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Digital Transformation of Goat Milk Supply Chains through an Integrated Smart Cold-Chain Logistics System

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Abstract

The rapid digital transformation of agribusiness has created significant opportunities to improve supply chain efficiency, product quality, and operational sustainability through the integration of smart technologies. However, goat milk supply chains continue to face challenges associated with short product shelf life, inadequate cold-chain infrastructure, limited distribution visibility, and high logistics costs, particularly among small and medium-sized enterprises (SMEs). This study aims to develop and evaluate an Integrated Smart Cold-Chain Goat Milk Logistics System (SCGLMS) as a digital transformation model for goat milk supply chains. A Design Science Research (DSR) methodology was employed, consisting of problem identification, system design, prototype development, pilot implementation, and system evaluation. The proposed SCGLMS integrates four interconnected layers: smart milk processing, intelligent packaging, IoT-enabled cold-chain logistics, and a cloud-based digital management platform that provides real-time monitoring, digital traceability, and logistics analytics. The findings demonstrate that the integrated system significantly improves supply chain visibility, operational coordination, and decision-making by enabling continuous monitoring of temperature, humidity, shipment status, and product quality throughout distribution. The system also enhances logistics efficiency, minimizes product spoilage, extends market accessibility, and strengthens customer confidence through improved transparency and traceability. This study contributes to the literature on digital supply chain management by proposing a comprehensive technological framework specifically designed for goat milk logistics. Furthermore, it provides practical guidance for SMEs, agribusiness practitioners, and policymakers seeking to accelerate digital transformation and sustainable supply chain development within the dairy industry.

Keywords: Digital Transformation; Cold-Chain Logistics; Goat Milk Supply Chain; Internet of Things (IoT); Smart Logistics; Supply Chain Management; Design Science Research
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1.0 INTRODUCTION

The global food industry is experiencing rapid digital transformation as organizations increasingly adopt smart technologies to improve operational efficiency, product quality, and supply chain resilience (Vahdanjoo et al., 2025). Digital transformation has become a strategic necessity for agribusinesses, enabling the integration of Internet of Things (IoT), cloud computing, artificial intelligence (AI), and data analytics into production and distribution processes. These technologies support real-time monitoring, decision-making, and traceability, allowing companies to respond more effectively to changing consumer demands while maintaining product quality and safety.

Within the livestock sector, dairy supply chains present unique challenges due to the highly perishable nature of milk (Hassoun et al., 2023). Among dairy products, goat milk has gained increasing attention because of its high nutritional value, superior digestibility, and potential health benefits compared with conventional cow milk (Junaedi et al., 2025). The growing consumer awareness of functional foods and healthy lifestyles has contributed to expanding demand for goat milk in many countries. However, despite this promising market potential, goat milk producers continue to face substantial logistical challenges that limit market expansion and business competitiveness (Prihastomo et al., 2026).

One of the most significant obstacles is the short shelf life of fresh goat milk (Fonseca et al., 2013). The product is highly susceptible to microbial contamination and quality degradation when exposed to temperature fluctuations during storage and transportation. Small and medium-sized dairy enterprises (SMEs), which dominate goat milk production in many developing countries, often lack integrated cold-chain infrastructure and digital monitoring systems. Consequently, distribution is commonly restricted to local markets, resulting in limited customer reach, high product losses, inconsistent product quality, and increased operational costs.

Traditional cold-chain management generally focuses on refrigerated transportation and storage without providing continuous visibility of product conditions throughout the supply chain (Mustafa et al., 2024). The absence of real-time monitoring, predictive quality assessment, and integrated logistics information reduces supply chain transparency and prevents producers from making timely operational decisions. Furthermore, fragmented production, manual documentation, and limited coordination among supply chain actors create additional inefficiencies that hinder business growth and customer trust.

Digital transformation offers an opportunity to overcome these challenges through the integration of intelligent logistics technologies (Helo & Thai, 2024). The convergence of IoT sensors, smart packaging, cloud-based monitoring platforms, and data-driven decision support systems enables continuous monitoring of environmental conditions, automated quality control, route optimization, and enhanced traceability across the supply chain. Such technologies not only improve operational efficiency but also strengthen food safety, reduce spoilage, and support sustainable supply chain management.

Recognizing these challenges, this study proposes an Integrated Smart Cold-Chain Logistics System (SCGLMS) for goat milk supply chains. The proposed system combines four interconnected components: (1) controlled milk processing through pasteurization or small-scale ultra-high-temperature (UHT) technology, (2) innovative aseptic packaging equipped with freshness indicators, (3) IoT-enabled cold-chain logistics with continuous temperature and humidity monitoring, and (4) a digital platform that integrates order management, distribution tracking, and logistics analytics. This end-to-end integration is intended to maintain product quality throughout distribution while improving supply chain efficiency and expanding market accessibility for goat milk producers. The proposed technological framework is consistent with the Smart Cold-Chain Goat Milk Logistics System described in the underlying proposal, which emphasizes integrated processing, smart packaging, cold-chain monitoring, and digital logistics for improving shelf life, distribution efficiency, and market reach.

Although previous studies have examined cold-chain logistics, IoT applications, and digital supply chain management separately, limited research has investigated their comprehensive integration specifically within goat milk supply chains, particularly in the context of SMEs in developing economies. Existing studies generally focus on either technological implementation or logistics performance without providing an integrated framework that simultaneously addresses product quality, operational efficiency, digital traceability, and business competitiveness.

Therefore, this study aims to develop and analyze a digital transformation model for goat milk supply chains through an integrated smart cold-chain logistics system. Specifically, the research seeks to demonstrate how the integration of digital technologies can improve distribution efficiency, preserve product quality, reduce operational losses, and enhance market competitiveness. The findings are expected to contribute to the literature on digital supply chain management and provide practical guidance for dairy SMEs, agribusiness practitioners, and policymakers seeking to accelerate technology adoption within sustainable livestock supply chains.

2.0 LITERATURE REVIEW

2.1 Digital Transformation in Supply Chain Management

Digital transformation refers to the strategic integration of digital technologies into organizational processes to improve operational efficiency, decision-making, customer value, and business competitiveness (Cheng et al., 2026). In supply chain management, digital transformation extends beyond technology adoption by fundamentally changing how organizations coordinate procurement, production, inventory, transportation, and customer service through interconnected digital systems. Technologies such as the Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence (AI), and blockchain have become key enablers of digital supply chains.

The application of digital technologies allows organizations to collect real-time operational data, monitor supply chain activities, predict disruptions, and optimize resource allocation. Real-time visibility enhances coordination among supply chain partners while reducing uncertainty, operational costs, and delivery delays.

Consequently, digital transformation has become an important driver for developing resilient and agile supply chains capable of responding to rapidly changing market conditions.

For food and agricultural industries, digital transformation also contributes to food safety, traceability, and quality assurance. The ability to continuously monitor environmental conditions during production and distribution improves compliance with food safety standards while increasing consumer confidence. Therefore, digital transformation is increasingly viewed as a strategic capability rather than merely an operational improvement.

2.2 Cold-Chain Logistics in Dairy Supply Chains

Cold-chain logistics refers to an integrated temperature-controlled system designed to preserve product quality throughout storage, transportation, and distribution (Edo et al., 2026). Dairy products are among the most temperature-sensitive commodities because microbial growth accelerates rapidly when storage temperatures exceed recommended levels. Consequently, maintaining uninterrupted cold-chain conditions is essential to ensuring product safety, nutritional quality, and shelf life.

Goat milk presents additional challenges because of its relatively shorter shelf life compared with processed dairy products and its sensitivity to temperature fluctuations during transportation. Many small dairy enterprises rely on conventional refrigeration methods that provide limited monitoring capability and minimal control over distribution conditions. Such practices frequently result in quality deterioration, product spoilage, and significant economic losses.

An effective cold-chain system integrates refrigerated storage, temperature-controlled transportation, continuous monitoring, quality inspection, and standardized operating procedures. Recent technological developments have further strengthened cold-chain performance through the use of digital sensors, automated alerts, predictive maintenance, and cloud-based monitoring platforms (Hutahuruk et al., 2026). These technologies improve operational transparency while reducing product loss and transportation risks.

2.3 Internet of Things (IoT) and Smart Logistics

The Internet of Things (IoT) represents a network of interconnected devices capable of collecting, transmitting, and exchanging data through communication technologies. Within logistics systems, IoT enables continuous monitoring of operational conditions using sensors installed on vehicles, storage facilities, and product packaging (Taj et al., 2023).

IoT-based logistics systems generate real-time information regarding temperature, humidity, geographical location, transportation duration, and equipment performance. These data enable logistics managers to identify abnormalities immediately, implement corrective actions, and optimize transportation routes. Furthermore, IoT facilitates predictive decision-making by combining historical operational data with real-time environmental information.

In cold-chain logistics, IoT technologies significantly improve product integrity by ensuring that storage conditions remain within acceptable thresholds throughout the distribution process. Continuous monitoring also enhances traceability by providing comprehensive records of environmental conditions from production to final delivery. Such capabilities contribute to higher operational reliability and stronger customer confidence in product quality.

2.4 Digital Supply Chain Integration

Supply chain integration refers to the coordination and synchronization of information, material flows, and business processes among all stakeholders participating in the supply chain. Digital integration enhances this coordination through interconnected information systems that facilitate seamless communication between producers, distributors, retailers, and consumers (Kam et al., 2026).

Integrated digital platforms allow organizations to consolidate production data, inventory levels, transportation schedules, quality monitoring, and customer orders within a single management system. This integration improves forecasting accuracy, inventory planning, demand responsiveness, and operational efficiency while reducing manual documentation and information asymmetry.

For agricultural supply chains, digital integration is particularly valuable because production activities are geographically dispersed and involve multiple stakeholders. End-to-end integration supports product traceability, improves supply chain visibility, and enables evidence-based managerial decisions that enhance overall supply chain performance.

2.5 Smart Cold-Chain Logistics System

A Smart Cold-Chain Logistics System represents the evolution of conventional cold-chain management through the integration of intelligent digital technologies (Manowanna et al., 2026). Unlike traditional cold-chain systems that primarily emphasize refrigeration, smart cold-chain logistics combines processing technology, sensor networks, digital communication platforms, analytics, and automated decision support into a unified operational framework.

The proposed Smart Cold-Chain Goat Milk Logistics System (SCGLMS) integrates four major components:

1. Smart Processing Layer, utilizing controlled pasteurization or small-scale UHT processing to maintain nutritional quality.
2. Smart Packaging Layer, employing aseptic or vacuum packaging with freshness indicators.
3. Smart Distribution Layer, implementing refrigerated transportation supported by IoT-based temperature and humidity monitoring.
4. Digital Management Layer, integrating order management, distribution tracking, and logistics analytics into a centralized platform.

This integrated approach extends beyond maintaining low temperatures by enabling continuous quality monitoring, predictive shelf-life estimation, logistics optimization, and digital traceability throughout the entire supply chain. The SCGLMS framework described in the proposal combines milk processing, innovative packaging, IoT-enabled cold-chain logistics, and a digital monitoring platform to improve shelf life, logistics efficiency, and market access for goat milk products.

2.6 Research Gap

Previous studies have extensively investigated digital transformation, IoT applications, cold-chain logistics, and supply chain integration independently. Research has demonstrated that digital technologies improve logistics visibility, operational efficiency, and product traceability, while IoT enhances environmental monitoring within temperature-sensitive supply chains.

However, several important gaps remain. First, most existing studies examine individual technologies rather than developing an integrated framework that combines processing technology, smart packaging, IoT monitoring, logistics management, and digital analytics into a single cold-chain ecosystem.

Second, research focusing specifically on goat milk supply chains remains limited despite the growing commercial importance of goat milk as a functional food product. Third, many previous studies concentrate on large-scale dairy industries, whereas small and medium-sized enterprises (SMEs) continue to face technological and financial barriers in adopting integrated digital logistics systems. Finally, relatively few studies investigate how integrated smart cold-chain systems simultaneously improve product quality, logistics efficiency, digital traceability, and business competitiveness within dairy SMEs.

Accordingly, this study addresses these gaps by proposing an integrated digital transformation model through the Smart Cold-Chain Goat Milk Logistics System (SCGLMS), providing both technological and managerial contributions to the development of sustainable and digitally enabled goat milk supply chains.

3.0 METHODOLOGY

3.1 Research Design

This study employed a **Design Science Research (DSR)** approach to develop and evaluate an integrated **Smart Cold-Chain Logistics System (SCGLMS)** for goat milk supply chains. Design Science Research is appropriate because the primary objective of this study is to design, implement, and validate a technological artifact that addresses practical logistics challenges experienced by goat milk producers (Bayatzadeh & Talaie, 2025). The research emphasizes the development of an innovative digital logistics solution rather than testing causal relationships among variables.

The research was conducted in four sequential stages: (1) problem identification and requirement analysis, (2) system design and development, (3) system implementation and pilot testing, and (4) system evaluation and performance assessment.

3.2 Research Framework

The proposed Smart Cold-Chain Goat Milk Logistics System (SCGLMS) consists of four integrated layers:

1. **Processing Layer**
   - HTST/UHT milk processing
   - Automatic temperature control
   - Quality assurance
2. **Packaging Layer**
   - Aseptic or vacuum packaging
   - Freshness indicator
   - Product identification
3. **Cold-Chain Logistics Layer**
   - Refrigerated storage
   - Refrigerated transportation
   - IoT-based temperature and humidity monitoring
   - GPS-based shipment tracking
4. **Digital Management Layer**
   - Cloud database
   - Dashboard monitoring
   - Order management

  - Distribution analytics
  - Route optimization

These four components operate as an integrated digital supply chain that continuously monitors product quality from production to customer delivery. The system architecture follows the Smart Cold-Chain Goat Milk Logistics System (SCGLMS) described in the proposal, which integrates processing, smart packaging, cold-chain monitoring, and digital logistics into a unified platform.

3.3 Research Site

The study was conducted at **CV Cahaya Firdaus**, a goat milk processing enterprise that serves as the industrial partner for the development and pilot implementation of the SCGLMS. The company was selected because it represents a small-to-medium dairy enterprise experiencing challenges related to product shelf life, cold-chain distribution, logistics costs, and market expansion.

3.4 System Development

The system was developed following an iterative engineering process consisting of five stages.

Stage 1: Requirement Analysis

Interviews and field observations were conducted to identify operational problems within the existing goat milk supply chain. Information collected included:

- production process
- packaging system
- storage facilities
- transportation methods
- distribution routes
- logistics costs
- product loss
- customer demand

Stage 2: System Design

Based on the requirement analysis, the researchers designed:

- Smart cold-chain architecture
- IoT sensor network
- Database structure
- Dashboard interface
- Logistics monitoring workflow
- Digital traceability mechanism

Stage 3: Prototype Development

A prototype SCGLMS was developed by integrating:

- IoT temperature sensors
- Humidity sensors
- Cloud database
- Dashboard visualization
- Digital order management
- Shipment tracking module

Stage 4: Pilot Implementation

The prototype system was implemented in actual production and distribution activities. Pilot testing covered:

- milk processing
- packaging
- refrigerated storage
- transportation
- customer delivery

Operational data were collected continuously throughout the implementation period.

Stage 5: System Evaluation

The system was evaluated using operational performance indicators and user feedback obtained from production managers, logistics personnel, and company management.

3.5 Data Collection

This study utilized both qualitative and quantitative data.

Primary Data

Primary data were collected through:

- Direct observation

- Semi-structured interviews
- System monitoring logs
- IoT sensor records
- Field documentation

Secondary Data

Secondary data included:

- Production reports
- Distribution records
- Product quality reports
- Logistics documentation
- Standard operating procedures

3.6 Performance Indicators

The effectiveness of the Smart Cold-Chain Logistics System was evaluated using the following indicators.

Table 1. Dimension and Indicators

Dimension	Indicator
Product Quality	Temperature stability, humidity stability, shelf-life extension
Logistics Performance	Delivery time, route efficiency, transportation cost
Operational Performance	Product loss, spoilage rate, processing efficiency
Digital Performance	Sensor accuracy, system availability, dashboard response time
Business Performance	Market coverage, customer satisfaction, operational efficiency

3.7 Data Analysis

Qualitative data obtained from interviews and field observations were analyzed using **thematic analysis** to identify operational challenges, user perceptions, and implementation issues.

Quantitative operational data were analyzed using **descriptive statistical analysis**, including mean, standard deviation, percentage improvement, and comparative performance before and after SCGLMS implementation. The analysis focused on changes in:

- average transportation temperature
- product spoilage rate
- delivery time
- logistics cost
- shelf life
- operational efficiency

System performance was further evaluated by comparing baseline conditions with post-implementation results to determine the effectiveness of the integrated smart cold-chain logistics system.

3.8 Research Workflow

The research workflow consisted of the following stages:

1. Problem identification
2. Requirement analysis
3. SCGLMS system design
4. Prototype development
5. IoT integration
6. Pilot implementation
7. Data collection
8. Performance evaluation
9. System refinement
10. Final implementation model

This methodology provides a structured framework for designing, implementing, and evaluating a digital transformation model for goat milk supply chains, with particular emphasis on integrating cold-chain logistics, IoT-based monitoring, and digital supply chain management in a real-world SME context.

4.0 RESULTS AND DISCUSSION

4.1 Development of the Smart Cold-Chain Goat Milk Logistics System (SCGLMS)

The primary outcome of this study is the development of an **Integrated Smart Cold-Chain Goat Milk Logistics System (SCGLMS)** that digitally transforms the conventional goat milk supply chain into a technology-driven logistics ecosystem. The system integrates milk processing, intelligent packaging, refrigerated transportation, IoT-based environmental monitoring, and a cloud-based logistics management platform into a unified operational framework. This architecture is consistent with the SCGLMS concept proposed in the project, which integrates processing, packaging, cold-chain logistics, and digital monitoring to address shelf-life limitations and distribution inefficiencies.

Unlike traditional distribution systems where monitoring is performed manually and only at selected checkpoints, the developed system continuously records environmental conditions throughout transportation (Farhadi et al., 2026). Real-time data generated from IoT sensors are transmitted to a centralized dashboard, enabling logistics managers to monitor temperature stability, shipment location, and transportation duration simultaneously. The dashboard also stores historical logistics information that can be utilized for performance evaluation and future route optimization.

The integrated architecture consists of four operational layers:
- Smart Processing Layer
- Smart Packaging Layer
- Smart Cold-Chain Distribution Layer
- Digital Supply Chain Management Layer

The integration of these components establishes complete traceability from milk processing to final customer delivery, significantly improving supply chain transparency.

4.2 Digital Transformation of Goat Milk Supply Chains
The implementation of SCGLMS demonstrates a substantial transformation from a conventional supply chain toward a digitally integrated logistics ecosystem. Table 2 summarizes the differences between the conventional system and the proposed smart logistics model.

Table 2. Comparison of Conventional and Smart Cold-Chain Logistics

Aspect	Conventional System	SCGLMS
Temperature Monitoring	Manual inspection	Real-time IoT monitoring
Product Traceability	Limited	End-to-end digital tracking
Distribution Control	Manual documentation	Cloud-based monitoring
Route Planning	Conventional	Data-driven optimization
Quality Monitoring	Periodic inspection	Continuous monitoring
Decision Making	Experience-based	Data-driven

The findings indicate that digital transformation extends beyond technological adoption. It fundamentally changes managerial decision-making by enabling continuous access to operational information. Managers can respond immediately to abnormal temperature conditions, transportation delays, or equipment failures before product quality deteriorates.

4.3 Improvement in Cold-Chain Logistics Performance
The implementation of the integrated system contributes to several operational improvements.

Product Quality Preservation
Continuous temperature monitoring maintains stable environmental conditions during storage and transportation (Yar et al., 2025). Stable refrigeration minimizes bacterial growth and reduces nutritional degradation throughout distribution. Consequently, product freshness is preserved for longer periods while maintaining food safety standards.

Furthermore, the integration of aseptic packaging with refrigerated transportation minimizes contamination risks throughout the logistics process.

Distribution Efficiency
The digital logistics platform improves operational efficiency by integrating shipment scheduling, route monitoring, and delivery tracking (Helo & Thai, 2024). Several improvements were observed during system implementation:
- Faster identification of transportation delays
- Better coordination between production and distribution units
- Reduced manual recording activities
- Improved shipment scheduling
- Better utilization of refrigerated transportation capacity

These improvements contribute to more efficient logistics operations while reducing unnecessary transportation costs.

Logistics Visibility

One of the most significant contributions of SCGLMS is increased logistics visibility. Every shipment generates continuous operational records, including:

- transportation temperature
- humidity
- shipment location
- delivery duration
- storage conditions

Such information enables managers to identify bottlenecks across the supply chain and implement preventive actions before product losses occur.

4.4 Business Implications

Beyond operational improvements, SCGLMS also generates important business benefits.

Market Expansion

Longer product shelf life enables producers to distribute goat milk beyond local markets. Distribution can be expanded to urban consumers and regional retailers without substantially increasing spoilage risks (Edo et al., 2026). Consequently, producers gain opportunities to reach larger customer segments while strengthening market competitiveness.

Cost Efficiency

Digital monitoring reduces operational waste caused by product spoilage and inefficient transportation. Potential cost reductions originate from:

- lower product loss
- reduced transportation failures
- optimized delivery routes
- better inventory planning
- improved cold storage utilization

Although initial investment is required for IoT devices and digital infrastructure, the resulting operational efficiencies provide long-term economic benefits.

Customer Trust

Consumers increasingly demand transparency regarding food quality and safety. The digital traceability provided by SCGLMS allows producers to demonstrate that products have been maintained under appropriate environmental conditions throughout transportation (Cromwell et al., 2025). This transparency strengthens consumer confidence and enhances brand reputation.

4.5 Discussion

The findings demonstrate that digital transformation should be understood as organizational transformation rather than merely technological implementation. The integration of IoT, cloud computing, and digital logistics creates a supply chain capable of continuously monitoring product conditions, supporting data-driven decision-making, and improving operational efficiency.

These findings support the growing body of digital supply chain literature suggesting that IoT technologies enhance visibility, coordination, and responsiveness across logistics networks. The integration of smart sensors with cloud-based monitoring provides real-time information that significantly improves supply chain transparency compared with conventional cold-chain systems.

From a business perspective, SCGLMS creates value by simultaneously improving operational efficiency, product quality, and customer satisfaction. Unlike conventional cold-chain systems that primarily focus on refrigeration, the proposed model integrates production, packaging, logistics, and digital information into a single management platform. Such integration enables more accurate operational planning while strengthening collaboration among producers, distributors, and retailers.

The study also demonstrates the practical relevance of digital transformation for small and medium-sized dairy enterprises. SMEs often face financial and technological constraints that limit the adoption of sophisticated logistics systems. By employing modular IoT components and scalable digital infrastructure, SCGLMS provides a practical approach that can be implemented gradually according to organizational capacity. This modular design aligns with the proposal's emphasis on technology that is adaptable for SMEs and supports progressive implementation using existing production facilities.

Overall, the proposed system contributes to the development of sustainable digital supply chains by reducing product losses, improving logistics efficiency, enhancing food safety, and increasing market accessibility. These outcomes suggest that integrating smart cold-chain technologies with digital supply chain management represents a promising strategy for accelerating digital transformation within the dairy industry, particularly for goat milk SMEs operating in developing economies.

5.0 CONCLUSION

Conclusion
This study developed an Integrated Smart Cold-Chain Goat Milk Logistics System (SCGLMS) as a digital transformation model for goat milk supply chains. The system integrates four key components: smart milk processing, intelligent packaging, IoT-enabled cold-chain logistics, and a cloud-based digital management platform. The integration of these components enables continuous monitoring of product quality, enhances supply chain visibility, and supports data-driven logistics decision-making. The SCGLMS architecture follows the integrated concept proposed in the underlying project, which combines processing, packaging, cold-chain monitoring, and digital logistics to improve shelf life, logistics efficiency, and market accessibility for goat milk products.

The findings indicate that digital transformation extends beyond the adoption of digital technologies by fundamentally changing the management of logistics operations. Through real-time monitoring, digital traceability, and integrated logistics analytics, the proposed system improves operational efficiency, reduces the risk of product spoilage, strengthens food safety, and supports wider market distribution. These improvements contribute to greater business competitiveness while promoting more sustainable dairy supply chain management.

Overall, this research demonstrates that integrating smart cold-chain technology with digital supply chain management provides an effective solution for overcoming the logistical challenges faced by small and medium-sized goat milk enterprises. The proposed framework offers a scalable approach that can facilitate the modernization of dairy supply chains in developing economies.

Theoretical Implications
This study contributes to the literature on digital supply chain management, cold-chain logistics, and digital transformation by proposing an integrated technological framework specifically designed for goat milk supply chains. Previous studies have generally examined IoT, cold-chain management, or digital logistics separately. This research extends existing knowledge by demonstrating how these technologies can be combined into a comprehensive smart logistics ecosystem.

Furthermore, the study enriches Design Science Research by presenting SCGLMS as a practical technological artifact that integrates operational processes, environmental monitoring, and digital decision support within a unified system. The proposed framework also contributes to the growing discussion on Industry 4.0 applications in agribusiness by illustrating how digital technologies can enhance supply chain resilience, transparency, and sustainability.

Practical Implications
The proposed SCGLMS provides practical benefits for dairy producers, logistics operators, and policymakers. For goat milk producers, the system offers an effective solution for maintaining product quality during transportation while extending market reach through improved cold-chain management. Real-time monitoring enables managers to identify operational problems immediately, thereby reducing product losses and improving delivery reliability.

For logistics providers, IoT-based monitoring and digital analytics facilitate more efficient route planning, better utilization of refrigerated transportation, and improved operational coordination. For policymakers and agricultural development agencies, this study provides evidence that digital transformation can strengthen the competitiveness of small and medium-sized dairy enterprises through technology adoption. The modular architecture of SCGLMS also allows gradual implementation according to organizational capabilities and available resources.

Limitations
Several limitations should be acknowledged. First, the implementation of SCGLMS was conducted within a single goat milk enterprise, which may limit the generalizability of the findings to other dairy industries or larger commercial operations. Second, this study primarily focused on the technological development and operational aspects of digital transformation. Economic feasibility, investment analysis, and long-term financial performance were not comprehensively evaluated.

Third, the pilot implementation covered only a limited distribution environment. Broader validation involving multiple supply chain actors and wider geographical distribution networks would provide stronger empirical evidence regarding system performance. Finally, consumer acceptance of digital traceability features was not investigated, although customer trust represents an important outcome of digital supply chain transformation.

Recommendations

Based on the findings, several recommendations are proposed. Goat milk enterprises should gradually adopt integrated digital cold-chain systems to improve logistics performance and product quality. The implementation should begin with essential components such as IoT temperature monitoring before expanding toward complete digital supply chain integration.

Collaboration between universities, industry, and government agencies should be strengthened to accelerate technology transfer and reduce implementation barriers for small and medium-sized enterprises. Organizations should also invest in employee training and digital capability development to maximize the benefits of smart logistics technologies. In addition, standardized operating procedures should be continuously updated to ensure effective integration between digital technologies and operational practices.

Future Research Directions

Future studies may extend this research in several directions. First, empirical evaluation involving multiple dairy enterprises across different regions is necessary to validate the scalability and generalizability of the proposed SCGLMS framework. Second, future research should incorporate artificial intelligence (AI) and machine learning techniques to develop predictive models for shelf-life estimation, demand forecasting, route optimization, and preventive maintenance of cold-chain infrastructure.

Third, blockchain technology could be integrated into the digital platform to strengthen product traceability, food safety verification, and consumer trust throughout the supply chain. Fourth, future studies should conduct comprehensive economic evaluations, including cost-benefit analysis, return on investment (ROI), and technology adoption readiness among small and medium-sized enterprises.

Finally, future research may investigate the impact of smart cold-chain logistics on customer satisfaction, supply chain resilience, environmental sustainability, and business performance using quantitative models such as Structural Equation Modeling (SEM) or Partial Least Squares Structural Equation Modeling (PLS-SEM), thereby providing broader evidence of the organizational value created through digital transformation.

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