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A Review of Research on Supply Chain Resilience Evaluation Indicator System and Evaluation Methods

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Abstract: In the context of intensifying globalization and escalating supply chain risks, the study of supply chain resilience has increasingly attracted significant scholarly attention globally. This paper provides a comprehensive review of the current research landscape on the definition of supply chain resilience, its evaluation metric systems, and assessment methodologies, with an in-depth analysis of pertinent literature from both domestic and international sources. The extant research reveals a lack of consensus on the precise definition of supply chain resilience. The predominant evaluation methodologies encompass index weighting methods, mathematical modeling approaches, and simulation techniques, each possessing distinct advantages and limitations. This paper underscores the necessity for future research to emphasize the contextual variability in supply chain complexity, bolster the inherent resilience of supply chains, and develop more objective and versatile evaluation models. Furthermore, the integration of emerging technologies such as big data, artificial intelligence, and blockchain is anticipated to play a pivotal role in enhancing supply chain resilience. The deployment of these advanced technologies not only offers novel avenues for theoretical exploration but also furnishes crucial tools and methodologies for practical supply chain management.

Keywords: Supply Chain Resilience; Evaluation Dimension; Evaluation Index System; Evaluation Method; Supply Chain Management

1. Introduction

In recent years, the global supply chain has experienced prolonged disruption due to the impacts of the COVID-19 pandemic and escalating international political tensions. To foster the reconstruction and regionalization of global supply chains and to support their continuous advancement, it is essential to focus on two key areas. Firstly, accelerating the digital transformation and innovation of supply chains should be prioritized as a pivotal driver for enhancing efficiency and collaborative synergy. Secondly, bolstering self-sufficiency and resilience within supply chains is crucial for ensuring their security and stability, which is arguably the more critical factor.

Enhancing supply chain resilience is crucial in mitigating the risk of disruptions, enabling enterprises to recover swiftly from crises and adapt effectively to environmental uncertainties. Thus, employing scientific methods to evaluate the resilience levels of supply chains is imperative. This evaluation should include a comprehensive analysis of strengths and weaknesses, identification of developmental directions, and assessment of potential growth areas. Based on these insights, targeted strategies can be formulated to strengthen supply chain resilience. Such measures are essential for not only enhancing the robustness of supply chains but also for promoting high-quality economic development and fostering new competitive advantages in international cooperation and competition.

Existing research on supply chain resilience is marked by heterogeneous definitions, complex and often subjective evaluation methodologies, and a wide range of enhancement strategies. This paper aims to systematically synthesize the relevant literature from both domestic and international sources. The focus is on providing a comprehensive review of the definitions of supply chain resilience, the dimensions for constructing evaluation indicator systems, the methodologies for selecting evaluation indicators, and the approaches for assessing resilience levels.

2. Literature Sources and Analysis

2.1 Literature Sources

The literature for this study was gathered from two major databases: CNKI and Web of Science. The collection process took place in April 2024. By using the search terms "Supply Chain Resilience" and excluding irrelevant documents (such as conference abstracts, reviews, and retracted publications), we obtained 543 relevant domestic articles and 2,887 relevant international articles.

2.2 Literature Statistics

A comprehensive statistical analysis of the collected domestic and international literature was conducted, accompanied by the construction of a line chart to elucidate the research trends in this domain.

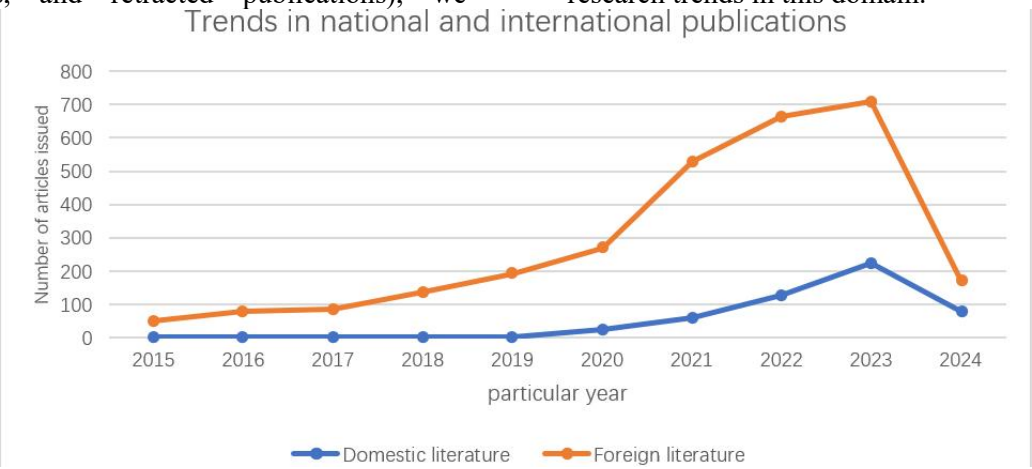

Figure 1. Trends in National and International Publications

As illustrated in Figure 1, it is evident that international research on supply chain resilience has consistently surpassed domestic research in both the initiation timeline and growth trajectory. Notably, international literature began addressing supply chain resilience as early as 2006. Analyzing the publication trends, it is apparent that research interest in supply chain resilience has been on a continuous upward trajectory globally. Since 2011, there has been a marked increase in international studies on this topic, though the rate of growth has moderated in recent years. Conversely, domestic research has experienced a substantial surge starting from 2019, coinciding with the frequent supply chain disruptions induced by the COVID-19 pandemic. This has led to a pronounced escalation in the volume of domestic publications on supply chain resilience, as detailed in Figure 1.

2.3 Definitions of Supply Chain Resilience

The concept of supply chain resilience remains variably defined across the literature. The term "Supply Chain Resilience" was initially introduced by Rice and Caniato in 2003. Its formal definition was subsequently articulated by Christopher and Peck in 2004, who defined it as "the capacity of a supply chain to return to its pre-disruption state or to achieve a more favorable state following a disruption." Since this seminal definition, additional definitions have emerged. A prominent contemporary definition describes supply chain resilience as "the ability of a supply chain to anticipate potential disruptions, respond swiftly to interruptions, and recover effectively". This definition delineates supply chain resilience into three distinct phases: the preparedness phase, the response phase, and the recovery phase.

The concept of supply chain resilience fundamentally underscores the capacity to anticipate, respond to, and recover from disruptions. Building upon this foundational understanding, researchers have approached supply chain resilience as a composite of capabilities or processes, which can be categorized based on the pre-disruption, disruption, and post-disruption phases.

Pre-Disruption: In this phase, supply chain resilience is defined by the ability to anticipate and prepare for sudden external shocks. Hollnagel emphasizes that anticipatory capacity is critical for the continuous enhancement of supply chain resilience, including the capability to respond to potential disruptions before they occur. Masoud et al. further conceptualize resilience as

encompassing three key capabilities: anticipation, resistance, and recovery response. Specifically, anticipatory capacity involves proactive measures and strategic planning to mitigate potential disruptions prior to their occurrence.

During Disruption: At this stage, supply chain resilience is characterized by the ability to maintain stability and operational continuity under the impact of disruptions. Soni et al. employ explanatory theoretical models to identify and rank factors affecting supply chain resilience, highlighting supply chain collaboration and agility as pivotal determinants. Novak et al. define resilience in this context as the ability of an organization or industry to preserve its existing structures and processes while effectively responding to disruptions, and subsequently to "bounce back" to a pre-disruption equilibrium or transition to a new, potentially more advantageous equilibrium with minimal cost and time.

Post-Disruption: In the post-disruption phase, supply chain resilience refers to the capacity or process through which an organization recovers and adapts following a disruption. This has been conceptualized in various ways. For instance, Ralston and Blackhurst describe resilience as the organization's ability to recover from disruptive events within a reasonable timeframe. Other scholars argue that supply chain resilience encompasses not only the ability to prepare for, respond to, and recover from disruptions but also the capacity to endure and rebound from such disruptions.

Nonetheless, some research differentiates the concept of enduring disruptions from resilience, labeling the former as robustness rather than resilience. As the study of supply chain resilience has evolved, there is an increasing consensus that resilience encompasses the organization's ability to return to normal operations and, in some cases, to achieve an improved state post-disruption. Recent studies also highlight that resilience should include the capability to reorganize, adapt, or reconfigure the supply chain network in response to disruptions, thus facilitating recovery.

3. Current Status of Research on Supply Chain Resilience Evaluation Frameworks

The evaluation of supply chain resilience represents a critical and evolving field of study. Developing a comprehensive evaluation framework is essential for assessing resilience, as it underpins the process of measuring resilience levels. The construction of evaluation frameworks for supply chain resilience typically involves two key steps: delineating the dimensions of the evaluation framework and selecting appropriate indicators.

3.1 Current Research on Dimensions of Evaluation Frameworks

To construct an effective evaluation framework, researchers must determine the relevant dimensions based on the characteristics of the evaluation subject. Current literature predominantly focuses on two principal perspectives: the structural dimension of the supply chain and the capability dimension. Researchers analyze these dimensions to develop a nuanced framework for evaluating supply chain resilience, reflecting various aspects of both structural integrity and operational capabilities.

3.1.1 Structural Perspective on Supply Chain Resilience

Evaluating supply chain resilience from a structural perspective involves categorizing resilience based on the components and elements within the supply chain's organizational framework. For example, Zhao et al. conducted a detailed literature review and analysis on resilience within green building supply chains. They identified and systematically categorized the influencing factors of resilience and applied the Weighted Sum Rate (WSR) methodology to define the evaluation dimensions. In adherence to established guidelines for framework development, they constructed a multi-tiered evaluation system for green building supply chain resilience, incorporating physical, managerial, and human dimensions [1].

Similarly, Zhu Lei et al. utilized an interpretive structural modeling approach to integrate concepts of supply chain resilience into prefabricated construction. They developed a comprehensive evaluation framework for prefabricated building supply chain resilience, organized into three levels—supply chain, design and supervision units, construction manufacturers, logistics enterprises, and

contractors—across six distinct dimensions [2].

3.1.2 Capability-based Perspective on Supply Chain Resilience

In evaluating supply chain resilience from a capability-based perspective, the focus is on delineating resilience according to the system's capacities to anticipate, resist, and recover from external shocks. For example, Shi Daqian et al. established that the construction of intelligent supply chains is intrinsically linked to the enhancement of supply chain resilience. They proposed a framework disaggregating resilience into three capability dimensions: proactive capabilities, reactive capabilities, and design quality, and provided an in-depth analysis of these components [3].

Similarly, Hu Yangbo reviewed extensive literature on supply chain resilience evaluation from both domestic and international sources. Adopting a capability-based approach, he categorized the evaluation dimensions for automotive supply chains into five core capabilities: predictive capability, absorptive capability, adaptive capability, recovery capability, and learning capability [4]. Ren Xiaoyang conducted a comprehensive synthesis of existing evaluation dimensions used by scholars. Integrating principles from Resource-based Theory, Dynamic Capabilities Theory, and Complex Adaptive Systems Theory, Ren developed a nuanced evaluation framework. This framework, designed for application to case enterprises, includes dimensions such as anticipatory capability, responsive capability, adaptive capability, recovery capability, and learning and growth capability [5].

3.2 Current Status of Research on Indicator Selection Methods for Evaluation Frameworks

The scientific and rational selection of indicators within an evaluation framework is a crucial element in enhancing supply chain resilience. Presently, experts and scholars both domestically and internationally primarily employ two methodologies for selecting evaluation indicators: qualitative and quantitative approaches.

Qualitative Selection Methods: These methods involve expert judgment, literature reviews, and case studies to identify and refine relevant indicators based on theoretical frameworks and empirical insights. Qualitative methods are useful for exploring complex concepts and understanding the contextual relevance of indicators.

Quantitative Selection Methods: These approaches use statistical techniques, such as factor analysis, principal component analysis, and data-driven models, to determine the significance and weight of each indicator. Quantitative methods provide a data-driven basis for indicator selection, allowing for objective and replicable assessments of their importance and reliability.

Both approaches are employed to ensure a comprehensive and robust evaluation framework, addressing various aspects of supply chain resilience and aligning with the specific needs and contexts of different supply chains.

3.2.1 Qualitative Selection Methods

Qualitative methods for indicator selection are essential for constructing nuanced evaluation frameworks that accurately reflect the multidimensional nature of supply chain resilience. For example, Zhu Yongguang et al. developed a comprehensive resilience indicator system for the Chinese copper resource supply chain. This system includes 10 secondary and 28 tertiary indicators, designed to address the specific characteristics and modernization needs of the copper industry chain [6]. Fan and Lu devised an indicator system for automotive supply chain resilience by synthesizing domestic and international literature on resilience factors and integrating these insights with the theoretical constructs of supply chain resilience [7]. Zhang and Gu classified supply chain resilience into two primary dimensions—resistance to external shocks and recovery capability—based on resilience definitions and existing research. They selected relevant indicators corresponding to these dimensions and employed composite indices to evaluate supply chain resilience [8]. Zhong et al. identified 15 critical capability factors through a rigorous literature review and expert consultations [9]. In a similar vein, Statsenko et al. used a qualitative multi-case study approach, which included 28 interviews with senior decision-makers from 17 companies, supplemented by five interviews with the Australian Defence Supply Chain organization and secondary data analysis [10]. Dmitry

developed an effective framework for managing and enhancing resilience during disruptions by analyzing relevant literature and constructing multiple case studies based on primary data [11].

3.2.2 Quantitative Selection Methods

Quantitative approaches for indicator selection are fundamental for constructing robust evaluation frameworks that enable objective and replicable assessments of supply chain resilience. Guo Yuyu et al. developed an urban safety resilience assessment framework by incorporating dimensions such as perturbation, absorption/adaptation, and recovery capabilities. They established an indicator system encompassing four dimensions—economic resilience, social resilience, infrastructure resilience, and ecological resilience. The framework employed entropy weighting methods to ascertain indicator importance and set resilience assessment levels, utilizing a normal cloud model to construct and iteratively validate the urban safety resilience assessment model [12]. Liu et al. investigated emergent risk scenarios and, through a comprehensive review of literature on supply chain elasticity, proposed a conceptual model aimed at mitigating supply chain vulnerability. They employed structural equation modeling on data collected from predominantly manufacturing sectors, empirically analyzing the mechanisms of vulnerability reduction and demonstrating the direct and significant influence of supply chain agility and flexibility on resilience [13]. Cai and Xiao conducted an in-depth quantitative analysis of supply chain resilience by utilizing multivariate coupling models. Their study reviewed existing methodologies and tools, offering a detailed quantitative examination of various supply chain disruptions. They explored the multivariate interaction mechanisms of different types of disruptions and analyzed the coupling effects and variability of resilience parameters. Their research led to the development of a non-redundant optimization method for enhancing supply chain resilience, validated through a case study addressing practical engineering applications [14]. Chih-Hung et al. integrated Multi-Criteria Decision-Making (MCDM) methods with Quality Function Deployment (QFD) to construct a framework for identifying and mitigating key sustainability risks. Their empirical investigation within the elevator manufacturing industry yielded valuable insights and practical guidance for improving supply chain resilience [15].

4. Research Status on Supply Chain Resilience Evaluation Methods

Research on evaluating supply chain resilience has developed diverse methodologies, each with distinct attributes and applications. This review categorizes these methodologies into three primary approaches: index weighting methods, mathematical modeling methods, and simulation methods.

4.1 Index Weighting Methods

Index weighting methods are fundamental in evaluating supply chain resilience, leveraging techniques such as the Analytic Hierarchy Process (AHP) or related approaches to derive weights for assessment indicators. These methods utilize statistical or mathematical procedures to assess the relative importance of each indicator, reflecting their contribution to the overall resilience evaluation.

Liu Jiaxin formulated an evaluation framework for automotive supply chains by integrating dimensions such as forecasting capability, responsiveness, adaptability, recovery, and learning, encompassing 14 specific indicators. This framework was developed based on a thorough analysis of automotive supply chain dynamics and existing resilience evaluation literature. Liu employed both ordinal analysis and entropy weighting methods to determine the composite weights of the indicators. Utilizing data from 2017 to 2021, the study assessed the resilience of the Chinese automotive supply chain, elucidated current development trends, and provided recommendations for enhancing resilience, focusing on information sharing, resource planning, and personnel training [16]. Zhao Li et al. applied a combination of AHP and entropy weighting methods to ascertain the weights of various indicators. Their analysis revealed the relative impact of different factors on resilience, highlighting areas of significant and minimal influence. This approach offered targeted insights for optimizing resilience within green building supply chains [1].

While index weighting methods are

appreciated for their simplicity and ease of application, they exhibit limitations in terms of systemic and holistic integration. The correlation between various factors and hierarchical levels may be inadequately defined, and the process of standardizing indicators prior to calculation can be problematic, especially when the number of factors is extensive.

4.2 Mathematical Modeling Methods

Mathematical modeling methods are grounded in the theoretical understanding of resilience and are employed to quantitatively evaluate its various components. These methods construct mathematical models based on the interdependencies among resilience elements to assess overall resilience.

He Qianqian et al. developed a mathematical regression model to evaluate the resilience indicators of China's manufacturing sector from the perspective of global value chain integration. Building upon existing literature, their model examined the impact of industrial robot adoption on supply chain resilience, thereby facilitating an empirical analysis of the underlying mechanisms and effects [17]. Zhang Wei et al. applied the CoDEA (Cross-efficiency Data Envelopment Analysis) model to assess the resilience of international trade supply chains under major disruptions. Their study, which integrates trade and industrial chain dynamics, proposed a multi-layered supply chain network model to accurately characterize the international trade network for critical mineral resources. This model effectively captures both the damage and recovery dynamics of international trade supply chains in response to significant disruptions [18]. Chowdhury et al. employed a mixed-methods approach, initially using qualitative field research to contextualize their study model and subsequently applying quantitative analysis through survey data. They utilized Partial Least Squares Structural Equation Modeling (PLS-SEM) to analyze the data and evaluate the proposed resilience framework [19].

Mathematical modeling methods are advantageous due to their ability to systematically represent the interactions among resilience components and address complexities associated with numerous factors. However, challenges arise from the absence of a universally accepted definition of resilience and the inherent difficulty in quantifying its components. These methods demand a high level of theoretical comprehension and analytical capability from researchers to effectively model and assess resilience.

4.3 Simulation Methods

Simulation methods offer a dynamic and in-depth approach to assessing supply chain resilience by modeling complex systems and their responses to various disruptions. These methods allow for the exploration of resilience through detailed simulations of risk scenarios and system behavior under stress.

Shen Xi et al. employed a simulation framework to analyze critical mineral resource supply chains. They developed a multi-layered complex network model and a risk propagation model to simulate the rebalancing process of supply chain networks after disruptions have altered the system's equilibrium. Their research introduced a novel metric for node-level resilience, derived from simulations under multiple risk scenarios, and applied this methodology to analyze disruptions within the global nickel ore supply chain network [20]. Moosavi et al. proposed a quantitative resilience assessment approach based on simulation outputs. This method enables decision-makers to develop contingency plans for scenarios involving pandemics or prolonged high-impact disruptions. The approach also provides a framework for evaluating supply chain resilience during interruptions, offering valuable insights for both scholars and practitioners [21].

While simulation methods provide the most direct evaluation of resilience outcomes and validate model feasibility, they present significant challenges. The complexity of simulation models necessitates advanced technical expertise, and the design, execution, and analysis of simulations can be resource-intensive and time-consuming. Consequently, although simulation methods are highly effective for detailed and scenario-specific analyses, their application requires careful consideration of technical requirements and resource constraints. Researchers should select the most appropriate evaluation method in alignment with the specific characteristics of their study subject and research objectives.

5. Research Outlook

Recent developments in the study of supply chain resilience have substantially expanded the scope and depth of research in this field. The current state of research can be delineated as follows:

Global Research Trends: The study of supply chain resilience has consistently attracted significant attention from scholars worldwide. International research exhibits a continuous upward trend in publication volume, reflecting sustained scholarly interest. In contrast, while domestic research has also been active, its focus is often more concentrated on specific aspects compared to the broader thematic range observed in international studies.

Research Focus: Keyword co-occurrence and clustering analyses indicate that international scholars predominantly address micro-level aspects of supply chain resilience. Their research typically employs a combination of qualitative and quantitative methodologies to enhance organizational or supply chain risk management capabilities. Conversely, domestic research tends to emphasize the role of supply chain resilience within the broader context of macroeconomic development. This includes investigating its impact on industrial and supply chain structures, high-quality development, and economic security, as well as its implications for global economic growth and the formulation of new development paradigms.

Methodological Approaches and Research Phases: The study of supply chain resilience generally employs conceptual modeling, quantitative analysis, and empirical research methods. Research in this field can be categorized into two distinct phases: the initial phase focuses on theoretical perspectives related to supply chain resilience, including risk identification and resilience measurement; the subsequent phase shifts towards practical enhancements of supply chain resilience in specific contexts or sectors, with an emphasis on empirical validation.

These insights highlight the dynamic nature of supply chain resilience research and underscore the need for ongoing theoretical and methodological advancements. Future research should aim to address emerging challenges and refine existing frameworks to better understand and enhance supply chain resilience in diverse and evolving contexts.

As globalization intensifies and the spectrum of supply chain risks expands, research on supply chain resilience is expected to maintain its prominence. Concurrently, advancements in technologies such as big data, artificial intelligence, and blockchain are anticipated to significantly bolster supply chain resilience. In light of these developments, the following directions for future research and practice in supply chain resilience are proposed:

Complexity and Contextual Variability: The continuous evolution of socio-economic landscapes is leading to increasingly intricate supply chain networks. Given the heterogeneous nature of these networks and their varying responses to identical external shocks, future research should focus on distinguishing between supply chains across different domains. This involves developing tailored evaluation and governance strategies that account for the unique attributes and environmental contexts of different supply chains.

Proactive Resilience Enhancement: Current research predominantly emphasizes rapid adjustment and adaptation strategies following disruptions. Future studies should extend this focus to proactive resilience enhancement, aiming to fortify supply chains against potential risks before they materialize. This involves investigating strategies that not only improve resistance to disruptions but also facilitate a swifter and more effective recovery, thereby minimizing overall losses and restoring operations to optimal conditions.

Advancement of Evaluation Methods: Existing supply chain resilience evaluation methodologies often suffer from limited applicability and significant subjectivity in indicator selection and scoring. Future research should strive to develop more objective, versatile evaluation models that can be applied across diverse scenarios. This includes refining existing methodologies to mitigate subjective biases and enhancing the robustness and generalizability of resilience assessment frameworks.

These proposed research directions underscore the need for ongoing theoretical and methodological advancements in the study of supply chain resilience. Addressing these areas will contribute to a deeper understanding and more effective management of resilience in

increasingly complex and dynamic supply chain environments.

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