# A Review of Research on System Dynamics in Supply Chain Management

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## Abstract

Based on bibliometric methods, this paper employs text mining techniques to generate a keyword cloud map and keyword co-occurrence networks. This approach aims to thoroughly explore and systematically identify the core application topics of system dynamics in supply chain management, along with its methodological framework. The findings indicate that system dynamics holds significant application value across some critical areas, including inventory management, risk management, supply chain finance, green supply chain management, supply chain coordination management, supply chain performance, and supply chain quality management. For the first four core application themes, this paper further extracts relevant keywords and constructs a co-occurrence network. This reveals specific research directions, methodologies employed, and their interrelationships within each sub-theme in detail. Additionally, to enhance the empirical foundation of the discussion, this paper references several representative studies that analyze simulations and numerical analyses conducted within the context of system dynamics. Key parameters from these studies are summarized for clarity. Finally, based on a comprehensive review and analysis of prior research efforts, this paper anticipates future research trends that will serve as valuable references for subsequent investigations.

**Keywords**: Supply Chain Management, System Dynamics, Bullwhip Effect, Risk Simulation Green Supply Chain

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## Introduction

Supply Chain Management And System Dynamics

The supply chain is a complex network centered around a core enterprise, encompassing the entire process from raw material procurement and product manufacturing to final delivery to consumers through a sales network. Within this network, suppliers, manufacturers, distributors, and end users are intricately linked together to form a robust chain structure (Cooper et al., 1997). The essence of supply chain management lies in the effective integration of its various components, ensuring that products are delivered accurately - considering location, condition, quantity, quality, and timing. Simultaneously, it aims to optimize total ownership costs through meticulous planning, coordination, operation, control, and optimization.

System dynamics is an interdisciplinary field that investigates information feedback systems and has demonstrated its significant applications across various domains since its inception by Professor Forrester in the 1950s (Forrester, 2007). This discipline integrates structural, functional, and historical approaches while combining qualitative and quantitative reasoning; it employs computer simulation techniques for an in-depth analysis of the dynamic behavior exhibited by complex systems. System dynamics emphasizes a holistic perspective on systems as well as considerations of connectivity, development processes, and movement patterns. It effectively captures causal relationships among different variables along with associated risk factors and their corresponding behaviors. This, in turn, facilitates both the visualization and quantitative analysis of complex dynamic systems.

In the field of logistics and supply chain management, system dynamics plays a pivotal role (Sterman & John, 1989). In the 1960s, Professor Forrester's research on the “bullwhip effect” revealed the phenomenon of demand information amplification within the supply chain. System dynamics offers profound insights and strategic solutions to address this issue. Furthermore, MIT Sloan School of Management’s ‘Beer Game’ effectively illustrates the practical value of system dynamics by simulating production and distribution processes in the supply chain. This simulation visualizes the dynamic characteristics of information flow and logistics, thereby enhancing our understanding of the complexities inherent in supply chain operations.

In conclusion, applying system dynamics in supply chain management not only enriches researchers' comprehension of dynamic behaviors but also provides a scientific foundation for strategy formulation through simulation and analysis. This further underscores its unique value and irreplaceability as a cross-disciplinary research tool in tackling modern supply chain challenges (Sterman, 2000). In our next article, we will delve into a detailed discussion on the application of system dynamics in supply chain management along with an examination of achieved outcomes.

The technical roadmap of this paper is depicted in Figure 1

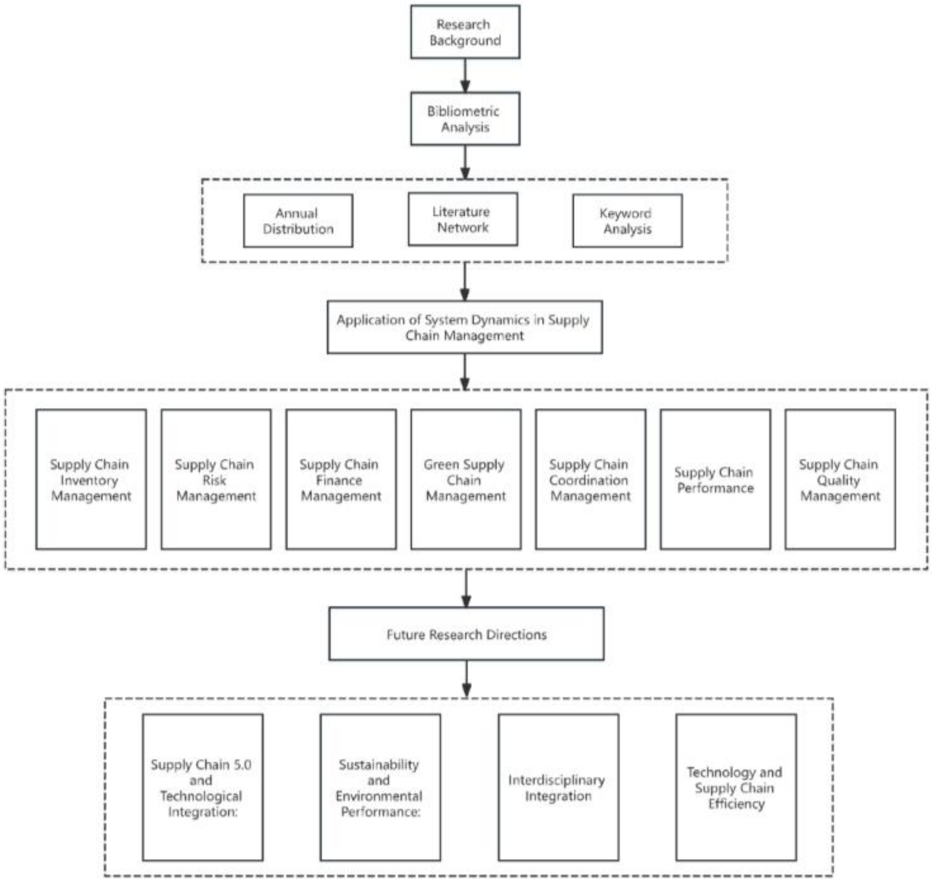


**Figure 1** Technical Roadmap

Bibliometric Analysis

Based on the text analysis strategy employed by Chen et al. (2022), we conducted a bibliometric analysis using the Connected Papers tool, the Word Cloud package in Python and VOS viewer software. As an interactive visual graphic interface tool, Connected Papers offers an intuitive way to understand research progress and interrelationships within a specific field. By entering a key paper, Connected Papers can construct a visual graph that includes similar papers in the field, enabling us to quickly identify key papers and their interconnections. This is crucial for building a comprehensive research lineage and discovering new research trends. Simultaneously, the Word Cloud package generates visual representations, or cloud maps, of single-word keywords that vary in size according to their frequency, thereby providing an effective means of identifying research hotspots. Furthermore, VOS viewer serves as a powerful bibliometric tool that has been extensively used in numerous prior studies. It not only facilitates the visualization of academic network features such as co-authorship and co-citation networks but also excels at constructing co-occurrence networks for keywords. In our analysis, VOS viewers were employed to dig deeper into the intrinsic connections among these keywords, allowing us to categorize them into distinct groups. This process enabled us to identify the research directions represented by each keyword group, offering robust support for further exploration of the research lineage within this field.

We conducted a comprehensive search for English-language journal articles on "Supply Chain and System Dynamics" within the Web of Science core collection, specifically focusing on the SCI-EXPANDED and SSCI databases. Through a meticulous screening process that excluded conference papers, review articles, and retracted publications, we identified a total of 676 eligible articles.

Figure 2 illustrates the annual distribution of articles on supply chain and system dynamics, revealing a steady increase followed by a notable surge. From 1991 to 2005, the field was in its early stages with limited research interest, resulting in a modest number of publications that peaked at only six articles in the most productive year. However, beginning in 2006, there was an observable rise in attention towards this field, with particularly marked growth commencing in 2010. Despite minor fluctuations in subsequent years, the overall trajectory demonstrated consistent upward growth. A more pronounced escalation in article publication occurred from 2016 onward, with significant intensification noted post-2019. Notably, after 2021, the rate of article publication experienced substantial acceleration reflecting rapid expansion. By 2023, the number of published articles reached an unprecedented high exceeding eighty. Collectively, the integration of system dynamics within supply chain management represents an emerging and dynamic domain; its modeling and simulation capabilities exhibit considerable potential within today's digital landscape characterized by Internet connectivity and e-commerce advancements. Furthermore, disruptions to supply chains caused by the COVID-19 pandemic have further expanded opportunities for applying system dynamics methodologies.

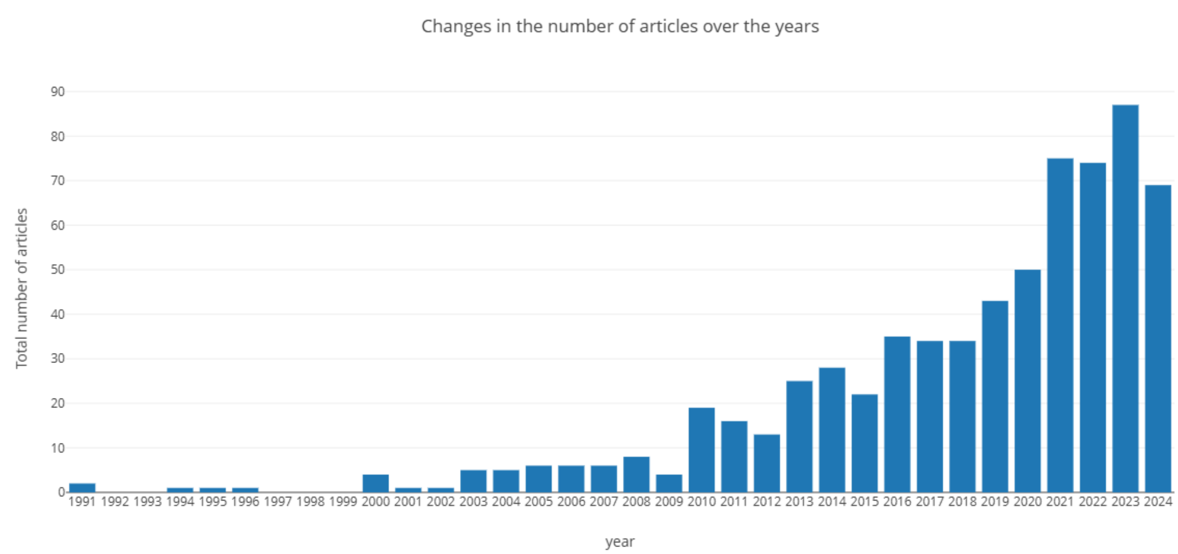


**Figure 2** Changes in the number of articles on supply chain and system dynamics over the years

Furthermore, On the Connected Papers platform, by inputting the document "Evolution of system dynamics in supply chain management," we constructed a literature network map (see Figure 3) that encompasses the fields of system dynamics and supply chain management. This map effectively reveals the research dynamics and associated papers within the domain. The key paper "Bernhard, 2000" prominently occupies a central position in the network map due to its larger node size, reflecting its significant impact and academic contribution to the field. By analyzing the timeline, we are able to trace the research outcomes from "Akkermans" in 1999 to "Raad" in 2019, showcasing the continuity and evolution of research in this area, thus providing a comprehensive understanding of its history and current state. Also, the connections of "Bernhard, 2000" with multiple nodes highlight the current hotspots and trends in research, revealing the extensive applications and pivotal role of system dynamics in supply chain management. Meanwhile, the nodes with fewer connections in the network map suggest potential gaps for future research, offering new directions and spaces for exploration in the academic community. Through this analysis, we can gain a deeper understanding of the application value and research prospects of system dynamics in the field of supply chain management.

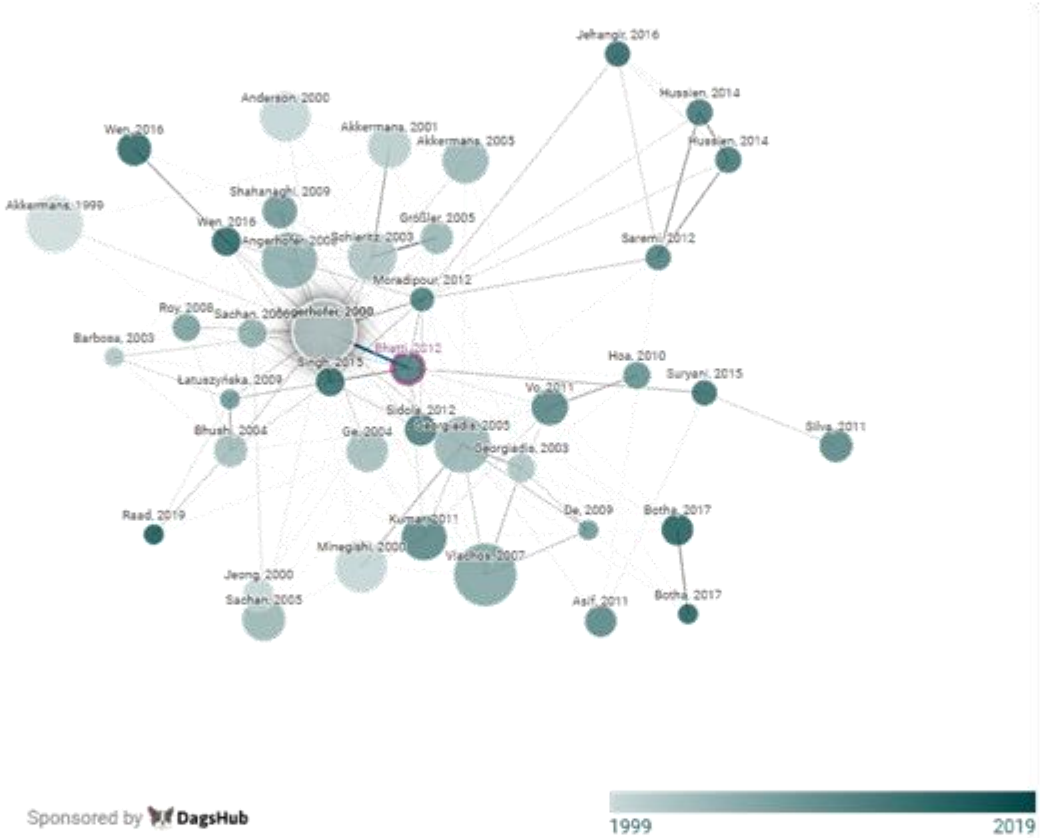


**Figure 2** Literature network map for system dynamics in supply chain management

Subsequently, we further extracted key words from the relevant literature to elucidate the research direction concerning the specific application of system dynamics in supply chain management. Figure 4 presents a keyword cloud, while Figure 5 and Figure 6 illustrate the keyword co-occurrence network, which were generated using VOS viewer.


**Figure 3** Word cloud of keywords for system dynamics in supply chain management

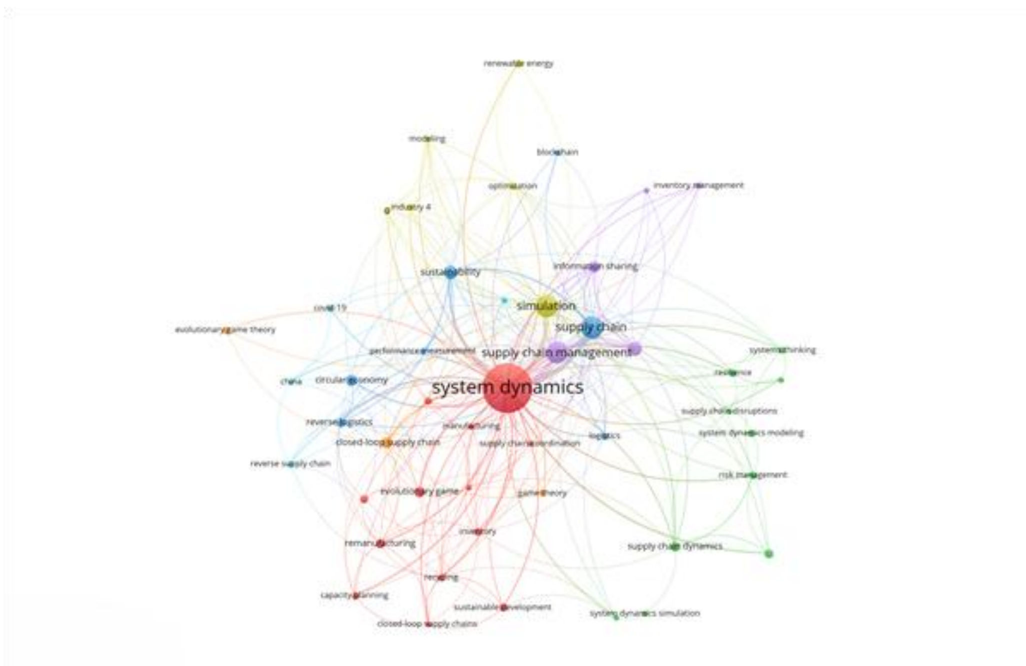


**Figure 5** Keywords co-occurrence for system dynamics in supply chain management



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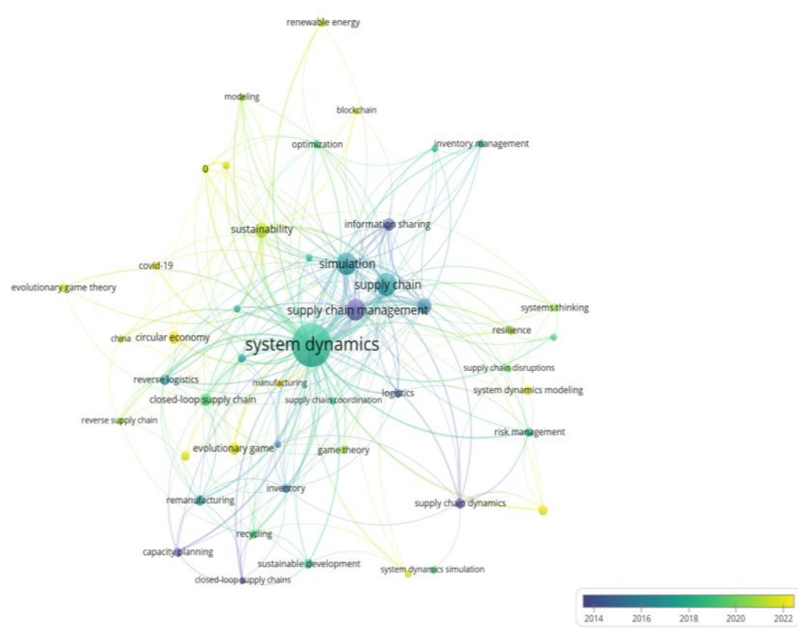


**Figure 6** Keyword Heat Trend for for system dynamics in supply chain management

Through a thorough analysis, we highlight the significant use of system dynamics in supply chain management and the main research methodologies involved. The application areas include inventory management, risk management, financial aspects, green supply chains, coordination efforts, and performance evaluation. Common research methods are simulation techniques and game theory. In the following sections, we will concentrate on these core domains and methodologies to provide a comprehensive overview of the application of system dynamics

Application of System Dynamics in Supply Chain Management

Supply Chain Inventory Management

System dynamics is crucial in inventory management, particularly for identifying and mitigating the bullwhip effect, which offers significant advantages. As a prevalent issue, the bullwhip effect can cause increased inventory volatility and cost escalation throughout the supply chain. To better understand research on system dynamics in supply chain inventory management, keywords from related literature were extracted and demonstrated by a co-occurrence network (see Figure 7), revealing five major research clusters detailed in Table 1.

1) Cluster 1 emphasizes inventory planning, control, and batch size determination by leveraging control engineering and control theory to optimize the management process.

2) Cluster 2 concentrates on improving the accuracy of inventory demand forecasting and risk management. It integrates time series analysis, machine learning, and statistical methods for forecasting while employing risk assessment and simulation techniques to effectively manage risks.

3) Cluster 3 explores environmental sustainability in inventory management. This cluster aims to develop environmentally friendly inventories and evaluate the sustainability of green supply chains and reverse logistics through life cycle assessments and other methodologies.

4) Cluster 4 focuses on applying simulation and optimization techniques within inventory management. It seeks to enhance inventory systems using discrete event simulation, and Monte Carlo simulation, among other approaches.

5) Cluster 5 addresses inventory management challenges in specific application areas such as e-commerce and disaster relief. It incorporates specialized techniques like response methodology to tackle these unique challenges effectively.

In conclusion, system dynamics in supply chain inventory management, along with control theory, data analysis, and optimization algorithms, offers effective solutions for key areas such as inventory control (Rizqi & Chou, 2024), demand forecasting (Zhang et al., 2024), and environmental sustainability (Becerra et al., 2024)

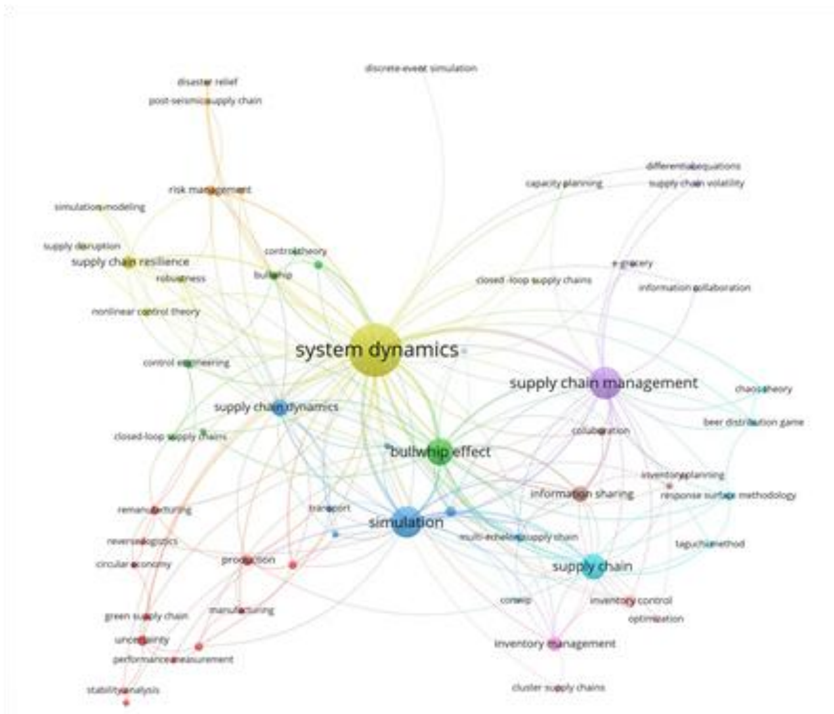


**Figure 7** Inventory management keyword co-occurrence network

**Table 1** Keyword clustering for supply chain inventory management

| Cluster | Keywords |
|---|---|
| 1 | Inventory control, inventory management, inventory planning, batch sizing, control engineering, control theory |
| 2 | Forecasting, demand forecasting, risk management, robustness, uncertainty |
| 3 | Circular economy, green supply chain, remanufacturing, reverse logistics |
| 4 | Simulation, simulation modeling, optimization, nonlinear dynamics, nonlinear control theory, stability analysis |
| 5 | E-grocery, disaster relief, production, manufacturing, transportation, transport, response surface methodology, taguchi method, taguchi methods |

In terms of empirical research, Yan et al. (2017) conducted an in-depth study on inventory management in cluster supply chains. They analyzed the system behavior patterns of the co-operation planning, forecasting and replenishment (CPFR), vendor-managed inventory (VMI), and jointly managed inventory (JMI) models of cluster supply chains. Then, using a system dynamics approach to establish a corresponding inventory management model for simulation. The results indicated that applying the CPFR model effectively mitigates the bullwhip effect, reduces inventory levels, and enhances overall supply chain efficiency. However, their focus was primarily on internal cluster dynamics without exploring external influences such as transport systems. Rathore et al. (2021) addressed this gap by employing a system dynamics approach to model dynamic feedback effects and complex interactions among risk factors impacting food transport systems. Their findings provided key recommendations for policymakers to enhance food supply chain efficiency. Building on this work, Zhou et al. (2022) further applied system dynamics to inventory management within the sulfur product supply chain. They analyzed distributor-retailer secondary inventory control strategies and found significant bullwhip effects influenced by changes in transport time and inventory adjustment periods at node firms. Based on these insights, they proposed optimization measures including establishing an information-sharing platform, implementing visual information management, and outsourcing logistics services to improve operational efficiency across the entire product supply chain.

Figure 8 presents the key parameters of the system dynamics simulations and numerical analyses applied in the three papers.

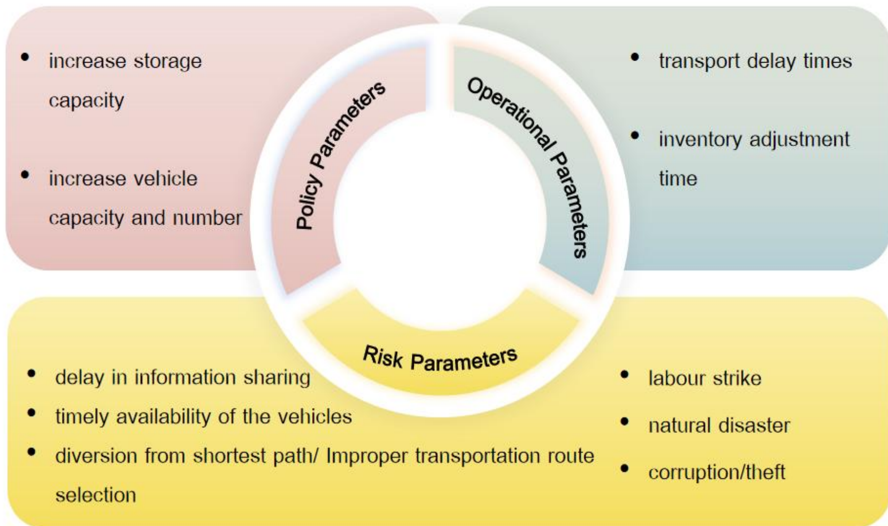


**Figure 8** Map of the key parameters used
by Yan et al. (2017), Rathore et al. (2021), and Zhou et al. (2022)

Supply Chain Risk Management

System dynamics plays an important role in managing supply chain risk and enhancing supply chain resilience by dynamically modeling and analyzing the intricate behaviors of supply chains, as well as their performance under risk. Similar to the previous section, we extracted keywords from relevant literature and constructed the co-occurrence network shown in Figure 9.

Cluster information is detailed in Table 2.

1) Cluster 1 emphasizes risk identification, assessment, and diffusion while enhancing the resilience and responsiveness of supply chains. This cluster frequently incorporates risk assessment models along with simulation and optimization techniques.

2) Cluster 2 investigates the integration of information technology and data science in risk management. Key areas include data sharing, digital transformation, and simulation optimization. It often combines these elements with simulation techniques and data analytics to enhance risk management processes.

3) Cluster 3 explores how risk management adapts to environmental changes and policy requirements to promote supply chain sustainability. This is typically conducted alongside life cycle assessments, environmental impact evaluations, and policy analyses.

4) Cluster 4 analyzes cooperation and coordination mechanisms within supply chains as well as the roles of logistics and reverse logistics in effective risk management. This analysis often employs game theory, coordination models, and service supply chain frameworks.

5) Cluster 5 highlights systems thinking to bolster the robustness and overall performance of risk

management systems. It is commonly integrated with systems thinking frameworks alongside resilience analysis for designing and evaluating these systems effectively.

In summary, system dynamics offers supply chain managers comprehensive solutions for risk management by integrating risk assessment models, simulation, and optimization techniques. This approach effectively addresses disruption risk (Ke et al., 2024), resilience enhancement (Liu et al., 2023), risk identification and assessment (Jahani et al., 2023), and improved responsiveness (Saarinen et al., 2024).

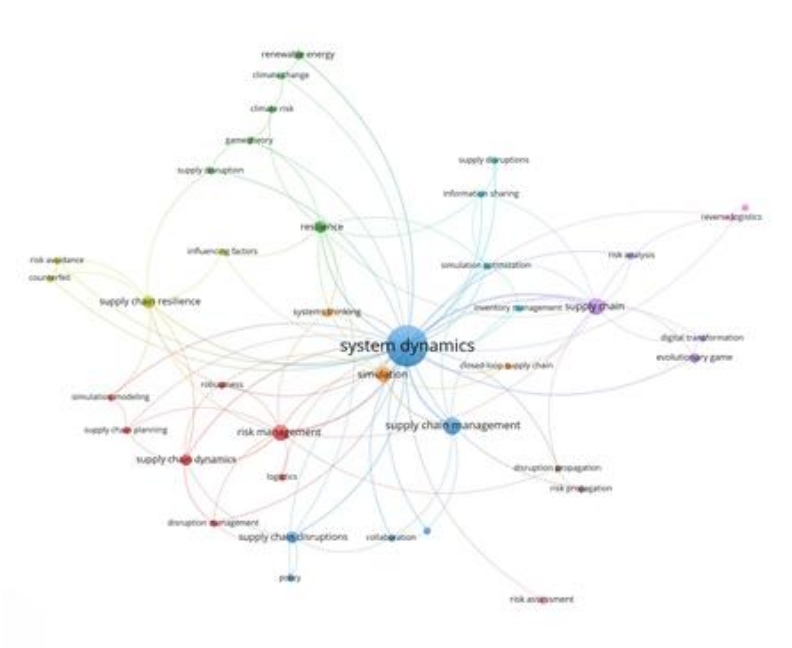


**Figure 9** Supply chain risk management keyword co-occurrence network

**Table 2** Keyword clustering for supply chain risk management

| Cluster | Keywords |
|---|---|
| 1 | Risk management, supply chain resilience, risk assessment, supply chain dynamics, risk avoidance, supply chain disruptions, risk propagation, supply chain planning, risk analysis |
| 2 | Information sharing, digital transformation, simulation, simulation modeling, simulation optimization, system dynamics |
| 3 | Climate change, climate risk, renewable energy, sustainability, closed-loop supply chain, policy |
| 4 | Supply chain management, supply chain coordination, service supply chain, reverse logistics |

5 Systems thinking, robustness, resilience

In empirical studies, Gu and Gao (2016) used a system dynamics model to simulate the effects of production disruptions on integrated remanufacturing/manufacturing (R/M) supply chains. They recommended that manufacturers establish multi-level inventories and develop contingency plans before disruptions occur. Building upon this foundation, Ghadge et al. (2022) expanded this research by designing four disruption scenarios to thoroughly investigate the propagation effects of supply chain disruptions. However, their study primarily concentrated on identifying and visualizing these impacts without offering specific solutions. To address this gap, Bussieweke et al. (2024) developed a model that integrates system dynamics with reinforcement learning, formulating a robust recovery policy that effectively mitigated chain reactions from supply chain disruptions while demonstrating significant resilience amid uncertainty and incomplete information.

Figure 4 Map of the key parameters used
by Gu and Gao (2016), Ghadge et al. (2022), and Bussieweke et al. (2024) presents the key parameters of the system dynamics simulations and numerical analyses applied in the three papers.

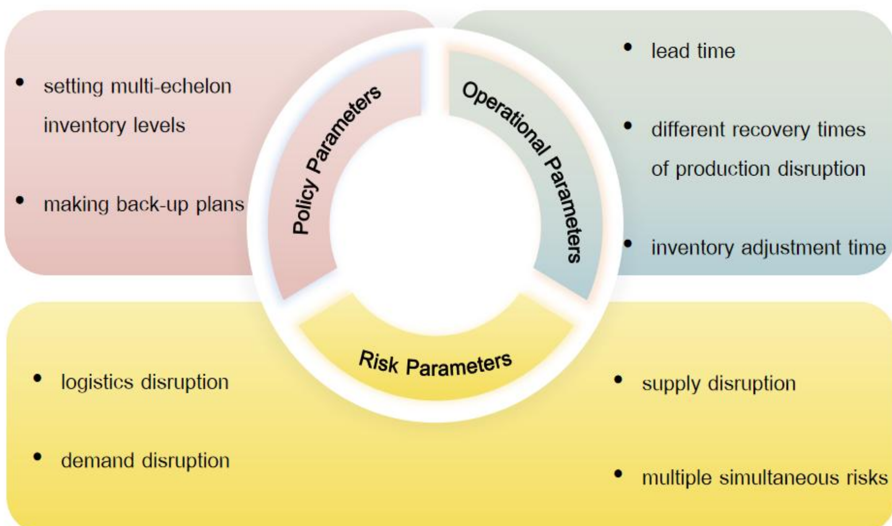


**Figure 4** Map of the key parameters used
by Gu and Gao (2016), Ghadge et al. (2022), and Bussieweke et al. (2024)

Supply Chain Finance Management

In supply chain finance, system dynamics has demonstrated potential for enhancing robustness, especially in credit assessment, capital flow management, and decision optimization. Figure 11 Supply chain finance management keyword co-occurrence network presents the topics and methodologies in this field, with keywords organized into five clusters as shown in Table 3.

1) Cluster 1 focuses on supply chain finance and risk management, examining operational mechanisms,

financing methods, risk management strategies, and trade risk assessment. This often involves the utilization of financial and risk assessment tools to optimize the entire supply chain finance process.

2) Cluster 2 explores technology and innovation in supply chain finance, particularly blockchain and big data analytics, aiming to enhance transparency and efficiency through the integration of these technologies.

3) Cluster 3 investigates the link between supply chain finance and environmental sustainability, assessing how it can foster low-carbon supply chains and green financial products while incorporating environmental impact assessments and sustainability indicators to evaluate their ecological effects.

4) Cluster 4 examines the relationship between supply chain finance and government policies. It aims to understand how these policies can drive development through analysis and studies that predict their impacts on supply chain finance.

5) Cluster 5 assesses the impact of supply chain finance on firm performance metrics such as economic value added, profitability, and customer satisfaction using financial analysis tools.

In summary, supply chain finance management integrates system dynamics with financial modeling, data analysis, and financial analysis to optimize and develop supply chain finance.

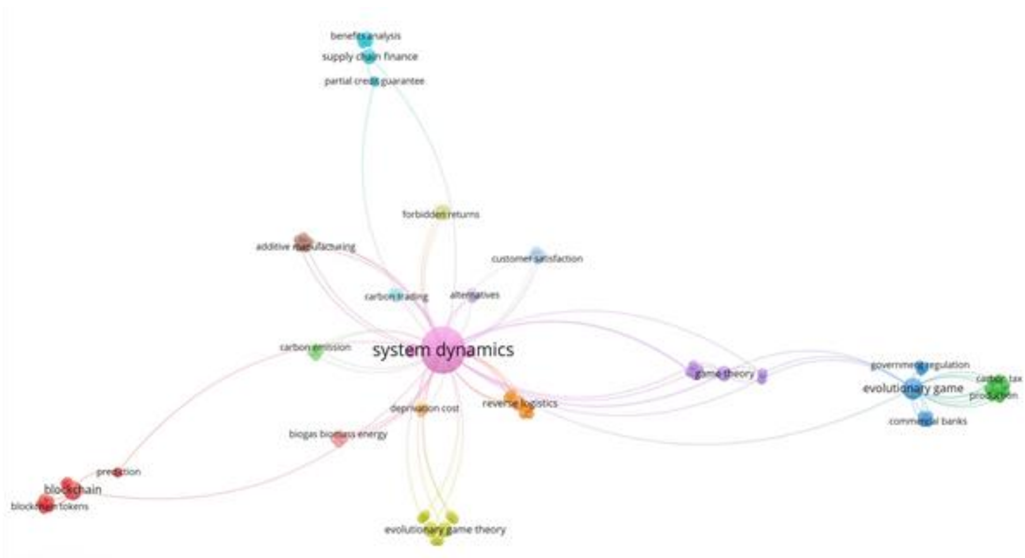


**Figure 11** Supply chain finance management keyword co-occurrence network

**Table 3** Keyword clustering for supply chain financial management

| Cluster | Keywords |
|---|---|
| 1 | Commerce supply chain financing, supply chain finance, reverse factoring, risk management, trade risk |
| 2 | Blockchain, blockchain tokens, big data, digital marketing analytics, technological innovation |
| 3 | Green supply chain finance, low-carbon supply chain, sustainability, carbon emission, carbon tax |
| 4 | Government, government intervention, government regulation, policy factors, incentive policy |
| 5 | Economic value added, profitability, performance measurement, customer satisfaction |

In empirical research, Ji et al. (2012) used system dynamics to examine how prepayment financing alleviates financial constraints for SMEs, finding it can optimize capital flow and enhance supply chain responsiveness and overall performance. However, their focus was primarily on prepayment finance rather than other forms of supply chain finance. Later, Dello Iacono et al. (2015) investigated reverse factoring arrangements and discovered that while these can provide economic benefits to all parties in the supply chain, such benefits are highly sensitive to market conditions and only feasible under specific circumstances. Supply chain finance still faces challenges, particularly in credit assessment. In this context, Zhang, H. Y. et al. (2023) proposed a dynamic credit assessment method using system dynamics, constructed a credit assessment index system for e-commerce micro and small enterprises, optimized weights through sensitivity analysis, and applied it within the TOPSIS-GRA model, which effectively enhancing both the accuracy of credit assessments and financing efficiency. Zhang, X. M. et al. (2023) further explored cash flow disruptions during the epidemic period with a focus on partial credit guarantees (PCG). They constructed models simulating various scenarios and found that PCG alleviates cash flow pressure while maintaining supply chain stability; additionally, price adjustments improve retailer performance and bolster supply chain robustness amid disruptions in manufacturers' production capacity.

Figure 12 presents the key parameters of the system dynamics simulations and numerical analyses applied in the three papers.

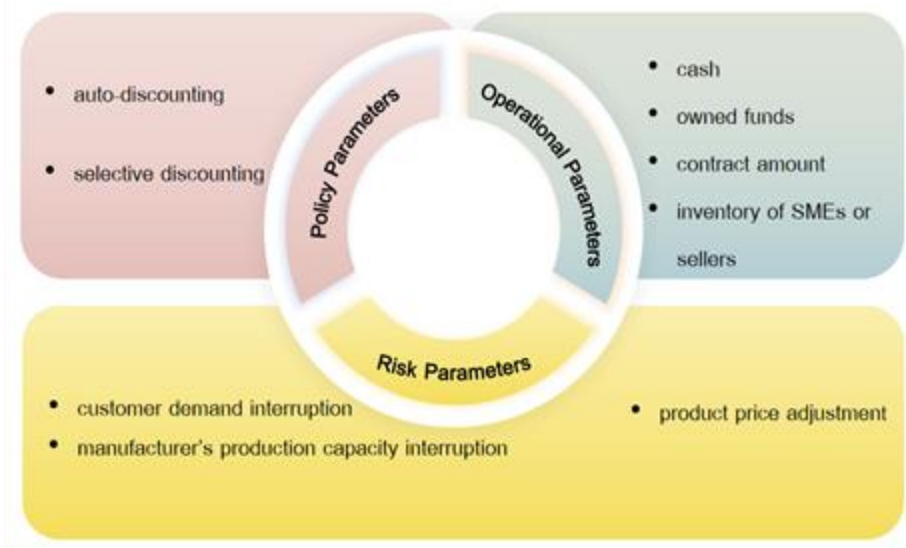


**Figure 12** Map of the key parameters used
by Ji et al. (2012), Dello Iacono et al. (2015) and Zhang, X.M. et al. (2023)

Green Supply Chain Management

System dynamics serves as a fundamental analytical tool for green supply chain management, enabling researchers to gain profound insights into the dynamic behaviors of supply chain participants and providing a scientific foundation for sustainable decision-making. Figure 13 illustrates the keyword co-occurrence network in green supply chain management, highlighting the themes and methodologies explored within this domain. The keywords are categorized into five distinct clusters, as detailed in Table 4

1) Cluster 1 focuses on green supply chain management and policy, exploring green product development, government incentives, and their effects on the supply chain through policy analysis and management models.

2) Cluster 2 emphasizes environmental impact and sustainability assessment by evaluating the ecological effects of green supply chain activities, including carbon trading and life cycle assessments. This cluster frequently combines environmental impact assessments with life cycle evaluations and sustainability indicators.

3) Cluster 3 explores technology innovation and data management in green supply chains, emphasizing the use of artificial intelligence, blockchain, and data strategies to enhance efficiency and transparency.

4) Cluster 4 analyzes supply chain finance and performance, investigating how green finance influences business outcomes through financial analysis tools.

5) Cluster 5 examines system dynamics and complexity using evolutionary game theory to study the intricate behaviors of green supply chains, simulating and analyzing their dynamics and strategic interactions.

In summary, within the realm of green supply chain management, system dynamics is often integrated with policy analysis, environmental impact assessment, financial analysis, and evolutionary game theory. This integration provides comprehensive analytical tools that facilitate the sustainable development of green supply chains.

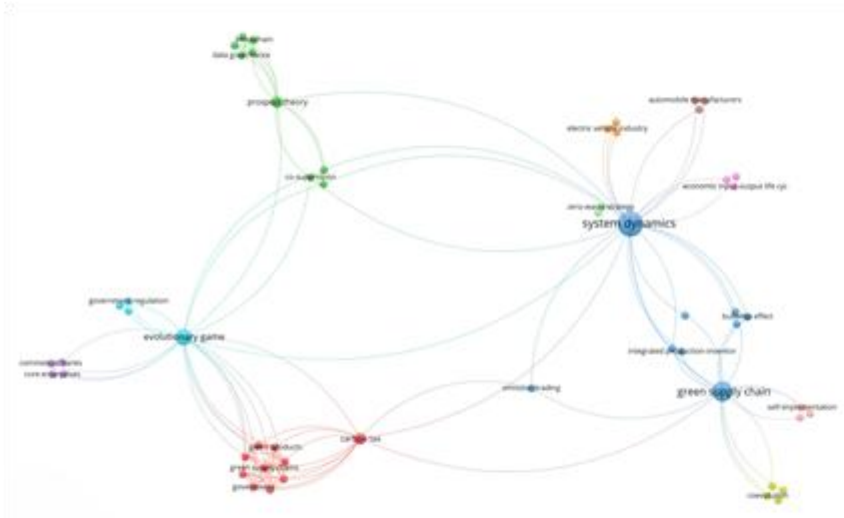


**Figure 13** Green supply chain management keyword co-occurrence network

**Table 4** Clustering of keywords for green supply chain management

| Cluster | Keywords |
|---|---|
| 1 | Green supply chain, green supply chain management diffusion, green products, green sensitivity, green strategy, government intervention, government regulation, policy factors, incentive mechanism, incentive policy |
| 2 | Carbon tax, emission trading, product carbon footprint, sustainable development, economic input-output life cycle assessment, zero-waste strategy |
| 3 | Artificial intelligence, blockchain, data governance, electric ships, electric vehicle industry, electronic products, recycling, traceability |
| 4 | Green supply chain finance, commercial banks, firm performance, core enterprises |
| 5 | System dynamics simulation, systems theory, complex evolution game, evolutionary game, tripartite evolutionary game, uncertainty |

In empirical studies, Tong et al. (2019) analyze the behavioral evolution of retailers and manufacturers under emissions trading policies using evolutionary games and system dynamics, emphasizing joint sustainable decision-making. However, their study primarily concentrates on the behavioral interactions between retailers and manufacturers, which remains insufficient for a comprehensive exploration of the overall design and management dimensions within green supply chains. To address this gap, Naderi et al. (2021) expand the research to include green supply chain design in a global market context, particularly optimizing production, inventory, and logistics decisions. Their system dynamics modeling identifies minimizing transport costs, optimizing warehouse capacity, and improving productivity as key strategies. Meanwhile, van Keeken et al. (2024) examine the long-term effects of product life extension on environmental impacts within the European automotive supply chain for aluminum rolled products. Their system dynamics simulation shows that extending product life effectively reduces global warming potential and supports the goals of the European Green Deal.

Figure 14 presents the key parameters analyzed through system dynamics simulation and numerical analysis in the three papers

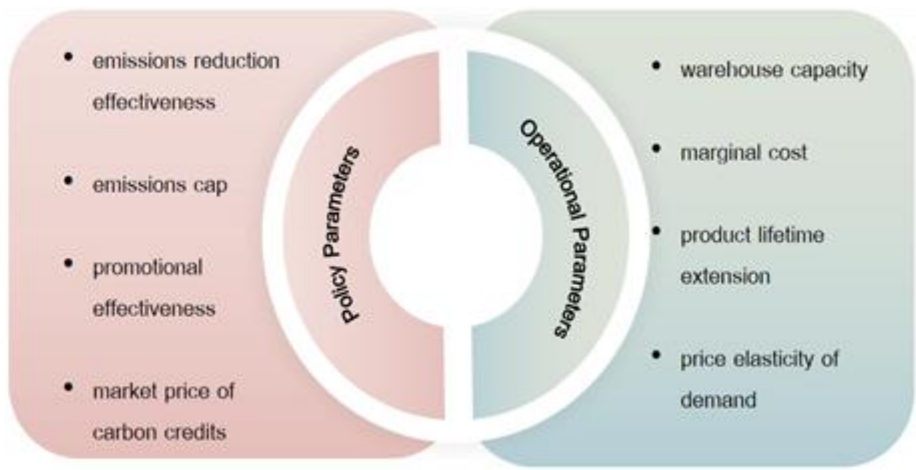


**Figure 14** Map of the key parameters used
by Tong et al. (2019), Naderi et al. (2021) and van Keeken et al. (2024)

In addition, the application of system dynamics in supply chain management is extensive, encompassing key areas such as coordination, performance assessment, and quality management. To provide a comprehensive overview of its applications, Table 5 summarizes additional significant literature on system dynamics in this field.

**Table 5** Additional Relevant Studies

| Category | Authors | Research Objective | Key Findings |
|---|---|---|---|
| Supply Chain Inventory Management | Khan and Hebbar (2021) | Evaluate SCI strategies in chemical supply chains. | Increased transportation time does not affect sales, but raw material inventory rises. |
| | Hong (2022) | Study the impact of system dynamics on supply chain finance collaboration. | Higher bank input levels improve supply chain financial performance and support. |
| Supply Chain Risk Management | Olivares-Aguila and ElMaraghy (2021) | Develop a multi-echelon disruption plan. | Disruptions significantly impact service levels, costs, and profits; prioritize downstream policies. |
| | Zhu et al. (2021) | Assess SCI strategies on disruption recovery. | Operational integration is optimal; information integration often underperforms. |
| Supply Chain Finance Management | Chen (2024) | Design an agricultural supply chain financial system. | Identified key factors affecting coordination and provided strategies for improvement. |
| Green Supply Chain Management | Wang et al. (2024) | Analyze carbon quota allocation under EU-ETS. | Green technology effectively reduces emissions; profits may vary with price changes. |
| | Rajeev et al. (2024) | Simulate biofertilizer impacts on supply chains. | Insights for policymakers on subsidy levels for sustainable transitions. |
| | Tian et al. (2014) | Analyze green supply chain diffusion in China using system dynamics and evolutionary game theory. | Subsidies to manufacturers promote green supply chain management more effectively than those to consumers. Environmental awareness also influences diffusion. |
| Supply Chain Coordination Management | Zhang, M. L. et al. (2024) | Study decision coordination to mitigate the bullwhip effect. | Shorter lead times increase supplier profits, while retailer profits decrease. |
| | Izadi et al. (2023) | Explore blockchain in humanitarian supply chains. | Blockchain is effective in crises; labor increases are better when demand is low. |
| | Li et al. (2024) | Examine strategy impacts on maritime supply chain revenue using game theory and system dynamics. | Shipping company costs and benefits drive strategy selection. Information sharing and pricing improvements are essential for sustainable development. |
| Supply Chain Performance | Farjana and Ashraf (2023) | Identify key performance indicators for waste wood. | Established 12 key indicators for waste processing and management. |
| Supply Chain Quality Management | Duan et al. (2024) | Address quality management in closed-loop supply chains. | Contract coordination can resolve quality issues and enhance CLSC profits. |

## Summary

Following an in-depth analysis of the key areas where system dynamics is applied in supply chain management, we have found that system dynamics plays a crucial role not only in inventory management, risk management, finance, and sustainability, but also in supply chain coordination management, and its potential extends far beyond current applications. To meet readers' expectations for a deeper understanding and innovative insights, we propose a series of innovative research directions in the following text, aimed at advancing the development of theory and the application in practice.

1) Supply Chain 5.0 and Technological Integration: As an advanced phase in the evolution of supply chain coordination, Supply Chain 5.0 embodies a significant leap towards digitalization and intelligentization. Future research should delve into the specific context and inherent requirements of this phase, by Integrating system dynamics with advanced technologies such as Big Data, Artificial Intelligence (AI), and the Internet of Things (IoT) to streamline processes and enhance the supply chain's ability to adapt to the complexities of modern business.

2) Sustainability and Environmental Performance: Based on the analysis presented earlier, system dynamics has been widely applied in various fields such as low-carbon green policy analysis, environmental impact assessment, and green finance. Looking ahead, as the issue of sustainability continues to gain prominence, system dynamics is expected to play a pivotal role in optimizing the environmental performance of supply chains and leading the development of green supply chains.

3) Interdisciplinary Integration: In light of the pivotal applications of system dynamics in supply chain management, particularly its notable impact in inventory management, risk management, and green supply chain management, future research can delve into the integration of system dynamics with behavioral science, psychology, and sociology. This integration will provide an in-depth analysis of how decision-makers' behaviors, cognitive biases, social interactions, and cultural differences influence the dynamic operations of supply chains. For instance, by simulating supply chain decision-making processes across different cultural contexts, research could explore how to refine supply chain strategies to cater to the diverse global market environment.

4) Technology and Supply Chain Efficiency: Building on the analysis presented earlier, the application of system dynamics in supply chain finance and performance evaluation has demonstrated its potential to optimize supply chain processes and enhance transparency. Future research could focus on the integration of system dynamics with advanced technologies such as blockchain and machine learning to further improve the transparency, security, and overall efficiency of supply chains. For example, studies could explore how to leverage blockchain technology to enhance traceability and trust within supply chains, or how to optimize inventory management and demand forecasting through machine learning algorithms.

These studies will significantly advance toward both theoretical understanding and practical applications in supply chain management.

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