

# A Review of Research on The Reliability Assessment of Fresh Product Distribution Networks Considering Product Perishability Constraint

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**Abstract:** A reliable and stable distribution network is fundamental for the effective operation of fresh agricultural product logistics, and network reliability is a crucial metric for determining whether fresh agricultural product logistics can complete specified tasks promptly and smoothly. To further clarify the current research status on the reliability of fresh agricultural product distribution networks considering transportation losses, this study reviews the literature from three aspects: research on transportation losses of fresh agricultural products, reliability of stochastic distribution networks, and methods for assessing the reliability of stochastic distribution networks considering transportation losses. The studies indicate that few documents introduce both quantity deterioration and quality deterioration simultaneously into network reliability research, which tends to overlook the market demand under reduced freshness, and seldom considers the dynamic changes of deterioration factors in complex environments.

**Keywords:** Fresh agricultural products, Transportation loss, Reliability assessment.

## 1. Introduction

The circulation of agricultural products is a key component of agricultural modernization and an important support for China's efforts to integrate security and development under the new development pattern. From the micro level, agricultural products occupy a central position in China's residents' consumption, and the quality of fresh agricultural products, in particular, is closely related to residents' needs for a better life. With the growing consumer demand for fresh produce, the reliability and efficiency of the distribution network has become a key factor affecting the development of the industry. Fresh produce is susceptible to losses during transportation, which not only increases costs, but may also lead to a decline in product quality, thus affecting consumer satisfaction. Therefore, the study of reliability assessment of fresh produce distribution network considering product perishability constraint of great practical significance. The purpose of this paper is to systematically sort out and analyze the studies on the reliability assessment of fresh produce distribution network considering product perishability constraint by reviewing the existing literature in terms of fresh produce transportation deterioration research, distribution network reliability and distribution network reliability assessment considering transportation loss, and to classify, summarize and evaluate the existing studies from various perspectives such as the research perspective, variable portrayal, model construction, and solving method, and on the basis of this, to provide a comprehensive and practical approach for the study. On the basis of this, we provide a reference direction for the next step to improve the research.

## 2. Current status of Research on Agricultural Deterioration

In daily life, fresh agricultural products such as vegetables, fruits, and meats have become indispensable consumer goods.

However, as a category of perishables with special characteristics, they are prone to spoilage, require rapid delivery, are seasonally produced and sold, and differ by region. These features make them highly susceptible to various factors during transportation, such as logistics methods and temperature changes. In addition to the obvious reduction in product quantity, this can also lead to a decline in the quality of fresh agricultural products, and even render them unsellable. Therefore, an increasing number of researchers are focusing on the comprehensive loss issues of fresh agricultural products during distribution. Losses can be categorized into quantity loss, quality loss, and dual loss, with research primarily addressing the connotations of distribution losses, quantification of losses, investment in preservation efforts, and supply-demand coordination strategies.

### 2.1. Research related to fresh produce transportation with quantity deterioration

During the transportation of fresh agricultural products, quantity loss is an issue that cannot be ignored. Liu et al.<sup>[1]</sup> utilized exponential functions to precisely describe the dynamic relationship between product quantity loss and time. Ji Yingfeng et al.<sup>[2]</sup> proposed a model where the integrity of perishable goods decreases with transportation distance, innovatively establishing a segmented decreasing function between the two, providing new ideas for solving the optimization problem of logistics distribution center location selection. Chen Shutong et al.<sup>[3]</sup> focused on distribution center cost optimization as a core objective, exploring the impact mechanisms of cargo loss costs in the construction of cold chain logistics networks, particularly the dynamic relationship between time and damage rates. Luo Liang et al.<sup>[4]</sup> innovatively constructed a vehicle routing model with time windows, taking into account multiple dimensions including time cost, fresh product loss cost, vehicle fuel consumption, and carbon emission costs, aiming to minimize comprehensive distribution costs. Zhao Zhong et al.<sup>[5]</sup> studied

cold chain perishable goods inventory issues considering a constant spoilage rate and time-varying demand. Ma et al.<sup>[6]</sup> viewed quantity loss as a function of preservation efforts, studying inventory coordination problems of three-tier fresh agricultural products under asymmetric information. Zheng<sup>[7]</sup> assumed quantity loss has an inherent property that changes over time, further exploring how retailers and suppliers can develop optimal strategies under different decision-making modes. Chen Jun et al.<sup>[8]</sup> focused on the agricultural product loss issue, thoroughly analyzing the per unit time profit and loss in the supply chain, and comprehensively studied the efficiency of investments in preserving fresh agricultural products within the supply chain.

## 2.2. Research related to the transportation of fresh produce with quality deterioration

Moreover, the quality and integrity of fresh agricultural products are directly related to product safety and value, with existing literature often constructing functional relationships to measure the quality loss of agricultural products. Zhang Jian et al.<sup>[9]</sup> based on the inherent principles of the impact of distribution distance on product quality, further constructed a location selection model for distribution centers. Cao Yu et al.<sup>[10]</sup> combined the continuous process of quality loss of fresh products to conduct a detailed comparative analysis of centralized and decentralized supply chains in terms of pricing, revenue, and preservation investments. Zhu Xiaolin<sup>[11]</sup> based on the sensitivity of perishable product quality to time changes, combined cargo loss with carbon emission costs, and then established a comprehensive multi-objective optimization model. Hsieh and Dye<sup>[12]</sup> considering the direct impact of product quality on demand, established an optimal dynamic pricing model to maximize total profits. Wang Lei et al.<sup>[13]</sup> used product freshness as a benchmark for measuring product value loss, setting the freshness function in an exponential form, thereby studying the coordination of the supply chain of fresh products. Wu Daqing<sup>[14]</sup> took the freshness of seafood as a consideration factor, studying how consumer preferences affect the pricing strategies and decision-making of supply chain members for fresh agricultural products.

## 2.3. A study related to the transportation of fresh produce with double deterioration

Additionally, some literature also considers both quantity and quality losses in strategic planning for the supply chain of fresh agricultural products. Chen et al.<sup>[15]</sup> studied the problems of quantity loss and quality loss under the consolidation of various fresh shipments. Lü Yang<sup>[16]</sup> based on Stenberg theory and related ideas on supply chain coordination, elucidated the significant role of quality loss and quantity loss in the operational strategies of the fresh e-commerce supply chain. Wang Lei et al.<sup>[17]</sup> while considering the inventory and profit model of fresh agricultural product retailers, explored how retailers choose the best preservation strategy and corresponding order and pricing methods under dual losses. Wang Shuyun et al.<sup>[18]</sup> respectively constructed functions for quality and quantity loss, aiming to find out how freshness affects fresh product demand and thus achieve optimal system profitability. Shi Baoyang et al.<sup>[19]</sup> by introducing the concepts of quality and quantity integrity, formed a consumer utility function considering price, freshness, and farmer production effort levels, and analyzed the coordination obstacles present in the connection between

agriculture and supermarkets.

## 3. Current Status of Distribution Network Reliability Research

The distribution network system is a complex dynamic system whose function is to provide users with specified logistics services, typically comprising multiple logistics facility nodes and transportation paths between nodes. Generally, the logistics nodes of fresh agricultural product distribution networks mainly include: the production end, distribution centers, and sales end as the three main parts<sup>[20]</sup>. Each edge connecting a pair of nodes represents a transportation segment, with the transported products regarded as network flows<sup>[21-22]</sup>. Reliability, as a crucial indicator for evaluating the performance of distribution networks, is naturally key to grasping the overall operational condition of the network.

### 3.1. The Evolution of Distribution Network Reliability

The theory of reliability has over 80 years of history and has gradually evolved into a practical discipline of reliability engineering through systematic research. As early as 1982, Japanese scholar Mine<sup>[23]</sup> proposed the concept of connectivity reliability, which reflects the probability of maintaining connectivity between two nodes in a traffic network, typically studying only two states of the road segments: connected (0) and failed (1). Subsequently, building on Mine's work, Iida<sup>[24]</sup> expanded the connectivity between two points to k-points and the entire network's reliability, known as bistate network reliability. However, in real life, the performance states of various network systems often exceed two, and bistate networks are insufficient to accurately describe the reliability of various network systems. Therefore, the necessity arose to extend the distribution network topology into a multistate network reliability that incorporates complex behavior indicators for road segments. Initially introduced into logistics transportation issues, reliability aimed to measure the robustness of logistics systems, i.e., the negative impacts on network connectivity caused by natural disasters, emergencies, or traffic accidents. The primary focus of reliability research is to analyze how these factors affect the robustness and efficacy of logistics systems. For example, Chen A et al.<sup>[25]</sup> analyzed in detail the effects and impacts of network connectivity, logistics capabilities, and transportation duration on the reliability of military logistics networks under combat readiness conditions, proposing that enhancing the redundancy of network capacity is key to improving network stability. Chen Na<sup>[26]</sup> considered the potential interruptions caused by secondary disasters, subsequently proposing a post-earthquake emergency logistics network optimization model from a reliability perspective.

### 3.2. Calculation of Distribution Network Reliability

Apart from military and emergency logistics networks, reliability analysis theories have also been successfully applied in the field of civilian logistics. Some scholars have developed various logistics indicator frameworks to analyze and evaluate the reliability of logistics networks and have applied heuristic algorithms in the assessment and optimization of logistics network reliability. Given the NP-

hard nature of reliability issues, conducting reliability assessments on network systems is a challenging task. Currently, researchers have proposed various methods for assessing reliability, and scholars<sup>[27-28]</sup> have reviewed the algorithms for network reliability, pointing out that the minimal path method or minimal cut method are simple yet most effective computational methods. Niu et al.<sup>[29]</sup>, based on a carbon emission calculation model, designed a comprehensive transportation network reliability assessment method that balances carbon emissions and cost factors. Feng Guobi et al.<sup>[30]</sup>, after considering transportation time constraints, used the minimal cut set method to conduct in-depth analysis and discussions on the reliability issues of agricultural product transportation networks. Lin<sup>[31]</sup> proposed an evaluation mechanism for the reliability of multi-state stochastic logistics networks considering time windows, and calculated it using the minimal path method and the recursive disjoin and algorithm. Zeng et al.<sup>[32]</sup> studied the reliability evaluation methods of multi-state logistics networks under cost constraints and introduced an innovative algorithm to reduce the search scope for minimal paths. Xu Xiuzhen et al.<sup>[33-34]</sup>, combining network redundancy edges and transcendental number theory, respectively constructed logistics network reliability assessment models and algorithms under transportation cost and distance constraints. Zhu Tingting<sup>[35]</sup> considered the constraints of network reliability and used the minimal path set-based method to solve the site selection and logistics distribution problems in multi-level coal transportation networks.

Additionally, some scholars have also applied other methods such as the GO method, Bayesian analysis methods, etc., to study distribution network reliability issues. Ban Ya<sup>[36]</sup> combined the spatio-temporal data model of emergency material layout scheduling with the GO method, proposing a time-varying network reliability analysis method. Bai Xiaoping<sup>[37]</sup> used the Bayesian-GO integrated assessment method to measure the reliability of express delivery, thus resolving the complex and lengthy calculations in traditional assessment methods for express delivery system performance. Cai Chao and Liu Yanqiu<sup>[38]</sup> combined fuzzy set theory with Bayesian network models, from a reliability perspective, successfully resolving the challenges of uncertain information in logistics service supply chain systems. Yin Xiaoqing et al.<sup>[39]</sup> effectively evaluated urban terminal delivery station location selection schemes using community detection and critical node identification methods. Zhao Furong<sup>[40]</sup> based on fuzzy bijective soft set theory, designed a reliability evaluation method for urban fresh product end delivery suitable for the new retail model. Considering the reliability of travel time, Zhang Jinghan<sup>[41]</sup> took the cold chain logistics distribution system for fresh agricultural products as the research object, sequentially converting the fault tree into a Bayesian network of cold chain distribution system failures, and assessed the reliability of the cold chain distribution system.

#### **4. Current Status of Research on Distribution Network Reliability Considering Transportation Deterioration**

Research analysis shows that the network models studied in the literature on distribution network reliability are all based on the premise that the flow entering the network (e.g.,

the quantity of products, or the input flow) always equals the flow leaving the network (i.e., the output flow). However, due to losses incurred, the quantity of goods that the distribution network can ultimately deliver often fails to fully meet market demand. Therefore, studying the reliability of logistics distribution networks under conditions of loss is particularly crucial. Lin et al.<sup>[42]</sup> were the first to incorporate product degradation into the study of multistate network reliability, associating each transport route (also known as a minimal path) with a fixed quantity loss rate, and proposed a method for assessing the reliability of distribution networks. Subsequently, Lin<sup>[43-45]</sup> expanded on the issue of product degradation by integrating factors such as supplier production capacity, time window constraints, and multimodal transportation network models. Niu and He<sup>[46]</sup>, under the condition of a fixed perishable product quantity loss rate, explored how the loss amount on a single transport edge affects the overall reliability of the network, starting from the interrelationship between transport routes and transport edges. Differing from the above, which constructed the distribution network as a multistate network, Zhang Yan<sup>[47]</sup> analyzed the failure modes of fresh agricultural product logistics systems such as delayed delivery, goods spoilage, and mismatch in quantity categories, and used the timeliness of delivery and the freshness of goods as indicators to judge the reliability of fresh agricultural product transportation. He Yajing<sup>[48]</sup> took the intact state of fresh agricultural products as an important indicator of product quality, proposed the concept and quantitative calculation model of the quality reliability of the fresh agricultural product transportation system, and used fault tree analysis and Bayesian network analysis to calculate the risk probability of top events in the transportation system and the overall system reliability.

### **5. Conclusion**

In recent years, both domestic and international research on transportation losses of fresh agricultural products and distribution network reliability has achieved significant results, providing insights and references for this paper from modeling and solution methods. Although researchers like Lin and Niu have studied the reliability issues of stochastic distribution networks considering transportation losses, given the product nature and diversity of fresh agricultural products, the above research may not be entirely applicable to the transportation loss studies of fresh agricultural products. Thus, further supplementation is needed in the following areas:

Firstly, existing research largely overlooks the issue of product losses during transportation, or only considers the impact of single quantity loss factors on the reliability of perishable goods transportation networks, rarely incorporating both quantity and quality losses into the related research of network reliability, nor paying attention to market demands under reduced freshness.

Secondly, in the literature considering transportation losses, to depict the product loss during transportation, the values of quality and quantity losses are often assigned static definiteness without considering the dynamic changes of loss factors in complex environments, leading to an inability to comprehensively and accurately describe the impact of transportation losses on the reliability of distribution networks.

Lastly, in the process of assessing the reliability of logistics distribution networks, existing literature often uses budget costs as a metric. However, under conditions where

transportation losses are considered, controlling and limiting transportation losses are also important indicators for evaluating the actual performance of distribution networks, and thus, loss constraints should be included in the reliability assessment of fresh agricultural product distribution networks.

Based on the existing issues in current research, the study of the reliability of fresh agricultural product distribution networks considering transportation losses will unfold in the following areas:

(1) Quantification of the dynamic loss process of fresh agricultural products

From the perspective of network reliability, focus on the capacity of the distribution network to meet market demands under constraints of quality loss, quantity loss, and budget. Introduce dynamic time functions and distance functions to quantify the quantity and quality losses of fresh agricultural products, performing a composite analysis of dual loss parameters while analyzing changes in single loss parameters.

(2) Developing network flow allocation strategies that meet constraint conditions

Model the stochastic distribution network of fresh agricultural products as a multistate flow network model, where each edge in the network has an independent, finite, non-negative integer random capacity. While considering transportation losses, research and establish a stochastic network flow allocation strategy that meets demand conditions based on demand flow, transportation edge capacity constraints, budget constraints, and loss constraints, and analyze the operating level and existing problems of the current network based on flow results.

(3) Building and solving reliability assessment models for fresh agricultural product distribution networks under different loss conditions

Introduce two types of dynamic loss factors given market demand, and through the form of commodity flow vectors, characterize the conditional relationships considering loss factors and meeting demands, establish a fresh agricultural product stochastic distribution network model that aligns with the research ideas of this paper, and use minimal capacity vectors to more accurately and reasonably reflect the impact of transportation losses on the reliability of the distribution network, providing decision-making guidance for managers in the operation and management of distribution networks.

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