Vol. 12, No. 2, 2025, Pages 131- 145

JIEMS
Journal of Industrial Engineering and Management Studies

journal homepage: www.jiems.icms.ac.ir

# Future of Blockchain Technology in the Iranian Dairy Supply Chain: A Scenario-Based Foresight Study

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Received: Nov 2025-05/ Revised: Dec 2025-15/ Accepted: Dec 2025-25

**Abstract**

This study aims to explore the future implementation of blockchain technology in the Iranian dairy supply chain by identifying and analyzing the most influential factors shaping its adoption. The research addresses the challenges faced by stakeholders in adopting this emerging technology and proposes future-oriented strategies to enhance supply chain transparency and trust. A scenario-based foresight methodology was employed using Cross-Impact Balance (CIB) analysis. Key drivers were identified through literature review and expert interviews with 15 senior managers and supervisors from a dairy supply chain company in Fars Province. The interrelationships among 37 factors were analyzed using MICMAC software, and plausible future scenarios were constructed using Scenario Wizard. The study identified seven critical factors influencing blockchain adoption: production system flexibility, trust among stakeholders, competitive pressure, readiness of business partners, social acceptance of technology, investment capacity, and supply chain collaboration. These factors formed the basis for developing optimistic, intermediate, and pessimistic scenarios, highlighting the strategic importance of coordination and preparedness across the supply chain.This study is among to apply a scenario-based, expert-driven foresight approach to blockchain adoption in the dairy supply chain of a developing country. By integrating systems thinking and participatory methods, it provides valuable strategic insights for policymakers and supply chain leaders aiming to navigate blockchain implementation under uncertainty.

**Keywords**: Blockchain, Dairy supply chain, Scenario planning, CIB, MICMAC

**Paper Type**: Original Research

## 1. Introduction

The global demand for milk, driven by its high nutritional value for both infants and adults, has significantly increased over the past three decades, with worldwide production rising from 522 million tons in 1986 to 798 million tons in 2016, a 53% increase (FAO, 2018). As of 2019, the Food and Agriculture Organization (FAO) reported that 6 billion people consume milk and dairy products, primarily in developing countries (FAO, 2019). However, the safety of milk and dairy products is at risk from contamination by biological, chemical, or physical agents, which can pose health threats to consumers (Montgomery et al.2020). The World Health Organization (WHO) highlights that one in ten individuals suffers from foodborne illnesses, emphasizing the vulnerabilities within food supply chains amid complex production processes and globalization. As consumer preferences increasingly focus on quality, safety, and nutrition, addressing these evolving demands is crucial, especially as food security has been identified as one of the top global risks by the World Economic Forum in 2023 (Duan et al., 2020). In recent years, there has been a surge of interest in distributed ledger technology, notably blockchain, which offers an immutable, secure, and trustworthy transaction model. With its peer-to-peer structure and cryptographic techniques, blockchain facilitates distributed consensus, making it a promising solution for various applications, including supply chain management (Chang et al., 2020). Supply chains are becoming increasingly intricate and automated, offering significant benefits in today's world. Supply chain management (SCM) encompasses processes aimed at maximizing customer value and competitive advantage; yet, the complexity and duration of these processes pose challenges in tracing quality issues to their source (Shahid et al., 2020). SCM is crucial for firms, especially in the dairy sector, to manage the flow of goods and services effectively. The complexity of supply chains significantly impacts organizational performance, making effective complexity management vital for the dairy industry, which is essential to the country's economy (Al-Rawashdeh et al., 2023; Iftikhar et al., 2023). Blockchain technology offers a decentralized, secure, and immutable ledger for real-time data sharing among supply chain stakeholders, enhancing transparency and efficiency. Its adoption in operations is driven by digital transformation trends and Industry 4.0, aiding in the management of supply chain complexity and disruption prevention (Akter et al., 2022; Chowdhury et

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al., 2023). Blockchain technology plays a pivotal role in enhancing transparency, preventing fraud, reducing operational costs, and improving the quality and safety of agri-food products, including dairy (Yontar, 2023). In recent years, several real-world applications have emerged. For instance, Turkey has implemented blockchain in dairy farms to support food traceability and sustainability efforts (Yogarajan et al., 2023). Similar initiatives by global companies like Alibaba and Walmart have demonstrated blockchain's potential in reducing counterfeiting and increasing trust in food supply chains (Kshetri, 2021). Academic research has also explored blockchain's impact on the dairy sector. Mangla et al. (2021) analyzed a Turkish dairy cooperative to show how blockchain can improve food security, animal welfare, and local development by tracing milk from farm to table. Casino et al. (2020) demonstrated the viability of a blockchain-based traceability system in a dairy company, emphasizing its benefits for both consumers and producers. In the U.S. dairy industry, Kasten (2019) proposed blockchain to ensure transparency and neutrality in milk testing, addressing concerns about lab affiliations and biased results. Further studies from India (Kumar & Kumar, 2023) and China (Yu, 2023) have highlighted how blockchain facilitates risk management, real-time verification, and information sharing throughout the milk supply chain. These features contribute to greater efficiency, reduced food safety risks, and stronger regulatory compliance. Vern et al. (2024) extended the analysis to agri-food systems more broadly, confirming that blockchain adoption enhances traceability, collaboration, and socio-economic sustainability. While several studies have examined the technical feasibility and potential benefits of blockchain in agricultural and food production, most of them are based on specific characteristics or theories in developed economies. These studies rarely consider the limited awareness and readiness among stakeholders in the dairy industry, especially in developing regions such as Iran, where blockchain is still a nascent and unfamiliar concept. Furthermore, the existing literature is devoid of prospective research that examines how different drivers such as technological, organizational, and regulatory may influence blockchain adoption in different contexts. There is a notable lack of scenario-based analyses that can help visualize possible futures and support strategic planning.This study was conducted with the aim of achieving two objectives. First, to identify the key factors affecting the future implementation of blockchain technology in the dairy supply chain. Second, to develop a scenario by examining the final factors obtained from a survey of dairy supply chain experts based in Fars province, focusing on the stages of animal feed preparation to milk production and collection from the farm. To comprehensively analyze the expert input, the data were processed using MICMAC software, which enabled structural analysis of the variables. The resulting key drivers were then applied in scenario building using the Cross-Impact Balance (CIB) approach. Overall, the study explores alternative futures in which blockchain may shape the evolution of Iran's dairy industry, offering strategic foresight for policymakers and supply chain actors.

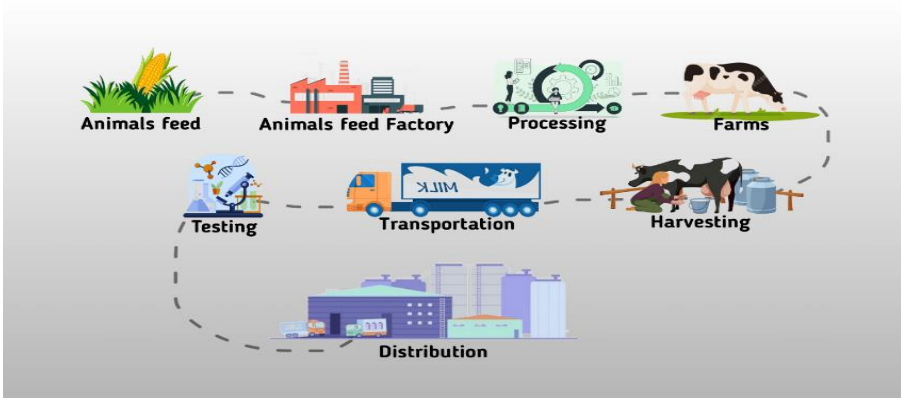


**Figure 1.** Structure of the dairy supply chain in Fars Province.

## 2. Literature Review

Blockchain technology, initially developed as the backbone of Bitcoin (Nakamoto, 2008), has rapidly gained attention for its potential to transform supply chains beyond the realm of cryptocurrencies. As a decentralized and immutable digital ledger, blockchain enables transparent, secure, and real-time tracking of transactions, thus improving traceability, stakeholder coordination, and supply chain integration (Tiwari, 2020; Chang et al., 2020). Within the agri-food sector, blockchain adoption has been motivated by increasing concerns over food safety, fraud, and supply chain inefficiencies. Pilot applications have illustrated how blockchain can enhance trust, minimize operational risks, and support sustainability goals (Casino et al., 2020; Vern et al., 2024). For instance, Mangla et al. (2021) examined the implementation of blockchain in a Turkish dairy cooperative, emphasizing improved animal welfare, food security, and rural development. Similarly, Kasten (2019) proposed a blockchain-based milk testing model in the U.S. to reduce potential bias and increase transparency in producer-affiliated labs. Several studies have also explored the broader impact of blockchain in the dairy supply chain. Yu (2023) highlighted blockchain's role in risk management and traceability across all stages of milk production, while Kumar and Kumar (2023) reported a positive effect on supply chain performance in the Indian dairy industry. Varavallo et al. (2022) discussed how leading dairy companies adopted blockchain solutions to meet growing consumer demands for transparency and efficiency. Furthermore, Li et al. (2023) and Duan et al. (2020) investigated blockchain's effectiveness in addressing food supply chain complexities, identifying key barriers such as technological limitations and lack of collaboration among stakeholders. Despite the growing body of literature, most studies remain focused on technical implementation or specific case studies, with limited attention to broader contextual factors—particularly in developing countries. The complexity of supply chains in regions like Iran, coupled with a general lack of awareness among stakeholders, poses significant challenges for blockchain adoption. Moreover, the future implications of this technology in such environments remain largely unexplored. To address this gap, the present study employs scenario planning and MICMAC analysis to map plausible futures for blockchain adoption in Iran's dairy sector. This approach offers strategic insight into enablers, inhibitors, and stakeholder dynamics, contributing to a more informed and context-sensitive understanding of blockchain's role in agri-food supply chains.

## 3. Methodology

This research is exploratory and prospective and aims to identify and construct possible scenarios for the implementation of blockchain technology in the dairy supply chain. Given the newness of blockchain technology and the low level of awareness of dairy industry stakeholders in Iran, the use of a scenario-writing approach was deemed appropriate for analyzing future developments under conditions of uncertainty. We used the Interaction Impact Balance (CIB) analysis approach to generate scenarios that are logically consistent with each other and reflect realistic interactions between variables. (Kurniawan, et al. 2022) This method is one of the qualitative and prospective approaches that is used to analyze complex systems with multi-sided interactions between variables.

### 3.1. Expert panel

Our study focuses on dairy supply chain systems in Iran for several reasons. First, despite the significant importance of industrial sectors in the Iranian economy, research and development in the areas of industrial management and supply chain is still in its infancy, as it faces challenges such as a lack of new technologies, weak integration with global markets, and institutional inefficiencies. Similarly, few studies of dairy supply chain issues and the impact of blockchain technology on them have specifically addressed the futures envisioned by this technology. The study was conducted in Fars's province and within the context of the activities of Saliz Company. The company is active in various stages of the dairy supply chain, including the production and distribution of animal feed, the collection of milk from farms, and its sale to dairy companies. (Stankov, et al. 2021) Fifteen experienced managers and supervisors in the dairy supply chain participated in the study, who were selected through purposive sampling based on their managerial and professional backgrounds. All experts had at least 5 years of relevant experience.

**Table 1**. Characteristics of experts involved in the cross-impact balance analysis

| Variable | Category | Frequency (n) | Percentage (%) |
|---|---|---|---|
| Gender | Female | 6 | 40 |
| | Male | 9 | 60 |
| Position | Manager | 10 | 67 |
| | Deputy Manager | 1 | 6 |
| | Senior Expert | 4 | 27 |
| Work Experience | Less than 5 years | 2 | 13 |
| | 5–10 years | 3 | 20 |
| | 11–15 years | 2 | 14 |
| | 16–20 years | 5 | 33 |
| | 21–25 years | 2 | 14 |
| | More than 25 years | 1 | 6 |
| Education Level | Bachelor's Degree | 4 | 27 |
| | Master's Degree | 6 | 40 |
| | PhD | 5 | 33 |
| Age Group | 25–35 years | 7 | 47 |
| | 36–45 years | 7 | 47 |
| | 46–55 years | 1 | 6 |

### 3.2. Data collection

Data collection was carried out in two stages:

### 3.2.1 Identification of key factors

First, by systematically reviewing scientific literature and conducting semi-structured interviews with experts, a set of factors affecting the implementation of blockchain technology in the supply chain was identified. Subsequently, a questionnaire was designed to examine the interaction of these factors on each other and distributed to the experts. The resulting data were analyzed using MICMAC software to extract the structure of dependence and influence between the factors. The factors were classified into four groups based on the degree of influence and dependence: input, intermediary, dependent and independent.

### 3.2.2. Scenario development using the CIB approach

In the second stage, compatible and possible scenarios were developed using the CIB approach. After identifying the key factors, three states (Desirable, Neutral and Undesirable) were defined for each factor. The experts were then asked to rate the intensity and direction of the influence of each state of one factor on the states of the other factors on a scale of +3 to -3. Out of the 37 extracted factors, 7 key drivers were selected and organized into a 21*21 matrix. To reduce cognitive load, each expert only responded to the relationships relevant to his or her area of expertise. The collected information was organized in the form of a CIB matrix and analyzed using the Scenario Wizard software. The software output included internally consistent scenarios that were reviewed and validated in collaboration with the experts.

### 3.2.3. Reasons for choosing the CIB approach

The CIB approach was chosen because of its ability to simultaneously analyze direct and indirect effects between factors in complex systems with high uncertainty. This method allows for the construction of coherent future-oriented narratives by identifying reinforcing or weakening relationships between different states of factors. Compared to traditional methods, CIB provides a deeper understanding of system dynamics and is very efficient for analyzing new technologies such as blockchain in the food industry supply chain. (Stankov, et al. 2021)

## 4. Results

### 4.1. Step one: Identifying the factors influence implementation blockchain in supply chain

In the first step, 37 factors influencing the implementation of blockchain in the dairy supply chain were identified through a literature review and confirmation by supply chain managers and experts. These factors are presented in Table 2.

**Table 2.** Factors affecting the application of blockchain in the dairy supply chain of Fars Province, Iran.

| Factor | References | Factor | References |
|---|---|---|---|
| **1.Flexibility of supply chain** | Mladenov et al. (2022)<br>Doriano et al.(2018) | 20.Logistics synchronization | Zhang et al. (2024) |
| **2.Senior management support** | Salim et al.(2022)<br>Clohessy & Acton (2019)<br>Holotiuk & Moormann (2019)<br>Chartier & Zweifel (2017)<br>Cerf et al. (2020) | 21.Competitive pressure | Wong et all., (2019) |
| **3.Diverse protocols across the supply chain** | Cheng et al. (2017)<br>Jabbar et al. (2021)<br>Litke et al. (2019)<br>Cafaggi & Iamiceli (2014) | 22.General consent and agreement | Kakarlapudi & Mahmoud (2021)<br>Jaiman & Urovi (2020) |
| **4.Timely identification of issues** | Muminova et al. (2020) | 23.Development of reliable suppliers | Bragadeesh & Umamakeswari (2020)<br>Bhattacharjee et al. (2020)<br>Xu et al.(2019)<br>Jamil et al. (2019) |
| **5.social influence to accept technology** | Mahri et al. (2023)<br>Wamba & Queiro (2019)<br>Albayati et al (2020) | 24.Demand sharing in the supply chain | Kumar et al.(2021) |
| **6.Increasing demand for fast delivery of service** | Yang et al. (2019)<br>Balani et al. (2022)<br>Jiang et al. (2018)<br>Murugan et al. (2019) | 25.Ability to curb illegal business activities | Bahanushali et al.(2020)<br>Steinmetz (2018)<br>Behanushali et al. (2020) |
| **7.Globalization of supply chains** | Chernov & Chernova (2018) | 26.Decentralized control authority | Zyskind & Nathan(2015)<br>Ge et al. (2020)<br>Nehe & Jain(2019) |

| | | | |
|---|---|---|---|
| **8.Globalization of supply chain risk and uncertainty** | Saberi et al. (2019)<br>Benton et al. (2018)<br>Dananajaya et al. (2022)<br>Zagurskiy & Titova (2019) | 27.Accountability to final consumers and retailers | Sciume et al. (2020)<br>Martinez et al. (2019) |
| **9.Control access to data in the supply chain** | Wu et al. (2019)<br>Pal (2020) | 28.governmental policies and regulations | (Suwanposri et all.,2021), Clohessy et al., 2020; Holotiuk & Moormann, 2018), Morabito (2017)<br>Alketabi et al. (2018)<br>Fan et al. (2019) |
| **10.Cooperation with information and communication technology providers** | Chaudhury et al. (2023) | 29.Save resources | Rodríguez-Espíndola et al. (2020) |
| **11.Readiness business partners** | Barnes et al. (2019)<br>Lustrnberger et al. (2021) Suwanposri et all.,2021), Clohessy et al., 2019) | 30.Financial and information exchange problems | Zachariadis et al. (2019)<br>Zheng et al. (2022)<br>Pradeep et al. (2021) |
| **12.Environmental compatibility** | Rana et al. (2019)<br>Li et al.(2022)<br>Gocen & kurubacak (2023)<br>Alhasan et al.,(2023)<br>Zang et al. (2020)<br>Prashar et al.(2020) | 31.Supply chain collaboration | Wright (2022)<br>Hyland,2015 |
| **13.Supply chain integration** | Zyskind & Nathan(2015)<br>Ge et al. (2020)<br>Nehe & Jain(2019) | 32.Cost reduction | Behnke and Janssen (2020) |
| **14.Blockchain as an emerging technology** | Wright (2022)<br>Clohessy & Acton (2019) | 33.Market dynamics | Hacioglu (2020) |
| **15.Multi-stakeholder governance and regulatory changes** | Matsuo & Ushida (2021)<br>Gurzawska (2020) | 34.Disintermediation | Wang et al. (2018) |
| **16.trust among supply chain members** | Centobelli et al. (2022) | 35.Investment | Loi (2023), Fang et all.,(2024) |
| **17.Blockchain capabilities** | Dujak & Sajter (2019)<br>Durach et al. (2021)<br>Lim et al. (2021)<br>Pournadar et al. (2020)<br>Chang et al. (2020)<br>Cole et al. (2019)<br>Tezel et al. (2020) | 36.Dispersion of data throughout the supply chain | Hu et al.(2020) |
| **18.Data privacy** | Clohessy & Acton (2019) | 37.Reliability of system | Bragadeesh & Umamakeswari (2020)<br>Bhattacharjee et al. (2020) |
| **19.Auditability in the supply chain** | Yang & Sun(2020)<br>Della & Oliver(2021)<br>Abidi_et al. (2021) | | |

## 4.2. Step two: Determining the key factors that influence the implementation of blockchain in the supply chain

To determine the key factors influencing blockchain implementation in the supply chain, the 37 identified factors were analyzed using MICMAC Software. Experts evaluated the degree of influence each variable in the rows had on the variables in the columns, and these evaluations were inputted into a two-dimensional matrix. Table 2 presents the MICMAC output, showing that; "Flexibility of supply chain"; had the highest direct influence (75) and indirect influence (145,126). In contrast; "multi-stakeholder governance and regulatory changes"; had the lowest direct (16) and indirect influence (35,273). Additionally; "Competitive pressure"; exhibited most significant direct dependence (78) and indirect dependence (153,761), while "Trust among supply chain members" had the least direct (10) and indirect dependence (25,765). Figure 2 visualizes the network of direct influences.

**Table 3.** MICMAC output – Direct and indirect influence and dependence of identified factors.

| N | Variable | Direct Influence | Direct Dependence | Indirect Influence | Indirect Dependence |
|---|---|---|---|---|---|
| **1** | Flexibility of supply chain | 75 | 29 | 145126 | 57666 |
| **2** | Senior management support | 54 | 75 | 111999 | 147889 |
| **3** | Diverse protocols across the supply chain | 27 | 29 | 62678 | 59438 |
| **4** | Timely identification of issues | 54 | 62 | 105298 | 128132 |
| **5** | social influence to accept technology | 49 | 23 | 96096 | 51822 |
| **6** | Increasing demand for fast delivery of service | 40 | 60 | 79249 | 119328 |
| **7** | Globalization of supply chains | 44 | 58 | 84536 | 110743 |
| **8** | Globalization of supply chain risk and uncertainty | 48 | 60 | 97570 | 118009 |
| **9** | Control access to data in the supply chain | 44 | 34 | 92088 | 73832 |
| **10** | Cooperation with information and communication technology providers | 59 | 50 | 112085 | 103553 |
| **11** | Readiness business partners | 61 | 43 | 120162 | 86245 |
| **12** | Environmental compatibility | 24 | 36 | 57961 | 75991 |
| **13** | Supply chain integration | 43 | 61 | 86082 | 117384 |
| **14** | Blockchain as an emerging technology | 46 | 59 | 91660 | 106134 |
| **15** | Multi-stakeholder governance and regulatory changes | 16 | 77 | 35273 | 149053 |
| **16** | trust among supply chain members | 56 | 10 | 107866 | 25765 |
| **17** | Blockchain capabilities | 52 | 74 | 98587 | 144891 |
| **18** | Data privacy | 28 | 63 | 59856 | 114285 |

| | | | | | |
|---|---|---|---|---|---|
| **19** | Auditability in the supply chain | 31 | 33 | 59005 | 69763 |
| **20** | Logistics synchronization | 39 | 40 | 78902 | 77418 |
| **21** | Competitive pressure | 50 | 78 | 99853 | 153761 |
| **22** | General consent and agreement | 56 | 76 | 113757 | 144870 |
| **23** | Development of reliable suppliers | 43 | 32 | 89570 | 64607 |
| **24** | Demand sharing in the supply chain | 44 | 26 | 87216 | 51784 |
| **25** | Ability to curb illegal business activities | 32 | 36 | 66643 | 70869 |
| **26** | Decentralized control authority | 43 | 41 | 85343 | 77886 |
| **27** | Accountability to final consumers and retailers | 35 | 21 | 70717 | 39953 |
| **28** | governmental policies and regulations | 54 | 32 | 104921 | 59490 |
| **29** | Save resources | 39 | 38 | 79757 | 82333 |
| **30** | Financial and information exchange problems | 41 | 21 | 84676 | 47480 |
| **31** | Supply chain collaboration | 50 | 32 | 98307 | 66510 |
| **32** | Cost reduction | 60 | 63 | 114431 | 128288 |
| **33** | Market dynamics | 49 | 52 | 98295 | 91692 |
| **34** | Disintermediation | 31 | 34 | 63108 | 74906 |
| **35** | Investment | 49 | 25 | 94578 | 62075 |
| **36** | Dispersion of data throughout the supply chain | 40 | 28 | 75148 | 62460 |

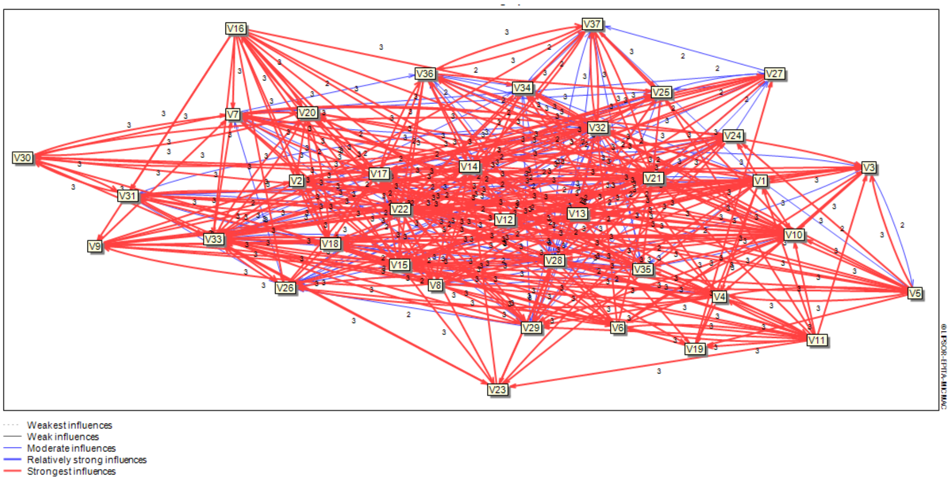


**Figure 2.** Direct influence graph of identified blockchain adoption factors.

Based on the influence and dependence values of the identified factors, MICMAC categorized them into four clusters and positioned them on an influence/dependence map, as illustrated in Figure 2. The findings from the MICMAC analysis are detailed in Figure 3, revealing distinct clusters of critical factors. Cluster 1: Autonomous Variables: These factors have weak influence and dependence. Identified factors include “Diverse protocols across the supply chain” (V3), “Control access to data in the supply chain” (V9), “Environmental compatibility” (V12), “Auditability in the supply chain” (V19), “Logistics synchronization” (V20), “Development of reliable suppliers” (V23), “Demand sharing in the supply chain” (V24), “Ability to curb illegal business activities” (V25), “Decentralized control authority” (V26), “Accountability to final consumers and retailers” (V27), “Save resources” (V29), “Financial and information exchange problems” (V30), “Disintermediation” (V34), “Dispersion of data throughout the supply chain” (V36), and “Reliability of system” (V37). These factors did not significantly impact the system. Cluster 2: Dependent Variables: These factors have limited driving force but substantial reliance on other variables. Identified factors include “Increasing demand for fast delivery of service” (V6), “Globalization of supply chains” (V7), “Supply chain integration” (V13), “Multi-stakeholder governance and regulatory changes” (V15), and “Data privacy” (V18). Although they have little power to drive the system, these factors heavily rely on other variables.
Cluster 3: Linkage Variables: These factors exhibit robust driving power alongside significant dependence. Identified factors include “Senior management support” (V2), “Timely identification of issues” (V4), “Globalization of supply chain risk and uncertainty” (V8), “Cooperation with information and communication technology providers” (V10), “Blockchain as an emerging technology” (V14), “Blockchain capabilities” (V17), “Competitive pressure” (V21), “General consent and agreement” (V22), “Cost reduction” (V32), and “Market dynamics” (V33). Due to their high dependency and influence, these factors were volatile they required particular managerial attention because any action taken on them would impact other components and vice versa .Cluster 4: Influence Variables: These factors have potent driving forces but limited dependence. Identified factors include “Flexibility of supply chain” (V1), “social influence to accept technology” (V5), “Readiness business partners” (V11), “Trust among supply chain members” (V16), “governmental policies and regulations” (V28), “Supply chain collaboration” (V31), and “Investment” (V35). Their inclusion was based on their direct and indirect influence and dependence scores, highlighting their critical importance in the applying of blockchain in the supply chain.

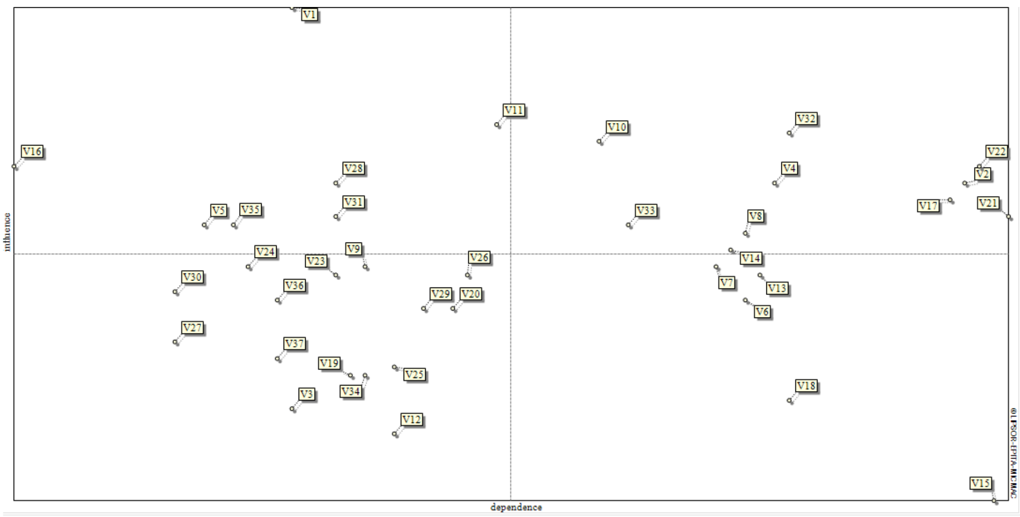


**Figure 3.** Influence/dependence map of key factors based on MICMAC analysis.

### 4.3. Step three: Develop scenarios for the implementation of blockchain in the supply chain.

Following the completion of the MICMAC matrix and identifying the critical elements, pertinent descriptors were developed, along with their prospective states of development, based on expert insights. Table 3 lists the study's descriptors and the variables that correspond to them, as well as possible states for each of these descriptors.

**Table 4.** Key factors and their desirable, neutral, and undesirable variants for scenario development.

| Key factors | Label | The Degree of Desirability | Variants |
|---|---|---|---|
| **Flexibility of supply chain** | A1 | Desirable | High flexibility in the supply chain |
| | A2 | Neutral | Average flexibility in the supply chain |
| | A3 | Undesirable | Lack of flexibility in the supply chain |
| **Trust among supply chain members** | B1 | Desirable | Complete and favorable trust among members |
| | B2 | Neutral | Relative trust among supply chain members |
| | B3 | Undesirable | Distrust of supply chain members to each other |
| **governmental policies and regulations** | C1 | Desirable | supportive governmental policies and regulations |
| | C2 | Neutral | Weakness in governmental policies and regulations |
| | C3 | Desirable | Instability, changes, and pregnant governmental policies and regulations |
| **Readiness business partners** | D1 | Undesirable | High readiness of supply chain partners |
| | D2 | Neutral | Low readiness of supply chain partners |
| | D3 | Desirable | Unpreparedness of supply chain partners |
| **social influence to accept technology** | E1 | Desirable | High social influence to accept technology |
| | E2 | Neutral | The relative social influence to accept technology |
| | E3 | Undesirable | Low social influence to accept technology |
| **Investment** | F1 | Desirable | Significant amount of investment in blockchain |
| | F2 | Neutral | Low acceptance of investors in blockchain |
| | F3 | Undesirable | Lack of investment in blockchain |
| **Supply chain collaboration** | G1 | Desirable | Optimal and integrated cooperation among supply chain members |
| | G2 | Neutral | Relative cooperation among supply chain members |
| | G3 | Undesirable | Inconsistency and poor communication between supply chain members |

Building potential scenarios using the seven key factors found by the cross-impact analysis was the next step. The experts reevaluated and distributed the key descriptors, which had been encoded using the CIB approach. A 21 x 21 matrix was created to evaluate the essential factors and investigate the possible effects of implementing blockchain technology in the supply chain. Based on the interrelationships between the critical factors, Scenario Wizard developed 2187 possible combinations of variants, of which seven scenarios, which showed high consistency and were deemed relevant for analysis, are presented in Table 4.

**Table 5**. Generated scenarios based on combinations of key blockchain adoption factors

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| **S1** | A2 | B1 | C3 | D2 | E2 | F1 | G2 |
| **S2** | A1 | B3 | C1 | D1 | E1 | F2 | G2 |
| **S3** | A1 | B3 | C1 | D3 | E1 | F2 | G2 |
| **S4** | A1 | B3 | C1 | D2 | E3 | F3 | G2 |
| **S5** | A1 | B3 | C1 | D1 | E1 | F2 | G1 |
| **S6** | A1 | B3 | C1 | D3 | E1 | F2 | G1 |
| **S7** | A1 | B3 | C1 | D2 | E3 | F3 | G1 |

A three-point Likert scale assessed each factor's; desirability, with the range from undesirable to desirable. The developed scenarios were divided into three categories based on their likelihood and desirability: probable, undesirable, and desirable. Desirability was evaluated using insights from the literature, and likelihood was calculated using the frequency at which the variants appeared in the scenarios.

### 5.1. The Path to Supply Chain Resilience: Navigating Desirable Scenarios (Scenarios 2,5)

Scenario 2: The dairy supply chain in Iran faces a complex situation characterized by high flexibility in production and adaptation among its members, along with significant social penetration of technology, indicating a readiness to embrace innovations. Despite relative trust and cooperation among supply chain members and successful collaboration with ICT providers for data collection and blockchain implementation, the unpreparedness of these partners in terms of hardware and software presents a substantial hurdle. Additionally, the low acceptance of blockchain technology by investors and companies complicates efforts to achieve widespread implementation. Consequently, although socially and operationally ready for technological advancement, the dairy supply chain struggles to realize the full benefits of blockchain due to infrastructural and investment-related limitations. Scenario 5: This scenario holds the highest desirability score and envisions a future where the dairy supply chain in Iran faces significant challenges despite high flexibility in production and adaptation among its members. There is relative trust and collaboration with ICT providers for data collection and blockchain implementation, However the low readiness of supply chain partners in terms of hardware and software remains a substantial barrier. Although there is high social penetration of technology and readiness among people to accept it, the low acceptance of blockchain technology by investors and companies undermines these efforts. Additionally, inconsistency and poor communication between supply chain members further complicate the situation. As a result, the dairy supply chain struggles to fully capitalize on the benefits of blockchain technology, despite operational flexibility and social readiness to embrace it.

### 5.2. Adverse Horizons: Navigating Blockchain Challenges in Supply Chain (Scenarios1,3,6)

Scenario 1: The dairy supply chain faces a transformative yet challenging future. Significant investments in blockchain technology by companies and trusted members are evident, However, the average flexibility in production and adaptation among supply chain members is not fully harnessed due to their low readiness in hardware and software capabilities. Despite complete and favorable trust among the supply chain members, their failure to effectively collaborate with ICT providers hampers the seamless collection and implementation of blockchain data. This issue is further exacerbated by varying levels of social penetration and readiness among stakeholders to embrace new technology. Consequently, the dairy supply chain experiences fragmented and inefficient blockchain deployment, falling short of its potential to enhance transparency and efficiency. Scenario 3: This scenario is characterized by high flexibility in production and adaptation among its members, with solid trust and cooperation within the supply chain. Despite successful collaborations with ICT providers for data collection and blockchain implementation, a significant challenge arises from the low readiness of supply chain partners regarding hardware and software. Although there is widespread social acceptance of technology and a general readiness among the population to embrace it, the reluctance of investors and companies to accept blockchain technology hinders its widespread adoption. Consequently, Consequently, the dairy supply chain, despite operational readiness and collaborative efforts, struggles to leverage blockchain technology due to infrastructural and investment related constraints fully. Scenario 6: The dairy supply chain in Iran shows high flexibility in production and adaptation among its members, supported by relative trust and cooperation with ICT providers for blockchain implementation. However, the unpreparedness of supply chain partners in terms of hardware and software remains a significant obstacle. While there is high social penetration of technology and readiness among people to accept it, the low acceptance of blockchain technology by investors and companies impedes further progress. Additionally, inconsistencies and poor communication between supply chain members exacerbate these challenges. As a result, the supply chain, despite its adaptability and collaborative efforts, struggles to fully leverage the potential of blockchain technology for enhanced transparency and efficiency.

### 5.3. Gloomy Trails: Obstacles to Blockchain Integration in Supply Chain (Scenarios 4,7)

Scenario 4: The dairy supply chain encounters significant challenges despite high flexibility in production and adaptation, as well as relative trust and cooperation among members. Strong collaboration with ICT providers for data collection and blockchain implementation is present, However the low readiness of supply chain partners in terms of hardware and software acts as a significant barrier. Additionally, low social penetration of technology and a lack of readiness among people to accept it, combined with the reluctance of companies and supply chain members to invest in blockchain, further impede progress. As a result, despite operational strengths and collaborative efforts, the dairy supply chain struggles to achieve the transparency and efficiency that blockchain technology promises due to these infrastructural and investment-related challenges. Scenario 7: The dairy supply chain encounters difficulties in realizing the full potential of blockchain technology despite high flexibility in production and adaptation among its members and relative trust. While collaboration with ICT providers for data collection and blockchain implementation is robust, the low readiness of supply chain partners in terms of hardware and software poses a significant challenge. This issue is compounded by low social penetration of technology and general reluctance to accept it, coupled with a lack of investment in blockchain technology by companies and supply chain members. Inconsistencies and poor communication further hinder progress, resulting in a supply chain that, despite its adaptability and initial collaborative efforts, struggles to achieve the transparency and efficiency that blockchain could offer.

## 5. Discussion

This study developed scenarios for implementing blockchain in dairy supply chains by analyzing various configurations of key influencing factors. A total of 37 drivers were initially identified through literature review and expert consultation, and seven critical ones were highlighted via MICMAC analysis: production system flexibility, trust among supply chain members, competitive pressure, readiness of business partners, social acceptance of technology, investment, and supply chain collaboration. Flexibility in sourcing, delivery, and manufacturing plays a pivotal role in adopting blockchain. Strategies to enhance this flexibility include strengthening coordination, improving process responsiveness, and building redundancy into operations (Nagariya et al., 2024). Trust a cornerstone of blockchain facilitates knowledge sharing and promotes reliable collaboration, which is essential in the decentralized environment blockchain fosters (Pattanayak et al., 2024; Notheisen et al., 2017). Additionally, the readiness of business partners especially in terms of financial, technical, and organizational resources remains vital. Top management commitment, policy alignment, and staff motivation all influence whether such innovation can be successfully adopted (Clohessy & Acton, 2019; Suwanposri et al., 2021). The study also found that social influence and cultural readiness significantly impact acceptance. Training programs, trust-building, and peer influence can accelerate adoption (Alazab et al., 2021). Moreover, regulatory frameworks need to evolve to support blockchain integration, especially regarding taxation, insurance, data security, and smart contracts (Suwanposri et al., 2021). Supply chain collaboration, requiring aligned goals and shared decision-making, is also crucial. Without collaborative behavior and information transparency, blockchain benefits may not be fully realized (Hyland, 2015; Simatupang & Sridharan, 2005). Finally, while investment in blockchain promises long-term gains such as traceability and reputation, the associated costs (e.g., infrastructure, training) must be weighed carefully (Fang et al., 2024). Strategic investments should consider risk profiles, industry branding, and ROI projections.

## 6. Conclusion

The dairy industry is projected to see an increase in milk production; however, various global factors such as climate change, political instability, population and growth pose significant challenges that may disrupt this trend. (Augustin, et al 2013) These instabilities can lead to fluctuations in the sector, impacting the quality and safety of milk and its products. In addition to biological hazards, the industry faces risks from chemical and physical contaminants, including foreign bodies, allergens, and mycotoxins. Given the significant challenges of contamination and fraud, continuous monitoring through various resources is crucial to ensure milk safety and quality in the face of evolving global parameters. (Montgomery, et al. 2020) The reviews and scenarios derived from the literature indicate that blockchain has the potential to effectively ensure the security of the dairy supply chain in terms of transparency, security, and efficiency. However, there are several obstacles and challenges that have been predicted in the derived scenarios.The most critical challenges across nearly all scenarios are the low readiness of supply chain partners in terms of hardware and software and the low acceptance of blockchain technology by investors and companies. These two factors consistently hinder progress, even in scenarios where social and operational conditions are favorable. This indicates that without proper infrastructure and investment support, the potential benefits of blockchain cannot be fully realized. Meanwhile, enabling factors such as high social penetration of technology and collaboration with ICT providers for data collection and blockchain implementation can support progress but are insufficient on their own. Factors like inconsistencies and poor communication between supply chain members further compound the difficulties. Therefore, managers should prioritize improving hardware and software readiness, incentivizing investment and organizational acceptance of blockchain, and strengthening communication across the chain. These strategic actions, combined with maintaining existing trust and cooperation, can pave the way for effective blockchain integration and enhanced transparency and efficiency in the supply chain.

This study provides a scenario-based outlook on blockchain adoption in the Iranian dairy supply chain. It identifies and analyzes key enablers and barriers, using MICMAC and CIB methodologies to simulate future pathways. The findings underscore that blockchain implementation is influenced not only by technical readiness but also by socio-cultural, regulatory, and strategic investment considerations. Furthermore, the success of blockchain adoption hinges on aligning internal capabilities with external regulatory and technological developments. The study offers strategic insight for policymakers, supply chain managers, and investors, especially in developing economies like Iran, where blockchain adoption is still emerging. Future research should explore the behavioral dimension of stakeholders more deeply and test implementation scenarios in real-world pilot programs.

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