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DOI:
10.1080/24725854.2023.2176951

Taylor & Francis
Taylor & Francis Group

IISE Transactions

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uiie21

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To cite this article: Dun Li, Bangdong Zhi, Tobias Schoenherr & Xiaojun Wang (2023) Developing capabilities for supply chain resilience in a post-COVID world: A machine learning-based thematic analysis, IISE Transactions, 55:12, 1256-1276, DOI: 10.1080/24725854.2023.2176951

To link to this article: https://doi.org/10.1080/24725854.2023.2176951

IISE TRANSACTIONS
2023, VOL. 55, NO. 12, 1256–1276
https://doi.org/10.1080/24725854.2023.2176951

Developing capabilities for supply chain resilience in a post-COVID world: A machine learning-based thematic analysis

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ABSTRACT
This study examines the past, present, and future of Supply Chain Resilience (SCR) research in the context of COVID-19. Specifically, a total of 1717 papers in the SCR field are classified into 11 thematic clusters, which are subsequently verified by a supervised machine learning approach. Each cluster is then analyzed within the context of COVID-19, leading to the identification of three associated capabilities (i.e., interconnectedness, transformability, and sharing) on which firms should focus to build a more resilient supply chain in the post-COVID world. The derived insights offer invaluable guidance not only for practicing managers, but also for scholars as they design their future research projects related to SCR for greatest impact.

ARTICLE HISTORY
Received 21 July 2022
Accepted 24 January 2023

KEYWORDS
Supply chain resilience; post-COVID world; literature review; thematic analysis; supervised machine learning

1. Introduction

Global supply chains have experienced significant disruptions during the COVID-19 pandemic ranging from the movement of people, raw materials and finished goods, to the disruption of factory and supply chain operations (Sheng *et al.*, 2020). This has led to unprecedented challenges for supply management professionals as they respond to this new reality (Araz *et al.*, 2020; Craighead *et al.*, 2020). Due to the worldwide impact of COVID-19 on virtually every sector, the pandemic represents a special case of supply chain disruption. As such, it is unlike any of the other major disruptions most frequently studied within the Operations and Supply Chain Management (OSCM) discipline; Zhang *et al.* (2020) identified these as supply chain disruptions brought by natural or man-made disasters (e.g., the Japanese earthquake and subsequent tsunami, the floods in Thailand, the earthquake in Haiti, and the 911 attacks), business model disruptions caused by the rapid development and applications of various Information and Communication Technologies (ICTs) (e.g., the Internet, the smart phone, Artificial Intelligence (AI), the Internet of Things, 5G, and blockchain), and disruptions associated with rapidly shifting customer attitudes or priorities (e.g., the shift from a profit-orientation to a sustainability-orientation triggered by public pressure towards environmental and social responsibility). Although guidance exists on how to predict, manage and respond to these disruptions (Bode *et al.*, 2011; Craighead *et al.*, 2020), the challenges associated with COVID-19 have brought the importance of risk management to the fore like no other disruption in the past. As such, Supply Chain Resilience (SCR) within the context of COVID-19, and ways in which companies can build up this resilience to be prepared for external shocks, is a critical area in need of further development and investigation.

SCR can be defined as a capability that enables supply chains to respond to disruptions and recover to their original state (Mena *et al.*, 2020). Resilience can be a vital strategic capability (Sheffi and Rice, 2005) that enables the supply chain to predict, respond, recover and learn effectively from unexpected events (Rice and Caniato, 2003), and can lead to the reduction of risks inherent in the supply chain (Zsidisin and Wagner, 2010). With the criticality of resilience being undisputed, this capability has been elevated to entirely new dimensions of importance under COVID-19. This is evidenced by the significant amount of research that has appeared since the start of the pandemic. It thus seems prudent to develop an overview of what has been investigated, also in light of relevant prior SCR studies, to offer a consolidated view and provide the foundation for even more impactful research in the future. This overview can enable scholars to start from a well-rounded foundation and make further contributions by differentiating their studies from what we already know. Within this context, the overarching research questions we aimed to answer were the following:

1. What are key themes in the existing SCR literature?
2. What capabilities should be developed to increase SCR in the post-COVID world?

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/24725854.2023.2176951.

To answer these questions, we first identified 1717 peer-reviewed papers related to SCR through a rigorous filtering process, followed by a systematic examination of this SCR literature and its classification into 11 clusters. To verify the classifications, a supervised machine learning approach was conducted to backward test the classification. Compared with traditional content analysis, which only reviews a small set of papers, we comprehensively examined a large amount of SCR literature and classified it into different research streams (Griffiths and Steyvers, 2004). To reduce the bias caused by irrelevant information, similar to Griffiths and Steyvers (2004) and Zhang *et al.* (2020), we captured the titles, keywords and abstracts of each paper and backward-tested the classification; word clouds are provided to illustrate the major themes in each cluster. In addition, building on the cluster analysis results and a further examination of the papers published since 2020 covering SCR within the context of COVID-19, this study proposes three capabilities to help firms foster their SCR in the post-COVID world (i.e., interconnectedness, transformability, and sharing).

The remainder of this article is structured as follows. After an overview of the methodology used to derive the 11 clusters in Section 2, the results are analyzed and discussed in Section 3. Based on these insights, Section 4 highlights three capabilities that firms should focus on to build a more resilient supply chain in a post-COVID world. Section 5 concludes the article and outlines future research avenues.

2. Methodology

2.1. Search and selection process

The Scopus database was used for the identification of relevant articles. Scopus is considered one of the most comprehensive and widely used literature databases, offering access to a wide range of scientific journals, books, and conference proceedings, amounting to over 57,000,000 records (Li *et al.*, 2020; Queiroz *et al.*, 2022). Within this database, we applied the search and selection process outlined in Figure 1, which is also further described in the following.

Our search was guided by the context of our investigation (i.e., the supply chain) as well as the specific focus (i.e., resilience and disruption). The term "supply chain" was thus conjunctively combined with the terms "resilien*" OR "disruption*". This combination was inspired by Xu *et al.* (2020), who suggested that these search terms are able to capture a comprehensive set of the supply chain resilience literature. We further restricted the language of the papers to English, and only considered peer-reviewed journals. Moreover, we selected the year 2000 as the start of the search, since the literature on SCR emerged around that time (Svensson, 2000). These search conditions yielded a total number of 4652 articles. These papers were further screened to ensure that they indeed related to SCR aspects. This was done by reading the titles, abstracts, and keywords of the papers. If no clear determination could be made based on this screening, the full text of these papers was read to affirm their relevance. For example, articles were removed from the sample if they only mentioned "disruption" a few times in passing, or if "resilience" was used to describe an organization or an individual, rather than the supply chain. This process yielded a total number of 1717 articles, out of which a total of 286 papers were set within the context of COVID-19.

2.2. Procedure for classifying SCR papers

To classify the SCR literature, we first randomly selected 200 papers from our sample, which were subsequently examined independently by two research team members to develop a classification and determine features associated with these clusters. When discrepancies emerged due to inconsistent classifications and/or features, these were discussed by the research team until a classification and associated features were agreed on. Subsequently, based on these agreed-upon features and classifications, two research team members categorized all remaining papers. If new clusters and/or features emerged, they were discussed by the research team and the

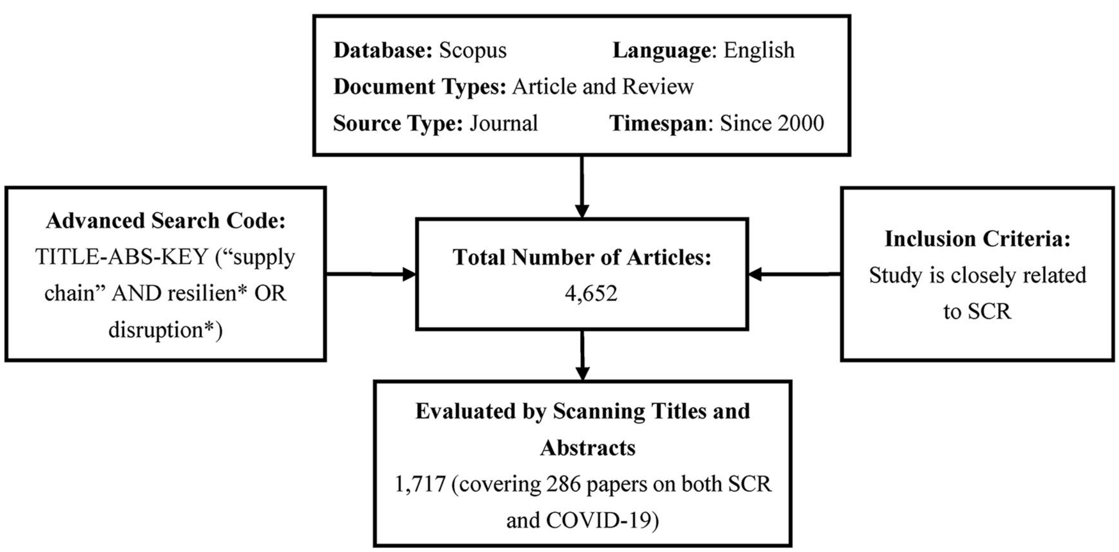


Figure 1. Literature search process.

Table 1. Result of the manual classification of 1717 SCR papers.

Topic (category)	Sub-topic (cluster)	Number	Main keywords
Network design (162)	Network design	162	Network; design; model
System design (301)	Decision support and measurement systems	177	Risk; model; system; decision
	Supply and inventory management	124	Supplier; risk; model; order; cost
Relationship management (185)	Supply chain coordination	54	Demand; coordination; supplier; retailer; contract
	Behavioural supply chain management	131	Information; social; share
Conceptual designs for SCR (809)	Approaches for building SCR	236	Management; strategy; plan
	Factors affecting SCR	195	Factor; effect; impact
	General framework designs	276	Framework; review
	Theoretical underpinnings	102	Theory; capability
Post supply chain disruption (260)	Risk mitigation	168	Risk; mitigation
	Operational and financial implications of SCR	92	Impact; performance; financial; stock
Total	1717		

classification framework was updated if warranted. This process led to the classification of the 1717 peer-reviewed articles into 11 clusters, which were grouped into five categories (Table 1). This structure was subjected to supervised machine learning to evaluate the accuracy of the classifications. The procedure for verifying these 11 clusters is detailed in the following section.

2.3. Supervised machine learning procedure for cluster verification

After manually classifying the SCR papers into the 11 clusters, a supervised machine learning approach was conducted to verify the accuracy of the classifications (Figure 2). This approach for verifying the clusters was the following:

Step 1: Preparing the text data. We scraped the titles, keywords, and abstracts from a CSV file containing the sample (Griffiths and Steyvers, 2004; Zhang *et al.* 2020) and transferred them into .txt files (one .txt file for each article). The files were then segregated into 11 folders according to their cluster membership, while at the same time ensuring that the information contained in these files was clean.

Step 2: Dividing the data into a training dataset and a test dataset. For each cluster tested, we randomly selected 80% of the sample as training data and the remaining 20% of the sample as the test data (Pang and Lee, 2004). For example, having identified 162 articles for the cluster named Network Design, we selected 130 (80% of 162) articles for the training dataset and 32 (20% of 162) articles for the test dataset. To contrast these articles for the Network Design cluster, we then randomly selected 162 articles from all the remaining 10 clusters, of which 130 articles were used to train the model and 32 articles were used as the test data. This was done to assess whether the trained model for the Network Design cluster can reliably identify the articles belonging to that cluster, in contrast with a trained model consisting of a random combination of the same number of articles from the remaining 10 clusters. The same approach was applied to confirm the classification for the other clusters.

Step 3: Creating a restricted vocabulary for the training data (Pang and Lee, 2004). To develop a restricted vocabulary for the training data, we carried out the following steps: (i) we split the words on blank space; (ii) we removed all punctuations; (iii) we removed all words that are not purely comprised of alphabetical characters; (iv) we removed all words that are known "stop words" (commonly used words without important meanings, such as "the", "a" and "an"); and (v) we removed all words that only occur once. The ensuing vocabulary was saved to a new file, which was later loaded and used to filter each text file prior to encoding the text data.

Step 4: Developing a Multilayer Perceptron (MLP) model. We used the bag-of-words model to prepare the training and test datasets. The bag-of-words model is an approach that extracts features from text, enabling the text input to be used with machine learning algorithms such as neural networks (Zhang *et al.*, 2010). With this approach, each text file was converted into a vector representation that can be used to train the MLP model.

Step 5: Integration of four methods with the MLP model to classify encoded documents as either belonging to the test cluster or not (Rivals and Personnaz, 2003). The four methods included the following: binary (indicates the presence of a word by using "1" for its presence and "0" for its absence), count (the frequency with which a word appears in each text), TF-IDF (Term Frequency – Inverse Document Frequency, which captures the relevance of a word in a given text), and frequency (a score using the ratio of words in a text) (Ketkar, 2017). Backward-tests were conducted with these four methods to evaluate whether the classification predicted by the model was consistent with the manual classification.

Step 6: Repetition of the fifth step 30 times to minimize bias caused by the stochastics.

Step 7: Repetition of the second step to fifth step 10 times to further avoid the potential bias caused by random sampling. With these approaches (steps 6 and 7), a total number of 300 test results were generated for each cluster.

The code used to carry out the above steps is available at https://github.com/Bangdong/cluster_verification.

Once all results were obtained, boxplots were generated to assess the accuracy of the classifications. These were complemented with word clouds to provide a further illustration of each cluster. As can be seen in the following sections, the word clouds were generally consistent with the identified themes, which provided further evidence for the appropriateness of the classifications.

3. Findings: Interpreting clusters

This section summarizes the 11 clusters and illustrates their content with word clouds.

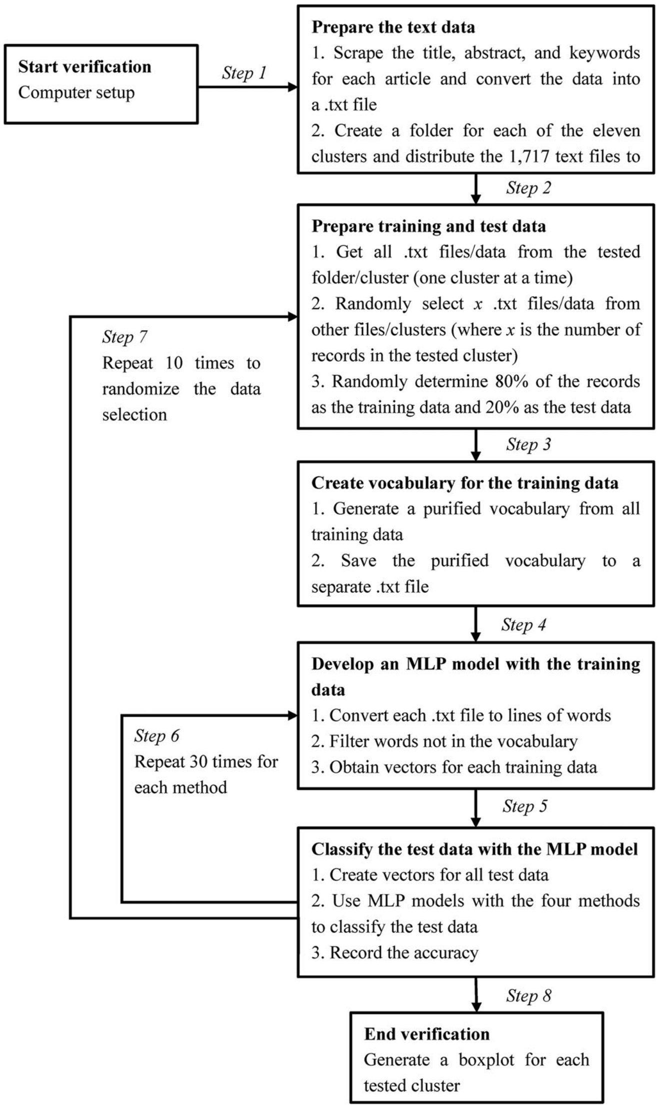


Figure 2. Verification flowchart.

3.1. Network design

This topic mainly addresses how supply chain networks can be redesigned to improve SCR. Specifically the topic investigates how to achieve SCR by designing transportation networks, retailer networks, supply chain networks, and supplier networks. The median accuracy of this cluster classification is high, reaching values of up to 92.19% (Figure 3(a)). The keywords include "network", "design" and "model" (Figure 3(b)).

Studies in this cluster focus on the improvement of the supply chain network through various mathematical models, such as linear programming (Childerhouse *et al.*, 2020), stochastic programming (Zare Mehrjerdi and Lotfi, 2019), agent-based modeling (ABM) (Nair and Vidal, 2011), and bi-level modeling (Ghomi-Avili *et al.,* 2020). What the results from these models have in common is that with a strengthened SCR, the supply chain network can withstand, adapt, and recover from disruptions to meet customer demand and ensure performance (Nguyen *et al.*, 2020). Further details are provided in the following.

Linear programming (LP) or linear optimization is a method to determine the best outcome (e.g., profit maximization or cost minimization) via a mathematical model where linear relationships are used to indicate the requirements. Exiting network design literature adopting LP focuses on how to make full use of existing resources to improve the ability of the supply chain network to overcome supply chain disruptions (e.g., Zare Mehrjerdi and Lotfi, 2019; Childerhouse *et al.*, 2020).

In contrast with LP, stochastic programming takes uncertainty into account. This seems prudent, since, as mentioned by Klibi and Martel (2013) and Yan and Ji (2020), it is difficult to accurately estimate the disruption probability, due to the non-repeatability and low frequency of disruptive events.

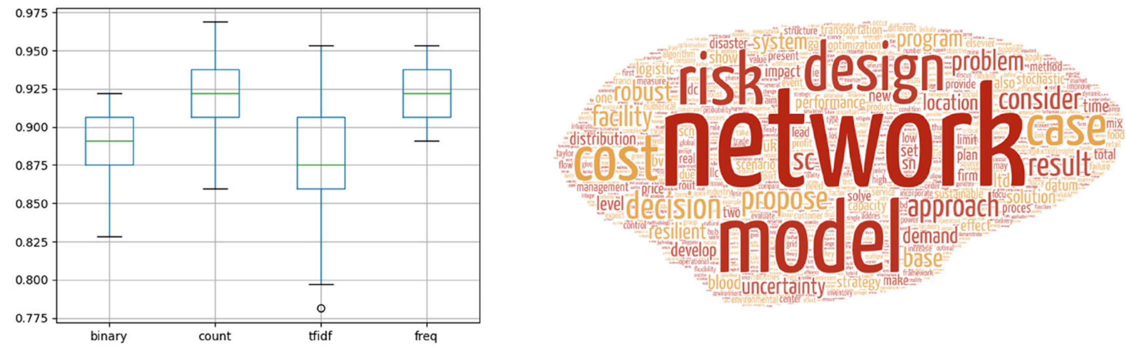
ABM is also a popular approach for providing decision support in designing supply chain networks. ABM belongs to a class of computational models that simulate the actions and interactions of autonomous agents to evaluate their effects on the supply chain network. Using this approach, Nair and Vidal (2011) examine the relationship between the topology of a supply network and its robustness under conditions of random failures and targeted attacks. ABM can also be used to validate the applicability of various complex network models to help in the design of resilient supply chain networks. The simulation results from Mari *et al.* (2015) for example indicate that, based on complex network theory, a scale-free network can be designed.

Bilevel optimization is a special optimization where one problem is embedded (nested) within another, and is also frequently used to design supply chain networks (e.g., Ghomi-Avili *et al.*, 2021). Although the models mentioned above have been widely used in the network design literature, other models have been emerging with which supply chain networks under disruption risks can be designed, such as Discrete-Time Markov chains and Dynamic Bayesian networks (Hosseini *et al.*, 2020).

Within the context of COVID-19, commonly used models include game-theoretic models (Gupta *et al.*, 2021; Nagurney, 2021; Besik *et al.*, 2022), epidemiological models (Nikolopoulos *et al.*, 2021; Berger *et al.*, 2023), and fuzzy inference systems (Govindan *et al.*, 2020). Among these models, the game-theoretic model is the one most widely applied within the context of COVID-19. It can be used to identify how supply chain members' pricing strategies (i.e., wholesale and retail prices) can be affected by the timing of supply disruptions (Gupta *et al.*, 2021). The unique characteristic of the epidemiological model is that it can consider the characteristics of COVID-19, enabling it to forecast infection growth rates. Considering these dynamics, the demand for products and services can be more accurately predicted (Nikolopoulos *et al.*, 2021; Berger *et al.*, 2023).

3.2. System design

This topic focuses on how systems can be designed to improve SCR. It includes the clusters decision support and measurement systems, and supply and inventory management.



a) Classification accuracy b) Word cloud for the cluster

Figure 3. Network design.

3.2.1. Decision support and measurement systems

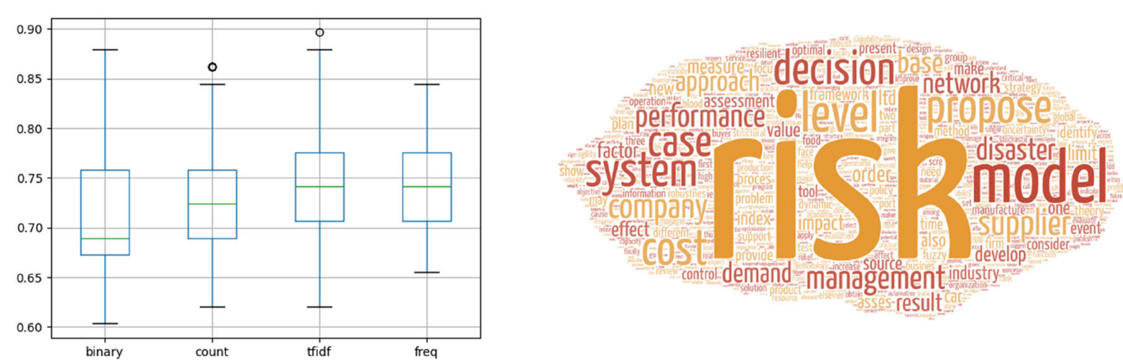
Papers classified under this topic aim to design decision support systems that can measure SCR and provide guidance on how supply chain disruptions should then be managed. The median accuracy of this classification is up to 74.14% (Figure 4(a)), with the keywords including "risk", "model", "system", "decision" (Figure 4(b)).

Studies in this cluster frequently took a broader supply chain perspective, considering risks related to uncertainties on both the supply and the demand sides (Tang and Tomlin, 2008; Chan and Wang, 2013), with these uncertainties being triggered for instance by natural disasters or terrorism (Tang, 2006a; Tang, 2006b; Wagner *et al.*, 2014). To explore risks within these contexts, Sinha *et al.* (2004) suggest as a first step to determine the risk sources and assess their respective risk levels in the supply chain, which in turn facilitates companies to take effective actions (Tang, 2006a). As such, literature in this cluster focuses on supply chain risk assessment to facilitate decision-making. For example, Schoenherr *et al.* (2008) apply the Analytical Hierarchical Process (AHP) to assess the risk associated with various supply chain designs, and Dong and Cooper (2016) propose an orders-of-magnitude AHP framework to identify pivot elements. Taking a process-performance paradox perspective, Tazelaar and Snijders (2013) investigate how supply chain risk management decisions can benefit from both general and specialized expertise.

Studies within this cluster also apply fuzzy set theory to reduce the uncertainty associated with the ambiguity of risk measures. Specifically, Aqlan and Lam (2015), by applying fuzzy inference logic, propose an integrated framework for supply chain risk assessment, which can be used to mitigate the aggregated probability of a negative event. In this vein, several scholars suggest that the combination of both fuzzy and AHP approaches facilitates the development of capabilities (i.e., addressing the qualitative nature of the problem and the inherent uncertainty) in assessing supply chain risk (Mangla *et al.* 2016). Other approaches, such as Data Envelopment Analysis (DEA), the risk matrix (Li *et al.*, 2013), sentiment analysis (Nguyen *et al.* 2022), and value-oriented process engineering (Neiger *et al.*, 2009), have also been applied to assess supply chain risks. For example, Kazemi Matin *et al.* (2022) propose an advanced DEA to measure the resilience of the blood supply chain. With the integration of AI, Nguyen *et al.* (2022) also explore how sentiment analysis can be used to evaluate demand volatility and support decision-making during supply chain disruptions.

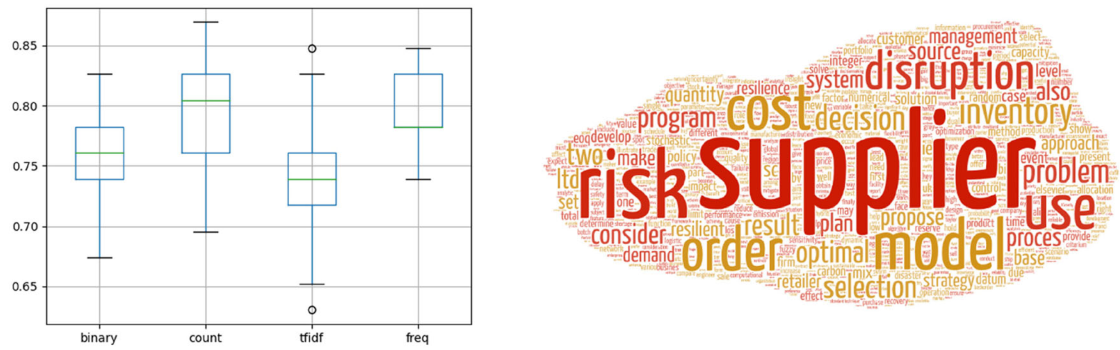
3.2.2. Supply and inventory management

Papers classified under this topic primarily address supply chain disruptions from a mathematical perspective. The accuracy of the classification is up to 81.26% (Figure 5(a)), and the keywords include "supplier", "risk", "model", "order" and "cost" (Figure 5(b)).



a) Classification accuracy b) Word cloud

Figure 4. Decision support and measurement systems.



a) Classification accuracy

b) Word cloud

Figure 5. Supply and inventory management.

We identified two topical sub-streams within this cluster, with the first one focusing on the role of procurement in SCR. As an illustrative paper serves Kaur and Singh (2018), who build a dynamic nonlinear mixed-integer model capturing environmental sustainability through the cap-and-trade method of carbon emissions, which is used to design sustainable procurement logistics for disaster supply chain management. A more recent paper includes Choi and Shi (2022), who examine the role of a supply guarantee deposit payment scheme in reducing supply disruption risk.

The second sub-stream focuses on the importance of supplier selection strategies in managing disruptions. An effective strategy in this regard is the reliance on multiple suppliers rather than just one (Babich *et al.*, 2007; Tucker *et al.*, 2020). Specifically, as noted by Burke *et al.* (2007), a company should pursue a single sourcing strategy only when supplier capacities are large compared with customer demand. In addition, when multi-sourcing, suppliers should be diversified in terms of size and geographic location (Kahiluoto *et al.*, 2020). What may also be considered is the level of competition among suppliers, which has the potential to impact wholesale prices (Babich *et al.*, 2007). Further, by using mathematic modeling, Ravindran *et al.* (2009) develop two risk models, i.e., value-at-risk and miss-the-target, to optimize the problem of supplier selection under supply chain risk (Parhouhi *et al.*, 2019). In the inventory management context, Mudrageda and Murphy (2007) consider a situation where closing down facilities is very difficult, due to excessive inventory buildup caused by the inability to move out production, and Sevgen and Sargut (2019) propose a mathematical model to determine optimal parameters of an order-up-to type policy for the retailer when both the retailer and the supplier suffer from disruptions that lead to inventory problems.

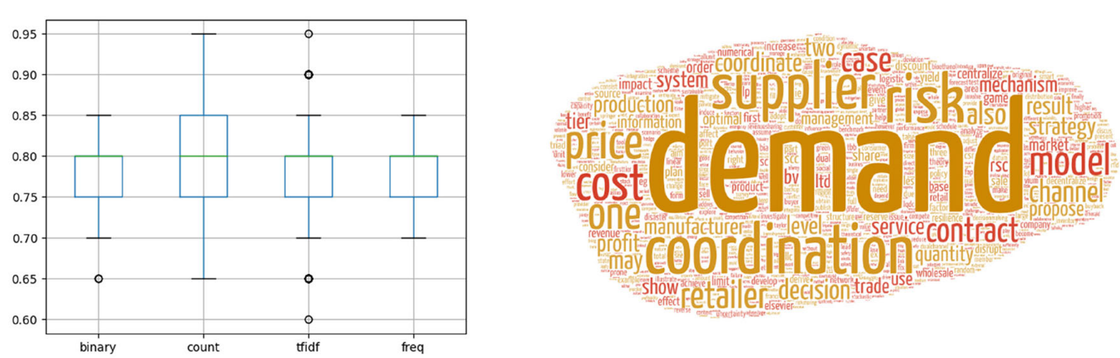
3.3. Relationship management

This category focuses on how supply chain members are able to improve SCR through relationship management. Specific clusters include supply chain coordination and behavioral supply chain management.

3.3.1. Supply chain coordination

Papers classified under this topic primarily focus on the coordination necessary among supply chain members to best address supply chain disruptions. A total of 54 papers are categorized into this cluster. The terms "demand", "coordination", "supplier", "retailer" and "contract" are included in this cluster (Figure 6(b)), which has a classification accuracy of up to 80.00% (Figure 6(a)).

Several papers in this cluster investigate how supply chain coordination can be formalized via contractual governance, often within the contexts of a retailer's demand disruption. Contracts considered by the papers in our sample include, but are not limited to, quantity discounts (Xiao and Qi, 2008), groves wholesale price schedules (Chen and Xiao, 2009),



a) Classification accuracy

b) Word cloud

Figure 6. Supply chain coordination.

revenue-sharing contracts (Zhang *et al*., 2012), transshipment contracts (Aslani and Heydari, 2019), and contracts applied in informal supply networks (Abushaikha *et al*., 2021). Specifically, under the quantity discount contract, to increase the order size, a linear quantity discount schedule is charged by the manufacturer. The main idea under this mechanism is to make each retailer's decisions consistent with those in the supply chain, enabling a simple channel-coordinating wholesale price (Chen and Xiao, 2009). The revenue-sharing contract can be implemented if supply chain partners obtain a profit level that is at least as great as that in the model without a revenue-sharing contract (Zhang *et al*., 2012). In addition, a transshipment contract facilitates the direct transshipment of products between two supply chain members at the same tier—a strategy that can be particularly effective during disruptions (Aslani and Heydari, 2019). An interesting article within this realm is Abushaikha *et al*. (2021), who research explicit contracts in refugee camps. In contrast to some of the other contractual mechanisms described above, the authors find that the transactions in these informal supply networks are governed by culturally guided convention (i.e., barter, trade and cash exchange) or market-guided convention (i.e., fixed fee-for-service/product).

While contracts can cover the basics and the foreseeable, they are not perfectly able to address unforeseen events, such as the COVID-19 pandemic. The pandemic has thus stressed the notion that contractual governance needs to be complemented with relational governance, and further research in this domain is encouraged (Katsoras and Georgiadis, 2022). Inroads in this regard were made by Gupta *et al.* (2021), who demonstrate that power relationships between supply chain members can influence the equilibrium price and the ensuing performance of firms in supply chains disrupted by COVID-19. Using the same context, Li, Wang, Ye, Chen and Zhan (2022) find that the breadth and depth of digital technology deployment can enhance supply chain coordination and thus yield more resilient supply chains.

3.3.2. Behavioral supply chain management

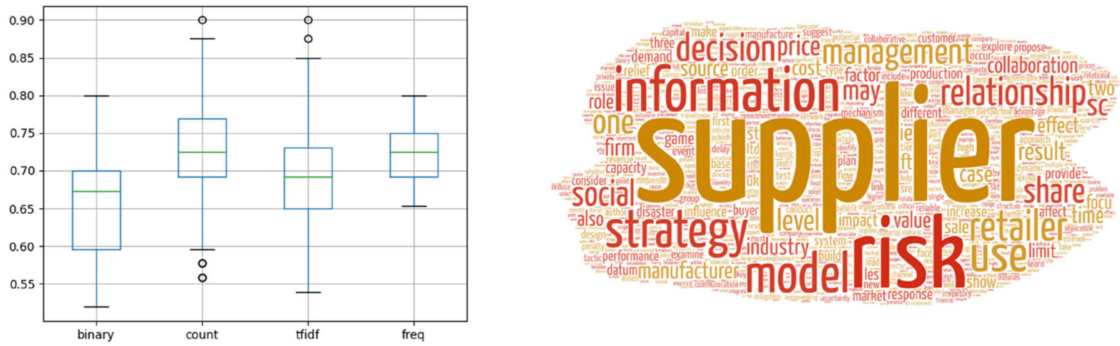
Papers classified in this cluster focus on how individual behaviors in the supply chain affect SCR. The terms, "information", "social" and "share", are included in the cluster (Figure 7(b)). The accuracy of this classification is up to 72.50% (Figure 7(a)). Although the behavioral OSCM literature is rich, only limited insight exists within the context of SCR (Fahimnia *et al*., 2019).

Studies in this cluster can be grouped into three main themes. The first theme relates to the issue of power and trust between buyers and suppliers (Handley and Benton, 2012; Terpend and Ashenbaum, 2012; Cislaghi *et al.* 2022). For instance, Terpend and Ashenbaum (2012) find that a supplier's performance is sensitive to power, including coercive, referent, expert, and legitimate power. Moreover, supplier network size is identified as playing a moderating role in the relationship between trust, power, and supplier performance. Handley and Benton (2012) suggest that a service provider's opportunism (i.e., shirking and poaching) can be affected by two factors (i.e., exchange hazards and outsourcing firm power). More specifically, by identifying three mediated (i.e., reward, coercive, legitimate) and one non-mediated power source (i.e., expert and referent), they illustrate that expert and referent power can eliminate opportunistic behavior, while opportunistic behavior is fostered by reward, coercive and legitimate power. Recently, Cislaghi *et al.* (2022) suggest that greater application of informal governance mechanism and greater relational rents are triggered by a reduction of power asymmetry between buyer and supplier.

The second theme involves the impact of a supplier's risk behavior on decision-making. For example, Reimann *et al.* (2017), using the fsQCA method, explore the role of a buying firm's managerial cognition on responding to supplier-induced disruptions. They find that cognitive, behavioral, and structural factors of the buying firm yield either dysfunctional conflict or constructive interaction. In addition, DuHadway *et al.* (2018) suggest that decision-makers are able to make riskier decisions when the level of supply risk is emphasized through organizational communication; however, this behavior does not change under reduced risk levels. Similarly, to minimize waste and cost in lean supply chain planning, Reyes *et al.* (2021) propose a theoretical framework that combines Industry 4.0 digital technologies with lean manufacturing tools, which carries the promise for managers to reduce the risk associated with their decisions.

The third theme refers to making risk-related decisions in response to supply chain disruptions. For instance, Ellis *et al.* (2011) apply enactment theory to propose a conceptual model related to the sense-making process during supply chain disruptions, and highlight environmental, organizational, and individual factors that impact buyers' risk perceptions of supply chain disruptions and the approach they adopt in managing them. Inspired by options theory, Hult *et al.* (2010) link various options, including unlocking options, staging and deferral options, scale, switch use, and abandonment options, with supply chain investment decisions. Studies about behavioral risk management also appear in the domain of supply chain inventory management (Croson *et al*., 2014; Gholami-Zanjani *et al*., 2021), supply chain forecasting (Scheele *et al*., 2018), supply chain design (Dutta and Shrivastava, 2020), and when discussing the ripple effect (Hosseini *et al*., 2020; Ivanov, 2022).

Given these foundations, coupled with the new reality provided by the pandemic, we foresee great potential for the application of behavioral OSCM going forward. This is especially in light of governments implementing measures to contain the spread of the virus (Belhadi *et al*., 2021), which can have significant behavioral implications. This not only applies to individuals, but also to how for instance buyer–supplier relationships are managed (Kumar and Managi, 2020; Spieske *et al*., 2022). For example, while micro-level supply network resilience focuses on the relationship between a buyer and a supplier, and macro-level supply network resilience on the relationship between firms, competitors and local governments, supply network resilience can also be explored at the meso-level (Azadegan and Dooley, 2021). This view emphasizes that multiple supply networks can collaborate on short- to medium-term supply chain risks, rendering this



a) Classification accuracy b) Word cloud

Figure 7. Behavioral supply chain.

collaboration at the meso-level as a complex adaptive system that exhibits self-organization and dynamism.

3.4. Conceptual designs for SCR

This topic investigates how SCR can be designed, with a particular focus on factors that can make SCR more robust and effective. Within this category, we identified four clusters, including approaches for building SCR, factors affecting SCR, general framework designs, and theoretical underpinnings. Across these clusters, several studies design research frameworks, with or without theories, to better manage SCR from a holistic design perspective.

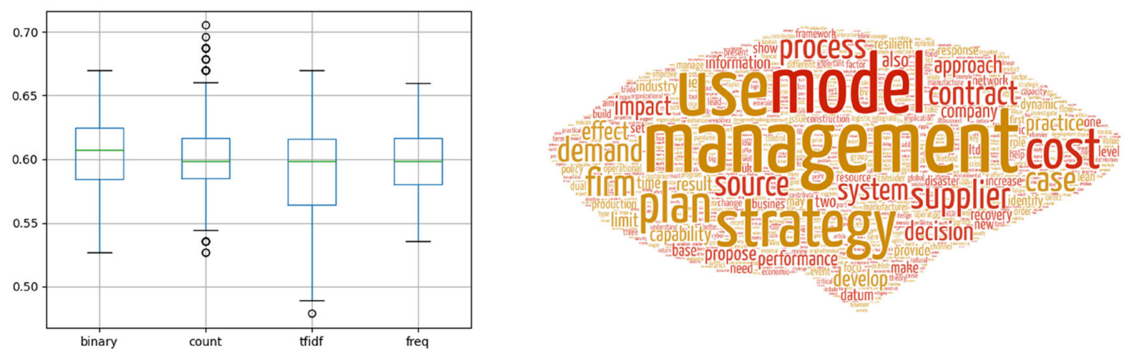
3.4.1. Approaches for building SCR

Papers classified under this topic mainly focus on exploring what strategies can be adopted to build and improve SCR. The median accuracy is 60.71% (Figure 8(a)). Although we acknowledge that this on the low-end, prior research has considered such accuracy levels for its analysis (e.g., Iwabuchi *et al.*, 2013; de Filippis *et al.*, 2019). The words, "management", "strategy" and "plan" stand out in this cluster (Figure 8(b)).

The literature on approaches for building a resilient supply chain generally considers either two (i.e., during-disruption and post-disruption) or three stages (i.e., pre-disruption, during-disruption, and post-disruption). More specifically, although SCR studies initially focused on how to respond during the disruption stage, followed by activities on how to best recover in the post-disruption stage (Christopher and Peck, 2004), Ponomarov and Holcomb (2009) emphasize that firms should take readiness as an element *prior* to a potential disruption into account to build resilience.

In the pre-disruption stage, our literature sample suggests various elements with which a firm's SCR readiness level can be assessed, serving as the foundation for a better anticipation or prediction of the potential hazard brought by disruptions. Specifically, the ability to identify a potential disruption through the setting of early warning strategies (Sáenz and Revilla, 2014) and developing appropriate plans (Pettit *et al.*, 2010) has been noted as essential for firms to be aware of their supply chain vulnerabilities (Melnyk *et al.*, 2010). Visibility is key in this regard, as it relates to, for instance, the end-to-end information flows about inventory and transportation in the supply chain (Smith, 2007). Knowledge sharing and collaboration with supply chain partners can enhance this transparency (Brandon-Jones *et al.*, 2014). In addition, robustness, an ability to resist changes, has been noted as beneficial, as it consists of the proactive anticipation of changes before they occur (Wieland and Wallenburg, 2013). Benefits derived from a robust supply chain include the ability to design a supply chain network that can ensure daily operations during a disruption (Tang, 2006a) and absorb any associated shocks (Wieland and Wallenburg, 2013). All these aspects culminate into the design of supply chain strategy, on which, for instance, Kamalahmadi *et al.* (2022) focus. The authors propose a strategy guided by flexibility enabled by backup suppliers, improving responsiveness and decreasing total cost.

During the disruption stage, four elements can be used to appraise the level of supply chain resilience and the associated responsiveness to react to disruption events: flexibility, redundancy, collaboration, and agility. First, flexibility has been highlighted by scholars to enhance SCR, with flexibility enabling firms to change quickly to maintain operational efficiencies when suffering adversity (Sheffi and Rice, 2005). Second, redundancy refers to the utilization of multiple suppliers or the access to additional supply capacity (Rice and Caniato, 2003; Sheffi and Rice, 2005). Third, the importance of collaboration is highlighted especially when disruptions strike, since then supply chain partners are more likely to share critical information and knowledge to address the situation (Jüttner and Maklan, 2011) or to engage in joint collaborative planning moving forward (Christopher and Peck, 2004). Collaborative capability also plays an important role in supply chain leader-member exchange, as is illustrated in the study by Shin and Park (2021). The authors find that a buyer's leadership can help a supplier to improve flexibility, agility, efficiency, and alertness. Although the latter two elements have the potential to significantly improve the resilience, the former two do not exhibit a significant relationship with resilience. And fourth, agility is defined as the ability to sense and respond to dynamic market changes to meet customer demand and ensure the continuity of



a) Classification accuracy b) Word cloud

Figure 8. Approaches for building SCR.

business operations (Wieland and Wallenburg, 2013; Ali and Gölgeci, 2019).

After a disruption, two elements emerge as dominant in the reviewed studies: resource reconfiguration and knowledge management. Resource reconfiguration enhances a firm's ability to redirect resources to solve problems and respond to dynamic market changes (Ambulkar *et al*., 2015), which can be essential in restoring and redesigning the supply chain. Knowledge management improves the ability to learn from the adversity experienced and to develop more resilient supply chains. Resilient supply chains are thus generally characterized by a high level of supply chain learning capability (Rice and Caniato, 2003; Blackhurst *et al*., 2011). Enhancing knowledge management is also beneficial for quickly deploying effective solutions for potential future disruptions, and can thus be regarded as a fundamental element of SCR in the post-disruption stage (Ponomarov and Holcomb, 2009). For example, Ali *et al.* (2021) argue that knowledge management practices, including knowledge acquisition, assimilation, and application, can help a company further build supply chain resilience through enhancing its risk management culture in the post-disruption stage (Umar *et al*., 2021).

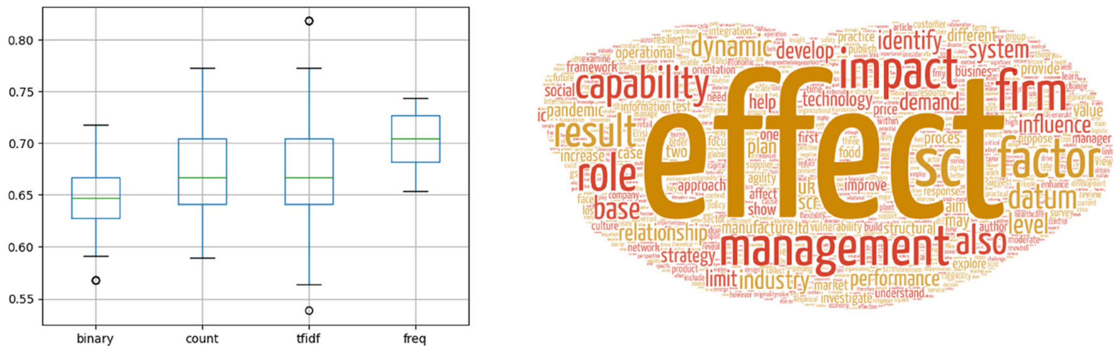
However, as experiences of firms during the COVID-19 pandemic have shown, even well laid-out plans have been difficult to adjust or implement due to the unprecedented nature of the crisis (Ergun *et a*l., 2023). Such challenges were also experienced by firms whose supply chains had been considered to be rather resilient (Belhadi *et al*., 2021). To address this issue, scholars have aimed to identify approaches to build SCR during the pandemic. Specific contexts investigated included the sport business (Sadeqi-Arani and Alidoust Ghahfarokhi, 2022), the hotel supply chain (Hussain and Malik, 2022), the vaccine supply chain (Kazancoglu, Sezer, Ozbiltekin-Pala and Kucukvar, 2022), the retail supply chain (Papanagnou *et al*., 2022), and the food supply chain (Ali *et al*., 2021; Kazancoglu, Ozbiltekin-Pala, Sezer, Luthra and Kumar, 2022). Moreover, except for the capabilities mentioned during the disruption stage, research has focused on developing various new capabilities to build SCR, such as improvisation and anticipation (Munir *et al*., 2022), and the leveraging of new technologies, including big data analytics (Behl *et al*., 2022; Papanagnou *et al*., 2022) and blockchain capabilities (Kazancoglu, Ozbiltekin-Pala, Sezer, Luthra and Kumar, 2022; Li, Xue, Li and Ivanov, 2022). However, there is still limited evidence on what new capabilities should be developed to develop SCR in the post-pandemic stage, serving as an area ripe for future research.

3.4.2. Factors affecting SCR

Papers classified under this topic focus on the investigation of factors impacting SCR. A total of 195 papers are in this cluster, and keywords include "factors", "effect" and "impact" (Figure 9(b)). The high median accuracy (70.45%) indicates this to be a reasonable classification (Figure 9(a)).

Studies within this cluster emphasize information asymmetry and technology as playing an important role in building SCR. For example, Schmidt (2015) examines how information asymmetry between the firm and its investors can influence supply chain disruptions, Rubbio *et al.* (2020) investigate how technology improves the ability to build up SCR, and Kim *et al.* (2011) examine the impact of technological dimensions related to manufacturing strategy and manufacturing flexibility on responsiveness in the supply chain. More recently, Chatterjee *et al.* (2022) demonstrate firms' intellectual capability, agility, and integration to significantly affect the adoption of emerging technologies, which in turn can have a positive impact on SCR.

Further studies in this cluster highlight the importance of relationship and organizational culture in affecting SCR. For example, Wieland and Wallenburg (2013) investigate the effects that relational competencies have on resilience, and Hendry *et al.* (2019) examine the role of both vertical and horizontal collaboration between supply chain members in anticipating the impact of disruptions. In addition, Dowty and Wallace (2010) explore the role of diverse organizational cultures in improving SCR, and identify collaboration as a critical capability to restore services and help ensure resiliency. Similarly, Acar *et al.,* (2022) find that both an organizational learning culture and supplier trust can have a positive relationship with SCR. A further finding includes that supplier trust, considered as a mediator, can have a positive influence on the relationship between an organizational learning culture and SCR. Authors in our sample took various



a) Classification accuracy   b) Word cloud

Figure 9. Factors that affect SCR.

approaches to identify these factors. For example, Lawson *et al.* (2019) develop a dataset comprising 407 pairs of suppliers and downstream manufacturing firms, followed by cross-classified hierarchical linear modeling to determine the drivers of organizational responsiveness.

AI in particular has been lauded during the COVID-19 pandemic as a promising approach in strengthening SCR. For example, Modgil *et al.* (2022) note that COVID-19 has pushed many supply chains to re-think and strengthen their resilience using AI. The authors suggest that adopting AI can help organizations to recognize, analyze, reconfigure, and activate operations quickly. The adoption of AI can improve a firm's data analytics capability, which in turn, improves information-processing capacity, and thus, helps the supply chain to recover quickly from disruptions (Dubey *et al.*, 2021).

3.4.3. General framework designs

Studies in this cluster focus on identifying various capabilities in SCR and propose frameworks to better understand the holistic nature of SCR. A total of 276 papers are in this cluster, with a median classification accuracy of up to 73.58% (Figure 10(a)). The keywords "framework" and "review" stand out in this cluster (Figure 10(b)).

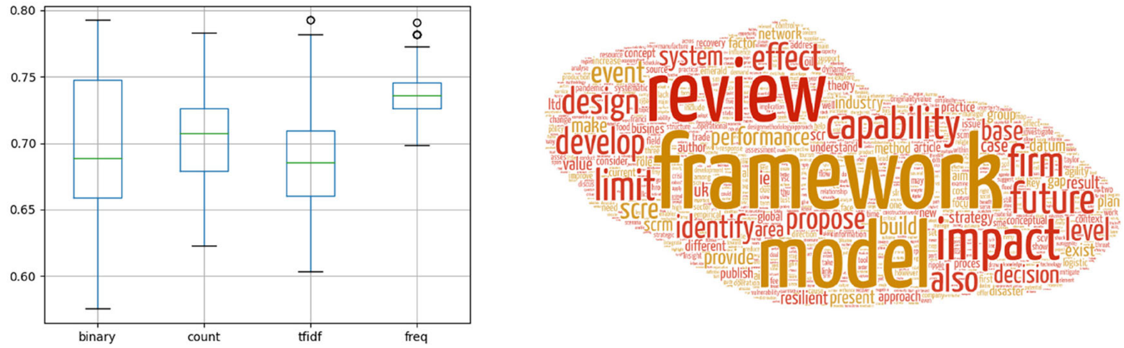
One stream in this cluster consists of papers that provide comprehensive literature reviews. For example, Xu *et al.* (2020) present, adopting a bibliometric review method, an overview of the literature on disruption risks in supply chain management, and highlight potential future research directions. In the review by Shekarian and Parast (2021), flexibility is identified as the most important capability to deal with demand, supply, process, and environmental risks, whereas collaboration, another critical capability, is linked with solving risks associated with a lack of control. Further capabilities identified include IT (Mandal, 2018), supply chain structural complexity (Birkie *et al.,* 2017), and knowledge management (Jüttner and Maklan, 2011), which are all found to positively relate to SCR.

Within this cluster, we would also like to highlight three key literature reviews that focused on SCR during the pandemic. Specifically, based on 74 articles, Chowdhury *et al.* (2021) reveal four themes associated with this topic area, which are related to the impacts of the pandemic on the supply chain, SCR strategies, the role of technology in SCR, and supply chain sustainability within the context of COVID-19. In addition, by using a critical review of 87 papers, Naghshineh and Carvalho (2021) review SCR from an additive manufacturing adoption perspective in the context of COVID-19. The authors identify 32 additive manufacturing adoption impacts and 25 additive manufacturing adoption barriers that have the potential to impact SCR, leading to a conceptual framework that can guide future SCR research. Similarly, Ergun *et al.* (2023) provide reasons for why supply chains fail, followed by determining the appropriate resilience needed via mathematical modeling. The authors then propose approaches to build SCR and delineate key principles and methodologies that could be applied. Although these review studies provide valuable insight into SCR within the context of the pandemic, we differentiate our work by employing a machine learning approach to capture a large sample of papers.

3.4.4. Theoretical underpinnings

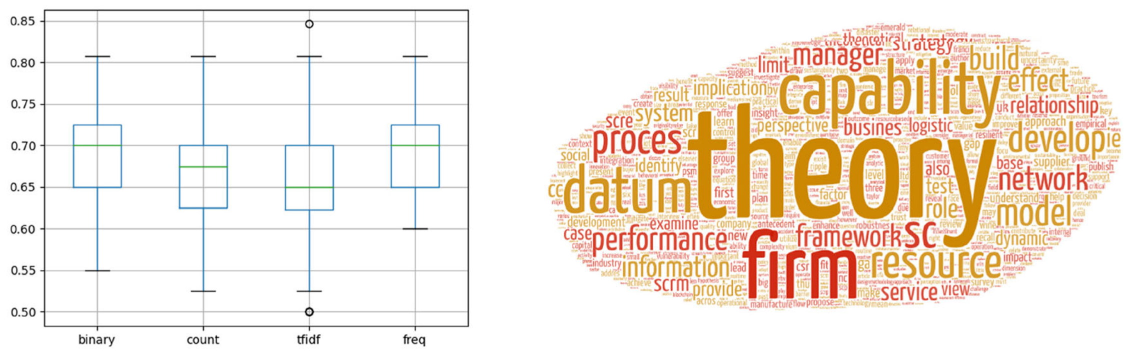
Studies in this cluster are characterized by their emphasis on a range of different theories, such the Resource-Based View (RBV), dynamic capabilities, information processing theory, and contingency theory, to develop SCR with a deep theoretical concern. This cluster has high classification accuracy (70.49%) (Figure 11(a)), with the keywords "theory" and "capability" being dominant across the 102 papers (Figure 11(b)).

Literature in this cluster approaches SCR from a theoretical perspective, offering further implications for SCR (Govindan *et al.*, 2020). For example, Tomasini and Wassenhove (2009) propose a theoretical framework for disaster management that consists of two phases (i.e., relief and development) and four elements (i.e., preparedness, response, rehabilitation, and mitigation). In addition, scholars suggest that response and rehabilitation should be included in the relief stage, whereas preparedness and mitigation should be part of the development stage, constituting a disaster management lifecycle (Loree and Aros-Vera 2018). What should also be part of these frameworks is the concern for the environment and society. As such, rebuilding activities need to ensure the repair of damaged infrastructures, while mitigation activities need to be put in place to prevent the impacts of similar disasters in the future. Disaster management within the context of COVID-19 also demands collaboration among private sectors and communities. For



a) Classification accuracy b) Word cloud

Figure 10. General framework designs.



a) Classification accuracy b) Word cloud

Figure 11. Theoretical underpinnings.

example, communities in the UK organized volunteers to deliver food to seniors who are vulnerable to COVID-19. In addition, community stores aimed to bridge the gap between supermarkets and food banks by providing more affordable food support for families. Based on the review of this cluster, we foresee the need to explore the role of collaboration via these means in mitigating the negative impact of COVID-19 as a promising research avenue (cf. Belhadi *et al*., 2021).

Various theoretical underpinnings have been applied to SCR within these contexts and stand out in this cluster. For example, one of the most widely used theories is the RBV, which suggests that firms utilize strategic resources and develop capabilities to obtain competitive advantage (Wernerfelt, 1984; Barney, 1991). SCR scholars note that resilience can be considered either as a capability for achieving integration and reconfiguration of various resources, improving relative performance and competitiveness (Yang and Hsu, 2018), or as the final performance outcome (Brandon-Jones *et al*., 2014). For instance, Essuman *et al.* (2022) find, by combining the RBV with the attention-based view, that resource slack can have a positive relationship with operational resilience, with organizational attention playing a mediating role in the relationship between resource slack and operational resilience.

The dynamic capabilities view, which focuses on achieving competitiveness in dynamic markets (Eisenhardt and Martin, 2000), is yet another common theory that has been applied in the SCR field (Chowdhury and Quaddus, 2017). Dynamic capability elements are associated with proposing dynamic organizational processes, making resource reconfigurations and obtaining competitive advantage (Teece *et al.*, 1997). SCR has thus been termed a dynamic capability (Dabhilkar *et al*., 2016; Chowdhury and Quaddus, 2017; Chari *et al*., 2022), encompassing sensing, resource reconfiguration, and transformation, triggered by environmental changes. This in turn enables a better prediction of supply chain operational vulnerabilities and the development of sustainable supply chains. Other theories applied to SCR include contingency theory (Treiblmaier, 2018), structural contingency theory (Drozdibob *et al*., 2022), complexity theory (Gunasekaran *et al*., 2015), and social exchange theory (Stevenson and Busby, 2015). Some mathematics-oriented theories, such as control theory (Dolgui *et al*., 2018) and game theory (Zahiri *et al*., 2017), are also applied to the SCR field. A comprehensive analysis of SCR-related theories can be found in Ali and Gölgeci (2019).

Due to the recent nature of the COVID-19 pandemic, relatively few theories have been applied to this context, with most of the studies being exploratory. Exceptions include Yu *et al.* (2021), who use organizational information processing theory to explore the impact of COVID-19 on supply chain integration in a hospital context, and Ketchen and Craighead (2020), who adopt resource orchestration theory to identify the relationship between entrepreneurship, supply chain management, and strategic management. More recently, Gebhardt *et al.* (2022) adopt resource dependence theory and find that firms prefer bridging rather than buffering approaches as long-term responses to build SCR. We encourage further research by the application of additional theories to the context of SCR during the pandemic and beyond. Craighead *et al.* (2020) provide guidance in this regard.

3.5. Post supply chain disruption

This topic focuses on how to reduce the effects caused by supply chain disruptions and evaluates the impact of SCR. Specifically two clusters were identified, with the first one focusing on risk mitigation, and the second one on operational and financial implication of SCR.

3.5.1. Risk mitigation

Papers classified under this topic focus on the adoption of effective mitigation strategies to manage SCR with an accuracy of up to 67.75% (Figure 12(a)). This is consistent with the word cloud that highlights the importance of "risk" and "mitigation" (Figure 12(b)).

Literature in this cluster provides guidance in the form of conceptual models to mitigate supply chain risks (e.g., Jüttner, 2005; Tang 2006a), complemented with papers on risk reduction capabilities. For instance Craighead *et al.* (2007) note that the effect of a supply chain disruption's severity is determined by three characteristics of supply chain design (i.e., density, complexity, node criticality), and Faisal *et al.* (2006) identify essential drivers for the mitigation of supply chain risk (i.e., supply chain agility, information sharing, trust, and collaborative relationships). In a similar vein, Christopher and Lee (2004) explore the role of alignment, adaptability, and agility. As such, alignment can address long-term risks, adaptability can help with medium-term risks, and agility with short-term risks (Tang and Tomlin, 2008).

Within the context of the COVID-19 pandemic, Nakamura and Managi (2020) argue that a more specific understanding of the short- and long-term implications of COVID-19 needs to be developed, to truly understand what it means for risk assessment. This would strengthen the mitigation capabilities of the supply chain for future events (Kochan and Nowicki, 2018). The unpreparedness that many firms have been struggling with is a testament to the fact that more foresight would have been in order, to at least be prepared that something could happen. Since this was not present, many firms were caught off-guard by the pandemic, leading to an unprecedented number of bankruptcies (Butcher, 2020).

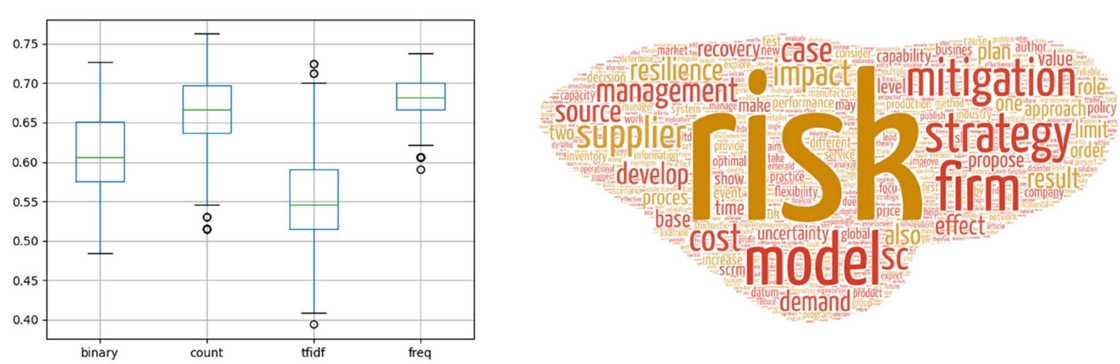
3.5.2. Operational and financial implication of SCR

Papers classified under this topic mainly focus on the impact of SCR on the operational and financial performance of a company or a supply chain. A total of 92 papers were identified to belong to this cluster. The median accuracy is up to 75.00% (Figure 13(a)). For this cluster, the terms "impact", "performance", "financial" and "stock" were dominant, which capture the theme of various disruptions and their financial implications (Figure 13(b)).

A subset of studies in this cluster explore how to manage supply chains facing production and demand disruptions, as well as the ensuing impact on overall higher costs (Soleimani *et al.*, 2016). Literature in this sample identified two approaches with which these disruptions can be managed: channel selection and contract design. For example, based on a closed-loop supply chain, Han *et al.* (2017) demonstrate the benefits of using a direct channel, whereas Xiao and Qi (2008) identify conditions under which discount contracts can be used to coordinate supply chains.

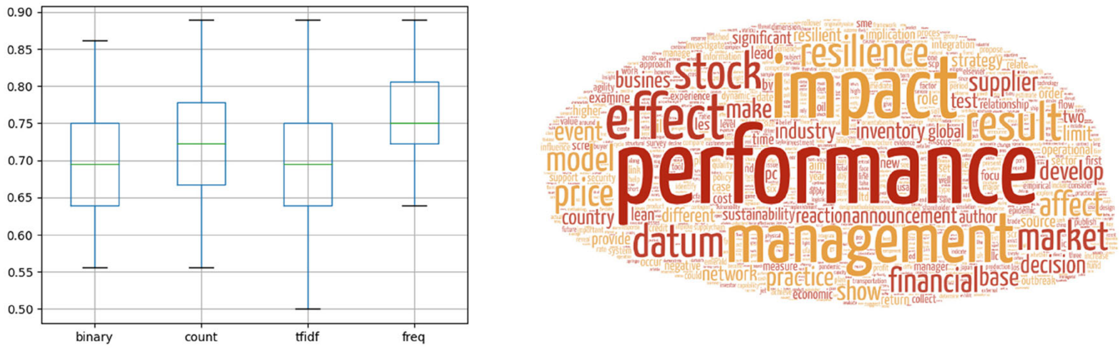
Impacts associated with distribution and logistics disruptions were also a theme in this cluster. Taking the trucking industry in the UK as an example, McKinnon (2006) demonstrates that a transportation disruption has the potential to collapse industrial, commercial, and welfare systems. Safety stock is unlikely to afford much protection in these instances, necessitating the building of redundancy into logistical systems, diversifying the supply base, and monitoring shipping lanes in intermediate countries (Calatayud *et al.*, 2017).

Studies in this cluster further illustrate the significant effect of supply chain disruptions on shareholder wealth. In most cases, associated negative effects are long-term (Hendricks and Singhal, 2005), but can vary by company. The effect of supply chain disruptions can also be related to the size of the company, with larger firms having higher growth rates that may be subject to a more negative reaction (Hendricks and



a) Classification accuracy b) Word cloud

Figure 12. Risk mitigation.



a) Classification accuracy b) Word cloud

Figure 13. Operational and financial implication of SCR.

Singhal, 2005). In addition, compared with firms that adopt a make-to-forecast approach, firms that adopt a make-to-order approach are less vulnerable during an abrupt supply disruption. A classic example is Dell's performance after the 1999 Taiwan earthquake. The sizable loss due to the price increase of memory components led to a significant decrease in the company's stock price (Papadakis, 2006).

More recently, during the COVID-19 pandemic, a surge in demand for personal computers and other electronics for work or school led to a supply shortage for chips, which threatened the production of products such as game consoles, TVs, smartphones, tablets, and smart cars (CNBC, 2021). Different dynamics also emerged during the pandemic, for instance, the significant increase in business for online companies such as Amazon and Ocado. In contrast, traditional brick-and-mortar stores have been struggling, due to the lack of customers that now rather go online for their shopping needs. This offers a formidable foundation to conduct research into how the future of online versus offline business may look like as we are moving out of the pandemic situation.

3.6. Current status of the SCR literature related to the pandemic

In addition to the exposition of the 11 clusters, we want to draw attention to the current overall status of the SCR literature within the context of COVID-19, including the early (i.e., ∼2020) and later (i.e., ∼2021 to date) stages of the pandemic. In the early stages of the pandemic, scholars made inroads to investigate this new reality by identifying associated challenges via primarily mathematical modelling and theoretical contemplations. For example, in the mathematical modelling domain, Ivanov and Dolgui (2021) integrate viability into an intertwined supply network by adopting a dynamic game-theoretic modelling approach to respond to COVID-19 challenges. Similarly, Ivanov (2020a) adopts a dynamic game-theoretic modelling approach to assess the viability of a supply chain, deriving insight that can be valuable for decision-makers to create SCR. Although Ivanov (2020b), through a simulation-based analysis, finds that the up-stream disruption duration or the speed of COVID-19 spread does not impact supply chain performance, he also finds that the timing of closing and opening of facilitates at different echelons can contribute to it. Ivanov and Das (2020) model the ripple effect of COVID-19 by considering factors such as the velocity of the COVID-19 spread, the duration of production, distribution, and market disruptions, and a demand decline, providing a path for firms' recovery. Taking a theoretical perspective, Remko (2020) proposes a conceptual framework, involving supply, demand, and control risk, to provide a potential path for SCR research (Pournader *et al.*, 2020). Craighead *et al.* (2020) review 10 theories to help scholars build knowledge about the impact of COVID-19 on SCM. In addition, El Baz and Ruel (2021), by using a survey, examine the role of supply chain risk management in reducing the impact of COVID-19 on SCR and robustness. Specifically, they identify the mediating role of supply chain risk management practices, including risk identification, risk assessment, risk mitigation, and risk control, which are found to be relevant in the development of SCR and robustness.

In the later stages of the pandemic, overall, we observe in our sample that scholars have gradually begun to empirically examine SCR more thoroughly within the pandemic context (Ergun *et al.*, 2023). Specifically, studies focused on examining how approaches need to be adapted to this new reality in order to remain resilient. For example, cultivating new strategies and technologies carry great promise as effective ways to develop SCR. In this vein, Munir *et al.* (2022) argue that a combination of improvisation and anticipation strategies can enhance SCR and responsiveness during the COVID-19 pandemic. In addition, the application of new technologies, such as big data (Behl *et al.*, 2022; Papanagnou *et al.*, 2022), AI (Dubey *et al.*, 2021; Modgil *et al.*, 2021), and blockchain (Kazancoglu, Ozbiltekin-Pala, Sezer, Luthra and Kumar, 2022; Li, Xue, Li and Ivanov, 2022), can serve as effective approaches for firms aiming to improve SCR in a post-pandemic world.

Undoubtedly, the reviewed studies represent a significant step toward the investigation of SCR within the COVID-19 context. However, due to the ongoing nature of the pandemic, it is not yet clear what the true and long-lasting impacts of COVID-19 on SCR will be, particularly considering the many unknowns that the pandemic has brought to bear, including new capabilities that may be essential to

Table 2. Capabilities to enhance SCR in the post-COVID world.

	Interconnectedness	*Transformability*	*Sharing*
What	A capability to align with stakeholders to derive a synergistic value proposition	A capability to transform existing production systems to better meet customer needs	A capability to absorb idle resources and utilize them to manage resource shortages
Why	Interconnecting with supply chain members and other stakeholders can facilitate information sharing, enabling improved communication, coordination, and collaboration	Faced by the negative effects brought by global shocks, firms should focus on the most critical customer needs first to ensure stability	Global shocks lead to various resource wastes, also in terms of labor. Firms should thus aim to best collectively leverage an idle workforce to improve their competitive advantage
How	Using ICT, such as Internet of Things (IoT) sensors, to improve the interconnectivity among dispersed resources	Leveraging ICT, such as big data, to gain visibility into supply chains to understand the market and predict customer demand.	Enhancing the coordination across and within supply chains to leverage idle resources

achieve continued resilience. Moreover, with the identified 11 clusters providing a thorough snapshot of the past SCR literature, including several relevant works conducted within the pandemic context, we believe that this area is ripe for further research. This is particularly true as firms and supply chains are now aiming to identify how to navigate a post-pandemic environment. Therefore, motivate the exploration of these avenues, we elaborate in the next section on three capabilities that were brought to the fore in particular during the pandemic, and that may play a central role in strengthening a firm's SCR in the future.

4. Discussion

Building on the analyses described in the preceding sections, we propose three key capabilities that firms should focus on to enable them to cope better with future pandemics or other global shocks of similar magnitude and impact: interconnectedness, transformability, and sharing. In the following, we describe each capability and discuss ways in which it can be further developed for enhanced SCR. Table 2 summaries the capabilities, why they are important, and how they can be enhanced in a post-pandemic world.

4.1. Interconnectedness

To mitigate the negative effects brought by global shocks, it is necessary for firms to develop their interconnectedness (Hartmann and Herb, 2015) as a capability to enhance linkage between actors, both within and across supply chains. This can be achieved by leveraging for instance ICTs and inventory buffers. We note though that interconnectedness is different from resilience capabilities, captured for example in cluster 2. We consider interconnectedness as an enhanced level of integration with which unprecedented events like the current pandemic can be better managed. Such capability would enable firms to quickly respond. We illustrate the concept of interconnectedness within two contexts.

Interconnectedness with supply chain partners: Rather than navigating the pandemic's repercussions independently, collaborating with supply chain partners on both the supply and demand sides is prudent, as this can lead to improved supply chain transparency and enable greater responsiveness. For example, by leveraging big data analytics, Amazon can determine which items are most needed by customers, which was particularly useful in the early stages of the pandemic (Marr, 2022). As such, Amazon strategically allocated its resources by reconfiguring its product structure with an emphasis on essential items, such as toilet paper and disinfectants, which was only possible through enhanced interconnectedness with its suppliers and the deep insight on the demand side.

Interconnectedness across supply chain partners: Establishing interconnectedness with partners outside a firm's direct supply chain or industry can also yield significant value. For example, when COVID-19 first broke out in Wuhan, there was not sufficient hospital bed capacity to meet the needs, and thus two new specialized hospitals (i.e., Huo-shen-shan and Lei-shen-shan hospital) were built in record time. This was only possible due to the interconnectedness of partners across the supply chain. Specifically, China Construction Third Engineer Company, a state-owned construction company responsible for building the Huo-shen-shan hospital, enhanced its interconnectedness by collaborating with firms in different supply chains to carry out the project. For instance, China Mobile and China Telecom provided information and communication support, including a 5G base station, and a sophisticated communication network and lines. In addition, Huawei not only assisted in building the 5G base station, but also created a technical telemedicine system integrating 5G and IoT so as to further support the construction of the Huo-shen-shan hospital. By enhancing the interconnectedness with partners across different supply chains, the hospital was completed within ten days.

4.2. Transformability

Transformability is a capability that senses change, triggered by environmental dynamics and uncertainties, and then quickly transforms a firm's footprint and setup to respond to associated challenges (Craighead *et al.*, 2020). Transformability can be viewed as a new network design model to respond to the pandemic and mitigate the risk. It can also be considered as a concept that is different to traditional network design models and other mitigation approaches summarized in clusters 1 and 3, respectively. Overall, since the impacts of COVID-19 on firms and society overall cannot be eliminated and controlled in the short-term, firms need to develop new business models, which have at its core transformability, which in turn can strengthen their SCR.

Transformability focuses on a more sustainable way to enhance SCR, which carries great promise for a better response to unexpected shocks like COVID-19 (Guan *et al.*, 2020). This is also emphasized by Sarkis (2020), who stresses the need to address sustainability issues so as to improve SCR. As such, we view transformability as inherently relying on economic, environmental, and social sustainability. Consider the following examples. According to Baijiahao (2020), Wuling, a Chinese car manufacturer, was faced with limited customer demand triggered by the pandemic. To deal with this challenge, the firm transformed its minivan production line into a mask machine production line. This yielded in the provision of much-needed supplies (i.e., masks) to society, reducing the shortage of personal protective equipment and creating significant social value, but also in the sustainability of the firm's daily operations. This ability to pivot was indicative of their resilience. Another example provides Penderyn, a popular whisky distillery in Wales, which stopped producing whisky to produce hand sanitizer (Wales Online, 2020). Similar to Wuling, through the transformation of its operating model, Penderyn demonstrated its resilience, not only making up some of the lost revenue from dwindling whisky sales, but also contributing to society by the provision of vital necessities.

4.3. Sharing

We define sharing as the utilization of idle resources to meet customer needs, enabled primarily by supply chain integration (Yu *et al.*, 2021), which also includes collaboration across supply chains. As an example for this capability serves Hema, a grocery supermarket by Alibaba, which experienced demand surges and labor shortages. To respond to this issue, Hema shared employees by collaborating with various firms (i.e., Xibei and Yunshuiyao) in different supply chains (i.e., the restaurant supply chain) (Jia *et al.*, 2020). Specifically, employees from these restaurant chains would temporarily work for Hema without losing their previous job, with Hema paying the salary. Hema's supply chain was consequently strengthened by absorbing this idle labor force, enhancing its delivery capability, avoiding a backlog of raw materials, and simultaneously lowering labor costs by sharing their staff. Another example is provided by the hotel chain Hilton, which also collaborated with firms that were suffering from labor shortages, such as Albertsons, Amazon, CVS, Lidl, Sunrise Senior Living, and Walgreens (ABC News, 2020). Similar to Hema, Hilton was able to save money and retain their employees in times of low demand, while at the same time helping firms in other industries with their labor shortage.

Sharing can also strengthen the buyer–supplier relationship. For example, JDH, a financial services platform in China, adopts mobile and blockchain technology to not only evaluate creditworthiness of buyers, but also predict the volume of idle capital resources of suppliers, providing qualified match-making services to both actors in the supply chain (Kuaibao, 2020). Consequently, buyers can use this to manage challenges associated with COVID-19, with suppliers still able to obtain economic returns. This shared financial foundation has strengthened the supply side and improved buyer–supplier relationships, in addition to reducing the risk of supply disruptions caused by suppliers' financial stress. This last example demonstrates the importance of ICTs, which form the core of the sharing economy business model (Jia *et al.*, 2020). This capability is especially related to the supply and demand sides, enabling aspects such as supplier coordination and behavioral supply chain risk management.

5. Conclusion

While the COVID-19 pandemic has been posing significant challenges for OSCM, it also provides intriguing research revenues for SCM scholars in the post-COVID world. In this article, we reviewed 1717 papers related to SCR and classified them into 11 clusters, which are further backward tested via a supervised machine learning approach. Furthermore, we examined these studies within the context of the pandemic, and proposed three important capabilities (i.e., interconnectedness, transformability, and sharing) that firms are encouraged to foster for improving their SCR.

Overall, the contributions of this article to the SCR literature are two-fold. First, to the best of our knowledge, this is the first study to adopt a supervised machine learning method to help conduct a comprehensive thematic analysis of a large quantity of the SCR literature review (i.e., 1717 papers). As such, we follow the lead by Zhang *et al.* (2020), who also used a machine learning approach to provide invaluable insight into the area of operations management research (focusing on managing flows and needed capabilities). Analogous to their contributions, our work identified underlying themes based on the existing SCR literature. An advantage of the machine learning approach is that it can help justify the accuracy of classifications. As such, review methodologies applied in the past pursued a content analytic approach that heavily relies on scholars' manual input, which is inherently subjective (Hohenstein *et al.*, 2015; Ali *et al.*, 2017) and is challenged when dealing with a large quantity of literature. Another approach applied in past review studies is the bibliometric method (Ali and Gölgeci, 2019; Hosseini *et al.*, 2020; Pournader *et al.*, 2020; Xu *et al.*, 2020) applying citation and reference co-citation analyses (Chen *et al.*, 2016) facilitated by VOSview (Ali and Gölgeci, 2019). Although this approach is able to process a large amount of literature, the inherent relationships among clusters needs to be further justified (Pournader *et al.*, 2020). In contrast to these two approaches, the method employed in this article combines traditional approaches with supervised machine learning, which generates a more comprehensive and objective assessment of the current state and future development of SCR.

Second, we explored SCR by overlaying the review with the characteristics inherent to COVID-19. More specifically, to achieve resilience, previous studies argue that it is essential for firms to develop certain operational capabilities, such as flexibility (Sheffi and Rice, 2005), visibility (Ivanov and Sokolov, 2013), robustness (Brandon-Jones *et al*., 2014), agility (Yang and Hsu, 2018), and redundancy (Sheffi and Rice, 2005). Ideally, these aspects should be pursued with supply chain partners to be able to better manage dynamic changes and uncertainties (Christopher and Peck, 2004). Complementing these works and stressing the impact of COVID-19 on the need to build SCR, we proposed three essential capabilities, i.e., interconnectedness, transformability, and sharing, that can help firms develop SCR to counter the global shocks in the post-COVID world.

By reviewing the existing SCR and COVID-19 literatures, this study also offered several future research avenues, providing guidance and direction for scholars interested in continuously exploring the development of SCR in the post-COVID world. First, we believe that the noted three capabilities are in need of further investigation. As such, the three capabilities were identified by conceptualizing the spherical features of COVID-19 combined with the SCR literature, and thus their investigation should be invaluable within our current context. Second, SCM scholars have illustrated how to utilize ICTs, including big data (Mishra *et al*., 2018) and blockchain technology (Min, 2019), to reduce supply chain risks and build SCR. However, we believe there is a significant opportunity to enhance ICT capabilities even more to foster SCR in the post-COVID world. Therefore, future research should explore the role of ICT for the design of effective and flexible mechanisms to accurately predict, effectively respond, and rapidly recover. Third, previous SCR literature notes the benefits of building a resilient supply chain, while the cost of building such resilience is often overlooked (van der Vegt *et al*., 2015). Specifically, although activities, such as buffer inventories and excess capacity, can significantly improve SCR, the cost implications cannot be neglected. Thus, future research should revisit such cost challenges, which may not pose as much of an obstacle than before, given the significant losses incurred by companies by not being better prepared during the current pandemic.

Being one of the first studies applying machine learning to review the SCR literature, this research is not void of limitations. First, the data is sourced from the core collection of Scopus, which may lead to deviations in the results. Future research is encouraged to include more databases in the review, such as WoS and EBSCO (Xu *et al*., 2020). Second, we only selected papers written in English, which may have led to the omission of important knowledge, given the rapid development of SCR research. A further valuable future extension lies in the incorporation of other analytical methods to improve the literature analysis. For example, network analysis can be employed to identify the relationships between various clusters and examine the characteristics of key themes within the SCR literature.

Acknowledgments

Comments and guidance provided by Department Editor Professor Jennifer Ryan, the Associate Editor and two anonymous reviewers have significantly improved this article.

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