Identification of the Barriers to Implementation of Blockchain Technology in Cold Food Supply Chain: An Integrated Approach of Fuzzy DEMATEL and Fuzzy-SBWM

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Fall 2022-MS L&SCM-00000402514-NBS

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A thesis submitted to the National University of Science and Technology, Islamabad,

in partial fulfilment of the requirements for the degree of

Masters in Logistics & Supply Chain Management

Supervisor: Dr. Waqas Ahmed

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(2024)

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I **Khansa Sadia** hereby state that my MS thesis titled "**Identification of the Barriers to Implementation of Blockchain Technology in Cold Food Supply Chain: An Integrated Approach of Fuzzy DEMATEL and Fuzzy-SBWM**" is my own work and has not been submitted previously by me for taking any degree from National University of Sciences and Technology, Islamabad or anywhere else in the country/ world.

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DEDICATION

This is dedicated to my Mama the most who helped me effortlessly through out this journey, my Dear Husband who provided me opportunity to continue my educational journey and my Dearest Son who sacrificed a lot for me.

ACKNOWLEDGMENTS

First and foremost, I would like to express my deepest gratitude to Almighty ALLAH, whose boundless blessings, guidance, and mercy have made this journey possible. His wisdom and grace have been my strength throughout this academic endeavor. I am thankful to my supervisor, Dr. Waqas Ahmed, for their invaluable guidance, insightful feedback, and unwavering support. I would also like to extend my sincere thanks to the entire university team, including the faculty and administrative staff, for providing me with the necessary resources, knowledge, and a conducive environment for academic growth. Their dedication and hard work have played a significant role in my educational experience. Finally, I wish to express my heartfelt appreciation to my family and friends. Their endless love, prayers, and encouragement have been a constant source of motivation for me. Without their support and understanding, this achievement would not have been possible.

Thank you all for your contribution to this significant milestone in my life.

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ABSTRACT

As we know, in this emerging era of technology organizations need to adopt the latest technologies to enhance their systems efficiently and effectively for the transparency and traceability of transactions. In this regard, blockchain technology, which is a decentralized digital ledger system initially used only for cryptocurrencies but now applied in different industries is used for the sake of the transability of data. In the context of supply chain management blockchain is used for the traceability and traceability of transactions from start to end customer. This study addresses barriers to the implementation of blockchain technology in the cold supply chain. The study highlights the importance of robust supply chain management in cold supply chains. It incorporates various terms, including cold supply chains, blockchain technology, and the use of the integration of Fuzzy SBWM and Fuzzy DEMATEL techniques in the methodology. These methodologies are used to identify the weights of the barriers and their respective sub-barriers without considering interdependencies and inner dependency. A review of the literature, an extensive methodology that includes interviews, and the Fuzzy SBWM and Fuzzy DEMATEL techniques are all part of the mixed methods approach. The research attempts to offer sophisticated insights and strategic recommendations for overcoming obstacles in the successful deployment of blockchain technology in cold supply chains by identifying and evaluating barriers through this varied methodology.

1. INTRODUCTION

Supply chain management involves the organized and strategic coordination of regular business functions and tactics both within a specific company and among various businesses in the supply chain. The goal is to enhance the overall performance of individual companies and the entire supply chain in the long term (Mentzer et al., 2001). A resilient supply network is essential for seamless supply chain management, fostering collaboration with suppliers and distributors. Leveraging technology and open communication helps identify and mitigate risks, enhancing operational efficiency in a dynamic business environment. Building strong supplier partnerships is crucial for agile supply chain management, fostering adaptability to market changes, creating joint development opportunities, and facilitating proactive management (Farida., 2023).

Considering the impact of COVID-19 on the supply chain, (Montoya-Torres et al., 2023), recommended strategies to enhance resilience including refining the supply chain structure, fostering collaboration, and embracing technology. These measures aim to address challenges and shape the future of supply chain management. Among the expansive realm of supply chain management, cold supply chains distinguish themselves with distinctive attributes, occupying a crucial role in global trade networks. Recognizing their unique status, a thorough examination of their characteristics becomes imperative from several key perspectives. Cold supply chains are designed to handle items, predominantly perishable food products, pharmaceuticals including medicines and vaccines, as well as biological tissues, that demand consistent refrigeration. They serve as the primary means for the transportation and management of two main categories of products: perishable food items and medical supplies.

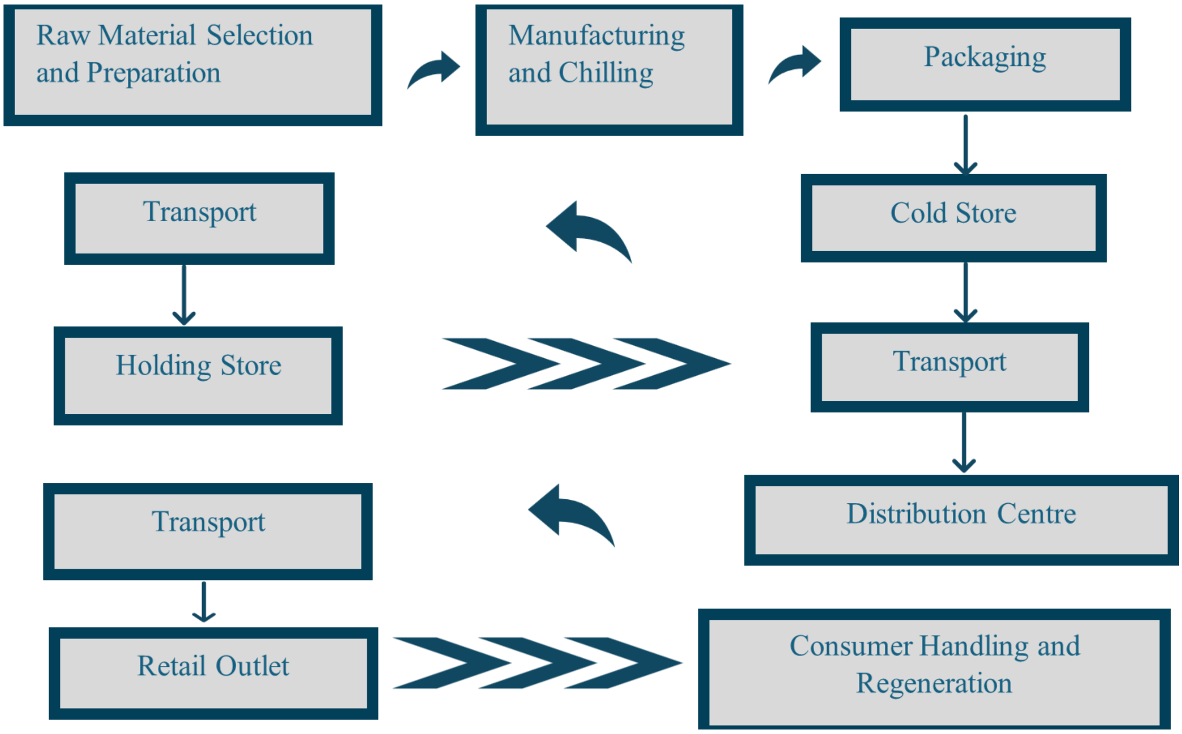

Figure 1.1: Process of Cold Supply Chain

A diverse range of products, including raw fruits and vegetables various types of meat and fresh proteins, frozen processed foods, pharmaceuticals drugs, vaccines, blood, and temperature-sensitive tissues, rely on an intricate global network encompassing sourcing, transportation, and storage (Bozorgi et al., 2014).

The supply chain engages various stakeholders and participants to carry out different operations from suppliers to customers (Nanda et al., 2023). Cold chain logistics meet consumer demand and mitigate deterioration during fresh product transportation, prompting firms to outsource to 3PL providers for cost reduction. However, the uncontrollable transportation chain still challenges fundamental deterioration solutions, leading to self-borne costs for retailers. To address these issues, the fresh industry is undergoing a digital transition, emphasizing the importance of accurate traceability information for enhanced quality management (Zhang et al., 2023a). In recent years, the focus of many researchers has shifted towards the application of blockchain technology in diverse industries (Xu et al., 2021).

Blockchain technology, known for its decentralization, encryption, and transparency is being adopted by firms in the cold supply chain to address various issues. Establishing blockchain-based traceability platforms enables accurate tracking of information and many other important aspects (Zhang et al., 2023b). Blockchains are made up of connected blocks, ensuring tamper-proof and secure data transactions. Each transaction has a unique ID, allowing easy identification and location tracking. Blockchain offers fault-tolerant data sharing, eliminates compromised nodes, and provides enhanced security, transparency, and trust for user data. The interconnected blocks, encrypted with hash values and timestamps, make tampering with data difficult. Miners in the blockchain network verify and approve each block through proof of work mathematical operations, ensuring data integrity (Nanda et al., 2023).

According to (Bhutta et al., 2021) blockchain technology gained prominence with the rapid rise of Bitcoin, and financial service organizations quickly recognized its significance in manufacturing, legal services, financial services, and electronics (Bhardwaj & Kaushik, 2018). Blockchain system enhances product tracking in the cold chain process. Using smart logistics, key data is recorded on a decentralized ledger, ensuring identity verification and access control. This includes certification, custom/quality checks, and IoT sensor data. Continuous updates through IoT devices track product condition, location, and status from origin, registering information on the blockchain. This ensures transparency and traceability throughout the cold chain logistics process (Wang et al., 2023).

Unique challenges are faced by the agri-food supply chain these challenges make it harder to maintain the product in good quality. Some of the challenges include perishability of products, shelf-life constraints, and the need for conditioned transportation and storage. There is a growing focus on managing the cold chain to maintain product quality and safety as food safety regulations and consumer awareness are increasing day by day. At all stages, there is a crucial need for temperature control to prevent loss of quality and spoilage. Proper cold chain management is important to make sure that the products are stored and transported under optimal conditions, meeting customer expectations for fresh and safe products (Kuo & Chen, 2010). Refrigerated food can be categorized based on storage temperature into frozen (below -18°C), cold-chilled (0-1°C), medium-chilled (5°C), and exotic-chilled (10-15°C).

Hence different kinds of foods like fish, meat, dairy, fruits, and vegetables are kept at different temperatures. This maintains the quality of each one of these foods at different temperatures (Ndraha et al., 2018). The vaccine cold chain starts with cold storage at the manufacturer, transport to the distributor, and provider, and in the end to the final user. Proper storage conditions at every stage are important otherwise exposure to extreme temperatures can cause irreversible damage to the vaccine. In Pakistan, the EPI supply chain distributes vaccines through a "Push" system, using air and road transportation. Provinces and districts use refrigerated vehicles, while passive containers are employed for distribution from district stores to health facilities. Storage facilities include both positive and negative cold rooms at the federal and provincial levels (Khan et al., 2017).

Cold chain management is a strategic approach for transporting and storing perishable goods, especially medicines, under controlled conditions to extend their shelf life. The main goal is to maintain the quality of medicines and ensure compliance with regulations. Proper temperature control is crucial, as mishandling can lead to significant financial losses, particularly with vaccines and biologics, which are sensitive to temperature changes. The pharmaceutical industry increasingly focuses on cold chain management due to the growing prevalence of temperature-sensitive drugs. It includes effective distribution systems, skilled personnel, robust inventory management, and integrated logistics activities. The use of advanced technology is essential for monitoring and maintaining optimal conditions throughout the supply chain. Azam, (2021) informs that many governments and companies are now adopting high-tech solutions to minimize waste and increase efficiency. However, the importance of quality assurance and forecasting methods is not to be ignored as they are key in managing risks for the timely availability of safe effective medicines.

Fuzzy sets is a mathematical subject that describes how we deal with uncertainty and, the complexity of human thinking. As opposed to usual sets with precise boundaries, fuzzy sets support both accurate subsets inside as well as likelihood steps that are appropriate for representing ambiguous or superficial information. These tend to be most useful in situations where an exact prioritization and constraints are not specified well. Fuzzy numbers allow the representation of vagueness, which represents linguistic terms through numerical values thus providing support in decision making using Fuzzy logic. These properties have made fuzzy sets an important tool for modeling and decision-making in contexts where precision is not desirable or unattainable, thereby enabling more realistic analyses (Kuzu, 2023). Fuzzy sets are used to represent uncertainty by allowing values to range within a spectrum rather than being fixed.

A fuzzy number, like a "triangular fuzzy number," represents an estimate with three key points: a lower bound, a most likely value, and an upper bound. For example, if estimating travel time, instead of saying exactly 30 minutes, you might say "between 20 and 40 minutes, but most likely 30 minutes." The degree of confidence in each estimate within this range is described by the membership function, which determines how belonging each value is to the fuzzy set. This function forms a shape that is often a triangle that peaks at the most likely value and declines towards the lower and upper bounds, reflecting decreasing certainty. This approach helps in decision-making by accounting for imprecision and providing a more flexible, realistic representation of uncertainty (Lin et al., 2018). When multiple experts interact with each other to reach a consensus on complex issues then it is a group decision-making process. These decisions are often evaluated using qualitative criteria in linguistic terms rather than precise numbers.

These linguistic terms make it very difficult to evaluate the results. To solve this problem fuzzy sets are used to transform those vague linguistic terms into triangular fuzzy numbers. These triangular fuzzy numbers help in quantifying the uncertainty in expert assessments. Mathematical operations like addition, subtraction, and multiplication can be applied to these fuzzy numbers. After that, the fuzzy numbers are converted to crisp values by defuzzification for further aggregation. The method of converting fuzzy data into crisp scores involves standardizing the fuzzy numbers, calculating left and right normalized values, and then determining a final crisp score based on the membership function (Zhou et al., 2011).

The DEMATEL technique is a method for analyzing complex decision-making problems by identifying cause-and-effect relationships. DEMATEL uses graphs to visualize interdependencies and influence values. It consists of the following steps first, an initial direct-relation matrix is constructed using linguistic assessments from knowledgeable decision-makers, converting these into real values. This matrix is then normalized. A total-relation matrix is calculated, showing both direct and indirect effects among criteria. A total-relation matrix is calculated, showing both direct and indirect effects among criteria. These provide the input message by giving us row and column sums, which are measures of each criterion's importance factor impact (Akyuz & Celik, 2015). DEMATEL, which was originally from the 1970s and particularly popular in Japan, is operated by directed graphs and gives both direct and indirect influence relation between factors. Finally, the approach generates a directed graph illustrating the significance and effects of each factor in the system (Wu & Lee, 2007).

This method builds an Influence Relation Matrix to reflect pair-wise influences between the criteria. Thus, the matrix gives us a causal diagram that reports all insights into direct and indirect effects. To deal with problems in uncertain and fuzzy environments, the DEMATEL method was applied including the concept of fuzzy information into its system. However, the adaptation is in terms of representing uncertainties and vagueness using fuzzy numbers and linguistic terms instead of just crisp values. However, it exists that some recent advances in DEMATEL use an alphabet of alpha-level sets. Besides, these sets can manage fuzzy information better and also prevent the loss of potential information while defuzzification is simply done to convert (Zhang et al., 2023).

DEMATEL method helps analyze complex relationships by the use of structural models, at the same time it can be difficult to conduct decision-making in fuzzy environments because of the presence of intricate factors. Since October last year, our information sources have been limited. Thus, in order to manage this and improve upon its accuracy both fuzzy and DEMATEL methods are incorporated into a single fuzzy DEMATEL method. Fuzzy theory provides us with membership functions such as these which give rise to linguistic variables describing whether some variables have more influence on another variable than others do or if they have no impact at all (Mirmousa & Dehnavi, 2016).

Understanding these relationships more precisely is the aim of the current research using this technique. Additionally, the CFCS algorithm has been applied to process and assess the correlations between different indices thus improving the accuracy of analysis within a fuzzy environment. This strategy serves as a valuable tool for addressing complexities and ambiguities in decision-making situations (Mirmousa & Dehnavi, 2016). The DEMATEL method is useful in making decisions based on building structural models that illustrate cause-effect links among diverse factors. Thereafter, clarification on what the decision goals is done together with forming committees for obtaining joint insights from people involved in various fields related to carrying out such studies; significant evaluative factors are then outlined; followed by designing a fuzzy linguistic scale that would fill gaps caused by ambiguity during assessment phases thereafter finalizing an initial direct-relation matrix whereby it remains necessary to provide crisp values converted from fuzzy evaluations as well as evaluating relationships among them too so that they can be calculated later at the computation phase wherein another matrix enters into existence called resultant direct-relation matrix (Wu, 2012).

The Best-Worst Method (BWM) is an MCDM tool. It is designed to be effective for you to prioritize and evaluate options. The BWM is used when there are uncertain or vague conditions. In addition, decision-making challenges that result from lacking of precise information or absence of accurate data can also be solved using BWM. These are situations often associated with real-world scenarios. BWM helps to compare the best and worst alternatives which leads to optimum decisions. BWM has been integrated with theories like fuzzy set theory as a way of managing uncertainty and ambiguity. These theories come up with complex mathematical models that enhance the decision-making process (Amiri et al., 2023). The fuzzy BWM method employs fuzzy logic, thus providing a more accurate environment for decision-making under multiple criteria conditions. It employs fuzzy pair-wise comparisons in order to express and denote preferences through linguistic terms, and then they are converted into fuzzy ratings. It is a more efficient method that requires fewer comparisons than traditional approaches, and it also translates fuzzy weights into crisp values (Amiri et al., 2020).

Decision-making becomes easier for managers because it reduces the need for comparison and increases consistency, especially when they are uncertain. It is advised to be used for many purposes such as evaluating suppliers and determining their performance (Amiri et al., 2023). In ship recycling, fuzzy BWM helps address environmental and health challenges posed by hazardous residues. It prioritizes risks and suggests improvements to mitigate environmental pollution, emphasizing the need for more data and further research (Li et al., 2023). This method is applicable across various industries to enhance sustainability and safety.

1.1. Problem Formulation

To fill the gap in the current literature, this study introduces a comprehensive and refined method for identifying barriers to blockchain technology implementation in the cold supply chain. By employing Fuzzy SBWM and Fuzzy DEMATEL methodologies. Organizations can systematically identify, prioritize, and understand the interdependency among these barriers. This robust framework enhances decision-making, strategic planning, and risk management, ultimately facilitating smoother and more successful blockchain implementation, improving supply chain performance, reducing costs, enhancing quality control, and strengthening relationships with partners and customers.

1.2. Research Questions:

1. What are the key- barriers and sub-barriers that should be considered in the implementation of blockchain technology in the cold food supply chain?
2. What is the effective approach to establish the relative importance (weights) of barriers and their sub-barriers in the implementation of blockchain technology in the cold supply chain?
3. How can the interdependencies among the barriers be determined and applied to their weights?
4. What can be an effective method to evaluate the impact of identified barriers?
5. How can the proposed integrated approach be applied to evaluate and address the barriers using a real-world case study scenario?

2. LITERATURE REVIEW

Blockchain has gained a lot of importance in recent years due to its ability to increase transparency, traceability, and efficiency. This literature review gives detailed research studies on adopting blockchain technology in the cold food supply chain. Mainly it focuses on implementation barriers and effective methodologies. This literature review covers various topics related to the research such as supply chain management principles, challenges in the cold supply chain, and the role of blockchain technology. Technological, organizational, and environmental barriers are identified, and multiple case studies and pilot projects are evaluated. To address these barriers relevant methodologies are discussed such as fuzzy DEMATEL and fuzzy SBWM. The aim is to provide a detailed understanding of the complexities.

2.1. Supply Chain Management

Supply chain management is efficiently handling the flow of products, services, and information from suppliers to consumers. Supply chain management makes sure there are no issues throughout the process, and everything is moving smoothly from the beginning till the end. Some of the key tasks of supply chain management are buying raw materials turning them into finished goods and supplying them to the customers. It also helps to manage information and materials to ensure on-time delivery, good quality, and the right costs. An additional benefit of supply chain management is that it helps businesses stay competitive (Bokrantz & Dul, 2023). The phases of supply chain management can be generally broken down into five phases. The first phase is product and inventory planning, which is carried out by checking the market for demand. The next phase is obtaining raw materials and other basic supplies from various. The third is transforming raw materials into finished products. The next step is sales and distribution of the final product and lastly sales support such as customer services, product returns, and recycling.

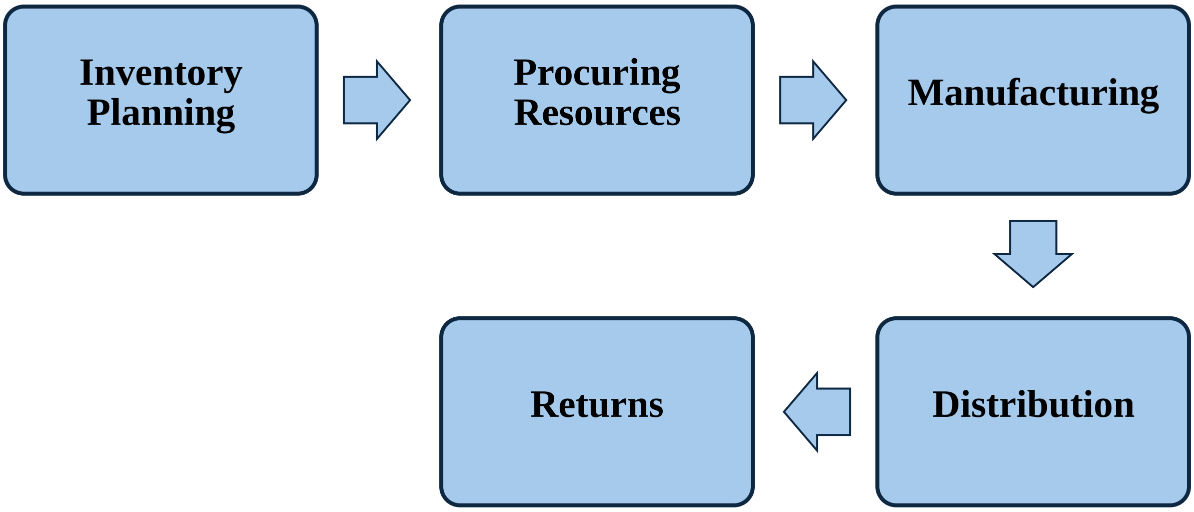

Figure 2.1: Process of Supply Chain Management

Supply chain management enhances efficiency and customer satisfaction. Supply chain management mainly has its focus on synchronizing the management of goods, information, and relationships from sourcing and through to consumption. To meet customer needs, supply chain management adopts process process-oriented approach which is to reorganize the traditional functions to meet customer needs. Some of the key processes of supply chain management involve managing customer relationships fostering loyalty, ensuring high-quality customer service, balancing supply and demand through demand management, accurately processing and delivering orders, overseeing production to align with demand, acquiring necessary goods and services, and developing new products for market introduction.

By the integration of these activities firms and companies can become more resilient and customer-centric supply chain (Mentzer et al., 2001). Supply chain management integrates product flow processes across functions and between channel members. Supply chain management efficiently handles inter-functional and inter-organizational management within a firm. Logistics are seen as a subset of supply chain management that aims to better activity administration within a firm (Ballou, 2007). Constant efforts to improve supply chain management can guarantee increased product availability and ensure on-time delivery. By understanding every stage of the process from suppliers to consumers companies can easily identify potential problems that might slow down the process of supply flow.

Supply chain management ensures close collaborations and strong long-term relationships with the suppliers that are essential for consistently providing raw materials supply, joint innovation, better price negotiations, and increased efficiency (Farida, 2023). Supply chain management opens new research opportunities in areas such as collaboration, technology adoption, knowledge sharing, and scenario planning, raising awareness and promoting sustainable, data-driven decision-making. When such strategies are implemented successfully companies can improve their operations even in tough circumstances. To build a sustainable and cohesive supply chain ecosystem, we must understand external factors and plan for multiple scenarios. Building cooperation, advanced technologies, and strategic plans make supply chains more resilient. These approaches help make performance better, enabling long-term sustainability in the supply chains (Montoya-Torres et al., 2023)

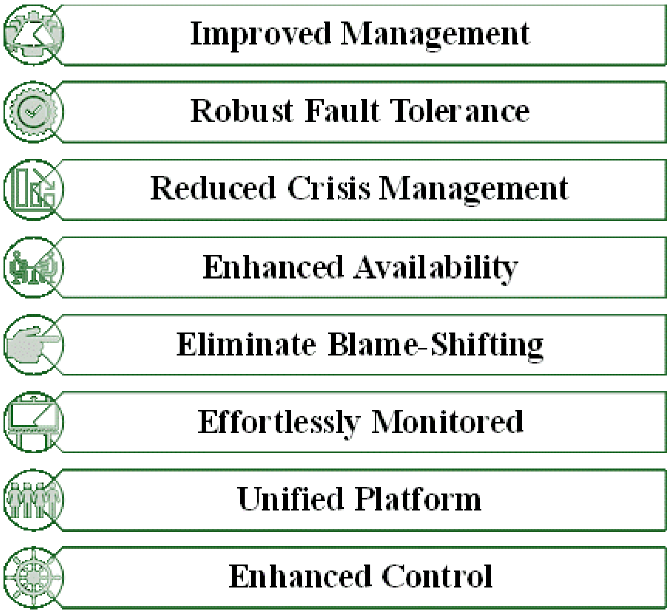

Figure 2.2: Benefits of Blockchain Technology

2.2. Blockchain Technology

Blockchain utilizes a decentralized framework to enable direct network connections which enhances data flow. Blockchain is well recognized for its innovation in ensuring data safety, transparency, and efficiency which has earned it a solid reputation for fostering sustainable global supply chains (Yu et al., 2024). When a supply chain uses blockchain technology information flows with more traceability of the goods and information (Tang & Veelenturf, 2019). Early on blockchain technology was only applied in the banking field for secure transactions now it has multiplied into various other fields with a notable impact among stakeholders in supply chains (Kalimuthu et al., 2024). To design sustainable supply chains blockchain technology offers transparency, encryption, and safe decentralization ledgers (Al Amin et al., 2023). Key features of blockchain technology like transparency, decentralization, traceability, and security help in diminishing supply chain risks (Dhingra et al., 2024).

2.2.1. Types of Blockchain:

Blockchain works in many categories such as strong medical records, tracking goods, recording, verifying transaction details, binding agreements, and so on. It is of a distributed nature, and it allows records to be stored in connected systems having the same data. There are four types of blockchains. Private blockchains also known as permission blockchains have one operator. Access and data addition are in the control of this single operator. The users are verified, and the system is thus centralized or partially decentralized. Properties of these types of block chains are reliable transactions but at the same time, it’s less secure as they can be modified by the editor. Public blockchains are decentralized blockchains as no individual or organization controls them. The network is open to everyone and allows

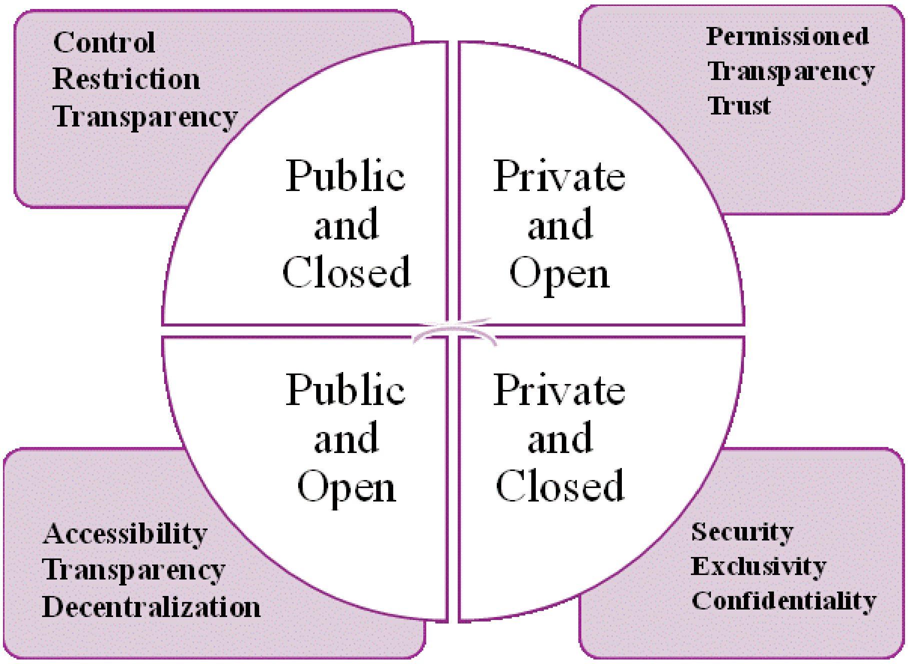

Figure 2.3: Different Types of Blockchain with Description

anonymous participation. These features make these types of blockchains permissionless.

These blockchains provide high security, immutability, and easy access. However, the drawback to this is high energy consumption and low throughput. Consortium blockchains are utilized when multiple organizations share data and conduct transactions. These are permissioned blockchains and a type of federated blockchain that offers a high level of decentralization and security as compared to private blockchains. Another type of blockchains is hybrid blockchains these are essentially a mixture of both private and public blockchains. Hybrid blockchains maintain a balance between control and freedom having both permissioned and permissionless features. These can be adapted to various situations and are highly useful (Dhingra et al., 2024).

Blockchain applications in the healthcare supply chain cover electronic records, vaccine-based applications, medication, and blood supply chains (Dhingra et al., 2024). The customers of seafood supply chains can scan a QR code and simply get to know about the journey of the product from the sea to the supermarket through the application of blockchain (Thompson & Rust, 2023). Some of the leading food companies of the world including Nestle, Walmart, and Dole utilize blockchain technology for food traceability (George & Al-Ansari, 2023). Supply chains have intricate networks that involve multiple stages, locations, entities, suppliers, manufacturers, distributors, and retailers. Blockchain is utilized in Supply chain management to address the complexity of challenges in modern supply chains.

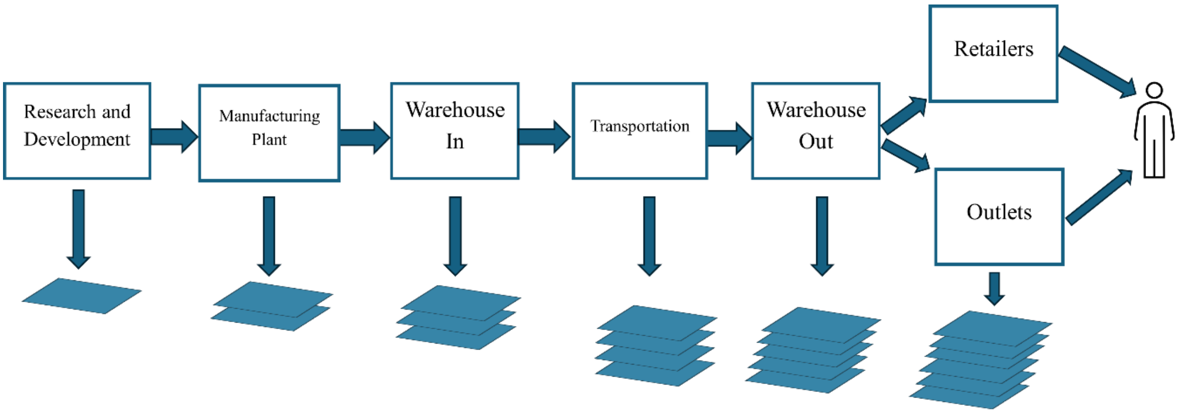

Figure 2.4: Process of Supply Chain Management in Blockchain

In addition to that blockchain also provides additional features such as enhanced product traceability, smart contracts, and data immutability. These benefits are really helpful in achieving proper transparency and efficiency in the supply chain (Nisar et al., 2024). Blockchain significantly enhances supply chain management and can be integrated at each step of the process.

Blockchain helps firms gather, process, and enhance the productibility of information more efficiently. This ultimately helps in making better decisions and reduces uncertainties during transactions leading to more trust among the stakeholders. BCT greatly ensures a smoother and more efficient supply chain (Vafadarnikjoo et al., 2023). Blockchain-based systems add features of sharing and verifying data with enhanced security and faster interface hence leading to a better traceability system (Collart & Canales, 2022). In seafood supply chains blockchain promotes efficiency by ensuring transparency, traceability, and trust and also prevents fraud and overall operations (Bharathi S et al., 2024).

Blockchain contributes to social sustainability by cultivating trust, and worker welfare and mitigating fraud in supply chains. (Munir et al., 2022). Despite the potential benefits of blockchain technology, there are still technical challenges faced by managers such as implementation, interoperability, scalability, data privacy, and security (Singh et al., 2023). Integration of blockchain and its implications can be costly because implementation costs for IT development hardware purchase, distribution, training, monitoring, application design, and testing are high. Such regulatory issues can be the non-technical issues regarding blockchain technology (Patil et al., 2021).

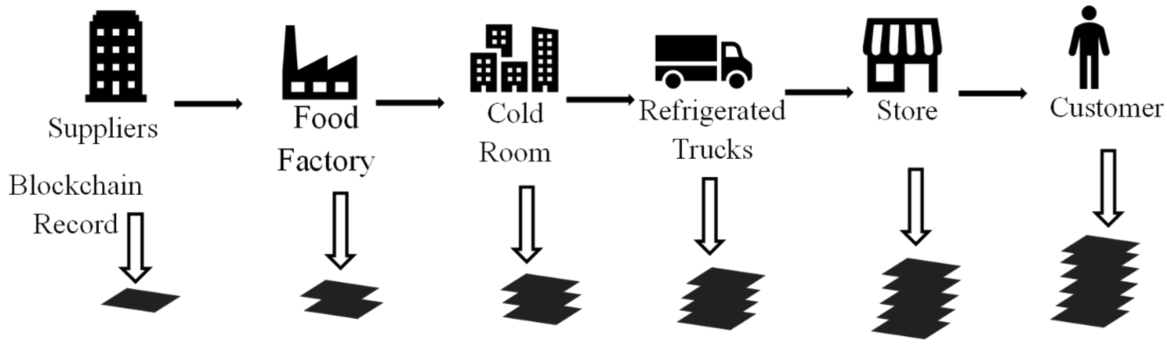

Figure 2.5: Challenges of Blockchain Technology in Supply Chain Management

2.2.2. Challenges

Blockchain scalability is a big challenge as the number of transactions keeps growing, making the blockchain bulky. For example, Bitcoin's blockchain is now over 100 GB. This size, combined with restrictions on block size and generation time, limits Bitcoin to handle about 7 transactions per second, which is far from enough for real-time, high-volume needs. To tackle this, solutions include optimizing storage by removing old transaction records and using lightweight clients. Another approach is redesigning the blockchain architecture, like in Bitcoin-NG, which separates block components to improve efficiency. While blockchain is considered secure, privacy leakage is a major concern. Even though transactions use pseudonymous addresses, the transaction values and balances are publicly visible, potentially exposing user identities.

Studies have shown that transactions can be linked to reveal user information, including linking pseudonyms to IP addresses. To enhance anonymity, mixing services shuffle transaction inputs and outputs to obscure relationships, and methods like Zerocoin and Zerocash use zero-knowledge proofs to hide transaction details. Selfish mining is a significant threat to blockchain security, where miners with less than 51% of computing power can manipulate the system for personal gain. Selfish miners keep their mined blocks private and reveal them strategically to override the public chain, causing honest miners to waste resources on outdated branches. This strategy increases revenue for selfish miners and can attract more miners to join selfish pools, potentially exceeding the 51% threshold. Solutions include methods for honest miners to choose more recent blocks and schemes like ZeroBlock, which impose strict time intervals for block acceptance to counter selfish mining tactics Top of For Bottom of Form (Wang et al., 2018).

2.3. Overview of Cold Supply Chain

A cold supply chain refers to a specialized system that manages the storage and transportation of decomposable agricultural products. Keeping items at low temperatures minimizes losses and promotes farmer income (Bai et al., 2023). Multiple challenges are faced by cold supply chains involving different mediators which make temperature control and accountability difficult throughout the process. There's often a lack of commitment from top-level management leading to insufficient performance measures and poor collaboration, delivery challenges, and food safety issues due to poor standardization and collaboration. Efficient cold storage and IT infrastructure also suffer from scarcity enabling illegal and unregulated products to enter the market which eventually causes food wastage. Inefficient tracking systems are also culprits to food safety and quality issues, shortage of skilled labor familiar with advanced equipment, dependability issues with third parties and lastly consumer awareness about quality and proper storage conditions all affect cold supply chain operations (Sharma et al., 2021).

2.3.1. Current Challenges

Cold supply chain is unique because rather expensive, requires strict food safety measures like enforcing laws and regulations (Food Safety Act 1990), and relies on strong industry partnerships (Aditjandra et al., 2024). Fragile foods or perishable foods must be kept at a certain temperature along the entire supply chain or else they may get spoiled. Spoilage means the products will contain microorganisms making the product inedible and if the defect is not reported then it will cause long-term issues when consumed by the clients (Mercier et al., 2017). Cold supply storage extends the shelf life of products. Therefore, temperature control in the cold chain is critical to maintaining the quality and safety of stored meat products as it significantly affects the color, composition and bacterial content (Guo et al., 2024). Temperature control of dairy products is important to ensure the successful storage, transportation, and distribution of dairy products which contributes to sustainability and reducing waste. The COVID-19 pandemic had impacted milk production largely, to manage the disruptions accurate forecasting was used for a steady supply of milk (Kashyap et al., 2023).

Challenges like traceability, spoilage and regulatory compliance are observed in the current cold supply chain. High operating costs are a big obstruction in the way of adopting advanced temperature monitoring systems, lack of efficient cold storage facilities is leading to environmental damage moreover the quality of the product is compromised. Improper tracking system often leads to arising concerns such as verifying Halal certification (Sharma et al., 2021). Logistics internet of things (L-IoT) is one of the technologies that's used in cold supply chain and was used in the vaccine supply for COVID-19.

However, there are several limitations to this technology. There are certain laws and regulations that need to be met during international transportation there is no research that suggests how the L-IoT ensures this regulatory compliance during international transportation. For tracking of vaccination there need to be a practical and effective way which is not addressed in the internet of things technology properly. Moreover, there's a need for smart contracts that can handle the unique processes and rules for products like COVID-19 vaccines. Difficulties in production and import of vaccines domestically and a clear plan for tracking system need to be observed and worked upon (Munasinghe & Halgamuge, 2023).

The implementation of blockchain technology in cold supply chains is highly efficient and has several positive aspects. Blockchain aids in food safety and assurance through accurate information on member profiles, inventory monitoring, and shipping processes reducing costs otherwise paid to third-party verifiers which also combats food theft. One of the main plus points for blockchain is its traceability, blockchain facilitates the capture, storage, and transmission of information throughout the cold chain which also helps in backward and forward tracking as well as quality. Transparency and trust are guaranteed by blockchains making fraud difficult. It also improves supply chain collaboration and efficiency by building knowledge and sales management while also reducing unstable demand risks. In this way bound efficiency is improved, planning is optimized, and inventory visibility is increased (Manjula et al., 2021).

2.3.2. Perishable Products

In the case of perishable products cold chain is an extremely essential part of food product supply chains. Perishable products can be foods like cooked foods, ready-to-eat foods, high-risk foods, and fresh foods like raw vegetables, raw fruits, milk, dairy products, fish, poultry, red meats etc. if these perishable goods are not kept in the correct humidity and ventilation control there's a high risk of food

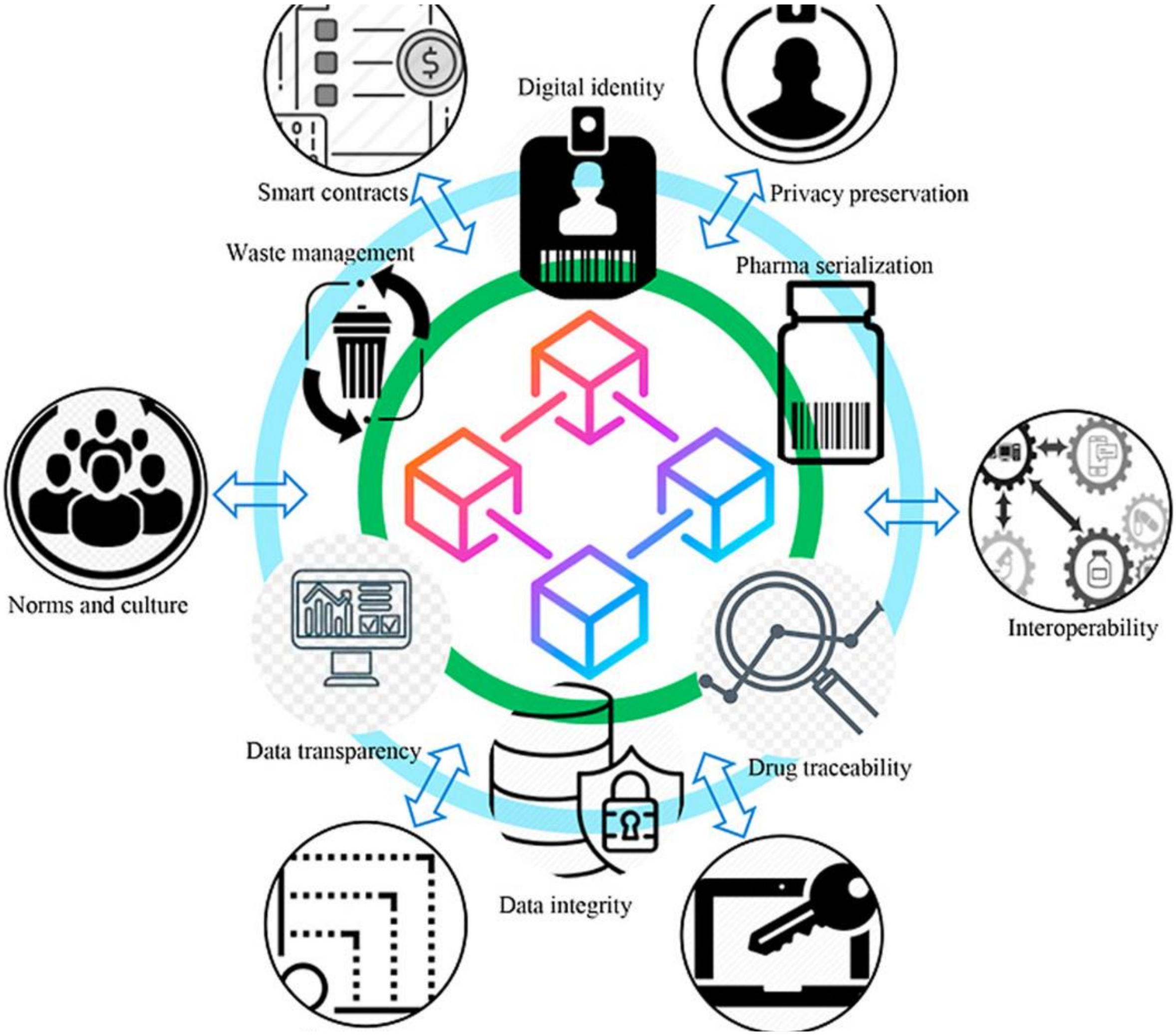

Figure 2.6: Blockchain-Enabled Pharmaceutical Chain

(Source: Adopted from Hosseini Bamakan et al.,2021)

wastes and often health risks. The supply chain management finds it challenging to control the conditions for perishable goods. To give the products better shelf the temperature of the products must be maintained. To maintain the quality it is also ensured that the humidity and lighting intensity is kept in the desired conditioned and products are handled well. Because these products have high risk of getting damaged hence the management has to take timely actions in order to keep the cold chain efficient for the products.

Some problems that can occur with the cold chain is that if specific conditions are not kept then there might be a chance of bacterial growth in the cold chain. Therefore, to control the conditions of the data at all stages there must be technology-based monitoring systems. These systems should have the capability to control the conditions of the products and save it from food wastage and protect the consumers from health issues (Hosseini Bamakan et al., 2021).

2.3.3. Blockchain in Cold Chain

Product safety is one of the most important aspects, however, traditional product traceability systems in cold chain logistics face many issues like centralized storage, low data reliability, susceptibility to tampering, etc. To solve these issues block chain blockchain-based traceability system is applied in cold chain. This system analyses the whole cold chain and designs a data structure that aims to enhance traceability and address security issues. The implementation of a blockchain-based traceability system

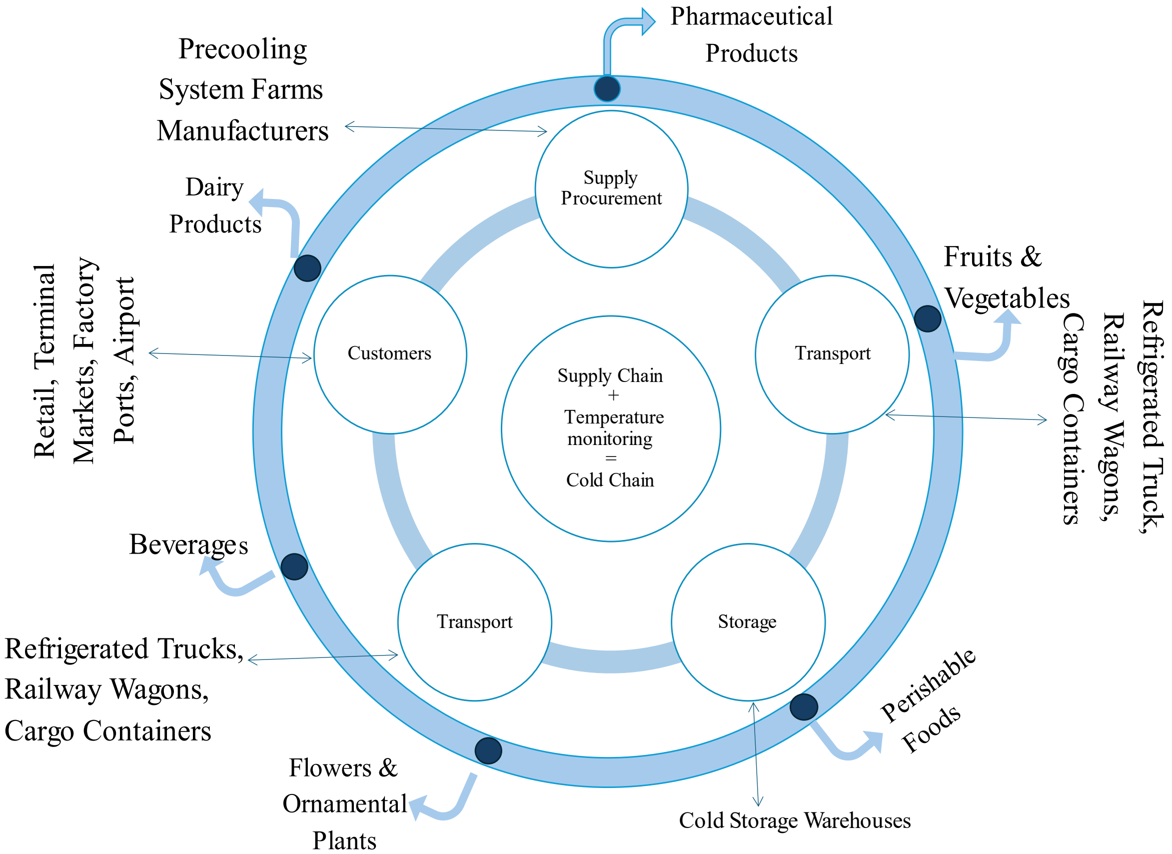

Figure 2.7: Products of Cold Supply Chain

in cold chain logistics offers numerous advantages over traditional methods. By leveraging blockchain technology, data is stored in a decentralized manner, ensuring higher data integrity and making it tamper-proof. This enhances transparency across the entire supply chain, as each transaction is recorded in an immutable ledger that can be accessed by all authorized parties. Moreover, blockchain enables

real-time monitoring of product conditions, such as temperature and humidity, ensuring that any deviations are promptly detected and addressed. This not only improves the overall safety and quality of products but also boosts consumer confidence, as they can verify the authenticity and journey of the products they purchase (X. Zhang et al., 2022).

2.3.4. Potential Barriers:

Although blockchain has struggled to achieve large-scale commercial access many organizations' attempts to gain a grip on the technology weren't as successful on a large scale and smaller organizations hesitate to operate new digital innovations. In addition, barriers like competition, distrust, and wrong labeling also hinder the implementation of blockchain's uptake. Another factor is the previous studies that have overlooked social, cultural, and institutional aspects that discourage the adoption of blockchain (Thompson & Rust, 2023). The incorporation of blockchain technology in the supply chain has been revolutionary in terms of enhancing transparency and efficiency. Blockchain makes secure and decentralized networks that track and verify products, reduce fraud, and improve visibility. It has real-time tracking features along with secure data sharing which are essential for sustainability. There's a significant boost in blockchain-based supply chain performance.

Blockchain also solves information asymmetry through accurate and timely data, trust and collaboration between supply chain participants, efficient streamlining processes, and reduced errors (Itohan

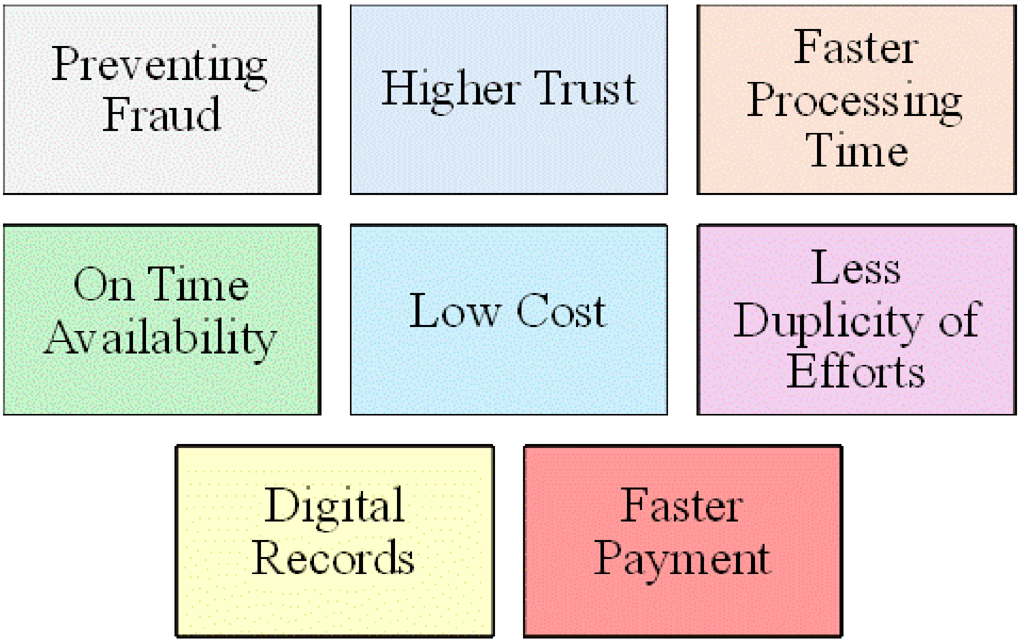

Figure 2.8: Blockchain in Cold Supply Chain

Oriekhoe et al., 2024). Implementation of blockchain in a dairy company shows the improvements in management, security, and strength of the supply chain. Furthermore, (Casino et al., 2020) explain several ways in which blockchain was successful. Using private blockchain and smart system of contracts, blockchain technology was able to create an end-to-end traceability flow that shows the product journey from raw materials to the customer possession. This specific approach led to significant improvements in the supply chain including how this system effectively manages various stakeholders and processes while also making sure that all recorded data is tamper-proof. This successful implementation highlighted the benefits of using blockchain technology in enhancing the traceability and efficiency of the supply chain.

2.3.5. Case Studies and Pilot Projects:

In the automotive sector, blockchain has been used to digitize the process of spare parts disposal. Each spare part can be uniquely identified and tracked throughout its lifecycle, from initial sale to the recycling eventually. The characteristics of blockchain like smart contracts utilized in processes such as verification of the authenticity of the part and also the disposal compliance with environmental regulations. This automation reduces the risk of errors or fraud (Itohan Oriekhoe et al., 2024).

The pharmaceutical industry faces stringent global regulations to ensure the integrity of temperature-sensitive products throughout the supply chain. As product portfolios expand, the importance of robust cold chain management has intensified, necessitating adherence to Good Storage and Distribution Practices. Manufacturers bear ultimate responsibility for maintaining control over environmental conditions, with a heightened focus on temperature monitoring and risk mitigation to prioritize patient safety. Regulatory guidelines from authoritative bodies such as the WHO, ICH, FDA, USP, Health Canada, and the EU emphasize the importance of preserving product quality during distribution. Compliance requires a comprehensive Quality Management System, ongoing risk assessments, and a trained workforce. To achieve this, manufacturers increasingly rely on advanced electronic data loggers for precise temperature monitoring, which must be regularly validated and calibrated.

Developing a reliable monitoring program is crucial to ensuring product quality and patient safety, given the complexity of variables in the supply chain (Bishara, n.d.). The paper by (Kim & Kim, 2018) put forward a creative blood cold chain system using blockchain technology to enhance transparency and traceability. Blockchain provides detailed information on blood usage and disposal, preventing data tampering which is unlike other centralized systems. The system includes blood contracts between hospitals for emergencies, facilitating efficient blood supply, especially for hospitals far from blood banks. This approach is highly helpful as surplus blood can be stored and utilized within its storage period. The study contributes to healthcare by applying blockchain to blood management and plans to expand to include scenarios like inspection failures and storage errors, potentially implementing the design with Hyper-ledger Fabric tools.

2.4. Identification of Barriers to Implementation

Going through the multiple research it was identified that different authors have recognized different sets of barriers using multiple methodologies such Delphi technique or previous literature etc. In this research complete set of barriers are identified through research.

2.4.1. Technological Barriers:

The adoption of blockchain in the supply chain has various technological barriers. One of which is scalability, there has been a major struggle by blockchain to handle many transactions efficiently which has caused delays and inefficient performance. Blockchain faces integration issues with the existing systems which is considered yet another barrier. The integration of blockchain with the existing systems block chain requires complex solutions that are often costly and lead to data security risks. There is a lack of standardization processes in blockchain used in the supply chain which makes team work hard mainly because of different protocols and standards for coding languages. Not only does the establishment of blockchain cost notable prices but also there is a shortage of well-trained technicians making the implementation demanding. Loss of cryptographic keys and software bugs are some of the irreversible threats.

The process of blockchain mining consumes a notable amount of electrical energy making the sustainability costs high and often higher than the financial rewards (Sahebi et al., 2020). A study conducted on blockchain adoption in the Security Services Value Network (SSVN) states some of the technological barriers one of which includes integration of blockchain with existing systems. According to the study when blockchain is integrated into the existing systems there are high chances of operational risk because of the persistence which further leads to difficulty in error correction. Although the continuous evolution of blockchain the potential adopters are still sceptical because of the immaturity of the technology. Another significant barrier to adopting blockchain in SSVN is that while blockchain has its benefits it still may cause security concerns within highly regulatory SSVN environments.

Data security concerns due to high-profile breaches are a major cause for hesitation and create a sense of insecurity in adoption of the blockchain technology. On one hand, blockchain benefits its users with reduced intermediaries hence there's lesser third-party interruption but on the other hand, it also poses a threat to traditional users that leads to resistance (Komulainen & Nätti, 2023). Blockchain technology uses peer-to-peer networks which can be a significant cause for privacy risks because public transactions can reveal user identities and transaction details ultimately compromising anonymity. Moreover, this technology is also vulnerable to cyber-attacks like denial of service (DoS) attacks that work by flooding nodes and fake requests (Biswas & Gupta, 2019).

2.4.2. Organizational Barriers

According to (Vern et al., 2023) the role of government and policymakers in implementing BCT is of much significance as policymakers can create such policies that can enhance blockchain technology implementations. Such new policies can ensure the organization's protection for trading secrets and data storage while also promoting innovation. Organizations that excel in adopting Blockchain Technology (BCT) often share certain traits. Key traits among these are their capacity for innovation and organizational learning. There is a higher rate of companies adopting blockchain technology who already are seeking out, storing, and applying new knowledge. They are more likely to take risks and tend to be willing to adopt new ideas.

Another big factor is the support from top management which plays a key role in the adoption of new technologies like blockchain technology. This is because leaders make strategic decisions and distribute the necessary resources to apply strategies, they have the authority to prove new technologies. Hence if the leaders approve then it is much easier to adopt a certain technology but if they don't back the idea, the adoption process is less likely to happen. Some studies suggest that due to a lack of proper information and awareness about the benefits of blockchain technology, the support from top management might not be as impactful (Malik et al., 2021).

2.4.3. Environmental Barriers:

Organizations are more likely to adopt Blockchain Technology (BCT) when they face strong competition, receive government support, and have ready trading partners. The adoption of innovative technologies like blockchain makes companies stay ahead of their rivals and drives competition. The development of policies and regulations by the government in support of blockchain technology boosts its confidence of it and more companies are inclined towards its adoption and become willing to invest in the technology. However, if the government changes the policies or regulations then it might also affect the adoption of block blockchain technology. So, the companies need to stay informed about the recent policies by the government (Malik et al., 2021).

To integrate blockchain technology with sustainable supply chain management the process involves going through a complex web of challenges. These challenges can be described as regulatory hurdles, industry-specific issues, and the competitive landscape and the dynamics between different companies. Another significant barrier is data confidentiality due to the reason that they are usually hesitant to share information because they fear that it can affect their competitive edge and they might be compromising important information. When there's a lack of communication among the partners or if the partners do not have enough information regarding blockchain technology complicates its adoption.

Due to cultural differences in different settings, it is difficult to adopt a new technology like blockchain because the implementation of blockchain requires rethinking and redesigning the business processes (Kouhizadeh et al., 2021).

2.5. Methodologies for Barrier Analysis

2.5.1. Fuzzy DEMATEL

The fuzzy DEMATEL method is an advanced technological method for the construction of structural models and analysing these models highlighting the causal relationships among complex factors in uncertain fuzzy environments. To better handle decision-making in uncertain environments fuzzy logic is incorporated into the DEMETAL method making the fuzzy DEMEDAL method an expansion of traditional DEMETAL and fuzzy logic (Wu & Lee, 2007). The DEMATEL method should be extended with fuzzy logic to make better decisions (Zhou et al., 2011).

To analyze the interrelationships between factors under uncertain and fuzzy environments fuzzy DEMATEL method has been used widely and high-yielding results have been obtained (Z. X. Zhang et al., 2023). To enhance decision-making efficiency DEMATEL evaluates systems and products by reducing the number of criteria. Fuzzy theory is incorporated in this method resulting in the fuzzy DEMATEL method. In addressing multi-criteria decision-making (MCDM) problems Fuzzy DEMATEL method is useful for addressing issues across various fields. To determine the most influential criteria fuzzy DEMATEL involves the process of defining evaluation goals, creating a fuzzy scale, obtaining a direct relational matrix through expert comparisons, and generating a causal-effect diagram (Muhammad & Cavus, 2017). American scientists developed the DEMATEL (Decision-Making Trial and Evaluation Laboratory) method as a part of the Human Affairs Program between 1972 and 1976. This was useful for addressing complex, intertwined problems.

To analyze the influence among the factors This method uses a directed graph or causal-effect diagram. Fuzzy DEMATEL helps understand the structural relationships within a system and identify solutions to complex problems researchers use this method by categorizing elements into causal and effect groups. DEMATEL was used to resolve fragmented and contradictory phenomena in the initial phase. Since then it has been applied in various fields because of its success rate. To represent the overall impact and net effect of factors DEMATEL method involves constructing a cause-effect relationship diagram based on calculated indices this approach creates a clearer understanding of the system’s dynamics (Zhou et al., 2011).

When this method is applied practically it is critically important to create a direct correlation matrix between various factors which are essentially based on expert opinions. it is often hard to see where the real influence factors lie because Real-world problems are complicated. Sometimes experts have different understandings of the problems, and their decisions are based on qualitative terms like ‘better’ or ‘satisfied’ rather than precise values (Feng & Ma, 2020). To simplify the analysis of the relationships and to make it effortless to see how the variables are influencing each other, the widely spread influential tool DEMATEL method is used to make it easier to understand and visualize complex cause-and-effect relationships in decision-making scenarios.

To capture both direct and indirect matrix influences the DEMATEL process creates a direct relation matrix through pair-wise comparison of variables which is then normalized and then the total relation matrix is calculated (Kuzu, 2023). To determine the overall influence given and received by each criterion, the sums of rows and columns of the total relation matrix is calculated. This summation identifies the importance and net effects of each factor. Finally, the complex interrelationships among factors are visualized through the cause-and-effect diagram, making the dynamics within the system understandable (Akyuz & Celik, 2015). Fuzzy logic is important in complex decision-making because real-life decisions are often imprecise and vague. This situational vagueness is not captured by traditional crisp values, leading to inadequate reflections of reality.

However fuzzy sets introduced a mathematical approach to handle uncertainty of decision making. This technique allows numbers between 0 and 1 to represent a partial truth that is not present in binary crisp sets. Vague and imprecise judgments are managed by mathematical expression. Linguistic variables that is, using terms instead of numbers in fuzzy sets make it easier to deal with quantitative expressions (Wu, 2012). In decision-making processes characterized by uncertainty and asymmetric information, fuzzy sets, introduced in 1965, are utilized to manage vagueness and imprecision. Fuzzy sets represent partial truths with values between 0 and 1, allowing for the mathematical handling of ambiguous judgments (Šmidovnik & Grošelj, 2023).

2.5.2. Fuzzy Simplified Best Worst Method (BWM)

BWM is a well-structured multi-criteria decision-making (MCDM) tool that was particularly designed to help decision-making better and easier by prioritizing and evaluating options in uncertain and vague conditions. To make the best decisions we need precise, error-free, and clear data. However, in real-world situations there is often a lack of precise and clear data, this type of exact and error-free data is rarely found which makes traditional decision-making hard. BWM aids in creating comparisons between the best and worst methods to regulate optimal decision-making. Over time BWM was adopted with other theories like fuzzy set theory and grey to manage uncertain and ambiguous situations during the decision-making process. These theories use intricate mathematical models to create a reliable decision-making process (Amiri et al., 2023).

By incorporating fuzzy logic in BWM we can create a better decision-making environment in uncertain multiple criteria. This method works by identifying criteria by using fuzzy pairwise comparisons (FPC). Those FPCs express preferences through linguistic terms and then translate those terms to fuzzy ratings. These ratings create a fuzzy comparison matrix that captures the importance of each criterion. Fuzzy BWM compares the best and worst criteria using triangular fuzzy numbers this enhances efficiency and requires fewer comparisons in contrast to traditional methods. Then fuzzy weights represent every criterion's relative importance that can be converted to crisp values for practical use. (Amiri et al., 2020).

To identify the most significant quality control criteria for the tempered glass manufacturing process, fuzzy DEMATEL was utilized by researchers. They kicked off the process by interviewing experts to determine and assess the criteria that affect glass quality. They next generated a fuzzy comparison matrix which utilized triangular fuzzy numbers to represent the m linguistic evaluations of their corresponding experts. The next step was to normalize this matrix and create the overall relation matrix Thus, we used influence vs relationship values for each criterion. The final step was defuzzification in which they converted these fuzzy values into clear, comparable results to understand the relative importance of each criterion. The benefits of using fuzzy DEMATEL are numerous. This method supports expert knowledge and ensures that assessments are grounded in practical experience. It handles uncertainty and imprecision by using fuzzy logic, which is particularly useful in complex decision-making environments.

The defuzzification process provides clear, actionable insights into the most critical criteria, helping companies focus their quality improvement efforts most effectively. Furthermore, the method identifies not only the most influential criteria but also the relationships and interactions between different criteria, providing a holistic view of the quality control process (Çelik & Arslankaya, 2023). A study conducted in the construction industry assessed the critical occupational hazards. This innovative method helps the construction managers to come up with functional strategies that will be helpful to prevent accidents. When the fuzzy linguistic scale is used all the imprecise and inaccurate data is successfully handled which makes the fuzzy DEMATEL method superior to the conventional techniques. The fuzzy DEMATEL approach is advantageous especially when there are problems that require group decision-making and uncertain environments.

This method further has applications not only in the construction industry but also in supply chain management and other industries that require understanding and managing complex relationships between the crucial factors for decision-making and improvement of strategies (Seker & Zavadskas, 2017). A study by (Amiri et al., 2023) was conducted on enhancing the decision-making process within organizations using the multi-criteria decision-making MCDM method, specifically under uncertain conditions. This method is useful especially for managers to make reliable decisions with the benefit of having multiple criteria and alternatives.

However, the traditional MCDM method is not as useful for incomplete or inaccurate information which often leads to imprecise and unclear decisions. For solving these issues the study adopts the fuzzy extension of the simplified best worst method involving fuzzy logic and triangular fuzzy numbers as the fuzzy best worst method is great for reducing comparisons, ensuring higher consistency, and also simplifying equations without complex software. This method identifies the decision criteria by selecting the most important and the least important criteria and using linguistic terms to determine their priorities. The study validates this method through numerical examples and comparisons with existing fuzzy approaches and demonstrates its effectiveness in prioritizing criteria under uncertainty.

The proposed method is recommended for various applications, such as supplier evaluation, investment prioritization, and performance assessment, and suggests future research directions like group decision-making and combining other MCDM methods to improve the process further. The ship recycling process possesses various significant environmental and health challenges because of the hazardous residues it produces. This residue influences human life and marine ecosystems. Hence, researchers and decision-makers are constantly seeking methods to mitigate these harmful effects. In this study, the fuzzy Best-Worst Method (BWM) is used to address these concerns. Best-worst method selects the hazards from the process of ship recycling and the use of fuzzy sets in expert evaluations helps to manage uncertainty and vagueness. It was found by the study that as compared to ship recycling hazards the impact of metal residues is higher on the environment.

For the protection of health and safety and the reduction of pollution, the study has provided detailed information on hazardous materials and has suggested improvements regarding ship structures as well as the equipment to prevent pollution in the environment. By adopting these suggestions, the harmful impacts not only on the environment but also on human health can be reduced. On the other hand, the study has further highlighted that there's a need for more data and analytical studies on the impacts of residues and marine pollution on the environment. The applications of fuzzy BWM are not only for marine and ship recycling they can be used in multiple industries and the contexts of the supply chain to prioritize and mitigate environmental and human health hazards successfully. Fuzzy BWM effectively deals with uncertainties in expert evaluations and offers flexible and comprehensive approaches, these opportunities improve sustainability and safety within different sectors (Li et al., 2023).

2.6. Summary of Literature of Implementation Barriers in Blockchain Technology

Table 2.1: Author Contribution Table

Author	Supply Chain Management	Cold Supply Chain	Blockchain Technology	Barriers	Fuzzy-SBWM	Fuzzy-DEMATEL	Methodologies
(Kouhizadeh et al., 2021)	✓		✓	✓			DEMATEL
(Yadav et al., 2023)	✓	✓	✓	✓	✓		
(Boutkhoum et al., 2021)	✓		✓				IFAHP DEMATEL
(Samad et al., 2023)	✓		✓				ISM-DEBATE
(Malik et al., 2021)			✓				Quantitative Method
(Hosseini Bamakan et al.,2021)	✓	✓	✓				Descriptive Analysis
(Nisar et al., 2024)	✓		✓	✓			DEMATEL
(Kouhizadeh et al., 2021)	✓		✓				TIM
(Vafadarnikjoo et al., 2023)	✓		✓				AHP
(Vern et al., 2023)	✓		✓			✓	
(Rejeb et al., 2022)			✓	✓			Delphi and BWM
(Khan et al., 2023)	✓		✓	✓			DEMATEL
(Kaur et al., 2024)	✓		✓	✓		✓	Fuzzy AHP
(Sahebi et al., 2020)	✓		✓	✓			Fuzzy Delphi and BWM
This research	✓	✓	✓	✓	✓	✓	Fuzzy SBWM F-DEMATEL

2.7. Research Framework

The research framework will thus be considered as the base for analysis of implementation of block-chain technology towards cold food supply chain. The model is adapted for this research and consists of five building bricks namely- Introduction, Literature Review, Research Methodology, Application of Methodology in real life and the Results. It provides a step by method to follow for the exploration of key barriers, identification of relevant methodologies and critical analysis .

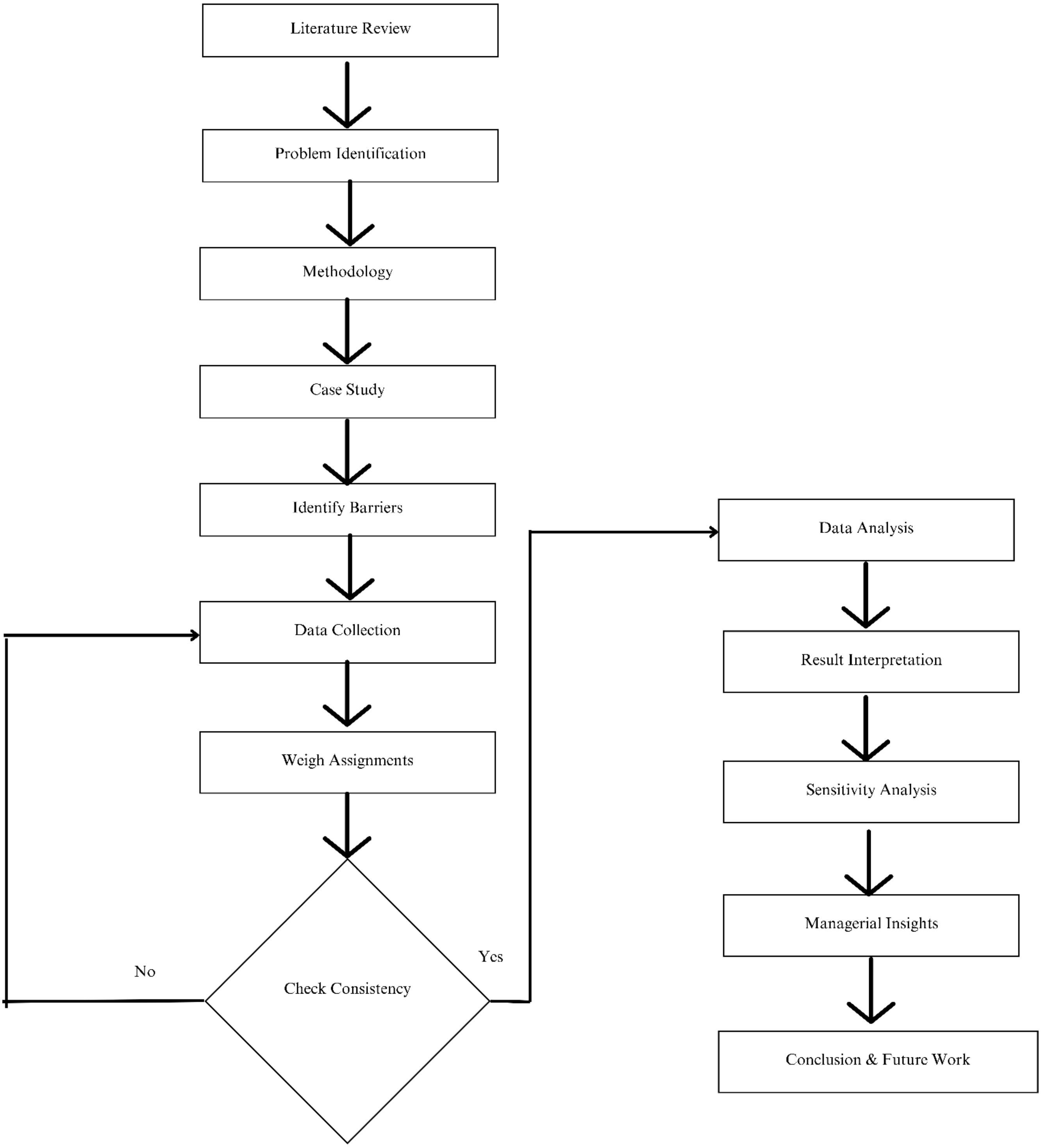

Figure 2.9: Flowchart of Research Framework

3. METHODOLOGICAL APPROACH

Despite the detailed studies on blockchain technology implementation in the cold supply chain, this research aims to address a methodological gap as illustrated in figure 3.1. Initially, thorough literature research is conducted to identify and develop barriers and sub-barriers to blockchain adoption from 41 articles using the TOE framework. In the second step, the Fuzzy Simplified Best Worst Method (F-SBWM) is used to assign weights to these barriers and sub-barriers without considering their interdependencies. The third step involves calculating the consistency ratio to ensure it falls within an acceptable range. Following recommendations by (Govindan et al., 2020), the fourth step uses the Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) approach to calculate the interdependencies among the barriers. In the fifth stage, the interdependency matrix is applied to the weights from stage 2 to calculate the final weights. In the final stage, barriers are ranked based on their combined impact scores, and strategies are developed to address the most critical barriers identified by these scores.

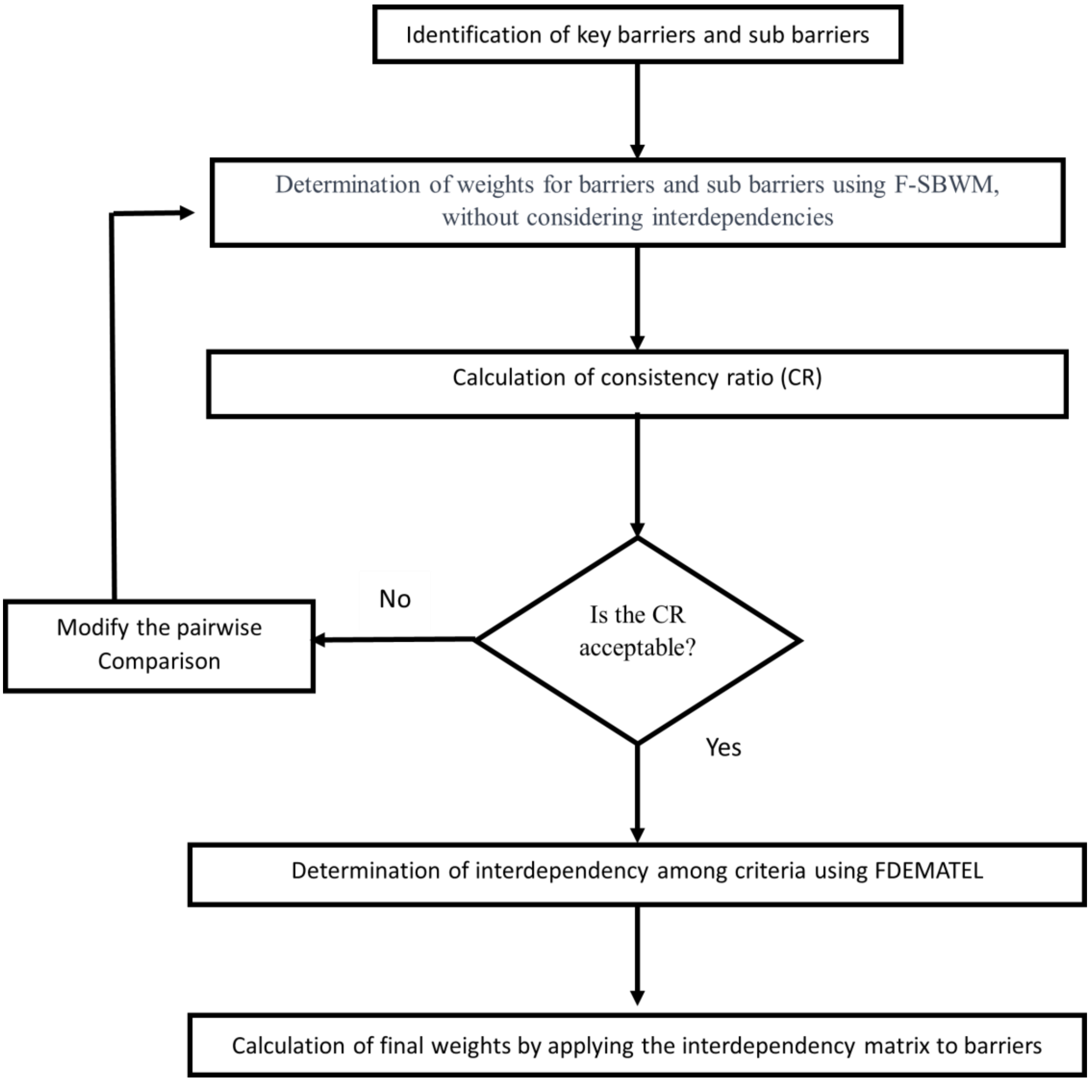

Figure 3.1: Flowchart of Proposed Methodology

3.1. Identifying Key Barriers and Sub Barriers:

In the initial stage of this study, a detailed assessment of existing literature and expert input is conducted to identify the key barriers and sub-barriers to blockchain implementation in the cold supply chain. Through this evaluation, technological, organizational, and environmental barriers are recognized as the primary categories for analysis. Additionally, sub-barriers associated with each main category are identified. Table 3.1 provides a detailed compilation of these barriers and sub-barriers, reflecting insights from the literature. The sub-barriers T1-T5 impact the efficiency and reliability of the cold supply chain, O1-O5 affect organizational readiness and adaptability for blockchain integration, and E1-E5 influence the broader environmental and market context.

Table 3.1: Selected Barriers and Sub-Barriers for Implementation of Blockchain Technology

Barriers	Code	Sub-Barriers	Description	References
Technological Barrier	TB1	Scalability of Technology	Blockchain is not fit for a huge range of transactions and scalability issues are being faced by many organizations.	(Yadav et al., 2023) (Boutkhoum et al., 2021) (Caldarelli et al., 2021) (Samad et al., 2023) (Malik et al., 2021) (Nisar et al., 2024) (Thakker et al., 2024) (Vafadarnikjoo et al., 2023)
	TB2	Immaturity of Technology	This is a significant technical problem due to the immaturity of blockchain. Blockchain cannot manage high volumes of transactions and has not only coped with larger blocks but also become slow to download. These will be the shortfalls of technology.	(Kouhizadeh et al., 2021) (Kumar Singh et al., 2023) (Samad et al., 2023) (Vafadarnikjoo et al., 2023)
	TB3	High Cost of Technology	Collecting information through the supply chain, converting to new systems, and adopting sustainable practices are all costly endeavors that strain the limited financial resources of organizations.	(Moretto & Macchion, 2022)
	TB4	Data Privacy and Security Issues	Although Blockchain Technology is very safe but not completely immune to being attacked or data stolen, hence the integrity of its Data and Information are possibly more prone to security	(Kouhizadeh et al., 2021)(Yadav et al., 2023) (Boutkhoum et al., 2021) (Caldarelli et al., 2021) (Malik et al.,

			breaches by unauthorized users. One of the principal issues with data privacy.	2021) (Nisar et al., 2024) (Thakker et al., 2024)
	TB5	Blockchain immutability challenge	Immutability posits that records cannot be deleted from ledgers. However, while an errant record can have information added to it later on the blockchain and thus be "updated", its history as a mistake will forever live with that record in perpetuity.	(Kouhizadeh et al., 2021)(Yadav et al., 2023) (Kumar Singh et al., 2023) (Caldarelli et al., 2021) (Malik et al., 2021) (Vafadarnikjoo et al., 2023)
Organizational Barrier	OB1	Lack of new Organizational policies for Using Blockchain Technology	Organizations need to establish new policies for adopting blockchain technology including guidelines on the appropriate usage, such as where and when to implement it.	(Kouhizadeh et al., 2021) (Boutkhoum et al., 2021) (Nisar et al., 2024) (Mohammed et al., 2023)
	OB2	Lack of Knowledge and Expertise	Lack of technical know-how on blockchain and sustainable supply chains	(Vafadarnikjoo et al., 2023) (Sahebi et al., 2020) (Mohammed et al., 2023)
	OB3	High Implementation Cost	Learning the blockchain technology greatly DE-incentivizes a large portion of companies both big and small (specifically those existing with low profit margins)-because it costs money.	(Nisar et al., 2024) (Kumar & Barua, 2023)
	OB4	Stakeholder Resistance to Blockchain Culture	Differences in the geographic or corporate-cultural supply chain of the stakeholders/partners may prevent wholehearted adoption by them when presented with blockchain technology.	(Boutkhoum et al., 2021)
	OB5	Lack of tools for blockchain technology implementation in sustainable supply chains	No standards for blockchain technology implementation and measurement of sustainability performance in organizations, and No appropriate methods/tools/ metrics/ techniques.	(Kouhizadeh et al., 2021)
Environmental Barrier	EB1	Challenges in Integrating Sustainable Practices and Blockchain	It is not easy to incorporate traditional supply chain procedures into sustainability standards along with blockchain. Additionally,	(Kouhizadeh et al., 2021) (Boutkhoum et al., 2021) (Mohammed et al., 2023)

		Technology through SCM	future-proofing such sustainable practices requires innovations in technologies, materials, and processes.	
	EB2	Government Policy and Support	Government policies and support are essential for deploying blockchain technology. Regulatory hurdles and the lack of clear guidelines have hindered its adoption.	(Kouhizadeh et al., 2021) (Boutkhoum et al., 2021) (Caldarelli et al., 2021) (Samad et al., 2023) (Malik et al., 2021)
	EB3	Cultural differences between supply chain partners	Geographical spread - across different countries - or diverse organizational cultures among the various actors and partners in a supply chain will delay the acceptance of blockchain technology.	(Kouhizadeh et al., 2021)(Yadav et al., 2023)
	EB4	Lack of customer awareness and tendency about sustainability and blockchain technology	Casual acquaintanceship by consumers about what a blockchain is and how it can be used for supply chain sustainability practices	(Kouhizadeh et al., 2021)
	EB5	Market competition and uncertainty	This application of sustainable practices combined with blockchain technology takes time. It can hinder the market competitiveness of the firm and offer competitive risks. This could be uncertainty about market demands of sustainable consumer goods, customer intent to buy these products, or future sales e.g.	(Caldarelli et al., 2021) (Malik et al., 2021) (Vafadarnikjoo et al., 2023)

3.2. Computation of Weights without Consideration of Interdependencies using F-SBWM

At this stage, weights are allocated to barriers and sub-barriers meanwhile not considering the interdependencies among barriers. This stage is further divided into further steps. The important relationships and mathematical operators related to Triangular Fuzzy Numbers used in the suggested framework are detailed as follows (Amiri et al., 2023)

$$\bar{A} = (a^L, a^M, a^U)$$

$$\bar{B} = (b^L, b^M, b^u)$$

$$\bar{A} + \bar{B} = (a^L + b^L, a^M + b^M, a^U + b^U)$$

$$\bar{A} - \bar{B} = (a^L - b^L, a^M - b^M, a^U - b^U)$$

$$\bar{A} * \bar{B} \cong (a^L b^L, a^M b^M, a^U b^U)$$

$$\bar{A} \div \bar{B} \cong \left(\frac{a^L}{b^U}, \frac{a^M}{b^M}, \frac{a^U}{b^L}\right)$$

$$\frac{1}{\bar{A}} \cong \left(\frac{1}{a^U}, \frac{1}{a^M}, \frac{1}{a^L}\right)$$

$$\bar{A} * \lambda \cong (a^L\lambda, a^M\lambda, a^U\lambda), where\ \lambda \geq 0$$

Following are the key notations utilized and expanded are incorporated throughout multiple stages from (Amiri et al., 2023) in Table 3.2 below:

Table 3.2: Important Notations Used in F-SBWM

Notation	Description
B_i	The ith barrier from the barriers set
$\bar{P}_{Bj}$	The degree of preference for the best barrier about the jth barrier represented as TFN
$\bar{P}_{jW}$	The degree of preference for the jth barrier about the worst barrier, represented as a Triangular Fuzzy Number
P^L_{Bj}	The lower threshold of the Triangular Fuzzy Number is linked to the preference for the best barrier about the jth barrier
P^M_{Bj}	The central value of the Triangular Fuzzy Number is linked to the preference for the best barrier over the third barrier
P^U_{Bj}	The upper threshold of the Triangular Fuzzy Number is linked to the preference for the best barrier over the third barrier
P^L_{jW}	The lower threshold of the Triangular Fuzzy Number is linked to the preference for the jth barrier over the worst barrier
P^M_{jW}	The central value of the Triangular Fuzzy Number is linked to the preference for the jth barrier over the worst barrier
P^U_{jW}	The upper threshold of the Triangular Fuzzy Number is linked to the preference for the jth barrier over the worst barrier
$\widetilde{w}'_j$	The weight given to the jth barrier in the best to others reference comparisons
$\widetilde{w}'_j(T)$	The weight given to the jth sub barrier within the Technological barrier in the best to others reference comparisons

$\widetilde{w}_j'(O)$	The weight is given to the jth sub-barrier within the Organizational barrier in the best-to-others reference comparisons
$\widetilde{w}_j'(E)$	The weight given to the jth sub-barrier within the Environmental barrier in the best to others reference comparisons
$\widetilde{w}_j''$	The weight is given to the jth criteria in the others to worst reference comparisons
$\widetilde{w}_j''(T)$	The weight is given to the jth sub-criteria within the Technological barrier through others to worst reference comparisons
$\widetilde{w}_j''(O)$	The weight is given to the jth sub-criteria within the Organizational barrier through others to worst reference comparisons
$\widetilde{w}_j''(E)$	The weight is given to the jth sub-criteria within environmental barrier through others to worst reference comparisons
w_j^L	The lower threshold of the Triangular Fuzzy Number linked to the weight of the jth barrier
w_j^M	The lower value of the Triangular Fuzzy Number linked to the weight of the jth barrier
w_j^U	The upper threshold of the Triangular Fuzzy Number linked to the weight of the jth barrier
$\widetilde{w}_B'$	The weight given to the best barrier in the best-to-others reference comparisons
$\widetilde{w}_W''$	The weight is given to the worst barrier in the others to worst reference comparisons
$\widetilde{w}_j^*$	The final weight given to the jth barrier
$\widetilde{w}_j^*(T)$	The final weight is given to the jth sub-barrier within the technological barrier
$\widetilde{w}_j^*(O)$	The final weight is given to the jth sub-barrier within the organizational barrier
$\widetilde{w}_j^*(E)$	The final weight is given to the jth sub-criteria within the environmental barrier
CR	Consistency Ratio

Following is the step-by-step analysis of this stage:

3.2.1. Computation of the Best and the Worst Barrier:

In F-SBWM the first step that is involved in the computation of barriers in terms of B_i and identifying the best barrier and the worst barrier.

Table 3.3: Linguistic Terms used for Evaluation of Barriers (Amiri et al., 2020)

Linguistic Terms		Fuzzy Scale
Equally Important	EI	(1,1,1)
Weakly Important	WI	(1,2,3)
Moderate Important	MI	(2,3,4)
Moderate Plus Important	MP	(3,4,5)
Strong Important	SI	(4,5,6)
Strong Plus Important	SP	(5,6,7)
Very Strong Important	VS	(6,7,8)
Extreme Important	EX	(7,8,9)

3.2.2. Constituting the Preference of the Best Barriers over Other Barriers

The upcoming step consists of the computation of preferences of the best barriers over the other barriers using linguistic terms and Triangular Fuzzy Numbers in the order of $\bar{P}_{jw} = \left(P_{JW}^{L}, P_{jw}^{M}, P_{jw}^{U}\right)$. Linguistic terms and their corresponding TFN values are shown in Table 3.3 taken from (Amiri et al., 2023). During the process of making a decision TFNs provide an important basis to experts in the computation of preferences.

3.2.3. Constituting the Other to Worst Barriers Preferences

This step involves the computation of the relative importance of each barrier in relation to the worst barrier in terms of $\bar{P}_{jw} = \left(P_{jw}^{L}, P_{jw}^{M}, P_{jw}^{U}\right)$ by using the linguistic terms and Triangular Fuzzy Numbers.

3.2.4. Evaluating Barrier Weights Based on Best-to-Other Reference Comparisons

This step involves the use of reference comparison to determine the preference of each barrier where the best barrier is evaluated against the other barrier in terms of $\widetilde{w}_j' = (w_j^L, w_j^M, w_j^U)$. Equation (1) will be used to calculate the best barrier's preference in comparison with other barriers. The outcome will be the weight of the best barrier ($\widetilde{w}_B'$). Afterwards, Equation (2) will be used to determine the weights of the rest of the barriers substituting the weight of the best barrier.

$$\sum_j \frac{1}{\bar{P}_{BJ}} \widetilde{w}'_B = 1 \ \Rightarrow \ \widetilde{w}'_B = \frac{1}{\sum_j \bar{P}_{BJ}} \quad (1)$$

$$\widetilde{w}'_B - \bar{P}_{Bj}\widetilde{w}_j' = 0 \Rightarrow \bar{P}_{Bj}\widetilde{w}_j' = \widetilde{w_B'} \Rightarrow \widetilde{w}_j' = \frac{\widetilde{w}_B'}{\bar{P}_{Bj}} \ \forall\, j \quad (2)$$

3.2.5. Evaluating Barrier Weights Based on Other to Worst Reference Comparisons

This step involves the others to worst reference comparisons to calculate the weights of each barrier in the form of $\overline{w}_j'' = (w_j^L, w_j^M, w_j^U)$.The preference of every barrier will be calculated by using Equation (3) in relation to the worst barrier. The outcome will be the weight of the worst barrier attained.

Thereafter, the weight of the other barriers will be calculated by using the worst barrier weight in Equation (4).

$$\sum_j \widetilde{w}_W'' \bar{P}_{jW} = 1 \Rightarrow \widetilde{w}_W'' = \frac{1}{\sum_j \bar{P}_{jW}} \tag{3}$$

$$\widetilde{w}_j'' - \bar{P}_{jW}\widetilde{w}_W'' = 0 \Rightarrow \widetilde{w}_j'' = \bar{P}_{jW}\widetilde{w}_W'' \quad \forall\, j \tag{4}$$

3.2.6. Evaluation of Final Barriers Weights

In the last step of this stage, the final weights assigned to the barriers are calculated. Equation (5) will be used to determine final weights.

$$\widetilde{w}_j^* = \left(\frac{\widetilde{w}_j' + \widetilde{w}_j''}{2}\right) \tag{5}$$

3.2.7. Evaluation of Consistency Ratio (CR)

The next step involves in this proposed methodology, the calculation of the consistency ratio to evaluate the stability of the weights obtained through F-SBWM. Calculating the consistency rate is vital in the decision-making process which depends on pairwise comparisons. Results might be unstable if the ratio falls outside of the unsuitable range. In such circumstances to improve consistency experts will be requested to review their preferences. As a result, the consistency ratio is calculated by using Equation (6). Consistent comparisons are those in which the value of CR is close to zero. (Govindan et al., 2020). On the other hand, while managing many barriers attaining the perfect consistency can be tough. According to several researchers, CR below 0.1 signifies the acceptable threshold. They recommend that values surpassing this threshold require a thorough review and possible adjustments to expert preferences. In contrast, another group of experts supports for a stricter CR threshold of less than 0.05. (Pant et al., 2022)

$$CR = \sum_j \left|\widetilde{w}_j' + \widetilde{w}_j''\right|^2 \tag{6}$$

3.3. Computation of Interdependency among barriers using FDEMATEL

In this stage, interdependencies among barriers are calculated by using the FDEMATEL approach. To achieve this, this stage is further divided into the following steps:

3.3.1. Analysis of Impact

This step involves asking the expert to map the influence of each barrier visually according to their expertise and knowledge.

3.3.2. Formulating the Matrix of Barriers Impact

After evaluating the effects of the barriers, the next step involves presenting the experts with the pairwise comparison matrix and a table of linguistic terms, as presented in Table 3.4, taken from

Table 3.4: Table of Linguistic terms for FDEMATEL (Govindan et al., 2020)

Linguistic Terms	Fuzzy Scale
None	(0,0,0.1)
Very Low	(0.1,0.2,0.3)
Low	(0.2,0.3,0.4)
More or Less Low	(0.3,0.4,0.5)
Medium	(0.4,0.5,0.6)
More or Less Good	(0.5,0.6,0.7)
Good	(0.6,0.7,0.8)
Very Good	(0.7,0.8,0.9)
Excellent	(0.8,0.9,1)

(Govindan et al., 2020). This enables the analysis of how different barriers influence each other, which ultimately leads to the creation of a fuzzy direct-relation matrix.

3.3.3. Normalization of Matrix

In the next step Equation (7) is used to normalize the resultant matrix (Govindan et al., 2020).

$$\bar{A}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right) \; and \; s = \frac{1}{max_{1\le i\le n} \sum_j u_{ij}}, then \; \tilde{X} = s \times \bar{A} \tag{7}$$

3.3.4. Formation of the Fuzzy Relation Matrix

This step involves the formation of a complete fuzzy relation matrix by using Equation (8). For identity matrix symbol "I" is used in the equation. As a result, the matrix $\tilde{X}_{ij}$ is converted into three distinct defuzzified matrices. These three matrices contain entries representing the lower, middle, and upper values of triangular fuzzy numbers (Govindan et al., 2020)

$$X_1 = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1n} \\ l_{21} & 0 & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{n1} & l_{n2} & \cdots & 0 \end{bmatrix}, X_2 = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix}, X_3 = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}$$

$$\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}, \tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix} where \; \tilde{t}_{ij} = \left(l'_{ij}, m'_{ij}, u'_{ij}\right) then, Matrix\left[l'_{ij}\right] =$$

$$X_l(I - X_l)^{-1}, Matrix\left[m'_{ij}\right] = X_m(I - X_m)^{-1}, Matrix\left[u'_{ij}\right] = X_u(I - X_u)^{-1} \tag{8}$$

3.3.5. Evaluation of Interdependency Matrix

In the last step interdependency matrix will be calculated. For that Equation (9) and (10) derived from (Govindan et al., 2020) will be used for defuzzification and normalization of the total fuzzy relation matrix

$$Defuzzy\left(t_{ij}\right) = \frac{t_{ij}^{a} + 4t_{ij}^{b} + t_{ij}^{c}}{6} \tag{9}$$

$$Normalized\ Defuzzy\left(t_{ij}\right) = \frac{Defuzzy\left(t_{ij}\right)}{\sum_{i} Defuzzy\left(t_{ij}\right)} \tag{10}$$

3.4. Evaluation of Final Weights by Applying the Interdependency Matrix to Barriers Weights

The interdependency matrix from the previous stage is used on the barrier weights from phase 2, section 3.2.6. By doing this, we get the final weights of the barriers, considering how they affect each other. These final weights reflect both the experts' preferences and the interdependencies among the barriers.

4. CASE STUDY

In this section, the proposed methodology is implemented to examine and evaluate the barriers to implementing blockchain technology within the specific context of K&N's, a leading poultry and frozen food company in Pakistan. K&N's specializes in the production of a diverse range of poultry products, all of which are processed and manufactured exclusively in Pakistan and subsequently sold to both domestic and international markets. The company's operations are significantly dependent on maintaining an efficient cold food supply chain, which ensures the freshness and safety of its products. The process of the supply chain of K&N’s shows the major share of its operational expenses. That made it mandatory to adopt the latest technologies such as Blockchain Technology to manage the transaction efficiently and make the process effective, transparent, and traceable. To get a detailed understanding of the Operation of K&N’s it is important to analyze the current cold supply chain process of the Organization. This research will provide detailed basics for analyzing how blockchain can address all current barriers and improve overall performance. The section below highlights the structure and process of the cold supply chain of K&N’s.

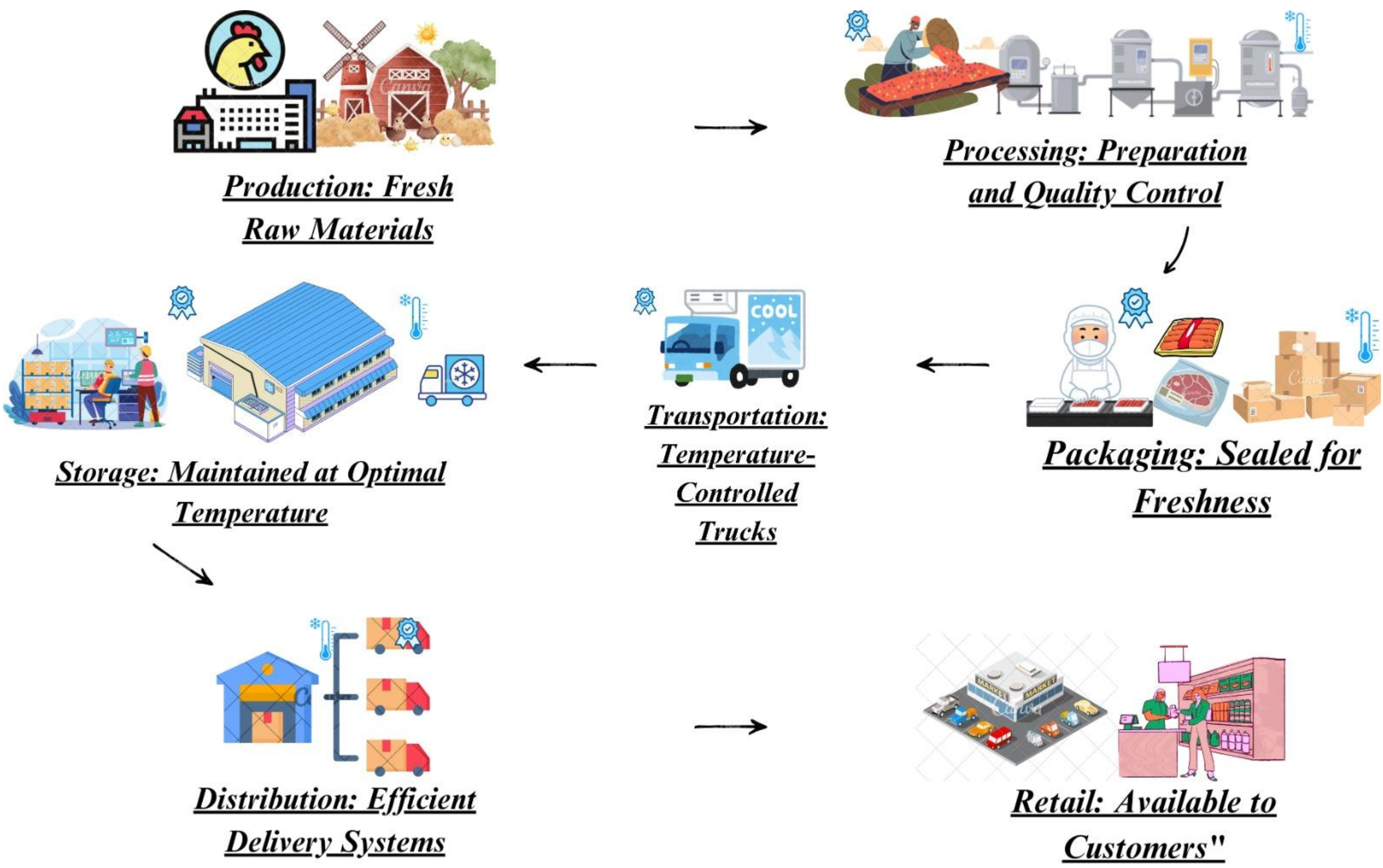

Figure 4.1: Cold Supply Chain of K&N's

4.1. Cold Supply Chain of K&N's:

The entirety of the food remains in the monitored temperature cold supply chain of K&N's consists of orderly management of the production, storage, distribution, and retailing of perishable products from raw material to end customer. Following is the detailed process of the cold supply chain of K&N's.

4.1.1. Fundamentals of K&N's Cold Supply Chain

The main components of the cold supply chain are discussed here

- **Sourcing and Procurement:** The process of obtaining raw materials is carried out by using reliable suppliers. They follow the strict guidelines and evaluation for the ensuring of quality and safety of production.
- **Processing and Production:** To prevent any loss or any unhygienic practices the process of raw material is carried out under controlled temperature. For that purpose, hygienic practices are adopted for the sake of quality of food safety.
- **Packaging:** To enhance the shelf life of products specialized packaging is used. It also helps to preserve the quality of the product. For that purpose, they use temperature monitor devices to monitor the form of quality during the process of transportation.
- **Cold Storage:** Processed products are stored in cold temperatures. For that purpose, those products are kept in warehouses that are temperature-controlled. Special refrigeration technologies are used for stable cold temperatures and to avoid instability in temperature.
- **Distribution:** Transporting systems that are used for the movement of products are temperature-oriented. They have real-time temperature mentoring systems. They are managed according to logistics to minimize the time for transportation of goods. They are validated for the on-time delivery of products to retailers and customers.
- **Retail and Consumer Delivery:** There are two means to transfer products to the end consumers that are retailing and doorstep delivery. Retailing products are displayed in refrigerators in their outlets and other supermarkets. For home delivery or doorstep delivery specialized refrigerated vehicles are used to ensure the quality of the products.
- **Monitoring and Control:** Every step of the cold supply chain is tracked and monitored throughout the process to ensure the traceability of the process. For the monitoring process of temperature and many other critical aspects, different kinds of technologies are used.
- **Quality Assurance and Compliance:** The continuous improvement of the process is verified through conducting regular audits and inspections. They follow local and international food safety regulations and standards.

  All the stages consisting of the cold food supply of K&N's try to maintain the quality and safety of products from raw material to final product. They use technology and strict regulatory measures to handle the complex process of a cold supply chain effectively.

4.1.2. Ensuring Product Quality and Safety at K&N's:

K&N's uses advanced technology in different steps of their processes such as procurement, storage, and transportation to monitor the quality and safety of the product. All products are temperature-sensitive and require well-managed processes.

- **Procurement**: In the process of procurement, K&N's on board those suppliers that meet the specific requirements of the organization such as quality and safety standards, conducting regular audits and inspections. All the raw material is tested upon check regularly for the verification process of quality and safety. They try to keep a detailed record of supplier performance and the quality of products. K&N's have clear contracts with their supplier that mention the requirements of quality, delivery schedules, and temperature control measures.
- **Storage**: For the storage of product a maintained cool temperature is required all the time. K&N's uses up-to-date refrigerated technologies in their warehouses that keep the perfect temperature for products. It prevents any kind of temperature instability. The latest technology is used to continuously monitor of temperature of the storage location. They have systems to alert staff if any kind of temperature-related issues arise. They utilize an efficient inventory management system of (FIFO) first-in-first-out that helps to keep the spoilage range minimum. This system can track inventory stock levels and can manage storage effectively.
- **Transportation**: For the transportation of products, K&N's uses specialized trucks that are equipped with the latest refrigerated technologies that keep the process of cold chain smooth. Those vehicles are regularly checked to keep the safety of the process. K&N's uses real-time GPS and temperature monitoring systems to track the location and status of the shipments. They provide proper training to the transportation team on how to handle temperature-sensitive products and how they should maintain the proper condition of the product throughout the process of transportation. K&N coordinates with its partners that help them reduce the transit time and the product remains in its proper condition. They plan the route efficiently with their distribution centers and retail outlets for timely and efficient deliveries. In the process of transportation, an effective contingency plan is a must to avoid loss in case of any uncertainty. Such plans involve the backup of refrigeration or generators in case the temperature goes off during transportation.

K&N's ensures the quality and safety of their products by effectively managing and orderly organizing every step of procurement, storage, and transportation. They ensure the safety of temperature-oriented products from raw materials to the end customer.

4.1.3. Technologies to Maintain the Required Temperature

K&N uses different kinds of latest technologies to keep their products at maintained temperature throughout the process of the cold supply chain. One of the latest technologies used by K&N is the IOT sensor device. They are installed to keep temperature monitored throughout the process. In case of any uncertainty, IOT helps to take immediate action for maintenance. All the issues are recorded and help to identify repeated issues and areas for maintenance. For remote monitoring and consistent adjustment of temperature in storage areas such as warehouses and trucks that are used for the transportation of products latest technologies are used. These technologies are also sustainable and help reduce operational costs and impact on the environment. One of the potential benefits of these technologies is they integrate GPS systems with temperature monitoring. This will eventually help to track the location and state of shipments in real time. Ultimately this will help the management to take on time decision if any kind of unexpected event occurs to ensure the delivery of product to the end customer with verified safety and quality standards.

4.1.4. Quality Control Measures to Ensure the Integrity of Cold Chain Products

K&N's make sure of the quality of the product and for that purpose, they adopt a strict quality control process. Partners of K&N's such as suppliers must follow the regular audit process, and review their facilities, processes, and records the meet the quality standards. These requirements are the part of the contracts. When raw material arrived at the processing centres of K&N's they went through several steps of quality control to meet the standards. These steps are visual inspections, laboratory testing, and the verification process of specification against the supplier. The most important factor encountered at this stage is the temperature of the incoming shipment to verify they are shipped under maintained temperature. K&N's has also established specific requirements for their processing centres to maintain standards of quality. Those requirements are to maintain strict hygiene, temperature control, sanitation, and quality of air. By following these regulations any kind of spoilage could be avoided. The latest technology of temperature sensors keeps monitoring the conditions of products at any stage throughout the supply chain. From the origin to end customer continuous tracking of products and records is generated. If any kind of uncertainty occurs automated alerts are sent to avoid any mishandling.

4.1.5. Compliance with Regulatory Requirements and Industry Standards for Cold Chain Management

K&N's uses multiple comprehensive approaches to follow the standard compliance requirements to manage their cold supply chain. They follow the local and international food safety standards. Those standards involve HACCP (Hazard Analysis and Critical Control Points), FDA regulations, and ISO standards. These standards help to maintain the required relative certification for validation of observance. They make sure to conduct regular audits. Mostly two audits are conducted one by the internal teams and one by a third-party organization to make sure the company is following safety standards. These audits are helpful for the continuous improvement of processes and systems. They schedule regular training for the teams to meet the safety standards, optimal strategies in the cold supply chain, and proper management of temperature-sensitive products. These programs get improvements regularly to show changes in standards. All those records for processes, temperature logs, audit reports, and standards checklist are recorded and updated in detail. This record helps to trace product status throughout the supply chain to handle any uncertainty.

4.1.6. Main challenges Faced in Managing the Cold Supply Chain

There are many challenges faced by K&N's to maintain the reliability of the cold supply chain. There could be a fluctuation in temperature due to environmental factors such as hot weather conditions through the process of storage and transport. These fluctuations are crucial to ensure the stability of refrigeration units and temperature monitoring devices. Things like failure of equipment, mechanical breakdowns, or transport vehicles can affect the cold supply chain. To prevent such challenges, it is important to keep maintaining the system. Another challenge in these processes is the complexity of logistics. It is hard to deal with on-time delivery of logistics for the long routes. Factors like traffic blockage and unforeseen delays can delay the deliveries. Another challenge is the variability of suppliers. It's hard to get the same quality standards from different suppliers when the company is sourcing from different regions. These challenges can add risks to the quality standards.

4.1.7. Mitigate Potential Disruptions or Failures in the Cold Chain

To keep the reliability of the cold supply chain it is critical to maintain the backup systems. In case any of the refrigerators or any device fails then duplicative of these devices or systems and backup generators are available for backup to make sure that the system is continuously in process. For the monitoring conditions, real-time notifications play an important role in the entire process. If any kind of temperature fluctuation happens, those automated systems send notifications that help to take corrective actions. Very clear instructions are provided to follow to act in such cases and take proper steps to address these issues properly. To handle such uncertain situations contingency plans are there to deal with. A set of actions take place such as using different facilities for storage facilities or providing different routes. Moreover, a proper communication plan is designed which includes emergency contact lists to ensure that all those people related to such situations are notified on time in case of any problem. All the systems are repaired and maintained at regular intervals to avoid any disruptions. Preventive actions are taken to identify potential issues before they get complex to resolve.

4.1.8. KPIs to Assess the Efficiency and Effectiveness of the Cold Supply Chain

KEY Performance Indicators (KPI's) number of complex metrics that assess the effectiveness and efficiency of the process of cold supply chain. These KPI's consist of the standard rate of temperature which is measured for how much time a product remains in a certain temperature range, with the standard of high rate showing the effective temperature control. The on-time delivery rate helps to assess the delivery timelines, which helps to track the percentage of deliveries that occur on time. These on-time deliveries minimize the risk of fluctuation in temperature and loss of product. High standards are maintained by responding to the rate of return and number of complaints by consumers. The quality of the product is maintained by managing the rate of returns and complaints to improve the quality of a product. Efficient management of stock is shown by the rate at which inventory is replaced and effective inventory management reduces the risk of spoilage which shows the high turnover rate.

4.1.9. Recent Initiatives to Enhance Cold Chain Operations Technology Upgrades

The cold chain operations are enhanced by implementing the most recent initiatives and improvements in the industry which addresses the various aspects of reliability and efficiency. The integration of advanced monitoring technology is one significant development. Technologies like real-time tracking systems and IoT-enabled sensors provide continuous data on humidity, temperature, and other critical factors throughout the supply chain. This integration of technologies helps to monitor and allows correction of any deviation from required standards. The adaptation of an automated alarm system is another vital improvement. The supply chain managers are being notified by real-time updates sent to them by an automated alarm system if there is any issue detected which helps quick response to minimize the risk of any product spoilage. To enhance sustainability and to reduce dependency on traditional energy sources, Investments in renewable energy sources have been made, Solar-powered refrigeration units and backup generators ensure the continued cold chain supply operations are interrupted by power outages. Additionally, more robust contingency planning is part of supply chain operations. The protocols are defined for rerouting shipments and usage of alternative storage facilities is standard practice now which ensures any disruptions are handled timely and effectively to keep the products within the required variations of temperature range. As a final point, regular quality assessments and schedules of maintenance of machines are focused on reducing and preventing breakdowns during operations while frequent quality checks are made to consistently meet the product standards. The collective contribution of these initiatives creates a more efficient and reliable cold supply chain operation and helps to safeguard the quality of fast-moving consumable goods.

4.1.10. Coordination and Communication with Cold Chain Stakeholders

Coordination and communication with cold supply chain stakeholders are major factors in the efficiency of supply chain operations. To facilitate this coordination between suppliers, logistic providers, and other stakeholders various effective communication methods are used. Digital communication tools enable real-time interaction. To enhance the transparency and visibility of supply chain operations this platform provides access to shared data. Necessary regular meetings and scheduled check-ins with suppliers and logistic providers help to determine addressing issues, discussing performance, and planning improvements. From time to time performance reviews are conducted to evaluate key metrics which ensures alignment with goals. The E.R.P (Enterprise Resource Planning) systems are used to integrate data from various stages of the supply chain that facilitate continuous coordination between different departments and units of supply chain operations. In conclusion, specialized supply chain management software is deployed to effectively manage and optimize the interaction between suppliers and logistics providers.

4.1.11. The Role of Collaboration in Maintaining Cold Supply Chain Efficiency and Reliability

To maintain the efficiency and reliability of the cold supply chain, the engagement of stakeholders is very important therefore the involvement of stakeholders in decision-making and addressing issues ensures that their concerns and needs are addressed while the feedback from them helps to determine continued process improvement. Shared goals throughout the supply chain process are vital for effective collaboration which creates an anatomy to achieve aligned common goals. This collaborative effort also brings mutual benefits in many ways like, to reducing cost, enhancing quality, and improving efficiency. Joint problem-solving techniques are used to address the arising issues and challenges and to find solutions to them by working together. Stakeholders can improve and innovate cold supply chain processes for better performance by leveraging collective expertise among them. Transparent sharing of data and information and sharing of insights from the supply chain process helps to improve performance and decision-making.

4.1.12. The Role of Technology in Cold Supply Chain Management

The role of technology cannot be ignored in many key areas of cold supply chain management. Adaptation of automated data capturing is essential to reduce manual errors, improve accuracy, enhance performance, and increase efficiency. With the help of automated processes cold supply chain operations are modernized to fewer mistakes and increase productivity. The insights generated from Data Analytics of temperature and logistics add significantly to help identify and predict potential issues and trends to optimize the process. Data-driven insights support more effective decision-making, and time problem solving which allows more informed and effective management of the supply chain. Real-time monitoring techniques enhance the traceability of any issue that may occur which ensures the accurate tracking of the product to keep a comprehensive record of product safety throughout its journey. Continued tracking technique helps to meet the quality standards of the product. Immediate response to any issue is enabled by real-time data tracking for prompt actions being taken if any issue occurs.

4.1.13. Exploring New Technologies and Innovations to Improve Cold Chain Processes

To improve and enhance the cold chain supply process, continuous exploration of new technologies is key. In predictive analysis, AI (Artificial Intelligence) and Machine Learning are making meaningful developments. Whereas AI is used to optimize the process and forecast trends while Machine Learning Algorithms are implemented for auto decision-making to enhance process improvements. For better shelf life of the product and to keep it preserved new advanced packaging materials and techniques are being used that result in innovative packaging solutions to keep temperature-controlled products to minimum risk of any spoilage by reducing the risk of temperature deviations. A more effective and responsive management is becoming possible with the use of Remote Monitoring techniques and Real-time-based data analytics.

4.1.14. Procedures for Handling Emergencies and Unexpected Issues in the Cold Supply Chain

For effective and swift response in supply chain management, procedures for handling emergencies and unexpected issues are designed. Standard protocols are established to provide clear guidelines for managing equipment failures, temperature excursions, and other critical situations. These protocols state a clear and standard plan of action to isolate and address the issue to minimize its impact on the cold supply chain overall. Specially trained rapid response teams are deployed to handle emergencies, address issues, and mitigate the risk of problems quickly as they arise. Coordination among the team is essential for effective and efficient response. Alternative storage places and logistic routes are pre-planned in case of any disruption. These plans help to keep the integrity of the supply chain process even if any unexpected event occurs. Immediate notifications are sent to all stakeholders to keep them up-to-date with the status of the issue and action taken to resolve it as quickly as possible.

4.1.15. Ensuring the Effectiveness and Regular Updates of Contingency Plans

Several measures are taken to make sure the contingency plans are effective and up-to-date. To verify the effectiveness regular drills are scheduled. These drills help to identify the areas of improvement or any gaps, which allow us to make necessary adjustments to enhance the contingency plans. To incorporate inputs from all stakeholders, regular review meetings are conducted, in the results of these meetings and getting feedback from stakeholders and lessons learned continuous improvement to contingency plans are made to ensure that they remain effective and relevant. This continuous improvement is very vital aspect of contingency plans in cold supply chain management as lessons learned from past incidents and drills are being incorporated into the plan. All stakeholders and informed by ongoing updates of a plan to reflect any change in process or technology. K&Ns ensures the reliability, integrity, and efficiency of their cold supply chain by implementing these detailed measures and also ensures the quality and safety of their temperature-controlled products from procurement of raw materials to the delivery of final consumable products.

4.2. Application of Methodology to Case Study of K&N's

The blockchain implementation process holds significant importance in guaranteeing the continual fulfillment of K&N's production requirements, with a particular focus on maintaining high standards of quality and operational efficiency. The proposed methodology is utilized to assess the barriers to blockchain implementation within the organization, leveraging the knowledge and insights of a panel consisting of six experts. The panel includes individuals occupying significant positions within the organization, such as the IT manager, supply chain director, quality compliance manager, operations manager, blockchain specialist, and logistics manager. The methodology is executed methodically, adhering to a sequential procedure, as delineated in the following manner: conducting a literature review, forming an expert panel, identifying specific barriers, collecting data through surveys, and analyzing the data using fuzzy DEMATEL and fuzzy simplified Best Worst Method to determine the relationships and prioritization of the barriers. This structured approach ensures a comprehensive understanding of the challenges and provides actionable insights for overcoming them, thereby facilitating the successful integration of blockchain technology into K&N's cold food supply chain.

4.3. Identification of Blockchain Implementation Barrier and Sub Barriers

In this stage, barriers and sub-barriers are identified through an extensive literature review. Out of 41 articles and expert opinions, these 15 barriers with three main barriers are identified, listed in Table 2.1.

4.4. Calculation of Weights for Barriers and Sub Barriers without Considering Interdependencies using F-SBWM

This stage is further divided into the following steps.

4.4.1. Computation of the Best and the Worst Barriers from the Specified Set

At this stage, experts were asked to select the best and the worst barriers following the best and the worst sub-barriers within each barrier. Experts choose organizational barriers as the best and environmental barriers as the worst. In the set of sub-barriers, they select TB3, OB4, and EB3 as the best barriers and TB5, OB1, and EB5 as the worst barriers.

4.4.2. Constituting Best to Other (BTO) Preferences

At this step, experts were asked to use the linguistic scale provided in Table 3.3. and evaluate the best barrier with the other barrier and give reference comparisons. Following that, repeat the same step for the sub-barrier within each main barrier. Following are the preferences for best to other barriers and sub-barriers achieved by the experts:

Fuzzy BTO preferences for barrier:

[(3,4,5), (1,1,1), (6,7,8)]

Fuzzy BTO preferences for sub-barriers within technological barriers:

[(4,5,6), (2,3,4), (1,1,1), (1,2,3), (5,6,7)]

Fuzzy BTO preferences for sub-barriers within organizational barriers:

[(7,8,9), (5,6,7), (4,5,6), (1,1,1), (3,4,5)]

Fuzzy BTO preferences for sub barrier within environmental barriers:

[(5,6,7), (3,4,5), (1,1,1), (4,5,6), (7,8,9)]

4.4.3. Constituting Other to Worst (OTW) Preferences

At this step, experts were asked to use the linguistic scale provided in Table 3.3. and evaluate the other barrier with the worst barrier and give reference comparisons. Following that, repeat the same step for the sub-barrier within each main barrier. Following are the preferences for other to worst barriers and sub-barriers achieved by the experts:

Fuzzy OTW preferences for barrier:

[(2,3,4), (7,8,9), (1,1,1)]

Fuzzy OTW preferences for sub-barriers within technological barriers:

[(3,4,5), (1,2,3), (7,8,9), (2,3,4), (1,1,1)]

Fuzzy OTW preferences for sub-barriers within organizational barriers:

[(1,1,1), (3,4,5), (1,2,3), (7,8,9), (2,3,4)]

Fuzzy OTW preferences for sub barrier within environmental barriers:

[(3,4,5), (1,2,3), (7,8,9), (2,3,4), (1,1,1)]

4.4.4. Computing Barrier Weights Based on Best to Other Reference Comparisons

After getting the best-to-other and other-to-worst fuzzy vectors from the experts, the next step is to calculate the weights $\widetilde{w}_j'$ by using the best-to-other preferences that were obtained from experts. First weights will be calculated for barriers and then after that for sub-barriers within each barrier.

$\widetilde{\mathrm{w}}_{\mathrm{j}}'$ ***For Barrier:***

The weight of the best barrier is figured out through Equation (1).

$$\widetilde{w}_1' = \frac{1}{\frac{1}{(3,4,5)} + \frac{1}{(1,1,1)} + \frac{1}{(6,7,8)}} = \frac{1}{(1.5, 1.392, 1.325)}$$

$$\widetilde{w}_1' = (0.6667 \;\; 0.7179, 0.7547)$$

Following that, the weights of the remaining barriers will be calculated by replacing the weight $\overline{w}_1'$into Equation (2):

$$\widetilde{w}_2' = \frac{\widetilde{w}_1'}{\bar{P}_{12}} \frac{(0.6667,\;\; 0.7179,\;\; 0.7547)}{(3,4,5)} = (0.1333, 0.1794, 0.2515)$$

$$\widetilde{w}_3' = \frac{\widetilde{w}_1'}{\bar{P}_{13}} \frac{(0.6667,\;\; 0.7179,\;\; 0.7547)}{(6,7,8)} = (0.0833, 0.1025, 0.1257)$$

The weights for the sub-barriers within each barrier are calculated by using the same method mentioned above.

$\widetilde{\mathrm{w}}_{\mathrm{j}}'$ ***for sub barrier within technological barrier***

$$\widetilde{w}_1'(T) = (0.0564, 0.0909, 0.1320)$$

$$\widetilde{w}_2'(T) = (0.0847, 0.1515, 0.2641)$$

$$\boldsymbol{\widetilde{w}_3'(T)} = (0.3389, 0.4545, 0.5283)$$

$$\widetilde{w}_4'(T) = (0.1129, 0.2272, 0.5283)$$

$$\widetilde{w}_5'(T) = (0.0484, 0.0757, 0.1056)$$

$\widetilde{\mathrm{w}}_{\mathrm{j}}'$ ***for sub barrier within organizational barrier***

$$\widetilde{w}_1'(O) = (0.0576, 0.0717, 0.0881)$$

$$\widetilde{w}_2'(O) = (0.0741, 0.0956, 0.1234)$$

$$\widetilde{w}_3'(O) = (0.0865, 0.1148, 0.1542)$$

$$\boldsymbol{\widetilde{w}_4'(O)} = (0.5191, 0.5741, 0.6170)$$

$$\widetilde{w}_5'(O) = (0.1038, 0.1435, 0.2056)$$

$\widetilde{\mathrm{w}}_{\mathrm{j}}'$ ***for sub barrier within environmental barrier:***

$$\widetilde{w}_1'(E) = (0.0741, 0.0956, 0.1234)$$

$$\widetilde{w}_2'(E) = (0.1038, 0.1435, 0.2056)$$

$$\boldsymbol{\widetilde{w}_3'(E)} = (0.5191, 0.5741, 0.6170)$$

$$\widetilde{w}_4'(E) = (0.08653, 0.1148, 0.1542)$$

$$\widetilde{w}_5'(E) = (0.0576, 0.0717, 0.0881)$$

4.4.5. Computing Barrier Weights based on Others to Worst Reference Comparison

After calculating the weight for best to other $\widetilde{w}_j'$ for barriers and sub-barriers within each barrier, the next step involves the calculation of weights for barrier and sub-barrier for others to worst $\widetilde{w}_j''$, using the preferences obtained by experts. The example given below shows the calculated weights $\widetilde{w}_j''$ for barriers and then sub-barriers.

$\widetilde{\mathrm{w}}_{\mathrm{j}}''$ ***for barriers:***

The weight of the worst barrier is calculated by using Equation (3).

$$\widetilde{w}_3'' = \frac{1}{(2,3,4),(7,8,9),(1,1,1)} = \frac{1}{(10,12,14)}$$

$$\widetilde{w}_3'' = (0.071, 0.083, 0.1)$$

Following that, the weights of the rest of the barriers will be calculated by using Equation (4) by replacing the weights of the worst barrier.

$$\widetilde{w}_1'' = (2,3,4) * (0.071, 0.083, 0.1) = (0.142, 0.249, 0.4)$$

$$\widetilde{w}_2'' = (7,8,9) * (0.071, 0.083, 0.1) = (0.497, 0.664, 0.9)$$

The weights for the sub-barriers within each barrier are calculated by using the same method mentioned above.

$\widetilde{w}_j''$ ***for sub-barriers within technological barriers:***

$$\widetilde{w}_1''(T) = (0.1363, 0.2222, 0.3571)$$

$$\widetilde{w}_2''(T) = (0.0454, 0.1111, 0.2142)$$

$$\widetilde{w}_3''(T) = (0.3181, 0.4444, 0.6428)$$

$$\widetilde{w}_4''(T) = (0.0909, 0.1667, 0.2857)$$

$$\boldsymbol{\widetilde{w}_5''(T)} = (0.0454, 0.0555, 0.07143)$$

$\widetilde{w}_j''$ ***for sub-barriers within organizational barriers:***

$$\boldsymbol{\widetilde{w}_1''(O)} = (0.0454, 0.0556, 0.0714)$$

$$\widetilde{w}_2''(O) = (0.1363, 0.222, 0.3571)$$

$$\widetilde{w}_3''(O) = (0.0454, 0.1111, 0.2142)$$

$$\widetilde{w}_4''(O) = (0.3181, 0.444, 0.6428)$$

$$\widetilde{w}_5''(O) = (0.0909, 0.1667, 0.2857)$$

$\widetilde{w}_j''$ ***for sub-barriers within environmental barriers:***

$$\widetilde{w}_1''(E) = (0.1363, 0.222, 0.3571)$$

$$\widetilde{w}_2''(E) = (0.0454, 0.111, 0.214)$$

$$\widetilde{w}_3''(E) = (0.3181, 0.444, 0.6428)$$

$$\widetilde{w}_4''(E) = (0.0909, 0.1667, 0.2857)$$

$$\boldsymbol{\widetilde{w}_5''(E)} = (0.0454, 0.0556, 0.0714)$$

4.4.6. Constituting final Weights of Barriers and Sub Barriers

In this step, Equation (5) is used to calculate the final weights of the barrier and sub-barrier. Final weights are first calculated for the barriers and then for the sub-barriers within each barrier. By using the equation "Crisp value= $\frac{L+4M+U}{6}$" the crisp value of the final weights will be calculated.

Final weights $\widetilde{w}_j^*$***For Barrier:***

The final weights of the barriers are calculated using Equation (5) as follows:

$$\widetilde{w}_1^* = \left(\frac{\widetilde{w}_1' + \widetilde{w}_1'}{2}\right) = \frac{(0.133,0.179,0.251) + (0.142,0.249,0.4)}{(2,2,2)} = (0.137, 0.214, 0.325)$$

$$\widetilde{w}_2^* = \frac{(0.667,0.7179,0.7547) + (0.497,0.664,0.9)}{(2,2,2)} = (0.581, 0.690, 0.827)$$

$$\widetilde{w}_3^* = \frac{(0.0833,0.1025,0.12257) + (0.071,0.083,0.1)}{(2,2,2)} = (0.0771,0.0927,0.1128)$$

Final weights after defuzzification:

$$\widetilde{\boldsymbol{w}}_1^* = 0.21$$

$$\widetilde{\boldsymbol{w}}_2^* = 0.70$$

$$\widetilde{\boldsymbol{w}}_3^* = 0.09$$

The weights for the sub-barriers within each barrier are calculated using the same method as mentioned above.

Final weights $(\widetilde{w}_j^*)$***for sub-barriers within technological barriers:***

$$\widetilde{w}_1^*(T) = (0.0964,0.1565,0.2446) \Rightarrow \overline{w}_1^*(T) = 0.1612$$

$$\widetilde{w}_2^*(T) = (0.0651,0.1313, 0.2392) \Rightarrow \overline{w}_2^*(T) = 0.1382$$

$$\widetilde{w}_3^*(T) = (0.3285, 0.4494,0.5855) \Rightarrow \overline{w}_3^*(T) = 0.4520$$

$$\widetilde{w}_4^*(T) = (0.1019, 0.1969, 0.407) \Rightarrow \overline{w}_4^*(T) = 0.2161$$

$$\widetilde{w}_5^*(T) = (0.0469, 0.0656, 0.0885) \Rightarrow \overline{w}_5^*(T) = 0.0663$$

Final weights $(\widetilde{w}_j^*)$***for sub-barriers within organizational barriers:***

$$\widetilde{w}_1^*(O) = (0.0515, 0.0636, 0.0797) \Rightarrow \overline{w}_1^*(O) = 0.0643$$

$$\widetilde{w}_2^*(O) = (0.1052, 0.1589, 0.2402) \Rightarrow \overline{w}_2^*(O) = 0.1635$$

$$\widetilde{w}_3^*(O) = (0.0659, 0.1129, 0.1842) \Rightarrow \overline{w}_3^*(O) = 0.1170$$

$$\widetilde{w}_4^*(O) = (0.4186, 0.5093, 0.6299) \Rightarrow \overline{w}_4^*(O) = 0.5143$$

$$\widetilde{w}_5^*(O) = (0.0973, 0.1551, 0.2456) \Rightarrow \overline{w}_5^*(O) = 0.1605$$

Final weights $(\widetilde{w}_j^*)$***for sub-barriers within environmental barriers:***

$$\widetilde{w}_1^*(E) = (0.1052, 0.1589, 0.2402) \Rightarrow \overline{w}_1^*(E) = 0.1635$$

$$\widetilde{w}_2^*(E) = (0.07464, 0.1273, 0.2099) \Rightarrow \overline{w}_2^*(E) = 0.1323$$

$$\widetilde{w}_3^*(E) = (0.4186, 0.5093, 0.6299) \Rightarrow \overline{w}_3^*(E) = 0.5143$$

$$\widetilde{w}_4^*(E) = (0.8871, 0.1407, 0.2199) \Rightarrow \overline{w}_4^*(E) = 0.1452$$

$$\widetilde{w}_5^*(E) = (0.0515, 0.0636, 0.0797) \Rightarrow \overline{w}_5^*(E) = 0.0643$$

4.5. Computation of Consistency Ratio (CR)

In this stage, the consistency ratio for all the barriers and the sub-barriers within each barrier will be calculated. At this step, for evaluating the dependability and consistency of the established outcomes, the consistency ratio is challenging. Equation (6) will be used to calculate the CR for the barrier and sub-barrier within each barrier. By using $\frac{L+4M+U}{6}$ all $\overline{w}_j'$ and$\overline{w}_j''$are defuzzified by using Equation (6).

4.5.1. Consistency Ratio (CR) for Barriers

Consistency Ratio = $|0.183-0.256|^2 + |0.7155-0.6755|^2 + |0.1032-0.0838|^2 = 0.007$

Consistency Ratio for sub barrier within technological barrier:

Consistency Ratio = $|0.0920-0.2303|^2 + |0.1591-0.1173|^2 + |0.4475-0.4564|^2 + |0.2583-0.1738|^2 + |0.0761-0.0565|^2 = 0.0285$

Consistency Ratio for sub barrier within organizational barrier:

Consistency Ratio = $|0.0721-0.0565|^2 + |0.0967-0.2303|^2 + |0.1166-0.1173|^2 + |0.5721-0.4564|^2 + |0.1472-0.1738|^2 = 0.0322$

Consistency Ratio for sub barrier within environmental barrier:

Consistency Ratio = $|0.0967-0.2303|^2 + |0.1472-0.1173|^2 + |0.5721-0.4564|^2 + |0.1166-0.1738|^2 + |0.0721-0.0565|^2 = 0.0356$

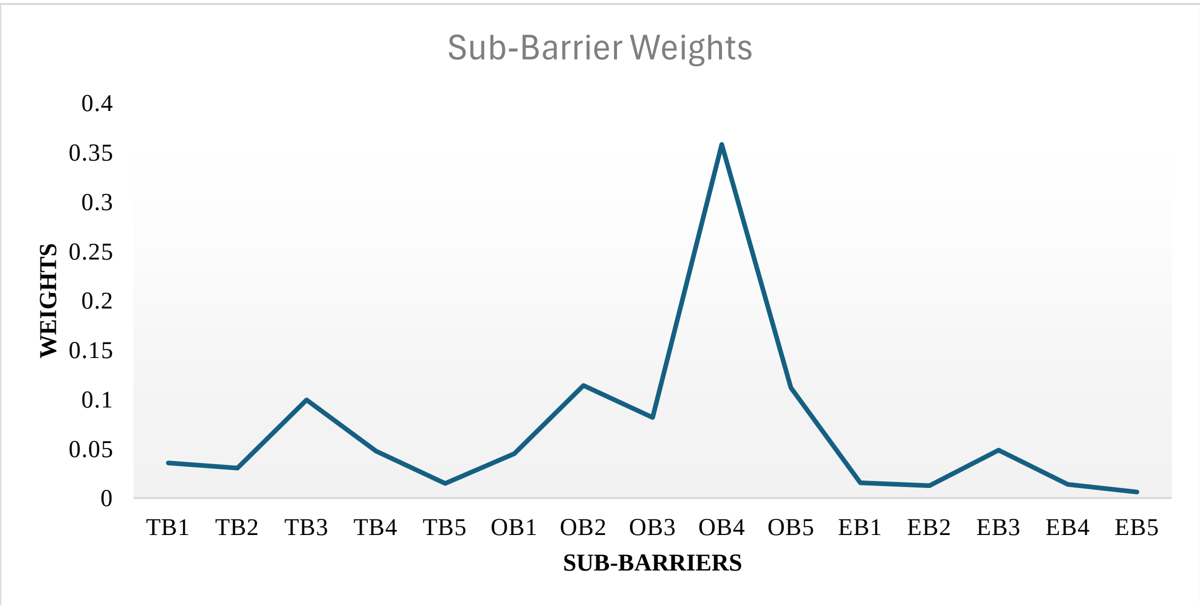

Figure 4.2: Weights of Sub-Barriers without Interdependency

Table 4.1: Sub-barrier weights obtained through F-SBWM without Interdependencies

Sub Barrier	Weights
TB1	0.03
TB2	0.03
TB3	0.1
TB4	0.05
TB5	0.01
OB1	0.04
OB2	0.11
OB3	0.08
OB4	0.354
OB5	0.11
EB1	0.01
EB2	0.02
EB3	0.04
EB4	0.01
EB5	0.006
SUM	1

The results of the consistency ratios indicate the uniformity in the obtained weights for all barriers and sub-barriers that fall under the threshold of 0.05. The resulting weights for the barriers and sub-barriers are consistent indicates experts did not need to adjust their preferences. Without accounting for the interdependency among barriers, the final sub-barrier weights obtained in this stage using the fuzzy simplified best-worst method are presented in Table 4.1 and Figure 4.2.

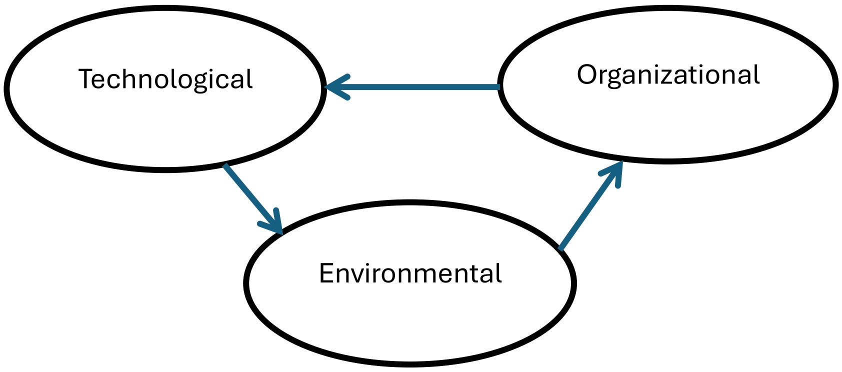

Figure 4.3: Visual Assessment of Impacts

4.6. Establishment of Interdependencies among Barriers

At this stage of research, the FDEMATEL method is used to determine the interdependencies among barriers. To determine final weights these interdependencies are then incorporated into the previously established barrier weights.

4.6.1. Impact Assessment

At this phase, experts were asked to illustrate the impact of barriers on each other graphically. The graphical illustration presented by the experts is shown in Figure 4.3

4.6.2. Establishment of Barrier's Impact Matrix

Experts were provided with the Triangular Fuzzy Numbers (TFN) using Table 3.4 to translate these impacts. Consequently, the barrier impact matrix was obtained, as shown in Table 4.2.

4.6.3. Normalizing Barrier's Impacts Matrix

In the next step of this phase, by using Equation (7) the normalized matrix is obtained by normalizing the barrier impact matrix. By taking the supper of higher values of each row a "s" factor is calculated. In each row of Table 4.2. In this case, in the first row, the highest value was 1.5, in the second row it was 1.6, and in the third row, it was 0.9. 1.6 is the maximum value, so the whole Barrier's Impact matrix is divided by the value of s. Table 4.3 presents the fuzzy normalized matrix that has been obtained as a result.

Table 4.2: Barrier's Impact Matrix for the Calculation of Interdependencies

Barriers	**Technological**	**Organizational**	**Environmental**
Technological	-	(0.5,0.6,0.7)	(0.6,0.7,0.8)
Organizational	(0.7,0.8,0.9)	-	(0.5,0.6,0.7)
Environmental	(0.2,0.3,0.4)	(0.3,0.4,0.5)	-

Table 4.3: Fuzzy Normalized Matrix for Interdependency Calculation

Barriers	Technological	Organizational	Environmental
Technological	-	(0.3125, 0.375, 0.4375)	(0.375, 0.4375, 0.5)
Organizational	(0.4375, 0.5,0.5625)	-	(0.3125, 0.375, 0.4375)
Environmental	(0.125, 0.1875, 0.25)	(0.1875, 0.25, 0.3125)	-

4.6.4. Establishment of the Full Fuzzy Relation Matrix:

In this step, Equation (8) is used for the determination of the fuzzy relation matrix. At first, the normalized matrix is converted into three distinct matrices as follows:

$$X_1 = \begin{bmatrix} 0 & 0.3125 & 0.375 \\ 0.4375 & 0 & 0.3125 \\ 0.125 & 0.1875 & 0 \end{bmatrix}, X_2 = \begin{bmatrix} 0 & 0.375 & 0.4375 \\ 0.5 & 0 & 0.375 \\ 0.1875 & 0.25 & 0 \end{bmatrix},$$

$$X_3 = \begin{bmatrix} 0 & 0.4375 & 0.5 \\ 0.5625 & 0 & 0.4375 \\ 0.25 & 0.3125 & 0 \end{bmatrix}$$

Following that, the equation $\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}$ is used to obtain $T_1, T_2\ and\ T_3$. Where "I" is representing the identity matrix. Following are the resulting matrices:

$$T_1 = \begin{bmatrix} 0.317 & 0.536 & 0.661 \\ 0.667 & 0.334 & 0.667 \\ 0.29 & 0.317 & 0.208 \end{bmatrix}, T_2 = \begin{bmatrix} 0.631 & 0.872 & 1.041 \\ 1.026 & 0.652 & 1.068 \\ 0.562 & 0.576 & 0.462 \end{bmatrix},$$

$$T_3 = \begin{bmatrix} 1.422 & 1.666 & 1.94 \\ 1.885 & 1.455 & 2.017 \\ 1.195 & 1.184 & 1.116 \end{bmatrix}$$

4.6.5. Determination of the Interdependency Matrix:

In this step, out of matrices $T_1, T_2\ and\ T_3$, The interdependency matrix will be calculated using Equation 9.

$$Defuzzy\ (t_{11}) = \frac{0.317 + 4(0.631) + 1.422}{6} = 0.711$$

For the remaining components similar calculations will be performed, which will give the following matrix:

$$Defuzzy\ (t_{ij}) = \begin{bmatrix} 0.711 & 0.948 & 1.128 \\ 1.109 & 0.733 & 1.159 \\ 0.622 & 0.634 & 0.529 \end{bmatrix}$$

Afterward using Equation (10), the obtained matrix is normalized by dividing each element by the sum of its corresponding column. Following is the outcome of the interdependency matrix

$$Interdependency\ Matrix = \begin{bmatrix} 0.291 & 0.41 & 0.401 \\ 0.454 & 0.317 & 0.412 \\ 0.255 & 0.274 & 0.188 \end{bmatrix}$$

4.6.6. Determination of the Final Weights

After calculating the Interdependency matrix, the final weights of the barriers are calculated by applying this matrix to the barrier weights acquired in section 4.4.6, which are as follows

$$\begin{bmatrix} 0.325 & 0.533 & 0.612 \\ 0.556 & 0.275 & 0.316 \\ 0.119 & 0.192 & 0.072 \end{bmatrix} \times \begin{bmatrix} 0.21 \\ 0.70 \\ 0.09 \end{bmatrix} = \begin{bmatrix} 0.5 \\ 0.34 \\ 0.16 \end{bmatrix}$$

4.6.7. Cross Comparison of Final Weights with and without Interdependency Considerations

In this section, cross-comparison of final weights of barriers is covered by considering Interdependencies and without Interdependencies using the Fuzzy Simplified Best Worst Method approach as shown in Table 4.4. As shown in Figure 4.4, it is analysed that the weights of the barriers have an impact on interdependency. In the case study, it is clearly shown that by considering the interdependency there is a notable change in the weights of barriers.

Table 4.4: Comparison of Barrier Weights with and without Interdependency

Barriers	**F-SBWM (without Interdependency)**	**F-SBWM (with Interdependency)**
Technology	0.21	0.5
Organizational	0.70	0.34
Environmental	0.09	0.16
SUM	**1.00**	**1.00**

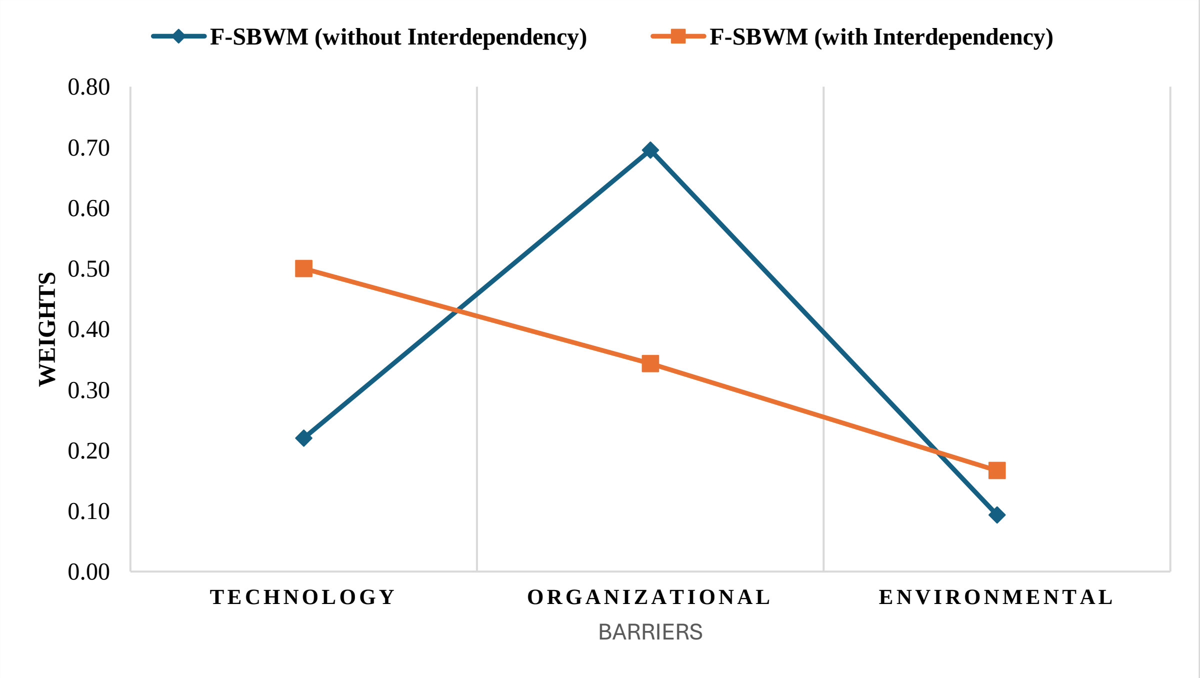

Figure 4.4: Comparative Visualization of Barrier Weights with and without Interdependency

In the case of sub-barriers, Table 4.5 shows a comparative analysis of the final weights given to the sub-barriers by considering the interdependency and without interdependencies using the Fuzzy Simplified Best Worst Method. As shown in Figure 4.5, it is analysed that there is a visible impact on weights by considering the interdependencies.

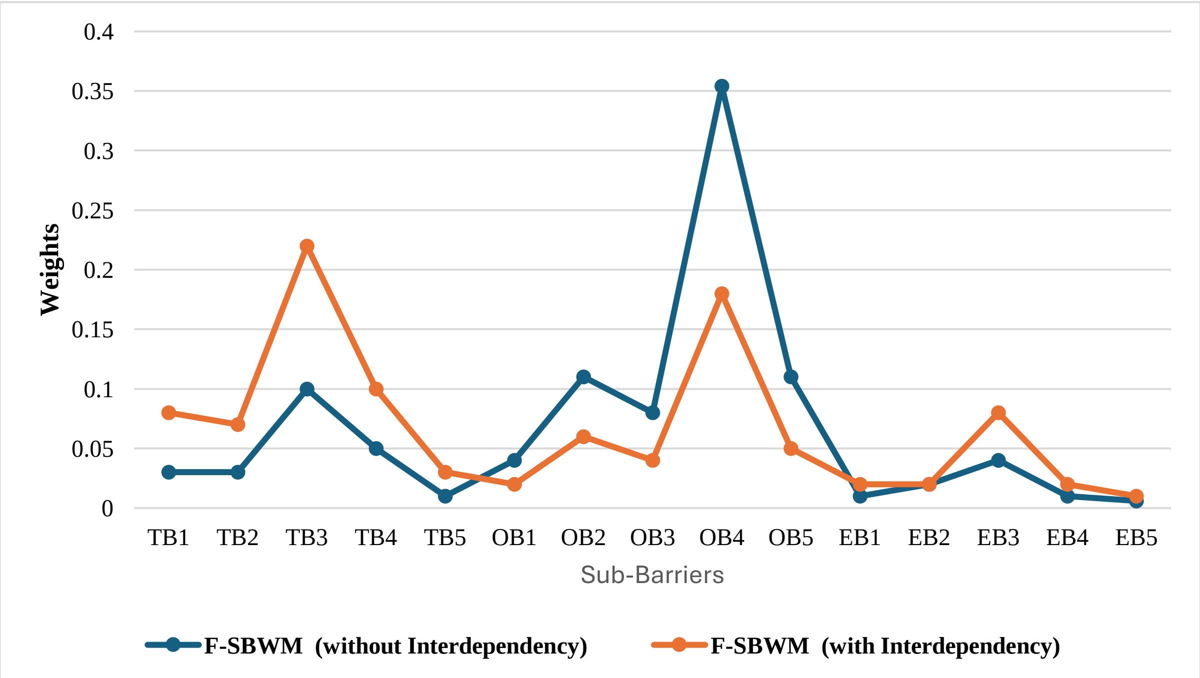

Figure 4.5: Visualization of Weights of Sub Barriers with and without Interdependency

Table 4.5: Weights of Sub-barriers with and without Interdependency

Sub-Barriers	F-SBWM (without Interdependency)	F-SBWM (with Interdependency)
TB1	0.03	0.08
TB2	0.03	0.07
TB3	0.1	0.22
TB4	0.05	0.1
TB5	0.01	0.03
OB1	0.04	0.02
OB2	0.11	0.06
OB3	0.08	0.04
OB4	0.354	0.18
OB5	0.11	0.05
EB1	0.01	0.02
EB2	0.02	0.02
EB3	0.04	0.08
EB4	0.01	0.02
EB5	0.006	0.01
SUM	1.00	1.00

5. RESULTS AND DISCUSSION

5.1. Results

The objective of this research is to identify and analyze the barriers to the implementation of blockchain technology in the cold food supply chain by using the integrated approach of Fuzzy simplified best worst method and Fuzzy DEMATEL. Data was collected through purposive sampling consisting of expert's preferences using Triangular Fuzzy numbers. The fuzzy simplified best-worst method is applied to calculate the weights of the barriers and sub-barriers without considering interdependencies among them. While Fuzzy DEMATEL is applied to calculate the weights with interdependencies. The insights obtained from the results while considering both the interdependencies and without interdependencies are as follows.

5.1.1. Main Barriers with and without Interdependencies

Technological barriers are the most critical barrier when interdependencies are considered which indicates a strong interdependent relationship with other barriers. While without considering the interdependencies technological barriers are less critical. Organizational barriers are most critical without considering the interdependencies whereas it is less critical when considered independently. Environmental barriers are the least significant when considering both the interdependencies and without interdependencies, but the importance increases slightly with interdependencies.

5.1.2. Sub-Barriers with and without Interdependencies

The sub-barrier of technological barriers, the high cost of technology is a critical sub-barrier when interdependencies are not considered whereas considering the interdependencies it is even more critical as compared to Organizational sub-barriers is Resistance to blockchain culture among stakeholders is critical when considering the interdependencies but in case of without interdependencies its significance decreases and the lack of knowledge and expertise is more critical barrier though its importance reduces when interdependencies are accounted for. Environmental sub-barrier that is Cultural differences between supply chain partners is critical when both interdependencies and without interdependencies are considered, but they are less significant in comparison with Organizational and Technological sub-barriers.

5.2. Discussion

In this case study by applying the methodology an impactful change can be observed in barrier weights with consideration of both with and without interdependencies. This methodology effectively captured the weights using the TFN (triangular fuzzy number) scale and provided consistent results that can be analyzed using the consistency ratio which proves by integrating the Fuzzy Simplified Best-Worst Method and Fuzzy-DEMATEL results are more accurate and consistent. Those can lead to making an accurate and more informed decision. Decision-makers can assess how barriers influence each other when taking interdependencies into account. This methodology provides a more organized way to address multi-criteria decision-making problem that considers all aspects.

5.3. Sensitivity Analysis

In this Section administrating the sensitivity analysis to check the robustness of the applied model. We analyze the robustness and stability of the outcomes as per different weights of barriers. In this section, a sensitivity analysis is conducted by changing the preferences of the main barriers assigned by the experts. We are analyzing two scenarios as compared to the original ones. In the first scenario Best another barrier that was originally an organizational barrier is changed to a technological barrier rest are the same then the results are analyzed. In the next scenario Environmental barrier is chosen as the Best Other Barrier and the Organizational barrier as the worst barrier while maintaining the rest of the barriers uniform.

Alternate responses for the Sensitivity analysis are:

5.3.1. 1st Scenario

Fuzzy BTO preferences for barrier:

[(1,1,1), (3,4,5), (7,8,9)]

Fuzzy BTO preferences for sub-barriers within organizational barriers:

[(7,8,9), (5,6,7), (4,5,6), (1,1,1), (3,4,5)]

Fuzzy BTO preferences for sub barrier within environmental barriers:

[(5,6,7), (3,4,5), (1,1,1), (4,5,6), (7,8,9)]

Fuzzy OTW preferences for barrier:

[(7,8,9),(1,2,3), (1,1,1)]

Fuzzy OTW preferences for sub-barriers within technological barriers:

[(3,4,5),(1,2,3),(7,8,9),(2,3,4),(1,1,1)]

Fuzzy OTW preferences for sub-barriers within organizational barriers:

[(1,1,1), (3,4,5), (1,2,3), (7,8,9), (2,3,4)]

Fuzzy OTW preferences for sub barrier within environmental barriers:

[(3,4,5), (1,2,3), (7,8,9), (2,3,4), (1,1,1)]

5.3.2. Results of Sensitivity Analysis with Comparison to Original Preferences

Weights of Barriers with and without Consideration of Interdependency Using Fuzzy- SBWM

Table 5.1: Weights of Barriers with and without Interdependency (Sensitivity Analysis)

Barriers	F-SBWM (without Interdependency)	F-SBWM (with Interdependency)
Technology	0.73	0.39
Organizational	0.19	0.49
Environmental	0.09	0.13

Weights of Sub-Barriers with and without Consideration of Interdependency using Fuzzy- SBWM

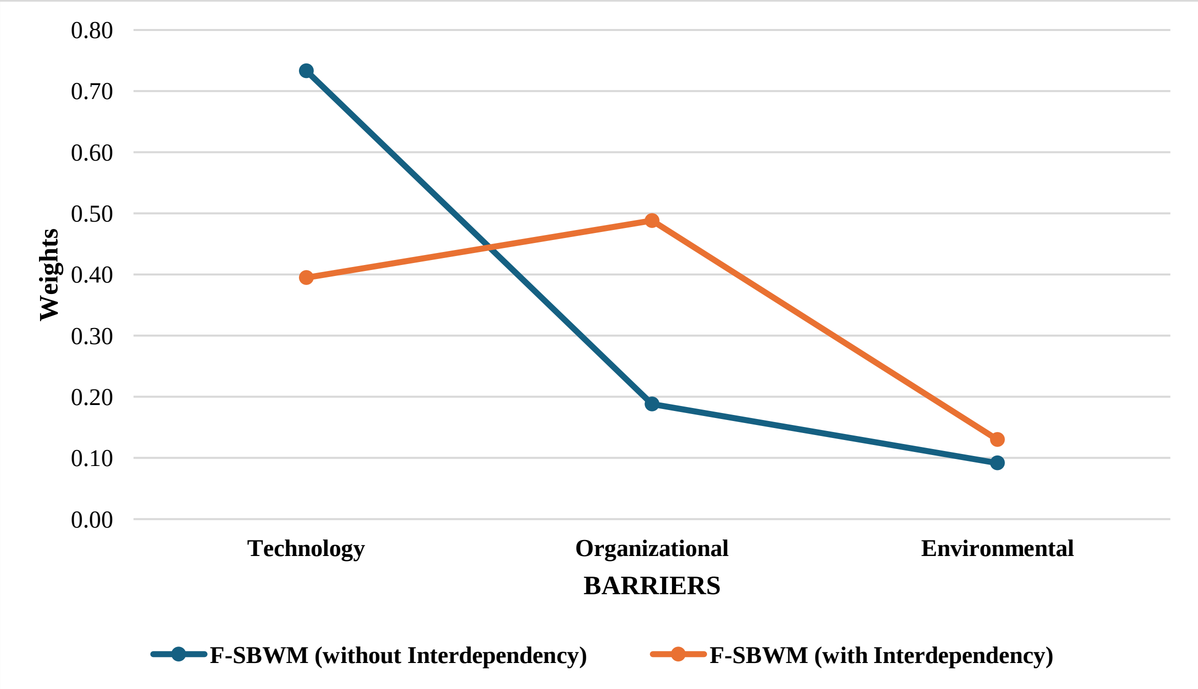

Figure 5.1: Weights of Barriers with and without Interdependency (Sensitivity Analysis)

Table 5.2: Weights of Sub-Barriers with and without Interdependency (Sensitivity Analysis)

Sub-Barriers	F-SBWM (without Interdependency)	F-SBWM (with Interdependency)
TB1	0.11	0.06
TB2	0.1	0.05
TB3	0.33	0.18
TB4	0.15	0.08
TB5	0.04	0.03
OB1	0.01	0.07
OB2	0.03	0.05
OB3	0.02	0.25
OB4	0.09	0.07
OB5	0.03	0.02
EB1	0.01	0.02
EB2	0.02	0.07
EB3	0.04	0.02
EB4	0.01	0.02
EB5	0.01	0.01
SUM	1	1

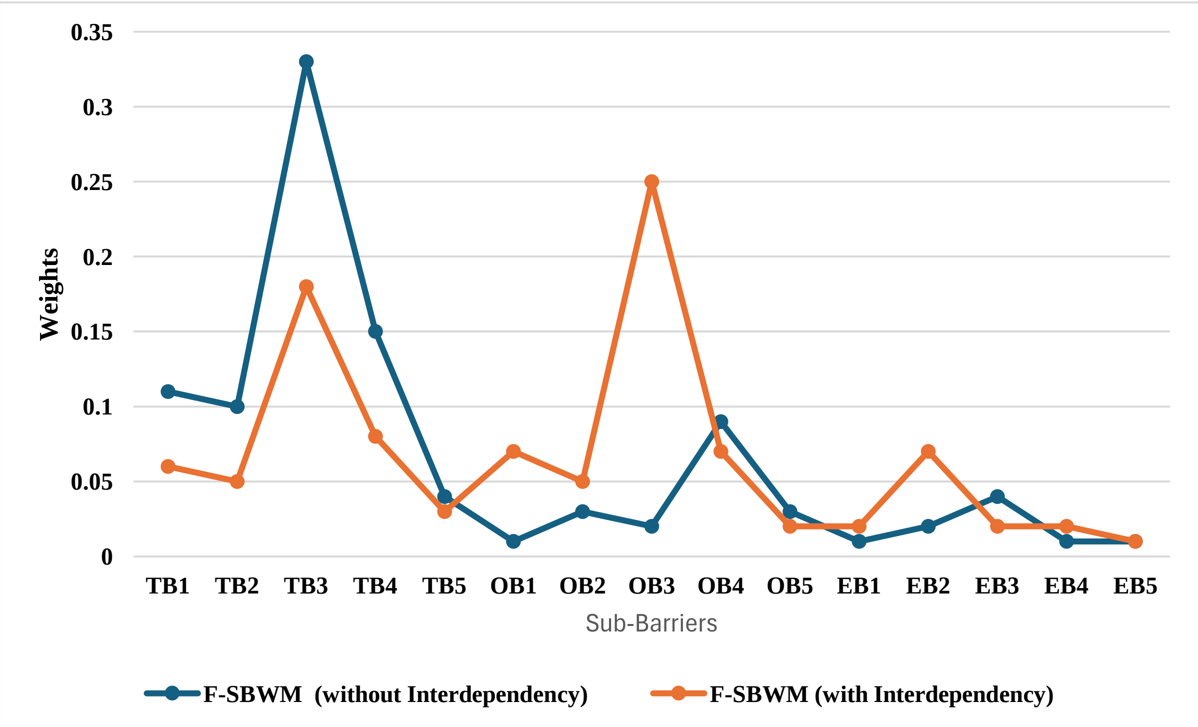

Figure 5.2: Weights of Sub-Barriers with and without Interdependency (Sensitivity Analysis)

5.3.3. 2nd Scenario:

In this scenario, the environmental barrier is given the preference as the Best to Others while the Organizational Barrier is Considered as the worst barrier.
Responses for sensitivity analysis:

Fuzzy BTO preferences for barrier:

[(3,4,5), (6,7,8), (1,1,1)]

Fuzzy BTO preferences for sub-barriers within technological barriers:

[(4,5,6), (2,3,4), (1,1,1), (1,2,3), (5,6,7)]

Fuzzy BTO preferences for sub-barriers within organizational barriers:

[(7,8,9), (5,6,7), (4,5,6), (1,1,1), (3,4,5)]

Fuzzy BTO preferences for sub barrier within environmental barriers:

[(5,6,7), (3,4,5), (1,1,1), (4,5,6), (7,8,9)]

Fuzzy OTW preferences for barrier:

[(2,3,4), (1,1,1), (7,8,9)]

Fuzzy OTW preferences for sub-barriers within technological barriers:

[(3,4,5), (1,2,3), (7,8,9), (2,3,4), (1,1,1)]

Fuzzy OTW preferences for sub-barriers within organizational barriers:

[(1,1,1), (3,4,5), (1,2,3), (7,8,9), (2,3,4)]

Fuzzy OTW preferences for sub barrier within environmental barriers:

[(3,4,5), (1,2,3), (7,8,9), (2,3,4), (1,1,1)]

5.3.4. Results of Sensitivity Analysis with Comparison to Original Preferences:

Weights of Barriers with and without Consideration of Interdependency Using Fuzzy- SBWM

Table 5.3: Weights of Barriers with and without Interdependency (Sensitivity Analysis)

Barriers	F-SBWM (without Interdependency)	F-SBWM (with Interdependency)
Technology	0.22	0.55
Organizational	0.09	0.37
Environmental	0.70	0.09
SUM	1.0	1.0

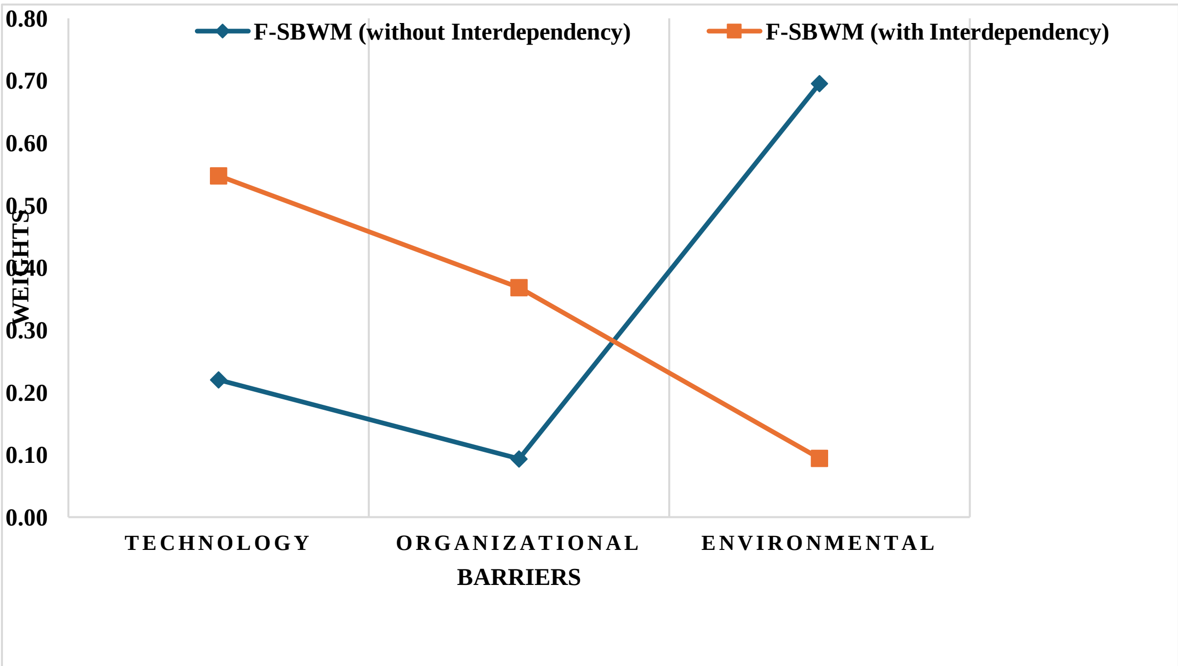

Figure 5.3: Weights of Barrier with and without Interdependency (Sensitivity Analysis)

Weights of Sub-Barriers with and without Consideration of Interdependency using Fuzzy- SBWM

Table 5.4: Weights of Sub-Barriers with and without Interdependency (Sensitivity Analysis)

Sub-Barriers	F-SBWM (without Interdependency)	F-SBWM (with Interdependency)
TB1	0.03	0.09
TB2	0.03	0.08
TB3	0.09	0.24
TB4	0.05	0.11
TB5	0.01	0.04
OB1	0.01	0.02
OB2	0.01	0.06
OB3	0.01	0.04
OB4	0.05	0.18
OB5	0.01	0.05
EB1	0.11	0.02
EB2	0.09	0.01
EB3	0.36	0.04
EB4	0.1	0.01
EB5	0.04	0.01
SUM	1	1

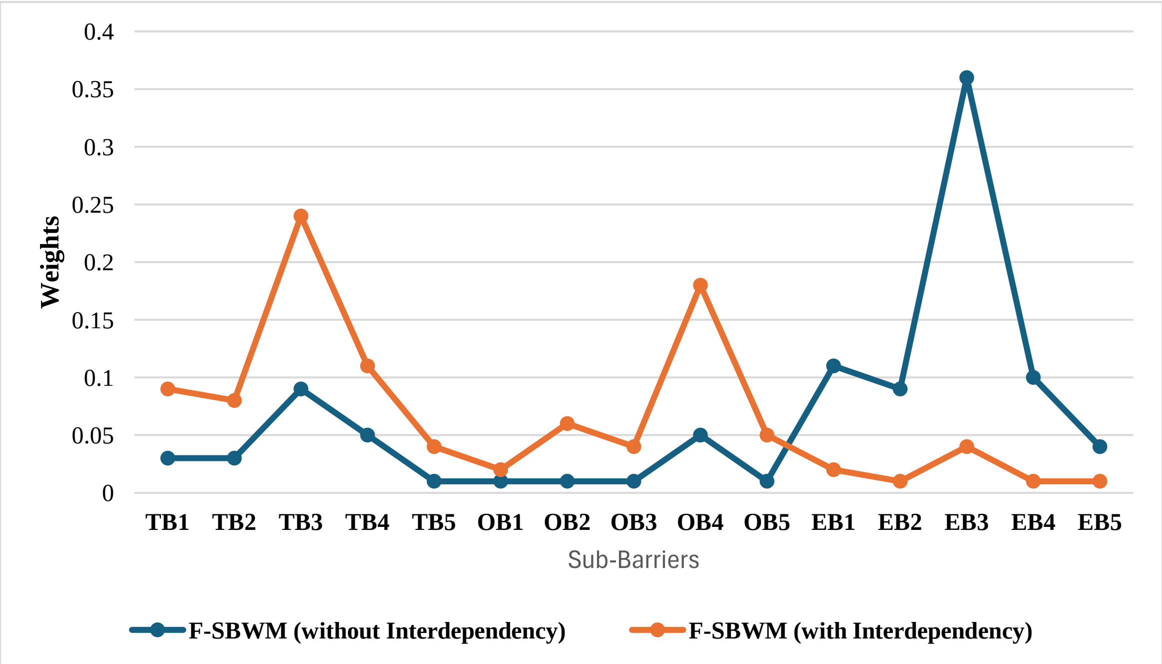

Figure 5.4: Weights of Sub-barriers with and without Interdependency (Sensitivity Analysis)

5.3.5. Sensitivity Analysis Outcomes:

Performing sensitivity analysis by changing the preferences reveals the importance of the order of expert preferences in determining the weights of barriers and sub-barriers. This approach helps identify which barriers and sub-barriers are most sensitive to changes in preference order, providing valuable insights into the robustness and reliability of the decision-making model. In scenario 1 by changing the Best barrier to the Technological barrier we have analyzed that the most critical sub-barrier shifted from "Stakeholder resistance to blockchain culture" to "High cost of technology" and the least critical barrier is "market competition and uncertainty" while in the 2nd scenario where the environmental barrier is chosen as the best barrier and Organizational barrier as the worst barrier. In this situation the most critical barrier that was "stakeholder resistance to blockchain culture" changed to "cultural differences of supply chain partners" and "Lack of new organizational policies for using blockchain technology" is identified as the least critical barrier. By understanding g these sensitivities, decision-makers can make more informed choices and ensure the stability of their decisions in various scenarios.

5.4. Managerial Insights

The outcomes of this study provide a list of managerial insights for organizations that are interested in implementing blockchain technology in cold supply chains.

- **Prioritize Technological Barriers**

  According to the results when considering the interdependencies technological barriers have high significance. This entails that the high cost of technology and data privacy issues are strongly interconnected with other barriers and boost their impact overall. For the sake of implementing blockchain technology, managers should prioritize addressing these barriers. This will enhance overall supply chain efficiency.

- **Addressing Organizational Barriers**

  Without interdependency among barriers organizational barriers have the highest significance while their impact is reduced when considering the interdependencies. The impact of its sub barriers such as stakeholder resistance to blockchain culture and lack of knowledge and expertise are notable. Their impact can be reduced through better management practices. Managers can organize training programs and workshops to enhance their knowledge and expertise. They should restructure their organizational policies and develop a culture that focuses more on innovation and technology adoption.

- **Mitigating Environmental Barriers**

  Though environmental barriers are the least significant when considering the interdependencies their importance increased. Cultural differences between supply chain partners have an indirect influence. To address these barriers managers should collaborate with supply chain partners, be involved with regulatory authorities, and raise awareness among customers.

- **Integrated Approach to Barrier Management**

  To evaluate and address barriers, the integration of fuzzy simplified best worst method and fuzzy-DEMATEL provides a comprehensive framework. This provides an organized way to assess barrier weights by considering the all impacts of interdependencies among them. Managers can use this integrated approach to make sure they are making reliable and accurate decisions in the process of implementing blockchain technology in the field of cold supply chains.

- **Utilization of Expert Insights**

  Managers should make the most use of available professionals and better include them due to their ample experience with blockchain technology and supply chain aspects. This will make sure the weights are nicely allocated reliably and consistently. Experts' input will lead to credible and secure implementation of the blockchain technology which in turn gets you better results.

- **Simplified Approach**

  The integrated and convenient method of Fuzzy- simplified best-worst method with Fuzzy DEMATEL can provide the weights that would be used by managers. It is a straightforward process and there is no complex software or any sort of math programming needed during the process. This enables organizations to keep a clear focus on the most challenging barriers and sub-barriers - helping them restore some much-needed clarity during their decision-making process while organizing how they implement blockchain technology.

6. CONCLUSION

The research provides a detailed analysis of the barriers to the implementation of blockchain technology in the cold food supply chain, using a case study of K&N's. This study offers a detailed understanding of Technological, Organizational, and Environmental challenges faced in the adoption of blockchain technology, using the integrated approach of the Fuzzy Simplified Best worst Method (F-SBWM) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL).

According to this research technological barriers are the most significant for the implementation of blockchain technology when considering the interdependencies among barriers. Those barriers are important to address when they are influenced by organizational and environmental barriers. Getting a detailed understanding of the interaction of these barriers can help to develop more effective and comprehensive strategies in the adoption of blockchain technology. When interdependencies are not encountered Organizational barriers have a huge impact. The effect of these barriers can be reduced by effective management practices and strategic inventions.

Organizations need to focus on restructuring their polices and improving improve internal expertise to implement blockchain technology. Organizations can make their culture that adapts innovations and provide training to effectively overcome these barriers. Environmental barriers were the least significant but their criticality slightly increased when interdependencies were encountered. This indicates the need for an external supportive environment and reliable policy framework to encourage blockchain technology implementation.

To mitigate these barriers organizations can collaborate with the government and other stakeholders to develop favorable situations. In this research, the integrated applied approach of Fuzzy Simplified Best Worst Method and Fuzzy-DEMATEL proved to be an effective approach for systematically weighing barriers. This provides us with a more reliable and accurate understanding of barriers by considering interdependencies. This simplified approach demotivates the complex mathematical models and software. This helps managers to develop targeted strategies to overcome those barriers. By considering the interdependencies organizations can adopt more organized ways to manage these barriers. Organizations can improve their willingness for integration of blockchain technology and enhance their overall supply chain efficiency.

6.1. Findings

This research produces several findings regarding the implementation barriers of blockchain technology in cold supply chains derived by applying the integrated approach of Fuzzy- Simplified Best Worst Method and Fuzzy- DEMATEL. They provide a detailed understanding of the critical challenges faced.

- **Analysis of Barriers**

  Technological barrier highlights the interconnectedness of challenges in the field of technology. They have a substantial impact on the implementation process. While organizational barriers are substantial their effect can be mitigated through effective management practices. Environmental barriers have an indirect influence through interactions with other barriers that can affect the adoption of blockchain technology.

- **Management of Barriers**

  An organized and fully impactful assessment of the weights of barriers and sub-barriers provides a more accurate and robust understanding of the challenges faced. The integration of the Fuzzy-Simplified Best Worst Method and Fuzzy-DEMATEL highlights the importance of considering interdependency among barriers.

- **Practical Benefits of F-SBWM**

  The F-Simplified Best Worst Method proves to be an effective tool for obtaining weights rather than applying complex mathematical modeling or any software. It helps managers to utilize it when they have constraints.

- **Significance of Interdependency**

  Addressing the interdependencies among barriers is important. For the development of effective strategies for Blockchain technology implementation, these interconnected relationships are important to understand.

- **Role of Expert Knowledge**

  The process of taking preferences from experts ensured reliable and consistent results. Their knowledge and insights make the process more believable.

6.2. Future Research Work

This research provides further investigation into other supply chain sectors beyond cold chain or other subcategories of Cold supply chain. Integrating other methodologies can describe different perspectives and enhance the robustness of barrier analysis. To improve the implementation of blockchain technology process different strategies could be designed. Researchers can track changes over an extended period to observe how these barriers develop and change. These studies can evaluate how well different strategies work in overcoming these barriers. Investigating different areas of barriers like geographical and cultural differences and their impact on interdependencies can help adapt strategies for blockchain technology implementation. Investigating the barriers to integration of the latest technologies such as (IOT) the Internet of Things and artificial intelligence (AI) enhances the understanding of management and ultimately drives innovation and efficiency in the industry.

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