

# Identifying and Ranking Barriers to Implementing Internet of Things in Food Supply Chains: A Case Study of Kalleh Company

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## ABSTRACT

The implementation of Internet of Things (IoT) technology in food supply chains faces significant barriers that hinder its potential to enhance traceability, efficiency, and sustainability. This study identifies and analyzes these barriers by conducting a case study of Kalleh Company, a leading Iranian food producer, using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. Through conducting a literature review and expert interviews, 11 key barriers were categorized into technological, financial, human capital, regulatory, and infrastructural dimensions. The DEMATEL analysis revealed critical insights into the causal relationships among these barriers. Inadequate infrastructure emerged as the most prominent barrier, heavily influenced by financial constraints such as high implementation costs and limited funding access. Meanwhile, lack of interoperability was identified as the strongest causal barrier, creating systemic challenges by preventing seamless integration across IoT systems. Interestingly, while the shortage of skilled labor showed balanced influence/dependence, its high prominence underscored its operational significance. The study highlights the complex interdependencies among IoT adoption barriers, demonstrating that infrastructure limitations cannot be resolved without addressing the underlying financial and technological challenges. These findings suggest that successful implementation of IoT requires coordinated strategies addressing multiple dimensions simultaneously including standardization efforts, financial support mechanisms, and workforce development programs.

## KEYWORDS

Adoption Barriers, Causal Analysis, DEMATEL Method, Food Supply Chains, Internet of Things (IoT).

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## Introduction

The Internet of Things (IoT), a revolutionary technological paradigm, is rapidly transforming industries worldwide, and the food industry is no exception. The IoT, characterized by the interconnection of physical objects embedded with sensors, actuators, and software, enables data collection, analysis, and communication on an unprecedented scale. This interconnected network of devices facilitates real-time monitoring, automation, and data-driven decision-making, offering immense potential for enhancing efficiency, safety, and sustainability across various sectors. Recent research papers from 2020 to 2024 highlight the transformative potential of IoT in diverse applications, ranging from smart agriculture (Bhavana et al., 2024) to precision manufacturing (Javadi et al., 2024) and intelligent healthcare (Tarik et al., 2025). However, the adoption of IoT technologies within the food industry, a sector characterized by complex supply chains and stringent safety regulations, faces significant barriers. This introduction delves into the intricacies of the food industry supply chain, the transformative potential of IoT, and the critical need to address the challenges hindering its widespread adoption.

The food industry supply chain, a complex network spanning from farm to fork, involves numerous stages, each presenting unique challenges. From agricultural production and harvesting to processing, packaging, distribution, and retail, the journey of food products is fraught with potential risks and inefficiencies. Traditional methods often lack the real-time visibility and data-driven insights necessary for optimal management. Inefficient processes lead to significant food waste, estimated at one-third of all food produced globally (Betty et al., 2024), resulting in substantial economic losses and environmental damage. Furthermore, maintaining food safety and quality throughout the extended supply chain is paramount, requiring stringent monitoring and control measures to prevent contamination and ensure consumer safety. The lack of transparency and traceability in traditional systems makes it difficult to identify and address issues promptly, leading to product recalls and reputational damage. Research papers published between 2020 and 2024 underscore these challenges, emphasizing the need for innovative solutions to enhance food safety, reduce waste, and improve overall supply chain efficiency (Akinbamini et al., 2025; Tanwar et al., 2022; Vasanthraj et al., 2023). The integration of IoT technologies offers a promising pathway to address these critical issues.

The application of IoT in the food industry holds the potential to revolutionize various aspects of the supply chain. Smart sensors embedded in agricultural fields can monitor soil conditions, weather patterns, and crop health, enabling precision farming techniques that optimize resource utilization and enhance yields (Bhavana et al., 2024). Real-time data on crop growth and environmental factors allows farmers to make informed decisions regarding irrigation, fertilization, and pest control, minimizing waste and maximizing productivity. In processing facilities, IoT-enabled equipment can monitor temperature, humidity, and other critical parameters, ensuring optimal conditions for preserving food and preventing spoilage (Mawardi et al., 2023). Automated systems can

streamline production processes, reducing labor costs and improving efficiency. During transportation and distribution, IoT devices can track the location and condition of food products, ensuring timely delivery and maintaining product quality. Real-time monitoring of temperature and humidity prevents spoilage and ensures food safety. At the retail level, smart shelves and inventory management systems can optimize stock levels, reducing waste and improving customer satisfaction. The integration of Blockchain technology with IoT further enhances transparency and traceability, providing immutable records of food products' journey from origin to consumption (Ahmad et al., 2024; Kaur et al., 2022; Tanwar et al., 2022). This enhanced visibility allows for rapid identification and resolution of issues, minimizing the impact of contamination or spoilage incidents. Numerous research papers published in recent years demonstrate the significant benefits of integrating IoT in various stages of the food supply chain, highlighting its potential to improve food safety, reduce waste, and enhance overall efficiency (Alsayat & Ahmadi, 2023; Javadi et al., 2024; Liu, 2024; Mashayekhy et al., 2022; Maulana et al., 2021; Rui & Sundram, 2024; Sun & Wang, 2022).

Despite the significant potential benefits, the adoption of IoT technologies in the food industry faces numerous barriers. High initial investment costs associated with implementing IoT infrastructure, including sensors, software, and communication networks, can be a significant deterrent, particularly for small and medium-sized enterprises (SMEs) (Judijanto et al., 2024; Kuaban et al., 2024; Rui & Sundram, 2024). The complexity of integrating various IoT devices and systems across the entire supply chain presents technical challenges, requiring specialized expertise and robust data management capabilities. Concerns regarding data security and privacy are also paramount, as sensitive information about food products and supply chain operations needs to be protected from unauthorized access and cyber threats (Al-garadi et al., 2018; Hu & Shu, 2023; Stoyanova et al., 2020; Tarik et al., 2025). Lack of standardization and interoperability among different IoT devices and platforms hinders seamless data exchange and integration, creating compatibility issues and limiting the effectiveness of IoT solutions. Regulatory compliance and the need to adhere to stringent food safety standards add further complexity to the implementation of IoT. The lack of awareness and understanding of IoT technologies among food industry stakeholders, including farmers, processors, distributors, and retailers, also hinders their adoption. Resistance to change and a lack of skilled personnel capable of managing and maintaining IoT systems further exacerbate the challenges. Research papers published between 2020 and 2024 extensively discuss these barriers, highlighting the need for addressing these challenges to facilitate wider adoption of IoT technologies in the food industry (Hao & Demir, 2024; Khan et al., 2024; Kuaban et al., 2024; Nozari & Nahr, 2022; Pai et al., 2020; Sharma et al., 2024; Solanki et al., 2023; Zhao et al., 2024).

Addressing the barriers to IoT adoption in the food industry is crucial for ensuring food safety, reducing waste, and improving overall supply chain efficiency. The economic benefits of implementing IoT technologies are substantial, including reduced costs,

increased productivity, and enhanced profitability. Improved food safety and quality lead to increased consumer trust and brand loyalty, while reduced waste minimizes environmental impacts and promotes sustainability. The social benefits including improved working conditions, enhanced food security, and reduced health risks associated with foodborne illnesses are equally significant. The potential for innovation and technological advancements in the food industry is immense, with IoT playing a pivotal role in driving this transformation. However, realizing this potential requires a concerted effort from various stakeholders, including governments, industry organizations, technology providers, and research institutions. Policy support, including financial incentives and regulatory frameworks, is essential to encourage the adoption of IoT, particularly among SMEs. Investment in research and development is crucial to overcome technical challenges and develop cost-effective, interoperable, and secure IoT solutions. Education and training programs are needed to enhance the awareness and understanding of IoT technologies among food industry stakeholders. Collaboration and knowledge sharing among different actors in the food supply chain are essential to facilitate the seamless integration of IoT systems and ensure the successful implementation of IoT-based solutions. This research aims to contribute to this critical endeavor by identifying and ranking the barriers to IoT adoption, providing valuable insights for stakeholders to develop effective strategies for overcoming these challenges and realizing the full potential of IoT in the food industry.

## Literature Review

To have a holistic view of the literature first the authors extract the most updated papers with a Bibliometrics approach (e.g., [Farazmand et al., 2019](#); [Nourahmadi et al., 2022](#); [Rasti et al., 2024](#)). Then, after reviewing them, the most related papers are selected for the current study. [Rui and Sundram \(2024\)](#) examined the role of emerging technologies namely Blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI) in promoting the management of sustainable supply chain in Malaysia's food industry. Their research emphasized the benefits of these technologies in enhancing traceability, reducing waste, and improving efficiency. However, several barriers were identified, particularly for small and medium-sized enterprises (SMEs), including high implementation costs, lack of skilled labor, and concerns regarding data security and privacy. The authors suggested pilot programs, workforce training, and increased government support as key strategies for overcoming these obstacles. Similarly, [Akinbamini et al. \(2025\)](#) conducted a statistical analysis on the adoption of Supply Chain Collaboration Technologies (SCCTs) such as Blockchain, IoT, ERP, and AI within Nigeria's food industry. Their findings revealed that, despite the technologies' transformative potential, infrastructural deficiencies, regulatory constraints, weak trust-building mechanisms, and limited technical expertise hinder widespread adoption of IoT technologies. The study highlighted the importance of policy-driven interventions and targeted resource allocation to address these issues.

[Virmani and Singh \(2024\)](#) adopted the Best-Worst Method (BWM) and Graph

Theoretic Approach (GTA) to identify and prioritize the barriers to Blockchain adoption in agri-food supply chains. They found that technological barriers—particularly increased operational complexity and lack of interoperability were the most significant ones. They proposed a decision support framework to assist stakeholders in addressing these challenges systematically. [Kumar et al. \(2022\)](#) presented a comprehensive review on the integration of Blockchain and IoT technologies in food supply chains, emphasizing the barriers such as insufficient government regulation, low employee competency, and complex decision-making structures. These factors were found to significantly impact the rates of adoption.

[Cuéllar and Johnson \(2022\)](#) also explored the challenges of implementing Blockchain and IoT in agricultural supply chains, identifying poor infrastructure and limited user knowledge as major barriers. They argued that both the public and private sectors have a pivotal role in fostering the adoption of these technologies. [Anusha and Padma \(2021\)](#) investigated Blockchain applications in agriculture, pointing to benefits in traceability and smart contracts, but also noting limitations such as high energy costs, insufficient education, and immature technological infrastructure in the Indian context. [Vern et al. \(2023\)](#) conducted a broad review of barriers to Blockchain adoption in agri-food supply chains, noting that while IoT was not the main focus, its integration with Blockchain systems made the findings highly relevant. The study used multiple analytical methods to identify and rank the most influential barriers.

In another study, [Tsai et al. \(2023\)](#) utilized an interval-valued hesitant fuzzy DEMATEL approach to evaluate barriers to Blockchain adoption in Vietnam's agricultural supply chain. Their findings identified a lack of government regulation as the most critical impediment, underscoring the need for clearer policy frameworks. [Nisar et al. \(2024\)](#) explored the Chinese fisheries supply chain using a grey Delphi and DEMATEL approach, identifying regulatory compliance issues, high implementation costs, and the complexity of supply chain networks as key barriers to Blockchain adoption. [Khan et al. \(2022\)](#) employed the Best-Worst Method (BWM) to investigate the challenges of Blockchain implementation in food supply chains, revealing that technological and organizational barriers ranked highest in terms of influence. [Wang et al. \(2024\)](#) applied a hybrid interval-valued Fermatean fuzzy PROMETHEE-II model to analyze barriers to the adoption of resilient supply chain systems in the food sector. While not limited to IoT, the insights offered a broader understanding of the challenges associated with the adoption of advanced technologies in this industry.

Finally, [Gonçalves et al. \(2024\)](#) focused on SMEs and sustainable supply chain management (SSCM), identifying financial constraints—especially lack of funding—as major obstacles. Although not exclusively centered on IoT, the findings remain relevant given the investment-intensive nature of IoT integration. [Singh et al. \(2023\)](#) used a grey Delphi-DEMATEL approach to identify critical success factors for Blockchain-integrated IoT in food supply chains. They emphasized the importance of top management support, knowledge management, skilled personnel, technology readiness, and capital investment in enabling successful implementation.

## Methodology

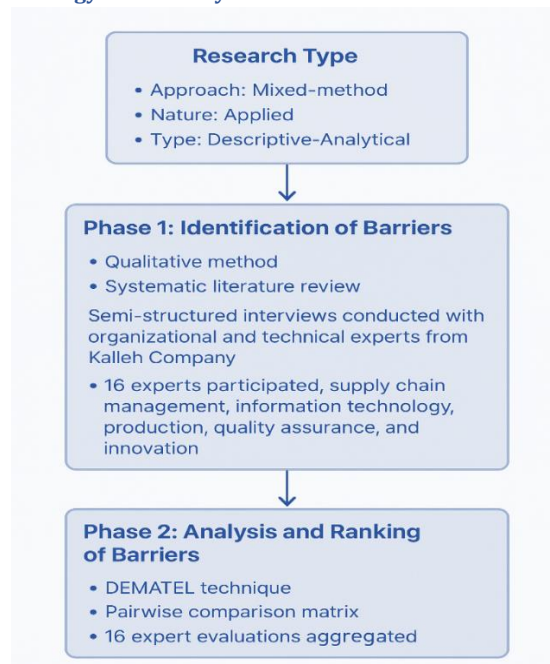
This study adopts a mixed-method and applied research approach (Sadeghi et al., 2013b). Given that the primary objective is to identify and rank the barriers to the implementation of Internet of Things (IoT) technology in the food supply chain and to analyze the causal relationships among them in a leading Iranian food company, the research is categorized as descriptive-analytical and falls within the scope of multi-criteria decision-making (MCDM) studies.

In the first phase, a qualitative method was used to identify the key barriers to IoT implementation. Initially, a comprehensive and systematic review of the literature was conducted to extract a preliminary list of potential barriers, but in some other research studies, it is common to use other qualitative methods to identify factors (Danaeefard et al., 2014; Danaeefard et al., 2015; Mostafazadeh & Sadeghi, 2014; Mostafazadeh et al., 2016; Sadeghi, et al., 2024). Next, to refine and validate this list, semi-structured interviews were conducted with organizational and technical experts from Kalleh Company. These experts were purposefully selected based on their familiarity and hands-on experience with technological projects and initiatives, particularly those related to implementing IoT. A total of 16 experts participated in this phase, all of whom held senior positions in areas such as supply chain management, information technology, production, quality assurance, and innovation. The decision to interview 16 experts was based on the principle of data saturation, where additional interviews were no longer yielding new insights or barriers. The participants had, on average, more than 10 years of professional experience and held at least a master's degree in relevant fields such as management, industrial engineering, information technology, or agri-industrial sciences. To examine the validity of this research study, triangulation was applied by cross-referencing findings from literature with expert interviews to ensure consistency. Expert selection was purposive, ensuring relevance and experience, while their responses were validated by using consensus-building and repeated evaluations. Additionally, the use of the DEMATEL method, known for modeling complex interrelations, strengthened the construct validity of the study by mapping logical cause-effect relationships among barriers.

There are some techniques to rank factors in different research papers (Molavi et al., 2013; Sadeghi et al., 2013a; Seyed Javadein et al., 2013). In the second phase of the current research study, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was employed to analyze the interrelationships among the identified barriers and to rank them based on their levels of influence and dependence. DEMATEL enables researchers to uncover and visualize the cause-and-effect structure among factors using expert judgments. The DEMATEL method was selected for this study because the barriers of IoT implementation are not isolated; they are interdependent and influence each other in complex ways. While AHP is effective for straightforward prioritization, it does not capture causal relationships between factors. DEMATEL, on the other hand, enables both the identification of influential (cause) and influenced (effect) barriers and their ranking based on their prominence (D+R), making it especially suitable for system-level analysis in complex environments like food supply chains.

For this purpose, a pairwise comparison matrix was developed with the participation of the same 16 experts. After aggregating their evaluations, the standard DEMATEL steps were followed to compute the direct-relation matrix, the total relation matrix, and the causal diagram. The final output enabled the classification and ranking of the barriers according to their influence and dependency degrees. The research methodology adopted in this study is illustrated in Figure 1.

**Figure 1.**  
The Framework of Research Methodology of the Study



(Source: Researcher's Findings)

## Findings

The barriers to IoT implementation in the food supply chain were identified through a comprehensive review of the literature and expert interviews. These barriers are presented in Table 1.

**Table 1.**  
The Identified Barriers to IoT Implementation in the Food Supply Chain

Barrier Category	Specific Barrier	Detailed Description	Source
Technological Barriers	Lack of Interoperability	Difficulty in integrating IoT devices and systems from different vendors; lack of standardized protocols and data formats.	(Aamer et al., 2021; Ahmad et al., 2024; Buthelezi et al., 2022, pp. 1–32; Mohammed et al., 2023, pp. 14236–14255; Sarkar et al., 2024; Virmani & Singh, 2024)
	Technological Immaturity/Limitations	Existing technologies may not be sufficiently advanced or reliable for applications of specific food supply chain; limited sensor capabilities or data analytics tools.	(Aamer et al., 2021; Ahmad et al., 2024; Derakhti et al., 2023; Koshta et al., 2024, pp. 13096–13108; Luo et al., 2022; Rui & Sundram, 2024; Virmani & Singh, 2024; Yadav et al., 2023, pp. 1215–1224)
	Challenges of Data	Difficulty in collecting,	(Aamer et al., 2021; Chen et al., 2024;

Barrier Category	Specific Barrier	Detailed Description	Source
	Integration and Analysis	processing, and analyzing large volumes of data from diverse sources; lack of appropriate data management and analytics tools.	Derakhti et al., 2023; Luo et al., 2022; Rui & Sundram, 2024; Serrano-Torres et al., 2025; Sharma et al., 2024; Yadav et al., 2023, pp. 1215–1224)
	Inadequate Infrastructure (Technology)	Lack of reliable Internet connectivity, especially in remote areas; insufficient power supply for IoT devices.	(Aamer et al., 2021; Ahmad et al., 2024; Derakhti et al., 2023; Koshta et al., 2024, pp. 13096–13108; Luo et al., 2022; Rui & Sundram, 2024; Sarkar et al., 2024; Virmani & Singh, 2024; Yap et al., 2023, pp. 419–441)
Financial Barriers	High Implementation Costs	Significant upfront investments required for hardware, software, integration, and training; ongoing maintenance and operational expenses.	(Buthelezi et al., 2022, pp. 1–32; Delouyi et al., 2023; Mishra et al., 2023; Mohammed et al., 2023, pp. 14236–14255; Pratama, 2024; Raman & Selvaraj, 2024; Rui & Sundram, 2024; Sarkar et al., 2024; Selvaraj, 2025; Serrano-Torres et al., 2025; Singh et al., 2023; Virmani & Singh, 2024; Yadav et al., 2023, pp. 1215–1224; Yap et al., 2023, pp. 419–441; Zhao et al., 2024)
	Return on Investment (ROI) Uncertainty	Difficulty in quantifying the benefits of IoT adoption; long payback periods; lack of clear business cases.	(Mohammed et al., 2023, pp. 14236–14255; Pratama, 2024; Raman & Selvaraj, 2024; Rui & Sundram, 2024; Sarkar et al., 2024)
	Limited Funding/Access to Capital	SMEs and smallholder farmers often lack access to sufficient funding for IoT implementation.	(Delouyi et al., 2023; Mishra et al., 2023; Mumba & Mwanza, 2025; Raman & Selvaraj, 2024; Rui & Sundram, 2024; Sarkar et al., 2024; Selvaraj, 2025; Ullah et al., 2025; Yap et al., 2023, pp. 419–441)
Human Capital Barriers	Lack of Skilled Labor/Expertise	Shortage of personnel with the necessary technical skills to implement, manage, and maintain IoT systems; lack of data analytics expertise.	(Aamer et al., 2021; Ahmad et al., 2024; Akinbamini et al., 2025; Cuéllar & Johnson, 2022; Hangl et al., 2022; Koshta et al., 2024, pp. 13096–13108; Mishra et al., 2023; Mumba & Mwanza, 2025; Raman & Selvaraj, 2024; Rui & Sundram, 2024; Selvaraj, 2025; Singh et al., 2023; Susanty et al., 2024, pp. 11–15; Yadav et al., 2023, pp. 1215–1224; Yap et al., 2023, pp. 419–441)
	Resistance to Change/Lack of Awareness	Reluctance of stakeholders to adopt new technologies; lack of understanding of the benefits of IoT; insufficient training and support.	(Aamer et al., 2021; Akinbamini et al., 2025; Hangl et al., 2022; Jamaluddin et al., 2024; Julian & Ameliana, 2024; Mumba & Mwanza, 2025; Rui & Sundram, 2024; Singh et al., 2023; Yadav et al., 2023, pp. 1215–1224; Yap et al., 2023, pp. 419–441; Zafar, 2024)
Regulatory Barriers	Lack of Clear Regulations/Standards	Absence of clear guidelines and standards for data security, privacy, and interoperability; inconsistent regulations across different jurisdictions.	(Ahmad et al., 2024; Akinbamini et al., 2025; Jamaluddin et al., 2024; Julian & Ameliana, 2024; Koshta et al., 2024, pp. 13096–13108; Kumar et al., 2022; Mohammed et al., 2023, pp. 14236–14255; Pratama, 2024; Selvaraj, 2025; Susanty et al., 2024, pp. 11–15; Yap et al., 2023, pp. 419–441)
	Complex Compliance Requirements	Difficulty in meeting various regulatory requirements related to data security, food safety, and traceability.	(Ahmad et al., 2024; Akinbamini et al., 2025; Jamaluddin et al., 2024; Julian & Ameliana, 2024; Mohammed et al., 2023, pp. 14236–14255; Pratama, 2024; Selvaraj, 2025; Susanty et al., 2024, pp. 11–15; Yap et al., 2023, pp. 419–441)

(Source: Researcher's Findings)

Experts provided pairwise comparisons between the barriers using a scale from 0 (no influence) to 4 (very high influence). The resulting values were organized into an initial direct-relation matrix (Table 2).

**Table 2.**  
**The Initial Direct-Relation Matrix for IoT Implementation Barriers**

Barrier	Lack of Interoperability	Technological Immaturity/Limitations	Challenges of Data Integration and Analysis	Inadequate Infrastructure	High Implementation Costs	ROI Uncertainty	Limited Funding/Access to Capital	Lack of Skilled Labor/Expertise	Resistance to Change/Lack of Awareness	Lack of Clear Regulations/Standards	Complex Compliance Requirements
Lack of Interoperability	0.00	4.00	2.00	4.00	4.00	1.00	2.00	2.00	2.00	4.00	3.00
Technological Immaturity/Limitations	2.00	0.00	1.00	3.00	1.00	3.00	4.00	0.00	3.00	1.00	4.00
Challenges of Data Integration and Analysis	3.00	0.00	0.00	2.00	2.00	1.00	3.00	3.00	2.00	3.00	3.00
Inadequate Infrastructure	0.00	2.00	4.00	0.00	4.00	0.00	1.00	3.00	0.00	3.00	1.00
High Implementation Costs	1.00	0.00	1.00	4.00	0.00	3.00	3.00	3.00	3.00	4.00	2.00
ROI Uncertainty	0.00	3.00	1.00	3.00	1.00	0.00	3.00	4.00	1.00	1.00	3.00
Limited Funding/Access to Capital	1.00	1.00	3.00	3.00	0.00	4.00	0.00	1.00	4.00	1.00	0.00
Lack of Skilled Labor/Expertise	3.00	3.00	3.00	4.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00
Resistance to Change/Lack of Awareness	3.00	2.00	2.00	0.00	2.00	2.00	0.00	2.00	0.00	1.00	1.00
Lack of Clear Regulations/Standards	0.00	3.00	0.00	3.00	1.00	0.00	4.00	2.00	3.00	0.00	2.00
Complex Compliance Requirements	0.00	2.00	4.00	2.00	0.00	4.00	1.00	2.00	0.00	1.00	0.00

(Source: Researcher's Findings)

The initial matrix was normalized by dividing all elements by the maximum row or column sum, ensuring that the sum of each row or column does not exceed one (see Table 3).

**Table 3.**  
**The Normalized Direct-Relation Matrix**

Barrier	Lack of Interoperability	Technological Immaturity/Limitations	Challenges of Data Integration and Analysis	Inadequate Infrastructure	High Implementation Costs	ROI Uncertainty	Limited Funding/Access to Capital	Lack of Skilled Labor/Expertise	Resistance to Change/Lack of Awareness	Lack of Clear Regulations/Standards	Complex Compliance Requirements
Lack of Interoperability	0.00	0.14	0.07	0.14	0.14	0.04	0.07	0.07	0.07	0.14	0.11
Technological Immaturity/Limitations	0.07	0.00	0.04	0.11	0.04	0.11	0.14	0.00	0.11	0.04	0.14
Challenges of Data Integration and Analysis	0.11	0.00	0.00	0.07	0.07	0.04	0.11	0.11	0.07	0.11	0.11
Inadequate Infrastructure	0.00	0.07	0.14	0.00	0.14	0.00	0.04	0.11	0.00	0.11	0.04
High Implementation Costs	0.04	0.00	0.04	0.14	0.00	0.11	0.11	0.11	0.11	0.14	0.07
ROI Uncertainty	0.00	0.11	0.04	0.11	0.04	0.00	0.11	0.14	0.04	0.04	0.11
Limited Funding/Access to Capital	0.04	0.04	0.11	0.11	0.00	0.14	0.00	0.04	0.14	0.04	0.00
Lack of Skilled Labor/Expertise	0.11	0.11	0.11	0.14	0.00	0.14	0.14	0.00	0.00	0.00	0.00
Resistance to Change/Lack of Awareness	0.11	0.07	0.07	0.00	0.07	0.07	0.00	0.07	0.00	0.04	0.04
Lack of Clear Regulations/Standards	0.00	0.11	0.00	0.11	0.04	0.00	0.14	0.07	0.11	0.00	0.07
Complex Compliance Requirements	0.00	0.07	0.14	0.07	0.00	0.14	0.04	0.07	0.00	0.04	0.00

(Source: Researcher's Findings)

The total relation matrix was obtained by applying the DEMATEL transformation formula (see Table 4). It reflects both direct and indirect influences among the barriers.

**Table 4.**  
**The Total Relation Matrix Representing Direct and Indirect Influences**

Barrier	Lack of Interoperability	Technological Immaturity/Limitations	Challenges of Data Integration and Analysis	Inadequate Infrastructure	High Implementation Costs	ROI Uncertainty	Limited Funding/Access to Capital	Lack of Skilled Labor/Expertise	Resistance to Change/Lack of Awareness	Lack of Clear Regulations/Standards	Complex Compliance Requirements
Lack of Interoperability	0.14	0.35	0.31	0.44	0.30	0.28	0.35	0.31	0.27	0.34	0.31
Technological Immaturity/Limitations	0.17	0.17	0.23	0.33	0.17	0.29	0.33	0.20	0.25	0.19	0.29
Challenges of Data Integration and Analysis	0.22	0.18	0.20	0.31	0.20	0.23	0.32	0.30	0.22	0.27	0.26
Inadequate Infrastructure	0.11	0.21	0.29	0.21	0.24	0.17	0.23	0.27	0.14	0.24	0.17
High Implementation Costs	0.15	0.19	0.24	0.38	0.14	0.30	0.33	0.31	0.26	0.30	0.23
ROI Uncertainty	0.11	0.26	0.22	0.32	0.15	0.19	0.30	0.30	0.17	0.17	0.24
Limited Funding/Access to Capital	0.14	0.18	0.26	0.29	0.12	0.28	0.17	0.20	0.26	0.17	0.14
Lack of Skilled Labor/Expertise	0.21	0.27	0.30	0.37	0.14	0.32	0.35	0.20	0.16	0.17	0.17
Resistance to Change/Lack of Awareness	0.19	0.20	0.21	0.19	0.17	0.21	0.17	0.21	0.12	0.16	0.16
Lack of Clear Regulations/Standards	0.10	0.24	0.16	0.28	0.14	0.17	0.30	0.21	0.23	0.12	0.19
Complex Compliance Requirements	0.09	0.20	0.28	0.25	0.10	0.27	0.21	0.22	0.11	0.15	0.13

(Source: Researcher's Findings)

The prominence (D+R) and relation (D-R) values were calculated for each barrier (see Table 5). Barriers with positive D-R values are classified as causes, while those with negative values are considered as effects.

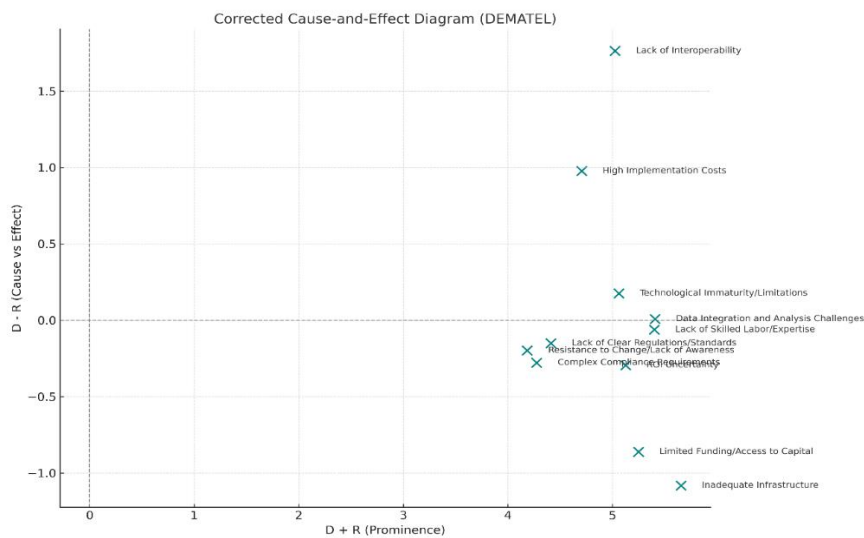
**Table 5.**  
**D, R, D+R, and D-R Values for Each Barrier**

Barrier	D (Dispatching)	R (Receiving)	D+R (Prominence)	D-R (Relation)
Lack of Interoperability	3.40	1.63	5.03	1.76
Technological Immaturity/Limitations	2.62	2.44	5.06	0.18
Challenges of Data Integration and Analysis	2.71	2.70	5.41	0.01
Inadequate Infrastructure	2.29	3.37	5.66	-1.08
High Implementation Costs	2.84	1.87	4.71	0.98
ROI Uncertainty	2.42	2.71	5.13	-0.29
Limited Funding/Access to Capital	2.19	3.06	5.25	-0.86
Lack of Skilled Labor/Expertise	2.67	2.73	5.40	-0.06
Resistance to Change/Lack of Awareness	1.99	2.19	4.19	-0.20
Lack of Clear Regulations/Standards	2.13	2.28	4.41	-0.15
Complex Compliance Requirements	2.00	2.28	4.28	-0.28

(Source: Researcher's Findings)

A two-dimensional graph (Figure 2) was drawn with D+R on the x-axis and D-R on the y-axis to visualize the barriers' prominence and causal roles in the system.

**Figure 2.**  
**Cause-and-Effect Diagram Based on DEMATEL Analysis**



(Source: Researcher's Findings)

The DEMATEL analysis reveals critical insights into the barriers hindering IoT implementation in the food supply chain. The findings demonstrate a clear distinction

between causal and effect barriers, with lack of interoperability emerging as the strongest causal factor ( $D-R=1.76$ ), significantly influencing other barriers through incompatible protocols and data formats that hinder the system integration. High implementation costs ( $D-R=0.98$ ) create substantial financial barriers, particularly for SMEs, by requiring considerable upfront investments in hardware and software, while technological immaturity ( $D-R=0.18$ ) reflects limitations in sensor durability and analytics capabilities that constrain IoT applications in perishable food environments. On the effect side, inadequate infrastructure ( $D-R=-1.08$ ,  $D+R=5.66$ ) stands out as the most prominent yet dependent barrier, where poor connectivity and power supply issues, exacerbated by funding shortages, create foundational challenges across the supply chain. Limited access to funding ( $D-R=-0.86$ ) directly results from ROI uncertainties and high initial costs, creating a cyclical financing gap that further compounds the implementation difficulties. ROI uncertainty itself ( $D-R=-0.29$ ) stems from technological immaturity and data integration challenges, making benefit quantification particularly challenging for stakeholders. The prominence values establish infrastructure deficiency ( $D+R=5.66$ ) as the most critical operational challenge, demanding immediate attention as unreliable connectivity fundamentally undermines all potential IoT applications throughout farm-to-fork stages. Data integration challenges ( $D+R=5.41$ ) highlight the pressing need for unified analytics platforms capable of processing heterogeneous IoT data streams, while skills shortages ( $D+R=5.40$ ) reveal an urgent human capital gap in IoT system management and data science capabilities that must be addressed. Regulatory ambiguity ( $D+R=4.41$ ), though less prominent, creates significant compliance risks that deter investment when combined with high implementation costs ( $D+R=4.71$ ), presenting a complex challenge for policymakers and industry leaders. The analysis uncovers important interdependence dynamics, particularly a financial constraint loop where high costs lead to capital shortages, which in turn create infrastructure gaps that reduce ROI visibility. Similarly, a technological bottleneck emerges where immature solutions cause interoperability failures that result in data silos and ultimately resistance to adoption ( $D+R=4.19$ ). These findings corroborate the existing literature on technology adoption challenges while providing new insights into the specific dynamics of IoT implementation in food supply chains. The unique positioning of infrastructure as both highly prominent ( $D+R=5.66$ ) and highly dependent ( $D-R=-1.08$ ) suggests it cannot be effectively resolved without first addressing the underlying financial and technological barriers, highlighting the need for comprehensive, system-wide strategies rather than isolated solutions. The results emphasize that overcoming these implementation barriers requires coordinated efforts across the technological development, financial support mechanisms, and workforce training programs to create an enabling environment for IoT adoption in the food supply chain sector.

## Discussion and Conclusion

This study revealed that implementing IoT technology in the food supply chain faces

multidimensional and interconnected challenges. The findings demonstrated that barriers operate as a complex system with causal interdependencies, meaning that addressing one challenge often requires simultaneous consideration of others. The DEMATEL analysis identified "inadequate infrastructure" as the most critical barrier, with the highest D+R value (5.66). This aligns with prior research on emerging technologies in food supply chains. However, a key insight from this study is that infrastructure limitations are themselves influenced by causal factors such as "high implementation costs" and "limited funding access". This finding carries important policy implications, suggesting that merely investing in physical infrastructure without addressing the underlying financial constraints will yield limited success. Among causal barriers, "lack of interoperability" emerged as the strongest driver (D-R=1.76). The absence of unified standards and communication protocols exacerbates other implementation challenges, reinforcing findings from international studies and underscoring the need for harmonized technical frameworks.

Notably, "lack of skilled labor" presents an interesting paradox. While its near-neutral D-R value (-0.06) indicates balanced influence/dependence, its high prominence (D+R=5.40) signals a substantial operational impact. This suggests workforce development should remain a priority despite its intermediate position in the causal network. The study ultimately demonstrated that overcoming IoT adoption barriers requires holistic, systems-level strategies rather than isolated interventions. Policymakers and industry leaders should prioritize:

- Encourage collaboration between food industry associations, tech companies, and regulatory bodies to create a national IoT interoperability framework tailored to agriculture and food sectors.
- Establish pilot programs using open-source platforms and standard communication protocols (e.g., MQTT, CoAP) to demonstrate integration feasibility.
- Incentivize vendors to adopt or align with internationally recognized standards (e.g., ISO/IEC 30141) through certification or government-backed endorsement programs.
- Launch government-subsidized grant or low-interest loan schemes specifically for SMEs adopting IoT in food supply chains.
- Develop public-private partnerships to co-finance infrastructure upgrades and IoT deployment in underserved regions.
- Provide tax credits or deductions for investments in IoT-related technologies and training, especially for smallholder producers.
- Collaborate with universities, vocational institutions, and IoT firms to offer modular training programs focused on IoT installation, maintenance, and data analytics.
- Introduce industry-specific certification programs to upskill current employees in the food supply chain.

- Leverage e-learning platforms and mobile apps to deliver flexible, localized training to rural and remote stakeholders.

### **Limitations of the Study**

Despite providing valuable insights, this study has several limitations. First, the research is based on a single-case study of Kalleh Company, which may limit the generalizability of the findings to other companies or regions. While Kalleh offers a representative context, food supply chains vary significantly across countries and industry segments. Second, the reliance on expert judgment for the DEMATEL analysis, though rigorous, introduces subjectivity and may reflect organizational biases or specific experiences rather than sector-wide realities. Lastly, the study primarily focuses on internal and technical barriers; broader environmental and geopolitical factors (e.g., trade policies, macroeconomic instability) were not explicitly examined but may significantly impact IoT adoption. Future research should explore multi-case comparisons across different countries and integrate broader systemic factors for a more holistic understanding.

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