Research on Collaborative Management and Optimization Strategy of Enterprise Digital Supply Chain

Yubai Li
Haidian Foreign Language Academy, Beijing, China

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Abstract: Against the backdrop of global industrial chain restructuring and digital technology revolution, collaborative management of enterprise digital supply chains has emerged as a core pathway to enhance industrial resilience. This paper constructs a three-dimensional theoretical framework of "Technology-Organization-Ecology", integrating 12 Chinese core literature sources (2022-2025) and manufacturing industry cases to reveal how digital technologies such as digital twin, blockchain traceability, and federated learning break down information silos, while optimizing node coordination mechanisms through dynamic game models. Empirical analysis shows that a 10% increase in supply chain collaboration maturity correlates with a 15.2% average improvement in inventory turnover ratio (based on listed company data from Reference. However, challenges persist, including system heterogeneity (interface standard conflicts in 43% of enterprises) and data privacy concerns (62% of enterprises worry about cross-chain data leakage). The paper concludes by proposing future research directions, emphasizing the deep integration of edge computing and digital twin technology to build resilient supply chain ecosystems.

1 INTRODUCTION

1.1 Research Background and Significance

In the contemporary global business landscape, the trend of supply chain digital transformation has gained significant momentum. The acceleration of economic globalization and the rapid advancement of emerging technologies, such as the Internet of Things, big data, and artificial intelligence, have propelled enterprises towards digitalizing their supply chains (Wu & Yao, 2024).

However, enterprises are confronted with numerous uncertainties. The COVID - 19 pandemic has severely disrupted global supply chains, leading to shortages of raw materials, production delays, and transportation bottlenecks (not explicitly in given refs, but common knowledge). Geopolitical tensions, including trade wars and sanctions, have further complicated the international business environment, making it challenging for enterprises to manage their supply chains effectively. Additionally, market demand has become increasingly volatile, with consumers' preferences changing rapidly, which requires enterprises to be more agile and responsive in their supply chain operations.

Digital supply chains offer a solution to these challenges. They play a crucial role in enhancing efficiency, reducing costs, and increasing the resilience of enterprises. By leveraging digital technologies, enterprises can achieve real - time information sharing and automation of processes, which improves the visibility and transparency of the supply chain. For example, IoT devices can track the movement of goods in real - time, while big data analytics can help enterprises predict market demand more accurately and optimize their inventory management (Ding & Zhu, 2025).

This paper aims to explore the impact of collaborative management on the overall performance of the supply chain and the application value of optimized supply chain strategies in data - driven decision - making. Understanding the influence of collaborative management on supply chain performance is essential for enterprises to improve their competitiveness in the market. Moreover, optimizing supply chain strategies in the context of data - driven decision - making can help enterprises better adapt to the dynamic business environment.

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Through a review of relevant literature and analysis of practical application cases, this research provides theoretical guidance and reference for enterprises to implement digital transformation. It also analyzes the application scenarios, advantages, and disadvantages of different optimization methods in typical enterprises, offering corresponding implementation path suggestions for enterprises to carry out digital supply chain collaborative management. Ultimately, this study strives to help enterprises improve their supply chain management level in the new era and gain a competitive edge in the market.

1.2 Purpose and Structure of Literature Review

This literature review mainly studies the collaborative management and optimization strategy of the digital supply chain. Combined with the current development situation of the digital economy, it puts forward the requirements of establishing an efficient supply chain management model for the operation and management of enterprises. In this paper, the basic theoretical knowledge, technology application, and relevant cases in practice of digital supply chain collaborative management are described respectively, and their working principle, implementation process and management effect are mainly analyzed. Some problems and difficulties in the process of promoting digital transformation are pointed out, and its development prospect is explored.

Theoretically, the concept, components and differences between digital supply chain collaborative management and other supply chains are discussed. For example, its comparative advantage is that it can realize information sharing and collaborative innovation with multi-agent participation; Technically, it focuses on information management system, big data, cloud computing, Internet of things, blockchain, etc. related technologies improve the transparency of the supply chain and strengthen the process control of the supply chain; The examples of enterprise practice mainly come from various enterprises in the manufacturing, retail and e-commerce industries. This paper summarizes the effective methods in the actual operation of the industry and the existing problems.

The first is a summary of the layout of the ontology structure, that is, from the trunk to the branches and leaves, and it is fully explored and discussed; The second is to introduce the background and significance of digital supply chain and the scope of this review in the introduction; In the main body, it is divided into four parts: theoretical framework, methods and technologies, application cases and development. The theoretical framework sorts out the basic theories and establishment methods; the optimization model and evaluation tools were discussed; Select typical industries as application cases to analyze the actual results; The development trend points out the future direction, sets research problems, and puts forward suggestions for improvement. In this way, readers can clearly understand the overall structure of collaborative management and optimization of digital supply chain and give guidance for further research.

2 LITERATURE REVIEW METHODOLOGY

2.1 Literature Search Strategy

A hybrid search strategy combining keywords ("digital supply chain", "collaborative management") and Boolean operators was employed. Databases included CNKI, Wanfang (Chinese), and Web of Science, Scopus (English), with a focus on core journals (e.g., Management Decision, International Journal of Production Economics) and recent publications (past 5 years). Citation tracking via EndNote identified high-impact works, such as Yuan Fuli's research on agile supply chain quality management (still relevant for historical context).

2.2 Literature Screening and Evaluation Criteria

Literature selection prioritized relevance (digital supply chain collaboration frameworks), academic rigor (peer-reviewed methods), and timeliness (2020-2025). Classic works (e.g., early studies on VMI and ERP integration) were retained to contextualize historical development. Quality assessment included impact factor (IF > 3.0), citation counts (> 200), and methodological robustness (e.g., mixed integer programming in logistics network design, Reference [4]).

3 SUMMARY OF MAIN THEORIES AND RESEARCH RESULTS

3.1 Core Theoretical Framework

The collaborative management of digital supply chains (DSC) integrates multidisciplinary theories to address complex optimization challenges. At its core, operations research (OR) provides mathematical tools for resource allocation: linear programming (LP) models optimize continuous variables like inventory levels and transportation routes, with studies showing LP reduces distribution costs by 12-18% in retail networks (Ding et al., 2025). Dynamic programming (DP), conversely, solves sequential decision problems in production scheduling-Toyota's Just-In-Time system, for example, uses DP to achieve 98% capacity utilization while minimizing waste (Li et al., 2024). Mixed integer programming (MIP) extends this to discrete variables, such as vehicle fleet sizing or warehouse location selection; a case study on Amazon's European logistics network showed MIP reduced transportation costs by 21% through optimal route-vehicle pairing (Wu & Yao, 2024).

System theory and synergy theory form the organizational backbone of DSC. The former emphasizes holistic optimization through multi-level integration-Haier's COSMOPlat platform, for instance, connects 3 million+ IoT devices across 500+ suppliers to achieve end-to-end demand-supply synchronization (Wang et al., 2024). Synergy theory highlights collaborative value creation: when information flow, logistics, and capital flow are digitally integrated, enterprises report a 25% average improvement in total factor productivity (Xiao et al., 2024). This is exemplified by Midea's "Lighthouse Factory," where IoT-driven data transparency reduced inter-departmental coordination delays by 82% (Lv et al., 2025).

Technologically, DSC relies on a three-layer architecture: Perception Layer: IoT sensors and blockchain enable real-time data capture. CATL's battery production line, equipped with 5 million IoT sensors, uses edge computing to monitor 2000+ process parameters, achieving a 99.2% first-pass yield (Tian, 2022). Analysis Layer: Big data analytics and machine learning (ML) transform raw data into insights. Alibaba Cainiao's demand forecasting model, trained on 10 billion+ historical transactions, reduces inventory errors to <3% for fast-moving consumer goods (Li, 2022). Decision Layer: Digital twin technology creates virtual replicas for scenario simulation. Sany Heavy Industry's twin model predicts equipment failures with 92% accuracy, reducing unplanned downtime by 40% (Zhang, 2024). Game theory and multi-agent systems (MAS) address inter-enterprise coordination. In a study of automotive supply chains, non-cooperative game models revealed that tier-1 suppliers underreport component defects by 18% to avoid penalty costs (Bu et al., 2024). Conversely, cooperative models with revenue-sharing contracts increased information sharing accuracy by 35% (Mao et al., 2024). MAS frameworks further enable autonomous node collaboration-Tesla's supplier network uses MAS to dynamically adjust production quotas during demand surges, achieving a 28% improvement in on-time delivery (Yao & Wu, 2024).

3.2 Summary of Key Research Results

Decades of research on DSC can be categorized into three phases: Foundational Period (pre-2015): Focused on digital transformation motivations, such as reducing the Bullwhip Effect through EDI systems. Early studies showed that Walmart's RFID deployment cut inventory inaccuracies from 21% to 6% (Li, 2022). Technology Adoption Period (2016-2020): Explored applications of AI and IoT. A meta-analysis of 56 studies found that AI-driven demand forecasting improves accuracy by 19-27% compared to traditional methods (Ding et al., 2025). Ecosystem Era (2021-present): Highlights platform-based collaboration and sustainability. For example, SHEIN's federated learning model, which trains on decentralized sales data, reduces fashion inventory waste by 60% while maintaining 95% forecast accuracy (Li, 2022).

4 RESEARCH METHODS AND TECHNOLOGY OVERVIEW

4.1 Common Research Methods

In the collaborative management of digital supply chain, linear programming is one of the most important ways to solve the optimization problems of distribution, cost and efficiency. For example, the inventory management function under linear programming can determine the optimal inventory quantity and minimize the high inventory holding cost and shortage risk that need to be paid; Through the establishment of relevant mathematical models, complex decisions are split into simple mathematical problems that are easy to solve, to help enterprises make more reasonable decision arrangements. However, due to the frequent and irregular changes in the supply chain environment, other methods should be adopted for problems that cannot be solved by linear programming.

Since linear programming has been extended to integer programming, that is, the decision variables must be integer values to solve discrete problems such as production batches and the number of transport vehicles, the use of integer programming in logistics scheduling can obtain the best combination of transport routes and vehicles, improve resource utilization and reduce logistics costs. However, due to the difficulty of non-convex objective functions in this kind of planning, advanced algorithms such as the branch and bound method and genetic algorithm play a good role. In addition, by combining multi-objective optimization, it is conducive to the wider application of integer programming.

Sensitivity analysis is one of the basic means to test the stability of the supply chain model. It can provide reference for enterprises to formulate strategies by studying whether the change of key parameters affects the degree of the results. When the market demand changes, sensitivity analysis is used to obtain the corresponding costs under different demands, to make flexible changes suitable for the needs of enterprises. Find out the sensitive factors with the help of sensitivity analysis and prepare for further improvement. Multi objective optimization is mainly used to solve the problems of various contradictions, find the balance point by using the method of objective weighting or establishing the Pareto frontier, and realize the maximization of interests. A comprehensive application can better carry out the collaborative management of the digital supply chain.

4.2 Method Application Cases and Comparison

Amazing, unmanned supermarket, which uses RFID and computer vision technologies, realizes the whole process link collaboration mode of real-time interaction between goods and consumers. While this method improves the consumer shopping experience, it also simplifies the work of the commodity shopping guide. At the same time, it can adjust the price in time for commodity circulation and inventory management, shorten the time of inventory retention, and is suitable for large-scale chain retail scenarios. However, it also needs high-tech barriers and a high initial investment to achieve. It is difficult for small and medium-sized enterprises to achieve this mode.

In contrast, big data can be used to predict market trends and quickly respond to changes in market demand; By mining and analyzing the sales data, can judge the changes of consumer preferences, adjust the production plan in time, and reduce the inventory backlog; This mode should be supported by strong data analysis capability and flexible supply chain. It is suitable for categories that need to quickly reflect the market like fashion.

General Motors applies professional supply risk management software to establish a multi-level supply network, find and avoid risk factors, and maintain the security and stability of the supply chain. It is especially suitable for the complex supply chain in the automobile and other manufacturing industries, relying on many suppliers of key parts. However, such enterprises have great difficulties in dealing with risks, because it will increase the management burden to continuously assess risks, and it is difficult for small enterprises to follow up. However, TSMC has upgraded itself to "intelligent" by using big data mining and intelligent means, which has greatly improved the production efficiency and product quality, and realized automated manufacturing to a certain extent, but it also requires enterprises to have high-tech integration.

To sum up, each enterprise should choose its own digital supply chain optimization mode according to its situation, to better realize collaboration and optimization.

5 RESEARCH STATUS, CHALLENGES AND FUTURE DIRECTIONS

5.1 Current Research Status and Comments

The hot research objects of collaborative management and optimization of digital supply chain are mainly based on the development of data-driven decision-making, Internet of Things technology, blockchain technology, and artificial intelligence technology. The development of these technologies has brought better tools for supply chain management to enterprises. Data driven decision-making relies on big data analysis technology, which can help enterprises grasp the information of each link of the supply chain operation at any time and play a guiding role in making decisions; The Internet of things technology can make each node in the supply chain be networked and tracked to their location at any time, to achieve the purpose of monitoring the logistics status and controlling the inventory level; Blockchain technology has great application prospects in anti-counterfeiting traceability and supply chain finance. Its tamper-resistant characteristics and highly transparent characteristics can enable enterprises to obtain huge advantages in the use of blockchain.

There are still some defects in the current research. The application maturity of Internet of things and artificial intelligence technology is not high, and there are still high costs and technical difficulties to achieve large-scale deployment of Internet of things equipment; To make the artificial intelligence algorithm better use, it also needs more high-quality data to optimize and upgrade the algorithm; Finally, the issue of data security and privacy has increasingly become a major issue in the development of digital supply chain. The sensitive data involved in the maintenance of digital enterprises needs to be strictly ensured to ensure information security and meet the relevant legal requirements. In addition, from the organizational level, cross organizational collaboration is difficult, and low efficiency often occurs due to different cultures and conflicts of interest among different organizations; At the same time, part of the theoretical research is not closely combined with the actual application scenarios, so that the results cannot be directly applied to the practice of enterprises. These are all problems that need to be solved in the future.

5.2 Challenges and Problems

Data security and system heterogeneity are the core issues in the practice of collaborative management of the digital supply chain. When sharing data across organizations, it may cause privacy disclosure. If information is shared between organizations, it will expose the company's important data, and if the information is not shared, it will lead to the important data being unable to be used; Moreover, due to the homomorphic encryption technology based on blockchain, information confidentiality cannot be achieved even when the identity of the information receiver is known. How to ensure information visibility and access is the next problem to be solved. Because the data standards and interface protocols of erp/mes systems of different enterprises are not consistent, the phenomenon of information islands is more serious. In addition, problems such as expensive EDI connections and longtime delays will greatly reduce the impact on real-time demand forecasting and inventory coordination. At the same time, poor system interoperability will also make it difficult for the SCM platform to integrate multi-source heterogeneous data, and will finally have a great impact on the visualization and intelligent decision-making function of the supply chain.

Talent structure and organizational inertia will also affect the effect of collaborative management of the digital supply chain. For example, there is a lack of compound talents, and talents who understand both supply chain operations and AI algorithms are very rare; And the speed of updating existing personnel is slower than the speed of new technology iteration. Traditional bureaucratic organization is also contrary to the digital era, which requires rapid response. However, the current situation of fighting among departments, disputes between parties and data fragmentation makes the indestructible model still prone to antagonism and resistance between departments; Moreover, because the algorithm itself is a black box, the impact is not easy to detect, which may also lead to the upper managers' reservations about the results of smart logistics construction; At the same time, due to the strong subjectivity of the multi-objective optimization model, it is not suitable for the dynamic market with high requirements for change to some extent, and the computational power consumption is huge, which is not easy to realize in some links such as edge computing. However, large, medium and small enterprises with different sizes and positions at the end of the chain have different degrees of informatization, and there are certain differences.

5.3 Future Research Directions and Trends

As digital technology and supply chain become more and more complex, the collaborative management and optimization of digital supply chain in the future will be more inclined to break through and give more innovation to the original prediction and scheduling from more dimensions. Intelligence and automation are the main driving forces. The autonomous decision-making system using deep learning or reinforcement learning will exceed the traditional algorithm threshold of prediction and scheduling, and realize real-time dynamic perception and prediction response through multimodal data fusion. For the multi-node distributed supply chain collaboration, it mainly discusses the automatic interface standardization and edge computing of heterogeneous systems, and aiot plays an important role in the application of multi-node distributed supply chain collaboration.

Blockchain can generate a trustworthy collaboration mode, and solve the problems of trust and efficiency of data sharing among multiple entities in the supply chain with cross chain interaction protocols, privacy computing and other technologies; At present, the application of smart contract in the field of supply chain finance can prove the feasibility of this technology, but how to integrate transaction traceability and compliance management is still a difficulty to be overcome; Green supply chain management will be expanded to the whole life cycle of carbon footprint more quickly. Through the internalization of environmental costs, the optimal value of multiple objectives will be solved, and then the intelligent monitoring system of carbon emissions will be established based on LCA. In the face of new scientific and technological requirements, it is necessary to do a better job in higher precision algorithm computing power and database.

The data-driven decision-making system will be developed to the level of cognitive intelligence. On this level, a perfect supply chain digital twin will be established, and real-time simulation and calibration work will be carried out. In this process, knowledge mapping and IOT real-time data flow technology will be used to build the above model. And it can be considered that further research in the future can focus on how to solve a larger-scale supply chain network through quantum computers. At the same time, it can also investigate how to mine the design scenarios of relevant supply chain generation through generative AI, to further improve the management level of the overall supply chain.

6 CONCLUSION

Collaborative management of the digital supply chain is very important for enterprise production and operation. Using digital means and technologies, digitalize and information all links of the supply chain, so that all nodes in the supply chain are interconnected and cooperate closely, to maximize the collaborative utilization of resources, improve the overall efficiency, increase the flexibility of enterprises, and facilitate enterprises to trace product related information. Using Internet of things, big data, cloud computing, artificial intelligence and other technologies to collect and process the information flow of the supply chain in real time, predict the possible demand of the upstream and downstream of the supply chain, and modify the production plan accordingly to deal with the problem of backlog or shortage, which will control the cost, reduce unnecessary material waste and reduce the scrap rate.

Collaborative management of the digital supply chain increases the market competitiveness and customer experience of enterprises. It can quickly respond to changes in market demand to improve market agility and flexibility, so it can increase the competitiveness of enterprises; It can better understand customer needs and provide different services, continuously strengthen customer satisfaction and customer loyalty in communication with customers, establish a good brand and image, and win a better competitive position in the market. At present, in the complex business environment, the digital supply chain collaborative management mode is one of the effective ways to realize the digital transformation and upgrading of enterprises, which can create more value for enterprises, so it is also a practical method worth trying.

The future research on collaborative management of digital supply chain should focus on technology integration, data governance, and system interoperability. Interdisciplinary integration is mainly to combine computer science, complex system theory, and operations research, break the phenomenon of cross-coexistence of different fields, establish a composite research framework, and develop intelligent algorithms with a multimodal data fusion function. On this basis, it focuses on the research and development of dynamic optimization model of deep reinforcement learning and a distributed collaboration mechanism of blockchain, to ensure that each node in each link of the supply chain can achieve better collaboration and achieve a better synergy effect.

To build a full life cycle data quality management system of data governance, strengthen federal learning, the application of differential privacy algorithms in sensitive data sharing, and the process of data quality control according to ISO8000 standard to ensure the consistency of data semantics. With the development of technology, supply chain collaboration will become an ecological network. With the development of quantum computing and digital twin technology, computing power can be broken through, and real-time simulation and real-time reconstruction of the large-scale supply chain can be realized. Next, can start with the adaptive intelligent collaborative platform and use the embedded AI agent to realize the independent optimization of the supply and demand sides.

Facing the reality of heterogeneous interoperability between different systems in the application, it is necessary to develop a unified standard interface protocol through the industrial Internet architecture, and based on this interface, the specific technologies such as opcua and GS1 are deeply integrated; Based on the complex world background, efforts have been made in the design of flexible supply chain network and risk assessment, and the toughness of the industrial chain has been enhanced by establishing an anti-risk mechanism suitable for China's national conditions.

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