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Research on the Reconstruction and Upgrading of the County-Level Mutton sheep Industry Chain Driven by Digital Technology: A Case Study of Wulian County, Shandong Province

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Abstract

Against the backdrop of rural revitalization and agricultural modernization strategies, the digital transformation of county-level specialized agricultural industry chains has become a key pathway to promote industrial upgrading and enhance the endogenous development capacity of rural areas. This paper takes the mutton sheep industry in Wulian County, Rizhao City, Shandong Province, as a typical case,systematically exploring the technologies and pathways for the digital upgrading of the county-level mutton sheep industry chain along the logical line of status diagnosis-technology adaptation-model innovation-implementation strategy-execution guarantee. Through field research,it diagnoses the collaborative bottlenecks and weak digital infrastructure across the industry chain; then constructs a digital technology adaptation system covering the six major segments of silage cultivation, breeding, slaughtering and processing, deep processing, cold chain logistics, and sales; proposes a trinity industry chain reconstruction model of “horizontal integration, vertical upgrading, and family farms”; and plans a three-stage implementation path of “foundation consolidation-key breakthroughs-system integration.” The study further builds a supporting system from four dimensions: infrastructure, data standards, collaborative mechanisms, and policy support, thereby forming a replicable digital upgrading solution for county-level animal husbandry and providing a reference for the high-quality development of the mutton sheep industry in hilly regions.

Keywords: Digital Transformation; Mutton Sheep Industry Chain; County-Level Economy

1. Introduction

1.1. Research Background

The report of the 20th National Congress of the Communist Party of China called for the comprehensive advancement of rural revitalization and the accelerated development of a strong agricultural nation, with promoting the digital transformation of agriculture as a key component. Subsequently, in 2024, the Ministry of Agriculture and Rural Affairs issued the “Guiding Opinions on Vigorously Developing Smart Agriculture,” explicitly proposing to advance the smart and large-scale development of livestock farming. Integrating digital technologies into the entire Mutton sheep industry chain can improve production efficiency, reduce costs, and increase farmers’ income, allowing practitioners to tangibly benefit from the digital economy and responding to General Secretary Xi Jinping’s call to accelerate rural modernization.

Currently, the digital transformation of the county-level Mutton sheep industry chain still faces numerous challenges: farmers generally lack digital equipment, making it difficult to accurately collect key data; sectors such as slaughtering, processing, and cold-chain logistics have yet to establish unified data standards, resulting in “data silos” across the industry chain that hinder efficient supply-demand matching and quality traceability; the technology application ecosystem remains underdeveloped, with insufficient digital service provision at the county level, high transformation costs for small and medium-sized farmers, and a shortage of multi-skilled talent.The penetration of digital technology will not only enhance operational efficiency but also drive the restructuring of the industrial value chain through the intelligent reorganization of production factors. Its systematic implementation will give rise to a new industrial paradigm of “data elements × modern agriculture,” thereby activating the endogenous momentum of rural revitalization.

1.2. Significance of the Study

(1) Theoretical Significance

1) Enriching the Theory of Industrial Chain Restructuring

This project focuses on the digital restructuring of the county-level Mutton sheep industry chain. By exploring restructuring models and pathways enabled by digital technologies and conducting an in-depth analysis of the application of digital technologies across all links of the industry chain, it refines the theoretical framework for industry chain restructuring, enriches the theoretical implications of agricultural industry chain restructuring, and deepens the theory of modern agricultural industry chain management.

2) Expanding the Theory of Digital Technology Application

This project focuses on the technological requirements for the digital transformation of the Mutton sheep industrial chain in Wulian County. It conducts a multidimensional analysis of the appropriate application of digital technologies across six key industrial chain segments: silage cultivation, Mutton sheep breeding, slaughter and processing, value-added processing, cold-chain logistics, and sales. It establishes a theoretical paradigm for digital empowerment and application with regional characteristics, thereby expanding the academic framework for industrial digital transformation.

(2) Practical Significance

1) Promoting the Digital Transformation and Industrial Chain Restructuring of Wulian County’s Mutton sheep Industry

By identifying digital technology needs, this project explores how digital technologies can integrate the Mutton sheep industry chain to achieve information sharing and resource consolidation, thereby fostering a restructured industry chain model that promotes coordinated development across all segments. Digital technologies enable full-process traceability in Mutton sheep farming, ensuring product quality and safety. Digital tools are utilized to build a Mutton sheep brand with regional characteristics, enhancing the industry's value-added potential. This initiative drives the development of Wulian County's Mutton sheep industry toward intelligent, green, and sustainable practices.

2) Supporting Rural Revitalization and County Economic Development in Wulian County

This project serves as a practical case study for leveraging digital technology to empower the rural revitalization strategy. The implementation of this project's plan will advance digital capabilities, thereby elevating the overall level of rural development, promoting employment, and increasing farmers' incomes. It will foster the sustainable development of the rural economy and provide strong support for the implementation of Wulian County's rural revitalization strategy. Additionally, the application of digital technology will optimize resource allocation during the farming process, reduce negative environmental impacts, and ensure the sustainability of agriculture.

3) Providing a Model and Reference for the Digital Reconstruction of the Mutton sheep Industry Chain in Other Counties

This project focuses on the Mutton sheep industry chain in Wulian County. The research findings and conclusions will establish a replicable and scalable model for the digital-enabled restructuring of the entire Mutton sheep industry chain. This will provide a reference for other counties exploring pathways toward agricultural modernization and rural revitalization, facilitate the exchange and learning of experiences across different regions, and jointly promote the development of the Mutton sheep industry.

1.3. Research Objectives

(1) Identify Technical Requirements for the Digital Reconstruction of Wulian County's Mutton sheep Industry Chain. By analyzing digital requirements—including silage cultivation, livestock breeding, slaughter and processing, value-added processing, cold-chain logistics, sales, and the construction of a big data service platform—this study will propose a targeted list of technical requirements and innovation directions to provide technical support for the project's restructuring. The ultimate goals are to enhance production efficiency, build a sustainable digital ecosystem, and provide replicable solutions for different regions.

(2) Restructuring the Operational Model of the County's Digitalized Mutton sheep Industry Chain. By designing a three-pronged restructuring model of "horizontal integration + vertical upgrading + family farms," we will establish a cross-entity data-sharing mechanism. This will drive the industry chain toward high-value segments such as deep processing and brand value enhancement, thereby achieving an organic integration of small-scale entities with the modern industry chain.

(3) Planning the Implementation Pathway for the Digital Restructuring of the County-Level Mutton sheep Industry Chain. This project establishes a three-phase implementation plan—"Laying a Solid Foundation—Achieving Key Breakthroughs—System Integration"—to scientifically map out the practical path for the digital restructuring of Wulian County's Mutton sheep industry chain and construct a phased, actionable, and sustainable implementation framework.

(4) Establishing a Support System for the Digital Reconstruction of the Mutton sheep Industry Chain. A four-dimensional support system comprising "infrastructure—data standards—collaboration mechanisms—policy safeguards" will be established to support the digital restructuring of the county's Mutton sheep industry chain. Through the systematic integration of these four support elements, the stability of technology penetration, the sustainability of stakeholder participation, and the fairness of value distribution during the restructuring process will be ensured, thereby providing a replicable support system model for the digital transformation of county-level specialty agriculture.

1.4. Current State of Domestic and International Research

1.4.1. Research on the Current Status and Key Bottlenecks of the Mutton sheep Industry Chain

Preliminary studies chiefly concentrated on macro-level strategies for the development of the Mutton sheep industry and enhancements in discrete segments. Zhang (2024) explored development pathways for the Mutton sheep industry as a leading sector from the perspectives of high-quality breed propagation, standardized farming, and brand building, using Huining County as a case study. Gao (2024) have focused on improving quality and efficiency across the entire Mutton sheep industry chain. They have proposed an integrated approach that combines key technologies such as high-quality breed propagation, large-scale fattening, and disease prevention and control. The aim of this approach is to guide the industry toward high-yield, high-quality, efficient, and sustainable development. These studies provide essential references for comprehending the foundational development model of the Mutton sheep industry.

However, as research has progressed, scholars have gradually recognized that coordination issues among various links in the industrial chain are becoming increasingly prominent. Li and Shao (2026) have identified extensive production, information silos in distribution, and inefficient supply-demand matching as the core bottlenecks hindering digital transformation at the broader level of agricultural product supply chains. This assessment can be extrapolated to the county-level Mutton sheep industry. In the beef cattle and sika deer industries of Jilin Province, research by Feng et al. (2025) revealed deficiencies in the deep processing segment, highlighting issues such as the generally low overall level of slaughter and processing enterprises and the high costs associated with new business models, indicating a lack of momentum for extending the industrial chain toward high-value segments. Yin(2024) similarly underscores that within the paradigm of "big agriculture," the digital transformation of the livestock industry confronts tangible challenges, including the dearth of a comprehensive information standardization system and the underutilization of data collection and analysis technologies. Furthermore, This analysis offers a new perspective on the challenges of the industry's green transformation. In their study on the digital transformation of small and medium-sized enterprises, Qian and Chen(2024) argue that efforts to transform individual enterprises are costly and difficult to implement. They contend that a shift toward structural reforms within enterprises and the restructuring of industrial chains is necessary.

1.4.2. Research on the Application of Digital Technologies in the Livestock Industry

In the realm of technological implementation, scholars predominantly acknowledge the promise of technologies such as the Internet of Things and artificial intelligence. As posited by Sui and Hu (2025), the integration of digital intelligent livestock farming systems, underpinned by the technologies of the Internet of Things,artificial intelligence,and big data, holds the potential to achieve precise monitoring of farming environments, animal health, and feed management. This, in turn, has the capacity to enhance production efficiency, reduce farming costs, and optimize resource utilization. Geng (2024) similarly posits that digital empowerment can facilitate enhanced monitoring of farming processes, intelligent decision-making, and efficient operations. Additionally, the implementation of blockchain technology in supply chain traceability has garnered considerable attention. Shen et al. (2026) employed a game theory model to systematically analyze the impact of blockchain traceability on pricing decisions and coordination mechanisms within agricultural supply chains. The proposed solution involved the implementation of a cost-sharing contract based on contributions and a smart contract execution mechanism. This theoretical framework aims to address the existing challenge of establishing and maintaining traceability systems, which have been noted to be difficult. This phenomenon is further substantiated by international research. Elanchezhian Arulmozhi et al. (2024) emphasize the considerable potential of digital twin technology in the livestock sector, noting that it facilitates the development and enhancement of virtual replicas of animal health, welfare, and productivity through the real-time exchange of data.

In the context of model restructuring and pathway exploration, Yin (2024) proposes strategies such as the establishment of an information standard system, innovation in the application of data collection and analysis technologies,and enhancement of the adaptability of digital management systems to advance the digital transformation of the livestock industry.These strategies are drawn from the broader agricultural context. In contrast, Liu (2025) methodically delineates the practical pathways for the digital transformation of the entire livestock industry chain across four dimensions: ensuring a seamless transition, fortifying the foundation for transformation, optimizing the level of transformation, and accelerating the pace of transformation. These include the intensification of technological research and development, the acceleration of the construction of digital infrastructure, and the promotion of the development of digital industrial clusters. Li and Shao (2026) further integrate four dimensions—technology-driven, data-empowered, collaborative networks, and ecosystems—to propose a progressive implementation pathway of scenario-based technology application—collaborative model transformation—digital capability building—evolution of ecosystem governance. This pathway offers a systematic solution to overcome the challenges of traditional supply chain transformation. Qi (2025) employed the transformation of agricultural machinery enterprises as a case study to illustrate the transition from a single-product seller to an integrated service provider, encompassing smart agriculture + intelligent agricultural machinery + technology demonstration bases. Huang and Li (2025) adopt a comprehensive perspective on the digital economy's role in promoting green agricultural transformation. They emphasize the mechanisms through which digital technologies influence transformation across multiple dimensions, including the construction of the entire agricultural industrial chain and rural environmental governance.

1.4.3. Literature Review

In summary, the existing literature provides a rich theoretical foundation and practical insights for understanding the restructuring and upgrading of the county-level Mutton sheep industry chain driven by digital technologies. Research has expanded from the application of technology in individual segments to the restructuring of the entire industrial chain, with a focus on the co-evolution of technology, organization, and institutions. However, how to construct a digital technology and model innovation system that covers the entire chain, is suitable for small and medium-sized entities, and coordinates the interests of all parties—tailored to the actual conditions of county-level areas—remains an important direction for future research to continue exploring. This study addresses the aforementioned shortcomings by conducting systematic research and designing solutions from the perspective of the county-level industrial chain.

1.5. Research Methodology

The technical route of this study is shown in Figure 1, covering five stages: status diagnosis, technology adaptation, model innovation, implementation path, and support system.

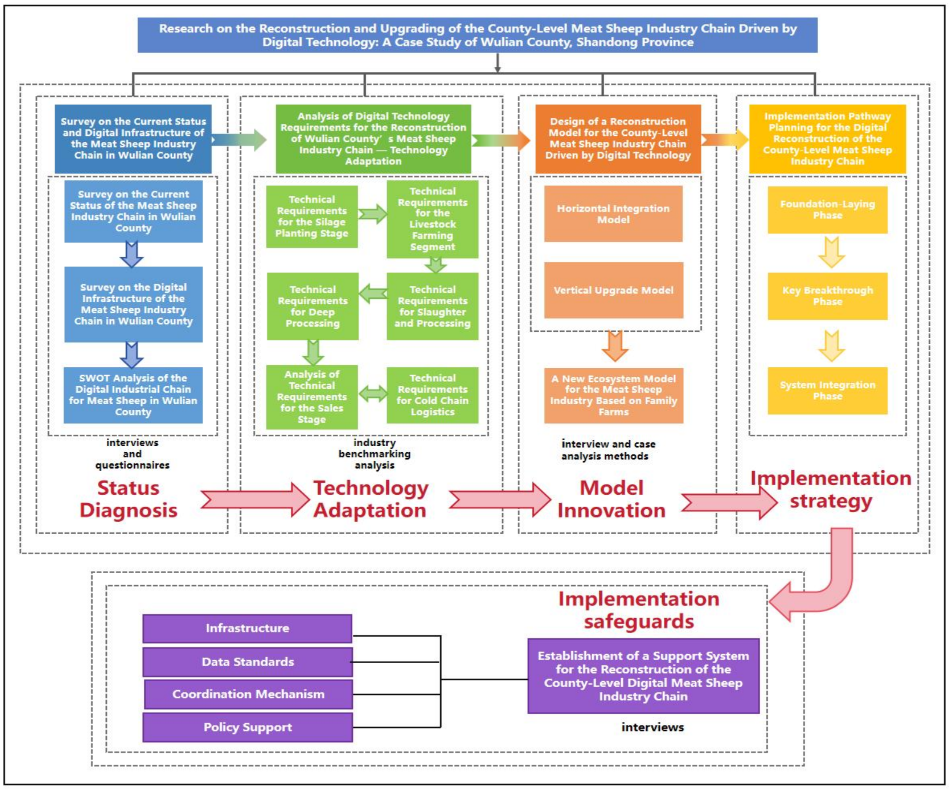

Figure 1. Research Roadmap

2. Survey on the Current Status and Digital Infrastructure of the Mutton sheep Industry Chain in Wulian County — Status Diagnosis

2.1. Industrial Chain Collaboration and Digitalization Basic Diagnosis

2.1.1. Silage Cultivation Segment

The cultivation segment is dominated by small-scale family farms, lacking unified variety planning and planting guidance. The selection of cultivated varieties does not align well with the feed requirements of the breeding segment, and the annual fluctuation rate of silage corn yield and quality reaches 15%–20%, making stability difficult to guarantee.Leading enterprises have innovatively utilized locally sourced coarse feeds—such as peanut vines and whole-plant corn—mixed into silage. This approach addresses the issue of excessive acidity when feeding exclusively whole-plant corn silage, enriching feed nutrition while regulating pH levels (Sun et al., 2023). However, this practice has not been widely adopted. Significant disconnects persist between the cultivation, harvesting, and livestock farming segments, and an effective mechanism linking crop production and livestock farming has not been established, thereby constraining the orderly development of the industry chain's upstream sector.

2.1.2. The sheep farming segment

The livestock farming sector is highly fragmented, and there is an urgent need to improve the levels of scale and standardization. Management typically relies on manual labor, which is not only time-consuming and labor-intensive but also prone to errors (Wang, 2024).The level of scale in the farming sector is low, with large-scale farms accounting for less than 20% of the total, while small and medium-sized scattered farmers make up 80%. There are significant disparities among farms of different sizes in terms of feeding management, disease prevention and control, and market-ready standards, resulting in inconsistent product quality. There is insufficient coordination between the farming sector and downstream slaughter and processing enterprises; order fulfillment rates are below 75%, and it is difficult to effectively align market-ready timing with quality standards.

2.1.3. Slaughter and Processing Sector

Slaughter facilities are underdeveloped, with traditional equipment accounting for 70% of the total. The vast majority of enterprises have relatively small designed slaughter capacities, and there is a severe shortage of precision cutting and cold storage capabilities (Feng et al., 2025). The coverage rate of automated cutting equipment is below 30%, which affects product yield and standardization.The product mix is dominated by primary whole carcasses and simple cuts (accounting for 85%); capabilities for fine-cutting and customized processing are weak, making it difficult to meet the market's diverse demand for mutton products and limiting the effective enhancement of product value.

2.1.4. Deep Processing Segment

The development of the deep processing segment lags significantly, and there is an urgent need to unlock product value-added potential. Currently, the market remains dominated by primary cut products, with the comprehensive utilization rate of by-products such as bones, blood, and offal remaining below 20%. There is a lack of R&D and production capabilities for high-value-added products such as ready-to-eat mutton products and pre-packaged meals. The product structure is monotonous, and a diversified deep processing product system has not been established, limiting the potential for improving the industry's overall profitability.

2.1.5. Cold Chain Logistics

Cold chain logistics infrastructure coverage is incomplete, and the level of specialization needs to be improved. Refrigerated storage capacity and distribution cannot yet meet industry demands, and there are shortcomings in the precision and stability of temperature control during transportation. Coordination between various cold chain segments is not sufficiently seamless, and the level of information management is low. This affects the quality assurance and timeliness of mutton products during distribution, increasing the risk of product wastage.

2.1.6. Sales Segment

Sales channels remain traditional and limited, with insufficient capabilities for brand building and market expansion. The industry primarily relies on wholesale markets and traditional retailers, with inadequate development and utilization of emerging channels such as e-commerce platforms and new retail models. While the "Wulian Black Sheep" regional brand has achieved some recognition, it lacks effective marketing strategies and consumer engagement mechanisms, making it difficult to establish stable high-end sales channels and achieve product premium pricing.

2.2. SWOT Analysis of the Digital Industrial Chain for Mutton sheep in Wulian County

After examining the current status of the system diagnostics industry chain and the digital foundation, this study applies the SWOT analysis framework to comprehensively assess the internal and external strategic environment of the digital transformation of the mutton sheep industry in Wulian County. The SWOT analysis indicates that the current state of the mutton sheep industry chain in Wulian County can be summarized as 'solid foundation but poor coordination; some attempts but shallow application; data availability but numerous silos.' The core contradiction in its digital transformation is not the technological backwardness of individual segments, but the dual absence of an overall industry chain coordination mechanism and a digital ecosystem. Therefore, the key path for industrial upgrading lies in leveraging digital technologies to empower the organizational model of the industry chain, data circulation rules, and value distribution mechanisms, thereby breaking existing bottlenecks, seizing strategic opportunities, and achieving a holistic leap in the industry chain. The SWOT analysis is shown in Figure 2.

3. Analysis of Digital Technology Requirements for the Reconstruction of Wulian County's Mutton sheep Industry Chain—Technology Adaptation

Based on the preliminary diagnosis of the current status of the six core segments of Wulian County's Mutton sheep industry chain, and in conjunction with the county's industrial foundation, sector structure, and resource advantages, this study has established a comprehensive digital technology adaptation system covering the entire chain (as shown in Figure 3).This system

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addresses the pain points and bottlenecks in each segment of the industrial chain by proposing corresponding digital solutions. It aims to break down data barriers, optimize resource allocation, and enhance total factor productivity, thereby providing technical support for the overall upgrading of Wulian County's Mutton sheep industry.

Dimension	Strengths (S)	Weaknesses(W)	Opportunities (O)	Threats (T)
Silage Cultivation Segment	abundant breeding resources; favorable geographical conditions	management relies on manual labor; disconnects between cultivation and livestock farming; lack of traceability system	remote sensing enables precision cultivation; growing demand for high-quality silage	high transformation costs for small farmers; extreme weather risks
Sheep Farming Segment	distinctive genetic resources; leading enterprises and demonstration bases	low adoption rate of smart equipment; difficulty in collecting key production data; weak early warning and traceability	mature IoT and AI technologies; growing market demand for high-quality mutton	risk of animal disease outbreaks; shortage of interdisciplinary talent
Slaughter and Processing Sector	stable raw material supply; initial automated production lines	incomplete end-to-end traceability; low level of intelligent production scheduling; insufficient environmental monitoring	blockchain and machine vision can improve quality and efficiency; consumption upgrading drives traceability	increasing regional competition; rising food safety and production standards
Deep Processing Segment	proximity to raw material sources; high freshness	dominated by primary processing; weak deep processing capacity; low brand influence; lack of key technologies like intelligent	significant market potential for ready-to-cook meals and functional products; high-value utilization of by-products	high R&D investment; market uncertainty for new products
Cold Chain Logistics	favorable location in Shandong; acceptable transportation access	incomplete cold chain facilities; risk of chain disruption; lack of cross-entity coordination; low resource utilization; outdated temperature monitoring	fresh food e-commerce and quality consumption drive cold chain demand; route optimization improves efficiency and reliability	high cold chain operating costs; pressure for energy conservation and emission reduction
Sales Segment	distinctive local breed (Wulian Black Sheep)	single sales channel; lack of consumer insight and precision marketing; weak brand building; low premium capacity	new models like e-commerce live-streaming can rapidly expand market; consumption upgrading creates branding opportunities; big data enables precision marketing	intense competition from other mutton-producing regions; high market price volatility

SWOT analysis chart of the six major links in the sheep industry chain of Wulian County

Figure 2. SWOT Analysis Chart of the Entire Mutton sheep Industry Chain in Wulian County

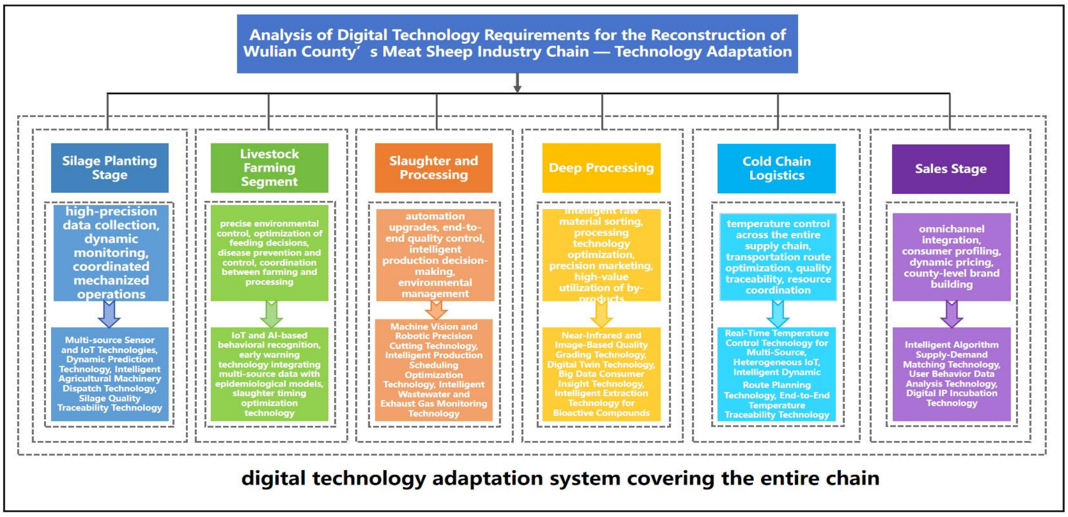

Figure 3. Technical Roadmap for the Study on Digital Technology Needs Analysis for the Reconstruction of Wulian County's Mutton sheep Industry Chain

3.1. Technical Requirements for the Silage Planting Stage

To address requirements for high-precision data collection, dynamic monitoring of county-level silage corn planting zones, mechanized operation coordination, and crop-livestock integration, a digital adaptation technology system for the silage cultivation stage has been established. A digital technology system covering the entire breeding process has been built, as shown in Figure 4.

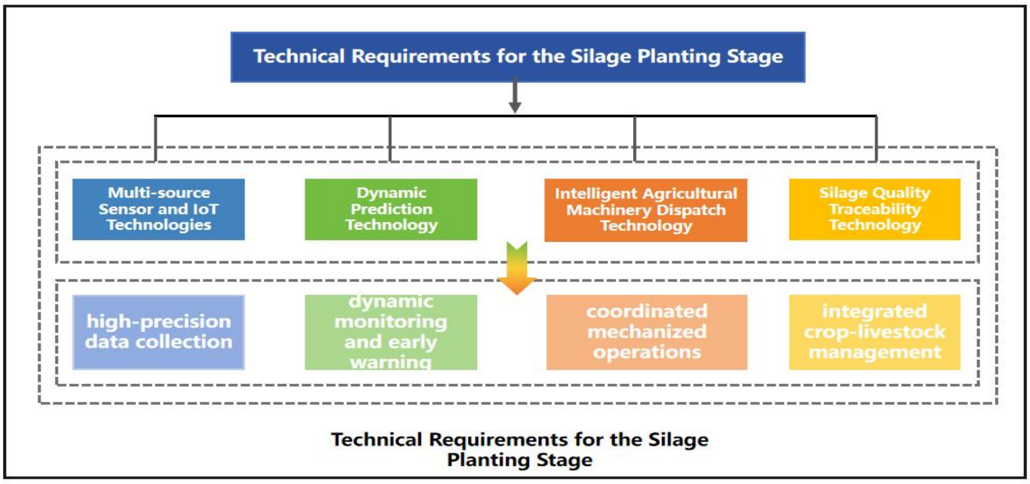

Figure 4. Diagram of the Digital Silage Planting Technology System

3.1.1. Multi-source Sensor and IoT Technologies

To meet the demand for high-precision data collection, a multi-source sensor and IoT technology system must be established. This system deploys various sensors—including those for soil moisture, nutrients, and meteorological conditions—to enable real-time collection and remote transmission of planting environment parameters. It achieves precise, continuous monitoring of the farmland environment, replacing traditional manual judgment based on experience. This provides a scientific data foundation for precision irrigation and fertilization, significantly improving resource utilization efficiency.

3.1.2. Dynamic Prediction Technology

To address the need for dynamic monitoring and early warning, a dynamic prediction technology based on remote sensing and machine learning must be established. By analyzing remote sensing data from satellites or drones and utilizing machine learning models, this technology evaluates the growth status of silage corn and provides intelligent early warnings for risks such as drought, pests, and diseases.This enables routine, non-intrusive monitoring of large-scale cultivation areas, allowing for the early detection of potential issues and guiding producers to take early intervention measures, thereby effectively reducing yield losses caused by natural disasters.

3.1.3. Intelligent Agricultural Machinery Dispatch Technology

To address the need for coordinated mechanized operations, it is necessary to develop intelligent agricultural machinery dispatch technology that integrates GPS with path optimization. This technology integrates GPS navigation systems into agricultural machinery and employs path optimization algorithms to provide optimal route planning. This significantly improves the precision and efficiency of agricultural machinery operations, reduces redundant work and missed areas, lowers fuel consumption and labor costs, and enables precision field management in large-scale farming operations.

3.1.4. Silage Quality Traceability Technology

To meet the needs of integrated crop-livestock management, it is necessary to develop silage quality traceability technology based on blockchain and RFID. This technology leverages the immutability of blockchain records and the uniqueness of RFID identifiers to track information throughout the entire process—from planting and harvesting to transportation to the livestock farm. This achieves transparency and reliable traceability of silage quality, ensuring feeding safety; simultaneously, it facilitates the alignment of supply and demand information between the crop production and livestock sectors, optimizes resource allocation, and enhances synergies across the industrial chain.

3.2. Technical Requirements for the Livestock Farming Segment

To address requirements such as intelligent sensing, precise environmental control, optimized feeding decisions, joint disease prevention and control, and coordination between farming and processing, it is necessary to establish a technology system tailored to the farming process.A digital technology system covering the entire breeding process has been built, as shown in Figure 5.

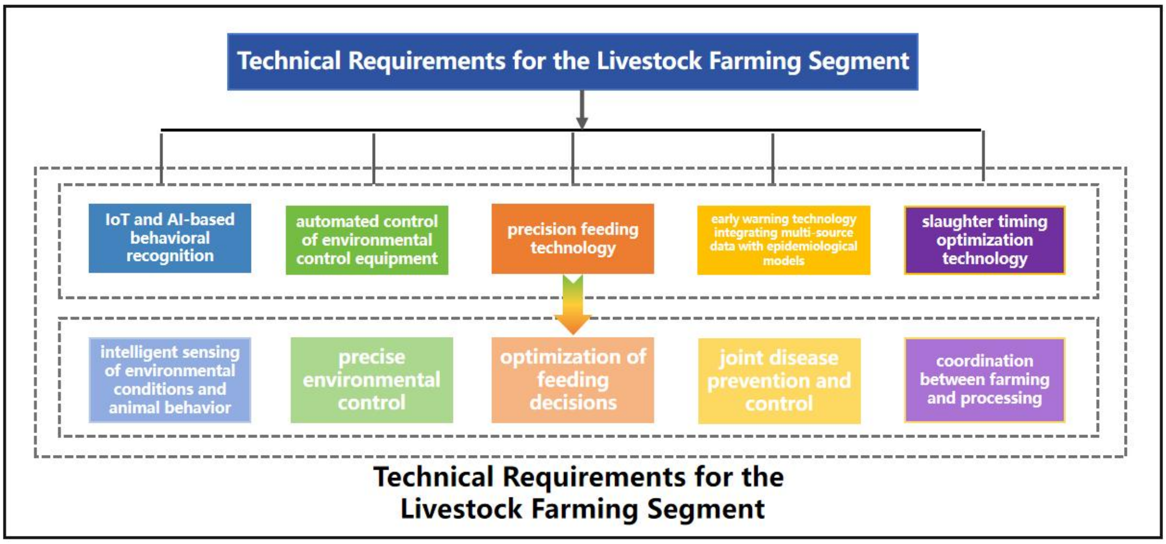

Figure 5. Diagram of the Digitalized Farming Process Technology System

3.2.1. IoT and AI Behavioral Recognition Technology

To meet the demand for intelligent sensing of environmental conditions and animal behavior, an IoT and AI-based behavioral recognition system must be established. This system deploys various sensors to monitor indoor environmental parameters and utilizes AI algorithms, such as video analysis, to identify sheep behaviors such as feeding and drinking. This enables 24/7 uninterrupted monitoring of the farming environment and the health status of the sheep, significantly improving management efficiency and facilitating the early detection of health issues through the identification of behavioral abnormalities.

3.2.2. Automated Environmental Control Technology

To meet the need for precise environmental control, an autonomous control system for environmental control equipment based on data models must be established. This technology automatically controls the activation and deactivation of environmental control equipment—such as fans and water curtains—based on real-time environmental data. This creates a stable and suitable growth environment for the sheep, reduces environmental stress, improves animal welfare and growth performance, and simultaneously achieves energy savings and reduced consumption.

3.2.3. Precision Feeding Technology

To optimize feeding decisions, a precision feeding technology based on dynamic nutritional models must be developed. This technology calculates and adjusts daily ration formulations and feeding amounts using dynamic nutritional models, based on the sheep's different growth stages, body condition, and real-time feeding data. It also customizes specialized ration formulations according to the nutritional requirements of different physiological stages, such as lambs (0–3 months old), growing sheep (3–6 months old), and pregnant ewes (Wei, 2025). This achieves "on-demand" precision nutrition, prevents feed waste, optimizes the feed-to-meat ratio, reduces feeding costs, and promotes uniformity and health in the flock.

3.2.4. Early Warning Technology Integrating Multi-Source Data and Epidemiological Models

To meet the needs of joint disease prevention and control, it is necessary to develop early warning technology that integrates multi-source data with epidemiological models. This technology consolidates data from various sources—including environmental, immunological, and distribution data—and utilizes epidemiological models to intelligently assess the risks of disease occurrence and transmission. This enables early warning and rapid response to disease risks, enhances biosecurity levels, and effectively reduces economic losses caused by diseases.

3.2.5. Slaughter Timing Optimization Technology

To address the need for coordination between farming and processing, it is necessary to develop slaughter optimization technology based on production capacity and market data. This technology uses big data analysis to predict market price trends and, combined with real-time inventory structures at farms, intelligently recommends the optimal timing and scale for slaughter. This achieves market-demand-oriented, refined slaughter management, smooths out production fluctuations, optimizes the connection between upstream and downstream segments of the industrial chain, and improves overall economic efficiency and market responsiveness.

3.3. Technical Requirements for Slaughter and Processing

To address requirements for automation upgrades, end-to-end quality control, intelligent production decision-making, and environmental management, a digitalized technical framework for the slaughter and processing segment has been established. A digital technology system covering the entire slaughtering and processing process has been constructed, as shown in Figure 6.

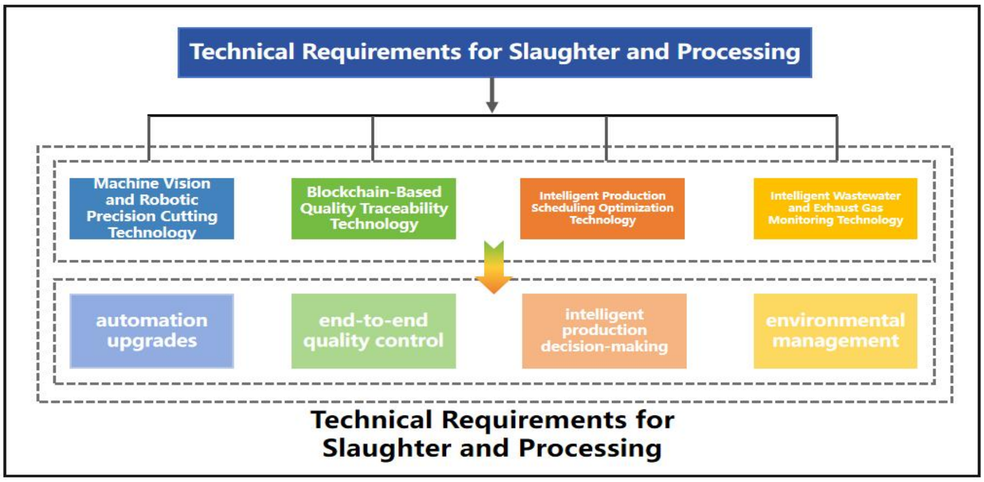

Figure 6. Diagram of the Digital Slaughter and Processing Technology System

3.3.1. Machine Vision and Robotic Precision Cutting Technology

To meet automation upgrade requirements, machine vision and robotic precision cutting technology must be implemented. This technology uses machine vision to grade carcasses and guides robotic arms to perform standardized cutting operations. This significantly improves cutting efficiency and standardization, reduces labor intensity and labor costs, and ensures product specification consistency.

3.3.2. Blockchain-Based Quality Traceability Technology

To meet the demand for end-to-end quality control, a blockchain-based quality traceability system must be established. This technology records key information from all stages—including slaughter, cutting, and quarantine—on the blockchain, creating an immutable traceability record. This achieves full transparency and traceability from farm to table, enhances consumer trust, and provides a strong guarantee of product quality and safety.

3.3.3. Intelligent Production Scheduling Optimization Technology

To meet the need for intelligent production decision-making, intelligent production scheduling optimization technology must be developed. This technology uses algorithms to automatically generate optimal production schedules based on data such as orders, energy consumption, and equipment status. This optimizes production processes, reduces waiting times and energy wastage, improves equipment utilization and on-time order delivery rates, and achieves cost reduction and efficiency gains.

3.3.4. Intelligent Wastewater and Exhaust Gas Monitoring Technology

To meet environmental compliance requirements, intelligent wastewater and exhaust gas monitoring technology must be implemented. This technology uses smart sensors to monitor the operational status of treatment facilities and emission indicators in real time. It enables real-time monitoring of environmental data and ensures compliance with emission standards, thereby guaranteeing production compliance, reducing environmental risks, and promoting green and sustainable development.

3.4. Technical Requirements for Deep Processing

To address needs such as intelligent raw material sorting, processing optimization, precision marketing, and high-value utilization of by-products, a technology framework tailored for the deep processing stage has been established. A digital technology system covering the entire process of intensive processing has been established, as shown in Figure 7.

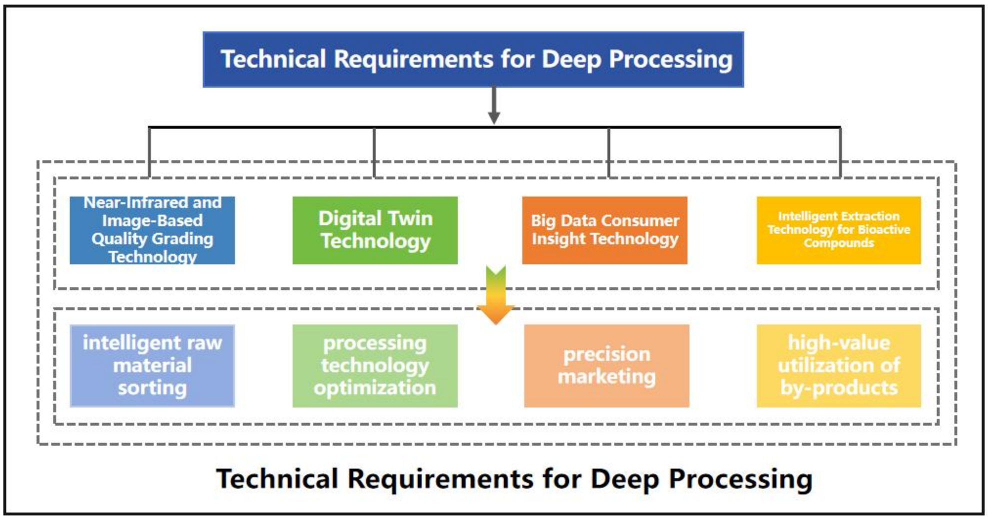

Figure 7. Diagram of the Digital Technology System for Deep Processing

3.4.1. Near-Infrared and Image-Based Quality Grading Technology

To address the need for intelligent raw material sorting, near-infrared and image-based quality grading technology must be developed. This technology utilizes near-infrared spectroscopy to analyze internal composition and combines it with image recognition of external characteristics to achieve automatic grading of raw meat. This enables refined and standardized classification of raw materials, providing a foundation for developing differentiated products and ensuring optimal utilization of high-quality materials, thereby enhancing the overall value of the raw materials.

3.4.2. Digital Twin Technology

To meet the need for processing technology optimization, a digital twin technology system must be established. This technology creates a virtual map of the physical production line to perform virtual debugging and simulation-based optimization of process parameters. This approach shortens R&D cycles, reduces waste of raw materials and energy consumption associated with physical testing, and significantly improves process stability and product quality.

3.4.3. Big Data Consumer Insight Technology

To meet the needs of precision marketing, a big data consumer insight system must be established. This technology analyzes market sales data and user behavior to accurately map consumer preferences and market demand trends. It guides product R&D and market strategies, facilitates the transition from a “production-oriented” to a “market-oriented” approach, and improves the return on marketing investment.

3.4.4. Intelligent Extraction Technology for Bioactive Compounds

To address the need for high-value utilization of by-products, we must develop intelligent extraction technology for bioactive compounds. This technology employs targeted separation and process control to efficiently extract high-value bioactive substances from by-products such as sheep bones and blood. This enables the tiered utilization and high-value development of by-products, turning waste into valuable resources, extending the industrial chain, and enhancing overall economic benefits.

3.5. Technical Requirements for Cold Chain Logistics

To address the needs for temperature control across the entire supply chain, transportation route optimization, quality traceability, and resource coordination, a tailored technical framework for cold chain logistics has been established. A digital technology system covering the entire cold chain logistics process has been established, as shown in Figure 8.

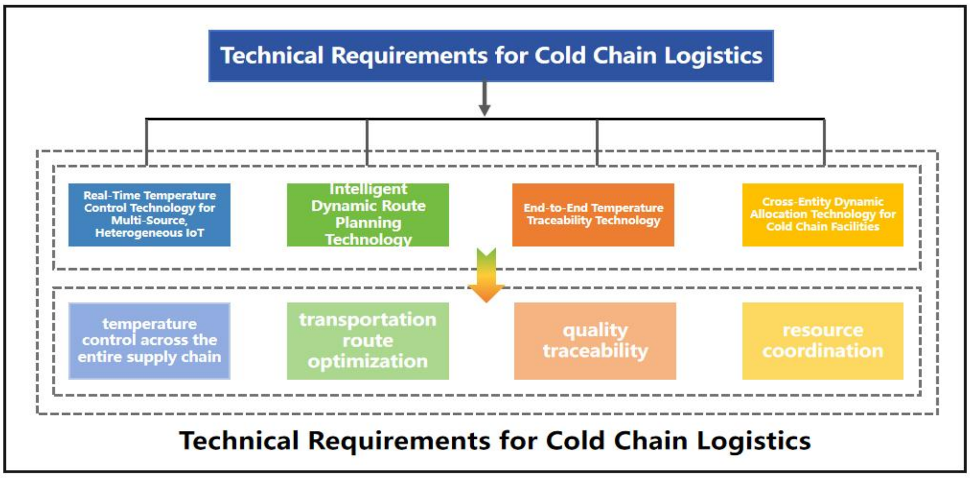

Figure 8. Diagram of the Digital Cold Chain Logistics Technology System

3.5.1. Real-Time Temperature Control Technology for Multi-Source, Heterogeneous IoT

To address temperature control requirements across the entire supply chain, it is necessary to develop real-time temperature control technology for multi-source, heterogeneous IoT systems. This technology integrates various types of sensors—including those for temperature, humidity, and location—to monitor the entire cold chain and trigger proactive alerts in the event of anomalies. This ensures that lamb products are transported in a consistently controlled temperature environment, effectively preventing quality degradation and safeguarding product safety and freshness.

3.5.2. Intelligent Dynamic Route Planning Technology

To address the need for transportation route optimization, it is necessary to develop intelligent dynamic route planning technology. This technology uses real-time traffic conditions, order distribution, and other factors to dynamically plan optimal delivery routes through intelligent algorithms. This achieves the goals of shortening transportation time, reducing fuel consumption and transportation costs, and improving vehicle utilization and customer service levels.

3.5.3. End-to-End Temperature Traceability Technology

To meet quality traceability requirements, an end-to-end product temperature traceability system must be established. This technology records historical temperature and humidity data at every stage of the cold chain, creating a comprehensive "temperature history." This provides data-backed evidence for product quality, facilitates the identification of responsibility in quality disputes, and enhances quality control capabilities and consumer trust.

3.5.4. Cross-Entity Dynamic Allocation Technology for Cold Chain Facilities

To address resource coordination needs, a technology for dynamic cross-entity allocation of cold chain facilities must be developed. This technology integrates social cold chain resources through a shared platform to enable online booking and intelligent scheduling. This approach revitalizes idle cold chain assets, reduces operational costs for small and medium-sized enterprises, and improves the overall utilization efficiency of cold chain resources across the county.

3.6. Analysis of Technical Requirements for the Sales Stage

To address demands such as omnichannel integration, consumer profiling, dynamic pricing, and county-level brand building, a sales-stage adaptation technology system has been established. A digital technology system covering the entire sales process has been established, as shown in Figure 9.

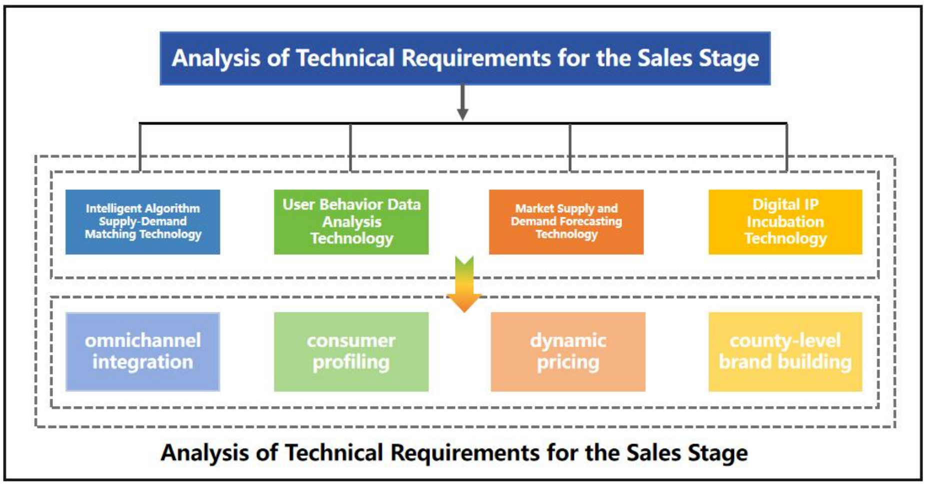

Figure 9. Diagram of the Digital Sales Phase Technology System

3.6.1. Intelligent Algorithm Supply-Demand Matching Technology

To address the need for omnichannel integration, intelligent algorithm-based supply-demand matching technology must be developed. This technology uses intelligent algorithms to coordinate inventory and order data across multiple channels, including online platforms and offline stores. It achieves real-time synchronization of inventory information and intelligent order allocation, thereby preventing stockouts or overstocking and improving order fulfillment efficiency and the consumer experience.

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3.6.2. User Behavior Data Analysis Technology

To address consumer profiling needs, user behavior data analysis technology must be developed. This technology collects and analyzes user transaction and browsing data to accurately map consumer preferences and price sensitivity. It enables a deep understanding of the target audience's needs and characteristics, providing data support for product positioning, personalized recommendations, and precision marketing.

3.6.3. Market Supply and Demand Forecasting Technology

To address dynamic pricing needs, market supply and demand forecasting technology must be developed. This technology utilizes time-series models and machine learning algorithms to predict changes in market demand and adjusts pricing based on price sensitivity models. This enables prices to respond sensitively to market changes, maintains a competitive edge, and maximizes sales revenue and profit margins.

3.6.4. Digital IP Incubation Technology

To address the needs of county-level brand building, digital IP incubation technology must be developed. This technology creatively packages and disseminates regional culture and industrial characteristics through digital means such as short videos and virtual avatars. This approach enhances the brand awareness and cultural value of "Wulian Mutton sheep," facilitates a transformation from selling products to selling brands, and strengthens the industry's core competitiveness.

4. Design of a Reconstruction Model for the County-Level Mutton sheep Industry Chain Driven by Digital Technology

Based on a diagnostic analysis of the current state of Wulian County's Mutton sheep industry chain and research on technological adaptation, this paper addresses key issues such as "loose chain structure, fragmented information, and inefficient coordination." Guided by social-technical systems theory, it proposes a three-pronged model for the digital restructuring of the county's Mutton sheep industry chain: "horizontal integration, vertical upgrading, and integration of family farms" (as shown in Figure 10). This model breaks down resource barriers through horizontal integration to establish a foundation for data sharing; drives value enhancement through vertical upgrading to reshape the industry's profit structure; and achieves inclusive development through a family farm integration mechanism to ensure that the benefits of transformation reach a wide range of farmers. These three dimensions mutually reinforce one another and progress in a stepwise manner, jointly constructing a modern county-level Mutton sheep industry ecosystem characterized by high-efficiency collaboration, value sharing, and inclusive development.

4.1. Horizontal Integration Model

The core of the horizontal integration model lies in breaking down "data silos" and "resource barriers" between various links in the industrial chain. By building a unified digital platform, it enables centralized management and digital analysis of data across six key segments—silage cultivation, Mutton sheep farming, slaughter and processing, deep processing, cold-chain logistics, and sales—thereby achieving efficient coordination among all links in the industrial chain.

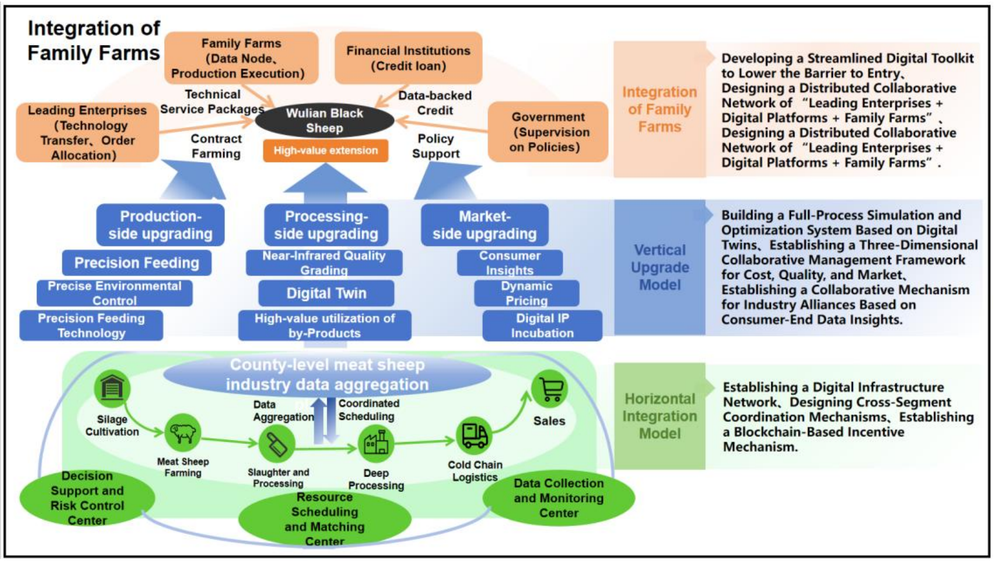

Figure 10. Technical Roadmap for the Design of a Digital Technology-Driven Reconstruction Model for the County-Level Mutton sheep Industry Chain

4.1.1. Establishing a Digital Infrastructure Network

By adopting unified interface standards and IoT technology, hardware facilities—such as smart sensors and environmental monitoring systems—dispersed across various stages are connected to a single network. This enables real-time data collection and remote transmission regarding cultivation environments, livestock conditions, inventory status, logistics locations, and sales orders, thereby establishing an efficient digital infrastructure network for the Mutton sheep industry.

4.1.2. Designing Cross-Segment Coordination Mechanisms

By designing cross-stage supply-demand matching algorithms, the platform can use sales-side order forecasts to drive backward planning for production schedules in the processing stage, slaughter arrangements in the breeding stage, and silage supply in the farming stage. Through the platform, the county-level sheep industry chain can achieve real-time information sharing, thereby improving the industry chain's response speed and resource utilization efficiency.

4.1.3. Establishing a Blockchain-Based Incentive Mechanism

By introducing blockchain technology to build a trusted traceability system, information from key nodes—including silage procurement, the rearing process, slaughter and quarantine, cold chain temperature control, and transaction flows—is recorded on the blockchain as evidence. This provides a basis for subsequent profit distribution, thereby upgrading simple transactional relationships into profit-sharing relationships based on data sharing.Through horizontal integration, the Wulian Mutton sheep industry will transition from fragmented operations to collaborative symbiosis, laying the organizational foundation for the restructuring and upgrading of the industrial chain.

4.2. Vertical Upgrade Model

The vertical upgrade model builds a digital upgrade framework to break down data silos across all industrial chain segments, foster the formation of industry alliances, and drive collaborative supply chain optimization. This model propels the industry's evolution from a focus on primary production and processing toward high-value segments such as deep processing and brand value enhancement, thereby achieving an overall improvement in the industrial chain's efficiency.

4.2.1. Building a Full-Process Simulation and Optimization System Based on Digital Twins

Leveraging full-industry-chain data accumulated through the horizontal integration platform, the vertical upgrading model employs digital twin technology to construct a virtual simulation model covering the entire "breeding, farming, processing, and sales" process.In the breeding segment, simulate the impact of different feeding regimens on growth performance; in the slaughter and processing segment, virtually debug the process parameters of automated cutting lines; in the cold-chain logistics segment, dynamically optimize delivery routes and temperature control strategies. Through a strategy of simulation followed by implementation, we can significantly improve operational efficiency and quality control standards in existing processes, providing technical support for the industry's transition toward refinement and standardization.

4.2.2. Establishing a Three-Dimensional Collaborative Management Framework for Cost, Quality, and Market

In the cost control dimension, real-time monitoring of energy consumption and waste via the Internet of Things (IoT), combined with big data analysis to identify cost anomalies, provides a roadmap for precise cost reduction. In the quality traceability dimension, a comprehensive quality record spanning from breeding to sales is established; through data correlation analysis, early identification of quality risks and rapid response are achieved, enabling end-to-end quality traceability across the entire sheep meat supply chain.In the market responsiveness dimension, big data analysis of consumer-end data is used to gain insights into demand trends, which are then fed back to all links in the industrial chain, facilitating a shift from a "production-oriented" to a "market -oriented" approach.

4.2.3. Establishing a Collaborative Mechanism for Industry Alliances Based on Consumer-End Data Insights

Based on consumer insights and market forecasts aggregated by the platform, leading enterprises can form strategic alliances with upstream and downstream entities to jointly establish production standards, collaborate on new product development, and share brand premium.Within the alliance, growers adjust crop varieties based on consumer feedback, breeders optimize slaughter schedules according to market demand, and processors develop new products centered on consumer preferences. All parties in the industry chain work toward the common goal of enhancing the brand value of "Wulian Mutton sheep," transforming the traditional loose supply-demand relationship into a strategic partnership of collaborative innovation, thereby improving the overall efficiency and effectiveness of the supply chain.

4.3. A New Ecosystem Model for the Mutton sheep Industry Based on Family Farms

Addressing the fundamental characteristic of the county-level Mutton sheep industry—where family farms constitute the majority of producers—this study develops a lightweight digital toolkit and designs a distributed collaborative network comprising “leading enterprises + digital platforms + family farms.” This approach resolves the challenges small-scale farmers face in integrating with the industry chain, achieving an organic connection between small-scale producers and the modern industry chain.

4.3.1. Developing a Streamlined Digital Toolkit to Lower the Barrier to Entry

Addressing the limited capital and weak technical capabilities of family farms, the model design eschews “one-size-fits-all” comprehensive smart solutions. Instead, it develops a digital toolkit comprising lightweight, modular, and mobile-based farming management systems and cloud-based technical service modules. Farmers can manage breeding records, consult experts remotely, purchase inputs, and receive orders simply through a smartphone, significantly lowering the barriers to transformation.

4.3.2. Designing a Distributed Collaborative Network of “Leading Enterprises + Digital Platforms + Family Farms”

Leading enterprises, through platforms in the form of 'contract farming' and 'technical service packages,' implement unified production standards and scientific management plans down to family farms. The platform records the data flows and financial flows during the cooperation process, forming credible collaboration evidence. Within this network, family farms are no longer isolated raw material producers but 'data nodes' on the digitalized industrial chain, with their production data fed into the platform in real time, serving as a micro-level foundation for driving industrial chain collaboration.

4.3.3. Building a Data-Driven Mechanism for Benefit Sharing and Empowerment

Through close collaboration with leading enterprises and the platform’s data-driven empowerment, family farms can access stable sales channels, scientific farming guidance, and financial services such as credit loans based on production data.The platform’s transparent operational mechanisms ensure that family farms receive a reasonable share of the value generated along the industrial chain, transforming them from passive suppliers of raw materials into indispensable components of the digital industrial ecosystem. This truly achieves the organic integration of small-scale entities with modern industrial chains, necessitating the construction of a new industrial ecosystem that is more resilient and equitable.

5. Implementation Pathway Planning for the Digital Reconstruction of the County-Level Mutton sheep Industry Chain

To facilitate the implementation and deployment of the digital restructuring and upgrading of the county-level Mutton sheep industry chain, a systematic analysis has been conducted. The future strategic implementation of the county-level Mutton sheep digital industry chain is currently divided into three phases: the Foundation Consolidation Phase, the Key Breakthrough Phase, and the System Integration Phase. This provides a systematic operational guide for the digital restructuring of county-level specialty agricultural industry chains. The digital upgrade path for the Wulian County Green Mutton sheep Industry Chain is shown in Figure 11.

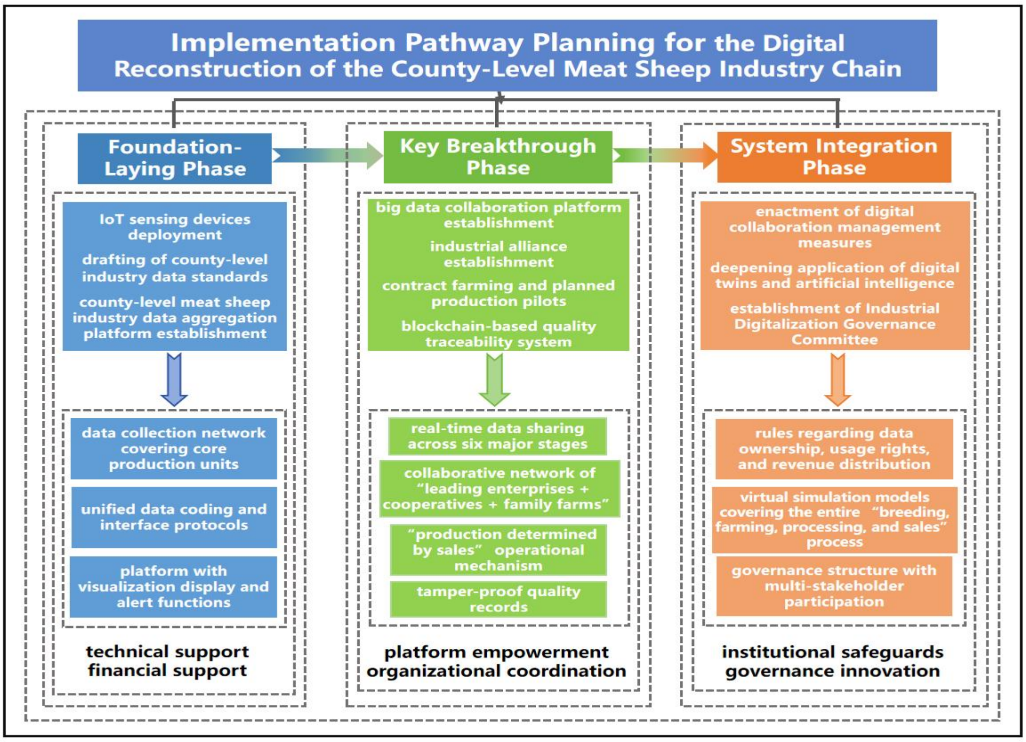

Figure 11. Technical Roadmap for the Reconstruction and Upgrading of the County-Level Mutton sheep Industry Chain Driven by Digital Technology

5.1. Foundation-Laying Phase

This phase focuses on establishing a digital sensing network and infrastructure that covers the entire industrial chain. To address data blind spots across various segments of Wulian County's Mutton sheep industrial chain, IoT sensing devices will be deployed according to priority. A regional agricultural data center will be constructed to integrate production environment data, temperature and humidity data from distribution channels, and market data from the consumer end, providing computing power and storage support for intelligent decision-making (Li & Shao, 2026). Form a data collection network covering the core production units. Simultaneously advance the drafting of industry data standards, unifying data codes and interface protocols across various links, laying the foundation for subsequent data integration. Initially establish a county-level Mutton sheep industry data aggregation platform to achieve centralized data storage and visual display, with functions such as data quality verification, anomaly alerts, and basic report generation, providing reliable data support for subsequent collaboration and decision-making.

5.2. Key Breakthrough Phase

This stage focuses on establishing a collaborative operation mechanism across different entities and links. Relying on a network of digital facilities, a county-level Mutton sheep industry big data collaboration platform is constructed to enable real-time data sharing across six major links. Efforts are made to promote the establishment of an industry alliance of 'leading enterprises, cooperatives, and family farms,' piloting order-based agriculture and planned production models. The platform automatically generates planting, breeding, and processing plans based on sales-end order forecasts, achieving collaborative scheduling of 'production based on sales, supply based on production.' At the same time, a blockchain-based quality traceability system is established, recording key node information such as silage procurement, breeding, slaughtering, and cold chain on-chain, reshaping collaboration among entities and creating conditions for full-chain integration.

5.3. System Integration Phase

This stage focuses on consolidating the collaborative mechanism and improving the governance system to form a sustainable industrial digitalization ecosystem. At the institutional level, the "Digital Collaborative Management Measures for the Mutton sheep Industry in Wulian County" will be introduced to clarify data ownership and profit distribution rules, and to establish an incentive and restraint mechanism shared across different entities. At the technical level, applications of digital twins, artificial intelligence, and other technologies will be deepened to build a full-process virtual simulation model, enabling intelligent optimization of production planning, inventory scheduling, and logistics routes. At the governance level, an Industrial Digitalization Governance Committee comprising the government, leading enterprises, cooperatives, and family farms will be established, responsible for platform supervision, standard revisions, and dispute coordination, ensuring that digitalization achievements benefit all stakeholders fairly and forming a replicable and scalable model for digital transformation in county-level livestock industries.

6. Establishment of a Support System for the Reconstruction of the County-Level Digital Mutton sheep Industry Chain

Based on the aforementioned planning for the restructuring model and implementation path of Wulian County's Mutton sheep industry chain, this study constructs a four-dimensional support system comprising "infrastructure—data standards—collaboration mechanisms—policy safeguards" to ensure the stability of technology penetration, the sustainability of stakeholder participation, and the fairness of value distribution throughout the restructuring process.

6.1. Infrastructure

The infrastructure focuses on eliminating blind spots in data collection and breaking through physical spatial barriers, providing hardware support for the circulation of data across the entire chain. This study proposes a digital infrastructure architecture of 'One Cloud, One Network, One Platform.' 'One Cloud' refers to the county-level mutton sheep industry cloud data center, which aggregates multi-source data across the entire industry chain and provides computing power and storage services; 'One Network' refers to the IoT sensing network covering all stages of planting, breeding, processing, cold chain, and sales, enabling standardized data collection at the front end and real-time transmission; 'One Platform' refers to the mutton sheep industry big data collaboration platform, serving as the core hub for data aggregation and business collaboration. Through overall planning and intensive construction, duplicated construction and system fragmentation are avoided, laying a unified hardware foundation for the reconstruction of the industry chain.

6.2. Data Standards

Develop a comprehensive chain-of-standards system covering data collection, exchange, and security. At the collection level, standardize basic data elements such as silage corn variety codes, sheep ear tag identifiers, and product batch codes; at the exchange level, formulate API interface specifications and data exchange protocols to ensure interoperability among heterogeneous systems; at the security level, establish a data classification and tiered management system, clarifying data access rights and privacy protection boundaries. The standard formulation adopts a 'government-led, enterprise-participated, expert-reviewed' model to ensure compliance with industry norms while accommodating the realities of county-level operations.

6.3. Coordination Mechanism

Establish a digital governance framework based on “government guidance + platform operation + entity self-governance.” At the government level, the Bureau of Agriculture and Rural Affairs will take the lead in establishing an Industrial Digitalization Promotion Committee in collaboration with representatives from leading enterprises and cooperatives, which will be responsible for strategic planning and cross-departmental policy coordination; at the platform operation level, an independent Industrial Digitalization Operations Center will be established to handle daily platform maintenance, technical upgrades, and data management;At the stakeholder self-governance level, a distributed decision-making mechanism comprising “industry alliances and family farms” will be established through the platform, granting stakeholders participation rights and a voice in matters such as order matching, production standards, and profit distribution.Simultaneously, smart contract technology will be introduced to enable automatic execution and transparent settlement based on predefined conditions. Transaction rules and profit-sharing schemes for segments such as silage supply, livestock services, and slaughtering and processing will be encoded, enabling automatic execution and transparent settlement based on predefined conditions. This will reduce coordination and trust costs from a technical perspective and establish a verifiable, decentralized trust mechanism.

6.4. Policy Support

Integrate four types of policy instruments: fiscal, financial, talent, and regulatory. At the fiscal level, establish special subsidies for digital infrastructure, implementing differentiated rewards and subsidies for the procurement of IoT devices and platform integration. At the financial level, leverage platform data to build "credit profiles for farmers," promote the development of credit financing products such as "data loans," and transform data assets into credit certificates. At the talent level, implement the "Digital New Farmer" training program, jointly carrying out targeted training of multi-skilled personnel in cooperation with universities and enterprises. At the regulatory level, explore pilot programs for the confirmation and trading of data assets, clarifying rules for data revenue ownership and distribution. These four types of policy instruments form an organic linkage, creating an incentive-compatible institutional environment that allows various stakeholders to naturally achieve synergy with the overall objectives of the industry chain while pursuing their own profit maximization.

7. Research Conclusions

7.1. Key Findings

(1) Constructed a systematic analytical framework for the digital reconstruction of the county-level Mutton sheep industry chain. The study overcomes the limitation of traditional research, which focuses solely on the application of technology in individual segments. From the perspective of the entire industry chain, it identifies structural contradictions in Wulian County's mutton sheep industry, described as 'having a foundation but poor coordination, having attempts but shallow application, having data but many silos.' This diagnostic framework provides an analytical tool for understanding the core barriers to the digital transformation of county-level agricultural industry chains.

(2) Establishing a Digital Technology Adaptation System Covering Six Major Stages. Targeting the core pain points in the six major areas of silage cultivation, mutton sheep breeding, slaughtering and processing, advanced processing, cold chain logistics, and sales, specific digital technology adaptation solutions have been proposed for each. This system encompasses cutting-edge technologies such as the Internet of Things, artificial intelligence, blockchain, and digital twins, forming a complete technological chain from data collection and intelligent decision-making to execution optimization, providing a clear technical blueprint and selection basis for full-chain digital reconstruction.

(3) The "Three-in-One" restructuring model innovatively resolves the challenges of industrial chain collaboration. Horizontal integration breaks down resource barriers by building a unified data platform, establishing the foundation for data sharing; vertical upgrading drives the value chain toward deep processing and brand value enhancement through digital twins and consumer insights; family farm integration achieves the organic connection between small-scale entities and modern industrial chains through lightweight digital toolkits and distributed collaborative networks. These three dimensions support each other, jointly constructing a modern industrial ecosystem that is collaborative, efficient, value-sharing, and inclusive in development.

(4) Establishing a phased implementation roadmap and a four-dimensional support system to ensure the successful implementation of the restructuring. A three-stage progressive implementation path of 'strengthening the foundation—achieving key breakthroughs—system integration' has been formulated, clarifying the objectives, tasks, and technological priorities for each stage. At the same time, a support system has been constructed from four dimensions: 'infrastructure—data standards—collaboration mechanisms—policy assurance,' providing systematic support for the reconstruction of the industrial chain and ensuring the stability of technology penetration, the continuity of stakeholder participation, and the fairness of value distribution. This framework offers a replicable model for the digital transformation of county-level characteristic agriculture in other regions.

7.2. Research Limitations and Outlook

7.2.1. Limitations of the Study

Due to limitations in the research period and data availability, some benefit assessments are based on theoretical models, and their economic feasibility and practical effects require verification through subsequent practice. In addition, the study focuses on a single case in Wulian County. Although a theoretically universal framework has been distilled, differences in industrial foundations and policy environments across other counties mean that the generalizability of the conclusions still needs validation in more contexts. Furthermore, the depth of discussion on fundamental institutional issues such as the definition of data property rights, the establishment of cross-entity trust mechanisms, and the design of benefit distribution rules still needs to be strengthened, as these factors are precisely the key variables affecting the sustainability of digital reconstruction.

7.2.2. Future Prospects

Track the implementation process of the digital reconstruction in Wulian County and conduct long-term dynamic evaluations to empirically verify the actual effectiveness of the reconstruction model; apply the "diagnosis—adaptation—model—path—guarantee" research framework developed in this study to other counties or different livestock types, and test its applicability and transferability through comparative studies; conduct in-depth exploration of the value creation mechanisms and distribution mechanisms of data elements in the agricultural industry chain, particularly focusing on institutional design issues such as data ownership confirmation, trading rules, and profit sharing, thereby providing theoretical support for the market-oriented allocation of data elements; under the background of technological empowerment, pay attention to changes in rural governance structures and the reshaping of farmers' agency, and explore feasible paths for the deep integration of digital technologies and rural society, achieving an organic unity of efficiency improvement and inclusive development.

Author Contributions:

Liu Sitian: Proposed the research idea; designed the industrial chain reconstruction model and implementation path; created charts and diagrams; conducted a diagnostic analysis of the current situation in Wulian County; determined research methods; performed formal analysis; conducted survey research; provided research resources; responsible for data collation; drafted the initial manuscript; reviewed and edited the manuscript; supervised the research process; responsible for project management. Wang Yibo: Proposed the research idea; conducted background research; conducted research on digital technology needs; carried out survey research; responsible for data collation; created charts and diagrams. All authors have read and agreed to publish this manuscript.

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Conflict of Interest:

The authors declare no conflict of interest.

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