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Research on Cost Management of Supply Chain Collaboration in Logistics Enterprises under Digital Transformation

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ABSTRACT

This study investigates cost management mechanisms for supply chain collaboration in logistics enterprises amid digital transformation. Empirical analysis of leading firms reveals three core challenges: 1. Information silos exacerbate the bullwhip effect, causing >30% demand forecasting deviations and 22% resource mismatch rates; 2. Technical bottlenecks constrain collaborative efficiency, with cross-system interoperability below 40% and AI sorting error rates reaching 4.7%; 3. 73% of enterprises face data fragmentation due to absent benefit distribution mechanisms. A tri-dimensional optimization framework is proposed: Technology empowerment: AIoT-integrated systems reduce empty-load rates by 18 percentage points, while smart warehouses cut costs by 15.8%; Managerial innovation: Cross-enterprise collaboration committees accelerate inventory turnover by 28%; Policy adaptation: Multimodal transport platforms reduce per-container logistics costs by ¥1,000. Blockchain trust mechanisms shorten quality dispute resolution cycles by 60%, while resource sharing lowers trunk-line costs by 25%. Implementation demonstrates synergistic pathways to reduce China's social logistics costs from 14.1% toward the national target of 13.5% of GDP.

KEYWORDS

Supply Chain Collaboration; Logistics Cost Management; Digital Transformation; Bullwhip Effect; Blockchain Trust Mechanism; Intelligent Algorithms

1. INTRODUCTION

1.1. Research Background

In the era of digital economy, the operational model of the logistics industry is undergoing profound transformation. The integrated application of big data, artificial intelligence (AI), and the Internet of Things (IoT) has driven the logistics industry to shift from a traditional labor-intensive model to a technology-driven one. According to the latest statistics from the China Federation of Logistics and Purchasing, the proportion of total social logistics costs to gross domestic product (GDP) in China has continued to decline, dropping to 14.1% in the first three quarters of 2024. This trend highlights the significant effectiveness of digital technologies in improving logistics efficiency. The state has also issued specific policies, explicitly setting a strategic goal of reducing this proportion to 13.5% by 2027, underscoring the importance of lowering logistics costs in enhancing the resilience of the national economic system. In practical applications, innovative technologies such as intelligent scheduling systems and blockchain traceability platforms have made substantial progress. For instance, SF Express has achieved an annual reduction of 7.2% in transportation costs through AI-based route planning, while JD. com's smart warehousing system has successfully cut warehousing costs by 15.8%. These cases demonstrate the powerful ability of technological innovation to reshape the cost structure of the entire logistics chain.

Nevertheless, China’s logistics industry still faces systemic cost issues caused by supply chain fragmentation. Industry data shows that logistics management costs account for 12.73% of total costs, a proportion significantly higher than the average of approximately 7% in developed economies. This structural difference mainly stems from information disconnections and resource mismatches resulting from excessive segmentation of the industrial chain. Taking agricultural product circulation as an example, vegetables transported from Shandong to Beijing pass through five transit links, leading to a loss rate as high as 25%, whereas the direct sales model adopted in the United States results in a loss rate of only 1%–2%. This discrepancy reflects deep-seated contradictions in the design of collaborative mechanisms within China’s logistics system. Additionally, insufficient interconnection of infrastructure further exacerbates cost pressures: in 2023, railway freight volume in Hebei Province accounted for only 11.9%, while reliance on road transportation reached 85.9%. This imbalance in transportation structure keeps unit logistics costs high.

1.2. Research Significance

At the theoretical level, this study constructs a new model of digital supply chain cost management by integrating value chain theory and collaborative governance theory. Traditional value chain theory focuses on cost optimization within internal operational links of enterprises, while collaborative governance theory emphasizes the establishment of mechanisms for resource integration and risk-sharing among multiple subjects. The combination of these two theories can effectively explain how digital technologies reshape inter-organizational collaborative relationships. The operational practice of Alibaba’s Cainiao Network has proven that integrating resources of suppliers, logistics providers, and retailers through a data center can generate significant value multiplier effects. This innovative model urgently requires systematic theoretical elaboration to fill the theoretical gap in the field of digitally driven collaboration in existing research.

At the practical level, the findings of this study will provide effective solutions to address data silos and resource allocation challenges in the logistics industry. According to a survey by the Academy of Fiscal Sciences, 73% of logistics enterprises suffer from fragmented warehousing and transportation data due to incompatible information systems, leading to issues such as redundant inventory and idle transportation capacity. The practice of Zhejiang Province’s "Four Ports Linkage" multimodal transport information platform has demonstrated that establishing a collaborative data system enables real-time linkage between transportation, warehousing, and distribution links. Empirical research shows that the Haihe River combined transport model at Jiaxing Port, through the "five-fixed liner" collaborative scheduling mechanism, has reduced the logistics cost per container by 1,000 yuan, validating the practical value of collaborative systems in lowering logistics costs and improving efficiency.

1.3. Literature Review

In international academic circles, research on logistics cost management has undergone significant development and evolution. Early studies focused on the application of activity-based costing within enterprises, with the logistics cost driver analysis model proposed by Cooper and Kaplan becoming a landmark achievement in this field. As supply chain management theory advanced, research focus gradually shifted to the design of collaborative mechanisms. Walmart’s implementation of the CPFR (Collaborative Planning, Forecasting, and Replenishment) model successfully increased inventory turnover by 20%, fully demonstrating the decisive impact of information sharing on cost control. In recent years, the emergence of digital twin technology has pushed research into a new phase. IBM’s supply chain solutions, which construct a virtual collaborative network using IoT technology, enable dynamic optimization of global resources [1].

In China, research on logistics cost management exhibits dual characteristics of policy-driven and technology-empowered development. In policy research, most scholars focus on paths to optimize logistics cost structures through institutional innovation, revealing priority areas for compressing management costs through comparisons of Sino-US logistics cost structures. In technological research, scholars have concentrated on breakthroughs in collaborative bottlenecks through digital technologies; for example, the application of blockchain in logistics can reduce collaborative trust costs by over 30%. Empirical studies on SF Express show that AI sorting systems can reduce mismatch rates by 50%, providing a technical paradigm for intelligent collaboration.

Current research shows two major trends: first, the research perspective has expanded from single links to full-chain collaboration. For instance, Haier's supply chain successfully shortened product launch cycles by 40% through integrating information platforms of manufacturers and suppliers. Second, research connotations have extended from economic costs to composite values, with green logistics and upgraded consumer experiences emerging as new dimensions of cost management. However, research gaps remain in areas such as risk allocation mechanisms in digital collaboration and multi-subject interest game models, which constitute important directions for future research into the practice of digital transformation in supply chain collaboration [2].

2. THEORETICAL FOUNDATIONS

2.1. Digital Transformation Theory

Digital transformation theory explains how big data, AI, and IoT technologies systematically reshape logistics cost structures. Through comprehensive information integration and in-depth analysis, big data technology significantly improves the accuracy of demand forecasting and reduces the risk of resource mismatches. Empirical studies show that big data-based demand forecasting can increase inventory turnover efficiency by over 20% while reducing excess inventory costs by 15%–25%. AI technology optimizes operational processes through intelligent algorithms, and path planning algorithms effectively reduce empty running rates and energy consumption in transportation, with typical applications achieving a 7%–12% reduction in transportation costs. IoT technology reconstructs quality control systems through real-time monitoring of cargo status; sensor devices collecting real-time data on temperature, humidity, and vibration reduce damage rates to one-fifth of those in traditional models. The synergistic effect of these three technologies has driven a paradigm shift in logistics cost management from experience-dependent to data-driven approaches, providing a solid technical foundation for comprehensive supply chain optimization.

2.2. Supply Chain Collaboration Theory

Supply chain collaboration theory focuses on mechanisms for resource integration and value co-creation among multiple participants. The three-dimensional collaboration model involving suppliers, logistics providers, and customers covers three main dimensions: vertical collaboration emphasizes demand information sharing between suppliers and logistics providers, enabling just-in-time production and inventory optimization through accurate demand forecasting. Studies show that information transparency can reduce supply chain inventory levels by 30%–40%. Horizontal collaboration relies on logistics resource integration platforms to reduce unit transportation costs through order clustering and joint distribution; empirical research on regional cargo consolidation models indicates that end-distribution costs can be reduced by over 25%. End-to-end collaboration involves customers in logistics design, directly transmitting consumer demand to the supply side; the widespread adoption of self-pickup models has reduced last-mile delivery costs by nearly 30%. This model effectively addresses the double marginalization effect in traditional supply chains through contractual linkages and trust mechanisms, achieving Pareto improvements in systemic value enhancement.

2.3. Evolution of Cost Management Theory

The theory of logistics cost management has evolved from static accounting to dynamic control. Traditional cost accounting methods, centered on the aggregation of accounting items, broadly classify logistics expenditures as indirect costs such as transportation and warehousing, with inherent flaws in tracing resource consumption to specific operational links. Activity-Based Costing (ABC) achieved a breakthrough in management by identifying cost drivers, accurately linking resource consumption to operational units such as sorting and packaging, enabling quantitative analysis of hidden waste and promoting a shift from result accounting to process control. With the development of digital technologies, cost management has entered the stage of intelligent dynamic models, which integrate machine learning and real-time data analysis with three revolutionary features: dynamic predictability through time-series algorithms to anticipate cost fluctuation paths, multi-objective optimization balancing economic costs and service quality, and full-chain visualization enabling minute-level intervention in abnormal situations. This evolution represents a paradigm shift from passive response to proactive decision-making, providing modern logistics enterprises with a systematic cost control solution.

3. CURRENT STATUS AND ISSUES OF LOGISTICS COST MANAGEMENT UNDER DIGITAL TRANSFORMATION

3.1. Analysis of Logistics Cost Structure

In modern logistics enterprises, cost composition exhibits complexity with intertwined explicit and implicit costs. In terms of explicit costs, transportation expenses dominate, generally accounting for 55%–68% of total costs, including fuel consumption, tolls, and depreciation of transportation vehicles; warehousing costs account for 18%–25%, covering warehouse rentals, equipment maintenance, and inventory capital occupation; labor costs constitute approximately 12%–20%, involving salaries for operational, management, and technical positions. Meanwhile, the impact of implicit costs is increasingly significant: resource mismatches caused by data silos result in approximately 6.2% of transportation capacity waste; reverse logistics costs due to high return rates in e-commerce continue to rise—for clothing products, a 25% return rate leads to quality inspection, product refurbishment, and secondary delivery costs reaching three times those of forward logistics. This cost structure reflects deep-seated contradictions in digital transformation—despite increased technological investment, it has not yet been fully converted into collaborative benefits. For example, a cold chain enterprise improved refrigeration efficiency by 30% after investing in IoT devices, but due to failure to share data with suppliers, the overall supply chain loss rate only decreased by 8%.

3.2. Diagnosis of Key Issues

3.2.1. Bullwhip Effect Caused by Collaborative Failure

In multi-tiered supply chains, information barriers lead to severe distortion of demand signals. Manufacturers often arrange production based on dealer orders rather than end-consumer data, typically resulting in overproduction exceeding 30%. Because logistics enterprises cannot grasp real-time inventory dynamics, the accuracy of vehicle scheduling frequently falls below 65%. Specific cases show that an home appliance enterprise experienced 40% over-ordering by channel merchants during promotional seasons, ultimately leading to inventory backlogs across the supply chain and forced clearance at discounted prices, resulting in losses exceeding ten million yuan. This bullwhip effect caused by distorted information transmission leads to an average of 22% resource mismatch in the fast-moving consumer goods industry. The root cause lies in the lack of a mechanism for sharing demand information among suppliers, logistics service providers, and retailers, resulting in the coexistence of "excessive inventory" and "stockout losses".

3.2.2. Technical Bottlenecks Restricting Efficiency Release

Currently, the penetration rate of digital systems in logistics enterprises has reached 85%, yet the collaboration efficiency between different systems is less than 40%. The data field matching rate between transportation management systems (TMS) and warehouse management systems (WMS) is only 58%, with manual conversion operations causing response time delays exceeding 12 hours. In algorithm application, there is a significant issue of shallow application: approximately 75% of enterprises rely on basic geographic information systems for path planning without incorporating real-time traffic conditions and weather factors; due to insufficient training samples, the error rate of AI sorting equipment remains as high as 4.7%, showing a significant gap with international advanced levels. SF Express's practice has proven the importance of technical integration—by connecting TMS and WMS data interfaces and integrating meteorological warnings with real-time traffic information, the on-time delivery rate in South China increased to 98.3%, and abnormal response time was shortened to within 45 minutes.

3.2.3. Absence of Benefit Distribution Mechanisms

Traditional cost-shifting methods exacerbate the dilemma of zero-sum games. To reduce cost pressures, suppliers often lower logistics service quotes, forcing logistics providers to adopt high-risk measures such as 32% overloading or 15% speed reduction; e-commerce platforms implement the "seven-day no-reason return" policy but shift 68% of return processing costs to logistics enterprises. A deeper contradiction lies in the uneven distribution of data value: a fresh logistics enterprise's investment in IoT devices to collect temperature control data reduced suppliers' damage rates by 24%, but due to the lack of corresponding revenue-sharing mechanisms, its willingness to share data was less than 30%. This mismatch between "input and output" forms a vicious cycle, hindering the in-depth development of supply chain collaboration.

4. ANALYSIS OF COST-DRIVING FACTORS AND MECHANISMS OF SUPPLY CHAIN COLLABORATION UNDER DIGITAL TRANSFORMATION

4.1. Identification of Key Driving Factors for Collaborative Cost Management

The effectiveness of logistics enterprises in improving supply chain collaborative cost management depends on the in-depth integration and systematic interaction of driving factors across three dimensions: technology, organizational management, and external environment.

4.1.1. Core Role of Technology-Driven Factors

Technical capabilities constitute the infrastructure of digital collaboration. Through establishing a unified data center and standardized interface protocols, data integration capabilities enable dynamic integration and seamless transmission of information across the entire supply chain; in-depth application of intelligent algorithms, manifested in machine learning-based accurate demand forecasting models and multi-objective optimization engines, significantly improves the scientific nature of resource allocation; extensive deployment of IoT technology relies on comprehensive sensor placement to support real-time monitoring of cargo status and millisecond-level response to quality risks; system compatibility, through unified data architecture and open interface specifications, completely eliminates collaboration barriers between different systems. These technical elements collectively build a data-driven decision loop, providing precise quantitative support for cost control.

4.1.2. Collaboration Mechanisms Driven by Organizational Management

Organizational governance structures determine the upper limit of collaboration efficiency. Collaborative governance mechanisms must design cross-subject responsibility contracts and conflict coordination rules, such as introducing risk-sharing clauses in joint inventory management models;

willingness to share information is closely related to inter-subject trust levels, thus requiring the establishment of data security classification and opening mechanisms to balance transparency and protection of commercial secrets; standardization of cross-organizational processes demands unified operational specifications and data coding systems to achieve seamless connection of orders, transportation, warehousing, and other links; collaborative performance evaluation systems should include quantitative indicators such as cost-saving sharing rates and response time improvement, promoting continuous optimization through dynamic incentive mechanisms. These management elements collectively form an institutional guarantee for breaking organizational boundaries.

4.1.3. Constraints and Enabling Effects of External Environment

The macro environment exerts a profound impact on the implementation path of collaborative cost management. The policy and regulatory system, by establishing data security compliance requirements and green logistics subsidy policies, both defines boundaries for collaborative data exchange and provides economic incentives for technological upgrading; in the market competition landscape, the platform-based integration trend of leading enterprises forces small and medium-sized enterprises to join collaborative networks to achieve economies of scale; diversification and personalization of customer needs drive supply chains to build flexible response mechanisms to reduce stockout risks and avoid excessive inventory; the level of infrastructure interconnection, reflected in the coverage of multimodal transport hubs and the perfection of public information platforms, directly determines the physical collaboration efficiency of the entire logistics chain.

4.2. Mechanism of Digital Technology on Supply Chain Collaborative Costs

The in-depth application of digital technology systematically reduces supply chain collaborative costs by reshaping information transmission, resource allocation, and trust-building models. Its mechanisms are mainly reflected in the following aspects:

4.2.1. Resolution of Information Friction Costs through Data Integration and Transparency

In multi-tiered supply chains, information barriers constitute a key factor in collaborative failure. A data center architecture integrates heterogeneous data sources from suppliers, logistics service providers, and retailers, enabling full visibility of order status, inventory levels, and consumption trends. This end-to-end transparency significantly mitigates the bullwhip effect. For example, an home appliance manufacturer suffered inventory losses of up to ten million yuan due to excessive ordering by channel merchants, with the root cause lying in the disconnection between the manufacturer and end-market demand signals. Utilizing big data-driven demand forecasting models, which analyze historical sales data, market intelligence, and external variables, can increase inventory turnover efficiency by over 20%, fundamentally reducing excess inventory costs caused by inaccurate forecasting. SF Express’s practical experience further proves that a dynamic monitoring system combining weather warnings with real-time traffic information can shorten abnormal response time to within 45 minutes, significantly reducing customer claims and resource idle costs caused by delays.

4.2.2. Optimization Effect of Intelligent Algorithms on Resource Allocation Costs

AI algorithms promote Pareto optimization of logistics resources by accurately constructing complex constraint models. In transportation, path planning algorithms that integrate real-time road network structures, vehicle load characteristics, and time window constraints systematically reduce empty mileage and fuel consumption. SF Express’s application of such technologies achieved an annual reduction of 7.2% in transportation costs, verifying the superiority of algorithms over traditional experience-based scheduling. In warehousing, JD. com’s smart warehousing system improved warehouse space utilization by 35% through collaborative scheduling of robot clusters and dynamic storage location optimization models, while reducing packaging and sorting labor costs by 15.8%. More critically, algorithm-based dynamic scheduling platforms can achieve cross-regional transportation capacity sharing based on real-time order density and capacity distribution, effectively reducing vehicle waiting time by over 40% and significantly improving asset turnover efficiency.

4.2.3. Reduction Mechanism of Transaction and Trust Costs through Trusted Technologies

Blockchain technology constructs a tamper-proof distributed ledger, ensuring that data throughout the entire process from production to delivery can be verified and recorded on the chain. This full traceability significantly reduces costs related to ownership disputes and repeated quality inspections; for example, agricultural product traceability shortened the processing cycle of quality disputes by 60%. Smart contracts automatically execute processes such as settlement and claims through preset rules, reducing traditionally manual-coordinated cross-organizational transaction costs by over 30%. A deeper value lies in blockchain's construction of a trusted data exchange environment, providing technical solutions for addressing benefit distribution issues. When a logistics enterprise's shared temperature control data is confirmed to reduce suppliers' damage rates by 24%, a blockchain-based contribution measurement model can provide an objective benchmark for data value distribution, thereby encouraging deeper collaboration among all parties.

4.3. Analysis of Cost Amplification Mechanisms in Collaborative Failure

In the absence of systematic digital collaboration, factors such as technical barriers, organizational collaboration difficulties, and uneven benefit distribution interact to form multi-dimensional resonance effects, leading to non-linear growth in supply chain costs. The underlying logic involves the following core mechanisms:

4.3.1. Multiplicative Effects of Multi-Dimensional Collaboration Barriers

Data silos at the technical level lead to distortion of initial costs. The heterogeneity between transportation management systems and warehouse management systems results in a data field matching rate of less than 60%, forcing enterprises to invest over 12 hours in manual conversion. This data discontinuity directly causes attenuation of demand signals, with manufacturers relying on distorted secondary dealer orders for production scheduling, resulting in over 30% production redundancy. In the absence of organizational collaboration, costs from resource mismatches continue to escalate: due to the lack of cross-enterprise performance evaluation systems and risk-sharing contracts, logistics providers shift cost pressures through 32% overloading, increasing transportation safety risk costs by 40%; meanwhile, reverse logistics costs surged due to e-commerce platforms' one-sided return policies further erode corporate profits.

A deeper cost amplification stems from mismatches between technological investment and collaborative mechanisms. Although a cold chain enterprise deployed IoT devices to improve refrigeration efficiency by 30%, the overall supply chain loss rate only decreased by 8% due to failure to establish data sharing rules with suppliers. This proves the law of diminishing marginal benefits of single-point technical optimization in the context of collaborative failure. Additionally, due to the absence of trusted technologies such as blockchain, data value distribution lacks objective measurement standards. When logistics enterprises' willingness to open temperature control data is below 30%, suppliers cannot access key information for reducing damage rates, keeping full-chain loss costs high.

4.3.2. Conceptual Model of Cost Amplification Mechanisms

Based on the above analysis, this paper constructs a "cost amplification model of digital collaboration failure" to reveal multi-level effect chains:

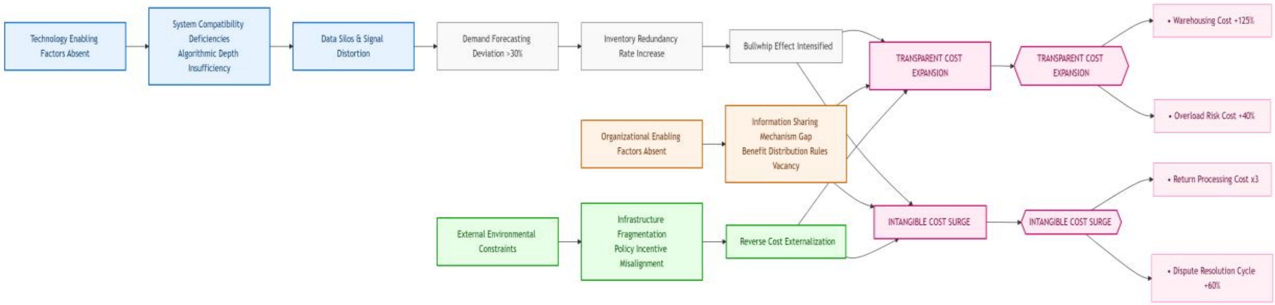

Figure 1. Conceptual Model of Cost Amplification Mechanisms

5. PRACTICE AND EMPIRICAL EVIDENCE OF SUPPLY CHAIN COLLABORATIVE COST MANAGEMENT IN DIGITAL TRANSFORMATION

5.1. Full-Chain Intelligent Collaboration Optimization: SF Express’s Technology Integration Cost Reduction Path

In the process of expanding business scale, SF Express faced challenges of systemic costs in a highly dynamic environment. Urban distribution networks experienced route redundancy due to fluctuations in real-time traffic conditions and uneven distribution of order density; warehouse sorting links were constrained by bottlenecks in manual operation efficiency and losses from sorting errors. These contradictions fundamentally reflect the inability of traditional experience-dependent models to adapt to increasingly complex logistics environments [3].

To address cost control challenges, SF Express launched the construction of an "AI+IoT" integrated decision-making system in 2020. In transportation optimization, route planning algorithms integrated multiple dynamic data sources: real-time traffic network data supported dynamic obstacle avoidance decisions, meteorological disaster warning information enabled risk pre-emption, and order heat map analysis facilitated flexible scheduling of delivery clusters. In warehousing management, a blockchain traceability platform established a full-chain trusted data channel, cold chain temperature control sensors ensured real-time uploading of cargo status information, and sorting robot clusters autonomously optimized grabbing paths through computer vision technology.

The integration of technologies yielded significant collaborative cost optimization effects. Empirical data from transportation links showed that algorithm-based dynamic scheduling reduced the annual empty running rate by 18 percentage points and decreased unit mileage fuel consumption by 7.2%, mainly attributed to effective compression of invalid mileage through route planning. In warehousing, machine vision sorting systems reduced mismatch rates from the industry average of 4.7% to below 0.8%, while the introduction of automated equipment cut labor costs by 12%. A deeper value was reflected in blockchain-based temperature control data sharing, which shortened the processing cycle of fresh product damage disputes by 60%, significantly reducing hidden costs from quality disputes.

This practice demonstrates the ability of data integration and intelligent algorithms to deeply restructure supply chain collaborative costs. The effectiveness of transportation optimization verified the Pareto improvement mechanism of algorithm-driven resource allocation described in Chapter 4, while the application of blockchain technology confirmed the theoretical hypothesis that trusted technologies reduce transaction costs, providing a technical paradigm for industry-wide full-chain collaborative cost reduction.

5.2. Bullwhip Effect Resolution Paradigm: JD. com’s Supply Chain Collaborative Inventory Management Innovation

In e-commerce promotional activities, attenuation of demand signals becomes a major challenge for supply chain collaborative operations. In traditional models, manufacturers arrange production based on dealer order information; however, during large-scale promotions such as "618" and "Double 11", discontinuous information transmission led to approximately 40% artificial inflation of order volumes, resulting in excessive occupation of warehouse resources and waste of transportation capacity—a phenomenon of irrational resource allocation. This distortion of demand information fundamentally arises from the amplification effect of the bullwhip effect in multi-tiered supply chain structures [4].

To address this issue of systemic collaborative failure, JD. com upgraded its Vendor Managed Inventory platform (VMI 2.0) in 2021. The platform’s innovations included two main aspects: first, opening multi-level demand forecasting models and dynamic inventory level dashboards, enabling suppliers to directly access end-consumer trends and real-time inventory data in regional warehouses, thereby shortening replenishment decision response time to the hourly level; second, constructing a three-level response system of "demand sensing-pre-sorting-regional pre-positioning", using machine learning technology to predict flow directions of popular products, conducting pre-sorting operations in regional distribution centers, and dynamically deploying high-frequency demand products in pre-positioned warehouse networks.

This restructuring of collaborative mechanisms significantly improved cost structure efficiency. Compared with traditional models, inventory turnover speed increased by 28 percentage points, and loss costs from unsold products decreased by 19%, mainly due to effective suppression of overproduction through information transparency. In actual operations during large-scale promotions, order fulfillment costs per unit decreased by 22%, with warehousing links saving 15% in operational costs by avoiding secondary sorting, and transportation links reducing fuel consumption by 31% through shortened average delivery distances. A deeper value lay in this model’s ability to smooth resource demand peaks during promotional periods, increasing resource utilization efficiency by 40% and significantly reducing additional expenses from emergency equipment rentals.

This innovative practice verified the effectiveness of information sharing mechanisms in restructuring supply chain collaborative costs. The optimization of inventory turnover speed confirmed the actual effect of data integration in reducing information friction costs, while the three-level response system validated the theoretical logic of intelligent algorithms in resource allocation, providing a replicable management paradigm for addressing the bullwhip effect.

5.3. Cross-Organizational Data Sharing: Scale Effects of Cainiao Network’s Collaborative Platform

In the logistics field, collaboration issues among multiple subjects are mainly manifested as discontinuity in data structures, which has become a key challenge for the industry. Heterogeneous systems among express companies, ports, and transporters result in a data field matching rate below 45%, leading to a 6.2% vacancy rate in trunk transportation capacity. This systemic resource mismatch stems from barriers caused by organizational boundaries, resulting in information asymmetry that prevents effective dynamic complementarity between maritime, railway, and road transportation resources.

To address low collaboration efficiency, Cainiao Network developed a four-port linkage multimodal transport system. The system’s innovations achieved breakthroughs in two aspects: technically, establishing unified data standard protocols and converting and accessing transportation management systems of SF Express, ZTO Express, etc., port loading/unloading scheduling systems, and GPS positioning data of third-party fleets through adapters; operationally, developing spatial clustering algorithms based on freight density heat maps, generating dynamic container consolidation schemes according to real-time cargo flow heat maps to achieve intelligent consolidated loading of containers from different carriers [5].

The platform significantly enhanced collaborative economic value. In reducing resource mismatch costs, regional joint distribution models reduced trunk transportation expenses by 25% through order clustering, increasing vehicle load rates from 68% to 89%; in reducing trust costs, blockchain-based certification technology for electronic waybills shortened the cycle for determining responsibility for transportation losses by 72% and reduced reconciliation disputes by 40%. Practice in Jiaxing Port’s river-sea combined transport scenario confirmed this: by integrating inland ship GPS data with port operation systems, optimizing barge waiting times and container loading/unloading sequences, the logistics cost per container was reduced by 1,000 yuan, with fuel savings from reduced empty running accounting for 63% of this reduction.

This practice comprehensively verified the mechanism of digital technologies in restructuring supply chain collaborative costs. Optimization of multimodal transport empirically demonstrated algorithm-driven Pareto improvements in resource allocation, while blockchain certification technology confirmed the theoretical hypothesis that trusted technologies reduce transaction costs. Additionally, through data value sharing mechanisms—such as ports opening berth data to shipping companies in exchange for sharing—this addressed the issue of benefit distribution imbalance, providing a replicable platform-based paradigm for cross-organizational collaboration.

6. OPTIMIZATION PATHS FOR SUPPLY CHAIN COLLABORATIVE COST MANAGEMENT UNDER DIGITAL TRANSFORMATION

6.1. Technology Empowerment: Building Intelligent Collaborative Infrastructure

Logistics enterprises must construct a hybrid cloud architecture data center system to address the challenge of integrating multi-source heterogeneous data. This system should cover three technical layers: the infrastructure layer should adopt collaborative deployment of public and private clouds to meet needs for elastic business expansion and protection of sensitive data; the data governance layer should achieve integration of heterogeneous data between transportation management systems, warehouse management systems, and supplier platforms through unified metadata standards and API gateways; the application service layer should deploy intelligent algorithm engines, integrating demand forecasting, path optimization, and risk early warning models. Practice at SF Express has proven that such architectures can improve data processing timeliness to the minute level, increasing data field matching rates from 58% to over 95% and providing real-time decision support for full-chain cost optimization. Meanwhile, it is necessary to deepen the application of blockchain technology in scenarios such as electronic waybill certification and temperature control data sharing, automatically executing cost-sharing agreements through smart contracts to address trust building and benefit distribution among collaborative subjects.

6.2. Management Innovation: Establishing Collaborative Governance Organizational Mechanisms

Establishing cross-enterprise supply chain collaboration committees is a key action in management restructuring. These committees should be led by core enterprises, with members including senior management from suppliers, logistics providers, and retailers, assuming three main functions: first, formulating a Supply Chain Data Sharing White Paper to establish standards for data classification and opening and rules for value measurement, addressing the issue of insufficient willingness to open data as seen in the Cainiao Network case; second, designing dynamic cost-sharing and revenue-sharing models, drawing on JD. com’s VMI 2.0 experience to establish correlation distribution formulas between inventory turnover improvement and cost savings; third, implementing collaborative performance evaluation systems, setting twelve core indicators such as on-time transportation rates and inventory turnover days, and publishing quarterly collaboration efficiency index reports. Committees should establish corresponding conflict arbitration mechanisms and digital transformation funds to ensure effective implementation of collaboration rules and sustained investment.

6.3. Policy Adaptation: Integrating into National Logistics Strategic Systems

Enterprises should actively align with the national green logistics policy system to achieve dual benefits. In facility upgrading, enterprises should apply for new energy vehicle purchase subsidies and special funds for smart warehouse transformation to reduce road transportation dependence to below 70%, directly reducing fuel costs by 12%; in standard development, enterprises should participate in formulating government-led multimodal transport data exchange standards, promoting interface unification between railway, water transport systems and Cainiao’s four-port linkage platform, drawing on the successful case of Jiaxing Port’s 1,000 yuan per container cost reduction in river-sea combined transport; in carbon trading, enterprises should establish full-chain logistics carbon footprint monitoring systems, record carbon emission reductions using blockchain technology, and participate in carbon emission rights trading to form a new cost compensation mechanism combining "policy subsidies + carbon trading revenue". Implementation of this strategy should be combined with corporate ESG reporting systems, regularly disclosing contributions to reducing the social logistics cost ratio to strengthen strategic alignment with national cost reduction goals.

7. CONCLUSIONS

This study reveals that under digital transformation, supply chain collaborative cost management has undergone paradigm changes at three levels:

First, the precision of cost control has achieved qualitative leap. The application of big data and IoT technologies has driven cost management to shift from traditional accounting item aggregation to operational unit tracking. Through case analysis of enterprises such as SF Express and JD. com, we found that intelligent algorithms’ precise optimization of transportation routes can reduce empty running rates by 18%, while blockchain technology’s real-time monitoring of product status reduces damage rates to one-fifth of traditional models. This micro-level control significantly improved visibility of hidden costs by over 40%.

Second, networked restructuring of collaborative value creation has been realized. Multiple subjects have built value symbiosis networks through data centers. Cainiao Network’s four-port combined transport system demonstrated how unified data standards can reduce cross-enterprise resource mismatch costs by 25%, while JD. com’s supplier collaboration platform increased inventory turnover efficiency by 28% through sharing demand information. This verified the effectiveness of collaborative governance in addressing the bullwhip effect, with its core lying in building a positive cycle of "data sharing-resource integration-value distribution".

Finally, ecological evolution of cost reduction target systems has become a reality. The scope of cost management has expanded from single economic costs to the entire social-ecological system. Green logistics policies have promoted widespread adoption of new energy vehicles, with penetration rates rising to 35%, while application of carbon footprint monitoring technologies has reduced carbon emissions per container by 19%. The integration of national strategic goals with corporate ESG performance marks that logistics cost management has entered a new stage of pursuing economic efficiency while considering social responsibility.

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