

Optimizing Cold Chain Logistics for Plateau Specialty Agricultural Products under the Company-Farmer Order Model

Siwen Wu, Xiaoyan Yan*

School of Economics, Yunnan Normal University, Kunming, China

*Corresponding author: Xiaoyan Yan, 277055349@qq.com

Copyright: © 2026 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), permitting distribution and reproduction in any medium, provided the original work is cited.

Abstract: Plateau specialty agricultural products are constrained by long transport distances, unstable temperature control, weak rural logistics infrastructure, and fragmented smallholder production. This paper reframes cold chain logistics under the company-farmer order model as an integrated problem of route optimization, temperature-risk control, and contract coordination. Based on a literature review and a case-based scenario reconstructed from a plateau agricultural supply chain, the study proposes a compact optimization framework that incorporates transport cost, delivery time, vehicle capacity, cold-chain loss, weather and road risk, and allowable temperature fluctuation. The scenario comparison indicates that optimized routing and digital temperature monitoring may reduce transport cost from 5,000 to 4,000 RMB per ton, shorten delivery time from 48 to 36 hours, reduce temperature-related loss from 10% to 5%, increase transport efficiency from 80% to 95%, and lower risk frequency from 15% to 8%. The results suggest that cold chain upgrading in plateau areas should not be treated as a purely technical routing problem. It requires coordinated investment in refrigerated infrastructure, information sharing between firms and farmers, incentive-compatible order contracts, and public support for rural logistics platforms. The paper contributes a policy-oriented analytical framework for improving agricultural supply-chain resilience in geographically disadvantaged plateau regions.

Keywords: Company-farmer model; Plateau agriculture; Cold chain logistics; Route optimization; Rural development

Online publication: June 19, 2026

1. Introduction

Cold chain logistics is a key condition for the commercialization of fresh agricultural products because quality deterioration is jointly determined by time, temperature, humidity, handling frequency, and transport uncertainty. In plateau regions, this general problem becomes more difficult. Agricultural production is often dispersed across mountainous villages, while roads are longer, gradients are steeper, weather is less predictable, and refrigerated storage facilities are unevenly distributed. As a result, the logistics system must solve two tasks

at the same time: it must reduce transport cost and delivery time, and it must maintain product quality under unstable temperature and road conditions ^[1].

The company-farmer order model provides an institutional response to fragmented production. Firms usually supply technical services, market channels, purchase contracts, and logistics organization, while farmers provide products according to agreed standards. The model can reduce market uncertainty and improve standardization, but it also creates coordination risks. If production information is incomplete, if farmers lack packaging and temperature-control knowledge, or if the firm cannot organize timely collection, the cold chain becomes discontinuous at precisely the point where quality loss begins. Therefore, the model should be evaluated not only as a marketing arrangement but also as a logistics-governance mechanism ^[2].

Previous manuscript argues that existing studies have discussed cold-chain route optimization, contract mechanisms, and intelligent logistics, but relatively few studies have integrated these dimensions for plateau specialty agricultural products. This paper therefore converts the original descriptive analysis into an international-journal style short article. Its core research question is: how can a company-farmer order system improve cold chain transport performance for plateau agricultural products while controlling cost, time, temperature loss, and operational risk? The answer proposed here is an integrated framework combining route optimization, digital monitoring, contract coordination, and public infrastructure support.

2. Literature-based analytical framework

Three literature streams support the framework as follows:

- (1) The first concerns route optimization for perishable goods. Cold-chain vehicle routing differs from ordinary routing because the objective is not only shortest distance or lowest fuel cost. It must include freshness decay, refrigerated energy consumption, delivery time windows, vehicle capacity, and the probability of delay. Domestic studies on fresh agricultural product distribution have used shortest-path methods and heuristic algorithms to reduce transport cost and improve timeliness, but they usually assume relatively normal road networks. Plateau regions require additional risk parameters for road closure, weather disruption, and temperature volatility;
- (2) The second stream concerns supply-chain coordination under the company-farmer model. Order agriculture can stabilize supply-demand relations, but contract incompleteness, market price fluctuation, and weather shocks may weaken farmer compliance and enterprise procurement stability. Weather-index contracts, futures or options, and game-theoretic incentive designs have been proposed to reduce default risk. For cold chain logistics, these mechanisms matter because stable delivery volume and predictable quality are prerequisites for efficient vehicle scheduling and warehouse utilization;
- (3) The third stream concerns digital and multimodal cold chain upgrading. International research increasingly emphasizes IoT sensors, real-time temperature monitoring, big-data scheduling, blockchain traceability, and railway or multimodal logistics networks. For long-distance plateau transportation, digital monitoring can reduce hidden temperature breaks, while multimodal or hub-based systems may lower cost where road transport is unstable. However, these technologies are effective only when they are embedded in a governance structure that links farmers, firms, logistics providers, and public agencies ^[3].

3. Materials and methods

This study uses a qualitative-quantitative case reconstruction method. The qualitative component summarizes the constraints of plateau cold chain logistics under the company-farmer order model. The quantitative component uses a scenario comparison derived from the original manuscript to compare logistics indicators before and after route and management optimization. Since the available data come from a course-paper case rather than a full audited enterprise database, the results should be interpreted as scenario-based evidence for model demonstration rather than as a statistically generalizable estimate^[4].

The optimization logic is expressed as a multi-criteria objective. Let C denote transport cost, T delivery time, L temperature-related loss, and R operational risk. A simplified objective can be written as minimizing $Z = \alpha C + \beta T + \gamma L + \delta R$, where α , β , γ , and δ are weights determined by enterprise priorities and product perishability (**Table 1**). The model is subject to vehicle capacity, road accessibility, cold-storage availability, allowable temperature fluctuation, delivery time windows, and order-volume constraints. This form is intentionally compact because the paper aims to provide a policy-oriented framework rather than a complete algorithmic solution.

The practical optimization procedure consists of four steps as outlined:

- (1) Production and order information are collected from farmers through a digital platform;
- (2) Candidate routes are evaluated by distance, road condition, travel time, and risk coefficient;
- (3) Cold-chain requirements are matched with vehicle capacity and product sensitivity;
- (4) The enterprise adjusts collection points, transfer links, and warehouse layout to reduce unnecessary handling and temperature exposure.

This procedure converts the company-farmer model from a simple procurement contract into an integrated supply-chain coordination mechanism.

Table 1. Core variables and constraints in the plateau cold chain optimization framework

Variable or constraint	Definition	Function in the model
Path length (D)	Total distance from collection point to market or warehouse	Affects cost, time, and exposure to road risk
Transport cost (C)	Fuel, labor, refrigeration, vehicle depreciation, and handling cost	Main economic objective to be minimized
Delivery time (T)	Total time from farm collection to market arrival	Determines freshness and order reliability
Temperature-control demand (T_c)	Energy and equipment needed to maintain target temperature	Links product quality with refrigerated capacity
Vehicle capacity (V)	Maximum load of refrigerated vehicle	Constrains dispatch frequency and consolidation
Risk coefficient (R)	Weather, road closure, slope, delay, or accident probability	Represents plateau-specific uncertainty
Temperature fluctuation (ΔT)	Allowable temperature deviation during transport	Defines cold-chain quality boundary

4. Results

The scenario comparison shows that the integrated optimization approach improves all five selected indicators. The most direct effect is cost reduction. Transport cost declines from 5,000 to 4,000 RMB per ton, a 20% reduction. This improvement is mainly associated with shorter routes, fewer transfer links, better vehicle loading, and reduced repeated handling. For smallholder-based plateau agriculture, this is important because

logistics costs often absorb a large share of product value and weaken competitiveness in external markets.

Delivery time decreases from 48 to 36 hours, a 25% reduction. This result indicates that route redesign and coordinated collection schedules can substantially improve timeliness. Time reduction is not only a commercial advantage; it also reduces the duration of temperature exposure and therefore supports quality preservation. In a cold chain system, cost and quality objectives are often connected: a shorter and more reliable route can reduce both transport expenditure and freshness loss.

Temperature-control loss declines from 10% to 5%, representing a 50% reduction. This is the strongest relative improvement in the scenario. It suggests that the primary bottleneck in the original system is not simply long distance, but discontinuous temperature management during collection, transit, transfer, and delivery. IoT temperature sensors, real-time alarms, and standardized loading procedures can help identify temperature breaks before product quality is irreversibly damaged.

Transport efficiency increases from 80% to 95%, while risk frequency decreases from 15% to 8%. These results imply that optimization improves both operational productivity and resilience. In plateau regions, risk reduction is particularly valuable because road interruption or weather delay can quickly transform a logistics problem into a quality and market-access problem. The results therefore support a central argument of this paper: plateau cold-chain logistics should be treated as a coupled system of routing, refrigeration, information, and institutional coordination (**Table 2**).

Table 2. Scenario-based performance changes after cold chain optimization

Indicator	Before optimization	After optimization	Change
Transport cost	5,000 RMB/ton	4,000 RMB/ton	-20%
Delivery time	48 hours	36 hours	-25%
Temperature-control loss	10%	5%	-50%
Transport efficiency	80%	95%	+15%
Risk frequency	15%	8%	-47%

5. Discussion

The findings generate four core implications. First, plateau cold-chain upgrading should begin from the route-temperature-risk nexus. A low-cost route is not optimal if it increases temperature fluctuation or weather exposure. Conversely, a technically stable refrigerated route may be economically infeasible if vehicle loading is low. The model therefore requires a multi-objective view in which cost, time, quality loss, and risk are jointly evaluated.

Moreover, the company-farmer order model must be strengthened through information integration. Farmers need clear standards for harvesting time, grading, packaging, pre-cooling, and delivery to collection points. Enterprises need timely production forecasts and quality data to arrange vehicles and cold storage. A digital platform can reduce information asymmetry and make procurement, scheduling, and quality monitoring more predictable. Without this information layer, even advanced refrigerated vehicles may be underused.

Moreover, contract design should be linked with logistics performance. Traditional order contracts often focus on purchase price, quantity, and quality grade. For plateau cold chains, contracts should also include delivery windows, packaging standards, temperature responsibility, and incentive clauses for timely and standardized delivery. Farmers who meet cold-chain-compatible standards can receive price premiums or

service subsidies, while firms can reduce losses caused by uncertain supply and non-standard handling.

Lastly, public policy remains necessary because many constraints exceed the capacity of a single enterprise. Plateau roads, rural collection stations, cold-storage nodes, inspection standards, and digital infrastructure have public-good characteristics. Government support should prioritize shared refrigerated warehouses, village-level collection points, road maintenance in key agricultural corridors, and subsidies for IoT monitoring equipment. Policy should not simply subsidize individual vehicles; it should build a network that lowers the fixed cost of cold-chain participation for small farmers ^[5,6].

6. Practical implications for rural development

For rural development, the proposed framework suggests that cold chain logistics should be understood as a form of productive infrastructure rather than as a downstream commercial service. In many plateau villages, farmers can produce differentiated products with strong ecological and regional value, but they cannot fully capture that value because quality deteriorates before products reach higher-value markets. This weakens farmgate prices and discourages standardization. A cold chain system that connects village collection, pre-cooling, refrigerated transport, and market distribution can increase the effective market radius of small farmers and make specialty agriculture more compatible with modern retail requirements.

The first implementation priority is the construction of shared collection and pre-cooling nodes. Individual farmers usually cannot afford independent cold-storage equipment, and single enterprises may hesitate to invest in scattered villages with unstable order volumes. Shared facilities located near production clusters can solve this coordination failure. These nodes should provide grading, packaging, pre-cooling, short-term storage, and digital registration. Once products are standardized at the collection point, the enterprise can consolidate loads and reduce both vehicle idling and repeated handling. This directly supports the route optimization mechanism proposed in the model.

The second priority is the formation of data-based procurement scheduling. The company-farmer model is often limited by delayed information. Farmers may report output only when products are ready for sale, while companies may arrange vehicles only after receiving fragmented supply information. This sequential decision process increases waiting time and temperature exposure. A platform that records planting area, expected harvest date, product grade, estimated volume, and collection-point inventory can transform logistics planning from reactive dispatching into anticipatory scheduling. This is especially important for plateau products because weather events may suddenly change road availability and harvest timing.

The third priority is contract design that internalizes cold-chain standards. A purchase contract should not only specify quantity and price. It should specify harvest maturity, packaging requirements, maximum waiting time before collection, responsibility for pre-cooling, temperature records, and quality-dispute procedures. Incentive clauses can reward farmers who meet standardized delivery requirements and compensate firms that provide shared logistics services. Such clauses reduce opportunistic behavior and create a clearer division of responsibility across the cold chain. They also make the empirical indicators in **Table 2** more operational, because cost, time, loss, efficiency, and risk can be linked to contract performance.

The fourth priority is targeted public support. Public investment should focus on bottlenecks that generate network-wide benefits: rural road maintenance, electricity reliability for cold storage, public inspection facilities, data platforms, and training services. Subsidies for refrigerated vehicles alone may create unused

capacity if collection points, order information, and storage nodes are absent. A better policy sequence is to support shared infrastructure first, then encourage enterprises to integrate farmers into stable procurement and logistics networks. In this sense, cold chain policy becomes a rural industrialization policy rather than a narrow transport policy.

Finally, the model has implications for future empirical research. Subsequent studies should collect high-frequency data, including GPS route trajectories, temperature and humidity logs, loading rates, fuel consumption, labor cost, spoilage rates, and delivery delays. These data would allow researchers to estimate the weights of cost, time, loss, and risk more rigorously and to compare different algorithms, such as genetic algorithms, simulated annealing, ant colony optimization, and mixed-integer programming. More importantly, cross-county comparison could identify whether the same optimization strategy works for vegetables, fruits, flowers, dairy products, mushrooms, and medicinal crops, which differ substantially in temperature sensitivity and market value.

6.1. Robustness, transferability, and measurement requirements

Although the scenario results are directionally clear, a rigorous international-journal version should distinguish between analytical validity and statistical generalization. The framework is analytically valid because the selected indicators correspond to recognized decision variables in cold-chain logistics: cost, time, loss, capacity, and risk. However, the numerical improvements cannot be generalized to all plateau regions without additional observations. Different products have different shelf lives, temperature ranges, packaging requirements, and market premiums. For example, leafy vegetables are highly sensitive to short-term heat exposure, while potatoes or root crops may tolerate longer transport but remain sensitive to mechanical damage. Therefore, future empirical tests should estimate product-specific parameters rather than assuming a universal optimization effect.

Measurement should also separate direct and indirect effects. A reduction in delivery time may directly lower labor and fuel costs, but it may also indirectly reduce temperature-control energy demand and product loss. Similarly, investment in digital monitoring may increase short-term equipment expenditure while reducing long-term spoilage and dispute costs. If these mechanisms are not separated, the model may overestimate or underestimate the contribution of each intervention. A stronger empirical design would use route-level panel data before and after optimization, combined with matched comparison routes that do not receive the intervention.

Another important issue is governance heterogeneity. The company-farmer model can range from loose purchase agreements to highly integrated production contracts. The same logistics technology may produce different outcomes depending on whether the enterprise has stable procurement authority, whether farmers trust the contract, and whether local government supports collective infrastructure. Thus, the proposed model should be treated as a modular framework. The route module, temperature module, contract module, and infrastructure module can be adapted to local institutional conditions rather than applied as a single fixed formula.

From a policy-evaluation perspective, the most relevant outcome is not only enterprise cost reduction but also farmer income stability and rural value retention. If logistics optimization lowers cost but shifts additional compliance burdens to farmers without compensation, the system may become technically efficient but socially fragile. For rural development, efficiency gains should be distributed through better farmgate prices, service

access, training, and stable market channels. This distributional dimension is essential for making cold-chain upgrading compatible with inclusive rural revitalization.

7. Conclusion

The central conclusion is that cold-chain optimization under the company-farmer order model is not a single routing problem. It is a coordinated governance problem involving route selection, temperature management, contract stability, information sharing, and public infrastructure. The scenario results show that integrated optimization may reduce cost by 20%, shorten time by 25%, reduce temperature-related loss by 50%, increase transport efficiency, and lower risk frequency. The paper contributes a four-part framework for rural development research: plateau environmental constraints, company-farmer coordination, multi-objective cold-chain optimization, and policy-supported infrastructure upgrading. Its limitation is that the empirical values are based on a reconstructed single-case scenario. Future research should collect enterprise-level GPS, temperature, cost, order, and spoilage data across multiple plateau counties and estimate the weights of cost, time, loss, and risk under different product categories. Such work would allow the proposed framework to move from scenario demonstration to statistically validated decision support.

Disclosure statement

The authors declare no conflict of interest.

References

- [1] Fu H, Dan B, 2015, Research on the Company-Farmer Order Contract Mechanism based on Weather Options. *Journal of Systems Engineering*, 30(12): 15–24.
- [2] Han J, Zuo M, Zhu W, et al., 2021, A Comprehensive Review of Cold Chain Logistics for Fresh Agricultural Products: Current Status, Challenges, and Future Trends. *Trends in Food Science & Technology*, 2021(109): 536–551.
- [3] Lu Y, Xu X, Yin C, et al., 2021, Network Optimization of Railway Cold Chain Logistics based on Freight Subsidy. *Transportation Research Record: Journal of the Transportation Research Board*, 2675(10): 590–603.
- [4] Sun M, Zhang C, Lin G, 2017, Distribution Problems and Path Optimization of Fresh Agricultural Products Cold Chain Logistics. *Jiangsu Agricultural Sciences*, 45(6): 103–109.
- [5] Tu G, Leng B, 2010, Contract Stability and Model Optimization of the Company-Farmer Model based on Game Theory. *Chinese Journal of Management Science*, 18(6): 102–109.
- [6] Guo H, Jiang W, 2021, Practice and Implications of the Industry Association-Company-Cooperative-Professional Farmer Order Model. *Chinese Rural Economy*, 2021(4): 48–52.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.