COVID-19 pandemic related supply chain studies: a systematic review

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Abstract

The global spread of the novel coronavirus, also known as the COVID-19 pandemic, has had a devastating impact on supply chains. Since the pandemic started, scholars have been researching and publishing their studies on the various supply-chain-related issues raised by COVID-19. However, while the number of articles on this subject has been steadily increasing, due to the absence of any systematic literature reviews, it remains unclear what aspects of this disruption have already been studied and what aspects still need to be investigated. The present study systematically reviews existing research on the COVID-19 pandemic in supply chain disciplines. Through a rigorous and systematic search, we identify 74 relevant articles published on or before 28 September 2020. The synthesis of the findings reveals that four broad themes recur in the published work: namely, impacts of the COVID-19 pandemic, resilience strategies for managing impacts and recovery, the role of technology in implementing resilience strategies, and supply chain sustainability in the light of the pandemic. Alongside the synthesis of the findings, this study describes the methodologies, context, and theories

used in each piece of research. Our analysis reveals that there is a lack of empirically designed and theoretically grounded studies in this area; hence, the generalizability of the findings, thus far, is limited. Moreover, the analysis reveals that most studies have focused on supply chains for high-demand essential goods and healthcare products, while low-demand items and SMEs have been largely ignored. We also review the literature on prior epidemic outbreaks and other disruptions in supply chain disciplines. By considering the findings of these articles alongside research on the COVID-19 pandemic, this study offers research questions and directions for further investigation. These directions can guide scholars in designing and conducting impactful research in the field.

Keywords: Supply chain disciplines; COVID-19 pandemic; supply chain disruptions; epidemic outbreaks; literature review.

1. Introduction

Business organizations have faced huge challenges due to unprecedented disease outbreaks in recent decades. The scope of the challenges faced by these organizations largely depends on the severity of the outbreaks in question. A widespread public health incident such as an epidemic or pandemic can have substantial negative impacts on businesses and supply chains, including reducing their efficiency and performance (Guan et al., 2020; Ivanov, 2020a; Sodhi, 2016), and propagating disruptions across the supply chains (known as ripple effects) that affect their resilience and sustainability (Ivanov, 2020b; Ivanov and Dolgui, 2020a). Supply chains have encountered many severe disease outbreaks in the recent past; thus far, the World Health Organization (WHO) reported 1438 epidemics just between 2011 and 2018 (Hudecheck et al., 2020). However, the current COVID-19 pandemic is unique. It has had even more severe, diversified, and dynamic impacts than that of previous epidemic outbreaks such as the 2003 SARS epidemic or the 2009 H1N1 epidemic (Haren & Simchi-Levi, 2020; Koonin, 2020). A report published by *Fortune* magazine on 21 February 2020, before the WHO reclassified the COVID-19 outbreak as a pandemic on 11 March 2020, revealed that due to the COVID-19 pandemic, 94% of the Fortune 1000 companies were facing disruption in their supply chains (Fortune, 2020). Moreover, unlike other previous outbreaks, this pandemic has impacted all the nodes (supply chain members) and edges (ties) in a supply chain simultaneously (Gunessee and Subramanian, 2020; Paul and Chowdhury, 2020a); hence, the flow of the supply chain has been disrupted substantially. For example, the demand for necessary items such as personal protective equipment (PPE), ventilators, and dried and canned foods has increased. Meanwhile, supply, transportation, and manufacturing face numerous challenges that reduce their capacities. These include border closures, lockdown in the supply market, interruption in vehicle movements and international trade, labor shortage, and the maintaining of physical distance in manufacturing facilities (Amankwah-Amoah, 2020; Paul and Chowdhury, 2020a). Due to these multidimensional impacts on supply chains, along with other economic and financial challenges (Dontoh et al., 2020), the pandemic is likely to have a severe effect on world international trade. For

example, the world trade organization (WTO) announced that world trade may decline by 13-32% in 2020 due to the COVID-19 crisis (WTO, 2020).

Given the severe impact of the COVID-19 pandemic on supply chains, scholars have increasingly turned their attention to the topic. As a result, a significant amount of research on the COVID-19 pandemic in supply chain disciplines has been published since 2020. With the topic becoming more and more important for researchers, it is worth reporting the current state of the literature and outlining future research opportunities at this early stage—in part, to help scholars avoid doing repetitive research in this area (Chowdhury and Paul, 2020; Iyengar et al., 2020). A systematic literature review can help summarize what we know, how we know it, and what can be done so that, going forward, supply chains can better deal with the impacts of this pandemic (Tranfield et al., 2003). Accordingly, we synthesize here the results of published articles and sketch research agendas that can contribute to the existing body of knowledge in this domain, to provide practitioners and policymakers with better insights in managing the impacts of COVID-19 pandemic. In particular, in this study, we advance the supply chain literature by answering the following research questions.

i. What are the main themes and contents of the published research on the COVID-19 pandemic in supply chain disciplines?
ii. What are the opportunities for future research on the COVID-19 pandemic in supply chain disciplines?

To the best of our knowledge, this is the first literature review of studies on the COVID-19 pandemic in supply chain disciplines. Although several review articles on the impacts of disease outbreaks have been published recently, none of them specifically focuses on research on the COVID-19 pandemic in supply chain disciplines. For example, previous literature reviews have synthesized findings concerning the impacts of epidemics (in general) on logistics (Dasaklis et al., 2012), the effects of past epidemics on supply chains (Queiroz et al., 2020), and the causes of panic buying during an epidemic or pandemic (Yuen et al., 2020). In contrast to these studies, our study focused on published articles related to the COVID-19 pandemic in supply chain disciplines. Although the COVID-19 pandemic is an extraordinary supply chain disruptions (Ivanov, 2020b; Ivanov and Dolgui, 2020b), we have also reviewed the literature on prior epidemic outbreaks and other disruptions to enhance our findings and to outline unique research opportunities. The findings can help scholars to conduct impactful research on the effects of the COVID-19 pandemic in the supply chain area, while also helping practitioners and policymakers understand what we already know on this topic so that they can deal with the actual impacts of the COVID-19 pandemic on the global supply chain. This study also explores the methodologies, contexts, and theoretical lenses used in the studies on COVID-19 pandemic in supply chain disciplines. We expect it can assist academics with issues of research design, such as deciding on the most appropriate methodology and context, in future studies.

The remainder of this paper is organized as follows. Section 2 provides the review methodology for the systematic literature review. The articles themselves are analyzed in section 3. Section 4 provides a review of studies on prior epidemic outbreaks and other disruptions in supply chain disciplines. Based on the analysis and findings, further research opportunities are discussed in section 5. Finally, section 6 concludes the paper.

2. Review methodology

In this review paper, we followed a systematic literature review (SLR) approach. SLR has proven to be a rigorous framework for literature reviews (Tranfield et al., 2003), and we illustrate in Fig. 1 the search methodology we undertook for this study. First, the research theme was finalized to conduct the literature search (Cooper et al., 2018). Second, multiple research databases (Scopus, Google Scholar, and the Web of Science) were used to search for relevant articles. We considered different types of articles, including research articles, opinion pieces, short notes, discussion papers, review articles, and letters to the editor published in scholarly journals. Finally, we conducted a reference check of the included articles to enrich the final list of articles. We considered articles published online, including articles in the press and pre-publication versions of articles, up through our 28 September 2020 cut-off date.

As depicted in Fig. 1, initially we searched in Scopus using the keywords "supply chain" and "COVID-19" or "SARS-COV-2" or "coronavirus" both for articles and review papers published since 2020 in English. The search yielded 198 results. We then excluded the irrelevant results by reading titles, abstracts, and full papers; this process excluded 142 articles, leaving 56 papers from the Scopus database. The inclusion criteria were: (i) articles focused on the supply chain in relation to the COVID-19 pandemic, and (ii) both the search terms "supply chain" and "COVID-19", "coronavirus", or "SARS-COV-2" appeared in the body text. The exclusion criterion was one or more keywords only appearing in reference lists without being discussed in the body text. Then, to enhance the search results we repeated our search in Google Scholar and the Web of Science, and also conducted reference checks of our 56 identified articles. In the process, we identified a further 77 articles; but 38 of these were removed because they duplicated our findings from the previous search. We then read, in full, the remaining 39 articles, of which we included 18 for further consideration and excluded 21 based on the exclusion criterion mentioned before. Finally, we checked the references of the additional 18 articles, and no further articles were identified. The entire process yielded a total of 74 articles for our analysis.

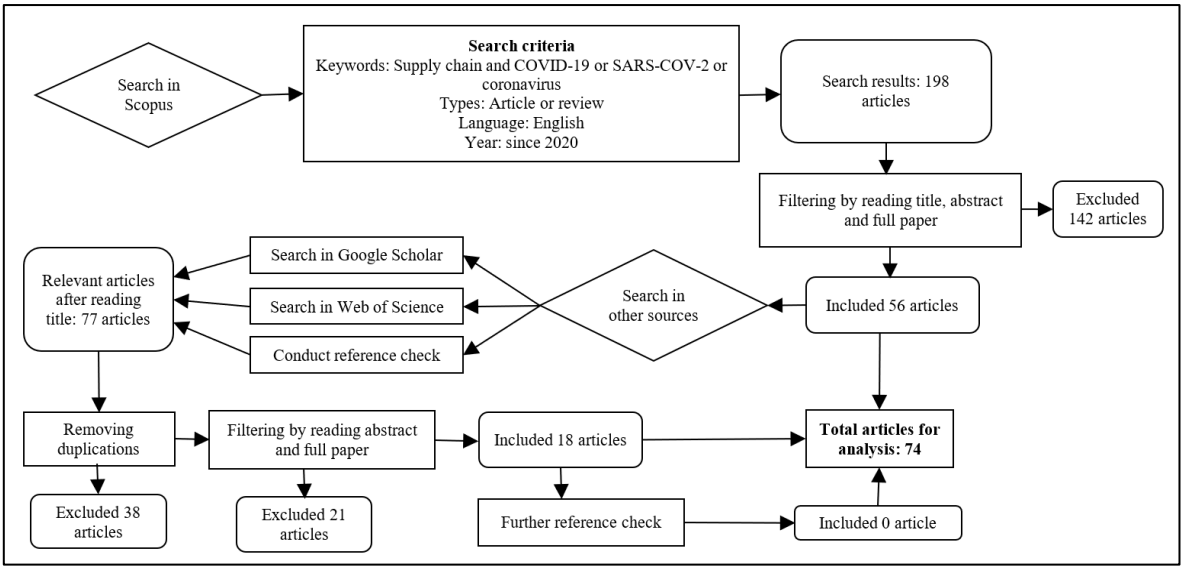

Fig. 1. Search methodology for finalizing the articles for analysis

These 74 articles are systematically reviewed and analyzed to synthesize the themes investigated and other aspects, such as the methodologies, contexts, and theories used in these studies. Furthermore, this study analyzes the studies from two closely related fields on prior epidemic outbreaks and other disruptions in supply chain disciplines to provide unique future research opportunities. Similar to the studies on the COVID-19 pandemic in supply chain disciplines, main themes and methodologies, contexts and theories used in the articles on these two fields are explored. Finally, this study discusses future research opportunities and outlines potential research questions by considering the research findings on COVID-19 and studies on prior epidemics and disruptions in supply chain disciplines. The framework of the analysis process of this systematic review paper is illustrated in Fig. 2.

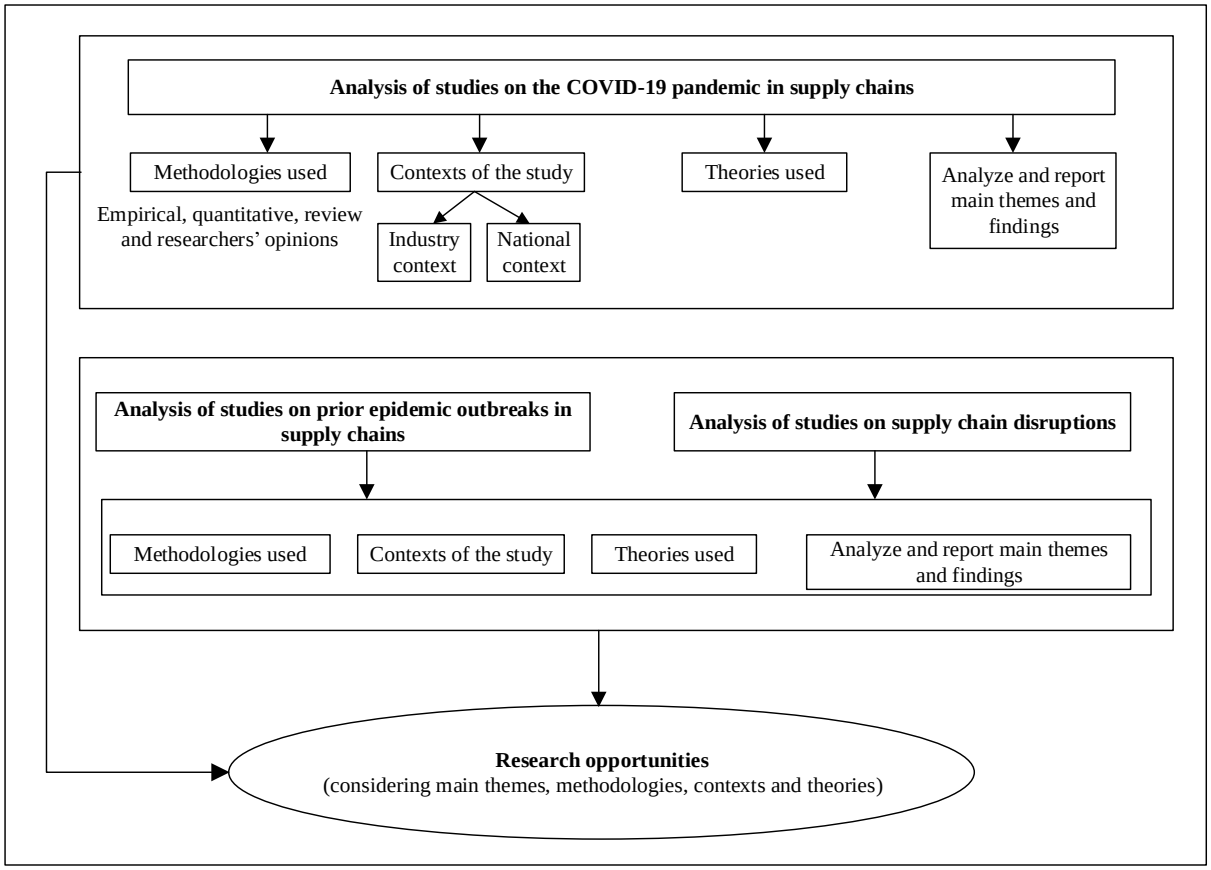

Fig. 2. Framework of the analysis process

3. Analyzing the reviewed articles on the COVID-19 pandemic in supply chain disciplines

This section investigates the methodologies, contexts, and theoretical underpinnings used in the 74 articles identified through our search methods. It synthesises the main themes investigated in these studies. However, a descriptive analysis is conducted to provide the selected articles' general landscape before this. The analysis uncovers journals that have extensively publish research on the COVID-19 pandemic in supply chain disciplines and the leading subject areas in these articles. The distribution of the identified articles by different source titles, as presented in Table 1, shows that a wide variety of journals have contributed to the literature in this domain.

Table 1: Articles by source title

Source title	Number of articles
Resources Conservation and Recycling	6
IEEE Engineering Management Review	5
Canadian Journal of Agricultural Economics	4
Sustainability	4
Annals of Operations Research	3
International Journal of Operations and Production Management	3
Transportation Research Part E: Logistics and Transportation Review	3
Trends in Food Science and Technology	3
Diabetes and Metabolic Syndrome Clinical Research and Reviews	2
Economic and Political Weekly	2
International Journal of Production Research	2

Science of the Total Environment	2
3D Printing and Additive Manufacturing	1
Applied Energy	1
Decision Sciences	1
Eai Endorsed Transactions on Pervasive Health and Technology	1
Economic and Labour Relations Review	1
Emerald Open Research	1
Energy Research and Social Science	1
Environment Systems and Decisions	1
European Journal of Operational Research	1
Global Journal of Flexible Systems Management	1
International Journal of Environmental Research and Public Health	1
International Journal of Global Business and Competitiveness	1
International Journal of Integrated Supply Management	1
International Journal of Logistics Research and Applications	1
International Journal of Physical Distribution and Logistics Management	1
International Journal of Production Economics	1
International Journal of Supply Chain Management	1
Journal of Business Research	1
Journal of Cleaner Production	1
Journal of Management	1
Journal of Occupational and Environmental Medicine	1
Journal of Risk Research	1
Journal of Service Management	1
Materials and Design	1
Modern Supply Chain Research and Applications	1
Nature Human Behaviour	1
Nature Reviews Materials	1
Naval Research Logistics	1
Omega	1
Problems and Perspectives in Management	1
Process Integration and Optimization for Sustainability	1
Production Planning and Control	1
Scientia Agropecuaria	1
Sustainable Production and Consumption	1
TQM Journal	1
Total	74

The selected articles' different subject areas are presented in Fig. 3, and show that business, management, and accounting, environmental science, engineering and decision sciences are at the top of the list. The other descriptive analyses of the selected articles are presented in Appendix A (supplementary material), which includes the affiliated countries of the authors (Table A1), the affiliated institutions of the authors (Table A2), the authors' names (Table A3) and word art showing the different keywords used in the articles (Fig. A1). The description of each paper is presented in Appendix B (supplementary material).

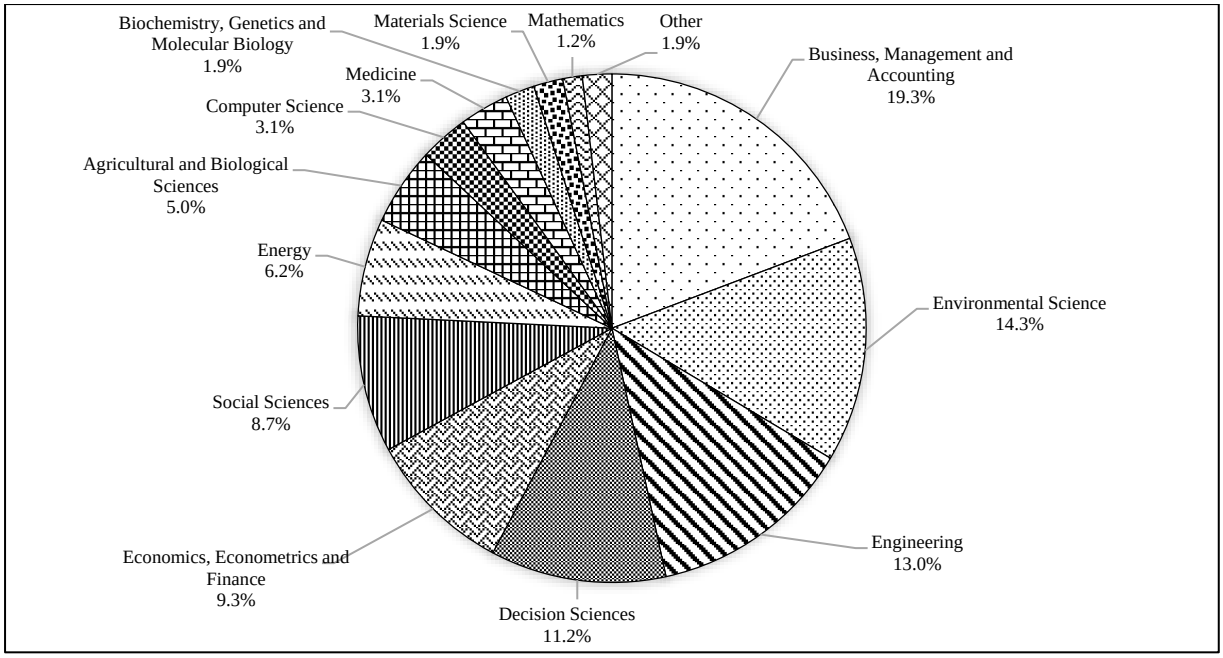

Fig. 3. Subject areas in the analyzed articles

3.1 Methodologies used

This subsection analyzes the reviewed articles in terms of the methodologies their authors use. For this purpose, we divided the articles into several categories, including empirical (e.g., studies involving interviews, case studies, focus groups, the Delphi technique, and surveys), quantitative (e.g., studies involving mathematical models, simulations, analytical modeling, and multi-criteria decision-making (MCDM) method), literature reviews (e.g., reviews, analytical reviews, and systematic or structured reviews), and researchers' opinions (opinion pieces, commentaries, and discussion articles). Table 2 shows the breakdown of methodologies used in the reviewed articles.

The analysis reveals that the largest number of articles (31 out of 74) relied on researchers' opinions as their main method of investigation. More specifically, at the start of COVID-19, researchers provided their perspectives and opinions on the potential impacts of and responses to this pandemic. Among the 31 articles that used researchers' opinions, 25 of them used the perspective or viewpoint of the researchers themselves, while four of them were discussion and two were conceptual papers. The prevalence of opinion pieces is understandable, considering the sudden occurrence and huge impact of the pandemic, and also the limited time that researchers had to collect and analyze relevant data. However, this pattern also suggests that further research is required, with real-world data, to understand the pandemic's impacts in different contexts, and to formulate strategies to address them.

Quantitative methods were the second-largest category, accounting for 27 of the 74 reviewed articles. Among the various quantitative techniques, seven studies used simulation modeling to predict the effects of the COVID-19 pandemic and to demonstrate the need for real-time visibility and structurally adaptable supply chains during a pandemic. Six studies used mathematical modeling techniques,

including game-theoretical modeling (Gupta et al., 2020; Ivanov and Dolgui, 2020b; Kargar et al., 2020), mixed-integer linear modeling (Lozano-Diez et al., 2020), stochastic optimization (Mehrotra et al., 2020), and non-linear modeling (Paul and Chowdhury, 2020a). One of the studies (Lozano-Diez et al., 2020) adopted an integrated mathematical and simulation model to recommend ways to reduce the shortage of medicines. Among the remaining articles, five studies used analytical modeling, nine relied on secondary data analysis including principal component analysis and cluster analysis, and one study applied stepwise weight assessment ratio analysis, which is one of the MCDM methods.

Literature reviews were used as the main research methodology in ten articles. Among them, five were simple review papers that did not employ systematic search and analysis methods. One of these articles (Iyengar et al., 2020) acknowledges this limitation explicitly. Four other literature review articles used a systematic or structured approach in analyzing the articles. However, none of them is confined to the COVID-19 literature specifically. These studies summarize the literature from broad perspectives, considering the supply chain resilience modeling literature published between 2017-19 and its implications for COVID-19 (Golan et al., 2020), the effects of past epidemics such as influenza, cholera, Ebola, malaria, and smallpox (Queiroz et al., 2020), the use of AI in the agri-food supply chain (Vaio et al., 2020), and the reasons for panic buying during a health crisis (Yuen et al., 2020). One article (Craighead et al., 2020) used an analytical review to investigate the theoretical underpinnings of response plans formulated by managers during health crises.

Only six of the studies that we reviewed used empirical methods in their research. Among them, three studies are qualitative, using a case study method in collecting and analyzing the data. The other three studies were survey-based and used descriptive statistics to report the findings. The lack of empirical studies confirms that researchers, thus far, have had limited opportunities to collect and analyze real-world data. However, the empirical studies are expected to reveal important supply chain issues and difficulties faced in different contexts, since the pandemic has caused unique challenges for supply chains.

Table 2: Research methodologies used in the reviewed articles

Methodology	Specific Methods	Number of Articles	References
Empirical	Case study	3	Handfield et al. (2020); Majumdar et al. (2020); van Hoek (2020)
	Survey (descriptive statistics)	3	Gurbuz and Ozkan (2020); Okorie et al. (2020); Veselovská (2020)
Quantitative	Mathematical model	6	Gupta et al. (2020); Ivanov and Dolgui (2020b); Kargar et al. (2020); Lozano-Diez et al. (2020); Mehrotra et al. (2020); Paul and Chowdhury (2020a)

	Analytical model	5	Choi (2020a); Govindan et al. (2020); Guan et al. (2020); Paul and Chowdhury (2020b), Rahman et al. (2021)
	Simulation	7	Ivanov (2020a, 2020b); Ivanov and Das (2020); Ivanov and Dolgui (2020c); Lozano-Diez et al. (2020); Singh et al. (2020); Zhu and Krikke (2020)
	Secondary data analysis	9	Derevyankina and Yankovskaya (2020); Farias and Araújo (2020); Gray (2020); Nikolopoulos et al. (2020); Novak and Loy (2020); Richards and Rickard (2020); Sharma et al. (2020a); Sharma et al. (2020b); Siche (2020)
	MCDM method	1	Sharma et al. (2020c)
Review	Literature review	5	Ibn-Mohammed et al. (2021); Ivanov and Dolgui (2020a); Iyengar et al. (2020); Kumar et al. (2020); Rizou et al. (2020)
	Systematic/structured literature review	4	Golan et al. (2020); Queiroz et al. (2020); Vaio et al. (2020); Yuen et al. (2020)
	Analytical review	1	Craighead et al. (2020)
Researchers' opinions	Perspective/opinion piece/commentary/ viewpoint	25	Abhishek et al. (2020); Amankwah-Amoah (2020); Armani et al. (2020); Baveja et al. (2020); Cappelli and Cini (2020); Chiaramonti and Maniatis (2020); Deaton and Deaton (2020); Dente and Hashimoto (2020); Hakovirta and Denuwara (2020); Hobbs (2020); Hosseini (2020); Jabbour et al. (2020); Ketchen and Craighead (2020); Larrañeta et al. (2020); Leite et al. (2020); Lemke et al. (2020); Quayson et al. (2020); Reardon et al. (2020); Rowan and Laffey (2020); Sarkis et al. (2020); Shokrani et al. (2020); Xu et al. (2020a); Yu et al. (2020); Yu and Aviso (2020); Zhu et al. (2020)
	Conceptual	2	Gunessee and Subramanian (2020); Mollenkopf et al. (2020)
	Discussion	4	Deshmukh and Haleem (2020); Ishida (2020); Trautrims et al. (2020); van Barneveld et al. (2020)

3.2 Context of the studies

This section systematically analyzes the contexts brought into focus by the articles included in our review. The contexts are presented in terms of the location, type, and size of the industries considered in these articles.

3.2.1 National context

The reviewed articles were categorized according to the national contexts on which they focused (Table 3). National context is an important factor for developing customized strategies for dealing with COVID-19, given that different countries have experienced different infection rates and adopted different lockdown strategies to manage the pandemic situation. Hence the industries in those countries faced contrasting challenges. The countries are also classified as developed (D) and

developing/emerging (E) economies in our analysis, based on a recent report published by the United Nations (United Nations, 2019). Among the 74 reviewed articles, three narrowed their scope to a particular region: two focused on South Asian countries, such as India and Bangladesh (Majumdar et al., 2020), and the other investigated the context of central European countries, such as Poland, Hungary, the Czech Republic, and Slovakia (Veselovská, 2020). Five studies considered multiple countries from various continents to demonstrate the global supply chain effects of the COVID-19 pandemic: comparisons included China, New Zealand, the United States, Vietnam, Nigeria, Malaysia, Kazakhstan, Jamaica, and Mongolia (Guan et al., 2020); India, the United States, Germany, Singapore, and the United Kingdom (Nikolopoulos et al., 2020); Brazil, India, the United Kingdom, and the United States (Okorie et al., 2020); the United States and the United Kingdom (Handfield et al., 2020); and the global context of many countries (Xu et al., 2020a). In terms of a specific country, four articles center on Canada and India, three on the United States, and one each on Australia, Brazil, Hong Kong, Ghana, Iran, Ireland, Mexico, Russia, and Turkey.

Table 3: The national contexts on which the reviewed articles focused

Country	**Economy**	**Number of Articles**	**References**
Central European countries	D	1	Veselovská (2020)
South Asian countries	E	2	Majumdar et al. (2020); Rahman et al. (2021)
Multiple countries from various continents	D, E	5	Guan et al. (2020); Handfield et al. (2020); Nikolopoulos et al. (2020); Okorie et al. (2020); Xu et al. (2020a)
Canada	D	4	Deaton and Deaton (2020); Gray (2020); Hobbs (2020); Richards and Rickard (2020)
Ghana	E	1	Quayson et al. (2020)
India	E	4	Abhishek et al. (2020); Deshmukh and Haleem (2020); Reardon et al. (2020); Singh et al. (2020)
Iran	E	1	Kargar et al. (2020)
United States	D	3	Lemke et al. (2020); Mehrotra et al. (2020); Sharma et al. (2020a)
Australia	D	1	van Barneveld et al. (2020)
Brazil	E	1	Farias and Araújo (2020)
Hong Kong	E	1	Choi (2020a)
Ireland	D	1	Rowan and Laffey (2020)
Mexico	E	1	Lozano-Diez et al. (2020)
Russia	E*	1	Derevyankina and Yankovskaya (2020)
Turkey	E	1	Gurbuz and Ozkan (2020)
* reported as the economy transitioning from developing to developed			

3.2.2 Industry context

Our analysis reveals that the major focus of existing research was on the food and healthcare supply chain. This finding makes intuitive sense, given that the healthcare industry is experiencing a major surge in demand, while a severe disruption has been observed in the food supply chain as it struggles to provide everyday essentials and meet high consumer demand. Among the 74 reviewed articles, 30 did not explicitly mention the industries under consideration.

As mentioned previously, the food and healthcare supply chains have received significant attention, with each of these two sectors being addressed in 16 and 14 articles respectively. Six articles reflected multiple industry sectors, such as service, production, transportation, construction, agriculture, and grocery sectors (Veselovská, 2020); transportation, equipment, retail, fast moving consumer goods, food, apparel and technology sectors (van Hoek, 2020); automobile and earth-moving equipment sectors (Handfield et al., 2020); aviation and tourism sectors (Ibn-Mohammed et al., 2021); healthcare, food, clothing, retail, automobile, airline and high-tech industry sectors (Xu et al., 2020a); and automobile, personal computer, and home furnishing sectors (Ishida, 2020). Among the rest of the articles, one each focused on the industries of service, oil, electronics, automotive, clothing, retail, aviation, toilet paper manufacturing, and ship-breaking. Table 4 shows a breakdown of the industry sectors in our reviewed articles. It is worth mentioning that only four articles (Craighead et al., 2020; Gurbuz and Ozkan, 2020; Quayson et al., 2020; Reardon et al., 2020) out of the 74 reviewed articles addressed issues faced by SMEs; the rest focused on large industries.

Table 4: A breakdown of the industry sectors in the reviewed articles

Industry Sector	**Number of Articles**	**References**
Food	16	Abhishek et al. (2020); Cappelli and Cini (2020); Deaton and Deaton (2020); Farias and Araújo (2020); Gray (2020); Gurbuz and Ozkan (2020); Hobbs (2020); Quayson et al. (2020); Reardon et al. (2020); Richards and Rickard (2020); Rizou et al. (2020); Sharma et al. (2020b); Siche (2020); Singh et al. (2020); Vaio et al. (2020); Zhu and Krikke (2020)
Healthcare	14	Armani et al. (2020); Deshmukh and Haleem (2020); Govindan et al. (2020); Iyengar et al. (2020); Kargar et al. (2020); Kumar et al. (2020); Leite et al. (2020); Lozano-Diez et al. (2020); Mehrotra et al. (2020); Rowan and Laffey (2020); Sharma et al. (2020b); Shokrani et al. (2020); Yu et al. (2020); Zhu et al. (2020)
Multiple industry sectors	6	Handfield et al. (2020); Ibn-Mohammed et al. (2021); Ishida (2020); van Hoek (2020); Veselovská (2020); Xu et al. (2020a)
Service	1	Baveja et al. (2020)
Oil	1	Chiaramonti and Maniatis (2020)
Electronics and automotive	1	Guan et al. (2020)
Clothing/Apparel	1	Majumdar et al. (2020)
Retail	1	Yuen et al. (2020)
Airline	1	Amankwah-Amoah (2020)

Manufacturing (toilet paper)	1	Paul and Chowdhury (2020b)
Ship breaking industry	1	Rahman et al. (2021)

3.3 Theories used

Although a variety of theoretical frameworks may give rise to strategies for overcoming the challenges of a pandemic (Craighead et al., 2020), the majority of the published studies are not based on any underpinning theory. The analysis reveals that only five articles on COVID-19 and the supply chain are theoretically grounded in this sense. The tenets of the theory of constraint are used in one study to formulate a pandemic management plan (Baveja et al., 2020). Dynamic system theory is used as a methodological principle in another article to design the digital twin necessary for disruption management (Ivanov and Dolgui, 2020c). Yet another article (Ivanov, 2020b) uses information control and communication theory to explain the relations between resilience and viability. In order to create value for customers, Mollenkopf et al. (2020) used a service-dominant logic paradigm to prepare a supply chain response plan to the current food crisis. The behavioral decision theory is used to understand how organizations behave and make decisions during ambiguous events such as the COVID-19 pandemic (Gunessee and Subramanian, 2020).

On the other hand, several studies suggest conducting research grounded by theoretical lenses. For example, Craighead et al. (2020) urge scholars and managers to use theoretical lenses to better understand the supply chain phenomena in play during a pandemic like COVID-19. Their study discusses how ten well-established and emergent theories, such as (i) the awareness–motivation–capability framework, (ii) event systems theory, (iii) game theory, (iv) institutional theory, (v) prospect theory, (vi) real options theory, (vii) resource dependence theory, (viii) resource orchestration theory, (ix) structural inertia, and (x) tournament theory, can all be used productively in this connection. Another study (Ketchen and Craighead, 2020) further suggests the use of the resource orchestration theory in future research on the COVID-19 pandemic; this could provide valuable insight into how organizational resources could be deployed for enhancing various capabilities, such as online distributions, and how such deployment may affect performance during the disruption. Similarly, Ivanov and Dolgui (2020b) and Queiroz et al. (2020) also urge researchers to conduct studies underpinned by operations research/management theories, such as network theory, complexity theory, graph theory and systems dynamics theory as well as empirical theories such as contingency theory, resource/knowledge-based views, dynamic capabilities models, and information processing theory.

3.4 Main themes in the existing research: A synthesis

Our analysis revealed that these studies focus on four broad areas (see Fig. 4). While several articles discuss only one of these four themes, others touch on two or more of the four themes. Among the themes, exploring and reporting the various impacts of COVID-19 on supply chains is the most frequently discussed, appearing in 60 articles. Many of these articles (47) also discuss and report

potential resilience strategies to reduce the impacts and to enable affected firms to make a quick recovery. Thirteen (13) of the included articles discuss the role of technology in the implementation of resilient strategies. Finally, 17 of the articles discuss issues of sustainability in light of the COVID-19 pandemic. The following sub-sections summarize each of these four themes.

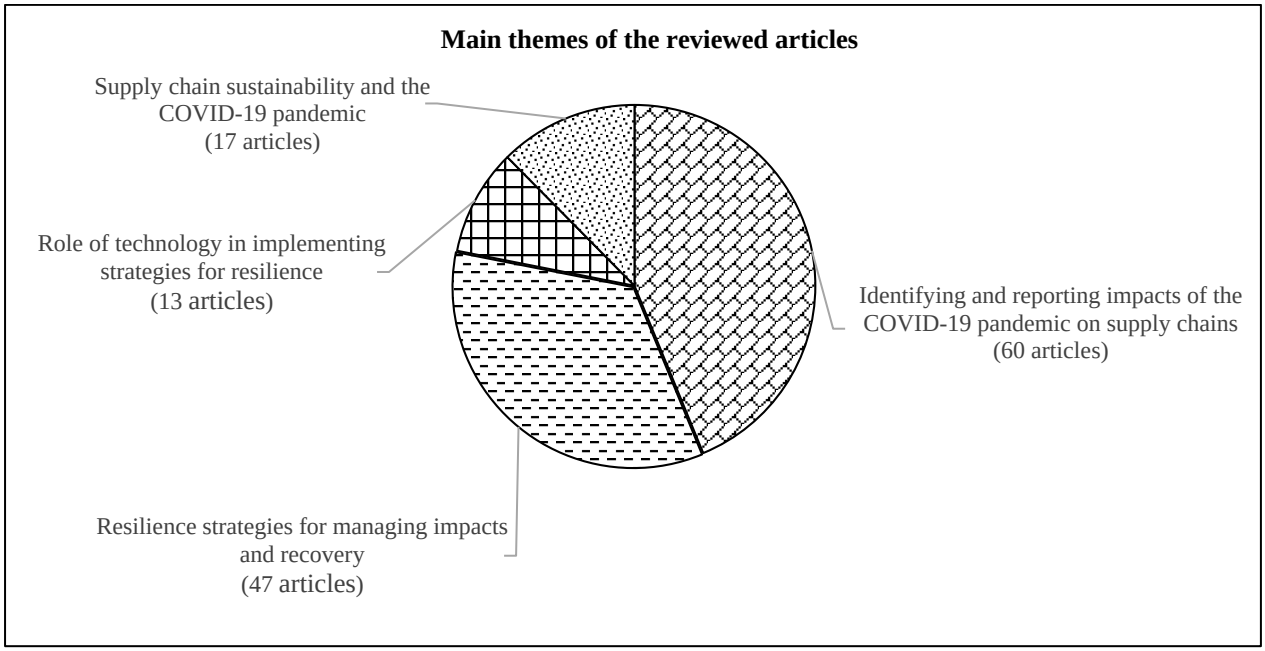

Fig. 4. Themes of the reviewed articles

3.4.1 Impacts of the COVID-19 pandemic

The majority (60) of the reviewed articles discuss the impacts of COVID-19 on supply chains. The reviewed articles report several impacts of COVID-19 related to various supply chain areas, as outlined in Table 5.

Table 5: List of impacts of the COVID-19 pandemic on supply chains

Impacted area	Specific impact	References
Demand management	Demand spikes for essential products	Govindan et al. (2020); Gunessee and Subramanian (2020); Hakovirta and Denuwara (2020); Handfield et al. (2020); Hobbs (2020); Ivanov and Dolgui (2020a); Iyengar et al. (2020); Jabbour et al. (2020); Ketchen and Craighead (2020); Leite et al. (2020); Mehrotra et al. (2020); Mollenkopf et al. (2020); Nikolopoulos et al. (2020); Okorie et al. (2020); Paul and Chowdhury (2020a, 2020b); Queiroz et al. (2020); Sharma et al. (2020a); Trautrims et al. (2020); van Hoek (2020); Yuen et al. (2020); Zhu et al. (2020)
	Shortage of essential products	Deaton and Deaton (2020); Farias and Araújo (2020); Hobbs (2020); Jabbour et al. (2020); Kumar et al. (2020); Larrañeta et al. (2020); Mollenkopf et al. (2020); Paul and Chowdhury (2020a); Queiroz et al. (2020); Rowan and Laffey (2020); Sharma et al. (2020a); Shokrani et al. (2020); Siche (2020); van Barneveld et al. (2020); Zhu and Krikke (2020)

	Loss of security with respect to essential items	Cappelli and Cini (2020); Reardon et al. (2020); Siche (2020)
	Failure of on-time delivery	Ivanov and Das (2020)
	Declining demand for non-essential products	Abhishek et al. (2020); Chiaramonti and Maniatis (2020); Derevyankina and Yankovskaya (2020); Gurbuz and Ozkan (2020); Handfield et al. (2020); Ibn-Mohammed et al. (2021); Ivanov and Dolgui (2020a); Majumdar et al. (2020); Nikolopoulos et al. (2020)
	Ambiguity or difficulty in forecasting	Gunessee and Subramanian (2020)
Supply management	Shortage of material supply/supply-side shock/supply disruption	Baveja et al. (2020); Gunessee and Subramanian (2020); Gupta et al. (2020); Handfield et al. (2020); Hobbs (2020); Ishida (2020); Ivanov and Das (2020); Ivanov and Dolgui (2020a); Iyengar et al. (2020); Leite et al. (2020); Lozano-Diez et al. (2020); Nikolopoulos et al. (2020); Paul and Chowdhury (2020a, 2020b); Singh et al. (2020); van Hoek (2020); Xu et al. (2020a); Zhu et al. (2020)
Production management	Production disruption and backlog	Ivanov and Das (2020); Iyengar et al. (2020); Lozano-Diez et al. (2020); Mehrotra et al. (2020); Paul and Chowdhury (2020a); Quayson et al. (2020); Richards and Rickard (2020); Shokrani et al. (2020)
	Reduced production capacity	Leite et al. (2020); Paul and Chowdhury (2020b)
	Unavailability of workforce	Gunessee and Subramanian (2020); Kumar et al. (2020); Leite et al. (2020); Mollenkopf et al. (2020); Trautrims et al. (2020); Xu et al. (2020a)
	Obsolescence and impairment of machinery and capital assets	Dente and Hashimoto (2020); Derevyankina and Yankovskaya (2020)
Transportation and logistics management	Delays in transportation and distribution	Chiaramonti and Maniatis (2020); Deaton and Deaton (2020); Gray (2020); Kumar et al. (2020); Xu et al. (2020a)
	Lack of international transportation/trade	Deaton and Deaton (2020); Handfield et al. (2020); Ibn-Mohammed et al. (2021); Xu et al. (2020a)
	Loss/lack of physical distribution channels	Choi (2020a); Dente and Hashimoto (2020); Ivanov and Dolgui (2020a); Ketchen and Craighead (2020); Mollenkopf et al. (2020); Richards and Rickard (2020)
	Shift of distribution and logistics pattern (offline to online or blended)	Mollenkopf et al. (2020)
Relationship management	Reduced social interaction	Baveja et al. (2020); Kumar et al. (2020)
	Information ambiguity	Gunessee and Subramanian (2020)
	Lack of supplier engagement/opportunistic behavior	van Hoek (2020)
Supply chain-wide impact (causing impacts in internal, upstream and	Ripple effect on all the operations involved in supply chains	Gunessee and Subramanian (2020); Ivanov (2020a); Ivanov and Dolgui (2020a, 2020b); Queiroz et al. (2020); Yuen et al. (2020)
	Supply chain collapse	Handfield et al. (2020); Ivanov and Dolgui (2020b, 2020c); Shokrani et al. (2020); Siche (2020); Yuen et al. (2020)
	Closure of facilities, including both	Ishida (2020); Quayson et al. (2020); Xu et al. (2020a); Yu and Aviso (2020)

downstream operations)	companies' production facilities and the facilities of supply chain partners such as suppliers and distributors	
Financial management	Reduced supply chain financial performance (e.g. loss/reduction of financial stability)	Baveja et al. (2020); Chiaramonti and Maniatis (2020); Deaton and Deaton (2020); Derevyankina and Yankovskaya (2020); Guan et al. (2020); Hakovirta and Denuwara (2020); Ivanov (2020a); Ivanov and Das (2020)
	Reduced cash inflow	Hakovirta and Denuwara (2020)
Sustainability management	Lack of focus on social and environmental sustainability practices/disruption of sustainability initiatives	Majumdar et al. (2020); Sharma et al. (2020a); van Barneveld et al. (2020)
	Threats to the health and safety of the workforce	Gunessee and Subramanian (2020); Hakovirta and Denuwara (2020); Mollenkopf et al. (2020); Rizou et al. (2020); Trautrims et al. (2020); van Barneveld et al. (2020)
	Contraction of the development of green and low-carbon energy sources	Hosseini (2020)
	Increase in waste	Dente and Hashimoto (2020); Derevyankina and Yankovskaya (2020); Farias and Araújo (2020); Sharma et al. (2020b); Trautrims et al. (2020)
	Increased in recyclable materials	Rahman et al. (2021)

In the area of demand management, researchers mention demand fluctuation and firms' ability to manage such changes in demand. COVID-19 has affected the pattern of consumers' purchasing behavior for both essential and non-essential products (Hakovirta and Denuwara, 2020; Mollenkopf et al., 2020). The demand for essential products (e.g., food, medicine and ventilators) increased sharply (Paul and Chowdhury, 2020a; van Hoek, 2020), leading to temporary product shortages (Deaton and Deaton, 2020; van Barneveld et al., 2020). Further, there have been delays in delivering products to customers via online and traditional distribution channels (Ivanov and Das, 2020), causing the loss of security concerning essential items, such as food (Siche, 2020). The reasons for such demand spikes include panic buying, uncertainty about the future, and stockpiling behaviors (Hobbs, 2020; Richards and Rickard, 2020). One study (Yuen et al., 2020) explored the causes of such panic buying and found that several factors, such as perceived threats, fear of the unknown, the copying of others' behavior, and other social psychological factors are in play. As a solution, one study (Zhu and Krikke, 2020) suggests that information that may lead to panic buying should not be disseminated to the public. At the same time, non-essential products have seen downward demand, because the income of customers has declined and they prefer to save money for an uncertain future (Abhishek et al., 2020; Chiaramonti and Maniatis, 2020). More generally, many industries, including aerospace, tourism, oil, gas, and apparel, are bearing the brunt of this extraordinary crisis (Majumdar et al., 2020). The sudden fluctuation in

demand creates ambiguity and uncertainty for supply chains, affecting both forecasting and decision-making (Gunessee and Subramanian, 2020). Moreover, this also affects the price of the products. While the price of the essential products has increased (Farias and Araújo, 2020), the price of non-essential products has declined.

In the area of supply management, governments have imposed full or partial lockdowns around the world, restricting vehicle movements to control the spread of the virus; such measures have substantially affected suppliers' ability to deliver products on time to customers (Ivanov and Das, 2020). In the modern globalized world, companies are sourcing materials from all parts of the globe. Even if the direct suppliers of a company are from the domestic market, its tier 2 or tier 3 suppliers are likely to be located overseas. As a result, the sudden closure of international suppliers' operations, in line with local restrictions created by lockdowns, have caused supply disruptions for manufacturers.

In the production management area, suppliers' failures create severe production disruptions and backlog for companies (Richards and Rickard, 2020). Moreover, the production capacity of the companies has been reduced due to several policy decisions, such as reduced office hours and having employees work on alternative days to maintain social distancing in the office (Leite et al., 2020). Because of these social distancing and safety measures, employees have been unable to work full time, causing a workforce shortage (Trautrims et al., 2020). Moreover, limited operations in the factory also resulted in the obsolescence and impairment of machinery and capital assets (Dente and Hashimoto, 2020).

In the areas of transportation and logistics management, different modes of transportation, including ocean shipping, air freight, trucking, and rail, have all been disrupted because of the restriction in vehicle movement (Gray, 2020). These transportation disruptions have created delays and negatively affected the smooth flow of products (Chiaramonti and Maniatis, 2020), while also disrupting international trade (Deaton and Deaton, 2020). Distribution and logistics patterns are shifting rapidly. While for many years physical channels were the main distribution mode, the pandemic has forced many companies to shift their business fully online, or to undertake a blended online-offline model. Moreover, physical distribution channels are either closed or have limited operations due to the restrictions (Dente and Hashimoto, 2020). Despite the efforts of companies to increase their capacity in the area of online sales, the loss or limited operations of physical channels has caused huge negative impacts on the flow of supply chains. Moreover, the sudden surge in online sales also outstripping the ability of the supply chains to cope. For example, while some retailers have developed 'dark-warehouses'—a distribution center designed to serve online customers exclusively—others are struggling to quickly implement logistical solutions to meet the new demand (Mollenkopf et al., 2020).

The COVID-19 pandemic has also impacted supply chain relationship management. The limited scope of social interactions among supply chain partners is reported in one study (Baveja et al., 2020). This decline in interactions causes information incompleteness, which can lead to information ambiguity and

a lack of clarity and precision (Gunessee and Subramanian, 2020). Moreover, this has reduced supplier engagement, making it harder for companies to develop a collaborative approach by integrating all the parties involved (van Hoek, 2020). Opportunistic behaviors might also increase, as Gupta et al. (2020) noted, and non-disrupted suppliers may charge higher prices if they see that other suppliers have been affected by disruptions.

Several of the impacts described in the studies are not related to a particular area of the supply chain, but rather linked to the entire supply chain management area. The activities in a supply chain are interconnected; hence, disruption in one of the functions leads to a ripple effect encompassing other functions (Gunessee and Subramanian, 2020; Ivanov and Dolgui, 2020b). This finding suggests that overall operations are disrupted when one segment does not function properly (Queiroz et al., 2020). The combination of these effects on demand, supply, production, transportation, logistics, and relationships can cause the total collapse of supply chains (Yuen et al., 2020). Moreover, supply chain partners, including manufacturers and their suppliers and distributors, may keep their facility centers closed or limit their operations, in line with government policies and guidelines (Quayson et al., 2020).

In the performance or financial management area, reductions in supply chains' financial performance (Ivanov and Das, 2020) and overall cash inflow (Hakovirta and Denuwara, 2020) are reported in the reviewed articles. Two studies (Guan et al., 2020; Ivanov, 2020a) also investigate how these losses increase or decrease based on other factors, such as restriction measures and their duration. The findings suggest that the extent of financial losses largely depends on the number of countries placing the lockdown or restriction measures into effect, and the duration of such measures rather than their strictness (Guan et al., 2020). The extent of losses also depends on the timing of facilities' closing and reopening at the different levels of a supply chain (Ivanov, 2020a). As a result of such performance reductions, the overall global gross domestic product is expected to decrease by 12.6 percent in 2020, which may rise to 26.8 percent because of the global lockdown (Guan et al., 2020).

The final set of impacts reported in the articles is related to sustainability management. In general, researchers found that the sustainability focus (both social and environmental) has been negatively affected, as companies struggle to survive (Sharma et al., 2020a). Likewise, creating a healthy and safe working environment has been given less priority since the pandemic began (Trautrims et al., 2020). Companies are also less committed to developing green and low-carbon energy (Hosseini, 2020). Furthermore, because of the transportation delays and demand variations, businesses dealing with food or other perishables are often left with large amounts of unsellable products and waste (Dente and Hashimoto, 2020; Trautrims et al., 2020). Moreover, transportation and labor crises would significantly increase recyclable materials and products. For example, Rahman et al. (2021) suggest that in the ship-breaking industry alone, there are expected to be around 300 million gross tonnages of recyclable material generated in the next five years, which would cost around $20 billion if they are not recycled.

In addition to citing these impacts, many of the studies that we reviewed agreed these impacts are likely to be long-lasting (Ivanov, 2020b, 2020a; Ivanov and Das, 2020; Veselovská, 2020). As such, Gunessee and Subramanian (2020) report that COVID-19 affects almost all existing supply chain decisions and suggests developing better strategies for resilience.

3.4.2 Resilience strategies

In the pre-COVID-19 era, in studies about supply chain resilience strategies, if researchers considered issues related to an epidemic or pandemic, they focused on a specific disruption scenario such as one involving supplier selection (Golan et al., 2020). However, these studies remained silent about the "unknown unknowns" of a pandemic like the current COVID-19 crisis, neglecting to consider, for example, how the effects of a disrupted node might be propagated throughout the supply chain. As a result, supply chains are not as resilient as they should be. In response to the current vulnerability, several studies (47) suggested various strategies for minimizing the impacts of COVID-19, recovering from the current pandemic, and preparing for future pandemics. By closely reviewing the arguments presented in these articles, we identified the range of strategies that have been proposed. To this end, we focused on three main dimensions of supply chain resilience, namely preparedness, response, and recovery (Chowdhury and Quaddus, 2016). A strategy is considered effective for preparedness if it is preemptive for future disruption readiness; for the response, if it can help members of the supply chain respond quickly to minimize the immediate impacts; and for recovery, if it can help the supply chain return to its original or even a better state (Chowdhury and Quaddus, 2016; Ponomarov and Holcomb, 2009). Table 6 summarizes the resilience strategies proposed in the articles we reviewed, and indicates which of the three dimensions of supply chain resilience they aim to enhance.

Table 6: Resilience strategies for managing the impacts of the COVID-19 pandemic

Resilience strategy	Resilience dimensions			References
	Preparedness	Response	Recovery	
Ramping up production early		✓		Lozano-Diez et al. (2020); Mehrotra et al. (2020; Veselovská (2020)
Increase in production capacity		✓		Leite et al. (2020); Paul and Chowdhury (2020a)
Building temporary capacity		✓		Leite et al. (2020)
Distributed manufacturing systems	✓	✓		Shokrani et al. (2020)
Modifying product characteristics (e.g. their basic quality and size)		✓		Paul and Chowdhury (2020b); Veselovská (2020)

Bespoke/redesigned production of emergency items		✓		Rowan and Laffey (2020); Shokrani et al. (2020); Okorie et al. (2020)
Maintaining/improving transportation capability		✓		Abhishek et al. (2020); Baveja et al. (2020); Deaton and Deaton (2020); Gray (2020)
Sharing resources		✓	✓	Mehrotra et al. (2020),
Enhancing visibility by mapping supply networks	✓	✓	✓	Gunessee and Subramanian (2020); Ivanov and Dolgui (2020c); Xu et al. (2020a)
Multiple and diversified sourcing and facilities; also, keeping backup suppliers at diversified locations	✓	✓	✓	Ivanov and Das (2020); Sharma et al. (2020a); Singh et al. (2020); van Hoek (2020)
Emergency sourcing		✓	✓	Paul and Chowdhury (2020a, 2020b)
Nearshoring or local sourcing/domestic production	✓		✓	Cappelli and Cini (2020); Deaton and Deaton (2020); Gunessee and Subramanian (2020); Ibn-Mohammed et al. (2021); Ishida (2020); Ivanov (2020b); Sharma et al. (2020b); van Barneveld et al. (2020); van Hoek (2020); Veselovská (2020); Zhu et al. (2020)
Creating a balance in domestic production and international trade	✓		✓	Deaton and Deaton (2020); Handfield et al. (2020); Sharma et al. (2020a); van Hoek (2020)
Shortening supply chains	✓		✓	Cappelli and Cini (2020); Farias and Araújo (2020); Gurbuz and Ozkan (2020); Jabbour et al. (2020); Mollenkopf et al. (2020)
Use of online sales, mobile (flexible) services, and home delivery	✓	✓	✓	Choi (2020a); Gray (2020); Gurbuz and Ozkan (2020); Ibn-Mohammed et al. (2021); Mollenkopf et al. (2020); Quayson et al. (2020); Richards and Rickard (2020); Xu et al. (2020a)
Digitalization and use of smart communication channels/ information technologies	✓	✓	✓	Choi (2020a); Gurbuz and Ozkan (2020); Ibn-Mohammed et al. (2021); Iyengar et al. (2020); Mollenkopf et al. (2020); Okorie et al. (2020); Quayson et al. (2020); Queiroz et al. (2020); Rowan and Laffey (2020); Sharma et al. (2020a); van Barneveld et al. (2020); van Hoek (2020)
Automated production systems	✓	✓	✓	Gurbuz and Ozkan (2020); Ivanov and Das (2020)
Contactless payment system and self service	✓	✓		Mollenkopf et al. (2020)
Finding and developing new supply chain partnerships		✓	✓	Veselovská (2020)
Supply chain collaboration and relationships	✓	✓	✓	Gunessee and Subramanian (2020); Hobbs (2020); Ishida (2020); Ivanov and Dolgui (2020b); Jabbour et al. (2020); Kumar et al. (2020); Leite et al. (2020); Lemke et al. (2020); Mollenkopf et al. (2020); Paul and Chowdhury (2020a); Sharma et al. (2020a)
Synchronizing strategic processes	✓		✓	Sharma et al. (2020a)

Knowledge management / Information sharing	✓	✓	✓	Jabbour et al. (2020); Zhu and Krikke (2020)
Integration of warehouses	✓	✓	✓	Singh et al. (2020)
Horizontal collaboration		✓		Paul and Chowdhury (2020b)
Strengthening supply chain contracts	✓			Gupta et al. (2020)
Real-time changes in strategies/flexible strategies/dynamic response	✓	✓	✓	Hobbs (2020); Ivanov and Das (2020); Ivanov and Dolgui (2020c); Leite et al. (2020); Lozano-Diez et al. (2020); Okorie et al. (2020); Sharma et al. (2020a); Veselovská (2020)
Price reduction		✓		Chiaramonti and Maniatis (2020)
Implementation of all appropriate safety measures for the workforce		✓		Abhishek et al. (2020); Majumdar et al. (2020); Mollenkopf et al. (2020); Reardon et al. (2020); Rizou et al. (2020); Sharma et al. (2020a)
Prohibit unauthorized subcontracting	✓			Majumdar et al. (2020)
Focus on producing cleaner, renewable, and bio-based energy	✓			Chiaramonti and Maniatis (2020)
Automated waste treatment process	✓	✓	✓	Sharma et al. (2020b)
Enlisting stakeholders such as NGOs and governments to participate in support and subsidy schemes		✓	✓	Chiaramonti and Maniatis (2020); Choi (2020a); Deaton and Deaton (2020); Gray (2020); Handfield et al. (2020); Ibn-Mohammed et al. (2021); Kumar et al. (2020); Majumdar et al. (2020); Mollenkopf et al. (2020); Okorie et al. (2020); Reardon et al. (2020)

During the current pandemic, shortages of essential food products and medicines are widely reported. To minimize the impacts of this problem and to ensure the supply of essential products, various strategies have been suggested in the literature. Among them, ramping up production early by taking rapid decisions, to minimize shortfalls, is suggested in various studies (Lozano-Diez et al., 2020; Mehrotra et al., 2020; Veselovská, 2020). In this connection, the optimal timing for ramping up production is a critical consideration, and should be determined by analyzing relative costs and benefits (Mehrotra et al., 2020). Further, supply chains can allocate resources from non-priority areas, and re-direct staff from non-critical activities while also hiring students and retired persons to accelerate their response (Leite et al., 2020).

Supply chains may also need to increase their production capacity (Paul and Chowdhury, 2020a). Given that pandemic-caused spikes in demand are for the short run, researchers have proposed building temporary capacities by removing non-essential operations, rather than increasing the permanent

capacities (Leite et al., 2020), and using distributed manufacturing systems (Shokrani et al., 2020). In general, establishing geographically-dispersed manufacturing facilities with the necessary logistical supports is considered effective as a proactive readiness strategy. At the same time, acknowledging the need to increase production capacities, a number of the studies have suggested strategies for modifying product features, such as their basic quality and size, to serve more customers with existing resources (Paul and Chowdhury, 2020b). To improve the responsiveness and diversified needs of the supply chain, some studies proposed redesigning and improving logistics, such as redesigning production facilities and diversifying their locations to accommodate emergency items, especially PPE items (Rowan and Laffey, 2020), and improving transportation routes for this purpose. The implementation of faster delivery modes, such as air transport, has also been recommended (Deaton and Deaton, 2020). Generally, the demand for services from the various entities involved in the supply chain will peak at different points; hence, resource sharing among these entities has been proposed, as a strategy for minimizing the impacts and recovering from this extraordinary disruption (Mehrotra et al., 2020).

It is neither practical nor possible to increase production if there is a shortage of raw materials. In their study, Paul and Chowdhury (2020a) reported that an Australian hand sanitizer company had to stop the production process due to a lack of raw materials. As a response to such issues, several studies suggested strategies for increasing upstream resilience. For example, Ivanov & Dolgui (2020a) proposed enhancing visibility by mapping supply networks, to predict potential disruptions and their consequences. This mapping can be useful for formulating node/supplier-specific strategies. Another recommendation is for supply chains to diversify suppliers across different locations, to avoid production breakdowns while a given location is under lockdown (van Hoek, 2020). Moreover, the use of emergency sourcing at times of crisis has been suggested as a strategy for responding to and recovering from the impacts of the COVID-19 outbreak (Paul and Chowdhury, 2020b).

Strategies related to logistics and supply chain restructuring, including location and size, have been proposed both as a way of minimizing current impacts and as a way of ensuring a more resilient supply chain in the post-COVID-19 era. Several studies (Cappelli & Cini, 2020; Deaton & Deaton, 2020; van Hoek, 2020) have suggested nearshoring or back shoring production facilities to increase domestic capabilities for dealing with the COVID-19 pandemic. In the pre-COVID-19 era, many firms adopted the offshoring strategy and set up production plants with necessary logistic supports in developing countries to minimize production costs. However, COVID-19 shows that during a pandemic it is harder to transport products from various locations. Therefore, even if companies decide to outsource products from overseas, they will still need to strike a balance between domestic production and international trade to reduce vulnerability (Deaton and Deaton, 2020). Designing short supply chains by reducing the number of partners can also be effective in accelerating recovery and preparing for the next disruption (Farias and Araújo, 2020). Other studies suggested improving IT capability in supply chains. The popularity and requirements of mobile services have increased substantially, with consumers now

preferring to receive services at their doorstep (Choi, 2020a; Richards and Rickard, 2020). Hence, firms should now use home delivery, online sales, and mobile services; and by the same token, digitalization and the use of information technology are required to monitor the supply chain and to reduce the impacts of disruption (Ibn-Mohammed et al., 2021; van Hoek, 2020). Several disruptive technologies such as cloud computing, 3-D printing, Internet of Things (IoT), artificial intelligence (AI), and big data analytics are suggested in this regard. Further, with the current social distancing measures, only a limited number of employees can work in the factory. To boost the production capacity despite limited staff, researchers have suggested automating the production system such that it can function with less human intervention (Ivanov and Das, 2020). Moreover, in line with the safety measures, it is recommended that companies develop and implement contactless payment systems, especially at the retail store level (Mollenkopf et al., 2020). Likewise, to deal with the shortage of capital for purposes of restructuring the supply chain and digitalization, Deaton and Deaton (2020) proposed easing capital flow.

Along with implementing restructuring strategies, supply chains need to develop new supply chain partnerships to smooth the flow of products and services (Veselovská, 2020). For example, while a company re-shores its production facility, it may need to find and build partnerships with new suppliers to ensure locational proximity. Improved supply chain relationships and collaborations can also safeguard companies from negative impacts, allowing for quick recovery as well as preparation for future events (Hobbs, 2020; Paul and Chowdhury, 2020a; Sharma et al., 2020a). Being connected drives supply chain partners to meet the requirements of each other; they can thereby reduce the impacts of disruptions. Knowledge management via sharing important information, ideas, and expertise (Jabbour et al., 2020), as well as synchronization of strategic processes (Sharma et al., 2020a), are also reported as helpful in dealing with the impacts of COVID-19. Such information and knowledge exchange can reduce information ambiguity, which is a significant problem for businesses during a pandemic or any other major disruption (Gunessee and Subramanian, 2020). The integration of shops and warehouses at various levels—such as central, state and district-level warehouses—is also necessary for maintaining responsiveness to and meeting demand during a pandemic (Singh et al., 2020). Focusing on the example of toilet paper, one study (Paul and Chowdhury, 2020b) suggested horizontal collaboration among similar types of producers at a national level to ensure the supply of necessary products during this crisis(Paul and Chowdhury, 2020b)(Paul and Chowdhury, 2020b). Along with steps taken to bolster relationships, a focus on strengthening contracts is also helpful, to prevent supply chain partners from engaging in opportunistic behaviors in the future (Gupta et al., 2020).

While developing resilience strategies, supply chains need to ensure real-time flexibility, or dynamic responses (Hobbs, 2020; Ivanov and Dolgui, 2020c). Proactive and flexible strategies can help make supply chains less sensitive to external disruptions (Ivanov and Das, 2020). Focusing specifically on low-demand items, Chiaramonti and Maniatis (2020) urged firms to reduce the price of products, this

being a common economic strategy for managing demand reduction. Several strategies for increasing sustainable practices have also been suggested, given the importance of sustainability for supply chain resilience. For example, the implementation of all appropriate safety measures for the workforce can reduce the probability of the spread of COVID-19 and help ensure the continuity of production/operations (Rizou et al., 2020). Moreover, the cancellation of unauthorized subcontractors (Majumdar et al., 2020), the production of renewable and bio-based energy (Chiaramonti and Maniatis, 2020) and the development of automated waste treatment processes (Sharma et al., 2020b) are suggested for the post-COVID-19 era. At the same time, several studies (Choi, 2020a; Kumar et al., 2020; Majumdar et al., 2020) recognized the need for support from stakeholders such as non-government organizations (NGOs) and the government to help organizations handle the impacts of the COVID-19 pandemic; hence, researchers have called for support and subsidy schemes.

In short, developing and implementing a holistic, resilient response plan, which integrates multiple strategies, is crucial—as emphasized in a number of the studies we reviewed (Baveja et al., 2020; Ivanov, 2020b; Jabbour et al., 2020; Leite et al., 2020). In the post-COVID-19 era, a viable supply chain, which is simultaneously agile, resilient, and sustainable, is essential, not just to recover from the current crisis but also to prepare well for the next pandemic or other major disruption (Ivanov, 2020b).

3.4.3 The role of technology in implementing resilience strategies

Researchers have suggested using a number of technologies, such as digital twins, industry 4.0, 3-D printing technology, artificial intelligence and mobile service operation, for managing supply chains during and after COVID-19 pandemic. Thirteen (13) of the papers we reviewed discussed the use of technology in implementing resilience strategies. They focused on low-tech solutions to the problem of obtaining sufficient quantities of medical equipment in healthcare supply chains (Armani et al., 2020); applications of digital supply chains and industry 4.0 (Deshmukh and Haleem, 2020; Ivanov and Dolgui, 2020c; Kumar et al., 2020; Okorie et al., 2020; Quayson et al., 2020); the use of additive manufacturing methods, such as 3-D printing technology, to meet the extra demand for ventilators and personal protective equipment (PPE) (Iyengar et al., 2020; Larrañeta et al., 2020; Novak and Loy, 2020); the use of mobile service operations to bring service directly into people's homes (Choi, 2020a); the use of a drone or hybrid truck-drone for ensuring on-time and contactless delivery (Quayson et al., 2020; Singh et al., 2020); and the use of artificial intelligence for developing sustainable business models (Vaio et al., 2020). Several studies also suggested that modern and emergent technologies may be helpful for managing the impacts of COVID-19, both during and after the pandemic (Gurbuz and Ozkan, 2020; Okorie et al., 2020).

With the supply chains for medical products such as PPE and ventilators being especially critical during the COVID-19 pandemic, researchers have suggested the use of 3-D printing technology, one of the concepts of additive manufacturing, to manufacture products for medical/healthcare supply chains

(Iyengar et al., 2020; Larrañeta et al., 2020; Novak and Loy, 2020). These studies have argued that the use of such technology can help the medical/healthcare supply chains most, given the surge of demand for PPE, ventilators, and other medical equipment during the pandemic. 3-D printing techniques, among other technologies, can help companies design and manufacture those products quickly.

3.4.4 The COVID-19 pandemic and supply chain sustainability

During the COVID-19 pandemic, sustainability practices have been substantially affected. Seventeen (17) of the studies that we reviewed discussed several issues under different dimensions of sustainability. Several of these studies considered environmental and social sustainability along with economic dimensions, including job loss, health and safety issues, the problem of domestic violence, social and health inequality (Hakovirta and Denuwara, 2020; Ibn-Mohammed et al., 2021; Sharma et al., 2020a; Sharma et al., 2020b; van Barneveld et al., 2020), the pandemic's impact on the labor market (van Barneveld et al., 2020), modern slavery risk (Trautrims et al., 2020), the dominant power of a few select brands, ethical violations by organizations (Majumdar et al., 2020), compliance with labor laws and social standards (Sharma et al., 2020c), and the broader social cost of the pandemic (Jabbour et al., 2020; Queiroz et al., 2020).

Several other studies considered issues of environmental sustainability vis-à-vis the current pandemic. These include reversal of the progress that has been made toward embracing green and low-carbon methods of energy generation (Hosseini, 2020); the environmental impact of the life cycle of pharmaceutical products, which has increased during pandemic progress (Yu et al., 2020); the pandemic's impacts on waste flows, resource use and air pollution (Dente and Hashimoto, 2020; Sharma et al., 2020c); the implementation of environmental sustainability policies (Amankwah-Amoah, 2020); the recyclability of end-of-life products (Rahman et al., 2021); and the increase in medical, plastic, and food waste (Sharma et al., 2020b) . Other researchers have suggested that the COVID-19 pandemic will have both positive and negative impacts on environmental sustainability, since both companies and the general population are expected to be more committed to sustainability in the post-COVID-19 era (Dente and Hashimoto, 2020; Sarkis et al., 2020). The positive environmental impacts include better air quality, low carbon dioxide and greenhouse gas emissions, a decline in energy use, and a decrease in environmental pollution (Dente and Hashimoto, 2020; Ibn-Mohammed et al., 2021; Sarkis et al., 2020; van Barneveld et al., 2020). Table 7 indicates how the studies we reviewed have considered different dimensions and issues of supply chain sustainability in the light of the COVID-19 pandemic.

Table 7: Dimensions and issues of sustainability vis-à-vis the COVID-19 pandemic

Reference	Dimension of sustainability		
	Economic issues	Environmental issues	Social issues

Hakovirta and Denuwara (2020)	--	--	Issues in health and safety, domestic violence, job loss, economic inequality
Hosseini (2020)	Decrease in price of gas fuel	Damaging the trend of green energy, damaging the low carbon energy progress	--
Yu et al. (2020)	--	Increase in environmental pollution due to increasing production of pharmaceutical products	--
Dente and Hashimoto (2020)	Increase in storage costs	Reduction in air pollution and energy consumption, increase in household waste, decrease in industrial waste	Increase in social innovation
Sarkis et al. (2020)	Slowdown in economic activity	Reduction in greenhouse-gas emissions and air pollution,	--
Amankwah-Amoah (2020)	--	Offsetting carbon emission footprint, environment-friendly practices	--
Jabbour et al. (2020)	Lack of sharing economy	--	Issues in health and safety
Queiroz et al. (2020)	Increase in supply chain costs	Impacts on climate change	
van Barneveld et al. (2020)	Stock market collapse	Reduction in oil consumption and pollution	Socio-economic inequality, health inequality, increased job loss for women
Trautrims et al. (2020)	--	--	Modern slavery risk, job loss
Majumdar et al. (2020)	--	--	Violation in code of conducts of social compliance, lack of social security
Rahman et al. (2021)	--	Inability to recycle end of life ships, lack of circular economy practices.	--
Sharma et al. (2020b)	--	Increase in medical, plastic and food waste. Increase in single-use plastic bags.	Health and safety issues
Sharma et al. (2020c)	Supply chain practices for cost reduction	Utilization of resource, recycling and waste management	Compliance of labor laws and social standards
Kargar et al. (2020)	How to minimize total cost in supply chain	How to minimize uncollected medical waste. Importance of waste treatment.	--
Ibn-Mohammed et al. (2021)	Global economic shock	Improvement in air quality, reduction in environmental noise, low carbon-di-oxide emission, decline in energy use.	Job loss, socio-economic inequality
Sharma et al. (2020a)	--	Greenhouse gas emission in supply chain	Issues in health and safety of employees across the supply chain

4. Review on prior epidemic outbreaks and disruptions in supply chain disciplines

In this section, we reviewed the articles related to prior epidemic outbreaks and other disruptions in supply chain disciplines, and explored how they might provide unique research opportunities.

4.1 Research on prior epidemic outbreaks

A recent review article (Queiroz et al., 2020) synthesizes the impacts of epidemics—including the COVID-19 pandemic—on logistics and supply chains by reviewing 32 articles. To make our review more streamlined and holistic, we also looked at existing studies on epidemic outbreaks in supply chain disciplines to analyze their main contributions and findings, as well as methodology, industry and country context, and theories used. To find articles, we searched Scopus using the keywords 'epidemics' and 'supply chain management'. Then we read the title, abstract, and full text to select the articles relevant to supply chain disruptions during epidemic outbreaks. Finally, we shortlisted 25 relevant articles, discussing their main finding below and presenting a summary of each article in Table C1 in Appendix C (supplementary material).

The majority of the articles (24 out of 25) focused on the different aspects of supply chain resiliency as strategies for managing disruptions. These articles broadly focus on two major areas: (1) allocating resources to increase supply chain capabilities during large-scale disruptions; and (2) redesigning logistics and supply chain networks to reduce vulnerability. In the first area, articles have highlighted resource shortages as a major obstacle during an epidemic (Enayati and Özaltın, 2020; Liu et al., 2020; Parvin et al., 2018; Rachaniotis et al., 2012; Savachkin and Uribe, 2012; Sun et al., 2014). Consequently, these studies offered various strategies for allocating minimal or further resources, such as controlling transportation costs and equitable policies (Savachkin and Uribe, 2012); undertaking threshold policy for inventory balancing; optimal area-based trans-shipment policy and planning horizon (Parvin et al., 2018); increasing capacity to manage disruptions (Hessel, 2009; Sun et al., 2014); implementing cost-sharing contracts (Mamani et al., 2013) or coordinating contracts (Chick et al., 2008); and appropriate capacity setting and the minimum budget (Liu et al., 2020). These studies mostly looked at the influenza epidemic, while a few were focused on outbreaks of ebola and malaria (Büyüktahtakın et al., 2018). Most of the studies have healthcare and pharmaceutical supply chain as their context.

In the area of redesigning logistics and supply chain networks, several articles studied methods for optimizing such networks. These studies suggested several strategies which include reconfiguration of facility location for food distribution (Ekici et al., 2014); designing/redesigning a distribution and logistics network for minimizing the total cost of vaccine supply, when considering the demand backlogs, vaccine shortage, and losses due to an Influenza outbreak (Hovav and Herbon, 2017; Orenstein and Schaffner, 2008); building isolated areas for animal slaughtering and establishing centrally controlled slaughterhouse facilities (Khokhar et al., 2015); and the use of dynamic logistics concepts for distribution network design, especially for medical products and resources (Liu and Zhang,

2016). One of the studies also suggested the use of flow-down of products to the lowest level in the network, and the permitting of sufficient warm-up to avoid the end of horizon effects for vaccine distribution, to prepare for the potential impacts of an epidemic, (e.g. vaccine shortages, transportation delays, and product losses during distribution, storage, and/or transportation) (Chen et al., 2014). Although not focused on commercial supply chains, Dasaklis et al. (2012) confirmed the importance of logistics operations and their efficient management for handling epidemic disruptions such as polio, smallpox, cholera, and HIV.

Other articles that suggested resilience strategies mainly focused on mitigating the immediate effects of the epidemic. Given that majority of the reviewed articles (16 out of 25) focused on pharmaceutical supply chains, a shortage in product supply was a common obstacle. As a result, these studies highlighted a few strategies to increase immediate product supply. These strategies include the use of emergency sourcing from unaffected parts of the world (Anparasan and Lejeune, 2018; Dasaklis et al., 2012); use of emergency operations and logistics such as new transportation modes (Huff et al., 2015); use of backup suppliers and contract agreement (Shamsi et al., 2018); outsourcing drugs from third parties to improve access, as well as the use of improved ordering policy, lead time, safety stock and replenishment policy (Dasaklis et al., 2012; Paul and Venkateswaran, 2020); and use of piggybacking, enabling satellite drug storage facilities, and removing barriers to local and regional trade (Min, 2012). Studies also considered collaborative strategies, such as the design of coordination mechanisms among stakeholders to manage financial losses and increase product availability (Anparasan and Lejeune, 2018; Mohan et al., 2009), and the use of coordinated supply chains to manage logistics systems more efficiently (Majić et al., 2009). One study suggested training to ensure that staff are capable of handling the immediate impacts of epidemic disruptions and are better equipped to deal with critical infrastructure (Huff et al., 2015).

Several papers discussed the impacts of an epidemic on supply chains; however, we found only one article that mainly focused on the impacts of an influenza outbreak using a literature review-based case study (Alders et al., 2014): it was focused on village poultry production, and listed several impacts of the influenza outbreak, such as adverse effect on employees and increased food insecurity. Several other impacts that were covered in other studies include the shortage of medical items, delays in transportation and distribution, unavailability of skilled manpower, demand backlogs, resource shortage, disruption in the logistics system, market and economic losses, and supply disruptions.

We observed that sixteen articles developed mathematical models. The mathematical models include linear or non-linear programming, integer or mixed-integer programming, game-theoretic modeling, and stochastic programming. Among other articles, four are conceptual studies, two are reviews, and one each used survey, secondary data analysis, and system dynamic model. Concerning the contexts of these studies, diverse national contexts were considered. However, the majority of the articles

considered pharmaceutical/medicinal supply chains. We also noticed that among the twenty-five articles, only one study considered SMEs (Khokhar et al., 2015), and no study used theories for conceptualizing or investigating the problems. Table C1 in Appendix C (supplementary material) presents details about the relevant epidemic outbreaks, findings, methodology, context, and theories used.

4.2 Research on supply chain disruptions

Research on disruption management has received increased attention in the recent past (Bier et al., 2020). With the increase in the numbers of available articles, several studies have also rigorously or systematically reviewed the published literature in this area and summarized the current knowledge. To avoid repetition while comprehensively reporting the state of the literature, we carefully identified and thoroughly reviewed 15 review articles that rigorously synthesize and report the findings of studies published until 2019 (presented in Table D1 in Appendix D under supplementary material). To ensure rigor and comprehensiveness, we also searched Scopus for articles published since 2020 using the keyword 'supply chain disruption', and found and reviewed another 26 articles (presented in Table D2 in Appendix D under supplementary material). The main observations of the review are described as follows.

Several studies investigated the potential types of disruptions in a supply chain, and ranked them in order to understand which disruptions could be the most critical (Fan and Stevenson, 2018; Fartaj et al., 2020; Ho et al., 2015). These studies detailed how various types of disruptions may occur, such as natural disruptions including earthquakes, floods, cyclones, and extreme weather; man-made and discrete events including disease, labor strikes, port/traffic congestion, theft, and fire; system failure including machine or technology breakdown, utility failure, and obsolescence; and financial disruptions including fluctuation of exchange rates and bank interests, and import/export restrictions. While such a wide variety of disruptions have been identified, the literature also suggests that such disruptions are difficult for a supply chain to predict given that they occur suddenly. As such, a recent study suggested adding agility to the data in predicting supply chain disruptions (Brintrup et al., 2020).

Assessments of disruptions show that the relative criticality of disruption depends on the context (both industry and country); because of this, different studies produced different rankings. For example, two recent studies looked at the transportation disruptions of two industries in Bangladesh: one pharmaceutical (Paul et al., 2020) and the other automotive (Fartaj et al., 2020). Several disruption assessment tools have been developed to support practitioners (Snyder et al., 2016), as it has been found they tend to underestimate disruptions if proper assessment tools are not available (Tang, 2006). While several studies assessing the disruption factors can be found in various contexts, these studies mostly identified or assessed disruption factors for a particular area/activity in a supply chain such as supply, demand, production, or transportation (Fartaj et al., 2020). However, thus far, research identifying or

investigating supply chain network-wide disruptions (i.e., assessing all disruptions simultaneously across various areas in a supply chain) is limited (Baryannis et al., 2019; Greening and Rutherford, 2011). For example, a recent review (Duong and Chong, 2020) reported that 64.9 percent of studies reviewed consider either supply disruptions or demand disruptions.

Several studies investigated and reported the impacts of supply chain disruptions (Ivanov et al., 2017), since Hendricks and Singhal (2003) confirmed a decrease in shareholder value, Hendricks and Singhal (2005a) reported a decrease in stockholder return, and Hendricks and Singhal (2005b) reported a decline in operating income, return on asset, and return on sales due to supply chain disruptions. These studies have confirmed the negative impacts of supply chain disruptions on several financial and non-financial performance indicators including, but not limited to, financial performance, supply chain performance, productivity, brand value, and reputation (Bier et al., 2020; Duong and Chong, 2020; Greening and Rutherford, 2011; Paul et al., 2016). However, the impacts of disruptions on supply chains differ based on differences in the network structures such as density, centrality, network tie, and structural holes (Greening and Rutherford, 2011). Moreover, disruptions cause structural dynamics leading to a ripple effect in the supply chain (Bier et al., 2020; Duong and Chong, 2020; Ivanov et al., 2017; Xu et al., 2020b). This ripple effect intensified with the complexity of supply chains (Birkie and Trucco, 2020). Given that majority of the studies in this area investigated disruptions in each area/function of a supply chain in isolation, it is still not clear how disruptions in one area are propagated to another in a supply chain (Ho et al., 2015; Snyder et al., 2016). A recent study, comparing the impacts of disruptions in the upstream and downstream part of supply chains, reports that the latter has more impacts on supply chain performance than the former (Olivares-Aguila and ElMaraghy, 2020).

The formulation of appropriate strategies for managing disruptions such as supply, demand, production, and transportation disruptions was the main focus of a vast number of studies (Albertzeth et al., 2020; Wu et al., 2020). These strategies include supply chain planning for disruptions, response plans for minimizing impacts, and action plans for quick recovery.

As a preparedness plan, various supply chain and logistics network design-oriented strategies such as network redesign (Fattahi et al., 2020; Fattahi and Govindan, 2020; Tolooie et al., 2020), optimal network design (Yan and Ji, 2020), supply chain flexibility (Shekarian et al., 2020), and careful selection of facility locations (Sundarakani et al., 2020) are suggested. A recent systematic review article examines various logistics and supply chain network types, such as hub-and-spoke, cross-docking, pick-up and delivery, and hybrid network design and evaluates their effectiveness for disruption management (Esmizadeh and Parast, 2020). While each network has its advantages, the hub-and-spoke network with flexibility (also known as routing flexibility) was more effective for disruption management. The research and development (R&D) investments are also important for identifying and preparing for potential disruptions (Parast, 2020). In particular, upstream supply disruptions formalized

processes for supplier selections, lot sizing, and scheduling (Mohammadi, 2020) along with optimum inventory level (Islam et al., 2020). For downstream demand disruptions, demand planning is effective as it can reduce the disruptions in the downstream supply chain via proactive strategies (Swierczek, 2020). Moreover, supply chain coordination is critical for managing demand disruptions (Zhao et al., 2020). To enhance supply chain coordination with the downstream supply chain members, a linear quantity discount contract is more effective than a revenue-sharing contract (Zhao et al., 2020).

Strategies are also developed for reducing impacts and quick recovery when supply chains experience a disruption (Birkie and Trucco, 2020). Four strategies such as collaboration, redundancy, flexibility and agility are the main suggestions for managing disruptions (Shekarian and Parast, 2020). Among these four, various collaboration practices are frequently suggested in the literature and are considered the most appropriate strategy for managing disruptions (Shekarian and Parast, 2020; Wu et al., 2020). A recent review (Duong and Chong, 2020) identified seven collaboration practices that were used by commercial supply chains for responding and recovering from supply chain disruptions: (i) contractual and economics practices; (ii) joint practices; (iii) relationship management; (iv) technological and information sharing practices; (v) governance practices; (vi) assessment practices; and (vii) supply chain design (integrated operations). The necessity of ensuring visibility in supply chains through gathering, processing, and sharing information among the partners is highlighted in the disruption management literature (Messina et al., 2020; Tao et al., 2020). Having timely information about second-tier suppliers from immediate suppliers is also important for disruption management (Yoon et al., 2020).

Other redundancy strategies typically considered for disruption management include inventory or capacity buffers, backup suppliers, flexibility strategies such as dual or multiple sourcing, and product and process flexibility (Albertzeth et al., 2020; Choi, 2020b; Gaur et al., 2020; Ivanov et al., 2017). While redundancy strategies are suggested more frequently than flexible strategies (Ivanov et al., 2017), the latter is applicable across various types of supply chains (Gaur et al., 2020; Tao et al., 2020). For example, flexibility in the procurement plan by considering sourcing, pricing, consumption, and delivery pattern is effective for managing the impacts of disruption in cruise ship supply chains (Rodrigue and Wang, 2020). Ensuring agility –the ability to respond rapidly to disruptions by quickly modifying product development cycle time, lead time, and customer services – is also suggested in the literature. In fact, the ability to respond rapidly (agility) is more effective than long-term or fundamental changes (flexibility) in reducing the effect of a disruption (Shekarian et al., 2020). Due to the sudden nature of disruptions, risk acceptance (Albertzeth et al., 2020) and risk transfer such as undertaking insurance are also suggested (Fan and Stevenson, 2018).

With such strategies in place and supply chains' involvement in business continuity management (Azadegan et al., 2020b) and relevant business continuity programs (Azadegan et al., 2020a), supply chains can contain the damage of disruptions. However, in formulating the strategies, these studies

mostly ignored complexity in supply chain network structures and investigated disruptions and network structure separately; hence, the disruption-structure-interfaces remain unclear (Bier et al., 2020). Similar to disruption identification, assessment, and impact analysis, strategies were developed by considering disruptions in only one area of supply chains (Duong and Chong, 2020; Paul et al., 2016). As such, firms use different strategies to manage supply, demand, and production during a major disruption (Tang, 2006; Tang and Musa, 2011). Of the disruptions in various areas of supply chains, demand disruptions received the greatest attention for strategy development (Shekarian and Parast, 2020). This may be because demand disruptions have greater impacts or are more closely linked to revenue than other disruptions (Olivares-Aguila and ElMaraghy, 2020).

One of the common observations in almost all of the literature review articles is that studies on supply chain disruptions predominantly used a quantitative modeling approach (Baryannis et al., 2019; Bier et al., 2020; Duong and Chong, 2020). The quantitative modeling approach includes mathematical, simulation, and analytical modeling. Looking at the high amount of research using quantitative modeling or management science models, the main focus of four review articles (Fahimnia et al., 2015; Ivanov et al., 2017; Paul et al., 2016; Snyder et al., 2016) was to synthesize the quantitative models used for managing supply chain disruptions. These studies suggested that there has been rapid development of quantitative modeling for supply chain disruptions and these models are used widely for a variety of purposes such as evaluating disruptions, developing strategic decisions under disruptions, and assessing various disruption management strategies (including recovery strategies). However, these studies mostly considered single disruption, i.e., supply or demand or production or transportation, compared to dual or multiple disruptions when designing recovery models (Paul et al., 2016).

5. Research opportunities

The analysis of the articles reveals abundant opportunities for research on the COVID-19 pandemic in the context of supply chains. While several articles have been published since the COVID-19 pandemic began, studies that are systematic, methodologically sound, and well-grounded in theoretical tenets are still scarce. Based on the thematic synthesis of the articles provided in Section 3 and considering existing literature on prior epidemic outbreaks and other disruptions in supply chain management disciplines, in this section, we suggest some key areas that still need to be investigated. Table 8 highlights key future research questions and opportunities in different areas.

Table 8: Summary of research questions and opportunities

Theme of the studies	Research questions and opportunities	Other suggestions for future research
Impacts of the COVID-19	a) What are the potential short-term, medium-term, and long-term impacts of the COVID-19 pandemic on a particular supply	**Methodology:**

pandemic on supply chains	chain (e.g., the supply chain for high-demand or low-demand items)? b) How do the impacts of the COVID-19 pandemic differ for various supply chains based on the differences in network structures and complexity? c) How are the various impacts of the COVID-19 pandemic interconnected (e.g., which impacts are in the cause group and which impacts are in the effect group)? d) How are the COVID-19 disruptions in one area of a supply chain propagated throughout the chain? e) How and to what extent may short-term demand mismatch with reduced production capacity influence the bullwhip effect in the supply chain? f) How did the COVID-19 pandemic affect SME supply chains? g) What contextual factors influence the impacts of the COVID-19 pandemic, and how?	Use of empirical methods by collecting real-world data **Context:** a) Use of diverse contexts b) Comparative analysis of countries with different socio-economical contexts **Theory:** a) Use of theory in the: • Conceptualization of the research • Design, measurement, and analysis of the studies • Discussion of the findings b) Building new theory on pandemic disruption management, leveraging the existing theories
Resilience strategies for managing impacts and recovery	a) What combination of strategies is most appropriate for enhancing resiliency during and post-COVID-19 era? b) Which resilience strategies can best handle which impacts? c) How can supply chains for low-demand items minimize the impacts during a pandemic like COVID-19? How can they recover in the post-pandemic era? d) How does the level of complexity in supply chain network structures affect the optimal resilience strategies for managing the impacts of the COVID-19 pandemic? e) What are the challenges in implementing resilient strategies (e.g., re-shoring, back-shoring, and near-shoring) during and post-COVID-19 era? How can supply chains overcome such challenges? f) How does the restructuring of logistics and supply chain networks affect global supply chains? g) How can various stakeholders (e.g., governments, NGOs, firms, and supply chain partners) support the implementation of resilience strategies? How can supply chains collaborate with various stakeholders to achieve such support? h) What logistics and supply chain network types are most suitable during a global disruption like COVID-19? i) What collaboration strategies are most suitable during a global disruption like COVID-19? j) How can supply chains be safeguarded if the current demand mismatch causes the bullwhip effect? k) How can the social networks of various supply chain players (e.g., networks of transportation providers or truckers) contribute to achieving supply chain resilience? l) To what extent do the global supply chains need to customize their resilience strategies for a quick recovery, and how should they do so? m) How can supply chains effectively monitor and utilize pre-warning signals to reduce the impacts of a pandemic like COVID-19? n) How can SMEs respond to and recover from the effects of COVID-19? o) How can SMEs enhance their supply chain resiliency and be better prepared to tackle a pandemic like COVID-19? p) What supply chain resilience strategies used by large firms can SMEs adapt to improve their resiliency?	
Role of technology for	a) How can emergent technologies support various supply chains (e.g., supply chains of high demand and low demand items) to manage the impacts of the COVID-19 pandemic and improve responsiveness?	

implementing strategies	b) To what extent can 3-D printing support manufacturing and maintaining the supply of medical, healthcare, and essential products during a pandemic? c) How can emerging technologies support last-mile delivery during a global pandemic to achieve greater responsiveness and reliability? d) How can drones be integrated with other transportation modes to ensure on-time delivery while maintaining social distancing? What would be the potential challenges and strategies in this regard? e) How can omni-channel be used effectively by retailers to improve responsiveness and customer experience during a pandemic? f) How can the emergent technologies mitigate the challenges that complex supply chain networks face in formulating resilience strategies during a pandemic like COVID-19?	
Supply chain sustainability and the COVID-19 pandemic	a) How are sustainable practices in various supply chains affected by the COVID-19 pandemic? b) To what extent, if any, has the stakeholder pressure, focus and support for implementing stringent sustainable practices changed during the current COVID-19 pandemic? c) How can sustainable practices contribute to or impact the supply chain performance during a global disruption like COVID-19? d) How can sustainable practices minimize the impacts of global disruption, like COVID-19, and enhance resiliency? e) How can closed-loop supply chains or circular economy contribute to managing the higher level of waste created during a pandemic like COVID-19?	

5.1 Impact focus

Several studies have discussed, as reported in Section 3.4.1, the impacts of the COVID-19 pandemic on supply chains. Earlier research on epidemic outbreaks and other disruptions also reported several impacts on the operations in supply chains. However, no study thus far comprehensively explored all the potential short-term, medium-term, and long-term impacts of disruptions, including COVID-19 pandemic or other epidemics, on a particular supply chain (whether a supply chain for a high-demand or a low-demand item) to guide policymakers in this regard. Given that the impacts of a pandemic like COVID-19 are different for different types of products (Paul and Chowdhury, 2020b), future studies should explore these impacts by considering various product types. Prior studies on disruptions indicate that the impacts of disruption are likely to vary due to differences in network complexity, such as the number of nodes and edge (ties), network characteristics such as high vs low density and network ties, and structural holes (Bier et al., 2020). Therefore, the impacts of the COVID-19 pandemic should be explored with consideration for the complexity in the network structures. Reviewing the literature on COVID-19 pandemic, epidemics and other disruptions, we observe that there is a lack of articles investigating supply chain network-wide impacts, considering all potential disruptions simultaneously (Baryannis et al., 2019; Duong and Chong, 2020; Greening and Rutherford, 2011). As such, the complex relationships between the impacts of the COVID-19 pandemic and how disruptions propagated throughout the supply chain is not yet clear (Xu et al., 2020b) and should be investigated. Investigating the relationships between the impacts, such as revealing the cause group and effect group, would also

enable understanding of the most critical impacts; this would provide information to aid prioritization of the resilience strategies.

The literature on epidemic outbreaks and COVID-19 pandemic suggest that the sudden spikes in demand and reduction of production capacity are likely to cause a huge bullwhip effect for supply chains (Ivanov and Dolgui, 2020b). Hence, we suggest research questions on this issue to better understand these impacts. The research also should be carried out to investigate the impacts on SMEs as the previous studies in this area mostly ignored SMEs. For example, our review of 25 studies on epidemics and 26 studies on other disruptions published in 2020 shows that only one article in each category has considered SMEs along with large firms. Likewise, we found that only four studies thus far have discussed the implications of the COVID-19 pandemic on SMEs. Yet small firms are the companies that have been most substantially impacted by this pandemic (Quayson et al., 2020). Another study (Ketchen and Craighead, 2020) stressed that it is hard to conceptualize the full impacts on SMEs without proper investigation. Hence, further studies are needed to understand the effect of the COVID-19 pandemic on SMEs, which are the most common type of business in the world and the main contributor to economies worldwide (Chowdhury et al., 2019).

5.2 Resilience focus

As noted in Section 3.4.2, studies have also outlined several resilience strategies designed to deal with the impacts of the COVID-19 pandemic. Some of the resilience strategies we found in Section 3.4.2 are also suggested in previous studies on epidemic outbreaks or other supply chain disruptions. For example, resource allocation, restructuring supply chains, and developing collaboration and relationships are suggested in the research on COVID-19, other epidemics, or supply chain disruptions. This denotes that some of the existing strategies to improve supply chain resilience can be useful during a global crisis like the current pandemic. However, it is also clear that the current COVID-19 pandemic has severely impacted almost all supply chains, highlighting the vulnerability of supply chains and requiring better resilience strategies. Therefore, further investigations are needed to understand the extent and how the strategies provided in previous studies helped supply chains handle issues related to COVID-19 and the best combination of strategies to deal with the impacts of the pandemic. Hence, by considering the findings and strategies suggested in studies on epidemics and other disruptions, we suggest several research questions that need to be explored to develop better resilience strategies for managing the impacts.

We noticed that most articles on disruptions only investigate one strategy in their studies (Snyder et al., 2016). However, a single strategy may not be able to safeguard supply chains from all impacts of a pandemic and ensure a quick recovery. Hence, selecting an optimal combination of strategies that can ensure better resilience is important and should be explored. In this regard, future studies should map impacts using the strategies, i.e., outline which strategy can deal most effectively with which impact. A

study of this sort can help policymakers to formulate a recovery plan. Our analysis of the studies on COVID-19 revealed that most of the studies focus on high-demand essential and medical products, as reported in Section 3.3.2. A similar observation is also noted from the review of studies on prior epidemic outbreaks, as discussed in Section 4.1. Low-demand items, such as textiles, oil, and automobiles, are bearing the brunt of this pandemic as sales of these products—and thus cash inflow and profit—have decreased substantially (Majumdar et al., 2020). Given that customized strategies are needed by firms in various industries (Ishida, 2020), future studies exploring how supply chains for these low-demand items can survive during this pandemic, and recover in the post-COVID-19 era, are needed. As complexity-disruption-interfaces are not explored in the previous studies, we also suggest considering this in future studies on designing resilience strategies.

Future studies should also explore the challenges and requirements associated with implementing resilience strategies. For example, a number of studies of both COVID-19 pandemic and other epidemics suggest restructuring of logistics and supply chains by using techniques such as nearshoring, re-shoring, and back-shoring (Deaton & Deaton, 2020; van Barneveld et al., 2020). None of the articles, however, discussed the specific challenges to relocating production facilities in this manner, or what kinds of capabilities are required to do so. Restructuring supply chains along with implementing short supply chains will potentially affect the global supply chain. For example, current popular sourcing destinations and associated logistics networks will be affected by the restructuring, hence this issue should also be explored. It is also important to explore the role of various stakeholders, such as government policymakers, NGOs, firms, and supply chain partners, in implementing strategies for creating resilience. Exploring the roles of stakeholders in implementing such strategies would guide not only practitioners but also national policymakers when it comes time to formulate the necessary strategies. For example, to re-shore the production of medicines, a country may need to develop internal capabilities for supplying active pharmaceutical ingredients as well as required skillsets for the workforce. To develop such capabilities, active support from the government and policymakers is needed, and future studies should consider the mechanisms that might be used to obtain such support. Those studies should also explore how supply chains can collaborate with governments and policymakers to implement the needed strategies. Two previous literature reviews on supply chain disruptions identify the types of logistics and supply chain networks (Esmizadeh and Parast, 2020) and collaboration practices (Duong and Chong, 2020). It would be insightful if further studies could explore which of the logistics and supply chain networks and collaboration practices are most suitable during a large-scale global disruption like the COVID-19 pandemic.

Moreover, future studies should investigate how supply chains can be safeguarded if the current demand mismatch causes the bullwhip effect mentioned previously. In line with a recent study (Lemke et al., 2020), we also suggest exploring the role of social networks of various supply chain players, such as transportation providers or truckers, in achieving supply chain resilience. Previous studies on

epidemic outbreaks and other disruptions suggest that flexibility and agility in resilience strategies (e.g., being able to customize the plan quickly) is critical for achieving a quick recovery. This should be further explored to better understand the extent that the plant should be customized during a pandemic and how to achieve that. During COVID-19, it seems that supply chains were not able to utilize the pre-warning signals to minimize the potential impacts, although several reports warned supply chains at the beginning. This suggests that a more robust disruption monitoring framework is needed. Indeed, disruption monitoring is received the least attention in the supply chain disruption literature (Fan and Stevenson, 2018; Ho et al., 2015). We suggest further research on SMEs to improve their resilience and understand which large firm resilience strategies SMEs can adapt.

5.3 Technology focus

In the literature on the COVID-19 pandemic, as reported in Section 3.4.3, several studies suggested that technologies such as 3-D printing, digital supply chains, and industry 4.0 be used to manage the impacts of the COVID-19 pandemic. These studies argue that such technologies can help the healthcare supply chain immediately ramp up the production of PPE, ventilators, and other needed items. In the long term, investigation of the use of other emergent technologies such as blockchain, AI, the Internet of things (IoT), data analytics, robotics, and so on could help improve supply chain resiliency and sustainability. Such investigations would enable us to understand how technologies and data analytics help manage pandemic disruptions (Choi, 2021). Investigating the applicability and benefits of using emergent technology to manage the impacts of the COVID-19 pandemic is, we suggest, an important research topic. The previous research on epidemics in commercial supply chains has not focused on the use of emergent technologies in the recovery process. Moreover, two recent literature reviews on supply chain disruptions (Baryannis et al., 2019; Xu et al., 2020b) highlighted that studies investigating the use of recent and emerging technologies for managing disruption and ensuring resilience are particularly rare. As a result, how the supply chain can use technologies for flexibility and rapid response remains unclear.

We noticed that 3-D printing is suggested for producing and maintaining the supply of essential medical items. It would be insightful to investigate to what extent 3-D printing can support in this regard. We noticed a lack of research investigating how the disruptive and sophisticated technologies can help in the last mile of delivery associated with supply chains during a pandemic or epidemic; hence, future studies should investigate how the technologies can be used to manage such last-mile delivery during a pandemic to achieve greater responsiveness and reliability. A specific potential research area is the use of drones or drone integration with other transportation modes to ensure the supply of essential products while maintaining social distancing. Moreover, future studies can investigate the use of omni-channels by retailers to improve responsiveness during a pandemic or other crisis. Finally, future studies can

explore the roles of technologies in overcoming the challenges that complex supply chain networks face in formulating and implementing resilience strategies during a pandemic.

5.4 Sustainability focus

As reported in Section 3.4.4, studies have reported that the focus on sustainability practices has reduced during the current COVID-19 pandemic. It is worthwhile to investigate the underlying reasons behind such reduction of focus. We suggest the impacts on sustainable practices during the current COVID-19 pandemic should be explored rigorously to understand how disruptions impact sustainability. This is an area that is not explored well in previous studies on epidemics or general supply chain disruptions. Therefore, future studies could explore the changes in stakeholder pressure, focus and support for sustainable practices. Moreover, no study investigated the relationships between sustainable supply chain strategies and supply chain performance during a pandemic or epidemic disruption. Therefore, it would be valuable to analyze the impact of practising sustainable strategies on firms' performance and resiliency, so as to manage more effectively the impacts of large-scale disruptions like the COVID-19 pandemic. A number of studies have reported that a higher level of waste has been created during the COVID-19 pandemic as the distribution systems of perishable and other products have been heavily affected. As such, we suggest exploring how the circular economy concept or closed-loop supply chain contribute to waste management during a pandemic like COVID-19.

5.5 Other aspects

In our analysis, as reported in Section 3.1, we found that only six out of 74 studies used empirical methods to collect and analyze data, while many articles (31) were based on researchers' opinions, as given via perspective pieces, commentary, and discussion papers. Meanwhile, another 27 articles used quantitative modeling without using any empirical data. The lack of empirical focus is a concern reported in almost all the reviews on supply chain disruptions or epidemic outbreaks (Esmizadeh and Parast, 2020; Greening and Rutherford, 2011; Ho et al., 2015; Shekarian and Parast, 2020; Tang and Musa, 2011), which is also reported in our findings in Section 4. Opinion-based and quantitative studies with simulated data can provide valuable information at the start of an unprecedented crisis like the current pandemic. Still, it is now time to go one step further and conduct rigorous studies using empirical data to demonstrate real-world scenarios of how the COVID-19 pandemic impacts various issues related to supply chains, and how such impacts can be managed using the evidence of the practices that real-world supply chains have adopted. Research with evidence-based empirical data can strengthen the overall acceptability of the strategies proposed in those articles. In this regard, researchers can use both exploratory empirical methods, such as case studies, focus groups, and the Delphi technique, as well as empirically-based quantitative methods, such as survey-based modeling. It should also be pointed out that none of the six studies that employed empirical methods used inferential statistics to analyze the

data. As such, we urge researchers to use inferential statistics such as regression and structural equation modeling to analyze the causal relationships among the various factors, i.e., resilience strategies and firm performance. In this way, future research can improve the generalizability of the relevant findings.

We acknowledge that the studies reviewed here have considered diverse geographical locations, as reported in Section 3.2.1. Having said that, some of them just take the context as an example, without collecting any primary empirical data, as mentioned before. Therefore, we suggest diversifying the range of national and industry contexts considered in future work. The review of supply chain disruptions in Section 4.2 also suggests that the impacts of disruptions vary in different contexts. We also suggest conducting comparative studies of developed and developing countries. Such studies can provide valuable information about whether the impacts of this pandemic vary in different contexts, where organizational and technological set-ups are different. This would also enable us to understand how contextual factors influence the impacts of COVID-19 pandemic.

Finally, we found that only five studies, as reported in Section 3.3, used theoretical tenets as the basis for the research reported. The lack of theory in the research is another concern reported in previous literature on epidemic disruptions (Queiroz et al., 2020) and other supply chain disruptions (Majumdar et al., 2020). In our review, we noticed that only six studies on supply chain disruptions were published in 2020 and none of the studies on epidemics applied a theory. In line with the suggestions of recent studies (Craighead et al., 2020; Ketchen and Craighead, 2020; Queiroz et al., 2020), we call for more studies grounded in theory. It is important to ensure that arguments and analyses fit with the lenses of theory; in this way, studies can enhance the theoretical base and lead to new theory building in the field of disruption management. We, therefore, suggest that researchers should use theory more deliberately in conceptualizing, designing their studies and in discussing the results.

6. Conclusions

In this review, we have systematically identified and critically analyzed 74 articles that addressed supply chain issues arising from COVID-19. Moreover, we have reviewed the studies on prior epidemic outbreaks and disruptions in supply chain disciplines to make the findings comprehensive and provide unique and impactful research opportunities. Our analysis reveals that the main focus of the published articles relates to the impacts of this pandemic along with creating resilience strategies to manage those impacts. We observed that high-demand essential items and medical products received the highest attention and that most of the published articles are opinion-based, lack an empirical focus, and are not grounded in theory. Overall, we believe our efforts will help researchers and practitioners obtain an overview of the existing literature on pandemic management in the supply chain, identify areas that require further investigation, and guide their future research.

This is the first study, to the best of our knowledge, which systematically identifies and analyzes the existing research in the area of COVID-19 pandemic and supply chains. This study contributes to the literature in several ways. First, we synthesized the findings of the reviewed studies by grouping them into four main themes impacts of the COVID-19 pandemic on supply chains, strategies for dealing with those impacts, the role of technology in implementing such strategies for resilience, and sustainable practices during this pandemic. The synthesis reports what we already know in the area of COVID-19 and supply chains. Second, the study categorizes the impacts of the COVID-19 pandemic to demonstrate how various supply-chain-related issues, such as demand, production, sourcing, transportation and logistics, relationships, performance, and sustainability have been affected. This aspect of the article promises to illuminate the impacts of COVID-19 on supply chains. Third, we reported how each of the suggested strategies can help in achieving the three main dimensions of supply chain resilience: namely, preparedness, response, and recovery. In this way, we attempt to improve understandings of the strategies in question, i.e., which strategy is useful for which dimension, and provide a guide for future studies in this area. Fourth, in addition to summarizing what we know about COVID-19 and supply chains, we summarized how we know (methodology), and in which contexts the knowledge applies. These findings can help shape decisions about methodology and context in future work. Fifth, focusing on an issue that has not been discussed in most of the previous systematic literature reviews in the area of supply chain risk and disruption management (Fan and Stevenson, 2018), we considered the theories used by the researchers whose studies we reviewed. Sixth, we reviewed the literature on disruptions and prior epidemic outbreaks in supply chain disciplines to comprehensively report the findings and provide unique research opportunities. Finally, we identified research gaps in the domain of inquiry and suggested unique research questions and opportunities for impactful future research to fill those gaps.

While the research thus contributes substantially to this area of inquiry, it also has some limitations. First, we considered only journal articles published on or before 28 September 2020, and only those written in English. Thus, book chapters, books, conference papers, and unpublished works were not considered in this research. As a result, the summary provided in this research may not reflect complete knowledge on the topic. Second, we used Scopus, Web of Science, and Google Scholar to search for articles, but did not search for relevant studies via the websites maintained by individual publishers such as Emerald and Elsevier. We may also have missed some other articles that were not included in the databases that we did use. Finally, we conducted our study by focusing on the academic point of view, without involving practitioners in our research.

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Appendix A: Descriptive analysis of selected articles

Table A1: Articles by author's affiliated country (N>=2)

Name of the country	Number of articles
United States	19
United Kingdom	15
India	12
Germany	9
Australia	6
France	6
China	5
Italy	4
Canada	3
Brazil	2
Greece	2
Hong Kong	2
Iran	2
Japan	2
Netherlands	2
Philippines	2
Singapore	2

Table A2: Articles by author affiliation (N>=2)

Name of the Affiliation	Number of articles
Berlin School of Economics and Law	8
IMT Atlantique	4
Indian Institute of Technology Delhi	3
Arizona State University	2
Indian Institute of Technology Kharagpur	2
CNRS Centre National de la Recherche Scientifique	2
Hong Kong Polytechnic University	2
University of Kent	2
RMIT University	2
Auburn University	2
University of Nottingham	2
University of Saskatchewan	2
National Institute of Industrial Engineering	2
University of Technology Sydney	2
De La Salle University-Manila	2
Laboratoire des Sciences du Numérique de Nantes	2
Kent Business School	2

Table A3: Articles by name of the author (N>=2)

Author's name	Number of articles
Ivanov, D.	8
Dolgui, A.	4
Choi, T.M.	2
Chowdhury, P.	2
Craighead, C.W.	2
Ketchen, D.J.	2
Paul, S.K.	2

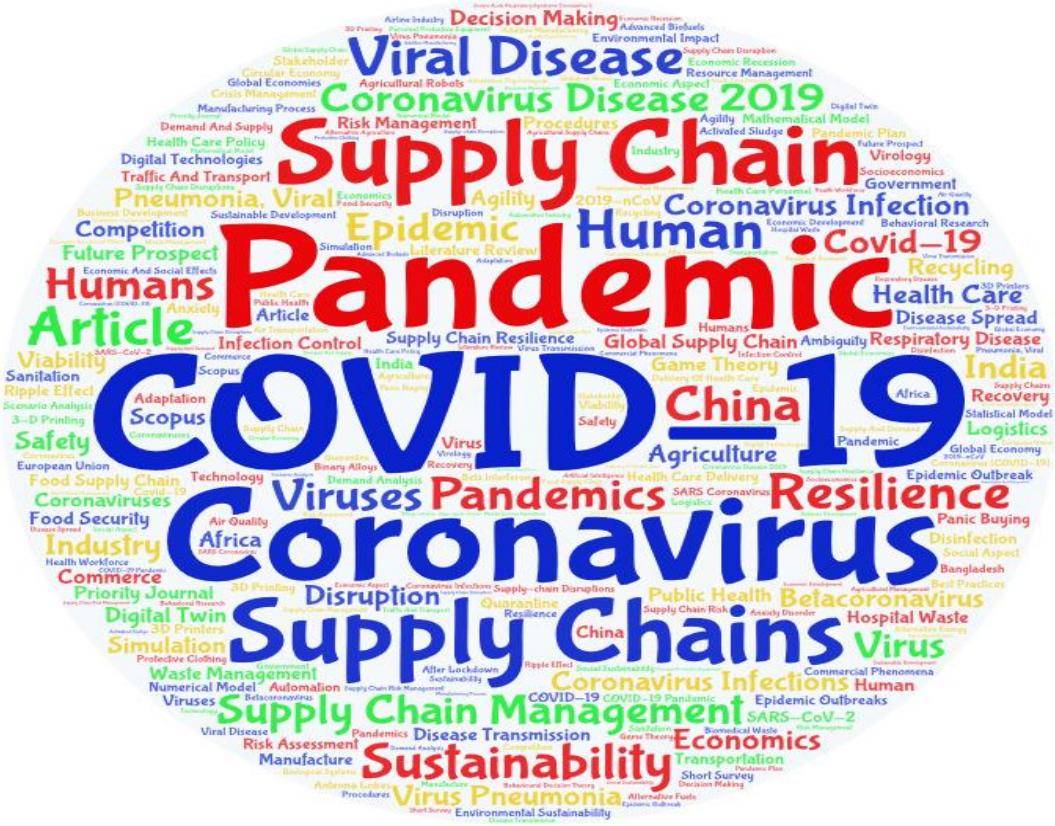

Fig. A1. Word art for the keywords used in the analyzed articles

Appendix B: Description of the reviewed articles

Table B1: Description of the 74 articles reviewed on COVID-19 pandemic in supply chain disciplines

Sl.	Reference	Research description	Themes of the study	Methods	Industry context	Country context	Focused on SMEs (Yes/No)	Theory used
1	Abhishek et al. (2020)	Discussed how disruptions can be mitigated in food supply chains during this global incident and suggested that the movement of necessary goods and safety of laborers are effective strategies.	Reported impact and suggested resilience strategies	Commentary	Food	India	No	---
2	Armani et al. (2020)	Discussed the use of low-tech solutions for medical equipment. Suggested that they will have a real impact in times of global crisis and the manufacturing community also can play a major role in this.	Discussed the role of technology in managing crisis	Perspective	Healthcare	---	No	---
3	Baveja, Kapoor, and Melamed (2020)	Discussed how the pandemic can be managed and suggested a "Shutting-down Transmission of Pandemic (STOP COVID-19 plan)" to be implemented in four stages for 90 days to reduce COVID-19's impact.	Discussed impact and proposed resilience strategies	Perspective	Service	---	No	Theory of constraints
4	Cappelli and Cini (2020)	Discussed the relevance of short food supply chains during COVID-19 and suggested that short supply chains and local production can help maintain food access.	Discussed impact and proposed resilience strategies	Perspective	Food	---	No	---
5	Chiaramonti and Maniatis (2020)	Discussed the consequences of the COVID-19 pandemic in the transport fuel sector and suggested that, while the low oil price is good in the short term, Renewable and Recycled Carbon Fuels (RRCF) should be considered in the long term as a primary energy supply.	Discussed impact and proposed resilience strategies	Perspective	Oil	---	No	---
6	Craighead, Ketchen, and Darby (2020)	Reported issues related to various aspects of the supply chain to assist practitioners to better prepare for future pandemics. Suggested ways the key tenets of various theories can enlighten understanding, obstacles, and prospective solutions.	Discussed impact and suggested how theories can help to formulate resilience strategies	Analytical review	---	---	Yes (discussed both SME and large industry)	Resource dependence theory, institutional theory, resource orchestration theory, structural inertia, game theory, real

								options theory, event systems theory, awareness-motivation–capability framework, prospect theory, and tournament theory
7	Deaton and Deaton (2020)	Discussed the pandemic's impact on the security of Canadian food supply chains and suggested three ongoing considerations to ensure food availability in the long term: a balance of local and international trade, support from the government to ease the capital flow, and maintenance of transportation.	Discussed impact and proposed resilience strategies	Perspective	Food	Canada	No	---
8	Golan, Jernegan, and Linkov (2020)	Reviewed supply chain resilience literature and noted that specific disruption scenarios are considered when developing and testing resilience models but the uncertainty associated with unknown disruptions remains rare. Hence, a resilience model capable of managing global disruptions like COVID-19 is needed.	Reviewed supply chain resilience modelling and quantification	Systematic literature review	---	---	No	---
9	Govindan, Mina, and Alavi (2020)	Analyzed demand management in the healthcare supply chain during COVID-19 and proposed a decision support system that classifies community members into different groups based on their risk levels and suggests different regulations for them to follow. Demonstrated the effectiveness of the proposed strategies using a case study.	Discussed impacts and demand management in healthcare	Analytical model (Fuzzy inference system)	Healthcare	---	No	---
10	Gray (2020)	Reported how transportation disruptions due to COVID-19 could impact agricultural supply chains in Canada and made recommendations for policymakers and government agencies.	Reported impact and suggested resilience strategies	Secondary data analysis	Food	Canada	No	---
11	Guan et al. (2020)	Analyzed the impacts of COVID-19 on supply chains by using the latest global trade modeling framework and suggested that supply-chain losses during the pandemic depend on the number of countries imposing restriction measures. Suggested that such economic losses are more sensitive to the duration of the restriction measures rather than the strictness.	Analyzed impact of different lockdown scenarios	Analytical model (extended version of Adaptive Regional Input-	Electronics and automobile	China and Germany	No	---

				Output (ARIO) Model)				
12	Gupta et al. (2020)	Analyzed whether pricing for substitute products is impacted by the timing of supply chain disruptions and suggested that order quantity from disrupted suppliers is determined based on price leadership. As the non-disrupted supplier imposes a higher price for an emergency order, the order quantity increases when non-disrupted suppliers play the role of price leader.	Analyzed impact and proposed resilience strategies	Mathematical model (game-theoretic model)	---	---	No	---
13	Hakovirta and Denuwara (2020)	Discussed sustainability during COVID-19 and reported that while animal species are threatened, social issues (e.g., domestic violence) have grown sharply. They proposed that human health should be treated as the fourth pillar/dimension of global sustainability.	Reported impact and discussed sustainability issues	Perspective	---	---	No	---
14	Hosseini (2020)	Discussed the impact of COVID-19 on the renewable and sustainable energy sector and suggested energy and climate policies may need restructuring to handle a global pandemic. Also suggested governments should offer beneficial stimulus to private sectors and society to encourage them to invest in renewables.	Discussed the impact on the renewable and sustainable energy sector and proposed strategies for sustainability	Perspective	---	---	No	---
15	Ivanov (2020a)	Assessed the effects of COVID-19 on the global supply chain and suggested that the timing of closures and reopenings dictate the impact, rather than the duration of disruption or the speed of the propagation of the pandemic.	Analyzed the impact of the pandemic on the global supply chain	Simulation	---	---	No	---
16	Ivanov (2020b)	Theorized regarding Viable Supply Chain (VSC) by integrating the angles of sustainability and resilience strategies. Suggested that the VSC model is likely to be beneficial to decision-makers for adapting to positive changes, absorbing negative disturbances, and recovering and surviving during disruptions.	Discussed viability from the perspective of resilience and sustainability	Simulation	---	---	No	Information control and communication theory
17	Ivanov and Dolgui (2020a)	Theorized the concept of digital supply chain twin (i.e., a computerized model to represent network states in real-time). Discussed the conditions related to the design and implementation of these digital twins while managing disruptions and suggested that the digital twin concept can help manage COVID-19 by ensuring visibility in the supply chain network.	Discussed impact of the pandemic, suggested resilience strategies, and mentioned the role of technology in this regard	Simulation (anyLogistix software)	---	---	No	Dynamic system theory

18	Ivanov and Dolgui (2020c)	Theorized the concept of Intertwined Supply Network (ISN) and proposed its integrity and viability for ensuring supply chain resistance to an extraordinary disruption like COVID-19.	Discussed impact and proposed resilience strategies	Mathematical model (dynamic game-theory model)	---	---	No	---
19	Iyengar et al. (2020)	Critically analyzed the role and supply of ventilators during COVID-19 and investigated the use of applied innovative technologies in increasing the supply of ventilators. Reported a substantial shortage of ventilators and highlighted the impact of innovative technologies in solving the deficiency crisis.	Discussed impact of COVID-19 pandemic, proposed resilience strategies, and the role of technology to address this	Literature review	Healthcare	---	No	---
20	Lozano-Diez, Marmolejo-Saucedo, and Rodriguez-Aguilar (2020)	Discussed the public sector drug supply procedure, analyzed the impact of COVID-19 pandemic on drug supply, proposed a resilient supply chain model using optimization techniques to manage high demand, and suggested that quick reactions can be achieved with efficient, robust, flexible designs.	Discussed impact of COVID-19 in healthcare and proposed resilience strategies	Mathematical model and simulation (mixed-integer linear modelling and anyLogistix software)	Healthcare	Mexico	No	---
21	Mehrotra et al. (2020)	Investigated allocation, reallocation of ventilators, and estimated shortfall. Suggested that resource sharing can improve supply chain efficiency and a central agency can coordinate the sharing of critical resources.	Analyzed impact and proposed resilience strategies	Mathematical model (stochastic programming and optimization)	Healthcare	United States	No	---
22	Reardon et al. (2020)	Discussed how COVID-19 affects food supply chains (FSCs) in India. Indicated that the entire food supply chain and its components (e.g., farms, downstream and upstream supply) will be impacted and suggested two different strategies for the government: i) implement robust public health measures to slow the spread of disease; and (ii) address food security, especially its impact on income and employment.	Discussed the impact of the pandemic on the food supply chain and suggested resilience strategies	Perspective	Food	India	Yes	---

23	van Hoek (2020)	Provided guidelines for reducing the gap between research initiatives in supply chain resilience and current resilience practices in the industry. Suggested that the current response plan and readiness are inadequate, and the supply chain needs to be more resilient.	Reported impact and resilience strategies	Case study	Transportation, equipment, retail, fast moving consumer goods, food, apparel and technology	---	No	---
24	Richards and Rickard (2020)	Discussed the effects of COVID-19 on the food supply chain (fruits and vegetables) and suggested that short- and long-term effects that should be observed. The short-term effects will be caused by consumers preferring to obtain food through retail channels as service outlets close, which will result in supply chain realignment for fresh produce. The long-term effects will be observed in input markets (e.g., labor) and changes in industry structure.	Reported impact on fruit and vegetable market and proposed resilience strategies	Secondary data analysis	Food	Canada	No	---
25	Paul and Chowdhury (2020a)	Analyzed COVID-19's influence on high demand and shortage of supply in manufacturing supply chains. Developed a production recovery model, which can play a significant role in recovering the impacts for high-demand items.	Analyzed impact and proposed resilience strategies	Mathematical model (constrained non-linear mathematical programming)	---	---	No	---
26	Rowan and Laffey (2020)	Reported shortages of personal protective equipment (PPE) and proposed solutions to address these shortages in a regional Irish hospital. Recommended that communication lines should be improved to manage PPE stock more effectively, the use of websites and mobile applications, and the use of medical-grade materials in the production of customized PPE.	Discussed impact on healthcare essential items and proposed resilience strategies	Perspective	Healthcare	Ireland	No	---
27	Shokrani et al. (2020)	Discussed the redesign of medical face shields and suggested that domestic and distributed manufacturing will help reduce the supply shortage.	Reported impact and proposed resilience strategies	Perspective	Healthcare	---	No	---
28	Siche (2020)	Discussed the impact of COVID-19 on agriculture and predicated a significant impact on agriculture and food supply chains globally. Suggested that the largest impact would be on food demand and	Reported the impact on agriculture	Secondary data analysis	Food	---	No	---

		consequently food security, and it will have a greater impact on the most vulnerable populations.						
29	van Barneveld et al. (2020)	Discussed economic and labor market impact. Suggested that COVID-19 will create health inequalities and will impact diverse groups of people, such as people from First Nations or developing countries, women, permanent residents, and younger generations.	Reported impact, and proposed strategies for resilience and sustainability	Discussion	---	Australia	No	---
30	Yu, Razon, and Tan (2020)	Discussed sustainability issues related to pharmaceutical supply chains during COVID-19 and suggested that a supply chain system-wide perspective is needed to address sustainability issues in rapid production scale-up.	Reported strategies for sustainability	Perspective	Healthcare	---	No	---
31	Yu and Aviso (2020)	Reported the impact of COVID-19 on global supply chains and provided a roadmap to evaluate vulnerability. Suggested that well-developed economic models in conjunction with epidemiological models and network analysis techniques will generate comparatively realistic assessments and help to select an effective strategy.	Discussed the impact of disease outbreaks	Perspective	---	---	No	---
32	Yuen et al. (2020)	Discussed impact of the pandemic on consumers and synthesized the psychological causes of panic buying in four categories: i) individuals' perception of the threat and scarcity of products; ii) fear of the unknown resulting from negative emotions and uncertainty; iii) coping behavior, to relieve anxiety and regain control; and iv) social psychological factors.	Reported impact of the pandemic on panic buying	Systematic literature review	Retail	---	No	---
33	Dente and Hashimoto (2020)	Discussed the viability of current supply chains and highlighted the impacts of COVID-19 on resources, waste flows, and stock. Suggested that effects can be better understood using analytical tools (e.g., material flow analysis, life-cycle assessment, network analysis, and input-output analysis).	Reported impact, and sustainability issues	Perspective	---	---	No	---
34	Deshmukh and Haleem (2020)	Discussed a framework to re-align the manufacturing industry after the pandemic in India and suggested that traditional manufacturing facilities need to integrate industry 4.0 and automation in their manufacturing processes.	Discussed the role of technology in managing crisis	Discussion	Healthcare	India	No	---
35	Novak and Loy (2020)	Analyzed the use of 3D printing to respond to COVID-19. Highlighted that the majority (60%) of current projects use 3D printing for PPE, with printed face shields accounting for 62%.	Discussed the role of technology in managing crisis	Secondary data analysis	---	---	No	---

		Recommended that policymakers integrate 3D printing into response plans for better management.						
36	Sarkis et al. (2020)	Discussed the need for a sustainable supply and production chain. Provided future research directions for moving towards sustainable supply and demand in the post-COVID-19 era.	Reported strategies for Sustainability	Perspective	---	---	No	---
37	Jabbour et al. (2020)	Discussed important areas that will require immediate attention from supply chain managers in the post-pandemic era. Provided some recommendations for researchers and practitioners to help address supply chain management challenges.	Reported impact, and proposed strategies for resilience and sustainability	Perspective	---	---	No	---
38	Queiroz et al. (2020)	Systematically analyzed COVID-19's effect on supply chains using a structured literature review. Indicated that influenza was the most significant outbreak covered in the literature and therefore optimization techniques for resource allocation and distribution received considerable attention from researchers.	Reported impact and proposed strategies for resilience and sustainability	Systematic literature review	---	---	No	Dynamic capabilities, contingency theory, organizational information processing theory, game theory, simulation theory, and queuing theory
39	Ivanov and Das (2020)	Analyzed the ripple effect of COVID-19 in global supply chains, caused by the rapid spread of the outbreak causing declined demand, market disruption, and production and distribution disruption. Proposed strategies for risk mitigation in the supply chain along with a guideline for future researchers to re-design the global supply chain.	Analyzed impact and proposed resilience strategies	Simulation	---	Global supply chain - China, Brazil, Germany, USA	No	---
40	Paul and Chowdhury (2020b)	Analyzed the disruptions caused by COVID-19 and proposed strategies to improve service levels. Suggested that manufacturers need to work together to share resources during emergencies and concentrate on providing products with basic quality to help more customers, rather than producing premium products.	Analyzed impact and proposed resilience strategies	Analytical model (mathematical equations)	Manufacturing	---	No	---

41	Choi (2020a)	Analyzed how static services can be brought to customers using mobile service operations by incorporating logistics and technology. Suggested that this will be an effective strategy to mitigate service disruptions and governments should provide appropriate support to service providers to achieve this.	Reported impact, proposed resilience strategies, and discussed the role of technology in this regard	Analytical model	---	Hong Kong	No	---
42	Trautrims et al. (2020)	Discussed the effect of COVID-19 on the threat of modern slavery in the supply chain and highlighted that a dynamic, value-driven, long-term management approach will help to achieve a sustainable supply chain.	Reported impact and proposed strategies for sustainability	Discussion	---	---	No	---
43	Sharma et al. (2020a)	Offered strategic insights about issues firms are facing and strategic options they are contemplating. Indicated that firms are facing demand-supply mismatch, difficulties in technology, developing resilient supply chains, and constructing sustainable supply chains.	Discussed impact and proposed resilience strategies	Secondary data analysis	---	United States	No	---
44	Rizou et al. (2020)	Reported about foods and food supply chains as possible COVID-19 transmission vectors and suggested that more safety measures should be undertaken, as many people are involved in food supply chains. Suggested a bioanalytical protocol should be developed to adapt in the process.	Discussed impact and suggested resilience strategies	Literature review	Food	---	No	---
45	Farias and Araújo (2020)	Discussed the likely impact of COVID-19 on food supply chains and suggested that the price of food depends on the regions where the transaction took place as well as when the trading occurred. Highlighted the need for short supply chains to ensure food security.	Reported impact on food supply in distribution centers and proposed resilience strategies	Secondary data analysis	Food	Brazil	No	---
46	Hobbs (2020)	Discussed an early estimate of the impact of COVID-19 on food supply chains, indicating that demand-side surprises, supply-side disturbances, and long-lasting consequences have occurred. Suggested measures to improve resilience through tactical inventory management plans and dynamic procurement strategies.	Discussed impact and resilience strategies	Perspective	Food	Canada	No	---
47	Lemke et al. (2020)	Discussed the role of commercial drivers' network in supply chain resilience and recommended network-centered prevention strategies and collection of detailed data in this regard.	Reported resilience strategies	Perspective	---	United States	No	---

48	Larrañeta, Dominguez-Robles, and Lamprou (2020)	Discussed the importance of 3-D printing to mitigate the impacts of COVID-19. Mentioned how 3D printing can be utilized in this scenario to support the supply chain and suggested that all safety regulations should be followed when the printed items are used in a hospital environment.	Reported impact of COVID-19 pandemic and highlighted the role of technology	Perspective	---	---	No	---
49	Amankwah-Amoah (2020)	Discussed current challenges faced by the global airline sector to implement environmentally sustainable practices amid COVID-19. Suggested that several airlines and industries also tried to sideline environmentally sustainable obligations and activities when faced with issues including cost increases, survival risks, and de-prioritization of measures for achieving a sustainable environment.	Reported Sustainability strategies	Perspective	Airline	---	No	---
50	Majumdar, Shaw, and Sinha (2020)	Discussed the reasons for a lack of measures aimed at achieving a socially sustainable supply chain in the South Asian apparel industry and suggested the following measures to address this: i) stakeholders (e.g., manufacturers, suppliers, businesses, and NGOs) should work together to address lack of social security in this sector; ii) a new procurement model needs to be employed to guarantee social safety benefits for employees; iii) use of a permanent workforce should be encouraged rather than delegating to subcontractors.	Reported impact and proposed strategies for resilience and sustainability	Case study	Clothing/Apparel	South Asian countries	No	---
51	Kumar et al. (2020)	Discussed the difficulties of providing effective services experienced by retailers. Provided a pathway to mitigate the effect of the pandemic by incorporating Industry 4.0, which is expected to play an important role, and suggested that supply chain partners and governments need to make strategic decisions to improve the quality of service.	Reported impact of COVID-19 outbreak, discussed resilience, and the role of technology in this regard	Literature review	Healthcare	---	No	---
52	Veselovská (2020)	Reported disruptions and changes in supply chains due to COVID-19 and suggested changes in operating volumes, new market development, and new supply chain partnerships as the main strategies to ensure resilience.	Discussed resilience strategies	Survey (descriptive statistics)	Service, production, transportation, construction, agriculture, and grocery	Central European countries (Poland, Hungary, the Czech Republic, and Slovakia)	No	---

53	Leite, Lindsay, and Kumar (2020)	Reported the effect of COVID-19 on healthcare systems' demand, resources, and capacity. Suggested management strategies such as collaboration for supply, building temporary capacity and eliminating non-essential operation for capacity, rescheduling, reorganizing current staff, and hiring students and retirees.	Discussed impact and proposed resilience strategies	Viewpoint	Healthcare	---	No	---
54	Quayson et al. (2020)	Discussed the impact of COVID-19 on a food supply chain and proposed strategies to achieve SC resilience in the post-pandemic era through digital transformation. Highlighted some challenges related to digital inclusion: i) collaboration between existing platforms with emerging technologies, and ii) the responsibilities of different stakeholders and organizations in this transformation process.	Discussed impact of COVID-19 pandemic and proposed resilience strategies and the role of technology in this regard	Opinion	Food	Ghana	Yes	---
55	Nikolopoulos et al. (2020)	Used secondary data to predict infection growth rates and supply chain disruptions. Indicated that during the early stages of the pandemic the demand for groceries and electronic products increased while the demand for fashion and automotive products decreased.	Discussed impact of COVID-19 pandemic on supply chain	Secondary data analysis	---	India, the United States, Germany, Singapore, and the United Kingdom	No	---
56	Okorie et al. (2020)	Discussed the barriers and enablers of manufacturing resilience in the wake of a pandemic. Provided some recommendations, such as the redesign of the manufacturing toolbox, building organizational flexibility, and the use of digital technology and rapid decision-making to ensure manufacturing capabilities and operations during the pandemic and post-pandemic era.	Reported impact of COVID-19 outbreak and discussed resilience strategies and the role of technology in this regard	Survey (descriptive statistics)	---	Brazil, India, the United Kingdom, the United States, China, Nigeria, Estonia, Greece, Mexico, and Hungary	No	---

57	Rahman, Kim, and Laratte (2020)	Reported the effect of COVID-19 on the ship recycling industry and suggested that 300 million Gross Tonnage of ships will be available for demolition in the next five years, costing 20 billion dollars if it is not possible to recycle.	Discussed impact on ship breaking industry and proposed strategies for sustainability	Analytical model (Weibull distribution)	Shipbreaking	South Asian countries	No	---
58	Sharma et al. (2020b)	Assessed the obstacles, possibilities, and innovations for waste management before and after COVID-19. Indicated that the amount of biomedical, plastic, and food waste has increased during the outbreak and recommended the use of an automatic waste treatment process to address this.	Reported impact and proposed strategies for resilience and sustainability	Secondary data analysis	Food and Healthcare	---	No	---
59	Sharma et al. (2020c)	Identified and analyzed factors to enhance the survivability of a sustainable supply chain and suggested that supply chain network viability is the main factor in this regard.	Reported strategies for sustainability	MCDM method (SWARA method)	---	---	No	---
60	Singh et al. (2020)	Analyzed the effects of COVID-19 on the food supply chain and suggested that backup facilities and integration of warehouses have a positive influence in this regard.	Analyzed impact and proposed resilience strategies	Simulation	Food	India	No	---
61	Xu et al. (2020a)	Discussed the impacts of COVID-19 on the global supply chain (GSC). Highlighted that the pandemic has adversely affected GSCs and caused major turbulence in manufacturing, processing, transport, and logistics, and suggested that supply chain resilience will be the key driver to reduce vulnerabilities.	Reported impact and resilience strategies	Perspective	Healthcare, food, clothing, retail, automobile, airline, and high tech	North American, South, and Central American, European, and Asian countries	No	---
62	Zhu, Chou, and Tsai (2020)	Discussed the relationship between supply chain operations and the COVID-19 pandemic. Suggested that there will be significant negative impacts on the medical supply chain and mitigation strategies that can help to reduce the loss.	Reported impact and resilience strategies	Perspective	Healthcare	---	No	---
63	Zhu and Krikke (2020)	Analyzed the effects of COVID-19 on perishable food supply chains and suggested that information that can trigger endogenous demand is harmful to the whole supply chain and should be stopped.	Discussed impact and proposed resilience strategies	Simulation	Food	---	No	---

64	Ivanov and Dolgui (2020b)	Discussed state-of-the-art and future research directions considering the ripple impact of COVID-19. Suggested that adaptation strategies and capabilities will play a major in managing these supply chain disruptions.	Reported impact on the pandemic context	Literature review	---	---	No	Mentioned operational research (OR) theories such as agent-based Simulation, Bayesian networks, complexity theory, discrete-event simulation, entropy analysis, graph theory, linear/mixed-integer programming, Markov chains, Monte-Carlo simulation, optimal control, Petri nets, reliability theory, robust optimization, statistical analysis, stochastic optimization, and systems dynamics.
65	Mollenkopf, Ozanne, and Stolze (2020)	Discussed the role of the supply chain ecosystem in maintaining the health and welfare of workers and consumers. Established a baseline for further study in this area using transformative lenses.	Reported impact and resilience strategies	Conceptual	---	---	No	Service dominant logic paradigm
66	Ketchen and Craighead (2020)	Discussed research avenues at the intersection of entrepreneurship, supply chain management, and strategic management. Suggested	Reported impact of COVID-19 pandemic	Commentary	---	---	Yes	Resource orchestration theory

		that research findings utilizing concepts from multiple fields provide better guidance than those grounded in a specific field.						
67	Derevyankina and Yankovskaya (2020)	Analyzed the impact of COVID-19 on supply chain management and identified impacts such as low sales, impairment of assets, cash flow, and more waste.	Reported impact of COVID-19	Secondary data analysis	---	Russia	No	---
68	Gurbuz and Ozkan (2020)	Discussed a business model for the supply chain post-COVID-19 and suggested that automation is inevitable in the post-pandemic world. Noted that technologies, such as IoT and blockchain, are expected to play an effective role in increasing input production, quality, and savings.	Reported impact and discussed resilience strategies and the role of technology	Survey (descriptive statistics)	Food	Turkey	Yes	---
69	Ishida (2020)	Discussed the distribution management strategies of the product supply chain post-pandemic and suggested that the automobile industry is transitioning to a centralized management approach, the personal computer industry is focusing on both local suppliers and global supply chains, and the home furnishing industry requires closer vertical integration.	Discussed impact and resilience strategies	Discussion	Automobile, personal computer, and home furnishing	---	No	---
70	Vaio et al. (2020)	Discussed the role of artificial intelligence (AI) in the agri-food supply chain and suggested that businesses, especially in the agri-food industry, are likely to benefit from the use of such AI-based technologies.	Discussed the role of technology in the agri-food system	Structured literature review	Food	---	No	---
71	Gunessee and Subramanian (2020)	Conceptualized ambiguity and discussed the role of ambiguity-coping mechanisms in the operations management context. Suggested that visibility and collaboration help to cope with ambiguous events.	Reported impact and resilience strategies	Conceptual	---	---	No	Behavioral decision theory
72	Handfield, Graham, and Burns (2020)	Discussed how the pandemic will impact the design of future global supply chains and suggested that resilience strategies that can ensure contingency and leanness are most effective.	Reported impact and resilience strategies	Case study	Automobile and earth-moving equipment	The United States and the United Kingdom	No	---
73	Ibn-Mohammed et al. (2021)	Reported negative and positive impacts of the pandemic on global economy and ecosystems. Provided perspectives to steer towards a more resilient low-carbon economy.	Discussed impact and proposed strategies for	Literature review	Aviation and tourism	---	No	---

			resilience and sustainability					
74	Kargar, Pourmehdi, and Paydar (2020)	Discussed medical waste management and developed a reverse logistics network model for efficient waste management to minimize the cost and risks related to transportation and treatment of infectious medical waste and uncollected waste.	Discussed strategies for sustainability	Mathematical model (Revised Multi- Choice Goal Programming (RMCGP))	Healthcare	Iran	No	---

Appendix C: Studies on prior epidemic outbreaks in supply chain disciplines

Table C1: Summary of the studies on prior epidemic outbreaks in supply chain disciplines.

Reference	Name of epidemic and year and location of the outbreak	Research description	The focus of the study	Methods	Industry context	Country context	Focused on SMEs (Yes/No)	Theory used
Anparasan and Lejeune (2018)	Cholera (2010, Haiti)	Investigated the cholera outbreak in Haiti following the 2010 earthquake and developed a multi-period supply chain response model considering time-series patient data to assist emergency health response, allocate medical resources and staff, and design coordination mechanisms among stakeholders.	Developed recovery strategies	Mathematical model (integer linear programming)	Healthcare supply chain	Haiti	No	No
Alders et al. (2014)	Influenza (1997, Hong Kong)	Discussed the impacts of HPAI H5N1 in village poultry production and relevant mitigation strategies.	Reported impact of HPAI H5N1 influenza pandemic	Review-Case study	Village poultry production	No	No	No
Chen et al. (2014)	General	Analyzed vaccine distribution issues and developed a mathematical model for vaccine distribution in the developing countries of the world.	Developed a distribution network	Mathematical model (constrained mathematical programming)	--	Niger, Thailand, and Vietnam	No	No
Dasaklis et al. (2012)	Polio, smallpox, cholera, and HIV	Critically reviewed the role of logistics operations to tackle epidemic outbreaks. Suggested that there have been limited research efforts on supply chain activities in the aftermath of an epidemic.	Discussed resilience strategies	Literature Review	--	No	No	No
Hovav and Herbon (2017)	Influenza (1997, Hong Kong)	Developed a distribution network for minimizing the total cost of the influenza vaccine supply and suggested that the developed model is very efficient for tackling the epidemic outbreak with limited resources.	Developed a distribution network	Mathematical model (mixed-integer programming)	Pharmaceutical supply chain	Israeli Health Services	No	No
Huff et al. (2015)	Ebola (2014 West African Ebola)	Discussed the impact of the Ebola virus outbreak on the USA's food system and suggested that if a pandemic causes a 25 % reduction in labor availability, it is likely to create significant and widespread food shortages.	Developed a resilience strategy	System dynamics model	Food supply chain	USA	No	No

Min (2012)	Malaria (Africa, 21st century)	Discussed the lack of accessibility to anti-malarial drugs and proposed a comprehensive map to improve access while minimizing disruption in supply.	Reported recovery strategy	Conceptual	Healthcare logistics	Sub-Saharan African countries	No	No
Mohan et al. (2009)	Avian influenza (1997, Hong Kong)	Discussed potential risk factors related to the avian influenza pandemic and proposed mitigation strategies in the poultry supply chain.	Proposed resilience strategies	Conceptual	Poultry supply chain	India	No	No
Rachaniotis et al. (2012)	Influenza A (2009 USA)	Proposed a deterministic model to manage limited resources during a pandemic. Suggested that the proposed model can minimize the forecast error and improve supply chain performance.	Proposed resource allocation model	Mathematical model (constrained non-linear mathematical programming)	--	Attica region and Greece	No	No
Liu and Zhang (2016)	Influenza (1997, Hong Kong)	Developed a dynamic logistics model for resource allocation (particularly for medical resources) and distribution network design to control the influenza outbreak. Suggested that the proposed model can control the epidemic outbreak in a centralized system.	Developed a distribution network	Mathematical model (mixed-integer mathematical programming)	Medical resources	No	No	No
Mamani et al. (2013)	Influenza (1997, Hong Kong)	Discussed vaccine production shortfall and developed a model to analyze vaccine allocation inefficiency and contractual mechanisms in the supply chain.	Proposed resource allocation model	Mathematical model (game-theoretic model)	Healthcare supply chain	No	No	No
Büyüktahtakın et al. (2018)	Ebola (2014, West African Ebola)	Analyzed resource allocation issues during the Ebola virus outbreak. Proposed a mathematical model to minimize the number of infections and fatalities under limited resources.	Proposed resource allocation model	Mathematical model (mixed-integer programming)	--	West Africa	No	No
Majić et al. (2009)	Influenza (1997, Hong Kong)	Discussed the airport infrastructure and logistics procedures in the airports in Croatia for handling dangerous goods transportation and suggested that activities related to this should comply with international regulations.	Explored resilience strategies	Survey	Pharmaceutical supply chain	Croatia	No	No
Liu et al. (2020)	Influenza (1997, Hong Kong)	Developed a modified epidemic-logistics model to control the influenza epidemic in China. Suggested that the model efficiently controlled the outbreak by offering appropriate capacity-setting with limited resources.	Proposed resource allocation model	Mathematical model (mixed-integer non-linear programming)	Healthcare supply chain	Jiangsu Province, China	No	No

Sun et al. (2014)	Influenza (1997, Hong Kong)	Developed a network model to allocate resources and patients, considering the cost for patients to access hospital services. Suggested that the model shows that decision-makers can optimally allocate the additional resources.	Analyzed resource and patient allocation	Mathematical model (multi-objective constrained mathematical programming)	Healthcare supply chain	Metro Louisville, Kentucky	No	No
Khokhar et al. (2015)	Influenza (2013, china)	Investigated the distribution channels of the poultry meat supply chain in China and suggested how small/medium scale producers can be integrated into the supply chain to respond to a pandemic.	Analyzed distribution channels	Secondary data	Poultry meat supply chain	China	Yes	No
Hessel (2009)	Influenza (1997, Hong Kong)	Discussed the challenges of vaccine supply chain planning, production, and distribution. Proposed key success factors for ensuring vaccine availability, with special consideration for distributing vaccines within a short time.	Discussed resilience strategies	Conceptual	Vaccine supply chain	No	No	No
Orenstein and Schaffner (2008)	Influenza (1997, Hong Kong)	Discussed issues related to influenza vaccine production, distribution, and management, focusing on lessons learned from the influenza epidemic. Suggested that influenza vaccines should also be offered beyond the typical vaccination season.	Discussed resilience strategies	Conceptual	Drug supply chain	No	No	No
Shamsi et al. (2018)	Cholera (1991–1994 outbreak in South America)	Developed a model to minimize the social and procurement cost for vaccine supply targeting an epidemic outbreak via contract agreement. Suggested that policy-maker decisions are likely to be influenced by the season in which the disaster occurs.	Developed resilience strategies	Mathematical model (non-linear mathematical programming)	Pharmaceutical supply chain	Iran	No	No
Parvin et al. (2018)	Malaria (Africa, 21st century)	Analyzed drug distribution for the malaria epidemic and proposed a methodology considering strategic and tactical aspects of a three-tier health system.	Analyzed resource allocation model	Mathematical model (stochastic programming)	Pharmaceutical supply chain	Malawi	No	No
Savachkin and Uribe (2012)	Influenza (1997, Hong Kong)	Investigated distribution of pharmaceutical products and proposed a mathematical model to distribute the vaccine and antiviral drugs by generating dynamic strategies over a network of regional outbreaks.	Analyzed resource allocation model	Mathematical model (constrained mathematical programming)	Pharmaceutical supply chain	Florida, USA	No	No
Ekici et al. (2014)	Influenza (1997, Hong Kong)	Analyzed food distribution in the context of an influenza pandemic and developed a mathematical model considering facility location and resource allocation.	Analyzed resource allocation and developed	Mathematical model (mixed-	Food distribution	Georgia	No	No

			network design	integer linear programming)				
Enayati and Özaltın (2020)	Influenza (1957, Asian flu)	Developed an optimization model to allocate vaccines efficiently during an epidemic outbreak. Suggested that the model can efficiently control an outbreak.	Analyzed resource allocation model	Mathematical model (constrained mathematical programming)	Pharmaceutical supply chain	Asian countries	No	No
Chick et al. (2008)	Influenza (1997, Hong Kong)	Proposed a mathematical model for vaccine supply considering two actors: manufacturers and governments. Suggested that the model can trade-off the costs of delivering the vaccine.	Analyzed resource allocation model	Mathematical model (game-theoretic model)	Pharmaceutical supply chain	No	No	No
Paul and Venkateswaran (2020)	General	Investigated policies for mitigating pandemics and developed two models for this purpose: i) supply shortage of medicine and ii) integrated model.	Developed recovery strategies	Mathematical model (Exploratory Modelling and Analysis approach)	Drug supply chain	No	No	No

Appendix D: Summary of studies in the area of supply chain disruptions

Table D1: Summary of review articles published in the area of supply chain disruptions

Reference	The main focus of the review	Timings of the articles	Main observations
Baryannis et al. (2019)	Reviewed 276 papers regarding AI methodology in supply chain risk and disruption management.	1978 to 2018	• Only a handful of papers applied big data-based techniques in supply chain risk and disruption management. • Mathematical modelling techniques are mostly used in supply chain risk and disruption management. • There is a lack of holistic approaches that simultaneously identify and assess the disruptions and provide response strategies.
Bier et al. (2020)	Provided an overview of methods currently used for supply chain disruption mitigation.	Up to 2018	• Disruption management received increased attention in the recent past. • Quantitative methods were most popular (88.32 percent) in the reviewed articles. • Disruption and network structure were investigated separately; hence, future research needed on the risk-structure-interface.
Duong and Chong (2020)	Discussed the usefulness of collaboration in responding and recovering supply chain disruptions.	2000 to 2019	• Seven collaboration practices are used by the commercial supply chains: (i) contractual and economics practices; (ii) joint practices; (iii) relationship management; (iv) technological and information sharing practices; (v) governance practices; (vi) assessment practices; and (vii) supply chain design (integrated operations). • Observed a lack of empirical research. The majority (86.92 percent) of research used either mathematical modelling or simulation. Hence, it is unclear how firms collaborate to manage disruptions. • Observed lack of articles investigating supply chain network-wide disruptions (considering all potential disruption simultaneously). The majority of the papers (64.9 percent) investigated supply disruption or demand disruption separately.
Esmizadeh and Parast (2020)	Evaluated logistics network design.	2000 to 2018	• Each network has different advantages and is appropriate in particular situations. Therefore, a hybrid logistics model was suggested. • The hub-and-spoke network with flexibility (known as routing flexibility) more effectively minimizes the impacts of disruptions. • The majority of the articles used mathematical modeling; only 7 percent were empirical. • The study in the post disruption period was limited.
Fahimnia et al. (2015)	Reviewed papers on mathematical, optimization, and simulation modelling in supply chain risk management.	1978 to 2013	• There is rapid development in quantitative modeling in supply chain risk management. • Further research can be conducted on the applications of theories and conceptual models in supply chain disruption management.

Fan and Stevenson (2018)	Provided an overview of studies on supply chain risk management.	2000 to 2016	• Risk transfer (e.g., insurance) is more appropriate for managing supply chain disruptions as such disruptions have low probability but high impact. • Very limited studies on supply chain disruptions use (apply, test, or build) theory.
Greening and Rutherford (2011)	Provided an overview of disruptions in the supply network.	Not Found	• Lack of research considering supply chain network-wide disruptions. • Lack of empirical research on supply chain disruptions. • Provided several propositions by considering supply chain network structures such as density, centrality, structural holes, and types of ties.
Ho et al. (2015)	Provided a synthesis of supply chain risk (both micro and disruption) management literature.	2003 to 2013	• Each type of disruption is considered in isolation. It is not clear how disruption in one function is propagated to another in a supply chain. • Disruption mitigation strategies are proposed but not effectively assessed to conclude their effectiveness. • The literature on macro risk such as disruptions is scarce compared to micro (own managerial problems). • Studies on risk monitoring and using empirical data are limited.
Ivanov et al. (2017)	Provided disruption recovery measures.	Not found	• Typically considered redundancies include capacity, buffers, and backup suppliers while flexibility strategies include dual or multiple sourcing and product or process flexibility. However, redundancy measures are most prevalent. • Organizational behavior for formulating recovery strategies is not well explored. • Various mathematical models such as optimization, simulation, and control science are widely used in disruption recovery strategies.
Paul et al. (2016)	Reviewed papers focusing on mathematical models and solution approaches used in managing risk and disruption in supply chains.	Not found	• Operations research models have mostly been developed for disruption recovery models. • Search algorithms, heuristics, and simulation approaches are used to solve the models. • There is a lack of research that considers multiple disruption factors when developing disruption recovery plans. • There is a lack of real-life case studies to judge the applicability of the developed models.
Shekarian and Parast (2020)	Assessed the usefulness of various strategies for managing supply chain disruptions.	2000 to 2017	• Flexibility, collaboration, agility, and redundancy are the most frequently discussed strategies for managing disruptions. • Collaboration is identified as the most appropriate strategy for controlling disruptions. • Modeling, simulation, and conceptual methods are dominant while there is a lack of empirical research. • Most of the articles investigated demand disruptions.
Snyder et al. (2016)	Reviewed OR/MS models used in supply chain disruptions.	Not found	• OR/MS models are used to investigate various disruption issues (e.g., evaluating disruptions, sourcing, and strategic decisions) and assess various disruption management strategies. • The majority of the articles considered one strategy. • Studies on multi-echelon systems, i.e. how risk propagates throughout a supply chain, are scarce.

Tang (2006)	Provided an overview of the literature on supply chain risks.	Not found	• Firms underestimate the disruptions if proper assessment tools are not available. Again, assessment is hard due to a lack of data. • Firms use different resilience strategies to manage supply, demand, and product during a major disruption. • Research on disruption risk compared to operational risk (own managerial problems) is lacking.
Tang and Musa (2011)	Provided an overview of the literature on supply chain risks.	1995 to 2009	• Strategies for disruption management vary based on the types of risks, e.g., supply disruption, demand disruption, political disruptions, and natural disasters. • Research considering industrial practices is lacking.
Xu et al. (2020b)	Conducted bibliometric analysis based on 1,310 publications in the area of supply chain disruptions.	Up to 2019	• There is an improvement in the application of emerging technologies (such as big data analysis, digital technology, Industry 4.0, and blockchain) for managing disruptions and building resiliency in the supply chain. • How to use technologies for Flexible mechanisms and rapid response to disruption is still not clear. • Current research mainly uses quantitative modeling. • Need for further investigation into the complex relationships of the disruption factors and ripple effects in the supply chain due to disruption.

Table D2: Summary of articles on supply chain disruptions published since 2020

Reference	Research description	Focus of the study	Industry context	Country context	Methods	Theory used	Focused on SMEs (Yes/No)
Albertzeth et al. (2020)	Addressed disruption issues in the transportation of goods and explored four strategies: risk acceptance, redundant stock, flexibility, and redundant-flexibility strategy.	Explored strategies for transportation disruption	---	---	Simulation	---	No
Azadegan, Parast et al. (2020)	Discussed the usefulness of business continuity programs for improving company performance. Suggested that they are effective for containing the damage to supply chain disruptions.	Explored strategies for impact	Manufacturing (Diverse)	Italy	Survey (SEM)	Structural contingency theory and organizational information processing theory	No
Azadegan, Syed, et al. (2020)	Assessed the effectiveness of business continuity management and supply chain involvement in business continuity planning. Suggested that they are effective for containing the damage to supply chain disruptions	Investigated strategies for impact	Manufacturing (Diverse)	Europe (Germany, Sweden, and Switzerland)	Survey (Regression)	Control framework	No
Birkie and Trucco (2020)	Investigated the influence of supply chain complexity and suggested that it increases the ripple effect of disruptions. Noted that resilience capabilities are important to mitigate the impact of disruption.	Investigated strategies for impact	Diverse	---	Secondary data analysis (PLS-SEM)	---	No
Brintrup et al. (2020)	Analyzed risk prediction and suggested that adding agility to the data can predict the supply chain disruption.	Investigated risk prediction	---	---	Analytical model (experiment)	---	No
Choi (2020b)	Investigated and developed a scenario-based model for a logistics service supply chain to stop the ripple effect of market disruption.	Analysed capacity planning for recovery	---	---	Mathematical model and optimization	---	No
Fartaj et al. (2020)	Analyzed transportation disruption factors, explored their relationship and ranking, and suggested that the most critical disruption factors include infrastructural bottlenecks and inadequately skilled labor.	Investigated disruption factors analysis	Automotive parts manufacturing company	Canada	MCDM (best-worst method and rough strength relation analysis method)	---	No

Fattahi and Govindan (2020)	Developed a dynamic model to design a supply chain network to respond to demand uncertainty and facility disruption.	Explored supply chain network design	---	Iran	Mathematical model (two-stage stochastic programming and optimization)	---	No
Fattahi et al. (2020)	Developed a new metric for supply chain resilience in the event of possible disruptions. Suggested that in some business environments the increase of a supply chain's capacity may not be a suitable strategy for designing resilient supply chains.	Investigated recovery and network redesign	---	Iran	Mathematical model (two-stage stochastic programming and optimization)	---	No
Gaur et al. (2020)	Developed a model to integrate multi-sourcing in a closed loop supply chain to manage the impacts of disruption. Suggested that multi-sourcing produces higher net the present value of total profit when compared to single sourcing when considering the risk of supply chain disruption.	Investigated impact and strategies for supply chain reconfiguration	auto-parts manufacturing	India	Mathematical modeling and optimization (mixed-integer non-linear programming)	---	No
Islam et al. (2020)	Investigated and developed a model for determining the optimal inventory level in a three-stage supply chain, to manage supply disruption.	Addressed supply chain planning	---	---	Mathematical modeling and optimization (genetic algorithm)	---	No
Messina et al. (2020)	Described the ways of gathering, processing, and using the information to manage supply chain operational disruptions.	Discussed recovery strategy	Assembly sectors of cars, trucks, and aircraft wings	Europe	Conceptual modeling (interviews and focus group)	Information processing theory	No
Mohammadi (2020)	Investigated and developed a model for supplier selections, lot sizing, and scheduling of supply chain planning under disruption when raw materials are hazardous.	Addressed supply chain planning	---	---	Mathematical modeling and optimization (mixed-integer programming and stochastic modeling)	---	No
Olivares-Aguila and ElMaraghy (2020)	Introduced a system dynamics framework to observe supply chain behavior and suggested that downstream disruptions have a greater impact on supply chain performance than upstream supply disruptions.	Analyzed the impacts of disruption	---	---	Mathematical modeling (system dynamics)	---	No

Parast (2020)	Explored impact minimization strategies and suggested that research and development (R&D) investment minimizes the effects of supply chain disruption on supply chain and firm performance.	Investigated strategies for minimizing the impact	Diverse including manufacturing and services	US	Survey (SEM)	Dynamic capability theory	No
Paul et al. (2020)	Assessed the transportation disruption risks and suggested that the most significant transportation disruptions include corruption in customs, gasoline-related issues, infrastructural bottleneck, political unrest, and machine breakdown.	Analyzed and ranked the risk factors	Pharmaceuticals	Bangladesh	Analytical modeling (Bayesian belief network)	---	No
Rodrigue and Wang (2020)	Investigated factors such as sourcing pattern, pricing, consumption patterns, and delivery pattern that influence the procurement process of cruise ships during hurricane disruptions. Suggested that cruise lines servicing the Caribbean will need to adopt mitigation strategies to maintain sustainability.	Reported impacts and Resiliency analysis	Cruise supply chain	Caribbean region	Discussion and secondary information analysis	---	No
Shekarian et al. (2020)	Analyzed strategies to respond to disruption and suggested that both agility and flexibility improve supply chain responsiveness under disruptions. Noted that the effect of agility is greater than flexibility.	Developed disruption response strategy	---	---	Mathematical modelling (multi-objective optimization methods)	---	No
Sundarakani et al. (2020)	Investigated and confirmed the usefulness of Robust Optimisation (RO) and Mixed Integer Linear Programming (MILP) in sustainable facility location decisions in the face of disruptions.	Analyzed supply chain design	Apparel	Global	Mathematical modelling (RO and MILP)	Disruptive innovation theory	No
Swierczek (2020)	Investigated the role of demand planning in mitigating disruptions and suggested that demand planning practices significantly mitigate supply chain disruptions driven by operational risk.	Explored operational risk mitigation	Diverse (Manufacturing and service)	Seven European countries	Survey (PLS)	Dynamic capability theory	Yes - both SMEs and large organizations
Tao et al. (2020)	Investigated and developed a decision-making model to handle transportation disruption with one buyer and two competitive suppliers where they acquired and shared information.	Analyzed supply chain resiliency and network design	---	---	Analytical model (non-cooperative game)	---	No

Tolooie et al. (2020)	Developed a model for supply chain network design under facility disruptions and demand uncertainty. Suggested that the model is capable of solving large-scale problems and avoiding long run times.	Explored supply chain planning	---	USA	Mathematical model and optimization (two-stage stochastic mixed-integer problem)	---	No
Wu et al. (2020)	Investigated the use of trade promotions under demand disruptions and provided a suitable trade promotion strategy, considering the severity of disruptions.	Analyzed recovery strategy	---	---	Analytical model (integral mathematics)	---	No
Yan and Ji (2020)	Investigated supply chain network design and developed a three-stage supply chain optimal network design model for managing uncertain disruptions.	Explored supply chain network design	---	China	Mathematical model and optimization (constrained programming and genetic algorithm)	---	No
Yoon et al. (2020)	Analyzed manufacturer's procurement decisions and suggested that the visibility of first-tier and second-tier suppliers is important for disruption management, particularly when information about the second-tier suppliers is obtained from the first-tier suppliers.	Analyzed supply chain under disruption	---	---	Mathematical model and optimization	---	No
Zhao et al. (2020)	Explored supply chain coordination mechanisms under demand disruption. Suggested that demand disruption enhances supply chain coordination and the linear quantity discount contract is more effective than a revenue-sharing contract for supply chain coordination.	Addressed supply chain planning	Fashion industry	---	Mathematical model and optimization	---	No