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Research paper

Technology-Driven SCM Practices and Operational Efficiency in The Milk Sector: A PLS-SEM Study

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Abstract

This study investigates the consequential interplay between SCMP (Supply Chain Management Practices) and integration technology within milk sectors, with a primary focus on their combined impact on operational efficiency. In an era marked by rapid technological advancements, the milk sector stands to benefit significantly from the strategic incorporation of innovative SCM practices and technology adaptation. Through a comprehensive analysis of case studies and empirical data, this research focuses on delineating how technology-driven SCM initiatives can revolutionize and optimize various facets of the milk supply chain. The findings aim to shed light on the intricate relationships between these key variables and their direct influence on operational efficiency metrics. As the milk sector grapples with increasing demands and global complexities, understanding and harnessing the synergies between SCM practices and technological adaptation becomes essential for fostering resilience, reducing operational costs, and ultimately elevating the overall performance of the milk supply chain. The integration of advanced technologies in SCM processes has the potential to revolutionize the way milk operations are managed, from production to distribution.

Keywords: *Operational Efficiency; Supply Chain Management; Supply Chain Management Practices; Technology Adoption.*

1. Introduction

The milk sectors touch all people's lives worldwide, so it feeds the global supply chain. In recent years, the business has gone through a great transformation, thanks to the convergence of supply chain management (SCM) methods and technology innovation. The unique integrated implementation of these two fundamental concepts adds to the impressive advancement toward unparalleled operational efficiency. SCM strategies have once again been confirmed to boost productivity in many other sectors, alongside being renowned for process optimization, resource allocation, and simplified logistics flow (Christopher, 2016). This is a combination that creates broad-ranging effects in convergence between SCM practices and technology adaptation. At the same time, the milk and milk industries have spearheaded technology adoption in their operation through RFID systems, Internet of Things (IoT) sensors, and data analytics (Wadhwa et al., 99). Managing these complicated supply chain systems demands skilled workers and a huge investment, though (Dibb & Kock, 2020). This endeavor would be engaged in defining how SCM technological adaptation would change operational efficiency in the milk and milk sectors. Through the analysis of the advantages, challenges, and potential outcomes of this merger, the report opens up areas to how these two factors are driving adaptation, efficiency, and sensitivity to responsive demands by consumers and global supply chain dynamics in the milk and milk industry.

The integration of modern Supply Chain Management Practices (SCMP) with new technologies in the milk sector has important economic effects, especially regarding cost efficiency. By improving production, inventory management, and distribution processes, tech-driven SCM cuts waste, reduces spoilage, and helps with better demand forecasting. This directly leads to lower operating costs through improved logistics, reduced holding costs, and more effective resource utilization (Chien et al., 2019; Madcap Dairy Software, 2023; Role of Digitalization and Technology, 2022; Hassoun et al., 2023). For instance, using digital tracking and automated quality control systems reduces the need for manual labor and cuts errors, which together lower the overall cost per liter of milk from farm to consumer (Madcap Dairy Software, 2023; Hassoun et al., 2023).

Beyond immediate operational savings, technology-enabled supply chain management (SCM) fosters long-term economic strength for the milk industry. By improving transparency and coordination throughout the supply chain, companies can negotiate better contracts with suppliers, lower procurement costs, and avoid unnecessary expenses in transportation and warehousing (Chien et al., 2019; Madcap Dairy Software, 2023; Role of Digitalization and Technology, 2022). These efficiencies not only boost profit margins but also improve scalability. This allows producers and distributors to handle changing market demands with minimal extra costs (Chien et al., 2019). Essentially, the combination of SCM practices and integration technologies creates a lasting competitive edge. Cost savings and efficiency improvements strengthen profitability while keeping quality standards high in a complex and demanding market (Chien et al., 2019; Madcap Dairy Software, 2023; Hassoun et al., 2023).

1.1. Background of The Study

In today's context, information technology is increasingly of interest to academics and practitioners. It is crucial in supply chain readiness to adapt to market changes by reducing costs and improving quality. Hence, the objective of this article is to explore the effect of information technology integration (ITI) and supply chain information management (SCIM) on supply chain integration (SCI) and its association with supply chain performance (SCP) and firm performance in the automotive supply chain (Omar Boubker, Ibn Zohr University, Agadir, Morocco, 2022).

1.2. Problem Statement

Milk production and marketing are studied by various authors, such as Berhan (2012), Meryem (2013), Eyassu and Doluschitz (2014), and Asnakech et al. (2016), among whom a few case studies focus on value chain analysis of milk production (Betela, 2015), milk and feed value chain analysis (Kitaw et al., 2012), and milk value chain and quality analysis. Many of those who were primarily researching milk production, with few knowing the prevalent milk marketing-related challenges, were unable to identify the characteristics that determine milk supply chain integration. This indicates that there is poor identification of the important determinants of milk supply chain integration among the producers and traders. On the contrary, good supply chain management should work in such a way that it collaborates effectively with its supply chain partners. To provide the most value to the client at a low cost and at a fast speed, supply chain actors must work together strategically and efficiently to move product and service information and money. In the study district, producers and traders work together to integrate information, coordinate resources, and link organizational relationships. Given these factors, we investigated possible solutions to the following problematic areas by integrating the milk supply chain into the selected study area.

2. Review of Literature

2.1. Role of Blockchain and AI in The Supply Chain Management

Blockchain provides transparency, traceability, and security in the dairy supply chain. It enables real-time verification of product origin and quality while reducing fraud and administrative inefficiencies (Kumar & Kumar, 2023; RSC Publishing, 2025). At the same time, AI-driven data analysis and machine learning techniques optimize demand forecasting, inventory management, and logistics. This leads to notable improvements in operational efficiency and waste reduction (RSC Publishing, 2025; Science Direct, 2024). The combination of these technologies helps create more resilient and flexible supply chain networks. It allows for smooth information sharing among stakeholders and supports predictive decision-making in uncertain conditions. PLS-SEM studies during this time confirm the positive impact of adopting blockchain and AI on performance metrics. This supports technology-driven supply chain management innovations that are essential for addressing the changing challenges in dairy supply chains (Kumar & Kumar, 2023; RSC Publishing, 2025).

Recent literature highlights how technology-driven Supply Chain Management (SCM) practices can transform operational efficiency in the milk sector. This change is particularly evident through the use of Partial Least Squares Structural Equation Modeling (PLS-SEM) techniques. A major study using SmartPLS showed that SCM practices positively affect technology adoption. This adoption then improves operational efficiency in dairy supply chains (Chien et al., 2024). The research points out that technology adoption plays a key role in SCM practices and performance results. It confirms that using technologies like IoT, blockchain, and real-time data analytics can improve demand forecasting, inventory control, and distribution processes. Implementing these technological solutions not only cuts costs but also reduces waste and spoilage. This leads to higher profitability and better service levels in a sector known for tight margins and perishable goods (Kumar & Kumar, 2023; Madcap Dairy Software, 2023).

2.2. Innovations in Supply Chain Management

Innovations like Inventory Management Systems, Transport Management Systems, and online delivery platforms significantly cut costs and improve responsiveness across the supply chain. They do this by optimizing logistics, demand forecasting, and inventory control (Dairytech.ai, 2023). The use of AI and data analytics allows for more precise demand forecasting, better maintenance predictions, and improved cold chain monitoring. Together, these factors reduce waste and enhance product quality and safety (FoodTech Folio3, 2025). These technology-driven practices support lean, agile, and transparent dairy supply chains. They also align with goals for sustainability and compliance. Additionally, PLS-SEM studies show a strong positive connection between adopting technology in supply chain management and key performance indicators of operational efficiency. This highlights the transformative nature of digital integration in the milk industry (RSC Publishing, 2025).

The increased complexity in technology-driven supply chains can positively affect cost efficiency in the milk sector. The integration of layered systems, such as real-time data tracking, automation, and digital platforms, creates complex networks. However, this complexity supports more flexible management, smarter resource use, and accurate demand matching (FoodTech Folio3, 2025). Instead of causing inefficiency, a sophisticated supply chain structure allows for better visibility across operations and helps with predictive analytics for inventory optimization and reducing costly disruptions (FoodTech Folio3, 2025; McKinsey & Company, 2025). Complex supply chains make use of collaborative frameworks, end-to-end traceability, and diverse partnerships. These elements help spread risk, simplify procurement, and secure cost advantages, especially when responding to market or logistical changes. PLS-SEM studies from this period confirm that embracing complexity, along with supporting technology and management practices, allows milk companies to adjust, grow, and lower operational costs as industry demands change (McKinsey & Company, 2025).

The level of information quality within technology-driven supply chain management (SCM) has been shown to positively impact cost-based efficiency in the milk sector from 2023 to 2025. High-quality, accurate, and timely information enables dairy supply chains to implement precise demand forecasting and optimize inventory management, reducing wastage and operational costs (Milk Movement, 2024). Advanced sensor technologies, such as IoT devices and real-time data analytics, provide critical insights into parameters like temperature, microbial content, and product movement, which safeguard milk quality and minimize spoilage during transit and storage (FoodTech Folio3, 2025). Additionally, blockchain enhances traceability and compliance by maintaining immutable records of product history, thereby reducing risks associated with recalls and regulatory penalties. The positive effects of superior information quality, validated through PLS-SEM studies, include improved decision-making, reduced errors, and optimized resource allocation, collectively leading to better cost efficiency across complex dairy supply chains (Kumar & Kumar, 2023; Milk Moovement, 2024).

Key drivers of this transformation include the use of Industry 5.0 technologies like IoT sensors, blockchain, and generative AI. These technologies support real-time monitoring, traceability, and data-driven decision-making across the supply chain (RSC Publishing, 2025). Blockchain, in particular, improves transparency and security by creating unchangeable records of product origin and movement. This, in turn, builds consumer trust and ensures regulatory compliance (Kumar & Kumar, 2023). The literature also notes the increasing importance of collaborative supply chain networks and automation. These elements help reduce lead times and operational costs while keeping the flexibility to respond to market changes (Dairytech.ai, 2023; McKinsey, 2025). Together, these advancements help create a more resilient and efficient milk supply chain that can meet changing consumer demands and sustainability goals.

Further studies from 2023 to 2025 have improved the understanding of Industry 5.0 technology adoption in the milk sector. New research finds that key factors include data-driven decision making, regulatory compliance, improved transparency, and collaboration through blockchain and AI. These elements are crucial for supply chain management innovation and operational resilience (RSC Publishing, 2025). These technologies also promote sustainability by lowering environmental impact and ensuring flexibility in a complex global market. The PLS-SEM approach has played an important role in confirming these relationships by measuring the direct and indirect effects of technological capabilities on operational results. Thus, the evidence shows that technology-driven supply chain practices are essential for milk industries that want to balance efficiency, compliance, and customer-centered customization in their supply chain operations (Kumar & Kumar, 2023; RSC Publishing, 2025).

2.3. Role of Technology Adoption in Operational Efficiency

Technology adoption in the milk sector is key to improving operational efficiency and profitability. Studies show that advancements such as automation, data analytics, robotics, and Internet of Things (IoT) applications boost milk production efficiency by increasing yield per cow, lowering labor and operational costs, and allowing for better supply chain management with real-time tracking and quality control (Gopalakrishnan, Kumar, & Singh, 2018; Okello et al., 2025). Technologies like automated milking systems and advanced refrigeration help reduce waste and extend product shelf life, thus increasing profitability (Sandey et al., 2017; Lyons et al., 2022). Additionally, precision dairy farming, supported by big data and IoT, enhances decision-making, animal health monitoring, and milk quality assurance. These factors all positively impact farm profitability and sustainability (Yan et al., 2015; Zhang et al., 2021). However, firms in the milk sector must carefully consider the balance between the high upfront costs of technology investment and the long-term gains in efficiency and profits. This is necessary to optimize resource allocation and maintain a competitive edge (Simões et al., 2025).

2.4. Supply Chain Management

This study investigates the linkage between supply chain management (SCM) practices and operational performance. The SCM practices investigated include taking stock of Information and Communication Technology Practices, Supplier Relationship Practices, Supply Chain Manufacturing Practices, Warehousing Management Systems, Transportation Management Systems, and Customer Relationship Management from an exhaustive review of literature for establishing their relationship with operational performance (Rajeev Kumar, 2014). Moreover, how such firms have been obtaining and retaining a competitive advantage in an increasingly global marketplace while facing domestic as well as international competition has sometimes been the focus of research studies (Huo, Selen, Yeung, and Zhao, 2008; Kannan and Tan., 2005). The supply chain is a system of organizations linked by upstream or downstream connections to different processes and activities generating products and services for delivery to end consumers (Christopher, 1992).

2.5. Operational Efficiency

Operational efficiency of an organization is the capability to minimize waste or the use of time, efforts, and materials in the process of providing the service or product of the highest quality (Alexander S. Gills). Fiscal, operational efficiency is defined in terms of the ratio of the input to keep the organization going, with the output that is freed.

2.6. Implementation of Technology

According to research on the adoption of technology in the US milk sector, widespread application of productivity-enhancing technologies will lead to improved milk output, reduced pricing, and detrimental effects on profitability. This is consistent with the responses of those who have noted that superior and less milk industries tend to result from cheaper prices brought forth by the adoption of technology. While earlier research has examined how technology adoption affects the financial performance of the Brazilian milk industry, no prior study has quantified the dynamic effects of increased technology adoption on both market outcomes and farm-level success by farm-size groupings. Ceteris paribus, supply increases resulting from the adoption of productivity-enhancing technologies will have lower values; therefore, the advantages of productivity enhancement would be somewhat offset. These counterweighing effects are probably not going to be distributed uniformly across farm types and sizes. The springiness of the milk supply fluctuates over time, according to earlier research (Olaya, C., Cows., 2015), and supply and demand are dependent on market incentives that are delayed. So, it wouldn't be surprising if Brazilian milk industries started using productivity-boosting technologies, especially if we see complex effects on behavior that change over time. If relevant visions on the relationship between skill use and the behavior of milk prices in Brazil are present, these relevant questions can be addressed using an imitation representative method (Olaya, C. Cows., 2015). In the milk supply chain, blockchain technology has also become more well-known for its traceability and protection. Blockchain makes it possible for investors to safely store and retrieve data on the path taken by milk products as they leave the farm. This technology increases consumer trust by providing verifiable information about the creation origin, safety, and ethical sourcing, as highlighted by Tapscott D. and Tapscott A. (2016). Technology adoption in supply chain management (SCM) is important because it improves visibility, competency, and traceability throughout the supply chain, according to research. Internet of Things (IoT) technology is one significant advancement in the milk industry. Everything from the health and behavior of milk sector livestock to the temperature of milk during transportation is monitored by IoT-enabled sensors. Due to the real-time data generated by these sensors, prompt decision-making and a prompt reaction to any deviations in safety or quality are made possible (Oh S, Ryu YU, Yang H., 2019). Additionally, cloud-based supply chain management solutions have proven to be quite useful for instantaneous communication and information exchange across milk stakeholders. Coordination between milk producers, processors, and distributors is made easy by cloud technologies, which enable remote monitoring and management. In milk supply chain management, artificial intelligence (AI) and machine learning (ML) are also making significant advances. With the help of these technologies, milk producers may increase the overall effectiveness of their supply chains while cutting expenses and waste. Using technology has transformed supply chain management in the milk industry. In a business that is changing quickly, milk producers may stay competitive by improving operational efficiency, product quality, and sustainability with IoT, blockchain, AI, ML, and cloud-based technologies. Supply chain management (SCM) has evolved due to the combined accuracy and competency of RFID tracking and Internet of Things (IoT) sensors in several operations. Using RFID (radio-frequency identification) technology, commodities may be tracked in real time throughout the supply chain. Businesses can employ RFID tags to trace the movement of their products from the warehouse to the final customer. This approach reduces the likelihood of overstocking or stockouts by giving accurate data on stock levels, which improves inventory management. This real-time information contributes to minimizing spoilage and ensuring compliance with safety regulations. Within transport logistics, vehicle performance and cargo conditions are monitored by IoT sensors, enabling predictive maintenance and real-time adjustments to routes, Fig.1.

2.7. Theriodical Framework

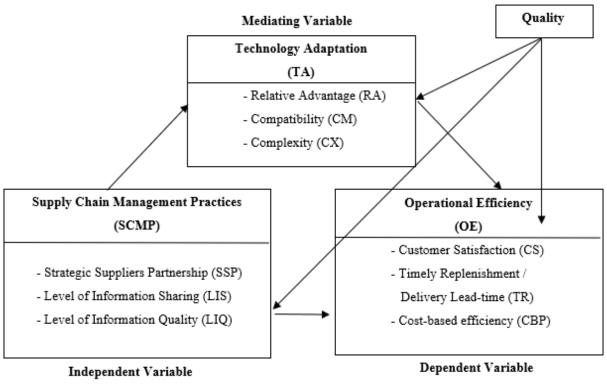

Fig. 1: Research Framework: Mediated Model.

Source: author's own work.

2.8. Independent Variables

2.8.1. Supply Chain Management Practices (SCMP) in The Milk Sector

SCM procedures are a result of the supply chain's growing environmental concern. SCM methods include planning and management, acquiring and converting raw materials into final goods, logistics management, and collaboration among supply chain participants (Mancilla-Leytón JM, Morales-Jerrett E, Delgado-Pertinez M, Mena Y., 2021). A diverse and dynamic manufacturing sector, the milk industry depends on efficient supply chain management (SCM) techniques. In the milk sector, supply chain management (SCM) encompasses a number of standardized processes that extend from procurement and production to delivery and customer support, per a study by Mahadevan B. (2015). In order to guarantee consistent creation quality and satisfy customer requests, advanced supply chain management techniques have emerged as the best method for streamlining these processes. The procurement, manufacturing, and supply of finished items to customers are all parts of any supply chain (Mor RS, Bhardwaj A, Singh S., 2018; Mor RS, Bhardwaj A, Singh S., 2018; Datta PP. 2017) in Figure 2. Dealers in raw milk, farmers, granaries, and final consumers make up the supply chain. Effective SCM is necessary because of changes in consumer preferences, increases in milk crops, and the milk industry's fixation on prices. Moreover, cold chain management poses a risk to the safety and hygiene of milk products. Throughout the supply chain, milk firms can monitor the status of their products thanks to technologies like RFID tags and temperature monitoring devices. When a supply chain has a talented consumer appeal, it joins all relevant meetings, whether they are direct or indirect (Rawal A., Wood B., 2018). Six supply chain participants are given greater weight as milk product consumption rises, which is a significant correlation between milk dispensing and supply chain management (Suryanto T, Komalasari A., 2019). Supply chain management (SCM) is a crucial component in establishing and preserving genuine, long-term connections and collaborations with suppliers. Accordingly, supply chain management (SCM) strategies are actions taken by businesses to ensure a supply chain is efficient (Kumar A, Kushwaha GS, 2018). Accurate forecasting lowers the danger of overstocking or understocking milk products by enabling milk companies to match manufacturing heights with market demands. The milk industry can react quickly to changes in the market thanks to advanced forecasting technologies and data analytics. Another essential SCM procedure in the milk industry is effective inventory management. According to research by Rajeev A, Pati RK, and Padhi SS (2019) and Pattnaik S and Pattnaik S (2019), it is crucial to maintain optimal inventory heights in order to reduce carrying costs and guarantee product obtainability. Real-time stock level monitoring and just-in-time (JIT) inventory solutions help manage inventories effectively while cutting expenses and waste. A growing emphasis in SCM procedures in the milk industry is on sustainability. Market success is aided by SCM methods, which are regarded for their modest benefits (Maina C, Njehia BK, Eric BK, 2020).

2.8.2. Strategic Suppliers Partnerships (SSP)

The partnership with stakeholders is a strategy to build long-term relationships with suppliers. It aims to leverage the strategic and operational capabilities of all participating organizations to create significant ongoing benefits. This effort encompasses all necessary actions to enhance the current performance of suppliers. Strategic partnerships emphasize long-term, direct interactions and encourage both sides to collaborate on planning and problem-solving. To save time and effort, the supplier organizations can collaborate more closely (Li S, Lin B., 2006).

2.8.3. Level of Information Sharing (LIS)

The level of the information shared refers to the scale regarding how much critical and proprietary information is shared with a supply chain partner. Shared information can be as diverse as strategic to tactical concerning logistics activities or more general regarding the market and its customers. The act of gathering and disseminating information among various supply chain collaborators can confer a distinct competitive edge (Monczka, R.M., Petersen KJ, Handfield RB, Ragatz GL, 1998). The concept of "level" (or "quantity") about information sharing denotes the volume of sensitive and proprietary data exchanged with a business associate within a supply chain context. The designation "information sharing" encapsulates a firm's capacity and effectiveness in transmitting data and expertise to its supply chain collaborators. Within an interactive supply chain framework, the exchange of information occurs not solely among immediate partners but also across the broader supply chain network. Consequently, information sharing is pivotal for the establishment of successful collaborative partnerships.

2.8.4. Level of Information Quality (LIQ)

The advent of information technology (IT) in supply chain management has made it easier for supply chain partners to communicate quality quantitative data. Many businesses have now realized that having a competitive supply chain is as important as having internal efficiency. It is essential to maintain the integrity of the information supplied since different private, confidential data is often shared along the supply chain. (Bregaj & Alma Sheko, 2016).

2.9. Dependent Variables

2.9.1. Operational Efficiency (OE) Practices in The Milk Sector

Operational efficiency is also based on efficient supply chain management. In the context of a globalized market, it is imperative to optimize logistics, inventory management, and distribution procedures in order to save expenses and guarantee the freshness of milk products. Through supply chain optimization, the milk industry can quickly and effectively satisfy consumer expectations. In the milk sector, operational efficiency is a crucial component that includes a range of procedures and technologies essential to the industry's sustainability and competitiveness.
The modern milk industry aims to reduce expenses and resource usage while meeting the growing demand for milk products. Modern technologies have transformed milk farming, increasing the productivity and quality of milk production. Examples of these technologies include data-driven management tools and automated milking systems. The milk industry continues to prioritize operational efficiency in its attempts to manage changing market conditions. The sector can successfully satisfy customer demands while maintaining long-term sustainability by adopting sustainable practices, streamlining supply chain operations, and embracing technological improvements. Good performance is the ultimate goal of companies, even though studies always provide different definitions of firm performance (Kirima & Murigi, 2019). Accordingly, a company's performance can be defined as its ability to successfully and efficiently accomplish its goals (Lebans & Euske, 2006; Rasula, Vuksic & Stemberger, 2012; Muchemi, 2014; Talaja, Miocevic, Pavicic & Alfirevic, 2017). It's interesting to note that despite the large number of studies on company performance, there are still disagreements over how to operationalize it (Ongeti, 2014; Njoroge et al., 2016). Information about the quality of processes that guarantee businesses meet their goals is included in the measuring process (Gavrea & Stegerean, 2011).

2.9.2. Customer Satisfaction (CS)

In order to examine and understand the data on consumer satisfaction with milk products in the milk sector, percentage analysis was used. Milk companies need to understand customer satisfaction if they want to stay competitive and improve their products. The purpose of this study is to identify client preferences and areas that require improvement by analyzing the opinions of 400 respondents. According to Kant (2017), supply chain management implies the increased satisfaction of the customer, which, in turn, also influences or affects the customer's probability of returning. Furthermore, enduring partnerships with suppliers and customers would bring about a greater understanding among members within the SC, thereby enhancing flexibility.

2.9.3. Timely Replenishment/Delivery Lead Time (TR)

Effective replenishment and delivery operations require a complete plan that involves exact demand projections, flexible logistics, and cooperative supplier relationships. Shortening lead times mitigates the risks associated with volatile markets and changing demand while also increasing customer service. Supply chain infrastructures, rapid assessment, and furnishing with reliable data, along with better partner interface, significantly strengthen supply chain integration and thereby detect possible disruption much earlier (Ivanov and Dolgui, 2020). Supply Chain Management operations function to analyze and give timely information; create interfaces between SC partners for better integration of SC processes, and identify potential disturbances at early stages before they aggravate (Ivanov and Dolgui, 2020). Supply Chain Management operations concern the analysis and timely provision of reliable data, and enhanced interface creation among SC partners to further lead them into SC integration.

2.9.4. Cost-Based Efficiency (CBP)

Operational efficiency is typically related to cost and time reductions, which are mostly beneficial in the short term. Kaplan and Norton, 2001. It calculates the ratio of outputs to inputs in the value-creation process and has two dimensions: cost-based efficiency and time-based efficiency. (Madhavan and Grover, 1998)(Priem and Butler, 2001). Time-based efficiency can be evaluated using parameters such as quality costs, engineering modifications, and manufacturing costs" (Yeung, 2008). Managers, on the other hand, may prioritize operational effectiveness over strategic flexibility. Stakeholder pressures or simplified evaluation methods may have contributed to this mismatch, which prioritizes short-term earnings above long-term adaptation. (Doyle, 1992); (George and van de Ven., 2001); (Kaplan & Norton., 2001). Similar to the significance of strategic flexibility, operational efficiency is "a necessary, but insufficient, condition for sustained competitive advantage," according to Krause et al. (2013).

2.10. Mediating Variables

2.10.1. Technology Adaptation (TA) Practices in The Milk Sector

In addition to automation, data analytics has become an essential component in decision-making processes in the milk sector. Sophisticated analytics platforms examine extensive datasets from various sources, offering insights into herd wellness, milk quality, and production effectiveness. Moreover, the use of technology has greatly enhanced traceability and quality assurance. For instance, blockchain technology enables the creation of clear and secure records of the milk supply chain, guaranteeing the product's authenticity and safety. This technology provides consumers with comprehensive information regarding the treatment of milk products and their origins. Furthermore, precision agricultural technology improves resource efficiency on dairy farms. For example, intelligent irrigation systems use soil moisture and meteorological information to distribute precise amounts of water, minimizing waste and ecological effects (Boag AE, Hughes AE, Wilson NC, Toppy A, MacRae CM, Glenn AM, Muster TH, 2009). These technologies aid in reaching sustainability goals by reducing resource usage. The milk industry has undergone a substantial change thanks to the adoption of technology, resulting in altered management of milk operations as well as the production and distribution of dairy goods. In the milk industry, automation signifies an important area of technological progress. Studies on automated milking systems show that robotic feeding technologies and sophisticated sensors have revolutionized milk production. These technologies simplify labour-intensive processes, improve animal welfare, and increase operational accuracy. The technological adoption in the milk industry has ushered in a new era marked by improved efficiency, product quality, and sustainability. Automated systems, data analysis, traceability tools, and precision farming technology are transforming operations in the milk industry, keeping the business competitive and responsive to changing consumer needs. Information and communication technology is examined as a part of supply chain management, emphasizing various types of organizational performance, like financial and market outcomes. The research indicates that ICT (information and communication technology) significantly influences the performance metrics of milk companies (Rajeev Kumar, 2022).

2.10.2. Relative Advantage (RA)

Users' decisions to adopt new technology are affected by the perceived relative advantage. Investigate the benefits the organization claims, lower costs, to assess the degree of advantage that accepting an invention represents. This statement claims that relative advantages are connected to success, growth, expansion, and new items. A crucial factor in the decision to implement an invention is the perceived relative advantage. This is because adopters and non-adopters make different choices regarding adoption. For these reasons, the relative advantage fosters the spread of innovations. (Kant, 2017) says that supply chain management (SCM) creates a situation that increases customer satisfaction, resulting in a greater likelihood of repeat purchases by that customer. In addition, long-term relationships with both suppliers and customers create a mutual understanding among members and lead to the flexibility of the SC.

2.10.3. Compatibility (CM)

Compatibility is a critical component in encouraging a corporation to adopt new technologies. Compatibility is the most critical aspect in SMEs rapidly embracing ICT. (Amini and Bakri, 2015) discussed compatibility as one of the leading factors influencing technology adoption by employees within organizations. According to Tan et al. (2009), compatibility emerged as the main reason behind such a hasty adoption of ICT by the SMEs. Reliably, when SMEs seek information for decision-making regarding ICT adoption, they are very often unable to find it (Eze et al, 2019). Corporate operations, an existing IT infrastructure, and appropriate work practices can then formulate a connection between ICT adaptation (Sutanonpaiboon & Pearson, 2008; Tripopsakul, 2018) and MCC (Multi-Country Consolidation). As mentioned, the adoption of innovation has produced several studies about the characteristics that drive digital transformation in companies (Chatterjee et al., 2021; Chen & Tan, 2004; Gangwar et al., 2013; Ghobakhloo & Tang, 2013).

2.10.4. Complexity (CX)

Rogers (1995) described "complexity" within an innovation in terms of the challenge of understanding and putting it into use. Technological complexity has always played a major role in both the creation of new technologies and their commercial viability. The complexity of technologies is very hard to measure, let alone understand. One approach, among others, to technical complexity is conceiving technological progress as an information-collecting process. Interestingly, using US patent data, Fleming and Sorenson (2004) found that inventors' perceptions of the complexity and difficulty involved in procedures needed to produce a new technology were recorded.

2.10.5. Quality (QUL)

Delivery, quality, cost, and flexibility are the basic metrics for evaluating operational performance. SC improves its total operating efficiency to enhance performance, as shown by the operational performance of the company, which also serves to highlight the competitive position of the company amongst other SC (Supply Chain) firms (Santoso et al., 2022). Operational performance is defined as the organization's efficiency with which it exploits its resources in limited areas, especially as discussed by Hallgren and Olhager (2009), discuss quality, affordability, flexibility, and time delivery.

2.11. Research Gap

One of these gaps is the lack of understanding regarding the types of technologies that can most significantly improve operational efficiency in the complexities of the milk supply chain. While some broad categories of technology are mentioned, many important specific technologies, for example, blockchain, IoT devices, and data analytics, and their much more specific impacts at each node, remain under-researched. In addition, very few studies deal with socio-economic and cultural aspects that constrain the integration of technology into SCM practices successfully for the milk industry. Understanding how different stakeholder farmer, processors, and distributors respond to and interact with technology, given their regional peculiarities and cultural influences, will help develop strategies that resonate with the unique milk landscape.

2.12. Research Questions

The research examines how partnership, collaboration, and integration affect the supply chain performance of milk agencies in Andhra Pradesh, India. The study puts forward three research questions to achieve this:

- To what extent do Supply chain partnerships influence relative advantage?
- To what extent does the Level of Information sharing on Compatibility?
- To what extent does the Level of Information quality affect Complexity?
- To what extent does the Relative advantage affect Customer satisfaction?
- To what extent does Compatibility affect the Timely Replacement / Delivery Lead time?

- To what extent does the Complexity of Inventory Control?
- To what extent do Supply chain partnerships with suppliers affect Customer Satisfaction?
- To what extent does the Level of information sharing affect the Timely Replacement / Delivery Lead time?
- To what extent does the Level of information quality affect Inventory Control?

2.13. Purpose of The Study

The study's major goal is to evaluate the influence of supply chain partnership, collaboration, and integration, and relationship commitment as predictors of supply chain performance in Andhra Pradesh Milk agencies.

2.14. Research / Empirical Objectives

- To investigate the influence of Supply chain partnerships with suppliers on Relative advantage.
- To investigate the influence of the Level of information sharing on Compatibility.
- To investigate the influence of the Level of information quality on Complexity.
- To investigate the influence of Relative advantage on Customer satisfaction.
- To investigate the influence of Compatibility on Timely Replacement / Delivery Lead time.
- To investigate the influence of Complexity on Inventory Control.
- To investigate the influence of Supply chain partnerships with suppliers on Customer Satisfaction.
- To investigate the influence of the Level of information sharing on Timely Replacement / Delivery Lead time.
- To investigate the influence of the Level of information quality on Inventory Control.

Table 1: Research Questions & Objectives

S. No	Research Questions	Research Objectives
1	To what extent do supply chain partnerships with suppliers influence relative advantage?	To investigate the influence of Supply chain partnerships with suppliers on Relative advantage.
2	To what extent does the Level of Information sharing affect Compatibility?	To investigate the influence of the Level of information sharing on Compatibility.
3	To what extent does the Level of Information quality affect Complexity?	To investigate the influence of the Level of information quality on Complexity.
4	To what extent does the Relative advantage affect Customer satisfaction?	To investigate the influence of Relative advantage on Customer satisfaction.
5	To what extent Does Compatibility affect the Timely Replacement / Delivery Lead time?	To investigate the influence of Compatibility on Timely Replacement / Delivery Lead time.
6	To what extent does the Complexity of Inventory Control?	To investigate The Influence of Complexity on Inventory Control.
7	To what extent Do Supply chain partnerships with suppliers affect Customer Satisfaction?	To investigate the influence of Supply chain partnerships with suppliers on Customer Satisfaction.
8	To what extent does the Level of information sharing affect the Timely Replacement / Delivery Lead time?	To investigate the influence of the Level of information sharing on Timely Replacement / Delivery Lead time.
9	To what extent does the Level of information quality affect Inventory Control?	To investigate the influence of the Level of information quality on Inventory Control.

Source: Nematatane Pfanelo, January 2017; Rajeev Kumar, January 2014.

3. Research Methodology

3.1. Overall Methodology

This chapter explains the overall methodology used to carry out the research. This section addresses the research design, population, sampling design, frame, procedures, sample size, data collection methods, instruments, analysis, and presentation. The major purpose of this research was to investigate supply chain technology adoption in the milk industry. This study examines company units employing two or more people in Tirupati, Chittoor, Palamaner, and Madanapalle in Andhra Pradesh, India. During 2017, 400 surveys were delivered randomly to milk retailers and customers. The questionnaire included inquiries regarding the demographic profile (retailer's name, age, educational qualification, location, duration in business, code number) along with 34 additional questions. It sought to assess elements of information exchange and quality between supply chain partners, SCM-IT barriers, and IT facilitators in SCM. Instruments evaluating information sharing and quality were adapted from Li and Lin (2006) and employed a 1-5 Likert scale, ranging from "Strongly Disagree" on one end to "Strongly Agree" on the other. Participants were asked about how often they faced problems while utilizing SCM methods and IT in their division.

3.2. Size of The Sample

A sample, according to Nachmias and Nachmias (1996), is a subset of units drawn from a population. Sampling is used to learn about a broader group's characteristics (Lucy, 1996). The survey covered supply chain managers, logistics managers, suppliers, and their employees, with a sample size of 364 people representing 10% of the target population from 400 milk retailers. To ensure adequate representation of all sectors, 364 respondents were selected by stratified sampling. Size of the Sample Calculated with the given formula:

$$n = \frac{Z^2 \times \sigma^2}{e^2}$$

Where

n sample size
Z value of Z in a normal distribution curve
The level of precision
σ2 variance of an attribute in the population
n 400.
To ensure statistical reliability, we chose 400 customers and workers to participate in the study.

3.3. Research Design

(Kerlinger, 1986) defines a research design as a planned investigation to answer research questions. It describes the research process, from hypothesis formulation to data analysis. It guides data gathering, measurement, and analysis. (Borg and Gall, 1983) defined a research design as a precise plan for conducting a study. A data collection plan is used to efficiently study a research hypothesis or question. This study followed an exploratory research strategy. According to Kothari (2003), an exploratory research approach is flexible and allows for the consideration of various facets of an issue, leading to fresh insights and ideas. According to (Saunders et al., 2003), exploratory research aims to develop a deeper grasp of a topic. (Kamariah et al., 2008) used an exploratory design to explore supply chain technology adoption in Malaysia's automotive sector. The sample has been identified as per the samplings of SEM PLS, which are about 10 times more than the indicators, which sum up to a total of 364 samples in this study, to warrant that SEM PLS is fit for use. The respondents in the research are milk agencies, from which a random sampling is derived. As a result, data collection approaches used in this study include observation, interviews, questionnaires, and document studies. Allow me to clarify: this study is classified as descriptive or explanatory because it attempts to explain the relationship (cause-and-effect) between the research variables while also testing hypotheses. This means that the respondents to this survey were picked at random from milk agencies. The data was collected using observation, interviews, and questionnaires, as well as document analysis. The study employed descriptive and analytical research methods to investigate and comprehend supply chain management procedures in the Indian milk industry.

3.4. Target Population

A population, according to Mugenda and Mugenda (2003), is an entire group of humans, events, or objects that share observable features and correspond to a particular specification. According to Lumley (1994), a population is a collection of all subjects from which a sample is collected. The target population refers to the specific demographic that the researcher aims to investigate. The target demographic for this study included all 500 agencies/dealers and retail locations in the state, ensuring that products were available to customers.

3.5. Data Collection

This study made use of a variety of data collection methods. A systematic questionnaire with Singleton et al. (1993) used open- and closed-ended items. This strategy ensured neutrality and gave sensible solutions. The surveys were pretested on ten respondents to ensure that the responses were fine-tuned and accurate. The pretested questionnaire responses were reviewed with the supervisors, and changes were made to account for any missing information. To distribute the questionnaires, the researcher sought the help of three research assistants who had been trained to evaluate all aspects of the study, both before and after pretesting.

3.6. Measures of Variables

According to Li and Lin (2006), this invention was intended to be a five-item scale ranging from "strongly disagree" to "strongly agree" for assessing information quality and interchange. Respondents were asked to indicate whether they agreed or disagreed with the occurrence of any of these frequency ranges caused by the use of IT and SCMs in their business unit. The items provided by Tatoglu et al. (2015) for SCM-technology adaptation were rated on a 1-to-5 Likert scale. The data analysis methodology in this study used structural and measurement models to analyze the tools with Smart PLS.

3.7. Data Analysis

The study model was validated using PLS-SEM, a variance-focused structural equation modelling technique (Rigdon et al., 2017). This research selected PLS-SEM due to its use of reflective measurement models and its ability to address different kinds of relationships among variables, such as direct and mediation hypotheses. Additionally, PLS-SEM is suitable for smaller sample sizes and data that do not adhere to a normal distribution (Hair et al., 2017; Hair et al., 2014a). Evaluating a model with the PLS-SEM method requires two steps: first, an analysis of the measurement model, and second, an evaluation of the structural model. Evaluate the measurement model through reflective indicators, focusing on the reliability of those indicators, as well as construct reliability and construct validity with an emphasis on convergence. To evaluate the structural model using PLS-SEM, it is necessary to examine path coefficients, R^2 values, effect size f^2, predictive relevance Q^2, and effect size q^2 (Hair et al., 2017; Ali et al., 2018). These components are crucial.

4. Model

Three latent constructs are expected to be included in the research model that is being suggested for this study: operational efficiency, technological adaptation, and SCM practices. Fig. 2 illustrates the causal relationships between the various constructs.

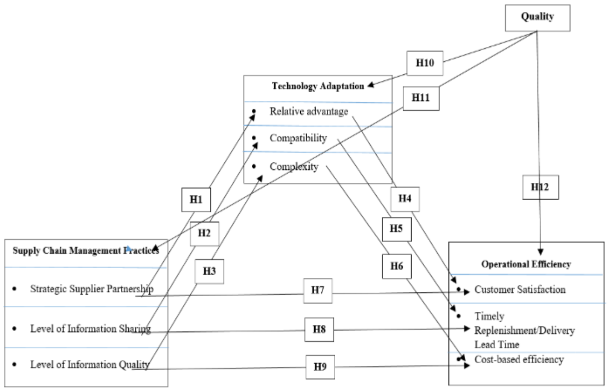

Fig. 2: Framework of the SCM on Operational Efficiency.

Source: Authors' own work.

4.1. Hypothesis of The Study

H1: Strategic Supplier partnerships have a positive impact on relative advantage.
H2: The Level of information sharing has a positive impact on compatibility.
H3: The Level of information quality has a positive impact on complexity.
H4: Relative advantage has a positive impact on customer satisfaction.
H5: Compatibility has a positive impact on timely replenishment and delivery lead time.
H6: Complexity has a positive impact on cost-based efficiency.
H7: Strategic Supplier partnerships have a positive impact on customer satisfaction.
H8: The Level of information sharing has a positive impact on timely replenishment and delivery lead times.
H9: The Level of information quality has a positive impact on cost-based efficiency.
H10: Quality has a positive impact on technology adaptation.
H11: Quality has a positive impact on supply chain management practices.
H12: Quality has a positive impact on operational efficiency.

5. Findings

The results of the study offer perspectives on enhancing performance in milk agencies. Thus, agencies should pay attention to the following SCM practices: Supplier development, logistics management, purchase management, customer relationship management, and information and communication technology. These dimensions are strong indicators of SCM practices. According to the study, the corporations have undoubtedly spent resources to facilitate the transportation of products to the final site of consumption; they have used the SC as a strategic weapon to outperform competitors in the milk market. These findings align with the industry advice that emphasizes efficient supply chain and distribution practices. These practices are crucial for milk quality and competitiveness (BCG, 2022).

The respondents did agree that the firms engaged suppliers and customers on service delivery, quality, and feedback aspects. Intensifying competition leads organizations to narrow their focus on core areas of competency, as it affects competitive advantage. Consumer demand for higher quality service, added value, and better prices adds to the pressure for efficiency gains or performance improvements forever.

The second part of the research is about the design of the market practices. This gives lots of dimensions on the cost incurred by the firms concerning an imbalanced demand and supply. It identifies potential for profit improvement; decision-making supports the entire company's profitability. Cost trade-offs are accurately modeled, and alternative strategies are quantitatively compared. Design for Profitability practice constraints on lead times in the two establishments increased the cost of being able to avail a product to the consumer, for example, when delivery of a product was requested earlier than the firm's stipulated time. The firms then sought to balance supply with the demand for milk and other products. Other challenges faced by milk processing firms are: delivering fresh, safe, and best-of-all possible standards products in the local milk cases. These findings support the documented problems in the Milk retail supply chains that affect customer satisfaction and operational efficiency (Kotni, 2022; Your Retail Coach, 2025).

5.1. Findings From the Analysis of The SCM Operations of The Agent

1) The agent has a limitation on the number of products they are selling.
2) Agents sell only very few products because all products are very high and they are of high-quality. These findings do not align with the models that suggest more decentralized collection networks with improved technology integration for real-time milk quality monitoring (Korir, 2023)

5.2. It Has Been Observed That The Supply Chain Procedures of The Company Failed in Delivering The Product to The Exact Place at The Exact Time

5.3. Findings from The Analysis of The SCM Operations of The Retailer

1) It has been discovered that the shops claim that their supply of milk is not on time.
2) This has been learned that stores accuse the company of not giving timely information in case of delay.
3) Most retailers claim that the products sell more due to their high quality.
4) Most of the customers are inclined toward buying homogenized full cream milk (HFCM).
5) The supply is not consistent, and poor packaging has been found as the major problem faced by the retailers.

5. 4. Findings from The Analysis of The SCM Operations of The Customer

1) Several consumers primarily base their choice of a brand of milk on its quality.
2) Most of the parents seem to be giving Aroghya milk to their children in the age group of six to twelve months.
3) It has been found that the majority of consumers got to know the Aroghya milk products through dealers.

5.5. Findings from The Analysis of The SCM Operations of Milk-Collecting Agents

1) The analysis has found that the company provides all agents engaged in collecting milk with transport assistance to carry the milk.
2) Most of these agents receive between eighty and one hundred liters of milk.
3) Most of these milk collection agents were under an agreement with the company. These findings align with Kotni (2022).

6. Results and Discussion

It has become evident through meticulous investigation and practical proof that the incorporation of new technology into SCM significantly enhances operational efficiency in the milk sector. Supply chain performance has shown concrete enhancements due to technological innovations. In addition, the discussions explore the intricate connections between these enhancements and the ability of milk companies to stay competitive. There are various manifestations of this enhancement, including reduced expenses and improved resource utilization, as well as heightened quality control and traceability. Milk firms are gaining unprecedented insight and control over their supply chains by implementing cutting-edge technology such as data analytics, IoT, and RFID. This results in lower prices, less waste, and higher product quality, all of which are important elements in achieving consumer demands and regulatory standards. These developments further strengthen the milk sector's commitment to sustainability.
Despite the significant improvements brought about by technology-driven supply chain management practices, the adoption of new ideas in the milk sector often faces major socio-economic and cultural challenges. Rural areas, where most milk production occurs, may have low digital literacy and poor access to stable internet, making it hard to use complex tools like IoT sensors, data analytics systems, and blockchain ledgers (RSC Publishing, 2025). Economic factors also play a big role. The upfront costs and ongoing maintenance for advanced technologies can be too high for small and marginal Milk farmers. This situation increases the competitiveness gap between large-scale and small-scale producers (Kumar & Kumar, 2023). Culturally, traditional stakeholders may resist change. They often prefer established methods based on generational knowledge and local customs over new systems (RSC Publishing, 2025). Social hierarchies and a lack of trust in digital systems can slow down adoption. Concerns about data privacy and losing control over proprietary information can also be obstacles. To overcome these challenges, we need targeted education, supportive policies, and technology design that includes everyone. This approach will help ensure that the milk industry benefits from technology-driven supply chain management.

6.1. Measurement Model

A measurement model measures the latent variables or composite variables (Hoyle, 1995, 2011; Kline, 2010). The quality of a model is evaluated by how well it predicts endogenous constructs. The first evaluation criterion is based on the internal consistency of the measurement model. As shown in Fig. 3, this approach involves examining the relationships between the measurement items and the observed variables. The latent variable used in this study, which indicates how much variance the items capture and consequently the dependability of each item, should be highlighted. The standardized outer loadings of the latent construct, which represent absolute correlations, are expected to be more than 50%, according to Chin (1998). Table 2 shows the absolute correlations between the construct and its matching measurement items based on the PLS measurement analysis results. Notably, the factor loadings range from 0.706 to 0.866, exceeding Chin's recommended minimal criterion of 0.50 (1998, 2009).

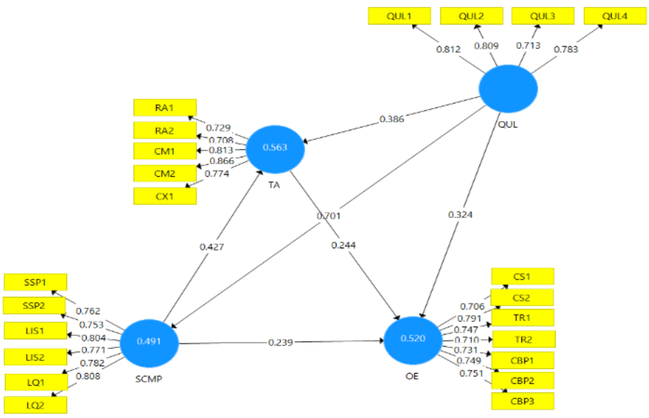

Fig. 3: Measurement Model (PLS-Algorithm with Outer Loading).

Source: Authors' own work.

6.2. Indicators

In this study, 22 indicators were used for data analysis to design the model. The mean value ranges from 2.670 to 3.563, and the standard deviation value ranges from 1.405 to 1.696, as shown in Table 2. These are directly measured observations (raw data), also known as items or manifest variables, and they are shown as rectangles in path models. These are also accessible data (such as survey answers or information gathered from business databases) that are utilized in measurement models to gauge the latent variables.

Table 2: Statistical Indicators

	No.	Missing	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
SSP1	1	0	2.992	2	1	5	1.534	-1.579	0.106
SSP2	2	0	3.099	2	1	5	1.587	-1.656	0.052
LIS1	3	0	2.854	2	1	5	1.673	-1.677	0.210
LIS2	4	0	3.080	3	1	5	1.550	-1.612	0.062
LQ1	5	0	2.854	2	1	5	1.696	-1.692	0.250
LQ2	6	0	2.857	2	1	5	1.568	-1.555	0.264
CS1	7	0	3.170	4	1	5	1.506	-1.526	-0.171
CS2	8	0	3.272	4	1	5	1.490	-1.504	-0.218
TR1	9	0	3.423	4	1	5	1.419	-1.241	-0.434
TR2	10	0	3.563	4	1	5	1.406	-1.089	-0.597
CBP1	11	0	3.492	4	1	5	1.405	-1.264	-0.436
CBP2	12	0	3.390	4	1	5	1.377	-1.256	-0.435
CBP3	13	0	3.288	4	1	5	1.536	-1.566	-0.205
RA1	14	0	3.162	3	1	5	1.499	-1.530	-0.082
RA2	15	0	3.368	4	1	5	1.405	-1.347	-0.316
CM1	16	0	2.912	2	1	5	1.568	-1.568	0.228
CM2	17	0	2.810	2	1	5	1.588	-1.548	0.293
CX1	18	0	2.670	2	1	5	1.628	-1.537	0.377
QUL1	19	0	3.146	4	1	5	1.644	-1.698	-0.071
QUL2	20	0	3.135	4	1	5	1.523	-1.568	-0.074
QUL3	21	0	3.319	4	1	5	1.372	-1.252	-0.370
QUL4	22	0	3.266	4	1	5	1.471	-1.480	-0.171

Source: Authors' own work.

6.3. Indicator Correlations

In this study, 22 indicators were used for data analysis to design the model. Here, correlation values represent the strength and direction of the relationship between two variables. They range from -1 or +1. -1 indicates a perfect negative correlation (as one variable increases, the other variable decreases). +1 indicates a perfect positive correlation (as one variable increases, the other variable increases). Where interpretation of correlation value 0 (e.g., e.g.0.1 to 0.3) indicates a weak relationship, 0.5 indicates moderate, 0.7 or higher (e.g., 0.7 or 0.9) indicates a strong relationship, and +1 or -1 indicates a perfect relationship. Indicator correlations are essential for evaluating the validity of measurement models, especially those using reflective measurement. High correlations among indicators suggest strong convergent validity; however, low correlations may signal issues with discriminant validity or inadequate reliability, as shown in Table 3.

Table 3: Indicator Correlations

	SSP1	SSP2	LIS1	LIS2	LQ1	LQ2	CS1	CS2	TR1	TR2	CBP1	CBP2	CBP3	RA1	RA2	CM1	CM2	CX1	QUL1	QUL2	QUL3	QUL4
SSP1	1.000																					
SSP2	0.660	1.000																				
LIS1	0.556	0.546	1.000																			
LIS2	0.474	0.531	0.588	1.000																		
LQ1	0.442	0.388	0.547	0.494	1.000																	
LQ2	0.453	0.431	0.558	0.531	0.760	1.000																
CS1	0.364	0.313	0.363	0.424	0.616	0.556	1.000															
CS2	0.331	0.383	0.376	0.428	0.490	0.533	0.607	1.000														
TR1	0.267	0.255	0.249	0.338	0.443	0.453	0.488	0.616	1.000													
TR2	0.249	0.262	0.223	0.353	0.319	0.364	0.379	0.427	0.436	1.000												
CBP1	0.278	0.274	0.243	0.355	0.276	0.324	0.358	0.440	0.440	0.556	1.000											
CBP2	0.246	0.270	0.286	0.366	0.349	0.395	0.383	0.481	0.422	0.555	0.613	1.000										
CBP3	0.400	0.403	0.352	0.414	0.435	0.504	0.411	0.471	0.470	0.454	0.474	0.503	1.000									
RA1	0.385	0.361	0.402	0.443	0.365	0.426	0.281	0.332	0.364	0.244	0.340	0.290	0.451	1.000								
RA2	0.316	0.335	0.379	0.418	0.359	0.505	0.296	0.463	0.415	0.273	0.342	0.357	0.484	0.477	1.000							
CM1	0.416	0.491	0.463	0.454	0.430	0.442	0.298	0.369	0.328	0.237	0.265	0.277	0.482	0.456	0.420	1.000						
CM2	0.463	0.451	0.481	0.436	0.503	0.522	0.420	0.454	0.417	0.310	0.380	0.385	0.578	0.513	0.451	0.745	1.000					
CX1	0.351	0.364	0.408	0.376	0.443	0.490	0.332	0.364	0.341	0.258	0.297	0.340	0.429	0.450	0.433	0.526	0.603	1.000				
QUL1	0.822	0.627	0.568	0.545	0.529	0.550	0.476	0.474	0.394	0.365	0.386	0.396	0.526	0.418	0.385	0.510	0.580	0.511	1.000			
QUL2	0.471	0.442	0.436	0.374	0.399	0.438	0.322	0.392	0.303	0.317	0.327	0.326	0.426	0.380	0.406	0.426	0.521	0.494	0.546	1.000		
QUL3	0.235	0.331	0.224	0.281	0.232	0.295	0.298	0.366	0.364	0.341	0.382	0.383	0.391	0.237	0.380	0.276	0.354	0.328	0.373	0.448	1.000	
QUL4	0.356	0.371	0.280	0.343	0.277	0.317	0.280	0.394	0.359	0.334	0.395	0.322	0.454	0.303	0.390	0.373	0.436	0.418	0.458	0.509	0.564	1.000

6.4. Construct Reliability and Validity

6.4.1. Measures of Reliability

The reliability of the construct was evaluated at the composite level using composite reliability and Cronbach's alpha. Cronbach's alpha values range from 0 (no reliability) to 1 (perfect reliability), with values above 0.7 widely accepted, 0.8 indicating good reliability, and 0.9 or higher indicating excellent reliability. Cronbach's alpha of Operational efficiency (OE) = 0.864, a good reliability, Quality (QUL) =

0.789, is accepted, Supply Chain Management Practices (SCMP) = 0.871, a good reliability, and Technology adoption (TA) = 0.837, a good reliability. As demonstrated in Table 2, both composite reliability and Cronbach's alpha were greater than the recommended values of 0.6 and 0.70 by Cronbach (1951). Convergent validity is assessed using the guidelines of Hair, Black et al. (2009) and Mertler, Vannatta et al. (2021), who determine how effectively the items convey the underlying theoretical idea. Convergent validity ensures that results from several measurements correlate and fit into the same conceptual framework (Henseler, Ringle, et al. 2009).

6.4.2. Convergent Validity

To examine convergent validity, we used a recognized approach termed "Average Variance Extracted (AVE)," as described by Hudson (Than et al., 2013). We adhered to the principles provided in the works of (Tabachnick, Fidell et al., 2007); (Hair, Black et al., 2009); and (Henseler, Ringle et al., 2009). According to the principles proposed by Fornell and Larcker (1981), each core notion explained more than half of the variation in the observed items. This was confirmed by Table 2, which demonstrated that the Average Variance Extracted (AVE) values for each underlying variable were higher than the threshold of 0.5 (50%). The AVE of Operational efficiency (OE) = 0.550, AVE of Quality (QUL) = 0.608, AVE of Supply Chain Management (SCMP) = 0.609, AVE of Technology Adoption (TA) = 0.608, which is > 0.5, is acceptable, as shown in Table 4.

Table 4: Construct Reliability and Validity

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
OE	0.864	0.870	0.895	0.550
QUL	0.789	0.811	0.861	0.608
SCMP	0.871	0.873	0.903	0.609
TA	0.837	0.845	0.885	0.608

Source: Authors' own work.

Note: Measurement model – Composite reliability (CR) and Convergent validity (CV) values should be greater than or equal to 0.70. Average variance extracted (AVE) value greater than 0.50 (Hair et.al).

6.4.3. Discriminant Validity

In this study, a series of assessments was used to thoroughly examine the discriminant validity of the items for the constructs. It began with the Fornell-Larcker Criterion, which entails computing the root of the Average Variance Extracted (Hudson, Thal et al., 2013) for each construct and comparing it to the correlations between that construct and the others in the model. They also ran cross-loading tests. The HTMT method was then employed to conduct the examination. This criterion states that the square root of AVE should be greater than the intercorrelations. This implies that a concept is more effective in explaining its items than others.

The cross-loading matrix, the second approach for measuring discriminant validity, requires that item loadings on one construct be higher than loadings on other constructs. This demonstrates that the desired constructs were correctly measured (Straub, Boudreau et al., 2004). The cross-loading technique used in this study, as indicated in Table 4, supports the expected assessment result because all items have the highest loadings on their respective constructs. A general rule of thumb when conceptualizing discriminant validity is that values starting at r = 0.85 are considered high. According to SmartPLS documentation, discriminant validity, specifically the Heterotrait-Monotrait ratio (HTMT), is normally assessed with a value less than 0.90, and the average variance extracted (AVE) is advised to be greater than 0.50. HTMT values near one imply a lack of discriminant validity. Discriminant validity of the construct and its indicators are Operational efficiency (OE) = 0.741, Quality (QUL) = 0.780, Supply Chain Management (SCMP) = 0.609, Technology Adoption (TA) = 0.780, is shown in Table 5.

Table 5: Discriminant Validity

	OE	QUL	SCMP	TA
OE	0.741			
QUL	0.659	0.780		
SCMP	0.636	0.701	0.780	
TA	0.633	0.686	0.698	0.780

Source: Authors' own work.

Note: Fornell–Larcker Criterion (Higher values than the off-diagonal values in rows and corresponding columns).

6.4.4. Heterotrait - Monotrait Ratio (HTMT)

The HTMT (Heterotrait-Monotrait) ratio, which is superior to cross-loadings and the Fornell-Larcker criterion, is the third method used to demonstrate discriminant validity. The HTMT (Heterotrait-Monotrait) ratio is the third strategy used to ensure discriminant validity, and it has been shown to outperform cross-loadings and the Fornell-Larcker criterion. To follow this strategy, Henseler, Ringle, et al. (2015) advocated keeping HTMT values below 0.90. In the current investigation, the maximum threshold value was set at 0.782 of quality (Table 6), which meets the discriminant validity criteria because it is less than the specified threshold of 0.90.

Table 6: Heterotrait - Monotrait Ratio (HTMT)

	OE	QUL	SCMP	TA
OE				
QUL	0.782			
SCMP	0.717	0.802		
TA	0.727	0.821	0.815	

Source: Authors' own work.

Note: Heterotrait - Monotrait Ratio (HTMT Ratio is calculated using a threshold value of less than 0.90.

6.4.5. Cross Loadings

(Hair et al., 2017) state that the outer loadings for indicators on a construct should be greater than all cross-loadings with other constructs. To demonstrate uniqueness and discriminant validity, the cross-loading scores must differ by 0.1. The results revealed that the cross-loading value of "Operational Efficiency (OE)" constructs were CS1 = 0.706, CS2 = 0.791, TR1 = 0.747, TR2 = 0.710, CBP1 = 0.731, CBP2 = 0.749, CBP3 = 751, "Quality (QUL)" constructs were QUL1 = 812, QUL2 = 809, QUL3 = 713, QUL4 = 783, "Supply Chain Management Practices (SCMP)" constructs were SSP1 = 762, SSP2 = 753, LIS1 = 804, LIS2 = 0.771, LQ1 = 0.785, LQ2 = 0.808 and "Technology Adoption (TA)" constructs were RA1 = 0.729, RA2 = 0.708, CM1 = 0.813, CM2 = 0.866, CX1 = 0.774 as shown in the Table 7.

Table 7: Cross Loadings

	OE	QUL	SCMP	TA
CS1	0.706	0.455	0.568	0.422
CS2	0.791	0.527	0.546	0.511
TR1	0.747	0.455	0.433	0.479
TR2	0.710	0.435	0.381	0.340
CBP1	0.731	0.474	0.375	0.418
CBP2	0.749	0.457	0.411	0.425
CBP3	0.751	0.583	0.539	0.625
QUL1	0.590	0.812	0.776	0.621
QUL2	0.471	0.809	0.547	0.575
QUL3	0.487	0.713	0.342	0.406
QUL4	0.494	0.783	0.415	0.495
SSP1	0.419	0.651	0.762	0.498
SSP2	0.424	0.590	0.753	0.515
LIS1	0.411	0.511	0.804	0.548
LIS2	0.520	0.514	0.771	0.544
LQ1	0.573	0.484	0.782	0.542
LQ2	0.612	0.533	0.808	0.613
RA1	0.451	0.442	0.509	0.729
RA2	0.517	0.497	0.497	0.708
CM1	0.446	0.524	0.575	0.813
CM2	0.579	0.621	0.611	0.866
CX1	0.462	0.573	0.522	0.774

Source: Authors' own work.

6.4.6. Collinearity Statistics (VIF)

To assess multicollinearity (VIF), we used the method provided in Pallant 2020. According to this technique, a VIF value of 1 means no collinearity, >1 indicates the presence of multicollinearity, and a value higher than 10 indicates severe multicollinearity, which leads to unstable coefficient estimates and unreliable regression results. The results in Table 8 show that the greatest Outer VIF value is 2.746, and the lowest is 1.453. These results show that there is multicollinearity among the variables.

Table 8: Outer VIF Values

	VIF		VIF
CBP1	1.898	Supply Chain Management Practices	
CBP2	1.969	SSP1	2.018
CBP3	1.621	SSP2	2.052
CM1	2.334	LIS1	2.054
CM2	2.746	LIS2	1.830
CS1	1.688	LQ1	2.532
CS2	2.167	LQ2	2.652
CX1	1.709	Operational Efficiency	
LIS1	2.054	CS1	1.688
LIS2	1.830	CS2	2.167
LQ1	2.532	TR1	1.831
LQ2	2.652	TR2	1.732
QUL1	1.528	CBP1	1.898
QUL2	1.675	CBP2	1.969
QUL3	1.553	CBP3	1.621
QUL4	1.735	Technology Adoption	
RA1	1.552	RA1	1.552
RA2	1.453	RA2	1.453
SSP1	2.018	CM1	2.334
SSP2	2.052	CM2	2.746
TR1	1.831	CX1	1.709
TR2	1.732	Quality	
		QUL1	1.528
		QUL2	1.675
		QUL3	1.553
		QUL4	1.735

Source: Authors' own work.

The results revealed that the outer VIF Values of construct and its indicators are "Operational Efficiency (OE)" constructs were CS1 = 1.688, CS2 = 2.167, TR1 = 1.831, TR2 = 1.732, CBP1 = 1.898, CBP2 = 1.969, CBP3 = 1.621, "Quality (QUL)" constructs were QUL1 = 1.528, QUL2 = 1.675, QUL3 = 1.553, QUL4 = 1.735, "Supply Chain Management Practices (SCMP)" constructs were SSP1 = 2.018,

SSP2 = 2.052, LIS1 = 2.054, LIS2 = 1.830, LQ1 = 2.532, LQ2 = 2.652 and “Technology Adoption (TA)” constructs were RA1 = 1.552, RA2 = 1.453, CM1 = 2.334, CM2 = 2.746, CX1 = 1.709 as shown in the Table 8.

6.4.7. Inner VIF Values

The results in Table 8 show that the greatest Inner VIF value is 2.383, and the lowest is 1.000. These results show that there is multicollinearity among the variables, as shown in Table 9.

Table 9: Inner VIF values

	OE	QUL	SCMP	TA
OE				
QUL	2.306		1.000	1.965
SCMP	2.383			1.965
TA	2.289			

Source: authors’ own work.

Note: Collinearity index – Variance Inflation Factor (VIF) values - (Outer and Inner should be Less than 5).

6.4.8. Outer Loadings

Outer loadings are bivariate correlations between a construct and its indicators. They calculate an item's absolute contribution to its allocated construct. Loadings are particularly important in the evaluation of reflective measurement models, but they are also interpreted when formative measurements are used. Manifest variables with outer loadings of 0.7 or more are rated highly satisfactory, whereas 0.5 is deemed acceptable. Outer loadings of 0.4 are acceptable, according to (Henseler et al., 2009); however, manifest variables with loadings ranging from 0.4 to 0.7 should be eliminated. Outer loading above 0.5 is considered appropriate, while factors with loading values less than 0.5 should be discarded.

Table 10: Outer Loadings

	OE	QUL	SCMP	TA
CS1	0.706			
CS2	0.791			
TR1	0.747			
TR2	0.710			
CBP1	0.731			
CBP2	0.749			
CBP3	0.751			
QUL1		0.812		
QUL2		0.809		
QUL3		0.713		
QUL4		0.783		
SSP1			0.762	
SSP2			0.753	
LIS1			0.804	
LIS2			0.771	
LQ1			0.782	
LQ2			0.808	
RA1				0.729
RA2				0.708
CM1				0.813
CM2				0.866
CX1				0.774

Source: Authors’ own work.

The results revealed that the Outer loadings Values of construct and its indicators are "Operational Efficiency (OE)" constructs were CS1 = 0.706, CS2 = 0.791, TR1 = 0.747, TR2 = 0.710, CBP1 = 0.731, CBP2 = 0.749, CBP3 = 0.751, “Quality (QUL)” constructs were QUL1 = 0.812, QUL2 = 0.809, QUL3 = 0.713, QUL4 = 0.783, “Supply Chain Management Practices (SCMP)” constructs were SSP1 = 0.762, SSP2 = 0.753, LIS1 = 0.804, LIS2 = 0.771, LQ1 = 0.782, LQ2 = 0.808 and “Technology Adoption (TA)” constructs were RA1 = 0.729, RA2 = 0.708, CM1 = 0.813, CM2 = 0.866, CX1 = 0.774 as shown in the Table 10.

6.4.9. Outer Loadings – Bootstrapping

The results revealed that the Outer loadings with bootstrapping Values of construct and its indicators are "Operational Efficiency (OE)" constructs (see in Table 11) were CS1 <- OE = 0.706, CS2 <- OE = 0.791, TR1 <- OE = 0.747, TR2 <- OE = 0.710, CBP1 <- OE = 0.731, CBP2 <- OE = 0.749, CBP3 <- OE = 0.751, “Quality (QUL)” constructs were QUL1 <- QUL = 0.812, QUL2 <- QUL = 0.809, QUL3 <- QUL = 0.713, QUL4 <- QUL = 0.783, “Supply Chain Management Practices (SCMP)” constructs were SSP1 <- SCMP = 0.762, SSP2 <- SCMP = 0.753, LIS1 <- SCMP = 0.804, LIS2 <- SCMP = 0.771, LQ1 <- SCMP = 0.782, LQ2 <- SCMP = 0.808 and “Technology Adoption (TA)” constructs were RA1 <- TA = 0.729, RA2 <- TA = 0.708, CM1 <- TA = 0.813, CM2 <- TA = 0.866, CX1 <- TA = 0.774.

Table 11: Outer Loadings – Bootstrapping

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
CBP1 <- OE	0.731	0.732	0.030	24.302	0.000
CBP2 <- OE	0.749	0.749	0.030	25.181	0.000
CBP3 <- OE	0.751	0.752	0.022	34.159	0.000
CM1 <- TA	0.813	0.814	0.022	37.764	0.000
CM2 <- TA	0.866	0.866	0.012	69.295	0.000
CS1 <- OE	0.706	0.707	0.033	21.432	0.000

CS2 <- OE	0.791	0.792	0.021	37.031	0.000
CX1 <- TA	0.774	0.774	0.024	32.732	0.000
LIS1 <- SCMP	0.804	0.804	0.024	32.995	0.000
LIS2 <- SCMP	0.771	0.772	0.028	27.272	0.000
LQ1 <- SCMP	0.782	0.782	0.022	35.132	0.000
LQ2 <- SCMP	0.808	0.810	0.021	39.091	0.000
QUL1 <- QUL	0.812	0.811	0.019	43.845	0.000
QUL2 <- QUL	0.809	0.808	0.023	35.494	0.000
QUL3 <- QUL	0.713	0.709	0.039	18.426	0.000
QUL4 <- QUL	0.783	0.782	0.026	30.023	0.000
RA1 <- TA	0.729	0.727	0.032	22.664	0.000
RA2 <- TA	0.708	0.707	0.030	23.756	0.000
SSP1 <- SCMP	0.762	0.762	0.029	26.219	0.000
SSP2 <- SCMP	0.753	0.754	0.030	25.334	0.000
TR1 <- OE	0.747	0.745	0.030	24.791	0.000
TR2 <- OE	0.710	0.710	0.036	19.636	0.000

Source: authors' own work.

6.4.10. Path Coefficients

As stated by Joseph F. Hair et al. (2017), path coefficients are standardized beta (β) values that vary from -1 to +1. As stated by (Joe F. Hair et al. (2020), route coefficient values nearer to 0 are less effective in predicting dependent (endogenous) constructs, whereas values approaching 1 are more effective in predicting dependent structures. In addition, the path coefficient has to be statistically significant. Figure 3 displays a robust and meaningful path coefficient (β = 0.324) from QUL to OE, (β = 0.239) from SCMP to OE, and (β = 0.244) from TA to OE as indicated in Table 12.

Table 12: Path Coefficients

	OE	QUL	SCMP	TA
OE				
QUL	0.324		0.701	0.386
SCMP	0.239			0.427
TA	0.244			

6.4.11. Path Coefficients - Bootstrapping

Path coefficients or regression coefficients (β) are computed for path relationships in the structural model (between its constructs). They correlate to the standardized betas in a regression analysis. (Huber et al., 2007). The path coefficient must be at least 0.100 and have a significance level of at least 0.05.

The SmartPLS bootstrapping technique produces the path coefficients or regression coefficient (β)/Original Sample (O), t-statistic, p-values, and confidence ranges (see Table 18). The regression coefficients for the routes connecting QUL -> OE (quality and operational efficiency) = (β = 0.324), indicating a weak and negative relationship. QUL -> SCMP (Quality and Supply Chain Management Practices = (β=0.701), indicating a strong and positive. The associations between quality, supply chain management practices, technology adoption, and operational efficiency are all modest and negative (β = 0.386, 0.239, 0.427, and 0.244, respectively) as shown in Table 13.

Table 13: Path Coefficients

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statics (|O/STDEV|)	P Values
QUL -> OE	0.324	0.323	0.062	5.272	0.000
QUL -> SCMP	0.701	0.702	0.026	27.031	0.000
QUL -> TA	0.386	0.384	0.053	7.321	0.000
SCMP -> OE	0.239	0.238	0.066	3.604	0.000
SCMP -> TA	0.427	0.432	0.050	8.532	0.000
TA -> OE	0.244	0.250	0.062	3.913	0.000

6.4.12. Model Fit

While analysing how well our model fits the data, the SRMR (Standardized Root Mean Square Residual) shows a value of 0.084, indicating a good fit of the model; the values of d_ULS and d_G, 1.784 and 0.651, respectively, indicate that the outfits are tailored to perfection; and the values of Chi-square, which is the final check, show values of 1229.311, indicating that a good outfit passes the ultimate test. Finally, the NFI (Normed Fit Index) value is 0.740, indicating that you look great and that the model fits the data reasonably well in both outfits. As a result, given the realities of model fitness, they make an outstanding fit for our dataset.

Table 14: Model Fit

	Saturated Model	Estimated Model
SRMR	0.084	0.084
d_ULS	1.784	1.784
d_G	0.651	0.651
Chi-Square	1229.311	1229.311
NFI	0.740	0.740

The SRMR ranges from zero to one, with well-fitting models giving values less than 0.05 (Byrne, 1998; Diamantopoulos and Siguaw, 2000), while values as high as 0.08 are regarded as acceptable (Hu and Bentler, 1999). As a result, NFI values range between 0 and 1. The closer the NFI is to 1, the better the match. NFI values greater than 0.9 are usually regarded as an adequate fit. Based on the SmarPLS model fit, the SRMR and NFI values are considered to be good fits, as shown in Table 14.

7. Structural Model

The structural model employs path analysis to test all conceivable dependencies. The suggested structural model was examined after the measurement model's analysis, validity, and reliability had been checked. The probability of collinearity among the structural model's outer constructions must be investigated. Collinearity among independent components (according to Hair et al., 2017) is not a significant issue for this model.

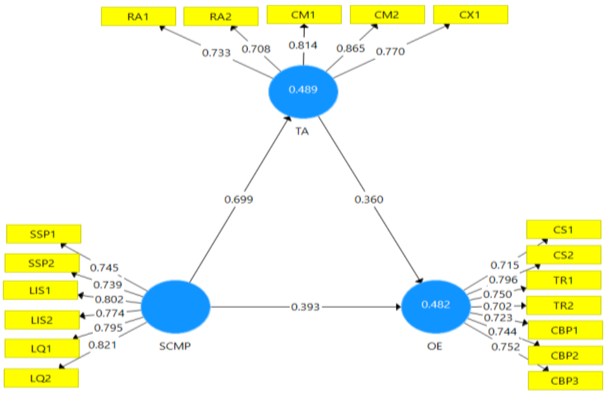

Fig. 4: Structural Model: the Conceptual Framework Under the Process Method. (Come Analysis) (Inner Model with P-Values)

Source: Authors' own work.

7.1. R Square

The coefficient of determination (R^2) assesses the model prediction accuracy. Hair et al. (2017) found that for big target structures, an appropriate level of R^2 is typically more than 0.25. The suggested model predicts operational efficiency ($R^2 = 0.482$) and technological adaptation ($R^2 = 0.489$) with moderate accuracy, as indicated in Table 15.

Table 15: R Square

	R Square	R Square Adjusted
OE	0.482	0.479
TA	0.489	0.488

Note: R2 values 0.75= strong, 0.50= moderate and ≤ 0.25= weak

7.2. f Square

After assessing and confirming the structural model, Table 16 shows an examination of the effect size (f^2) for each association. The first column shows the external construct, followed by the first row, which shows the endogenous structures. Information sharing and supply chain management methods have a small impact on technology adoption in supply chain systems ($f^2 = 0.152$, $f^2 = 0.127$, and $f^2 = 0.958$). There is an uneasy relationship between supply chain management and technology adoption, as shown in Table 16.

Table 16: F Square

	OE	SCMP	TA
OE			
SCMP	0.152		0.958
TA	0.127		

Note: F-Square F^2 effect sizes of 0.02, 0.15, and 0.35 are concluded as small, medium, and large effect sizes.

7.3. Path Coefficients (Direct Effect)

As stated by Joseph F. Hair et al. (2017), path coefficients represent standardized beta (β) values that vary between -1 and +1. As stated by Joe F. Hair et al. (2020), route coefficient values nearing 0 are less effective in forecasting dependent (endogenous) constructs, whereas values nearing 1 are more effective in forecasting dependent structures. Additionally, the path coefficient needs to be statistically significant. Figure 20 illustrates a robust and noteworthy path coefficient ($\beta = 0.393$) from SCMP to OE, and ($\beta = 0.360$) from TA to OE as indicated in Table 17.
Path coefficients or regression coefficients (β) are computed for path relationships in the structural model (between its constructs). They relate to the standardized betas found in a regression analysis. Huber et al. (2007). The path coefficient should be a minimum of 0.100 and must achieve a significance level of at least 0.05.

Table 17: Path Coefficients

	OE	SCMP	TA
OE			
SCMP	0.393		0.699
TA	0.360		

7.3.1. Path Coefficients - Bootstrapping (Direct Effect)

The SmartPLS bootstrapping technique produces the path coefficients or regression coefficient (β)/Original Sample (O), t-statistic, p-values, and confidence ranges (see Table 18). The regression coefficients for the routes connecting SCMP -> OE (Supply Chain Management Practices and Operational Efficiency) = (β = 0.393), indicating a weak and negative relationship. SCMP -> TA (Supply Chain Management Practices and Technology Adoption) = (β=0.699), indicating a strong and positive and TA -> OE (Technology Adoption and Operational Efficiency) = (β=0.360), indicating a weak and negative.

Table 18: Path Coefficients - Bootstrapping (Direct Effect)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
SCMP -> OE	0.393	0.396	0.063	6.217	0.000
SCMP -> TA	0.699	0.701	0.028	24.839	0.000
TA -> OE	0.360	0.358	0.062	5.837	0.000

7.4. Indirect Effect

Indirect effect: a relationship between two latent variables is represented by a third construct (e.g., mediator). Suppose p represents the relationship between the exogenous latent variable and the mediator variable, and p represents the link between the mediator variable and the endogenous latent variable. In that case, the indirect effect is the product of path p and path p. The proposed research model suggested that the dynamic capabilities of the supply chain influence the relationship between SCMP (Supply Chain Management Practices) and the operational efficiency within the milk industry. The moderation test was carried out using a two-phase calculation method. This approach was employed by the proposal of (H. Y. Ching and M. A. Moreira, 2014), who indicated that when the aim of the research is to ascertain if a moderating variable significantly influences the connection between exogenous and endogenous variables. This research employed 22 criteria to assess if a moderation condition was present in order to examine the moderation hypothesis.

Table 19: Indirect effect

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
SCMP -> OE	0.252	0.253	0.047	5.388	0.000

Table 19 indicates that the correlation between SCMP and economic, environmental, and social performance is influenced by SCMP's dynamic capabilities (β = 0.252, t value = 5.388, p value = 0.000). These data suggest that SCMP plays a crucial role in mediating the relationship between TA and all operational efficiency metrics.

7.5. Total Effect

The total impact is the sum of the direct and indirect effects between an exogenous and an endogenous latent variable in the path model (Albers, 2009; Henseler, Ringle, and Sinkovics., 2009). Table 20 shows the relationship between SCMP and TA, moderated SCMP -> OE = (β = 0.645, t value = 19.068, p value = 0.000), SCMP -> TA = (β = 0.699, t value = 25.409, p value = 0.000), TA -> OE = (β = 0.360, t value = 5.541 p value = 0.000).

Table 20: Total Effect

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statics (|O/STDEV|)	P Values
SCMP -> OE	0.645	0.650	0.034	19.068	0.000
SCMP -> TA	0.699	0.704	0.028	25.409	0.000
TA -> OE	0.360	0.359	0.065	5.541	0.000

7.6. Model Fitness

While analysing how well our model fits the data, the SRMR value of 0.079, indicating a good fit of the model; the values of d_ULS and d_G, 1.057 and 0.349, respectively, indicate that the outfits are tailored to perfection; and the values of Chi-square, which is like the final check, show values of 733.428, indicating that a good outfit has passed the ultimate test. Finally, the NFI value is 0.796; you look amazing in both clothes. Given the facts of model fitness, they're a perfect fit for our data, as shown in Table 21.

Table 21: Model Fitness

	Saturated Model	Estimated Model
SRMR	0.079	0.079
d_ULS	1.057	1.057
d_G	0.349	0.349
Chi-Square	733.428	733.428
NFI	0.796	0.796

7.7. Hypothesis Testing

Table 22: Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statics (/O/STDEV)	P Values
SCMP -> OE	0.393	0.396	0.063	6.217	0.000
SCMP -> TA	0.699	0.701	0.028	24.839	0.000
TA -> OE	0.360	0.358	0.062	5.837	0.000

Hypothesis 1 (H1): The first hypothesis in this study investigated the possible association between SCM and TA. The study found a significant positive relationship between Supply Chain Management Practices (SCMP) and Technology Adoption (TA) = (β = 0.393, t = 5.837, p < 0.000), shown in Table 22.

Hypothesis 2 (H2): The second hypothesis sought to investigate the interaction of Technology Adoption (TA) with Operational Efficiency (OE). Our study shows a significant positive relationship between these two constructs ($\beta = 0.699$, $t = 24.839$, $p < 0.000$), shown in Table 22.
Hypothesis 3 (H3): The purpose of this study was to investigate the impact of Supply Chain Management Practices (SCMP) and Operational Efficiency (OE). Our findings indicate a significant effect, albeit in the opposite direction ($\beta = 0.393$, $t = 6.217$, $p < 0.000$), shown in Table 22.

8. Implications

8.1. Theoretical Implications

Most academic scholars and corporate leaders working on management and innovation tend to prioritize technological innovation and researching the variables that drive it. This dissertation, the first of its kind, assesses the impact of technology on milk innovation and provides a framework for rural milk farmers to improve it in the Tirupati, Chittoor, and Annamaya districts of Andhra Pradesh, India. This study report serves as a literature source, providing a conceptual foundation for future research in the field.

8.2. Practical Implications

The milk industry is striving for an enhancement of its overall creative capacity through the development of new products and procedures for milk. However, there is a potential improvement in the innovation performance that the industry could have achieved by emphasizing the direction and pace of the innovation processes (Lamprinopoulou et al., 2014; Hekkert et al., 2007). This will require practitioners of development to assess the effectiveness of their efforts to improve milk technology.
National and international dairy policies can use these insights to promote technology integration that improves hygiene, supply chain transparency, and customer feedback systems. This approach helps boost sustainability and consumer trust. However, adopting new technologies like blockchain or ERP systems may be difficult in developing or resource-limited areas. High upfront costs, lack of infrastructure, limited access to credit, and insufficient technical knowledge among smallholders and firms pose significant challenges (Korir et al., 2023; Kirimi, 2024). These financial and institutional barriers call for supportive policy measures such as affordable credit programs, extension services, and targeted training programs to ensure equal access. Furthermore, skepticism and a lack of awareness among stakeholders can slow down the adoption of these technologies. This highlights the need for awareness campaigns and gradual technology integration plans that fit local contexts and abilities. Tackling these obstacles directly would improve the effectiveness and sustainability of technology-driven supply chain advancements in the milk sector across different environments.

8.3. Managerial Implications

It can be challenging to adopt new technology in supply chain management, particularly in industries such as milk, where freshness and punctual delivery are essential. Moreover, the incorporation of these technologies into existing systems may necessitate considerable time and resources, potentially interrupting routine activities. To begin with, put money into scalable technological solutions that can be added to current processes step by step. This will minimize disruption and enable gradual benefits. By taking part in thorough staff training initiatives, any reluctance will be conquered, and the team’s readiness for the effective use of new tools will be guaranteed. In addition, effective partnerships with technology providers can offer vital support during the implementation stage and aid in customizing solutions to meet particular operational requirements. Real-time monitoring and analytics enable data-driven decision-making, which can enhance operational efficiency, inventory management, and overall supply chain responsiveness.

9. Need for Study

Supply Chain Management (SCM) is a critical component of organizational operations that may be utilized to improve customer satisfaction and corporate performance. It is analogous to an organization's backbone in that it handles critical business activities such as multinational corporations' rapid development, global expansion, and environmental issues, all of which have an indirect or substantial impact on corporate strategy. Customer service can be improved by implementing SCM. Effective supply chain management may enhance customer satisfaction by ensuring that required commodities are available at the appropriate time and place.

10. Limitations

1) Some retailers are unwilling to provide feedback.
2) Respondents may be hesitant to provide accurate data.
3) The researcher needs to visit multiple times to collect the necessary data.
4) Collecting data during working hours is difficult due to respondents' hectic schedules.
5) The research study focused solely on Andhra Pradesh and its surroundings; therefore, results may not apply to other areas.
6) Inaccuracies may have occurred due to time constraints and decreased engagement with respondents.
7) This report's SCM analysis is limited to PMPC Ltd. and may not apply to all firms.

Although descriptive studies are useful for offering detailed portrayals of current situations or phenomena, they have considerable limitations. A significant limitation is their lack of ability to show causality; while they can identify links and trends, they cannot determine cause-and-effect relationships among variables. Moreover, the focus of some descriptive studies is on particular populations or samples at just one moment in time. To establish causality and gain a fuller understanding of the phenomenon, it can be beneficial to combine descriptive research with other methodologies, including experimental or longitudinal studies.
The study offers useful insights into supply chain management practices in the milk industry. Since the research focuses only on Andhra Pradesh, the results mainly reflect the specific economic, cultural, and infrastructure conditions of that area. Factors like consumer preferences, distribution issues, regulatory rules, and supply chain development differ greatly from state to state in India and even more so between countries.

11. Suggestions for Further Study

Comparative studies of emerging and developed dairy sectors could offer valuable insights into how to scale and customize technology-driven SCM solutions. Additionally, including Environmental, Social, and Governance (ESG) metrics in dairy supply chain research would connect operational efficiency goals with broader sustainability and ethical concerns. This addresses growing demands from consumers and regulators. Future work could also look into the socio-economic impacts of adopting technology. This includes the effects on small-holder livelihoods and rural employment, as well as economic results. Expanding research to cover new technologies like Artificial Intelligence, IoT, and blockchain in different policy and market contexts would better inform strategies for resilience and innovation in the global Milk industry. These directions would give a complete view of technology's transformative potential, helping policymakers, industry stakeholders, and researchers create more inclusive, sustainable, and economically beneficial Milk supply chains. However, the researchers also narrated the following suggestions for this study:

11.1. Suggestions to The Agent

1) It is recommended that the agent set up his distribution channels to increase sales.

11.2. Suggestions to The Retailer

1) It is suggested that the agent and the merchant keep communicating often regarding a delay in the learning of the product.
2) The merchant is advised to focus on selling all the products of the company.
3) Retailers need to maintain good relationships with their clients to boost their sales.

11.3. Suggestions to The Customer

1) Browsing customers should have an unobstructed view of the product for a business to identify gaps.

11.4. Suggestions to Milk Collecting Agents

1) It is recommended to the agents that, due to the collection of milk, they can expand their wings in obtaining milk beyond a certain distance.
2) Milk transfer; milk-collecting agents must make good use of the transportation facilities provided. (V V Devi Prasad Kotni, GITAM University, May 2022).

The survey aimed to investigate supply chain design methods and commercial performance among milk processing companies in Andhra Pradesh. Additional research is needed to look into supply chain design techniques and company performance in additional Andhra Pradesh enterprises.

12. Recommendations

An examination of the pertinent literature indicates that the practice of SCM can enhance financial performance as well as operational performance achievement; therefore, the examination demonstrates a beneficial effect of SCM practice and customer collaboration, supplier information, information technology, and information sharing. The practice of supply chain management is closely linked to firm performance, and the role of IT as an SCM practice would be positively correlated with operational performance. Furthermore, the customer relationship has a positive effect on the organization's performance. This study may be cursory since the practice influenced business performance indirectly, via its impact on operational results.

13. Conclusion

The milk sector exemplifies a revolution rather than simply an innovative application of SCM methods and technologies in conjunction with each other. Going further into new frontiers or cutting-edge technologies, and effective supply chain management, shipping processes can thus enhance operational efficiency significantly for the milk business. Sometimes, improvements can mean more than reduced costs and better resource use, quality assurance, and traceability aspects. Manufacturers of milk and milk products can also improve the operations of their plants by using data-driven decision-making processes, which facilitate better real-time decision-making.

First, Objectives must be attained by milk agencies through some activities, and one such activity would be establishing a separate milk supply chain management department to handle all activities regarding the supply chain specific to the milk sector.

Secondly, implementing an ERP system is crucial for the Milk industry to synchronize business goals with cutting-edge technological solutions and the effective utilization of an organization's resources and assets.

Thirdly, Milk Sector companies need to establish a more trustworthy relationship with suppliers, as they are accountable for the direct distribution of milk and milk products to consumers.

Milk organizations ought to prioritize safe and hygienic milk production methods, particularly regarding product quality, as quality serves as the sole aspect that can elevate India to the international stage, achievable solely through effective manufacturing practices.

Fifth, milk agencies can utilize 3PL companies, particularly for outsourcing logistics, as it encompasses not just transportation, customs, and warehouse management but also various additional tasks such as freight bill payment, auditing, contract manufacturing and assembly, packaging, and labelling.

Sixth, organizations in the milk sector would employ milk runs alongside cross-docking and TL & LTL carriers, occasionally integrating package carriers. Products in high demand and necessity are sent straight to retail outlets; products with low demand or less necessary retail locations are moved to or from the distribution centre (DC), and ultimately, milk companies need to offer a platform for receiving customer complaints and feedback.

Complaints and other consumer feedback need to be lodged by milk companies on a dedicated website. A milk sector could set up its website and promote it among customers to facilitate all the required functions of receiving complaints and possible feedback, in addition to all the information that a customer would want.

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