted to ISME 2024

1 message

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To: vatansingh4669@gmail.com

Dear Author,
Greetings of the Day!

Manuscript ID **ISME2024_303**, entitled "Industry 4.0 Transformation: Prioritizing Challenges to Blockchain Adoption in Supply Chain using Best-Worst Method", submitted to ISME2024, has been reviewed.

We are pleased to inform you that based on the preliminary reviewer's report, the manuscript has been accepted for presentation at the conference ISME 2024.

You are requested to kindly deposit the registration fee and provide the payment details in the registration form by 26th May 2024 till 08:00 pm (Ignore if already registered).

Thank you for being so patient!

Regards,

ISME Editorial Team

List of Publications and their proofs

Title	Conference
Challenges in Supply Chain 4.0: A Bibliometric Analysis	4^{th} International Conference on A holy trinity of AI, Sustainability and Entrepreneurship (UAIIRC 2024)

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MR.TARUN SINGH ANAND
Chancellor - Universal Ai University

DR. ASHA BHATIA
Dean of Research Universal Ai University

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EDUCATION

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CBSE (Class XII)	2016	Indus Public School	95.00 %
CBSE (Class X)	2014	Indus Public School	91.20 %

INTERNSHIPS

Research Assistant ► Institute of Product Engineering, KIT, Germany
Feb 2020 - May 2020

- Increased the efficiency of communication within distributed teams to help with the Distributed Product Development.
- Found the Challenges faced by Distributed teams related to communication.
- Found the Measures to be taken by the Distributed teams to tackle the challenges in communication in collaboration in Distributed Product Development.

Vehicle Inspection ► Maruti Suzuki India Limited
Jun 2019 - Jul 2019

- Learned about the Vehicle Inspection and different tests carried out to inspect the vehicle.
- Worked on the Analysis of Diagnostic Trouble Codes to find the cause of a problem in the vehicles.

TECHNICAL SKILLS

VBA for Excel, Tableau (Basic)	Microsoft Office, Excel (Intermediate)	Python (Basic), SQL(Basic)

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- Organizing Committee member in Annual Athletics Meet, 2018 held at PEC
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- Six Sigma Tools for Define and Measure by University System of Georgia
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