sustainability

Systematic Review

Simulation Methods and Digital Strategies for Supply Chains Facing Disruptions: Insights from a Systematic Literature Review

Benjamin Korder [1], Julien Maheut [2,*] and Matthias Konle [3]

[1] BTS CSCO Advisory, Cloud Success Services, SAP Deutschland SE & Co. KG, Hasso-Plattner-Ring 7, 69190 Walldorf, Germany; benjamin.korder@sap.com
[2] Business Organization Department, ROGLE, Universitat Politècnica de València, Camino de Vera S/N, 46022 Valencia, Spain
[3] Department of Industrial Engineering, University of Applied Sciences Ansbach, Residenzstraße 8, 91522 Ansbach, Germany; matthias.konle@hs-ansbach.de
* Correspondence: juma2@upv.es

Abstract: Supply chain disruptions pose significant economic stability and growth challenges, impacting industries globally. This study aims to systematically review the literature on the use of simulation tools in managing supply chain disruptions, focusing on the historical evolution, prevalent simulation methods, specific challenges addressed, and research gaps. A systematic literature review was conducted using the PRISMA method. An initial pool of 236 articles was identified, from which 213 publications were rigorously reviewed. This study analyzed these articles to map the academic landscape, identify key clusters, and explore the integration of digital advancements in enhancing supply chain resilience. The review identified the chronological development of research in this field, highlighting significant contributions and influential authors. It was found that various simulation methods, including discrete-event simulation, agent-based modeling, and system dynamics, are employed to address different aspects of supply chain disruptions. Two primary research frontiers emerged from the analysis: the strategic reconfiguration of supply chain networks to mitigate ripple effects and the swift implementation of countermeasures to contain disruptions. The findings suggest a need for future research focusing on dynamic analysis and control theory applications to understand and manage supply chain disruptions better. This study also notes the increasing interest and need to use digital technologies (digital twins, artificial intelligence, etc.) in future research. It underscores the necessity for continued research to develop resilient and sustainable supply chain infrastructures aligned with the United Nations' Sustainable Development Goals. The identified research gaps offer a roadmap for future scholarly exploration and practical implementation.

Keywords: supply chain management; supply chain network; supply chain resilience; supply chain disruption; ripple effect; simulation methods

Citation: Korder, B.; Maheut, J.; Konle, M. Simulation Methods and Digital Strategies for Supply Chains Facing Disruptions: Insights from a Systematic Literature Review. *Sustainability* **2024**, *16*, 5957. https://doi.org/10.3390/su16145957

Academic Editor: Alessio Ishizaka

Received: 15 March 2024
Revised: 1 July 2024
Accepted: 2 July 2024
Published: 12 July 2024

1. Introduction

To cite the United Nations' 17 Sustainable Development Goals (SDGs) to transform our world: "[They] are a call for action by all countries–poor, rich and middle-income–to promote prosperity while protecting the planet. They recognize that ending poverty must go hand-in-hand with strategies that build economic growth and address social needs, including education, health, social protection, and job opportunities, while tackling climate change and environmental protection" [1]. Three SGDs that benefit from the deeper investigation of supply chain disruptions using simulation techniques are goals 8, 9, and 12. Goal 8 postulates that multiple crises, such as COVID-19 and several wars, place the global economy under serious threat. The effects of this crisis have also hit supply chains in recent years. Inventing strategies to better cope with the impact of such crises and build more resilient supply chains has already been postulated by authors such as Y. Wang [2] and D. Ivanov in collaboration with A. Dolgui [3]. Given that they are encouraging more intense research in this area, they are directly meeting the requirements for supporting the achievement of goal number 8 of the United Nations' SDG catalog.

In SDG 9.1, the United Nations (UN) emphasizes the development of reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure, to support economic growth and human well-being, focusing on affordable and equitable access for all [4]. The continuous evolution of management paradigms, supported by systematic network frameworks and simulation methods, will be key to building resilient and sustainable infrastructure [3]. Closed-looped supply chains (CLSCs), as required in UN SDG 12.5, should help to reduce waste generation by 2030. This aligns with Katsoras' and Georgiadis' paper [5,6], in which a system dynamics (SD) model for a single manufacturer/multi-echelon CLSC was created. These findings highlight the need for different mitigation policies based on the economic and inventory focus.

This paper aims to understand better the ripple effect in supply chains (SCs) and the influence of network structures on coping with this effect. It builds on the concepts of Dolgui and Ivanov, which state a need for future research in the dynamic analysis of the SC ripple effect (simulations and control theory) and its influence on network structures [3,7]. This is all conducted to support the SDGs through a better understanding of disruptions in SCs through a literature review. Based on these ideas, the following research questions (RQ) will be investigated:

RQ1: What is the chronological evolution of this scientific field?
RQ2: Which simulation methods are most commonly employed in this research domain?
RQ3: Which simulation methods are utilized for specific supply chain challenges?
RQ4: What are the existing research gaps and promising research directions?

These questions aim to guide researchers in reviewing the current situation in the propagation of disruptions in supply networks and understanding how this challenge is approached in the literature. Research question 1 (RQ1) aims to recognize how scientists have analyzed novel situations and included historical events to cover new research gaps and enrich the scientific literature. Likewise, recent advances in technologies and simulation tools are relevant factors that have led to novel proposals in the literature. Identifying whether domain clusters exist, and which types of simulation methods are preferentially and historically used, can serve as a guideline for future contributions (RQ2). Furthermore, the appearance of new types of disruptions (pandemic, war, etc.) poses new challenges to existing SCs. Determining whether specific simulation methods are used in such contexts would be an interesting point for future research (RQ3). Lastly, with such an extensive quantity of papers published over the last decade, categorizing the existing research gaps to highlight promising research directions would help the scientific community to identify potential novelties (RQ4).

This paper is structured as follows. Section 2 addresses previous literature reviews, describes the applied methodology in detail regarding the applied research protocol and information analysis, and introduces the PRISMA flow diagram. Section 3 includes a descriptive analysis of the results, including relevant information such as annual publications, relevant authors, and most-cited papers. Section 4 proposes clustering the existing literature, discussing the main research streams, gaps, and opportunities for each cluster, and finally analyzing the usage of simulation methods. Lastly, Section 5 presents the conclusions derived from the work carried out.

2. Systematic Literature Review

2.1. Previous Literature Reviews

The scientific literature contains several literature reviews of SC disruptions. Nevertheless, existing reviews that include studies on simulation techniques are scarce. Table 1 illustrates the previously conducted literature reviews with a research focus on using simulation methods to analyze the impact on SCs after a network disruption. The focus is split into two main areas within the research field. The first is supply chain management

(SCM), the classic definition of handling the downstream logistics chain. The second is manufacturing, focusing on the operative manufacturing of one participant in a SC.

Dy et al. [8] reviewed 82 publications and analyzed the applicability of digital twin (DT) technologies to cope with risk disruptions. The objective of this paper was to explore the integration of the metaverse and Quality 4.0 to enhance manufacturing system resilience during crises, with a focus on the COVID-19 pandemic. Through a comprehensive literature review, it offers insights into supporting technologies and applications, aiming to provide valuable guidance for greater resilience in global manufacturing processes. The paper explores DT applications in the energy sector, categorizing them into low-carbon city and smart grid levels while addressing interoperability and data processing challenges. It suggests solutions like knowledge graph analysis and emphasizes the role of AI in advancing DT applications for improved energy system resilience. Since DT technologies are not congruent with simulation techniques, this review can be delimited from the review executed for this paper.

Soto and Aguila [9] focus on manufacturing, reviewing 158 publications. Operational and disruption risks in manufacturing paradigms like Flexible Manufacturing Systems (FMSs), Reconfigurable Manufacturing Systems (RMSs), and Smart Manufacturing Systems (SMSs) are investigated. Distinctive risk strategies are identified, with FMSs emphasizing reactive approaches, RMSs prioritizing adaptability, and SMSs focusing on proactive measures, categorizing risks into facets such as investment, safety, and cybersecurity. The paper extensively maps risks and strategies for different manufacturing paradigms. It proposes diverse research directions for future exploration, including redesigning layouts, retrofitting paths, incorporating AI, studying DT, and involving SMEs.

El Jaouhari et al. [10] explore the metaverse and Quality 4.0 intersection to boost manufacturing system resilience, particularly during crises like the COVID-19 pandemic, utilizing a systematic literature review (SLR) from 2012 to 2023. It addresses key research questions about technologies, antecedents, stages, and pandemic-specific applications of metaverse-enabled Quality 4.0, aiming to provide insights for enhancing the resilience of global manufacturing processes. The main findings were a failure to use artificial intelligence and a sufficient exploration of integrating the metaverse (MV), citing approaches to MV-based Quality 4.0 and manufacturing resilience.

As Refs. [9,10] focus mainly on manufacturing execution, they are not comparative publications.

Llaguno et al. [11] provide an overview of nine disruption risk types in SCs, including natural disasters and delays, and discuss mitigation measures like backup suppliers and excess inventory. This paper explores conceptual frameworks for operational risk management, emphasizing the ripple effect in general SCs and delving into specific cases, with particular attention paid to the impact of digitalization in the Industry 4.0 context. It aims to understand disruption risks and mitigation strategies in SCM comprehensively.

Asan and Usta [12] address the research gap on risks in Service Supply Chains (SSCs) by systematically reviewing the existing literature. They identify and define associated risks, explore their interactions, and utilize Interpretive Structural Modeling (ISM) and Matrix-based Multiplication Applied to a Classification (MICMAC) for hierarchical representation. Validated through a real-world case study, this study provides clear definitions of SSC risk categories and a structural model illustrating the nature and consequences of these risks, ultimately aiming to enhance the understanding, identification, and management of risks in SSCs for improved overall performance.

Vieira et al. [13] emphasize simulations as a data integration tool, enabling the analysis to be conducted using data from multiple relevant sources, thereby improving the quality of such analysis. This paper explores digital twins to connect theoretical concepts with practical implementations. It analyzes historical DT efforts, assesses the impact of allied technologies like machine learning, and reviews domain influences on DT implementation. This paper evaluates current limitations, proposes a conceptualization for DT components, and explores its diverse facets to provide comprehensive insights into potential applications and advancements.

Table 1 shows an overview of the executed literature reviews and provides an overview of chronological data, the number of analyzed publications, the main findings, and the key objectives.

After comparing the objectives and key findings of the relevant publications summarized in the section above, it becomes clear that a new review is needed. It can be stated that no existing review covers the specific evolutionary steps in this research or how they are interconnected. Furthermore, it has not been clearly stated which simulation methods are used for which kind of simulative challenges or if the authors determined the technique based on their preferences. Additionally, it is unclear who the most influential authors in this research area are.

2.2. Literature Review Methodology

This paper proposes a systematic literature review (SLR) that follows [14], where approximately 240 publications have been carefully selected, analyzed, and classified. Starting with the scientific contribution made by answering the research questions, the relation to the literature protocol is provided in this section.

Concerning Research Question 1 (RQ1), the historical development of the research topic is thoroughly examined, encompassing the identification of the most relevant journals, influential authors, and pertinent publications.

To address Research Question 2 (RQ2), the employed simulation methods have been scrutinized across the entire spectrum of publications. In addition, the historical evolution of the utilized simulation methods has been elucidated, and redeployment effects have been considered.

In response to Research Question 3 (RQ3), a more in-depth examination has been conducted based on the evaluation carried out for RQ2. The entire collection of publications utilizing simulation techniques has been analyzed thoroughly. The specific simulation technique used by each author has been identified. Subsequently, the prior publications of each author have been scrutinized for instances of employing this simulation technique.

To answer RQ4, scientific maps have been used to highlight how the current research trends are delineated while identifying potential future research directions and open research areas.

The research protocol introduced a definition for the inclusion and exclusion criteria (Table 2). These criteria were significantly influenced by Ivanov's assertion that the ripple effect and related research constitute a relatively novel and underexplored area of inquiry [3]. Consequently, the decision was not to impose a chronological limitation within the research strategy. As the transition from the literature protocol to the SLR unfolded, this initial boundary condition was duly validated.

Furthermore, publications authored in English and German, identified as the most influential languages through the conducted SLR, were deemed relevant. The preliminary assumption guiding the limitation criteria also entailed excluding the research area of computer science and papers with a direct technological focus. This exclusion was deemed necessary due to the notable number of publications focused on software maintenance and development approaches that persisted within the query results.

Throughout the successive phases of the PRISMA procedure, the execution and inclusion criteria were continually refined. Notably, it became evident that as the research query evolved into its final form, the exclusion above criteria lost their applicability. As such, the definitive components of the search strategy are delineated in the table below.

Table 1. Previous literature reviews in the area of supply chain disruptions in combination with simulation techniques (SCM: supply chain management; Mnfg: manufacturing; SSC: service supply chain LR: literature review; SLR: systematic literature review; Dis: dissertation).

Paper	Year	Focus	Methodology	Publications Selected	Years Covered	Main Objectives	Main Findings
[9]	2023	Mnfg	SLR	158	2000–2021	This paper explores operational and disruption risks in manufacturing paradigms, specifically Flexible Manufacturing Systems (FMSs), Reconfigurable Manufacturing Systems (RMSs), and Smart Manufacturing Systems (SMSs). It categorizes risk strategies, identifying that FMSs focus on reactive approaches to disruptions, RMSs emphasize adaptability, and SMSs prioritize proactive strategies. Risks are classified into various facets: investment, ergonomics, safety, demand uncertainty, resource failures, low quality, substitution, and cybersecurity. The study considers the lifecycle stage in which risks are addressed for each paradigm.	Key findings include a detailed mapping of risks and strategies for each paradigm, highlighting the nuanced approaches to risk management. The paper suggests future research directions, such as exploring additional risks, redesigning layouts for RMSs, retrofitting paths for manufacturing systems, adopting a predict-then-optimize paradigm, incorporating AI and ML, studying the implications of digital twins, involving SMEs, and designing dynamic risk assessments for SMSs. Acknowledging limitations in the literature search, the paper proposes extensions to include conference articles and explore other manufacturing paradigms, such as Computer Integrated Manufacturing (CIM).
[10]	2023	Mnfg	SLR	182	2012–2023	This paper delves into the intersection of the metaverse and Quality 4.0 (Q4.0) to enhance the resilience of manufacturing systems during crises, with a specific focus on the COVID-19 pandemic. Through a SLR, the authors aim to answer key research questions regarding the supporting technologies, antecedents, stages, and pandemic-specific applications of metaverse-enabled Q4.0 in manufacturing resilience. The study spans publications from 2012 to 2023, revealing a growing interest in this interdisciplinary field. The overarching goal is to contribute valuable insights for navigating disruptions and improving the resilience of manufacturing processes on a global scale.	Considering the classification of reviewed papers, the findings show that artificial intelligence is especially well-suited to enhancing Manufacturing Excellence. Transparency and flexibility are the resilience enablers that gain the most from implementing MV-based Q4.0. Through analysis and synthesis of the literature, the study reveals the lack of an integrated approach combining MV-based Q4.0 and MFGRES. This is particularly clear during disruptions.

Table 1. *Cont.*

Paper	Year	Focus	Methodology	Publications Selected	Years Covered	Main Objectives	Main Findings
[11]	2022	SCM	SLR	50	2011–2020	This publication summarizes nine disruption risk types in SCs, such as natural disasters and delays. It discusses mitigation measures like backup suppliers and excess inventory and explores conceptual frameworks for handling operational risks. The context analysis focuses on the ripple effect in general SCs, with some articles delving into specific cases and the impact of digitalization in the Industry 4.0 context. Overall, the text aims to comprehensively understand disruption risks, mitigation strategies, and contextual considerations in SCM.	The paper underscores the importance of resilient SCs prepared for disruptions. Key findings highlight the significance of proactive and reactive measures, such as risk mitigation inventories and contingency plans. The impact of disruption causes, like low inventory and inflexible capacity, worsens the ripple effect on SC performance. Various disruptions contribute to this effect, including natural disasters and demand interruptions. The study explores conceptual frameworks and emphasizes the role of digital technologies, like Industry 4.0. The proposed framework is validated through a disruption simulation, aiding SC planners. Future research includes extending the literature review and evaluating sustainability. Overall, its findings contribute to understanding and enhancing SC resilience in disruptions.
[8]	2022	SCM	LR	82	Not available	This paper explores the role of digital twin (DT) technology in addressing global energy and environmental challenges. Specifically, it focuses on the energy sector, analyzing DT applications in areas like urban energy systems and smart grids. Its objectives include defining and classifying DT, examining its current state in the energy sector, discussing key techniques, and proposing future research directions. The paper concludes by summarizing insights into the diverse applications of DT in energy supply and contributing to the evolving field of intelligent energy systems.	The paper explores the applications and challenges of DT technology in the energy sector, focusing on power-related systems. It classifies DT applications into levels, such as low-carbon cities and smart grids. Identified challenges include interoperability issues, model repetition, and data processing limitations. The paper suggests solutions like knowledge graph analysis, model migration, and integration of AI technologies. It introduces a novel classification of DT levels in the smart energy field. Key technologies reviewed include AI integration, emphasizing its role in overcoming challenges. The paper concludes with insights into future challenges and directions for advancing DT applications in energy systems.

Table 1. *Cont.*

Paper	Year	Focus	Methodology	Publications Selected	Years Covered	Main Objectives	Main Findings
[12]	2021	SSC	SLR	832	2004–2021	This paper aims to fill the research gap concerning risks in Service Supply Chains (SSCs) and their management. It systematically reviews the existing literature to identify and define risks associated with SSCs, explores interactions between these risks, and employs Interpretive Structural Modeling (ISM) and Matrix-based Multiplication Applied to a Classification (MICMAC) to represent their interrelationships hierarchically. The study validates theoretical findings through a real-world case study of an ERP consulting firm. The outcome includes clear definitions of SSC risk categories and a structural model illustrating the nature and consequences of these risks. The objectives ultimately seek to enhance understanding, identification, and management of risks in SSCs for improved overall performance.	The paper identifies and defines seven types of risks in SSCs: financial, relationship, demand, operational, service delivery, IT, and external risks. The study categorizes these risks through a SLR and provides formal definitions, providing a shared vocabulary for SSC risk management. The research employs Interpretive Structural Modeling (ISM) and MICMAC to explore interrelationships between these risk types, providing a hierarchical and dependency-based model. Its findings reveal the highly interrelated nature of these risk types, with external and IT risks classified as influential and others as dependent variables. The study provides a macro picture of SSC risks, enhancing awareness and understanding for decision-makers.
[13]	2020	SCM	LR	93	2008–2018	This paper delves into the realm of DTs, aiming to bridge the gap between theoretical concepts and practical implementations. Its objectives include analyzing historical efforts in DT establishment, assessing the impact of allied technologies like machine learning, and reviewing the influence of different domains on DT implementation. The paper also evaluates current limitations and challenges and proposes a conceptualization for DT components and their interdependencies. In essence, it explores the diverse facets of DT to provide comprehensive insights into its potential applications and advancements.	The paper proposes a comprehensive conceptualization of DT, outlining elementary components (physical asset, digital asset, information flow) and imperative components (IoT devices, data, machine learning, security, and evaluation metrics). Key properties of DT, such as self-evolution, domain dependence, autonomy, and synchronization, are discussed. Real-life case studies demonstrate diverse DT implementations, including projects at the University of Cambridge, Italferr in Genoa, and Mater Private Hospital. Its findings emphasize the domain-specific nature of DT components and properties. The paper suggests future steps, including a formal definition, IoT standards, regulations, collaboration with domain experts, and global implementations, to advance the adoption of DT across sectors.

Table 2. Inclusion and exclusion criteria of the search strategy.

	Index	Criteria Description
Inclusion Criteria	1	Journal articles indexed in Scopus and Web of Science (WoS).
	2	Published in any year (including in the press).
	3	Research the ripple effect in supply chain networks worldwide.
	4	Written in English or German.
Exclusion Criteria	1	Articles, book chapters, conference articles, or any source that has not passed a sophisticated peer review process.
	2	Publications that refer to a ripple effect but without a relationship with supply chain management, business logistics management, or supply chain networks.
	3	Research that has no apparent relevance for further research on the ripple effect in supply chain networks.

Inclusion and exclusion criteria establish the framework to tailor the search strategy to the predefined objectives of an upcoming literature review. Given developments in the inclusion and exclusion criteria, along with a slight adjustment to the research question to encompass simulation techniques, the search queries must also be updated during the recent research activities. The following passage describes the progression from the initial search query used in the literature review protocol to the final query employed in the SLR. The initial search term, stipulated in the review protocol for WoS and Scopus, is provided below (Table 3). It was divided into three primary search blocks, interconnected through logical 'AND' operators. The first block restricts the search results to the subject area of SCM. The intermediate search block refines the results to SC networks as a specific topology within SCs. Lastly, relevant synonyms for 'disruption' are included to narrow the search outcomes further. Following the research protocol and the exclusion and inclusion criteria at that time, the research field of 'computer science' was excluded. The search yielded 82 pertinent records in WoS and 141 relevant records in Scopus.

Table 3. Initial research queries used in the SLR.

Database	Results	Criteria Description
Web of Science	82	TS = ((“supply chain management” OR “supply chain resilience”) AND TS = (“supply chain network” OR “supply network”) AND TS = (“ripple effect” OR ”cascading failure” OR “contagion” OR “disruption*”))
Scopus	141	TITLE-ABS-KEY ((“supply chain management” OR “supply chain resilience”) AND (“supply chain network” OR “supply network”) AND (“ripple effect” OR “cascading failure” OR “contagion” OR “disruption*”)) AND (EXCLUDE (SUBJAREA, “COMP”))

The in-depth exploration of the research topic facilitated the identification of potential open research areas. Furthermore, the research activities highlighted an underrepresentation of simulation techniques in the search query outlined in the protocol. These factors led to significant adaptations in the search terms utilized for the SLR, as delineated in the table below. Upon comparing the search phrases of the protocol and the SLR, it becomes evident that the overarching structure consisting of three blocks has been retained, albeit with underlying structural adjustments. The block that enumerates synonyms for 'supply chain disruptions' has been retained and now occupies the foremost position within the sequence of the search blocks. Conversely, the block elaborating on SC networks as distinct network topologies has been eliminated, making way for the term 'supply chain'. Throughout the research journey, it became apparent that narrowing the focus to a specific SC topology, such as SC networks, no longer aligned with the updated research question. The scope of the research was broadened, from disruptions exclusively within SC networks to disruptions in the broader context of SCM. Moreover, it was observed that the condition 'supply chain management' AND 'supply chain resilience' was inadvertently limiting the search results through a filter that no longer accurately mirrored the updated research focus. As a result, the blocks ('supply chain network' OR 'supply network') and ('supply chain management' OR 'supply chain resilience') were consolidated into a single entity, 'supply chain management'. Another aspect that had not been adequately addressed in the initial search query was the incorporation of simulation techniques. To rectify this, the primary simulation techniques ('agent-based modeling', 'digital twin', 'discrete event simulation', 'system dynamics') were incorporated into the third search block (Table 4).

Table 4. Final research queries used in the SLR.

Database	Results	Criteria Description
Web of Science	236	TS = ((“ripple effect” OR “cascading failure*” OR “contagion” OR “disruption*”) AND (“Supply Chain”) AND (“Agent-Based Modeling” OR “digital twin*” OR “Discrete Event Simulation” OR “System Dynamics”))
Scopus	21	TITLE-ABS-KEY ((“ripple effect” OR “cascading” AND “failure*” OR “contagion” OR “disruption*”) AND (“Supply Chain”) AND (“Agent-Based Modeling” OR “digital twin*” OR “Discrete Event Simulation” OR “System Dynamics”))

2.3. Screening and Selection Phase

The results obtained from the database queries established the scope for the bibliometric analysis of the research area. Utilizing these results, the screening phase of the PRISMA procedure commenced (Supplementary File S1). All chosen publication titles, keywords, and abstracts were meticulously categorized. This classification was based on the criteria predefined in the literature review protocol outlined below (Table 5).

Table 5. Classification of screened articles.

Code	Definition	When Used	Action
A: Approved	Title, abstract, and keywords are related to the research objectives.	When the item satisfies the inclusion criteria	Include the item in the reference list, tagging it as an item (A).
E: Excluded	The title, abstract, and keywords are unrelated to the study's objectives.	When the article satisfies the exclusion criteria	Exclude the reference, tagging it as an item (E).
Q: Questionable	The article and abstract are not related to the objectives of the study.	When there is no clear evidence that the summary is in accordance with the inclusion criteria but appears to be related to them	Analyze the full text to determine whether this reference should be included in the study, tagging it as item (A) or item (E).

Throughout the execution of the screening phase, following the application of the exclusion and inclusion criteria, a total of 15 publications were excluded. The ensuing eligibility phase, marked by the amalgamation of results from both query statements, yielded a tally of 148 publications classified as pertinent. In addition, 29 publications were omitted due to the unavailability of the full-text version, where access was requested but not obtained by the authors. Ultimately, 213 publications were identified for comprehensive full-text screening. A visual representation of the streamlined outcomes of the PRISMA procedure is presented in Figure 1.

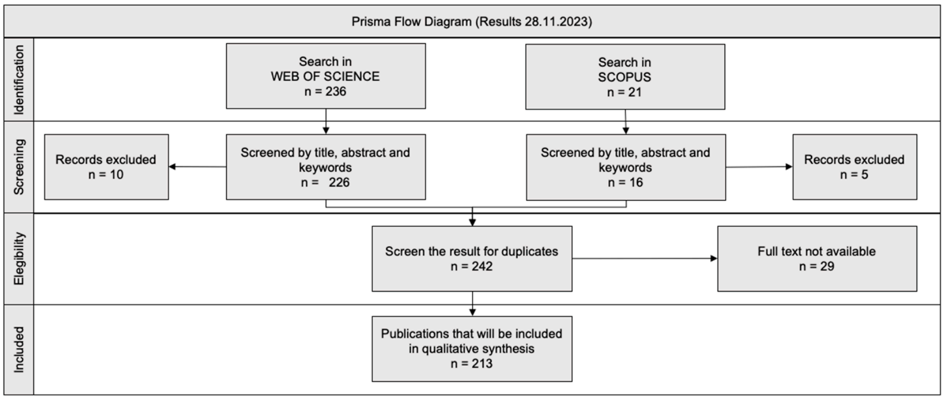

Figure 1. PRISMA flow diagram results.

In the screening process, 236 articles retrieved from WoS were identified as relevant. In addition, 21 articles from Scopus were added. The analyzed sample in the subsequent section comprises 213 publications authored by 568 authors affiliated with 135 institutions and published in 138 journals. These articles have been cited 4960 times (as shown in Table 6 below).

Table 6. Descriptive statistics of the used dataset.

Criteria	Definition
Publication	213
Authors	568
Journals	138
Institutions	135
Cited references	4960

3. Descriptive Analysis of the Information

3.1. Annual Scientific Production

The chronological distribution of publications within the dataset is depicted in Figure 2. The earliest article in the selected context dates to 2006, marking the inception of the trend. From that point onward, there is a discernible upward trajectory. This chronological development serves as compelling evidence for the rising relevance of the research area.

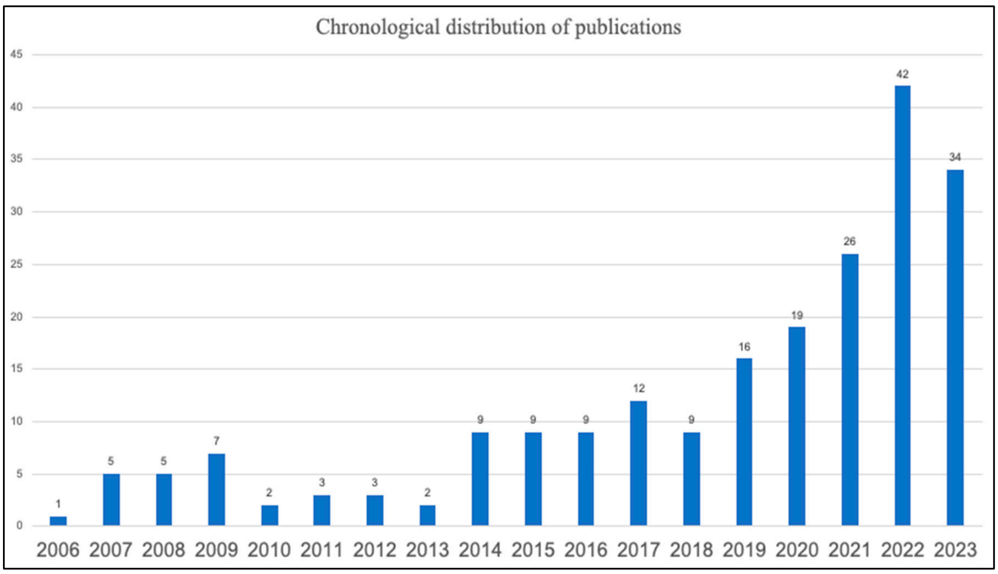

Figure 2. Chronological distribution of publications.

This growth pattern can be segmented into three distinct phases: (1) between 2006 and 2014, a phase of relative stagnation at a modest level is evident; (2) from 2015 to 2018, the number of publications ascended to a higher plateau, reaching an approximate average of 10 publications annually; and (3) since 2019, a substantial surge in publications occurred, culminating in 42 publications in the previous year. Projecting the figures for the first two quarters of 2023, it is plausible that the publication count will mirror that of 2022.

3.2. Most Cited Papers and Journals

The following study evaluates the most-cited publications in the adopted research field, limited to articles cited at least 100 times (Table 7). The average citation rate of the sample is 55 citations. Notably, 19.89 percent of all publications have not yet had any citations. The most-cited article, "Predicting the Impacts of Epidemic Outbreaks on Global Supply Chains: A Simulation-Based Analysis on the Coronavirus Outbreak (COVID-19/SARS-CoV-2) Case," has been cited 731 times. This article simulates the effects of epidemic outbreaks on SCs, using the example of the coronavirus outbreak [15–17].

Table 7. Most-cited publications in the research area.

Article Title	Citations	Journal	Year
[15]	731	Transport Res. E-Log	2020
[3]	449	Prod. Plan. Control	2021
[18]	330	Int. J. Prod. Res.	2020
[19]	298	Transport Res. E-Log	2007
[20]	202	Int. J. Prod. Res.	2020
[21]	151	Int. J. Prod. Res.	2017
[22]	134	Transport Res. E-Log	2021
[23]	118	Int. J. Prod. Res.	2018
[24]	108	Transport Res. E-Log	2016

The second most-cited article is "A Digital Supply Chain Twin for Managing Disruption Risks and Resilience in the Era of Industry 4.0" with 449 citations. This article proposes an approach for modeling a DT of a SC to enhance coping mechanisms for exogenous shocks and to extend SC visibility [3].

The third most-cited article, titled "'A Blessing in Disguise' or 'As If It Was not Hard Enough Already': Reciprocal and Aggravate Vulnerabilities in the Supply Chain" authored by D. Ivanov [18], investigates the interrelations of structural and operational vulnerabilities in the SC using DES.

A Pareto analysis (Figure 3) was conducted to find the most relevant journals in the research area. The "International Journal of Production Research (IJPR)" is the most relevant journal, having published 8.9 percent of all publications. The second-most relevant journal is the conference proceedings publication of the "Winter Simulation Conference (WSC)", which has published 6.3 percent of all analyzed articles. The third-most relevant journal is "Computers & Industrial Engineering (CAIE)", which has published 5.2 percent of all articles. These three journals have published over 20 percent of all articles. All relevant journals can be seen in the diagram below, which shows the number of publications arranged in a chronological cluster. The oldest cluster starts in 2009, the first year a publication in this dataset appeared, and ends in 2014. The middle cluster begins in 2015 and lasts through 2019, while the most recent cluster starts in 2020 and ends in 2023. The graph illustrates that the leading publications have appeared in the last three years, highlighting the relevance of this research journey. Looking at the bar chart of IJPR, it becomes clear that this topic increased relevance in this journal in the last three years because the green cluster is the biggest. Furthermore, it can be stated that this journal has gained interest in this research topic in recent history since no publications have appeared in the yellow cluster. The situation of the WSC and CAIE journals looks different: Publications in the yellow cluster can be seen to show how these journals showed early interest in this topic. The blue and green clusters (extrapolation through the end of the year) are increasing, suggesting that these journals have gained even more interest in this topic in recent years. This is even more striking given that these journals are top-ranked and renowned, underlining the relevance of this research topic. Additionally, the development of the journal "Computer-Aided Chemical Engineering" is worth mentioning. In the early beginnings of this journal, it concentrated on disruption analysis in chemicals SCs under simulation methods [25–27] but lost interest after 2017.

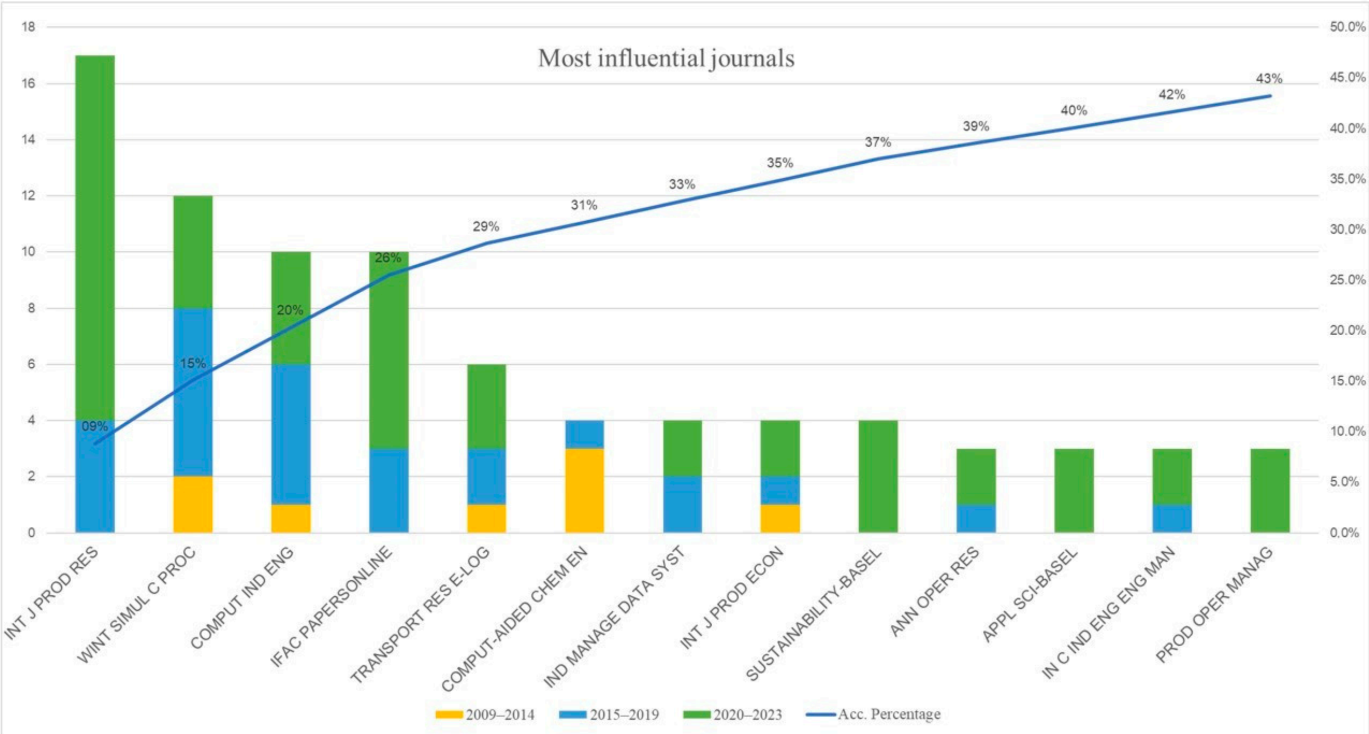

Figure 3. Most influential journals.

3.3. Most Cited Authors

The analysis reveals that 66.01 percent of the authors have published only one paper, while 10.34 percent have published three or more. Table 8 proposes an ordered list of authors who have published at least three articles. In addition, the table provides insights into the impact of the most active authors. According to the table below, A. Dolgui, with an average of 164.60 citations, emerges as the most prominent author, followed by D. Ivanov (140.44) and B. Sokolov (106.50). However, Ivanov stands out as the most productive and influential author in the research area when considering the number of publications.

After identifying the most influential authors, a robust relationship was observed among the key figures in this research domain, particularly in joint publications. Consequently, a correlation analysis was conducted on the co-authorship patterns of all authors within our scope, totaling 569 individuals. The analysis involved identifying and tallying pairs of authors who have collaborated on publications. After excluding pairs with no or only one joint publication, the resulting list of pairs is presented in Table 9. Upon examining the highlighted data, it becomes evident that the triumvirate of D. Ivanov, A. Dolgui, and B. Sokolov significantly dominates this research area.

Upon comparing the outcomes of the co-authorship analysis with the overall publication figures (Table 9), it becomes evident that these three authors predominantly collaborate on their publications. For instance, A. Dolgui has authored five papers, all co-authored by D. Ivanov. Similarly, B. Sokolov co-published all his papers with D. Ivanov, with three also involving A. Dolgui.

Table 8. Most influential authors in the research area.

Author	Publications	Citations	Citations/ Publication
Dolgui, Alexandre	5	823	164.60
Ivanov, Dmitry	16	2247	140.44
Sokolov, Boris	4	426	106.50
Georgiadis, Patroklos	3	108	36.00
Gaston Cedillo-Campos, Miguel	3	100	33.33
Ghadge, Abhijeet	3	95	31.67
Vieira, Antonio A. C.	3	58	19.33
Samvedi, Avinash	3	58	19.33
Dias, Luis	3	58	19.33
Chew, Ek Peng	3	58	19.33
Santos, Maribel Y.	3	58	19.33
Pereira, Guilherme A. B.	3	58	19.33
Heidary, Mojtaba Hajian	3	44	14.67
Gao, Tiegang	3	25	8.33
Behdani, Behzad	3	20	6.67

Table 9. Co-authorship mapping of the most relevant authors.

Authors	Chaudhuri, Atanu	Dolgui, Alexandre	Ghadge, Abhijeet	Ivanov, Dmitry	Pavlov, Alexander	Pavlov, Dmitry	Sokolov, Boris
Chaudhuri, Atanu	-	0	2	1	0	0	0
Dolgui, Alexandre	0	-	0	5	1	1	3
Ghadge, Abhijeet	2	0	-	1	0	0	0
Ivanov, Dmitry	1	5	1	-	2	2	4
Pavlov, Alexander	0	1	0	2	-	2	2
Pavlov, Dmitry	0	1	0	2	2	-	2
Sokolov, Boris	0	3	0	4	2	2	-

4. Classification and Analysis of the Information Obtained from the Selected Publications

4.1. Chronological Clustering of the In-Scope Articles and Analysis of the Most-Cited Articles

By setting the minimum threshold for the number of citations of a referenced work at ten, the original number of articles within the sample was reduced to 46 relevant articles. This was conducted to focus on the most relevant publications. Furthermore, this is the standard setting used in VosViewer v1.6 co-citation analysis.

Building upon these highly cited articles, a co-citation analysis was conducted (Figure 4), identifying the key literature in our research stream. This was carried out to show the interrelations of the articles in scope. By analyzing the articles more deeply, we identified a chronological development of the research area and that the identified clusters build upon each other.

The subsequent graph illustrates the 46 relevant references, segmented into three primary clusters. Notably, a discernible temporal evolution is evident across these clusters.

- Cluster 1 [in red]: The average publication date of this cluster aligns with the early 2000s, signifying its origins.
- Cluster 2 [in green]: Subsequently, the second cluster's average publication date centers around 2010, marking its emergence.
- Cluster 3 [in blue]: Encompasses the most recent publications, commencing around 2019.

This evolution underscores the progression of the interconnected research fronts (see Figure 5). Furthermore, the clustering shows that Cluster 1, which can be seen as the ground floor of this research area, is very pronounced.

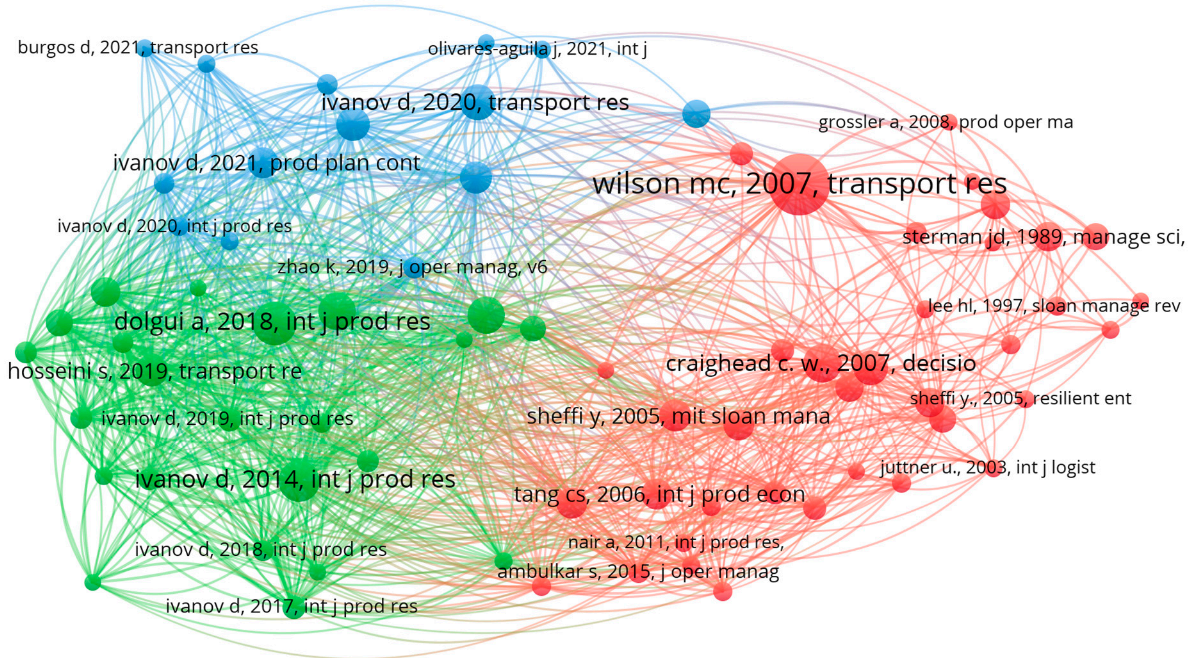

Figure 4. Scientific map of co-citations.

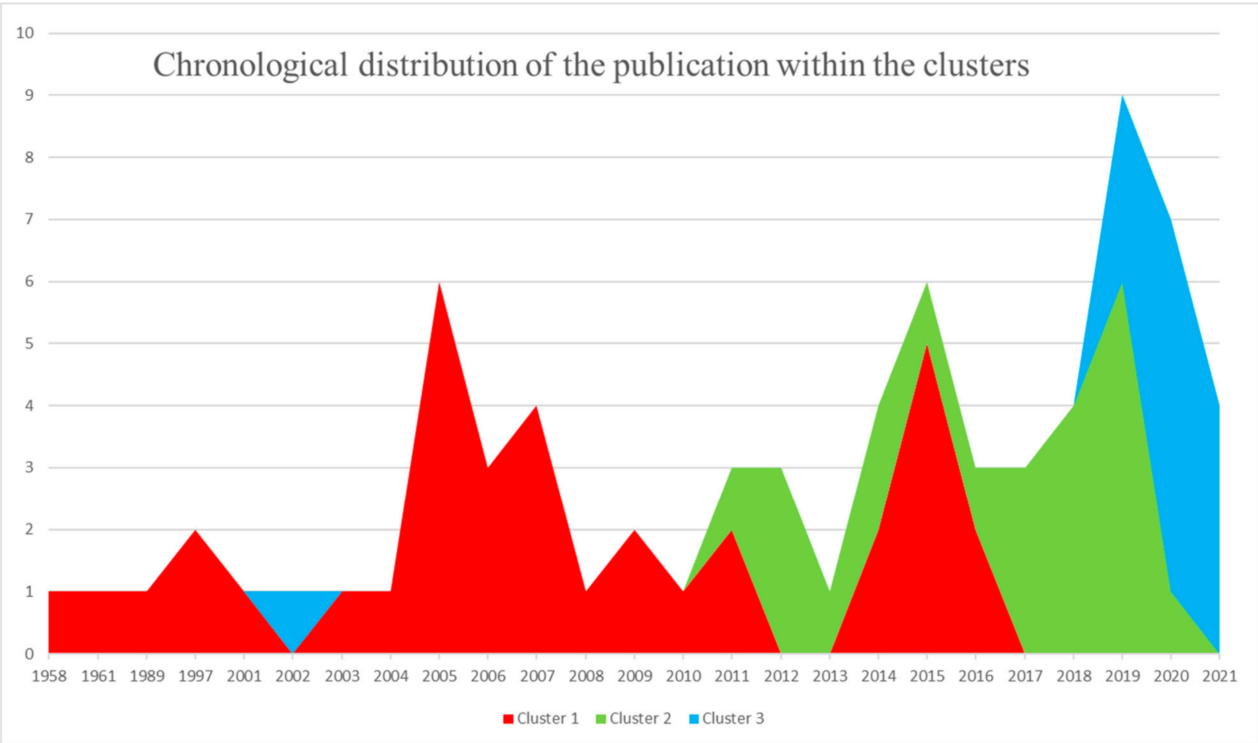

Figure 5. Chronological distribution of the publication within the clusters.

Cluster 1 comprises 18 publications, with prominent works authored by M. Wilson like "The Impact of Transportation Disruptions on Supply Chain Performance" [19], cited 44 times; C. Craighead et al. article titled "The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities" [28], cited 26 times; and Y. Sheffi's et al. "A Supply Chain View of the Resilient Enterprise" [29], with 21 citations.

Cluster 2 comprises 23 publications and is particularly noteworthy due to D. Ivanov's contribution, as he accounts for 10 out of the 23 articles. This prolific output establishes him as one of the authors with the highest publication rates. Notably, the article with the most citations within this cluster is "Ripple Effect in the Supply Chain: An Analysis and Recent Literature" [30], published by A. Dolgui et al. in 2018. This work is followed by Ivanov and Schmidt's publications, including "The Ripple Effect in Supply Chains: Trade-off 'Efficiency-Flexibility-Resilience' in Disruption Management" [31] and "A Quantitative Analysis of Disruption Risk in a Multi-Echelon Supply Chain" [32].

Cluster 3 encompasses six articles authored by seven distinct authors. Notably, all the most-cited articles within this cluster were penned by D. Ivanov. His notable contributions include "Predicting the Impacts of Epidemic Outbreaks on Global Supply Chains: A Simulation-Based Analysis on the Coronavirus Outbreak (COVID-19/SARS-CoV-2) Case" [15], published in 2021. The second and third most-cited publications, "Viable Supply Chain Model: Integrating Agility, Resilience and Sustainability Perspectives-Lessons from and Thinking Beyond the COVID-19 Pandemic" [33] and "Viability of Intertwined Supply Networks: Extending the Supply Chain Resilience Angles towards Survivability. A Position Paper Motivated by COVID-19 Outbreak" [34] were published one year prior.

4.2. Definition of Key Clusters

4.2.1. Cluster 1: Foundations of SC Disruption and SC Resilience

Cluster 1 corresponds to the foundational literature in SC disruption and resilience. In 2007, Wilson delineated and simulated the repercussions of transportation disruption on SCs [19]. As one of the pioneers, Craighead formulated the characteristics of SC design and mitigation capabilities, providing invaluable insights for management decisions and mitigating the financial consequences of exogenous shocks on SCs [28]. In her work "An Empirically Derived Agenda of Critical Research Issues for Managing Supply Chain Disruptions", J. Blackhurst delves into pertinent research topics that effectively address SC disruptions [35]. Another noteworthy contribution in Cluster 1 is P. Kleindorfer's publication, which outlines an approach to managing disruptions in SCs [36]. The analysis conducted on articles within Cluster 1 underscores its significance as the foundational literature that marked the initial stages of research on SC disruptions and risk management in conjunction with simulation techniques.

4.2.2. Cluster 2: Ripple Effect in SC, Optimization and Simulation Approaches

In Cluster 2, depicted in green, the research endeavors concerning management approaches for addressing disruptions in SCs have been augmented with quantitative and simulation methodologies to enhance the visualization and characterization of disruptions. Furthermore, the term 'supply chain resilience' was introduced in the discourse on strategies to contend with exogenous shocks in SCs. One of the pioneers in this domain, Hosseini, reviewed quantitative methods in the context of SC resilience [37]. Alongside the well-established bullwhip effect in SCs, Ivanov introduced the ripple effect in 2014, elucidating the cascading impact of disruption propagation on SC performance and the consequential alterations in SC structural design and planning parameters due to disruptions [31]. Extending the exploration of the ripple effect, Ivanov, Sokolov, Dolgui, and others further enriched the research landscape by incorporating simulation methods like SD and DES, thus reinforcing their investigative endeavors [31,38]. In summation, the articles within Cluster 2 can be regarded as an evolution of the research initiatives established in Cluster 1. A new scientific domain has emerged by introducing novel research trajectories through the exploration of the ripple effect and synergizing advanced SCM approaches with intensified utilization of simulation techniques.

4.2.3. Cluster 3: Technologies 4.0 and SC Survivability in Extreme Disruptions

Cluster 3, denoted in blue and characterized by the most recent average publication years, signifies a progressive evolution within this research area. Cluster 3 can be delineated into three primary research pathways. The first path commences with publications from 2020, when the COVID-19 pandemic struck the world. The research community responded by expanding the research domain to encompass the perspective of managing the pandemic's impact on SCs. Pioneering this avenue, Ivanov introduced the concept of SC survivability, revisiting existing SC models in light of the lessons derived from the pandemic [15,34].

- Path 1: This first research path in Cluster 3 primarily centers around the COVID-19 pandemic, exploring strategies to contain and mitigate the repercussions of pandemics on SCs.
- Path 2: The second research path is characterized by an extension into SC networks. This expansion is exemplified by publications such as Ivanov's "Reconfigurable Supply Chain: The X-Network" and "Viability of Intertwined Supply Networks: Extending the Supply Chain Resilience Angles towards Survivability. A Position Paper Motivated by COVID-19 Outbreak" [20,34].
- Path 3: The third research path introduces emerging digital trends into the research landscape. Building upon the established simulation methods of Cluster 2, this path incorporates emerging digital trends like digital twinning, artificial intelligence, and machine learning. Noteworthy examples include D. Burgos' "Food Retail Supply Chain Resilience [22,39] and the COVID-19 Pandemic: A Digital Twin-Based Impact Analysis and Improvement Directions" and Ivanov's "A Digital Supply Chain Twin for Managing Disruption Risks and Resilience in the Era of Industry 4.0" [3,40], both from 2021.

A word cloud analysis was conducted to validate the described characteristics in each cluster, incorporating the titles, abstracts, and keywords of each publication assigned to a cluster (Figure 6). A high-level comparison of the generated word clouds shows that we are dealing with a SCM-centric research area, with 'supply', 'chain', and 'disruption' being the most frequent words across all clusters. To enable a focus on the other important words, we have deleted them for the word cloud creation process.

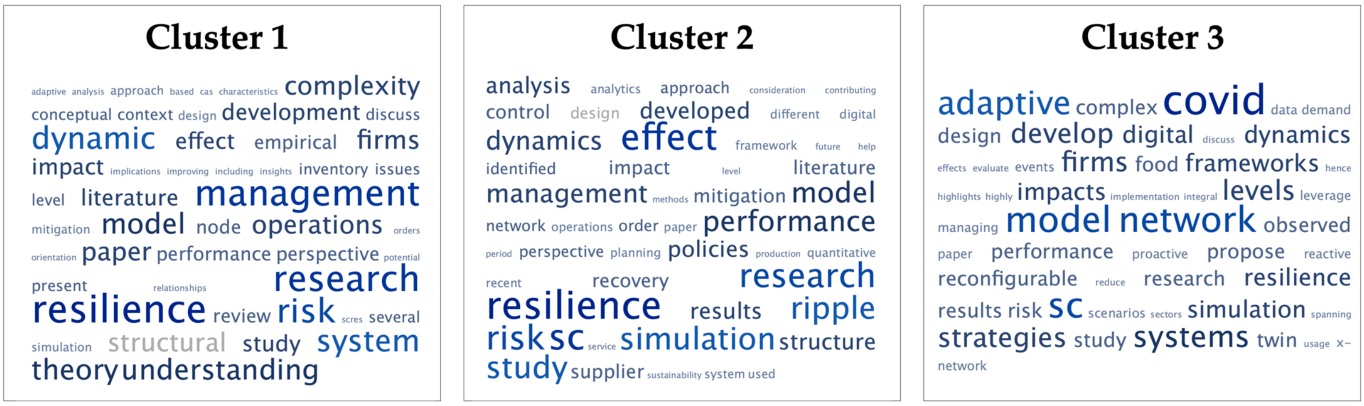

Figure 6. Detailed cluster definition and reflection in a word cloud by cluster.

Examining the other most frequently used words, the developmental progression outlined in the passage above becomes apparent. The word cloud of Cluster 1, defined as the foundation of the research area, is dominated by words such as 'management', 'resilience', and 'research'. This confirms the previously stated definition of Cluster 1 as the foundation of this research area. The assumption that this cluster covers the research area's basis is further reinforced by the appearance of the word 'understanding', frequently used together with 'complexity' in the papers. It can also be interpreted that this lack of understanding has pushed the usage of the word 'simulation' as a representative of simulation methods, comparing Clusters 1 and 2. By comparing the increase in the usage of the word 'performance' between Clusters 1 and 2, it can be suggested that after understanding the basic research scenarios in Cluster 1, the researchers took advantage of this and focused on increasing the performance of SCs through simulation techniques.

Turning to the word cloud of Cluster 2, the words ‘simulation’, ‘performance’, ‘ripple’, and ‘effect’ stand out. This aligns with the assertion that Cluster 2, the successor of Cluster 1, focuses on performance optimizations using various simulation methods. Further interest was also aroused by the word ‘politics’, which suggests that the research community has expanded its view of how SC disruption relates to political requirements. Compared to Cluster 1, it can also be stated that the word ‘management’ shrank. This suggests that the research community went beyond discussing basic management principles and redirected their focus on optimizing SCs under given management principles. The research focus changed again by comparing the increasing usage of the word ‘network’ from Cluster 2 to Cluster 3. Its rise from a nonexistent word in Cluster 2 to one of the most prominent ones in Cluster 3 supports the thesis that the research community has changed and adapted the developed practices for linear SCs into the upcoming world of SC networks.

In Cluster 3, the word ‘COVID’ and the related emphasis on the survivability of SCs come to the forefront. In addition, a new direction is indicated by the appearance of the word ‘network’. To provide an outlook for this, looking at the newly added words in Cluster 3 is interesting. By simply comparing the size, the most relevant ones are ‘adaptive’, ‘complex’, ‘COVID’, ‘firms’, ‘observed’, ‘systems’, ‘strategies’, and ‘twin’. It is obvious that the word ‘COVID’ will not be a dominating topic in future research, given that the pandemic is losing its momentum. Synthesizing the remaining words might give us a hint about future research directions. It seems that the research community will focus on complex SC network structures as a SC design principal and will develop new strategies to increase the adaptability of these SC networks to external disruptions, like COVID-19, under the usage of digital technologies (digital twins) as successors to the simulation methods.

4.3. Clusters’ Research Gaps and Opportunities

It can be observed that the open research areas presented in each cluster are interrelated. It has been identified that the research areas initially highlighted in Cluster 1 are explored further in Cluster 2, while the research areas from Cluster 2 are, in turn, expanded upon in Cluster 3. A common thread can be discerned in the chronological development of this scientific field. The following passage proves the scientific focus of each cluster by summarizing relevant publications. It provides a general overview of the research gaps and opportunities by giving a detailed overview in the corresponding tables.

Cluster 1 laid the foundation for this research path. C. Tan, in his publication “Perspectives in Supply Chain Risk Management”, confirmed the relevance of SC risk management by exploring disruptions in SCs using practical use cases and initially integrating them with quantitative simulation models [41]. This laid the groundwork for fundamental research areas within this domain. Subsequent investigations into supply management, demand management, product management, information management, and associated performance measures were deemed necessary. Sheffi and Rice also articulated a similar perspective in their article “A Supply Chain View of the Resilient Enterprise” [29]. This work analyzed relevant areas within an enterprise and demonstrated that the overall resilience of the enterprise can be enhanced by strengthening these areas with resilience capabilities. Another publication that reinforces Cluster 1 foundation is C. Craighead’s article “The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities”. In addition to defining relevant design parameters and mitigation capabilities to reduce disruptions in SCs, Craighead et al. [28] were one of the first to emphasize the need for simulation-based studies to analyze this context. This subsequently became the dominant research theme in Cluster 2. Besides these publications that underline the research focus of Cluster 1, all publications in Cluster 1 have been studied, and the identified research gaps and opportunities have been summarized (Table 10).

Table 10. Classification and summary of the gaps and opportunities in Cluster 1.

Paper	Type of Paper	Gaps/Opportunities
[42]	Empirical	This study suggests promising avenues for future research in enterprise resilience. It recommends exploring causality through alternatives like longitudinal data or event studies and diversifying data sources for a more accurate understanding. In addition, the paper proposes event studies to investigate resilience under specific circumstances and encourages focused research on specific elements of risk management infrastructure. Lastly, scholars are prompted to extend resilience concepts to encompass broader SC dynamics, exploring relational or SC resilience between multiple firms.
[35]	Empirical	This paper underscores the challenges of SCM, emphasizing visibility and capacity to mitigate disruptions. It suggests research areas, including cost–benefit analysis of visibility and the need for real-time SC reconfiguration. SC redesign is identified as a less-developed area, focusing on understanding global cost trade-offs and flexible optimization tools. The conclusion highlights the infancy of knowledge in managing disruptions, presenting a research agenda based on practical insights.
[43]	Simulation	This study reveals research gaps, including a low response rate and a focus on manufacturing firms. Future research should broaden its industry scope, involve multiple informants, and explore the dynamics of SC structures over time. In addition, incorporating more objective measures for key variables would enhance the reliability of findings. Addressing these gaps through methodological refinements and diversification across industries would contribute to a more comprehensive understanding of the studied phenomena.
[44]	Simulation	This study addresses gaps in the literature by proposing a dynamic model to quantitatively assess the impacts of security-disrupting events on export-oriented SCs resulting from terrorist attacks. It emphasizes the need for dynamic models that simultaneously evaluate the effects of risk across different SC areas. The research also highlights the necessity of measuring the impact of border crossing and understanding the economic implications of reaction time to disruptive events. These identified gaps contribute valuable insights for future research to address these critical aspects comprehensively.
[28]	Simulation	Closing research gaps in SC disruptions is imperative. Dynamic models must assess risk propagation and understand economic implications. The “reverse bullwhip” effect needs further exploration, global cost trade-offs, and robust optimization tools. Specific decisions like supply base reduction and global sourcing require scrutiny. Bridging these gaps is essential to effective management in the face of SC complexities.
[45]	Simulation	This paper highlights the value of SD in operations management but implies potential research gaps. These gaps include a need for specificity regarding the industries benefiting most, exploring challenges in real-world applications, and comparative studies with other simulation approaches. The transferability of insights, the balance between mathematical elegance and practical relevance, and integration with qualitative methods are also suggested as areas for further research.
[46]	Review	Zeng et al. identified gaps in understanding risks in underrepresented sectors like public and renewable energy. Service industries lack attention compared to manufacturing. Cost-effective risk monitoring and benchmarking of mitigation strategies are needed. Research on recovery strategies is scarce. Quantifying SCRM benefits and costs and case studies would offer valuable implementation insights.
[47]	Review	This research identifies conceptual and analytical limitations, opening avenues for future exploration. It highlights the need to consider varying probabilities of failure for nodes and arcs, incorporate practical variables like lead time differentials, and adopt dynamic models that account for substitution capabilities. Network size and structure constraints suggest the importance of exploring larger, more complex real-world scenarios. Future studies should address these limitations to enhance understanding and management of supply network disruption and resilience.
[36]	Theoretical	This paper emphasizes the challenges and areas where further research is needed, such as refining the SAM-SAC approach, developing indicators for specific sectors and SC archetypes, and addressing disruption risks at individual focal points and SC-wide systems.

Table 10. *Cont.*

Paper	Type of Paper	Gaps/Opportunities
[48]	Empirical	This study points to crucial future research areas: exploring adaptive mechanisms like inventory reassignment during disruptions, investigating fortification implications for specific network nodes, and emphasizing the need for empirical validation in real-world supply networks.
[49]	Empirical	SCM research should focus on emerging best practices in supplier selection and relations amid the shift from dyadic-only to network perspectives. Methodological exploration, including agent-based models, dynamic process models, and more extensive ensemble case studies, is crucial for studying Complex Adaptive Systems Networks (CASNs). Decision-making in supply networks requires a CASN perspective to navigate adaptivity, system complexity, and the broader environment. Understanding network-level decision effects is vital. Research should also examine how organizations interpret and leverage vast information in changing supply networks. Integrating complex scientific principles into SCM practices, guided by CAS analogies, requires further exploration. Establishing an agreed-upon foundation with constructs for CAS in supply network systems is essential. These research directions address the evolving challenges and opportunities in SCM.
[50]	Theoretical	This research outlines various open research areas in SC resilience. It advocates for diverse perspectives, emphasizing the need to explore poorly understood elements, relationships, and methodologies. The logistical perspective, empirical testing, qualitative approaches like grounded theory, and metrics for measuring resilience outcomes are key avenues for further investigation. These research spots collectively contribute to advancing the comprehension and management of SC resilience.
[51]	Review	Future research on SC resilience should focus on risk aversion, optimizing for worst-case scenarios, and considering risk-neutral decision-making. Developing robust techniques for uncertain parameter estimation is crucial. Integrated mitigation strategies, combining proactive and reactive approaches, enhance overall resilience. A deeper understanding of disruptions in multi-echelon systems is needed. Behavioral studies are crucial to model manager deviations during disruptions. Investigating endogenous disruptions influenced by a firm's actions and endogenous demand processes tied to disruption states are also vital research avenues. Tackling these aspects will provide a more comprehensive approach to SC resilience.
[52]	Simulation	Based on insights from a DC replenishment study, research on SC resilience highlights key areas for exploration. These include addressing the permanent offset in DC stock responses, optimizing control parameters for resilience and cost, understanding the impact of nonlinearities, exploring different demand patterns, and assessing resilience in multi-echelon SCs. Research opportunities also extend to the impacts of structural changes and the comparison of analytical methods for nonlinearities, offering practical insights for dynamic and adaptive SCM.
[53]	Theoretical/Review	This paper thoroughly reviews the literature on supply chain resilience (SCRES), achieving three key objectives: refining the SCRES definition to include 'cost-effectiveness', categorizing existing research, and proposing a theoretical perspective. The gaps identified suggest future research avenues, including exploring diverse SCRES strategies, understanding their synergies and trade-offs, conducting longitudinal studies, and extending research to neglected contexts like developing countries and service settings. Complex Adaptive Systems (CAS) theory emerges as a promising lens, aligning with identified gaps and offering insights for research and practical applications in SCRES.
[19]	Empirical	The research spot identified in this text is the need for further exploration and analysis of alternative risk mitigation strategies, such as carrying additional inventory or having redundant suppliers. The text suggests that while these strategies have potential benefits, their feasibility and impact on SC operations require in-depth investigation.
[54]	Empirical	This research suggests potential extensions for the DA_NET methodology in managing disruptions in SC networks. Future directions include applying the methodology to larger-scale systems and various SC types, integrating embedded agents for proactive disruption detection, employing optimization methods for product flow redesign in disruptions, and using DA_NET to assess affected areas and aid in disruption management strategy and robust system design.

Exemplifying many publications in Cluster 2, Hosseini reviewed the recent research landscape of quantitative simulation techniques associated with SC disruptions [37]. His literature review points to nine open research avenues that primarily demand further investigation of simulation methods within SC disruptions. Building on this idea, A. Schmitt published her article "A Quantitative Analysis of Disruption Risk in a Multi-Echelon Supply Chain". In this article, she describes her discrete-event simulation (DES) approach to managing disruptions through strategically placed inventory along a SC. Furthermore, she advocates for the more intensive use of simulation models in specific SC disruption scenarios [32]. As a third example, D. Ivanov postulated in 2013 that recent research in simulations related to SC disruptions is limited to handling specific detailed issues [20]. He called for a broader approach in this context, which, among other publications, laid the groundwork for further investigation into the usage of simulation techniques in the broader context of digital twinning, a dominant topic in Cluster 3. Details of the mentioned research spots and opportunities of all 25 papers in Cluster 2 can be reviewed in Table 11.

Table 11. Classification and summary of the gaps and opportunities in Cluster 2.

Paper	Type of Paper	Gaps/Opportunities
[55]	Empirical	The identified open research spots in SCM include exploring the global applicability of resilience design strategies, understanding the nuanced interplay between strategies and performance metrics, conducting in-depth behavioral analyses of SC entities, developing additional performance measures, and comparing resilience strategies comprehensively. Further research could investigate moderating factors, long-term effects, real-world validation for simulation models, and implications for supply based management policies. Incorporating preemptive strategies for network restructuring and exploring SD in SCM offer promising avenues for future study.
[56]	Empirical	This paper introduces a novel approach to resilient supplier selection using Supervised Machine Learning (SML) algorithms in digital manufacturing. It emphasizes leveraging digital data to predict supplier disruptions and their impact on SC performance. Key contributions include deciphering deviations from resilient SC performance profiles and developing digital SC twins. This study suggests applications like identifying critical suppliers and re-engineering the supplier base. Limitations include the need for larger datasets, while future research involves exploring differentiation in supplier profiles, rule-based systems, deep learning techniques, and scalability across industries. Overall, the approach highlights the shift toward data-oriented, resilient supplier portfolios in SCM.
[30]	Theoretical	Open research spots in SC resilience include integrating dynamic recovery time and costs, empirical validation of simulation studies with real data, exploring the role of information technology, and incorporating Industry 4.0 and smart sensors. Complexity theory can provide a theoretical basis, while systematic performance management techniques need development. Key areas for investigation include disruptions in SCs for perishable products, competition, behavioral aspects, visualizing the ripple effect, and addressing sustainability challenges. In SC recovery, stress, and coordination efforts, human aspects also require attention.
[57]	Empirical	Based on a resource-based view, this study focuses on SC connectivity and information sharing but acknowledges limitations in considering other vital resources like human skills and learning culture. Its survey-based approach may not fully capture the complexity of behavioral uncertainty, suggesting the need for qualitative methods. While the paper explores resilience, it highlights the importance of investigating other aspects like redundancy, robustness, and rapidity through simulation-based modeling. In conclusion, the research makes significant contributions by addressing behavioral dimensions in SC resilience, emphasizing the roles of visibility, trust, and cooperation. Its findings suggest further exploration of resources, capabilities, and behavioral uncertainty in the context of SC resilience.

Table 11. *Cont.*

Paper	Type of Paper	Gaps/Opportunities
[37]	Review/Empirical	Advancing SC resilience research involves exploring diverse modeling approaches. Two-stage stochastic programming can be extended to include a second-stage objective for SC resilience. Robust optimization, an underexplored area, holds promise. Bayesian network modeling helps to mitigate the ripple effect in complex supply networks. Markov chain modeling, especially multistate processes, captures vulnerability and recoverability. Multi-criteria decision-making (MCDM) methods like TOPSIS and AHP warrant exploration. Investigating the ripple effect within the SC resilience framework is promising. Low-certainty-need SC designs offer a unique approach to disruption risk management. Hybrid approaches with digital technologies and Industry 4.0 need attention for potential vulnerabilities and benefits. Integrating resilience and sustainability in SC design requires multi-objective stochastic optimization models. Leveraging digital SC twins enhances real-time representation and decision-making in disruptions.
[58]	Empirical	Advancements in supply chain management (SCM) research are underway. Key areas include exploring human-centric adaptation features, alternative strategies (reliability maintenance, flexibility, and risk financing), and understanding the interplay between complexity, robustness, and economic performance. Information technology, Industry 4.0, and cyber–physical networks introduce challenges and opportunities. Interdisciplinary approaches, human factors in resilience, and resilience–sustainability integration are crucial. Dynamic modeling with time recovery constraints, MCDM in SCM, and digital SC twins for real-time decision-making offer promising research avenues. Quantitative systemization with existing tools can address practical SCM challenges, enhancing adaptability, stability, and crisis resilience in dynamic environments.
[31]	Review	The open research gaps in the ripple effect in SCM include the need for clear business process descriptions for SC control, integration of IT-process models, development of a taxonomy for SC control, specialized tools beyond planning tools, and adaptation of control techniques for human-driven SC adaptation. These gaps offer opportunities to enhance decision-making in SCM through interdisciplinary investigations and applying optimization methods with systems and control theoretic approaches.
[21]	Empirical	Explores diverse aspects of the ripple effect in SCM through simulation, considering sensitivity analyses, disruptions in perishable product chains, and ABM for collaboration resilience. Enhance visualization tools for a deeper understanding and delve into interdisciplinary connections with financial management and the ripple effect in the processing industry. These avenues promise valuable insights for optimizing decision-making in SC dynamics.
[59]	Review	Recent SCM research has delved into the ripple effect, covering SC resilience, flexibility, business processes, mathematical models, and ICT. However, in SC disruptions and planning (SCP) with recovery, quantitative analysis is often segregated from process and ICT considerations. Future research can bridge this gap by focusing on recovery policies and quantitative methods, ensuring clarity in control processes and assessing impacts on economic performance. Key areas for exploration include developing a comprehensive SC recovery taxonomy, optimizing information and communications technology integration, emphasizing data acquisition for performance and resilience measurement, and examining recovery policies, cost analysis, and performance measurement during the recovery stage. Addressing time aspects in disruptions and recovery policies is essential, as is exploring the interdisciplinary intersection of resilience and sustainability in SCs. This research aims to enhance decision-making and broaden our understanding of the broader impacts of disruptions on SC structures and objectives.
[60]	Empirical	The identified research opportunities within SC dynamics and resilience focus on integrating quantitative analysis techniques with process and ICT perspectives, developing a taxonomy for the SC recovery domain, enhancing information and communications technology for real-time detection of disruptions, and exploring advanced recovery policies. In addition, there is a need for systematic principles to compute disruption-related performance measures in SC design models, incorporating cost analysis into control models, considering time aspects in disruptions and recovery policies, and investigating the interfaces between resilience and sustainability. Managerial practices, such as dual-sourcing policies and risk-sharing contracts, should be explored, focusing on dynamic reconfigurations and sustainability assessments for backup suppliers and alternative transportation channels in the face of disruptions.

Table 11. *Cont.*

Paper	Type of Paper	Gaps/Opportunities
[61]	Empirical	The proposed research areas call for a nuanced exploration of the dynamics between demand variability, safety stock, and recovery policies, emphasizing optimal timeframes for implementing recovery strategies and refining control mechanisms. In addition, the need for a thorough examination of the interrelations among disruption duration, backlogs, and SC capacities is stressed, prompting the development of contingent inventory control policies. This study advocates for dedicated revival policies to navigate the transition from disrupted to recovered states. Generalizing findings to various industries and datasets is emphasized, along with a recommendation for analytical studies to yield broadly applicable theoretical insights and practical recommendations. These research directions aim to enhance our understanding of the impact of disruptions on production and distribution networks, facilitating the formulation of effective recovery and resilience strategies.
[62]	Review	Research in SC design aims to develop low-certainty-need (LCN) SCs that operate efficiently and resiliently in the face of disruptions. Key features include structural variety and complexity reduction, process and resource utilization flexibility, inexpensive parametric redundancy, and developing a decision-support system for LCN SCs. Specific areas of investigation include lean and resilient network structures, the impact of digitalization on SC resilience, optimization of network redundancy, efficient material classification schemes, comparative simulation experiments, and SC risk analytics for refining and testing the proposed framework. The goal is to create SCs requiring minimal uncertainty consideration in planning decisions and low recovery coordination efforts while maintaining optimal performance in diverse environmental states.
[63]	Theoretical	The open research gaps encompass a transformative shift in SC competition, moving from traditional models to focusing on competition between information services and analytics algorithms. Research areas include the impact of digital technologies like 3D printing and blockchain, emphasizing their role in reshaping SC structures. Further exploration involves SC analytics, particularly in descriptive analysis, predictive simulation, real-time control, and adaptive learning. Key areas of interest include integrated service-material flow SCs, dynamic allocation of processes, and risk analytics in the digital SC. Integrating analytics, optimization, and simulation in decision-support systems for proactive and resilient SC design is a critical research avenue. In addition, investigating the challenges and opportunities presented by smart factories in Industry 4.0, reducing structural complexity, exploring process flexibility, and optimizing parametric redundancy is essential to advancing SC research.
[64]	Review	The research suggests a comprehensive approach to bolster SC resilience through digital integration. Key focuses include balancing efficiency and resilience, implementing the LCN SC framework with digital solutions, and exploring flexibility in processes and resource utilization. Additional areas of interest involve optimizing network redundancy, leveraging additive manufacturing, and studying the impact of digital technologies on SC optimization and disruption propagation. The concept of SC digital twins emerges as a pivotal tool for decision-making, real-time control, and contingency planning. Simulation-optimization models are highlighted for risk analysis, covering factors like network design, disruptions, and performance impact. Integrating business intelligence tools with simulation models is recommended to leverage digital technologies for robust and efficient SC operations. The overall goal is to foster resilience through a comprehensive, technology-driven approach to risk management.
[65]	Empirical/Simulation	Future research in SCM could focus on refining hybrid simulation models for a nuanced understanding of the trade-offs between efficiency and resilience, particularly in the context of perishable products. It is crucial to investigate the concept of postponed redundancy and its impact on SC reactions to disruptions. In addition, exploring the sensitivity of SCs with extended order cycles to production disruptions and optimizing adaptive planning strategies is essential. Further examination of strategies like order cancelation during recovery periods for cost reduction while maintaining service levels is warranted. Metrics related to SC flexibility, such as the frequency of new production order allocations, merit deeper exploration. Exploring multi-product systems within multi-echelon SCs, integrating logistics disruptions, and studying coordinated production-ordering contingency policies offer promising avenues for future research.

Table 11. *Cont.*

Paper	Type of Paper	Gaps/Opportunities
[34]	Theoretical	Research on interconnected supply networks (ISNs) encompasses various critical areas. It delves into the evolution of SCs towards ISNs, exploring behavioral dynamics in buyer-supplier relations within these networks. The focus extends to understanding the viability of ISNs for ensuring survivability during extraordinary events, distinguishing this concept from resilience. Dynamic game-theoretic modeling aids in comprehending the formation of viability in ISNs. Detailed investigations into the methodology and control of ISNs, particularly during disruptions like epidemic outbreaks, emerge as essential research avenues. In addition, there is a call to explore disruption outbreaks in downstream SC parts within ISNs, considering the combined effects of ripple effects. The application of digital, data-driven technologies, such as digital SC twins, is suggested for supporting decision-making during severe disruptions in ISNs. Furthermore, researchers are encouraged to explore the capabilities of flexible and adaptable production and distribution systems within ISNs.
[18]	Empirical	This study delves into the intricate interplay of structural and operational dynamics within SCs. It emphasizes the significance of explicitly incorporating disruption timing for more informed decision-making. The research identifies and tests overlays of reciprocal and aggravate dynamics, shedding light on their impact on SC resilience and recovery policies. Counterintuitive findings challenge assumptions about disruption timing and demand periods. Recommendations highlight the need to vary resilience capability levels dynamically. Acknowledging the existing limitations, this study calls for further research to extend insight into diverse industries and datasets. Future avenues include exploring the timing effects of correlated disruptions and assessing severity beyond the performance impact.
[23]	Empirical	This research addresses the critical need for understanding the intricate interaction between SC shocks, the SC ecosystem, and investments in resilience. It contributes by developing a three-component framework, laying the foundation for theory-building in shocks and resilience. This study introduces an empirical approach to analyze an aggregated measure of resilience, demonstrating its ability to capture system subtleties. In addition, a simulation method is presented to facilitate structured experimentation, exemplified by its application in understanding the impact of resilience factors on SC performance. The research encourages further exploration of real-world scenarios to unravel the complex interplay of shock attributes, ecosystem dynamics, and resilience investments.
[66]	Review	SC research beckons exploration in several areas, including understanding the dynamics of interconnected supply networks (ISNs) during extraordinary events and the role of digital technologies like SC twins. Overlay dynamics in resilience, dynamic redundancy allocation, and multi-objective criteria for disruption risk mitigation present promising research avenues. A three-component framework and empirical approaches offer foundations, while case studies on best practices in inter-company risk management provide valuable insights for practical applications and future research.
[32]	Empirical	This study delves into a consumer packaged goods SC, emphasizing mitigation strategies for disruption risks. The findings, which apply to various SCs, underscore the need for quantitative risk assessment. A systemic approach, strengthening the weakest links, proves crucial to overall resilience. The research advocates proactive measures and calls for future exploration of practical policies, emergency operation thresholds, and the intricate dynamics of multi-echelon SCs to enhance coping mechanisms for SC risks.
[67]	Theoretical	This research underscores key areas for further exploration in SCM. It advocates for a quantitative assessment of economic impacts from disruptions, emphasizing the need for practical coping strategies and performance indicators. Understanding the dynamic interactions between resilience factors like the SC ecosystem and investments is crucial. The study also calls for a deeper investigation into multi-echelon SCs and their responses to disruptions at various levels. In addition, there is a push to examine the survivability and viability of interconnected supply networks during extraordinary events, leveraging digital technologies for decision-making. Exploring the overlays of structural and operational dynamics in SCs is essential, along with refining simulation models and developing efficient search methods for global optimization. These research gaps collectively aim to advance our understanding of SC dynamics and improve decision-making in the face of disruptions.

Table 11. *Cont.*

Paper	Type of Paper	Gaps/Opportunities
[68]	Empirical	Research in SCM should focus on the impact of disruptions from various sources and their economic consequences. Utilizing simulation models, researchers can explore the effects of disruptions on multiple echelons, assembly stages, and time delays. Factors such as capacity interactions, price/demand elasticity, and product quality should be considered for a comprehensive understanding. Developing efficient optimization search methods, exploring dynamic expediting triggers, and investigating disruption propagation factors are essential. In addition, the role of digital technologies, multi-objective criteria, and in-depth case studies can enhance insights into SC resilience and risk management.
[69]	Empirical	This study identifies several open research gaps within the realm of SC design. Firstly, it highlights the need for more sophisticated performance indicators beyond those used in network reliability analysis. In addition, the study points out the lack of detailed analysis in specific calculations due to the limited size of the research, emphasizing the importance of precise assumptions regarding initial conditions, inventory levels, demand, and dynamic capacity deployment. Another area for future exploration involves considering the costs of adaptation and developing a benchmarking method for industry-specific values of performance indicators. This study also recognizes the absence of exploration into the costs of flexibility and quick contingency plan deployment, which are deemed crucial for practical decision-making in SC design. Lastly, the research agenda addresses the assumption of complete absence without the option for restoration and recovery, emphasizing the need for a more comprehensive examination in future studies.

Following the primary goal of this research direction, a new research direction is available for exploration. This entails a deeper investigation into active reconfiguration strategies to effectively mitigate the ripple effect within SC networks [16,65,66]. Furthermore, an augmentation of insights gleaned from research paths that underscore the heightened utilization of digital trends merits attention [22,64,70]. This exploration inherently ushers in a fresh avenue of inquiry.

Another promising research trajectory, as proposed in [71], centers on the exploration of methods to contain exogenous shocks within a SC network, effectively curbing their impact at or near their point of origin. To elaborate, this research direction can be disaggregated into three consecutive research tasks.

The initial task involves building upon Liaguno Arrate's foundational work, which presents a state-of-the-art conceptual framework and simulation techniques to preempt the ripple effect in SCs [11]. This endeavor necessitates a more profound exploration of the pre-emptive and reactive measures stipulated therein, culminating in the creation of a comprehensive catalog of measures.

The second task entails delving deeper into the modeling of SC networks using simulation techniques, as Olivares-Aguila and ElMaragghy advocate [71]. This phase involves the meticulous selection and application of simulation techniques, facilitating a more robust understanding of SC network dynamics.

Once the potential simulation techniques have been exhaustively examined and the relevant measures for containing exogenous shocks in SC networks have been delineated, the third task can be initiated. This phase involves developing a foundational model for a SC network and, subsequently, exploring the applicability of individual measures or combinations thereof to mitigate the ripple effect within SC networks effectively.

This comprehensive research approach will undoubtedly pave the way for a richer understanding of how exogenous shocks can be managed effectively within SC networks, contributing significantly to the advancement of the field [72]. Details on the research gaps in Cluster 3 can be seen in the following table (Table 12).

Table 12. Classification and summary of the gaps and opportunities in Cluster 3.

Paper	Type of Paper	Gaps/Opportunities
[20]	Empirical	This text highlights key research areas in SCM, including applying disruption models to larger systems, using embedded agents for proactive detection, and optimizing methods for product flow redesign during disruptions. Introducing dynamic SC meta-structures and autonomous services in the reconfigurable SC opens new avenues. Detailed operationalization, thorough investigation into reconfigurable SC formations and control, and mathematical modeling for resolving trade-offs are emphasized. Research directions include holistic SC networks, intertwined supply networks, and cross-disciplinary analysis of reconfiguration frameworks, providing a comprehensive agenda for advancing SC resilience and reconfigurability.
[64]	Empirical	This research underscores the rising integration of model-driven and data-driven decision-making in SCM, focusing on data quality in the era of Industry 4.0. Digital SC twins are introduced as a pivotal framework, highlighting their role in providing comprehensive visibility for enhanced SC resilience. Real-time data are emphasized for simulating disruption impacts and crafting alternative resilient configurations. This study advocates for digital SC twin development to support proactive and reactive strategies, outlining methodological principles and a generalized design. Future directions include detailed technical analysis, incorporating data-driven techniques, and exploring organizational changes with an emphasis on AI algorithms. Acknowledged limitations include the absence of in-depth discussions on data processing capacities.
[71]	Simulation	The open research gaps identified in the text include exploring the effectiveness of reactive strategies beyond expediting, investigating different SC structures, analyzing the allocation of redundancies, integrating intelligence for preemptive mitigation, examining diverse types of expediting, refining parameter values for accuracy, and adopting comprehensive approaches to understanding disruptions in the entire SC dynamics. These areas present opportunities for further research to enhance the understanding and management of SC disruptions.
[73]	Empirical	This paper suggests several research avenues for addressing disruptions caused by the COVID-19 pandemic in SCs. It emphasizes the need for integrated warehouse strategies, the development of a synchronized truck-drones delivery system, and detailed modeling of public distribution networks. Furthermore, it encourages the adoption of rigorous mathematical and statistical approaches to analyze food SC issues and shortages of healthcare equipment. Exploring SC resilience frameworks, multi-factor analysis, and effective post-pandemic reviving strategies is also highlighted as crucial to future research in this domain.
[74]	Simulation	This research suggests extending decision-making strategies in agent-based models (ABMs) by considering geographical proximity and competition relationships. It highlights implications for supply based management policies and proposes improvements, including exploring upstream propagation effects and incorporating recovery dynamics. This study calls for analyzing preemptive strategies, the coevolution of large-scale SC networks, and considering disruptions caused by different processes. Acknowledging limitations, this study notes potential biases in supply network data and challenges in validating ABMs due to limited empirical data. It focuses on short-term reactions to disruptions, suggesting incorporating mid- or long-term reactions for a more comprehensive understanding.

4.4. Usage of Simulation Methods in the Clusters

After analyzing the clusters based on the open research avenues they point to, another relevant finding is how simulation methods have developed within these clusters. Since the clusters build upon each other chronologically, understanding how simulation methods usage has generally evolved is of greater interest.

What can be observed is a steady increase in the usage of simulation methods. In Cluster 1, only 14 percent of the published papers actively employed simulation methods. This percentage increased to 39 percent in Cluster 2 and 50 percent in Cluster 3.

When examining the specific simulation techniques used in this research area, comparing the overall structure of employed simulation techniques reveals that discrete-event simulation (DES) and system dynamics (SD) are the most frequently utilized methods. Agent-based modeling (ABM) and control theory (CT) appear to play a minor role in simulating disruptions in SCs.

Looking at the individual development of the usage of each simulation method, it is noteworthy that the utilization of DES increases from Cluster 1 to Cluster 2, reaching its peak in this time series. In Cluster 3, the high value of 67 percent usage seen in Cluster 2 could not be reached again, but a substantial usage rate of 57 percent for all simulation-related publications was achieved.

Analyzing the usage of SD across all clusters, it can be observed that the peak occurred in Cluster 1. Subsequently, the trend declined in Cluster 2 but rose again, reaching a 29 percent usage rate, equivalent to the usage of DES.

The usage of ABM and CT remains relatively low. Both methods started with an overall usage rate of 20 percent across all simulation-related publications but declined to 11 percent in Cluster 2. In Cluster 3, ABM was utilized in only one publication, and CT was not employed in this research area.

In conclusion, DES and SD are the leading and most promising simulation methods in this scientific area (Table 13).

Table 13. Simulation methods used by the cluster.

Cluster (Total Amount of Publications)	Publications with Simulation Method Usage	Using DES	Using SD	Using ABM	Using CT
Cluster 1 (36)	5 (14%)	0 (0%)	3 (60%) [15,38,39]	1 (20%) [48]	1 (20%) [52]
Cluster 2 (23)	9 (39%)	6 (67%) [21,23,32,55,61,65]	1 (11%) [60]	1 (11%) [67]	1 (11%) [58]
Cluster 3 (14)	7 (50%)	4 (57%) [15,18,22,75]	2 (29%) [71,76]	1 (14%) [74]	0 (0%)

Taking a deeper look into the simulations conducted by individual scientists, D. Ivanov stands out as the most frequent user of simulations in this research area, with seven simulation-related publications. A. Schmitt, who has published two simulative approaches to analyze SC disruptions, takes the second rank, followed by seven scientists who have each published 1 simulation-related paper.

Examining the evolution of simulation methods usage by Ivanov, in Cluster 2, three publications utilized a DES approach, in addition to one publication employing a SD Simulation and another using CT. In Cluster 3, Ivanov exclusively published papers employing DES, perhaps because he considers it as having the most potential among simulation techniques.

It can also be noted that Ivanov's peak in publications occurred in Cluster 2. However, this observation should consider that Cluster 2 had a longer duration than Cluster 3. Therefore, it is reasonable to expect that we will see more publications from Ivanov in Cluster 3.

DES and SD are the leading methods for simulating SC disruptions. The scientific community is currently engaged in a controversial discussion on whether SD or DES is the superior simulation approach in SCM. There is no clear consensus on which simulation method should be used in which context [77]. It appears that the main driver for this decision is the personal expertise and preference of the respective author [78]. However, scientific society has established a common understanding regarding using DES and SD. DES is generally employed to investigate problems at an operational level [78–81], whereas SD is predominantly used for strategic analysis [77,82]. This raises the question: Do authors follow the common understanding of the research community, using SD to simulate strategic SC problems and DES for tactical and operational simulation challenges? Or is the choice of using one simulation tool over the other explained by their personal preference?

To determine whether authors choose simulation methods for a problem based on personal preference, an analysis of all existing publications by authors has been conducted.

All publications were identified using the WoS author search, forming the basis for a comprehensive literature review. Titles, keywords, and abstracts were screened for the relevant simulation methods, specifically DES and SD. In cases where neither method was used in a publication, further scrutiny was applied to determine if the context of the simulation was addressed. The results affirm the assertion made by Tako and Robinson [77] that the primary decision driver for choosing one simulation method over the other is the personal expertise and preference of the individual author. To illustrate, A. Grossler has written ten publications, with six referencing SD and none based on DES methods. More insightful examples are found in the publication histories of J. Swanson and A. Dolgui. In Cluster 3, 15 percent of Swanson's publications are directly connected to SD, while a minor portion (below 3 percent) is related to DES. A similar pattern is observed in the publication history of A. Bueno-Solano, where approximately 75 percent of the publications reference SD, such as those found in Cluster 1. Considering these results, it can be concluded that choosing a particular simulation method is likely linked to the author's preference.

5. Conclusions

This systematic literature review aimed to explore the use of simulation tools in managing supply chain disruptions by addressing several research questions: the historical evolution of the field, the prevalent simulation methods, specific challenges addressed, and the identification of research gaps. Our review of 213 publications revealed a robust and evolving academic landscape characterized by significant milestones and contributions from key authors in the field. The chronological analysis highlighted simulation methods' progressive complexity and sophistication, from DES and agent-based modeling to SD. These methods have been pivotal in addressing various supply chain challenges, such as predicting disruptions, optimizing network configurations, and enhancing decision-making processes.

In addressing the first research question about the historical evolution of simulation in supply chain disruption management, our findings illustrate a gradual yet significant shift towards more complex and integrated simulation approaches. From 2000 to 2005, research focused on using discrete-event simulation (DES) to analyze supply chain dynamics and identify bottlenecks. Between 2005 and 2010, the focus shifted to agent-based modeling (ABM) and system dynamics (SD) to study complex supply chain systems. From 2010 to 2015, the emphasis was on strategic reconfiguration of supply chain networks using DES, ABM, and SD to enhance resilience. Since 2015, there has been a growing interest in digital technologies (e.g., digital twins, AI) for real-time monitoring and control of supply chains. Overall, research has evolved from basic modeling approaches to more complex simulations, combining various simulation techniques, and digital strategies, emphasizing network reconfiguration and technological advancements.

Regarding the second research question on the prevalent simulation methods, our analysis identified DES, ABM, and SD as the most relevant ones. ABM and SD are the most frequently employed techniques in recent studies. These methods offer robust frameworks for capturing the dynamic behaviors and interactions within supply chains, making them particularly suitable for studying disruptions and their cascading effects.

The third research question focused on specific challenges addressed by these simulation tools. Our review found that simulations are primarily used to tackle issues such as supply chain resilience, risk mitigation, and optimization of recovery strategies. DES excels in modeling operational processes, managing inventory, and enhancing responsiveness to disruptions. SD provides insights into long-term behavior, identifying bottlenecks and analyzing the impacts of demand or supply changes over time. ABM offers a perspective on individual agent behaviors, facilitating the analysis of complex interactions among suppliers, manufacturers, and other stakeholders. Finally, hybrid simulation integrates these approaches to provide a comprehensive understanding of supply chain networks, combining detailed process modeling with strategic feedback loops for enhanced decision-making and performance optimization. These tools have been instrumental in enabling researchers and practitioners to explore various disruption scenarios and develop effective mitigation strategies, thus enhancing the overall robustness of supply chains.

Regarding identifying research gaps posed by the fourth research question, our review highlighted several areas needing further exploration. Notably, there is a call for more dynamic analysis and control theory applications to understand disruptions' temporal aspects better. Additionally, integrating multiple simulation methods to address complex, multi-faceted disruption scenarios remains underexplored. Addressing these gaps could provide deeper insights and more comprehensive solutions for managing supply chain disruptions. Two primary research frontiers were identified: strategic reconfiguration of supply chain networks and the rapid implementation of countermeasures. The first frontier focuses on designing resilient supply chains that can withstand and quickly recover from disruptions. In contrast, the second emphasizes the need for swift, effective responses to minimize the impact of unforeseen events. These frontiers align with the growing recognition of supply chain resilience as critical to global economic stability and sustainability. Despite these advancements, this review also highlighted several research gaps. There is a need for more dynamic analysis and control theory applications to understand better the temporal aspects of disruptions and their propagation through supply chains. Additionally, future research should explore the potential of combining multiple simulation methods to address complex, multi-faceted disruption scenarios comprehensively.

In conclusion, this study provides a detailed overview of the current research on simulation tools for supply chain disruption management. It underscores the importance of continued innovation and integration of advanced technologies to build more resilient and sustainable supply chains. By addressing the identified research gaps, future studies can further enhance our understanding and capabilities in this critical area, contributing to global efforts toward achieving the United Nations' Sustainable Development Goals. Specifically, improving supply chain resilience directly supports SDG 9 (Industry, Innovation, and Infrastructure) by fostering resilient infrastructure and promoting inclusive and sustainable industrialization. Furthermore, enhancing supply chain robustness contributes to SDG 12 (Responsible Consumption and Production) by ensuring sustainable consumption and production patterns. This research advances academic knowledge and provides practical insights that align with the global sustainability agenda, facilitating a more sustainable and resilient future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16145957/s1, File S1: PRISMA Statement. Ref. [83] is cited in the Supplementary File.

Author Contributions: Conceptualization, B.K., J.M. and M.K.; methodology, B.K., J.M. and M.K.; software, B.K.; validation, B.K., J.M. and M.K.; formal analysis, B.K., J.M. and M.K.; investigation, B.K.; resources, B.K., J.M. and M.K.; data curation, B.K.; writing—original draft preparation, B.K.; writing—review and editing, B.K., J.M. and M.K.; visualization, B.K.; supervision, J.M. and M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. United Nations. 17 Goals to Transform Our World. Available online: https://www.un.org/sustainabledevelopment/ (accessed on 31 October 2023).
2. Wang, Y.; Wang, J.; Wang, X. COVID-19, Supply Chain Disruption and China's Hog Market: A Dynamic Analysis. *China Agric. Econ. Rev.* **2020**, *12*, 427–443. [CrossRef]
3. Ivanov, D.; Dolgui, A. A Digital Supply Chain Twin for Managing the Disruption Risks and Resilience in the Era of Industry 4.0. *Prod. Plan. Control* **2021**, *32*, 775–788. [CrossRef]
4. United Nations. Goal 9: Build Resilient Infrastructure, Promote Sustainable Industrialization and Foster Innovation. Available online: https://www.un.org/sustainabledevelopment/infrastructure-industrialization/ (accessed on 31 October 2023).

5. Katsoras, E.; Georgiadis, P. A Dynamic Analysis for Mitigating Disaster Effects in Closed Loop Supply Chains. *Sustainability* **2022**, *14*, 4948. [CrossRef]
6. Park, Y.W.; Blackhurst, J.; Paul, C.; Scheibe, K.P. An Analysis of the Ripple Effect for Disruptions Occurring in Circular Flows of a Supply Chain Network*. *Int. J. Prod. Res.* **2022**, *60*, 4693–4711. [CrossRef]
7. Xu, X.; Kim, H.S.; You, S.S.; Lee, S.D. Active Management Strategy for Supply Chain System Using Nonlinear Control Synthesis. *Int. J. Logist. Manag.* **2022**, *10*, 1981–1995. [CrossRef] [PubMed]
8. Dy, K.J.; Olivares-Aguila, J.; Vital-Soto, A. A Survey of Digital Supply Chain Twins' Implementations. In *Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action*; Kim, D.Y., Von Cieminski, G., Romero, D., Eds.; IFIP Advances in Information and Communication Technology; Springer Nature: Cham, Switzerland, 2022; Volume 663, pp. 502–509; ISBN 978-3-031-16406-4.
9. Vital-Soto, A.; Olivares-Aguila, J. Manufacturing Systems for Unexpected Events: An Exploratory Review for Operational and Disruption Risks. *IEEE Access* **2023**, *11*, 96297–96316. [CrossRef]
10. El Jaouhari, A.; Arif, J.; Samadhiya, A.; Kumar, A. Are Metaverse Applications in Quality 4.0 Enablers of Manufacturing Resiliency? An Exploratory Review under Disruption Impressions and Future Research. *TQM J.* **2023**, *36*, 1486–1525. [CrossRef]
11. Llaguno, A.; Mula, J.; Campuzano-Bolarin, F. State of the Art, Conceptual Framework and Simulation Analysis of the Ripple Effect on Supply Chains. *Int. J. Prod. Res.* **2022**, *60*, 2044–2066. [CrossRef]
12. Karadayi-Usta, S.; Serdarasan, S. Defining and modeling risks in service supply chains. *Int. J. Ind. Eng.* **2021**, *28*, 52–74. [CrossRef]
13. Vieira, A.A.C.; Dias, L.M.S.; Santos, M.Y.; Pereira, G.A.B.; Oliveira, J.A. Supply Chain Data Integration: A Literature Review. *J. Ind. Inf. Integr.* **2020**, *19*, 100161. [CrossRef]
14. Korder, B.; Maheut, J.; Konle, M. Ripple Effect in Supply Chains: A Systematic Literature Review Protocol. In Proceedings of the 4th International Conference Business Meets Technology 2022, Ansbach, Germany, 7 July 2022.
15. Ivanov, D. Predicting the Impacts of Epidemic Outbreaks on Global Supply Chains: A Simulation-Based Analysis on the Coronavirus Outbreak (COVID-19/SARS-CoV-2) Case. *Transp. Res. E Logist. Transp.* **2020**, *136*, 101922. [CrossRef]
16. Ivanov, D. Exiting the COVID-19 Pandemic: After-Shock Risks and Avoidance of Disruption Tails in Supply Chains. *Ann. Oper. Res.* **2021**, *335*, 1627–1644. [CrossRef]
17. Xu, X.; Sethi, S.P.; Chung, S.-H.; Choi, T. Reforming Global Supply Chain Management under Pandemics: The GREAT-3Rs Framework. *Prod. Oper. Manag.* **2022**, *32*, 524–546. [CrossRef]
18. Ivanov, D. 'A Blessing in Disguise' or 'as If It Wasn't Hard Enough Already': Reciprocal and Aggravate Vulnerabilities in the Supply Chain. *Int. J. Prod. Res.* **2020**, *58*, 3252–3262. [CrossRef]
19. Wilson, M.C. The Impact of Transportation Disruptions on Supply Chain Performance. *Transp. Res. E Logist. Transp.* **2007**, *43*, 295–320. [CrossRef]
20. Dolgui, A.; Ivanov, D.; Sokolov, B. Reconfigurable Supply Chain: The X-Network. *Int. J. Prod. Res.* **2020**, *58*, 4138–4163. [CrossRef]
21. Ivanov, D. Simulation-Based Ripple Effect Modelling in the Supply Chain. *Int. J. Prod. Res.* **2017**, *55*, 2083–2101. [CrossRef]
22. Burgos, D.; Ivanov, D. Food Retail Supply Chain Resilience and the COVID-19 Pandemic: A Digital Twin-Based Impact Analysis and Improvement Directions. *Transp. Res. E Logist. Transp.* **2021**, *152*, 102412. [CrossRef]
23. Macdonald, J.R.; Zobel, C.W.; Melnyk, S.A.; Griffis, S.E. Supply Chain Risk and Resilience: Theory Building through Structured Experiments and Simulation. *Int. J. Prod. Res.* **2018**, *56*, 4337–4355. [CrossRef]
24. Ivanov, D.; Pavlov, A.; Dolgui, A.; Pavlov, D.; Sokolov, B. Disruption-Driven Supply Chain (Re)-Planning and Performance Impact Assessment with Consideration of pro-Active and Recovery Policies. *Transp. Res. E Logist. Transp.* **2016**, *90*, 7–24. [CrossRef]
25. Behdani, B.; Lukszo, Z.; Adhitya, A.; Srinivasan, R. Agent Based Model for Performance Analysis of a Global Chemical Supply Chain during Normal and Abnormal Situations. In *Computer Aided Chemical Engineering*; Elsevier: Amsterdam, The Netherlands, 2009; Volume 26, pp. 979–984; ISBN 978-0-444-53433-0.
26. Behdani, B.; Lukszo, Z.; Adhitya, A.; Srinivasan, R. Agent-Based Coordination Framework for Disruption Management in a Chemical Supply Chain. In *Computer Aided Chemical Engineering*; Elsevier: Amsterdam, The Netherlands, 2011; Volume 29, pp. 1090–1094; ISBN 978-0-444-53895-6.
27. Behdani, B.; Adhitya, A.; Lukszo, Z.; Srinivasan, R. Mitigating Supply Disruption for a Global Chemical Supply Chain-Application of Agent-Based Modeling. In *Computer Aided Chemical Engineering*; Elsevier: Amsterdam, The Netherlands, 2012; Volume 31, pp. 1070–1074; ISBN 978-0-444-59505-8.
28. Craighead, C.W.; Blackhurst, J.; Rungtusanatham, M.J.; Handfield, R.B. The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities. *Decis. Sci.* **2007**, *38*, 131–156. [CrossRef]
29. Sheffi, Y.; Rice, J.B. *A Supply Chain View of the Resilient Enterprise*; MIT Press: Cambridge, MA, USA, 2005.
30. Dolgui, A.; Ivanov, D.; Sokolov, B. Ripple Effect in the Supply Chain: An Analysis and Recent Literature. *Int. J. Prod. Res.* **2018**, *56*, 414–430. [CrossRef]
31. Ivanov, D.; Sokolov, B.; Dolgui, A. The Ripple Effect in Supply Chains: Trade-off 'Efficiency-Flexibility-Resilience' in Disruption Management. *Int. J. Prod. Res.* **2014**, *52*, 2154–2172. [CrossRef]
32. Schmitt, A.J.; Singh, M. A Quantitative Analysis of Disruption Risk in a Multi-Echelon Supply Chain. *Int. J. Prod. Econ.* **2012**, *139*, 22–32. [CrossRef]
33. Ivanov, D. Viable Supply Chain Model: Integrating Agility, Resilience and Sustainability Perspectives—Lessons from and Thinking beyond the COVID-19 Pandemic. *Ann. Oper. Res.* **2022**, *319*, 1411–1431. [CrossRef]

34. Ivanov, D.; Dolgui, A. Viability of Intertwined Supply Networks: Extending the Supply Chain Resilience Angles towards Survivability. A Position Paper Motivated by COVID-19 Outbreak. *Int. J. Prod. Res.* **2020**, *58*, 2904–2915. [CrossRef]
35. Blackhurst, J.; Craighead, C.W.; Elkins, D.; Handfield, R.B. An Empirically Derived Agenda of Critical Research Issues for Managing Supply-Chain Disruptions. *Int. J. Prod. Res.* **2005**, *43*, 4067–4081. [CrossRef]
36. Kleindorfer, P.R.; Saad, G.H. Managing Disruption Risks in Supply Chains. *Prod. Oper. Manag.* **2005**, *14*, 53–68. [CrossRef]
37. Hosseini, S.; Ivanov, D.; Dolgui, A. Review of Quantitative Methods for Supply Chain Resilience Analysis. *Transp. Res. E Logist. Transp.* **2019**, *125*, 285–307. [CrossRef]
38. Ivanov, D.; Pavlov, A.; Sokolov, B. Optimal Distribution (Re)Planning in a Centralized Multi-Stage Supply Network under Conditions of the Ripple Effect and Structure Dynamics. *Eur. J. Oper. Res.* **2014**, *237*, 758–770. [CrossRef]
39. Badakhshan, E.; Ball, P. Applying Digital Twins for Inventory and Cash Management in Supply Chains under Physical and Financial Disruptions. *Int. J. Prod. Res.* **2022**, *61*, 50945116. [CrossRef]
40. Zhang, Q.; Fan, W.; Lu, J.; Wu, S.; Wang, X. Research on Dynamic Analysis and Mitigation Strategies of Supply Chains under Different Disruption Risks. *Sustainability* **2021**, *13*, 2462. [CrossRef]
41. Tang, C.S. Perspectives in Supply Chain Risk Management. *Int. J. Prod. Econ.* **2006**, *103*, 451–488. [CrossRef]
42. Ambulkar, S.; Blackhurst, J.; Grawe, S. Firm's Resilience to Supply Chain Disruptions: Scale Development and Empirical Examination. *J. Oper. Manag.* **2015**, *33–34*, 111–122. [CrossRef]
43. Bode, C.; Wagner, S.M. Structural Drivers of Upstream Supply Chain Complexity and the Frequency of Supply Chain Disruptions. *J. Oper. Manag.* **2015**, *36*, 215–228. [CrossRef]
44. Bueno-Solano, A.; Cedillo-Campos, M.G. Dynamic Impact on Global Supply Chains Performance of Disruptions Propagation Produced by Terrorist Acts. *Transp. Res. E Logist. Transp.* **2014**, *61*, 1–12. [CrossRef]
45. Größler, A.; Thun, J.-H.; Milling, P.M. System Dynamics as a Structural Theory in Operations Management. *Prod. Oper. Manag.* **2008**, *17*, 373–384. [CrossRef]
46. Ho, W.; Zheng, T.; Yildiz, H.; Talluri, S. Supply Chain Risk Management: A Literature Review. *Int. J. Prod. Res.* **2015**, *53*, 5031–5069. [CrossRef]
47. Kim, Y.; Chen, Y.; Linderman, K. Supply Network Disruption and Resilience: A Network Structural Perspective. *J. Oper. Manag.* **2015**, *33–34*, 43–59. [CrossRef]
48. Nair, A.; Vidal, J.M. Supply Network Topology and Robustness against Disruptions—An Investigation Using Multi-Agent Model. *Int. J. Prod. Res.* **2011**, *49*, 1391–1404. [CrossRef]
49. Pathak, S.D.; Day, J.M.; Nair, A.; Sawaya, W.J.; Kristal, M.M. Complexity and Adaptivity in Supply Networks: Building Supply Network Theory Using a Complex Adaptive Systems Perspective*. *Decis. Sci.* **2007**, *38*, 547–580. [CrossRef]
50. Ponomarov, S.Y.; Holcomb, M.C. Understanding the Concept of Supply Chain Resilience. *Int. J. Logist. Manag.* **2009**, *20*, 124–143. [CrossRef]
51. Snyder, L.V.; Atan, Z.; Peng, P.; Rong, Y.; Schmitt, A.J.; Sinsoysal, B. OR/MS Models for Supply Chain Disruptions: A Review. *IIE Trans.* **2016**, *48*, 89–109. [CrossRef]
52. Spiegler, V.L.M.; Potter, A.T.; Naim, M.M.; Towill, D.R. The Value of Nonlinear Control Theory in Investigating the Underlying Dynamics and Resilience of a Grocery Supply Chain. *Int. J. Prod. Res.* **2016**, *54*, 265–286. [CrossRef]
53. Tukamuhabwa, B.R.; Stevenson, M.; Busby, J.; Zorzini, M. Supply Chain Resilience: Definition, Review and Theoretical Foundations for Further Study. *Int. J. Prod. Res.* **2015**, *53*, 5592–5623. [CrossRef]
54. Wu, T.; Blackhurst, J.; O'grady, P. Methodology for Supply Chain Disruption Analysis. *Int. J. Prod. Res.* **2007**, *45*, 1665–1682. [CrossRef]
55. Carvalho, H.; Barroso, A.P.; Machado, V.H.; Azevedo, S.; Cruz-Machado, V. Supply Chain Redesign for Resilience Using Simulation. *Comput. Ind. Eng.* **2012**, *62*, 329–341. [CrossRef]
56. Cavalcante, I.M.; Frazzon, E.M.; Forcellini, F.A.; Ivanov, D. A Supervised Machine Learning Approach to Data-Driven Simulation of Resilient Supplier Selection in Digital Manufacturing. *IJMI* **2019**, *49*, 86–97. [CrossRef]
57. Dubey, R.; Gunasekaran, A.; Childe, S.J.; Papadopoulos, T.; Blome, C.; Luo, Z. Antecedents of Resilient Supply Chains: An Empirical Study. *IEEE Trans. Eng. Manag.* **2019**, *66*, 8–19. [CrossRef]
58. Ivanov, D.; Sokolov, B. Control and System-Theoretic Identification of the Supply Chain Dynamics Domain for Planning, Analysis and Adaptation of Performance under Uncertainty. *Eur. J. Oper. Res.* **2013**, *224*, 313–323. [CrossRef]
59. Ivanov, D.; Dolgui, A.; Sokolov, B.; Ivanova, M. Literature Review on Disruption Recovery in the Supply Chain. *Int. J. Prod. Res.* **2017**, *55*, 6158–6174. [CrossRef]
60. Ivanov, D. Revealing Interfaces of Supply Chain Resilience and Sustainability: A Simulation Study. *Int. J. Prod. Res.* **2018**, *56*, 3507–3523. [CrossRef]
61. Ivanov, D. Disruption Tails and Revival Policies: A Simulation Analysis of Supply Chain Design and Production-Ordering Systems in the Recovery and Post-Disruption Periods. *Comput. Ind. Eng.* **2019**, *127*, 558–570. [CrossRef]
62. Ivanov, D.; Dolgui, A. Low-Certainty-Need (LCN) Supply Chains: A New Perspective in Managing Disruption Risks and Resilience. *Int. J. Prod. Res.* **2019**, *57*, 5119–5136. [CrossRef]
63. Ivanov, D.; Dolgui, A.; Sokolov, B. The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics. *Int. J. Prod. Res.* **2019**, *57*, 829–846. [CrossRef]

64. Ivanov, D.; Dolgui, A.; Das, A.; Sokolov, B. Digital Supply Chain Twins: Managing the Ripple Effect, Resilience, and Disruption Risks by Data-Driven Optimization, Simulation, and Visibility. In *Handbook of Ripple Effects in the Supply Chain*; Ivanov, D., Dolgui, A., Sokolov, B., Eds.; International Series in Operations Research & Management Science; Springer: Cham, Switzerland, 2019; Volume 276, pp. 309–332; ISBN 978-3-030-14301-5.
65. Ivanov, D.; Rozhkov, M. Coordination of Production and Ordering Policies under Capacity Disruption and Product Write-off Risk: An Analytical Study with Real-Data Based Simulations of a Fast Moving Consumer Goods Company. *Ann. Oper. Res.* **2020**, *291*, 387–407. [CrossRef]
66. Scheibe, K.P.; Blackhurst, J. Supply Chain Disruption Propagation: A Systemic Risk and Normal Accident Theory Perspective. *Int. J. Prod. Res.* **2018**, *56*, 43–59. [CrossRef]
67. Schmitt, T.G.; Kumar, S.; Stecke, K.E.; Glover, F.W.; Ehlen, M.A. Mitigating Disruptions in a Multi-Echelon Supply Chain Using Adaptive Ordering. *Omega* **2017**, *68*, 185–198. [CrossRef]
68. Simchi-Levi, D.; Schmidt, W.; Wei, Y.; Zhang, P.Y.; Combs, K.; Ge, Y.; Gusikhin, O.; Sanders, M.; Zhang, D. Identifying Risks and Mitigating Disruptions in the Automotive Supply Chain. *Interfaces* **2015**, *45*, 375–390. [CrossRef]
69. Sokolov, B.; Ivanov, D.; Dolgui, A.; Pavlov, A. Structural Quantification of the Ripple Effect in the Supply Chain. *Int. J. Prod. Res.* **2016**, *54*, 152–169. [CrossRef]
70. Dolgui, A.; Ivanov, D. Ripple Effect and Supply Chain Disruption Management: New Trends and Research Directions. *Int. J. Prod. Res.* **2021**, *59*, 102–109. [CrossRef]
71. Olivares-Aguila, J.; ElMaraghy, W. System Dynamics Modelling for Supply Chain Disruptions. *Int. J. Prod. Res.* **2021**, *59*, 1757–1775. [CrossRef]
72. Xu, X.; Rodgers, M.D.; Guo, W. (Grace) Hybrid Simulation Models for Spare Parts Supply Chain Considering 3D Printing Capabilities. *J. Manuf. Syst.* **2021**, *59*, 272–282. [CrossRef]
73. Singh, S.; Kumar, R.; Panchal, R.; Tiwari, M.K. Impact of COVID-19 on Logistics Systems and Disruptions in Food Supply Chain. *Int. J. Prod. Res.* **2021**, *59*, 1993–2008. [CrossRef]
74. Zhao, K.; Zuo, Z.; Blackhurst, J.V. Modelling Supply Chain Adaptation for Disruptions: An Empirically Grounded Complex Adaptive Systems Approach. *J. Oper. Manag.* **2019**, *65*, 190–212. [CrossRef]
75. Dolgui, A.; Ivanov, D.; Rozhkov, M. Does the Ripple Effect Influence the Bullwhip Effect? An Integrated Analysis of Structural and Operational Dynamics in the Supply Chain. *Int. J. Prod. Res.* **2020**, *58*, 1285–1301. [CrossRef]
76. Swanson, J. Business Dynamics—Systems Thinking and Modeling for a Complex World. *J. Oper. Res. Soc.* **2002**, *53*, 472–473. [CrossRef]
77. Tako, A.A.; Robinson, S. The Application of Discrete Event Simulation and System Dynamics in the Logistics and Supply Chain Context. *Decis. Support Syst.* **2012**, *52*, 802–815. [CrossRef]
78. Tako, A.A.; Robinson, S. Model Development in Discrete-Event Simulation and System Dynamics: An Empirical Study of Expert Modellers. *Eur. J. Oper. Res.* **2010**, *207*, 784–794. [CrossRef]
79. Lane, D.C. You Just Don't Understand Me: Modes of Failure and Success in the Discourse between System Dynamics and Discrete Event Simulation. In *Operational Research Working Papers (LSEOR 00.34)*; Department of Operational Research, London School of Economics and Political Science: London, UK, 2000; p. 26.
80. Sweetser, A. A Comparison of System Dynamics (SD) and Discrete Event Simulation (DES). In Proceedings of the 17th International Conference of the System Dynamics Society, Wellington, New Zealand, 20–23 July 1999.
81. Serrano-Ruiz, J.C.; Mula, J.; Poler, R. Smart Master Production Schedule for the Supply Chain: A Conceptual Framework. *Computers* **2021**, *10*, 156. [CrossRef]
82. Rios, P.; Stuart, J.A.; Grant, E. Plastics Disassembly versus Bulk Recycling: Engineering Design for End-of-Life Electronics Resource Recovery. *Environ. Sci. Technol.* **2003**, *37*, 5463–5470. [CrossRef] [PubMed]
83. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef] [PubMed]