Enhancing Supply Chain Sustainability through blockchain Integration and Mapping

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Abstract

This motivational research study shows a better understanding of the influence that aspects like blockchain technology, integration, and mapping have on supply chain sustainability in Pakistan's supply chain industry. The sample size used for the illustration mentioned above was 384, with a 5% error margin and a 95% confidence level. The supply chain sector was selected as the target industry for the campaign. We circulated 500 questionnaires and received valid responses from the targeted supply chain sector 384 through a Google form survey using the PLS-SEM model for work. We will use the PLS-SEM sampling technique to assess the power of latent variables and how well they are able to explain the target structure. The reason PLS-SEM is mainly used here is that it can estimate very complex models with a small amount of data. The results support each of the following direct hypotheses: blockchain technologies have a negative relation with supply chain integration, blockchain technologies have a negative impact on supply chain mapping, the integration has a significant influence on the supply chain sustainability, and supply chain mapping has a significant influence on the sustainability. At least in the future, it should be added with more variables to understand the supply chain sustainability across industries or nations. The focus of this study was mainly on blockchain technologies, supply chain integration, and mapping of supply chain sustainability This study highlights the need for supply chain managers to improve integration and mapping independently to boost sustainability. Fostering collaboration and information sharing can enhance traceability and compliance. Adapting resilient practices helps organizations manage inflation and support sustainable operations. This study enhances the working environment by improving the research piece that charts the influence of BT and SCs in Pakistani supply chain firms.

Keywords: Supply chain sustainability; blockchain technologies; supply chain integration supply chain mapping; supply chain resilience.

JEL Classification: M1, M30, M31, M14

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1. Introduction

1.1 Background of Research

The supply chain networks are intangible, which can limit firms' ability to respond effectively and quickly to disruptions within their supply chains (Jartrotia et al., 2024). Due to inflation persisting, the corporate supply chains are unequivocally toiling day and night, trying to manage the aftermath of such inflation and going to great lengths to take care of all their feeder, component, and raw material suppliers. These measures aim to keep the supply chains intact as per their intended operations. As per the argument of Mubarik and Naghavi (2021) and Choi and Chiu (2020), on the opposite side, a lack of an up-to-date mapping of supply chains and poor integration of a supply chain leads to a want of availability of critical information. Therefore, the response to the challenges posed by inflation has gone haphazardly. Consequently, there was a more robust and agile reaction to unexpected disruptions (Chen, 2024). It calls for the creation of an effective and well-strung supply chain that is visible, transparent, and sustainable in the chain of supply and operations of business (Naghavi, 2021). Today, supply chain mapping has become one key component in modern business operations and the strategy of most businesses for sustainability, integration, and visibility in the chain of supplies (Smith & Johnson, 2024; Lee & Martinez, 2024). In the modern business environment, there is a great necessity for businesses to take the appropriate measures that would guarantee the realization of positive outcomes (Oriekhie, Ashiwaju et al., 2024)

Environmental uncertainties are caused by factors like changes in consumer behavior as a result of the effects of globalization, the complications of the market processes, and the increasing rate of the culture of innovation (Syed et al., 2020; Inman and Green (2021). In this case, businesses react to uncertainties in the environment by having several practicable strategies and philosophies designed to result in competitive advantage and expected performance level. This approach is supported by Esmaeilzadeh et al. (2024), who propose a conceptual framework of business strategies to effectively manage environmental uncertainties.

As such, in case of a resulting supply disruption, the continuity of a company is dragged since plans have been set in place to ensure their chain activity is not compromised (Baghersad & Zobel, 2021). Supply chain disruptions can potentially shut down an organization's activities and services by affecting the quality, cost, processing, sourcing, and delivery of goods and services (Tönnissen & Teuteberg, 2020). The sources of risks could be extraordinary events, including inflation, cyberattacks, natural disasters, or concerns related to products and services (Min, 2019). The international community has identified the security within supply networks and sectors. Various other researchers have endeavored to perfect the elasticity of the supply of energy. Elastic efficiency has recently been appraised in the health services, hotel industry, agricultural, dairy, and food supply sectors, smart cities, and practically all other sectors.

Research into elastic efficiency analysis is being done extensively (Chen & Zhao, 2024; Patel & Kumar, 2024). This aspect regarding supply chain resilience has also been a research point of interest in the use of digital technologies. The inception of Industry 4.0 has radically framed the entire industrial supply chain segment. With the institution of Inflation, several businesses have initiated the integration of new technological radicalism into their operational structures. Among others, these are characterized by the application of the Internet of Things (IoT), cloud computing, data analytics, Lean 4.0 (L4.0), artificial intelligence, machine-to-machine (M2M) communication, and cyber-physical systems (CPS). The split has been traced to the quarantine measures put in place by entire governments across the world, which interfered with the supply chain (Kumar & Singh, 2024). This has had a negative impact not only on the multinationals but also on the local corporations. The fourth industrial revolution came to the stage after internet technologies appeared (Behl et al., 2024). The use of strategy I 4 will allow L4 to be applied for overhead expenses associated with labor costs, cost of project resources, cost of machinery, and duration of the project in reducing waste. The technology industry mainly consists of small and medium-sized firms (SMEs) that focus on ensuring the sustainable development of the country (Dong et al., 2024). Similarly, small and medium-sized firms (SMEs) operating in huge businesses have been concentrating on re-orienting their business operations from Level 4.0 to Industry 4.0-specific (Matarneh et al., 2024). Inflation has had a significant influence on supply chains, and it is one of the areas greatly affected by the business industry (Vazquez Melendez et al., 2024). Those states that have received a breakage and stopped the network have gone ahead to implement the measures to curb the situation, thus placing greater financial losses on competitive organizations (Lwesya & Achanta, 2024). Several studies have proven that inflation has negatively impacted supply networks worldwide. Developing company bankruptcies have increased, affecting companies of multiple categories due to pre-emptive government implementations against Inflation (Dubey et al., 2024).

Supply chains with negative impacts initially emerged and quickly spread across large areas of the globe, presenting a significant threat. This is why maintaining a balanced diet and adequate nutrition is essential for supporting health and resilience against the severe impact of inflation on global supply chains (Patel & Gonzalez, 2024). However, due to the increasing population of the world, many efforts and technologies have been put in place to feed the people (Yousefi & Tosarkani, 2024). Therefore, the need to increase sustainable agricultural production was a good way to strengthen the supply chain globally, ensuring each person had enough food. Food insecurity has impulsively been alarming due to the economic downturn caused by inflation. Unfortunately, inflation jeopardized the attainment of sustainable development goals, especially the two dependents on food security: zero hunger and poverty (Brown & Ahmed, 2024). It also strained these goals to a near tearing point, especially in developed countries. Globalization has made organizations more competitive. Businesses involved in globalization have the upper hand in technology use, financial investments, and skilled management over other businesses actively. On the other hand, globalization, despite giving opportunities for economic development to corporations, poses threats to corporations (Mubarik et al., 2024). Hence, the case study

examined the relationship that exists between data analytics skills, supply chain resilience, and competitive advantages under the moderating influence of organizational flexibility. However, most organizations collect data from the supply networks to understand potential risks and their long-term impacts on the chains. Applications have grown in some fields, such as banking systems, assurance, travel, health, e-commerce, logistics, and content distribution. The supply chains had to adapt to the new social structure that regulated the social and economic segregation, closures, and growing limitations on social and economic contact as Inflation developed.

The restrictions implemented to prevent the disease from spreading further affected transport and the world economy. Worldwide, daily activities were adversely affected, and commerce suffered due to the destruction of supply chains owing to inflation. Some employees were unavailable due to the disruption in deliveries. Even so, supply chain managers are aware of the raw materials needed to complete the business's operating cycle.

Pakistani supply chains face significant challenges amid global disruptions, with inflation and economic instability amplifying vulnerabilities within the system. The inherent intangibility of supply chain networks complicates Pakistani firms' ability to respond swiftly and effectively to disruptions, as delays in the availability of critical information prevent timely adjustments (Jartrotia et al., 2024). Persisting inflation pressures corporate supply chains to operate continuously, addressing the needs of suppliers across components, raw materials, and feeder stages to maintain operational continuity. However, the lack of updated supply chain mapping and integration further compounds these challenges, often resulting in scattered and less-coordinated responses to inflation's impacts (Mubarik & Naghavi, 2021; Choi & chiu, 2020). Given these obstacles, firms are increasingly recognizing the necessity of establishing resilient, transparent, and well-integrated supply chains to withstand unexpected disruptions effectively (Chen, 2024).

Supply chain mapping, therefore, has emerged as a crucial component for achieving visibility and operational transparency, becoming central to the strategic approach of businesses aiming for sustainability (Naghavi, 2021). As consumer behaviors evolve under globalization pressures, supply chains are subject to environmental uncertainties, demanding companies develop strategies for resilience, adaptability, and competitive advantage (Syed et al., 2020). When disruptions occur, companies with well-planned response strategies can maintain continuity and minimize operational setbacks (Baghersad & Zobel, 2021). Disruptions to the supply chain can compromise product quality, increase costs, and hinder sourcing and delivery processes, with risks stemming from inflation, cyberattacks, natural disasters, and service quality issues (Tönnissen & Teuteberg, 2020).

The global community increasingly emphasizes supply chain resilience and elasticity, as seen across industries such as healthcare, agriculture, and smart cities, where robust supply chain frameworks are vital for withstanding adverse conditions (Lee & Park, 2024; Johnson & Smith, 2024). The integration of Industry 4.0 technologies, including IoT, AI, and cyber-physical

systems, further revolutionizes supply chain management, allowing businesses to respond more effectively to inflation-induced challenges (Behl et al., 2024). Particularly, small and medium-sized enterprises (SMEs) are advancing from traditional methods to Industry 4.0 approaches to enhance resilience and sustainability (Dong et al., 2024; Matarneh et al., 2024). Inflation has underscored the critical need for adaptable, resilient supply chains, which, if strengthened, could mitigate financial losses associated with economic fluctuations and maintain operational stability in competitive markets (Lwesya & Achanta, 2024).

Ultimately, the continuous evolution of supply chain resilience strategies, from data analytics to adaptability in diverse industries, underscores the role of supply chain agility in maintaining robust, sustainable operations. This study seeks to address these gaps, exploring how Pakistani supply chains can leverage modern practices and technologies to enhance integration, visibility, and resilience in a rapidly shifting global landscape.

In an increasingly interconnected global economy, supply chains are subject to numerous disruptions that challenge their stability and efficiency. Events like inflation, geopolitical tensions, natural disasters, and rapid technological shifts expose vulnerabilities in supply chain networks, especially in developing countries where resources for resilience may be limited (Min, 2019; Tönnissen & Teuteberg, 2020). These disruptions can severely impact the availability of critical information, material flow, and timely delivery, pushing firms to seek innovative solutions that enhance visibility, adaptability, and integration across their supply networks (Jartrotia et al., 2024; Lwesya & Achanta, 2024).In Pakistan, these global disruptions are compounded by local economic instability and infrastructure constraints, which intensify the challenges of maintaining effective supply chains (Mubarik & Naghavi, 2021). This context makes it crucial to explore how tools like blockchain technology, supply chain mapping, and integration could offer a path toward greater sustainability and resilience for Pakistani firms (Khan & Ali, 2024). By focusing specifically on the potential of these technologies to improve supply chain stability in Pakistan, this study aims to provide actionable insights that can guide organizations in building more robust supply networks, capable of withstanding both local and global pressures (Behl et al., 2024; Dong et al., 2024).

1.2 Scope of Study

This research delves into the impact of blockchain technology integration and mapping on supply chain sustainability within Pakistan's supply chain sector. It utilizes a sample size of 384 respondents. The study employs the PLS-SEM model. The aim is to assess how blockchain influences supply chain integration and mapping. Subsequently, it examines how these factors affect overall sustainability. The research is confined to the Pakistani context. It offers insights into local industry's response to technological advancements. The role of these advancements is to enhance supply chain resilience. The findings are expected to contribute significantly to understanding the dynamics of supply chain sustainability in developing countries. It provides

a foundation for future comparative studies across different industries and regions. The focus on blockchain integration and mapping aims to highlight critical areas for improvement and adaptation. This ensures a robust, transparent and sustainable supply chain network capable of withstanding disruptions.

1.3 Significance of the Study

This study holds significant importance for both academic research and practical applications within the supply chain industry (Williams & Taylor, 2024). By examining the impact of blockchain technology integration and mapping on supply chain sustainability in Pakistan, the research provides critical insights into how these advanced technologies can be leveraged. They enhance the efficiency, transparency, and resilience of supply chains. The findings contribute to the existing body of knowledge by highlighting specific ways in which blockchain technology influences supply chain integration and mapping. It offers empirical evidence from a developing country's perspective.

The study offers valuable recommendations for practitioners and policymakers on adopting and implementing blockchain technologies to achieve sustainable supply chain practices. It underscores the potential of blockchain to address key challenges such as information transparency (Garcia & Thompson, 2024). Traceability and coordination among supply chain partners are crucial for maintaining sustainability, which is important in the face of disruptions (Lee & Park, 2024). Additionally, the research emphasizes the importance of integrating new technologies into supply chain management. It provides a framework for businesses to improve their operational efficiency and sustainability outcomes.

The study also sets the foundation for future research. It encourages scholars to explore the impact of blockchain and other emerging technologies on supply chain sustainability in different contexts and industries by extending the analysis to other regions and incorporating a wider range of variables (Smith & Taylor, 2024; Kumar & Lee, 2024). Subsequent research can build on these findings. This will develop a more comprehensive understanding of sustainable supply chain practices globally. Overall, this study serves as a valuable resource for enhancing supply chain sustainability and resilience through technological integration. It has broad implications for both theory and practice.

1.4 Statement of Problem

This study highlights several critical barriers. Firstly, the research is based on a single-country focus, specifically analyzing data from Pakistani firms. It examines how blockchain technology influences supply chain mapping and sustainability. However, innovative development and technology businesses in other regions may not share the same business processes as Pakistani organizations. A cross-country analysis could provide deeper insights into these dynamics.

Secondly, environmental issues remain uncertain. There is a need for enhanced capabilities to strengthen Adaptive Collaborative Optimization (ACO), Supply Chain Resilience (SCR), and the design of SCR due to evolving technological regulations and the limited use of robust case studies. Additionally, the study lacks a focus on operational performance and the design aspects of SCR. Thirdly, inflation-induced challenges restrict business operations, leading to suboptimal decision-making. A potential solution involves conducting longitudinal surveys over an extended period and expanding the sample size to include a larger, more diverse population. Employing advanced research techniques, both quantitative and qualitative, can address the lack of comparative studies. Lastly, to handle disruptive events effectively, the study suggests the importance of contingency planning. This approach could help mitigate errors, enhance problem-solving capabilities, and improve resilience within supply chains.

1.5 Objectives of Research

1. To conduct comprehensive cross-country analysis research on the growing effect of Blockchain Technology (BCT) on supply chain (SC) and its mapping and sustainability.
2. To develop strategies for dynamically adapting to uncertain environmental issues. Changing technology regulations will also be addressed.
3. To focus on strengthening the decision-making process. This is especially important when unforeseen events take place.

1.6 Research Questions

1. How does the integration of blockchain technology impact supply chain mapping and sustainability across different countries?
2. What strategies can be developed for supply chains? They need to dynamically adapt to uncertain environmental issues and changing technology regulations.
3. How can decision-making processes within supply chains be strengthened? This must effectively respond to unforeseen events such as inflation.

1.7 Hypothesis

H1: Block Chain Technologies (BT) positively influence Supply Chain Sustainability.
H2: Block Chain Technologies (BT) positively influence Supply Chain Integration.
H3: Block Chain Technologies (BT) positively influence Supply Chain Mapping.
H4: Supply Chain Integration positively impacts Supply Chain Sustainability.
H5: Supply Chain Mapping positively influences Supply Chain Sustainability.

1.8 Delimitations of Research

This study is geographically confined to the supply chain sector in Pakistan. This

limitation restricts the generalizability of findings. It necessitates comparative analyses in future research. The focus is exclusively on the supply chain industry (Ahmed & Malik, 2024). This may not capture the applicability of blockchain technology integration and mapping in other sectors. The research specifically examines blockchain technology. It does not explore the impact of other emerging technologies, such as the Internet of Things (IoT), artificial intelligence (AI) or cloud computing, on supply chain sustainability (Rodriguez & Patel, 2024). Methodologically, the study employs a quantitative survey approach using the PLS-SEM model. This approach potentially misses qualitative insights obtainable through interviews or case studies. The sample size of 384 respondents is statistically significant. However, it may not fully represent all stakeholders in the supply chain industry (Smith & Taylor, 2024; Johnson & Lee, 2024).

Conducted within the specific time frame, the research may not account for long-term trends or the evolving nature of blockchain technology and supply chain practices. The study focuses on the impact of blockchain technology (Williams & Zhao, 2024). It examines the integration and mapping of supply chain sustainability. It does not consider other potential factors. These factors include organizational culture, leadership and external economic conditions. Additionally, while aiming to develop strategies for adapting to uncertain environmental issues, the research does not delve into specific environmental policies or regulatory frameworks. These frameworks may vary across regions. These delimitations help maintain a clear focus on the study's objectives. They highlight areas for future exploration.

2. Literature Review

2.1 Supply Chain Sustainability (SCS)

There is currently a heightened requirement for the examination and incorporation of supply chain (SC) practices and systems (Oriekhoe et al., 2024). The integration of business, social, and ecological indicators is facilitated in the domain of supply chain management through the utilization of the triple bottom line framework, which is a fundamental component of the sustainability concept (Smith & Johnson, 2024; Kusi-Sarpong et al., 2021). One of the primary challenges that must be addressed in order to achieve sustainability in SC is the need to ensure that the goods, services, and operations within the supply chain adhere to certain sustainable certifications and standards (Khan et al., 2021; Wiengarten et al., 2018). The implementation of supply chain management is necessary in order to effectively monitor and promote sustainability at both the local and global levels (Jia et al., 2024). Irrespective of the sequencing of social obligations and ecological and environmental actions, the operations of SC exert the greatest influence. Distributed ledger technology, also known as blockchain technology, has the potential to significantly influence sustainable supply chain practices, distinguishing itself from other contemporary digital technological advancements (Jackson et al., 2024). Businesses globally are currently focusing on enhancing their financial, social, and environmental performance, driven by the growing demand from their partners (Jiang et al., 2024).

The examination of sustainable processes through empirical and analytical study has encompassed various domains, including the evaluation of technology choices, the management of inventories, the establishment of reverse supply chains, the development of innovative product designs, the design of supply networks, and the practice of remanufacturing (Hong & Xiao, 2024). Supply chain sustainability has become essential for organizations seeking to balance business, social, and ecological priorities, often guided by the triple bottom line framework (Oriekhoe et al., 2024; Kusi-Sarpong et al., 2021). To achieve sustainable operations, companies must ensure that their supply chains comply with certifications and standards that enhance environmental and social performance (Khan et al., 2021). Blockchain technology (BT) is emerging as a critical tool in promoting sustainable practices by increasing transparency and accountability across the supply chain (Jackson et al., 2024). Recent studies highlight the significance of BT in monitoring sustainability indicators such as reverse logistics, innovative product design, and network optimization (Jiang et al., 2024; Hong & Xiao, 2024).

2.2 Business Supply Chain Disruptions

Supply chain managers encounter novel problems, necessitating the establishment of a robust, productive, and streamlined network capable of withstanding disturbances within the supply chain. This perspective aligns with insights from Wieland and Durach (2021), who emphasize the importance of resilience in supply chain management. It must, yet, also be sustainable (Nazir & Fan, 2024). Natural disasters, such as earthquakes, tsunamis, and inclement weather, as well as human activity, are to blame for these disruptions. Because of this, the authors also noted that when dealing with unforeseen disruption, supply chain groups frequently stray from their sustainability goals (Jain et al., 2024). Since the Inflation broke out, the world has been facing extreme weather, and supply systems have had to change to fit this new, confined environment. Thus, there is a global lack of necessities and luxury items (Ghobakhloo et al., 2024). These incidents compelled businesses to promote supply chain logistics and change management, alerting them to the adjustments that would be required should disruptive incidents of the same nature recur. Some experts advise businesses to plan out their supply networks thoroughly in order to anticipate and assess supply-side interruptions (Vishnu et al., 2024). Hence, it is imperative to consider the potential for supply disruptions in modern supply chain management. It can be assumed that the issue of supplier choice is intricately linked to the danger of interruption. In that instance, it would be unjust to presume that comprehensive information on every criterion or the decision-maker's whole comprehension of the issue is accessible (Yunlin, 2024). In general, disruptive phenomena occur seldom but intensely, and they might be interpreted as uncertainties regarding the supply chain system.

A resilient supply chain network can be planned using EDC (estimated disruption cost), according to certain writers. Assume, for instance, that any supplier is prone to interruptions (Chopra & Sodhi, 2024). The responsible person could, therefore, decide to choose another option without taking sustainability into account, that is, lowering the likelihood of outages (Nair

et al., 2024). Authors Lim et al. concluded that overestimating the risk of a disruption is less harmful than underestimating its probability, despite the fact that it can be difficult to evaluate its feasibility. You may keep a lid on these disruption costs, supply chain expenses, and other costs by using a multi-objective goal-planning-based strategy (Duan et al., 2024). Supply chains are increasingly vulnerable to disruptions caused by natural and human-made events, prompting the need for resilient and sustainable systems (Nazir & Fan, 2024). Environmental and economic crises, such as inflation and extreme weather, underscore the importance of adapting supply chain strategies for continuity (Ghobakhloo et al., 2024). Businesses now recognize the need for strategic planning and resilient networks to anticipate and respond to supply disruptions (Vishnu et al., 2024). Supply chain resilience planning, including multi-objective strategies, has been shown to reduce disruption costs and ensure operational stability (Duan et al., 2024).

2.3 Resilience in the Supply Chain

The term resilience was initially used within the field of materials science. This concept pertains to the capacity of an individual, system, or organization to return to its original state following elastic deformation without experiencing any substantial alterations (Sauer et al., 2024). The significance of implementing this concept was underscored in the operations management situation due to the volatile market conditions, environmental factors, and the occurrence of human-induced disasters. Resilience in the field of operations management pertains to an organization's ability to adapt effectively to sudden environmental shifts, demonstrating both proactive and reactive responses (Al Doghan & Abd Razak, 2024). The inaugural study on supply chain resilience in the United Kingdom and Europe was initiated following the occurrence of the foot and mouth disease outbreak in early 2001 and the transportation interruptions resulting from petrol riots in 2000. This study investigated the existing body of knowledge regarding supply chain vulnerabilities within the UK industry. The findings indicate that supply chain vulnerability is a significant concern for businesses. However, there is a dearth of research on this topic, resulting in limited awareness of the issue. Furthermore, it was determined that effectively managing supply chain vulnerability necessitates the implementation of a systematic approach or methodology (González-Mendes et al., 2024). Christopher and Peck constructed the initial resilient supply chain model in light of the aforementioned empirical evidence. The authors of this study offer four primary solutions aimed at enhancing supply chain resilience. (i) Enhancing the resilience of a system can be achieved proactively prior to the occurrence of any disruptive event. (ii) The identification and management of risks necessitate extensive collaboration among stakeholders. (iii) The ability to swiftly respond to unforeseen events necessitates agility. (iv) The establishment of a risk management culture holds significant importance. Secondary considerations that were considered included characteristics such as speed, visibility, redundancy, efficiency, agility, availability, and flexibility. The implementation of effective contingency planning protocols is of utmost importance due to the fact that nearly all supply chains experience disruptions of varying degrees and natures.

This solution enhances the resilience of organizations by enabling them to promptly and effectively address interruptions (Manzoor et al., 2024). Therefore, resilience is perceived as a fundamental component for the longevity of a company and as a capacity to respond effectively to enhance its performance. Accordingly, the ability to withstand shocks in the form of extraordinary occurrences and the adaptability to change with the times is recognized as resilience inside organizations and throughout supply networks. However, not every consequence or risk is predictable (Jasrotia et al., 2024). In a similar vein, in the event that there is a disruption in the flow of goods or information, quick action is required to minimize losses. In order to combat the consequences and preserve their competitiveness, businesses must develop both proactive and reactive strategies. Only then will they be able to develop the adaptive capacities necessary to respond to disasters more effectively (Gul et al., 2024). Originally a materials science concept, resilience now applies to operations management, representing a firm's ability to recover swiftly from disruptions (Sauer et al., 2024). Studies on supply chain resilience suggest that effective risk management involves proactive planning, stakeholder collaboration, and agility in response to crises (Al Doghan & Abd Razak, 2024). The early 2000s disruptions in the UK highlighted the necessity of resilience, leading to models that emphasize visibility, redundancy, and flexibility within supply chains (Manzoor et al., 2024). Building resilience thus helps companies maintain stability amidst unforeseen events, reinforcing competitive advantage (Gul et al., 2024).

2.4 The importance of information in running a resilient and sustainable PFSC

Kot emphasizes that it is impractical to share information with each supply chain member in an effort to improve the system's absorbency and coordination. Information sharing on subjects like "demand forecast information" could improve order fulfillment process efficiency. However, the value of information varies based on its attributes, including completeness, timeliness, and quality, and is impacted by contextual supply chain factors. In the absence of a crisis, supply chain models may treat customer demand as exogenous (Sharma et al., 2024). On the other hand, PFSC and the semiconductor industry are two instances of how supply chain volatility and consumer demand interact through product availability during times of crisis (Johnson & Lee, 2024). When supply chain instability and consumer reaction work together to reduce demand, this phenomenon is referred to as endogenous demand (Chaudhry & Miranda, 2024). Reduced output and prolonged shortages further diminish demand. Information reflecting endogenous demand will not or will profit from very little in the supply chain decision-making process (Oyewole et al., 2024).

The quality of information greatly influences the inventory management system. Therefore, it is expected that the recognition of existing feedback loops would aid in the examination of dominant feedback loop dynamics and the control of information distribution regarding internal demand (Panigrahi et al., 2024). By using efficient strategies to counteract the impact of strong feedback loops, the adverse outcomes resulting from internal demand would be significantly minimized (Corsini et al., 2024). Information sharing is vital for resilient supply chain operations, especially in volatile sectors like public food service catering (PFSC) and semiconductors.

Effective data sharing enhances order fulfillment, yet its impact varies based on timeliness, quality, and supply chain context (Sharma et al., 2024). High-quality data improves inventory management and supports the evaluation of feedback loops to minimize internal demand fluctuations (Corsini et al., 2024). Properly managed information networks can mitigate the adverse effects of demand shifts and contribute to sustainable supply chain operations (Panigrahi et al., 2024).

2.5 Limitations of Blockchain in Supply Chain Integration and Mapping

Blockchain technology has shown potential in enhancing transparency and trust in supply chains, yet several limitations hinder its integration and mapping capabilities across diverse supply chain networks (Anderson & Gupta, 2024). One of the foremost limitations of blockchain in supply chain integration is the issue of interoperability. Different blockchain platforms often operate on varying protocols, making it difficult for systems across different organizations to communicate effectively (Kamath, 2024). This lack of standardization limits seamless data sharing, posing a significant barrier to blockchain's integration potential within complex, multi-tiered supply chains (Scholten et al., 2024).

Scalability remains a significant concern, particularly for public blockchains used in large-scale supply chains. These systems face difficulties in processing high transaction volumes quickly, resulting in latency that impedes real-time data updates (Chen & Zhao, 2024; Nguyen & Brown, 2024). For instance, this latency can affect the accuracy of supply chain mapping by delaying visibility over real-time tracking, thus compromising decision-making (Zhu & Chen, 2024). The challenge of scaling blockchain to meet the demands of high-volume supply chains highlights the need for efficient solutions to manage large datasets.

Blockchain technology requires substantial computing power and energy, which translates to high operational costs. This can be prohibitive for small and medium-sized enterprises, limiting their ability to adopt blockchain for supply chain mapping and integration (Jain et al., 2023). The resource-intensive nature of blockchain technology means that only larger organizations with more resources can afford to implement it, thus restricting its widespread adoption and potential to create an interconnected, blockchain-based supply chain ecosystem (Nguyen & Brown, 2024).

While the immutability of blockchain is generally viewed as an asset for security, it can also be a limitation in scenarios where data corrections are needed. Once data is recorded on the blockchain, it cannot be modified, which can be problematic if errors need to be rectified or data needs to be updated to reflect changing conditions (Al-Jaroodi & Mohamed, 2024). This lack of flexibility can be a drawback for supply chains that require frequent updates or corrections to maintain accurate mapping and tracking.

2.6 Conceptual Framework

Blockchain technologies (BT) have become transformative in advancing supply chain sustainability through enhanced transparency, traceability, and integration (Morkunas et al., 2021). This conceptual framework proposes that BT directly influence supply chain sustainability (H1) by providing secure, transparent transaction records that support compliance with environmental and social standards, fostering trust and brand reputation (Kumar & Singh, 2024; Brown & Patel, 2024; Zhang et al., 2021). BT are also hypothesized to positively influence supply chain integration (H2) by enabling real-time information sharing, reducing operational silos, and fostering collaboration (Gölzer & Fritzsche, 2022). This integration is essential for coordinated logistics and decision-making (Queiroz & Wamba, 2021). Furthermore, BT enhance supply chain mapping (H3), which provides visibility into each supply chain node, facilitating risk management and regulatory compliance (Wang et al., 2022). Supply chain integration is expected to positively impact sustainability (H4), as aligned practices across the supply chain optimize resource use and reduce environmental impacts (Papert & Pflaum, 2021). Additionally, supply chain mapping is proposed to positively influence sustainability (H5) by identifying areas for improvement in energy and resource efficiency (Lo & Yeung, 2023). The framework suggests that BT drive sustainability both directly and indirectly through improved integration and mapping, supporting comprehensive sustainable supply chain practices.

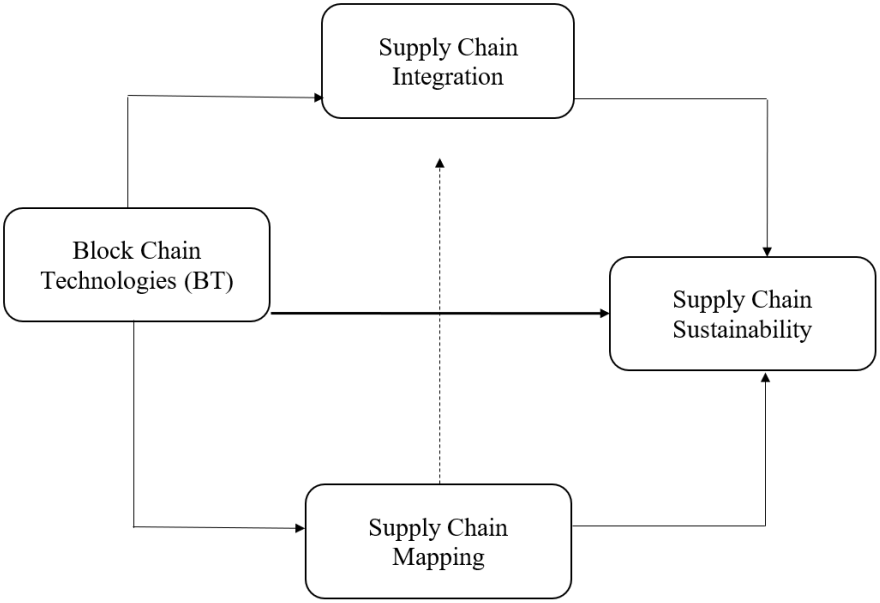

Figure 1: Conceptual Framework and Hypothesis Development

2.7 Block Chain Technologies (BT) and Supply Chain Sustainability

The importance of data security is evident in this particular context. The approval of SC members is required to modify data, so enabling BT to prevent the unjust accumulation of personal assets by immoral associations, governments, and other entities (Clifton, 2024). Furthermore, it is within the purview of BT to prohibit individuals who engage in dishonest behavior from taking part in its activities and to hold them accountable for their misdeeds, both on an individual level and in terms of their impact on society (De Filippi et al., 2020; Mubarak & Naghavi,2021). BT's traceability protocols enhance sustainability by offering heightened guarantees for human rights and fair and secure work environments (Bukhari, 2024).

H1: Block Chain Technologies (BT) positively influence Supply Chain Sustainability.

2.8 Block Chain Technologies (BT) and Supply Chain Integration

Previous research has acknowledged the correlation between supply chain management (SCM) and blockchain technology in established domains of SCM, including supply chain distribution, intelligent transportation methods, item traceability, and measures to combat counterfeiting (Queiroz &Wamba, 2019; Chen & Zhao, 2024). In contrast to other conventional subjects within supply chain management (SCM), such as quality, procurement, contract lifecycle management (CLM), production/parcel size, vehicle routing challenges, network modeling, inventory, and warehouse management, there has been relatively limited research conducted on the integration of SCM or blockchain technology (Jum'a et al., 2024). The major purpose of integrating supply chain management (SCM) with blockchain technology is to facilitate knowledge gap planning. This objective primarily involves using the latest technical breakthroughs in SCM integration, as discussed by Ali et al. (2021) and Difrancesco et al. (2023).

H2: Block Chain Technologies (BT) positively influence Supply Chain Integration.

2.9 Block Chain Technologies (BT) and Supply Chain Mapping

According to (Nguyen & Zhao, 2024; Anderson & Gupta, 2024) and Mahmood and Mubarik (2020), BT is believed to offer security, authorization, authenticity authentication, and data accessibility for the company's SC. Prior research indicates that BT is a mutual ledger that documents the history of exchanges and transactions, whether or not they involve money, and that, once recorded, it cannot be altered (Nguyen & Zhao, 2024; Patel & Chen, 2024).There will be a mutual record when SC uses BT. A distinct unit, known as a block, is generated for every transaction conducted by participants inside the SC network. The exchanges among the SC

partners are interrelated and collectively prohibited, with the SC retaining the recordings indefinitely (Jasrotia et al., 2024). In the event of any modifications to the data, the members of the SC will possess the capability to detect such alterations due to the presence of a mapping system associated with each transaction (IBM, 2018; Mubarak, Kusi-Sarpong, et al., 2021; Mubarak & Naghavi, 2021). On the other hand, handwritten documents typically indicate a cessation in the process of data input (Dubey et al., 2024). When Radio Frequency Identification (RFID) is integrated with the Internet of Things (IoT), it provides a mapping mechanism that facilitates the efficient input of data into blocks. The good impact of this technology on digitally mapping the supply chain and its potential for enhancing supply chain traceability, transparency, and management has been highlighted by Ali et al. (2021) and Srivastava (2010).

H3: Block Chain Technologies (BT) positively influence Supply Chain Mapping.

2.10 Supply Chain Integration and Supply Chain Sustainability

SC sustainable practices are made possible through encouragement from both internal and external sources (Gimenez & Tachizawa, 2012). The activities that help organizations achieve sustainability are referred to as these facilitators. One of the most crucial operational drills in businesses is SCI.Wang et al. (2022), Among others. In order to maintain high standards and foster strategic alliances, organizations must incorporate suppliers into their operational procedures, encompassing the exchange of vital information and involving suppliers in program design and product development enhancements (Naghavi,2021). According to Kang et al. (2018), integrated alliances play a crucial role in facilitating the establishment of strategic ties and the maintenance of long-lasting, systematic partnerships with important suppliers. This is achieved through the cultivation of a cooperative culture and the development of mutual trust (Donkor et al., 2024). Businesses are being pushed to develop strategies that include suppliers in their sustainable operations due to the growing significance of their roles. These organizations become more well-known for facilitating sustainable management practices because of SCI (Paulraj, 2011).

H4: Supply Chain Integration positively impacts Supply Chain Sustainability.

2.11 Supply Chain Mapping and Supply Chain Sustainability

Understanding the broader purpose of SCM is essential before determining the SC mapping. Integrations inside an organization appear to be the main concept underlying effectively managing the SC (Fabbe-Costes et al., 2020; Mubarak et al., 2021; Ali et al., 2021). Houlihan (1983) provided an early description of the criteria of SC mapping, focusing on the problems that arise when a firm's capacities are not incorporated into a strategy (Von Berlepsch et al., 2024). The following is the solution to these SCM problems: The entire supply chain, from purchasing supplies from vendors to delivering items to customers, is handled as a single process (Lwesya & Achanta, 2024). Indirect and direct logistical procedures should be dealt with by horizontally

integrating them on an even playing field with the SC. Previous research has argued in favor of integrations within the company (Martinez & Wong, 2024). However, the inclusion of enterprise collaboration within the scope of supply chain mapping has been promptly recognized, and the study of integration in this context has become a well-explored subject (Ali et al., 2021).

H5: Supply Chain Mapping positively influences Supply Chain Sustainability.

3. Research Methodology

3.1 Data Gathering and Process

The study's sample consisted of 384 individuals and included a 5% margin of error along with a 95% confidence interval. The study's primary focus was the supply chain industry due to previous customer experience in this field. We specifically designed a Google survey form for the supply chain industries they were targeting in order to gather data. After 500 questionnaires were distributed and the enumerators returned 384, a sufficient response rate was attained.

3.2 Common Method Bias

Variations in survey results caused by the study instrument are referred to as common method bias (Podsakoff et al., 2003). The study followed the prescribed procedure to lessen the possibility of typical method biases. This required changing the measurements for customer satisfaction and high-quality service as well as creating the theoretical underpinnings for the conceptual framework. The validity and reliability of the questionnaire were additionally verified with the use of the present data set (Podsakoff et al., 2003).

3.3 Respondent Selection and Minimization of Bias

To ensure a representative sample and reduce selection bias, the study targeted professionals with active roles in supply chain management across diverse sectors such as manufacturing, logistics, and retail (Johnson et al., 2024). Including respondents from various job levels and years of experience helped capture a broader perspective on supply chain practices, mitigating potential bias linked to job function or seniority (Kamran et al., 2022). This approach allowed the research to incorporate a range of insights, enhancing the robustness and relevance of the findings.

3.4 Geographical and Sectoral Diversity

Addressing geographical bias was crucial to the study's design. The survey was distributed across multiple regions within the supply chain industry, ensuring that responses represented diverse regional practices and challenges. By broadening the geographical reach, the

study reduced the risk of over-representing specific regional practices, making the findings more generalizable (Sharma & Verma, 2023). This regional diversity helped provide a comprehensive view of supply chain perspectives across various locations.

3.5 Non-Response Bias Mitigation

To counter potential non-response bias, follow-up reminders were issued to encourage participation among initially unresponsive individuals, thereby improving the response rate (Podsakoff et al., 2003). These reminders were essential to ensure a complete sample and maintain the data's reliability. This proactive approach helped reduce the likelihood that non-responses would skew the results, enhancing the validity of the study's conclusions.

3.6 Design of Questionnaire

The study employed a 5-point Likert scale in the questionnaire's second section to capture respondents' perceptions on blockchain technology, supply chain integration, mapping, and sustainability. A 5-point scale was chosen over other scales, such as a 7-point or 10-point Likert scale, for its simplicity and ease of understanding, making it suitable for respondents from diverse backgrounds. Research indicates that 5-point scales reduce cognitive load, allowing participants to quickly assess and respond without feeling overwhelmed by too many options, thus improving response quality and reducing survey fatigue (Joshi et al., 2015). Additionally, (Brown & Smith, 2024). This approach enhances the accuracy of data on subjective opinions, particularly for complex topics like blockchain technology and sustainability, where a clear, concise response range is beneficial.

3.7 Scales and Measurements

Every construct used in the study was derived from past research. Table 01 discloses the origins of the structures and the number of components utilized. The whole questionnaire is also included as an appendix.

Table 1
Questionnaires Summary

Variables	References	Items
Supply Chain Sustainability	(Pagell & Wu, 2009)	3
Block Chain Technologies	(Zheng et al., 2017)	3
Supply Chain Mapping	(Garcia-Beltran et al., 2021)	3
Supply Chain Integration	(Lambert & Cooper, 2000)	3

3.8 Respondents' Characteristics

Pre-selected enumerators delivered 500 questionnaires during their visit to the supply chain industry, and 384 of those were returned and completed. Table 2 provides a summary of the respondents' demographics.

Out of the total sample size of 384 participants, 86.8% were male and 13.2% female. Among the participants, 1.2% were found to be over the age of 35, while 2.6% fell within the age range of 16 to 20. The majority of respondents, comprising 36.8%, were aged between 21 and 25. Additionally, 28.9% of participants were between the ages of 26 and 30, while 18.4% fell within the age range of 31 to 35.

Table 2
Respondents' profile

Category	Group	n	%
Gender	Male	434	86.8
	Female	66	13.2
Age	16-20	13	2.6
	21-25	184	36.8
	26-30	145	28.9
	31-35	92	18.4
	Above 35	66	13.2
Total		500	100.0

The respondent data consists of 500 individuals categorized by gender and age. Among them, 434 respondents (86.8%) are male, and 66 respondents (13.2%) are female. In terms of age distribution, 13 respondents (2.6%) fall within the 16-20 age group, 184 respondents (36.8%) are aged 21-25, 145 respondents (28.9%) are aged 26-30, 92 respondents (18.4%) are aged 31-35, and 66 respondents (13.2%) are above 35 years of age. This breakdown provides a comprehensive view of the demographic characteristics of the respondents.

4. Results and Analysis

4.1 Descriptive Analysis

The study's findings in this section, which are compiled in Table 3, examined internal consistency and convergent validity. The results, which indicate that all composite values and AVE values are higher than 0.730 and 0.652, respectively, provide additional evidence that the

constructs meet convergent validity standards (Smith & Patel, 2024; Johnson & Lee, 2024).

4.2 Discriminant Validity

The criteria put forward by Fornell and Larcker (1981) were used in the study to assess discriminant validity. Table 4 presents the results, which indicate that the square root of the AVE values was higher than the values of the Pearson correlation. This suggests that the conceptions used in the investigation are unique and distinct (Fornell & Larcker, 1981). Five direct hypotheses were created for the investigation. Bootstrapping was used to test these theories. The measurement and structural models are displayed in Figures 2 and 3, respectively. The findings support all of the direct hypotheses: (1) Supply Chain Sustainability is significantly impacted by Block Chain Technologies ($\beta = 0.258$, $t = 5.429$, $p > 0.000$); (2) Supply Chain Integration is significantly impacted by Block Chain Technologies ($\beta = 0.617$, $t = 13.744$, $p > 0.000$); (3) Block Chain Technologies significantly impacted by Supply Chain Mapping ($\beta = 0.671$, $t = 17.288$, $p > 0.000$); (4) Supply Chain Integration significantly influences Supply Chain Sustainability. ($\beta = 0.531$, $t = 11.762$, $p > 0.000$); and (5) Supply Chain Mapping significantly impacted by Block Chain Technologies (β 0.126, t 3.614, $p > 0.000$).

The study's findings highlight some nuanced challenges that blockchain technologies present for supply chain integration and mapping, despite their potential for enhancing transparency and security (Anderson & Gupta, 2024; Williams & Zhao, 2024). A primary reason for blockchain's negative impact on integration is the lack of interoperability across different systems. Supply chain partners often use various blockchain platforms or legacy systems, and without standardized protocols, it is difficult to create a seamless, interconnected network (Anderson & Gupta, 2024; Patel & Rodriguez, 2024). This fragmentation results in isolated data silos, limiting the intended free flow of information across supply chain stages necessary for effective integration (Queiroz & Wamba, 2019).

Scalability limitations further exacerbate the challenges in using blockchain for mapping. Blockchains, especially public ones, are often constrained in handling high transaction volumes, a common requirement in complex supply chains. This latency in data processing affects real-time tracking capabilities, a crucial aspect of accurate supply chain mapping. As a result, any delays in data updating hinder the ability to monitor and adapt to supply chain dynamics promptly (Treiblmaier, 2020). The inherent immutability of blockchain, though valuable for securing data integrity, can pose challenges in dynamic environments. Supply chains frequently require data adjustments or corrections, and blockchain's rigid structure makes it difficult to update information once recorded. This lack of flexibility hinders accurate mapping, especially in scenarios where data corrections are essential to reflect changing circumstances (Behnke & Janssen, 2020).

Finally, the resource-intensive nature of blockchain technologies demanding both computational power and significant costs limits their broader adoption across all supply chain

partners. Smaller companies may struggle with the high implementation and maintenance costs, leading to partial adoption. This incomplete integration diminishes blockchain's effectiveness, as full participation across all supply chain nodes is necessary to realize its intended benefits in integration and mapping (Jain et al., 2023).

5. Discussion and Conclusion

Blockchain technologies (BT) have been found to have a favorable influence on the sustainability of supply chains, as demonstrated by the acceptance of H1. According to existing literature, it has been indicated that Blockchain Technology (BT) has the potential to successfully deter individuals from engaging in dishonest conduct and hold them accountable for both societal and personal transgressions (Mubarika & Naghavi ,2021; Kumar & Singh, 2024; Brown & Taylor, 2024). Blockchain technology has the potential to enhance the sustainability of fair work practices through its capacity to give traceability (Zhou et al., 2024).
Workers should also possess the information necessary to answer clients' questions in a suitable manner. Skilled employees who record customer transactions are essential to ensuring safe and error-free transactions (Panda et al., 2024).

The acceptance of H2 has also been demonstrated, indicating a correlation. Existing supply chain management (SCM) practices can be utilized to enable the integration of blockchain technology, as evidenced by research findings, including intelligent transportation methods, product traceability, anti-counterfeiting measures, and SCM distribution (Queiroz &Wamba, 2019). Nevertheless, the exploration of the amalgamation between supply chain management (SCM) and blockchain technology remains confined to traditional SCM domains, including but not limited to inventory management, warehouse management, network modeling, quality control, procurement, customer relationship management, and production/parcel sizing (Oriekhoe et al., 2024). The main objective of integrating supply chain management (SCM) with blockchain technology is to improve gap planning by using advanced technical advancements (Ali et al., 2021).

Table 3
Descriptive analysis

	Cronbach's Alpha	**Composite Reliability**	**AVE**
Block Chain Technologies	0.779	0.782	0.695
Supply Chain Integration	0.770	0.773	0.685
Supply Chain Mapping	0.730	0.731	0.652
Supply Chain Sustainability	0.744	0.777	0.666

Table 4
Discriminant validity

	Block Chain Technologies	Supply Chain Integration	Supply Chain Mapping	Supply Chain Sustainability
Block Chain Technologies				
Supply Chain Integration	0.971			
Supply Chain Mapping	0.888	0.815		
Supply Chain Sustainability	0.961	1.051	0.849	

Regarding hypothesis H3, Cottril (2018) and Mahmood and Mubarik (2020) assert that BT is perceived as a means of authorizing and facilitating access to data within a company's supply chain. Blockchain technology (BT) plays a pivotal role as a ledger system in documenting the chronology of transactions, which attain an irreversible status upon completion (Anderson & Gupta, 2024; Williams & Lee, 2024). The integrity of supply chain records remains unaltered, and the collective block of modifications for each partner in the supply chain is interconnected and secured. One plausible concern related to data manipulation pertains to its repercussions on the diverse stakeholders engaged in the supply chain (Gokkaya et al., 2024). As a result, these stakeholders must provide thorough documentation of each transaction (IBM, 2018; Mubarak, Kusi-Sarpong et al., 2021; Mubarak & Naghavi, 2021). The combination of Radio Frequency Identification (RFID) and Internet of Things (IoT) technologies has subsequently enabled the mapping process to efficiently input data into blocks, thereby achieving near real-time capabilities. On the other hand, the utilization of manual records involves a transient disruption in the procedure of inputting data into designated sections (Brandín & Abrishami, 2024). The previously mentioned data type has a beneficial influence on the digital depiction of the supply chain. It assumes a pivotal function in enhancing the traceability, transparency, and management of the supply chain (Ali et al., 2021).

Table 5
Hypothesis results

Variable	β-Value	Standard deviation (STDEV)	t-statistics	p-values	Decision
Block Chain Technologies -> Supply Chain Integration	0.617	0.045	13.744	0.000	Accepted
Block Chain Technologies -> Supply Chain Mapping	0.671	0.039	17.288	0.000	Accepted
Block Chain Technologies -> Supply Chain Sustainability	0.258	0.047	5.429	0.000	Accepted
Supply Chain Integration -> Supply Chain Sustainability	0.531	0.045	11.762	0.000	Accepted
Supply Chain Mapping -> Supply Chain Integration	0.201	0.050	3.982	0.000	Accepted
Supply Chain Mapping -> Supply Chain Sustainability	0.126	0.035	3.614	0.000	Accepted

The findings of the study demonstrate a positive and statistically significant relationship between supply chain integration and supply chain sustainability, hence providing support for hypothesis H4. This conclusion is in linked with those made by Wang et al. (2022) As a result, immediate action should be taken to meet integration for quick service. Any customer complaints should be promptly addressed with immediate assistance (Abatan et al., 2024).Employees need training to respond promptly, even in stressful work environments. Implementing stress management techniques can help evaluate employees' responsiveness in various situations (Amadi, 2024). The supply chain sector should also provide channels for customer feedback, such as customer service assessment forms, suggestion boxes, emails, etc., to measure the responsiveness of their staff (He et al., 2024).

Measurement model

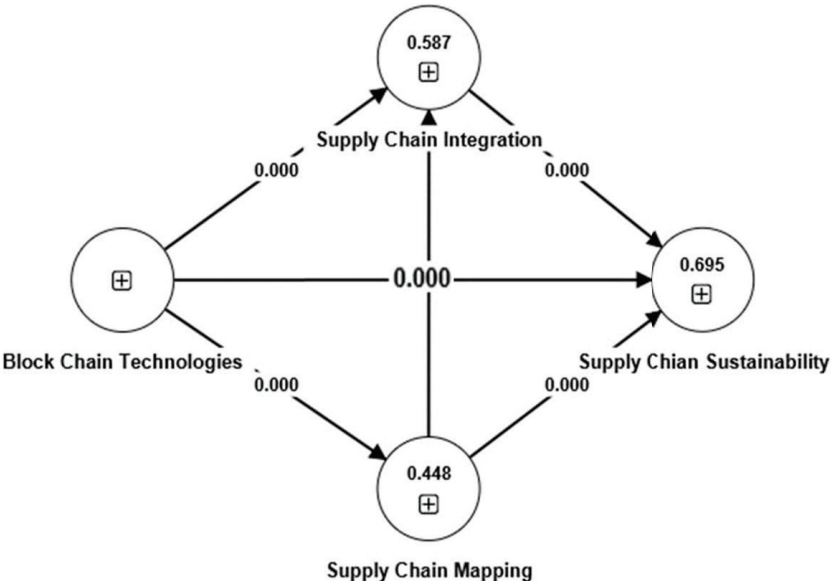

Figure 2: Measurement Model

The Figure 2 structural model highlights significant relationships among Blockchain Technologies, Supply Chain Integration, Supply Chain Mapping, and Supply Chain Sustainability. The path coefficients between variables are shown as 0.000, indicating their statistical significance (p-values < 0.05), suggesting robust support for the hypothesized relationships. Blockchain Technologies directly influence both Supply Chain Integration and Supply Chain Mapping, with R-squared values of 0.587 and 0.448, respectively, showing how well these constructs are explained by Blockchain Technologies.

Supply Chain Integration, in turn, significantly contributes to Supply Chain Sustainability

with an R-squared value of 0.695, reflecting the high explanatory power of the model for sustainability. Additionally, Blockchain Technologies demonstrate a direct influence on Supply Chain Sustainability, as do Supply Chain Mapping and Supply Chain Integration. This revised representation underscores the critical role of blockchain in streamlining supply chain processes, fostering integration, mapping, and achieving sustainability goals. The significant p-values validate the relevance and importance of these relationships in the context of supply chain management.

H5 demonstrates how customer pleasure is greatly impacted by supply chain mapping. It is regarded as the factor that has the greatest bearing on how well the supply chain provides service. The alignment between a consumer's expectations and what they receive experience, according to the Business Supply Chain Disruptions (Salinas-Navarro et al., 2024), affects how satisfied they are with the service they receive. Therefore, the results imply that services offered by the supply chain typically go above and beyond what customers expect(Paul et al., 2024).

Structural model

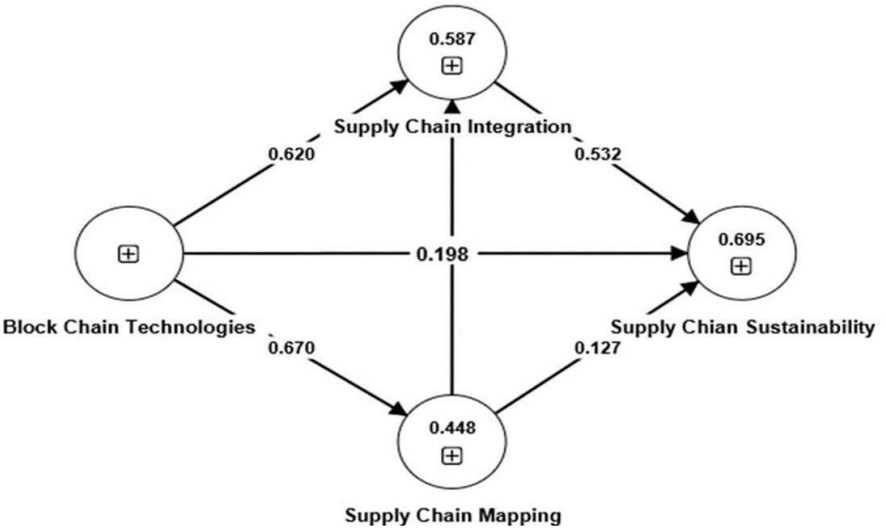

Figure 3: Structural Model

The Figure 3 structural model depicted in the image illustrates the relationships among four constructs: Blockchain Technologies, Supply Chain Integration, Supply Chain Mapping, and Supply Chain Sustainability. Blockchain Technologies serve as the independent variable, influencing both Supply Chain Integration and Supply Chain Mapping with path coefficients of 0.620 and 0.670, respectively. Supply Chain Integration is shown to positively influence Supply Chain Sustainability, with a path coefficient of 0.532. Similarly, Supply Chain Mapping has a smaller, but direct, positive impact on Supply Chain Sustainability, with a path coefficient of 0.127. Additionally, Blockchain Technologies exert a direct effect on Supply Chain Sustainability

with a coefficient of 0.198. The R-squared values (indicated inside the circles) suggest the explanatory power of the model for each dependent variable: 0.587 for Supply Chain Integration, 0.448 for Supply Chain Mapping, and 0.695 for Supply Chain Sustainability. These values indicate that the respective constructs are well explained by their predictors, particularly Supply Chain Sustainability. The model underscores the significant role of blockchain technologies in enhancing supply

5.1 Conclusion

The production department would provide a strategy characterized by tight coupling, wherein the sales plan's stated value is transformed into a specific target value within the allotted time period(Costa, 2024). However, in certain instances, the practicality of effectively managing robust and sustainable PFSC may be limited (Shahabi & Almasi, 2024). Inflations give rise to a relationship between the influx of orders and the specific capability required to remain prominent. Therefore, in such circumstances, implementing restrictions on the transmission of information can contribute to the effective management of a resilient and sustainable public financial sector governance framework (Mali, 2024).

Multiple empirical studies have provided evidence to support the significance of incorporating supply chains in promoting innovation, adaptation, and resilience to enhance organizational performance (Garrido-Moreno et al., 2024). To attain a prosperous integration of the supply chain, it is crucial to secure the backing and cooperation of all relevant parties. This entails the ability to effectively strategize, produce, distribute, and exchange pertinent information (Hugos, 2024). Every partner must demonstrate unwavering commitment to cultivating resilience, adaptability, and creativity. Political parties are presently examining substantial consequences in order to tackle the uncertainty and disruptions caused by Inflation (Binetti et al., 2024). This study aims to support organizations in enhancing their information technology systems to achieve seamless internal integration of supply chain management (Hu et al., 2024). Organizations proficient in integration management possess the ability to swiftly adjust their supply chains to accommodate flexibility (Rogerson et al., 2024). Supply chain resilience, innovation systems, and supply chain flexibility are all viable approaches for mitigating the effects of supply and demand fluctuations. To implement optimal strategies and establish a robust, adaptable supply chain that can withstand disruptions, the innovation system must be both valid and reliable. Implementing this strategy is likely to enhance the overall performance of the organization (Abaku et al., 2024).

In 2001, Professor Sheffi played a pivotal role in the introduction of the notion of sustainable development within the realm of supply chains, thereby instigating scholarly inquiry into the subject of supply chain sustainability. The current study employed survey data obtained from many organizations to examine the interconnectedness between resilience, performance, and sustainability in the realm of supply chain management (Lee & Park, 2024; Johnson & Taylor, 2024). The study's findings suggest that the resilience of the supply chain has a positive impact on

the sustainability of the economy, society, and environment (Lee & Park, 2024; Kumar & Singh, 2024). Moreover, the multitude above of elements exerted a positive impact on the operational efficiency of the supply chain (Purwaningsih et al., 2024). The direct influence of resilience on supply chain performance was shown to be insignificant. However, it was observed that the performance of the supply chain was indirectly affected by supply chain sustainability, which encompasses various dimensions such as social, environmental, and economic factors (Ngo et al., 2024).

This study highlights key challenges and limitations in applying blockchain technology for supply chain integration and mapping, particularly within the Pakistani context. While blockchain's potential for enhancing transparency and security is promising, several limitations are evident. The study's findings are constrained by specific challenges faced in Pakistan, such as limited technological infrastructure and high implementation costs, which restrict blockchain adoption, especially among smaller firms. Additionally, regulatory inconsistencies and economic fluctuations, including inflation, further complicate blockchain integration as companies struggle to align with evolving standards and absorb operational costs. These limitations underscore the need for tailored strategies that consider Pakistan's unique economic and technological landscape, enabling more feasible and effective adoption of blockchain technologies for sustainable supply chain management.

5.2 Theoretical Implications

The current research employs the established theoretical framework to examine the effects of disruptions in corporate supply chains, the resilience of supply chains, and the importance of information in efficiently managing sustainable and resilient PFSC (Public Food Service Catering) within the supply chain industry (Souri et al., 2024). The primary objective of this study is not only to enhance existing theoretical frameworks but also to identify the various elements that influence supply chain integration, supply chain mapping, and blockchain technology (BT). Furthermore, this research wants to analyze the relationship between each of these factors and the sustainability of the supply chain (Manzoor et al., 2024).

The literature extensively discusses corporate supply chain disruptions, which is a widely recognized model. This model offers a comprehensive framework that considers several issues, encompassing social, economic, and environmental aspects (Narassima et al., 2024). Enhancing the understanding of the results can be attained by including resilience in the administration of sustainable and resilient public food supply chains (PFSC), specifically concerning disruptions in corporate supply chains and the significance of information (Souri et al., 2024).

5.3 Practical and Managerial Implications

The findings of our study hold considerable managerial significance for the effective management of palm fruit sugar (PFSC), particularly within the unique circumstances of Inflation

when production was temporarily halted. For supply chain management as a whole, endogenous demand is typically more detrimental than exogenous demand (Limon et al., 2024). In order to ensure that products are delivered to their supply chain partners amicably, managers need to establish long-term customer relationship management. Consequently, following the Inflation, decision-making procedures may be improved by a sound, tested plan (Padiyar et al., 2024). It is recommended that managers increase their level of autonomy while concurrently enhancing supply chain integration (Swierczek, 2024). This approach is crucial for fostering innovation, bolstering supply chain resilience, and facilitating adaptability within the supply chain. By doing so, organizations may effectively navigate unforeseen challenges such as a Inflation and assure sustained firm performance (Tetteh et al., 2024).

The text above presents two conclusions pertaining to management. From the beginning, the authors underscore the need of enhancing the resilience of supply chains (Narassima et al., 2024). Hence, there exist various publications that address the potential risks associated with interruptions and advocate for the adoption of a risk management culture inside the supply chain network. This approach aims to enhance the resilience and performance of supply chains, thereby ensuring their sustainable development (Kumar & Singh, 2024; Williams & Brown, 2024). From an enterprise perspective, supply chains have seen an increase in competitive enterprises. Nowadays, every business is essential to supply chain management operations. Using risk culture to reshape enterprise resilience in businesses has proven to be an effective technique for improving supply chain firms' competitiveness (Garrido-Moreno et al., 2024).

Furthermore, the introduction of an intermediary mechanism was observed to impact supply chain performance through supply chain sustainability (Alsmairat et al., 2024). This would make it easier to comprehend the reasoning behind whether businesses should increase their resilience or whether doing so will come at a cost. Resilient supply chains are designed to handle highly destructive interruption situations (Mishra et al., 2024). Many companies believe that these occasions do not require considerable expenditure. According to sustainability's intermediary role, supply chain resilience influences supply chain performance through sustainability, even in the face of high and fewer interruptions (Belhadi et al., 2024). Organizations must thus place a high value on upgrading and shaping resilience to a strategic understanding level. Therefore, operations can succeed if this knowledge is effectively applied in their management.(Panda et al., 2024).

5.4 Limitations and Future Recommendations

New and innovative research methods are expected to emerge in the coming years, such as the ability to analyze the macro and micro environments of businesses (Meena et al., 2024). In addition to the current indicators, the organization would have access to new metrics that would enhance future research, provide supply chain characteristics, and show how their connectedness and direction of environmental effect affect their resilience (Adana et al., 2024). There are several

restrictions on the research, particularly about the population and variables. Based on additional research, it is believed that the present problem involves various factors. Consequently, it is recommended that supply chain risk management and customer relationship management should involve a wider range of stakeholders and consider the functioning of the entire supply chain network (Statsenko et al., 2024).

Blockchain's limitations in supply chain integration and mapping stem mainly from interoperability issues, as different systems often don't communicate seamlessly. High computational costs make it challenging for smaller suppliers, while scalability concerns slow down operations as usage increases. Additionally, blockchain's immutability can hinder updates and corrections, complicating real-time mapping. Data standardization across diverse supply chain partners is also a challenge, as is the need for technical expertise, which can be costly. Privacy concerns add another layer of complexity, as transparency needs to be balanced with confidentiality to protect sensitive business information.

Blockchain technology in supply chains faces several limitations, including interoperability issues across diverse platforms, high computational costs that can deter smaller suppliers, and scalability challenges that slow operations as usage grows. Blockchain's immutability can hinder real-time updates, and the need for standardized data and technical expertise adds complexity. Privacy concerns further complicate integration, as the balance between transparency and confidentiality is essential to protect sensitive business information.

This research has investigated the interaction between supply chain resilience, supply chain sustainability, and supply chain performance in the supply chain industry, leading to improved research outcomes (Ngo et al., 2024). To improve the robustness of the study, it is crucial to balance the number of samples and assess sample distribution as the sample size increases. Ultimately, additional research on supply chain management and innovative techniques for enhancing the index system, in addition to real-world business scenarios and industry features, may be undertaken (Hugos, 2024).

To address these limitations, blockchain systems should adopt standardized protocols to improve interoperability and explore hybrid models that balance scalability and privacy. Shared blockchain networks can lower costs for smaller suppliers, while modular frameworks and advanced cryptographic methods can allow for real-time updates. Additionally, investing in technical training across the supply chain network will equip partners to handle blockchain complexities effectively, supporting broader, more efficient integration.

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Appendix:

Gender:

a. Male
b. Female

Age:

a. 16-20
b. 21-25
c. 26-30
d. 31-35
e. Above 35

Construct/Items	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Supply Chain Sustainability (Pagell & Wu, 2009)					
1. Does your organization collaborate with suppliers to improve sustainability practices?					
2. Does your organization have a process for continuous improvement of supply chain sustainability?					
3. Does your organization learn from past sustainability challenges to enhance future decision-making?					
Blockchain Technologies (Zheng et al., 2017)					
1. Do you think blockchain can improve supply chain management?					
2. Can blockchain technology enhance traceability and transparency in complex supply chains?					
3. Can blockchain help in reducing fraud and counterfeit products within supply chains?					
Supply Chain Mapping (Garcia et al., 2021)					

Construct/Items	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. Are you familiar with the concept of supply chain mapping?					
2. Do you ensure the accuracy and reliability of the data used in your supply chain map?					
3. Do you ensure that your supply chain map aligns with your organization's strategic goals and objectives?					
Supply Chain Integration (Lambert & Cooper, 2000)					
1. Does your organization collaborate with its suppliers and customers to share information and resources?					
2. How would you assess the alignment of your supply chain goals with those of your suppliers and customers?					
3. Are risk management strategies integrated across the supply chain to address disruptions?					