COVID-19 and global supply chain risks mitigation: systematic review using a scientometric technique

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Abstract

Purpose – This paper aims to investigate how manufacturing firms behave to mitigate business risk during and post-COVID-19 coronavirus disease (COVID-19) on the global supply chain.

Design/methodology/approach – A systematic literature review for data mining was used to address the research objective. Multiple scientometric techniques (e.g. bibliometric, machine learning and social network analysis) were used to analyse the Lens.org, Web of Science and Scopus databases' global supply chain risk mitigation data.

Findings – The findings show that the firms' manufacturing supply chains used digitalisation technologies such as Blockchain, artificial intelligence (AI), 3D printing and machine learning to mitigate COVID-19. On the other hand, food security, government incentives and policies, health-care systems, energy and the circular economy require more research in the global supply chain.

Practical implications – Global supply chain managers were advised to use digitalisation technology to mitigate current and upcoming disruptions. The manufacturing supply chain has high uncertainty and unpredictable global pandemics. Manufacturing firms should consider adopting Blockchain technology, AI and machine learning to mitigate the epidemic risk and disruption.

Originality/value – This study found the publication trend of how manufacturing firms behave to mitigate the global supply chain disruptions during the global pandemic and business uncertainty. The findings have contributed to the supply chain risk mitigation literature and the solution framework.

Keywords COVID-19, Supply chain, Technology, Systematic literature review, Machine learning, Social network analysis

Paper type Literature review

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1. Introduction

The dependency on China's dominant suppliers has made most global manufacturing firms face difficulties dealing with shortages of raw materials and spare parts during the COVID-19 pandemic. In late January 2020, when the first wave of the COVID-19 epidemic began, manufacturing firms had difficulty getting raw materials, manufacturing and supplying products to the market. As a result, some manufacturing firms are accruing losses or even closure. The COVID-19 pandemic in China has disrupted global supply chains, and product scarcity has increased prices tremendously. The complexity of the business process, geographical and cultural distance, numerosity and multiple suppliers characterise the global supply chain (Koberg and Longoni, 2019).

The global supply chain involves multiple companies working together to produce and distribute products or services to the end users. Some products are manufactured, assembled and marketed in numerous countries. According to Fernando and Wulansari (2021), global supply chain managers must have a proper strategy to ensure firms meet their objectives during vulnerability. Ozdemir *et al.* (2022) argued that firms need to be innovative to manage supply chain resilience, and larger firms tend to be more effective in handling the supply chain risk disruption. Moktadir *et al.* (2023) argued that data-driven predictive supply chains and Internet of Things (IoT)-based communication platforms are critical technological drivers during the COVID-19 pandemic. Khan *et al.* (2022) postulated that effective supply chain alignment, adaptability and agility could improve post-COVID disruption performance. Innovation and empowerment were the critical domains of managing supply chain disruption during the crises. In addition, a strong relationship with employees and suppliers can enhance supply chain resilience (Ozdemir *et al.*, 2022). Nonetheless, previous studies on the manufacturing supply chain in dealing with COVID-19 have focussed on a single sample country setting. A comprehensive study with an extensive data set is required to understand past and post-COVID-19 global supply chain risk mitigation trends.

The recent epidemic has severely hit the global supply chain, and industries are struggling to meet market demand, especially for medical equipment. Academics have encouraged the exploration of proper guidelines to solve technical issues (Inoue and Todo, 2020). Most journals in technology, operations, logistics and supply chain management (SCM) are calling for a solution to the business impact of COVID-19 (Dohale *et al.*, 2022). Ivanov (2020) argued that much uncertainty exists because of the pandemic, and firms need to prepare their pandemic framework to guide their global supply chain strategy and direction. Technology, good governance, coordinated society behaviour and health-care service support can mitigate the uncertainty risk (Elavarasan and Pugazhendhi, 2020). Govindan *et al.* (2020) have developed a decision support system to mitigate the impacts of epidemics on the health-care supply chain. They proposed that more studies should look at controlling disruptions in the supply chain network.

SCM significantly influences how emerging technologies are adopted and integrated inside organisations (Wamba *et al.*, 2020). Evaluating and selecting the best technologies for a company's supply chain operations is critical for SCM specialists (Wang *et al.*, 2020). Some elements worth considering include price, scalability, integration potential and consistency with corporate goals. Additionally, SCM uses cutting-edge technologies such as Blockchain, the IoT and advanced analytics to improve visibility and transparency throughout the supply chain (Farouk *et al.*, 2020). SCM improves decision-making, lowers inefficiencies and raises customer satisfaction through inventory management, production process monitoring and logistics optimisation. SCM ensures that emerging technologies are applied efficiently, boosting operational effectiveness and reducing costs (Moons *et al.*, 2019).

Automation, robotics and sophisticated analytics technologies enhance warehouse operations, shipping and demand forecasting, leading to increased effectiveness and lower costs (Modgil *et al.*, 2022). SCM enables smooth collaboration between various supply chain stakeholders by integrating emerging technology with current systems and processes. A shared real-time data sharing, collaboration and coordination platform are offered via cloud-based platforms and online markets (Nandi *et al.*, 2020). SCM uses cutting-edge technologies to increase flexibility and adaptability in response to shifting market conditions. Organisations have proactively responded to client requests, optimised inventory levels and modified production and distribution plans through data analysis, pattern recognition and predictive capabilities (Oly Ndubisi *et al.*, 2005). Therefore, SCM is essential to successfully adopting and integrating developing technologies, which enhance supply chain performance and give businesses a competitive edge.

The COVID-19 pandemic has underscored the critical need for research on COVID-19 and the mitigation of supply chain risks on a global scale (Golan *et al.*, 2020). A comprehensive study is essential to be conducted and understand the profound impact of COVID-19 on global supply chains. The pandemic disrupted supply chains worldwide through factory closures, transportation restrictions, labour shortages and demand fluctuations. Conducting thorough analyses of these disruptions and their effects on different industries, regions and supply chain stages is critical. Additionally, scholars should investigate the vulnerabilities that were exposed and examine how disruptions propagated throughout the supply chain.

This study's contributions are discussed as follows:

- This paper has focussed on the impact of the adoption of emerging technology in SCM to mitigate risk and business disruptions. Lack of literature to investigate the role of technology comprehensively in mitigating the unpredicted pandemic that makes it unique compared that existing studies.
- COVID-19 has impacted the global supply chain. It has disrupted the supply of raw materials and distribution mainly when the manufacturing supply chains depend on a single country of origin. However, there is no consensus in the literature on the best model of supply chain resilience to overcome the impact of COVID-19 and post-pandemic.
- Khan *et al.* (2022) found that smart technologies can be useful in overcoming the COVID-19 impact on global supply chain performance. However, the findings have a limited scope focussing only on manufacturing firms' performance in Pakistan. The applicability of the proposed model is not yet tested in other countries' settings. As a result, there is a need to research how manufacturing firms behave to reduce the risk of COVID-19 on the global supply chain.
- Dohale *et al.* (2022) argued that firms could utilise the humanitarian supply chains (HSC) to mitigate various types of supply chain risk during the COVID-19 pandemic. Unfortunately, the findings are hard to generalise as the barriers of HSC were obtained from six Indian respondents. We argue that using large data analysis to validate the research model can overcome the small sample size issues. Our study has contributed to understanding the research patterns based on the extensive sample data using multiple scientometric techniques. Our proposed model can shed light on strengthening the supply chain risk mitigation theory and understanding global supply chain resilience more.
- Although the previous study has discussed the finding related to company response to the COVID-19 pandemic, Ali *et al.* (2022) argued that research gaps on elements of supply chain resilience within the more complex global value chain networks still

have been debated in the literature. Therefore, there is a need to study how critical technological adoption is able to mitigate supply chain disruption during and post-COVID-19. We argue that the study on risk mitigation in the global supply chain can be managed if the firms are aware of emerging technology to monitor the current and future risks.

- This current study is among the early works published on COVID-19 risk mitigation strategies using multiple scientometric techniques during and post-COVID-19. Accordingly, by investigating supply chain technology, this study contributes to the risk management literature on the effects of COVID-19 and global supply chain disruptions. We argue that our study has contributed to extending the supply chain mitigation literature and solution framework.

The structure of the paper is as follows. Section 2 discussed the literature review section, followed by the systematic procedure of a scientometric analysis in Section 3. The results, discussion and implications are presented in Sections 4, 5 and 6, respectively.

2. Literature review

The global supply chain is derived from the SCM concept, which states that a company must manage its vertical integration processes and activities, such as product movement, information flow and financial flow, throughout its horizontal operations. It has started to manage suppliers, production, distribution and warehousing and logistics for superior performance (Fernando *et al.*, 2022; Mentzer *et al.*, 2001). However, the definition and scope of the global supply chain are broader than the conventional supply chain, including inter-organisational relationships with the international network of firms (Thürer *et al.*, 2020). Thus, this study defined a global supply chain as a network of local and international firms participating in product or service development, manufacturing, distribution and offering better service value that manages the resource efficiency at each level of the supply chain. It is included supplier selection, product design, production process, distribution network and logistics.

External forces influence a global supply chain network and business environment (Chu *et al.*, 2020). For example, the capability of its partners in the network to carry out the objective of the supply chain and the impacts of politics, economy, society, technology, environment and laws are some of the external forces in a supply chain network and global business environment (Antonini *et al.*, 2020). Firms in a supply chain network can come from local and international firms, which participate in exchanging information, financial flow and products or services. These firms are involved in activities or practices ranging from supplier management to product design and development, production process, distribution and warehousing and logistics.

Supplier management involves selecting local or international suppliers and ensuring the supplier has relevant qualifications or certification (Ghode *et al.*, 2020). After selecting a supplier to supply raw materials, the following process is manufacturing a product. Product design practice entails identifying product features and deciding on the material for product development (Reche *et al.*, 2020). The production process begins when the materials have been received from a supplier. Production involves using efficient equipment or machinery and energy source decisions (Böttcher and Müller, 2015). After a product is manufactured, it is stored at a warehouse and distribution. This process is called distribution, and firms need to monitor the supply chain flow, where firms in the network are concerned with packaging the product and storage management (Demirkıran and Dizbay, 2020). The last process in the supply chain is logistics management, where firms in a supply chain network are concerned with the transportation of the product (Klemeš *et al.*, 2020). Due to the COVID-19 pandemic, the global supply chain has been heavily affected. At the time of this research, the COVID-19 literature is beginning to grow, and there is considerable evidence of COVID-19 impacts on firms' global supply chains.

Businesses that depended heavily or solely on China's production of parts and materials were the most vulnerable as the output of Chinese factories declined for months. The coronavirus outbreak in Wuhan, China, disrupted the global supply chain and Chinese exports (Araz *et al.*, 2020). This pandemic has had the largest impact on the global supply chain. Many supply chains became clogged or broken at different stages ranging from lockdowns and sanitisation procedures in different countries. Thus, the struggle against the coronavirus has broken the supply chain of raw materials, products and operations and impacted human resources availability. The impact of COVID-19 widespread is crystal clear and even to average consumers who cannot find typical products on market shelves.

Transportation, tourism and retail are among the industries of interest. Other than enterprises, China is expected to release a survey on the sector's growth that may better address current economic constraints. A chain of shops, restaurants and theatres is expected to fall in sales, especially as people take precautions against coronavirus infection by not being in a crowded areas. The situation worsened as many traders closed their operations after authorities announced additional leave to curb the spread of the disease. In the aftermath of the pandemic, governments have begun issuing economic stimulus packages to help industries that COVID-19 directly affects to ensure that a country's economy remains stable and that no industry or company will fail. Such measures have included stimulus packages in the USA and other countries.

2.1 Global supply chain risk mitigation

There are four main strategies to mitigate risk:

(1) identifying and accepting the risk toward the organisation;

(2) avoiding the risk;

(3) controlling the risk so it will not spread or become uncontrollable; and

(4) monitoring the threat.

Identifying the risk requires an organisation to select the appropriate method before accepting the risk. For example, a study by Wu *et al.* (2023) on automotive technology methods to instantaneously identify risk found that machine learning and deep learning were able to reduce traffic conflicts and turbulence risks effectively. While technological tools can effectively identify risks, we argue that it is insufficient without a proper framework to identify and assess risks. A study by Iaiani *et al.* (2023) investigating past incidents regarding cybersecurity using two rigorous frameworks to identify major accident hazards and operability issues found that integrating both frameworks can provide better support in the characterisation of the facility, threat assessment, vulnerability assessment and countermeasures identification.

Once risk identification is completed, organisations can avoid the risk by integrating the whole supply chain network for information sharing, collaboration and innovation. The integration is made possible by digitising key activities (Soelistijanto and Siringoringo, 2023). Similarly, a study by Wang *et al.* (2023) successfully predicts that despite several unavoidable financial risks, waiting for a certain period before expanding can reduce the investment problem, cost and exposure. Controlling can be completed by selecting the best strategy according to the situation or type of risk. The data visualisation is frequently used for risk monitoring and to verify that organisational performance fulfils the stakeholders' and shareholders' expectations. For example, Galeone *et al.* (2023) found the significant use of reporting business models to mitigate climate change and improve sustainability. Additionally, Allal-Chérif *et al.* (2023) found that supply chain integration and digitisation are key to business sustainability. All these findings show the importance of managing supply chain networks and technology when dealing with risk.

Literature findings were also like the understanding of resilience theory. Resilience theory explains how individuals or organisations recover from failure or adversity and overcome the failure to grow. Several studies have confirmed that resilient organisations can sustain their businesses (Farsari, 2023; Salem *et al.*, 2023) even recovering from COVID-19 through sustainable business models and technology (Jiang *et al.*, 2023; Guan *et al.*, 2023). Therefore, this study proposed that the global supply chain can recover from the COVID-19 pandemic and future similar pandemics through risk mitigation strategies, including technology and a good business model.

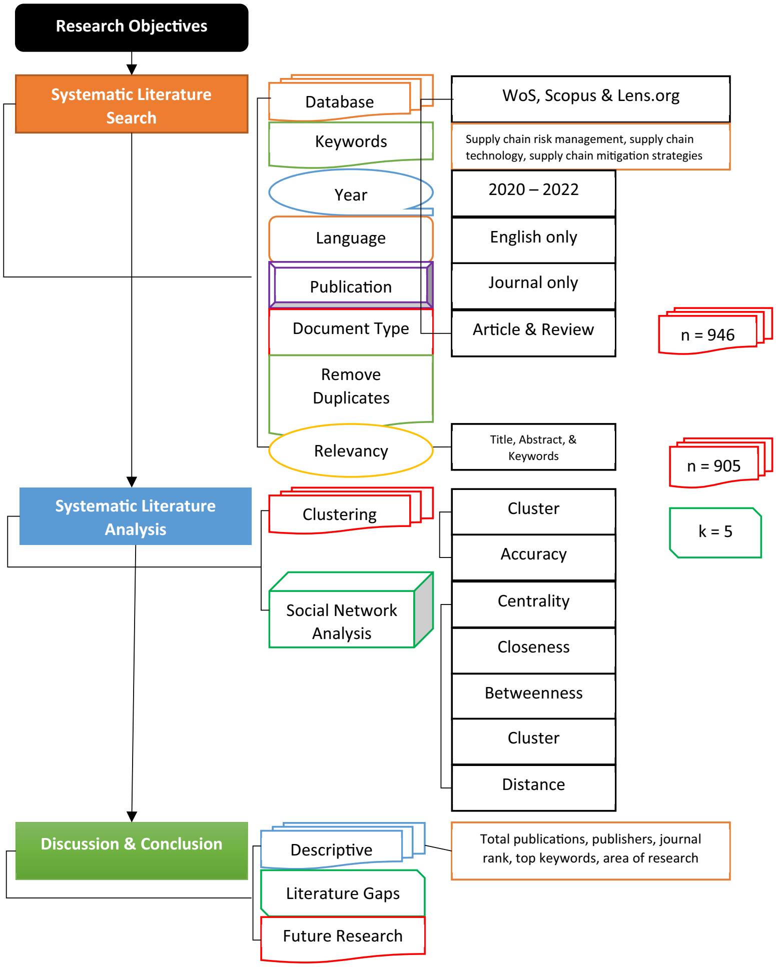
3. Methods

We conducted a systematic literature review using scientometric analysis. We have incorporated the bibliometric, machine learning and social network analysis data mining approach to answer the research objective. Figure 1 shows the systematic literature review procedure adapted from Shaharudin *et al.* (2019). This study started by identifying the research objectives to investigate how the firms handle risk mitigation strategies in the supply chain during the COVID-19 pandemic. A systematic literature review was conducted, with the database selected based on high-quality peer-reviewed journals. We have retrieved the published papers indexed in the Web of Science, Scopus database and Lens.org. The papers indexed in Scopus contributed from over 7,000 global publishers (Elsevier, 2022), and the Web of Science has major indexes in science and technology. Both databases have consistently been reviewed and selected to avoid predatory publishing and integrity issues. We have selected papers from Lens.org because the database is among the most extensive academic records. It comprises over 197 million scholarly journals from Microsoft Academic, Crossref and PubMed. In addition, the Lens has recorded over 111 million patent records (Tay, 2018).

To understand how firms dealt with the impact of COVID-19, we only used keywords related to supply chain risk management, supply chain technology and supply chain mitigation strategies. These keywords were aligned with the research objective to investigate risk mitigation strategies on how firms recover from the COVID-19 pandemic. While an individual firm can be part of the study, we hypothesised that its impact is dissimilar to the supply chain network. Additionally, the literature review pointed towards technology being significantly related to risk management and assessment. Thus, we have included the keyword in our findings supported by resilience theory.

In addition, we only selected English peer-reviewed articles published from 2020, when the pandemic started, until October 2022. It ensures that only relevant, timely and high-quality articles are gathered. The non-journal articles have been excluded from the analysis. Articles published and indexed in Web of Science, Scopus and Lens.org represent the quality and exclude predatory journals. After removing the duplicates from both databases, we identified 946 documents that met the selection criteria. The title, abstract and keywords served as inclusion criteria. Some of the articles we discovered were editorial papers. We excluded those papers from the analysis, leaving only 905 documents.

After the data entries, the next step is to analyse the papers based on the clustering procedure. We have utilised the clustering technique using the k-means algorithm. This



Source: Authors' own work

Figure 1.
Research process

technique has been classified as an unsupervised machine learning applicable when no specific label exists on raw data. We found five clusters ($k = 5$) based on the k-means algorithm. The clustering accuracy was determined after the data successfully labelled each point according to the group (e.g. Cluster_0, Cluster_1, Cluster_2, Cluster_3 and Cluster_4).

After confirming the prediction model's accuracy, we analysed the social network. The aim is to calculate the distance between nodes or actors given the nodes' distance and the edges' weights. The nodes refer to the datapoint labelled as the cluster, and the edges were the connection each node had with other nodes. We have obtained the Euclidean distance for centrality, closeness and betweenness before providing descriptive analysis, literature gaps and future research discussions.

4. Results

Although we have identified $k = 5$ clusters, the statistical predicting power indicated three dominant clusters with a prediction accuracy of 98.86% (Table 1). It demonstrates that the model has high accuracy and prediction of the clusters. Therefore, we have concluded that the $k = 5$ clustering analysis shows sufficient evidence that the prediction model is valid and reliable (Squared_correlation: 0.700 ± 0.483; micro average: 0.932). The next step is to compute the cluster performance. The cluster performance analysis was calculated in ten steps. The steps are as follows:

(1) Retrieve the cleaned data set after a systematic literature search (Figure 1).
(2) Select attributes.
(3) Normalise the data to ensure no single attribute holds an imbalance frequency.
(4) Perform the k-means procedure with $k = 5$ as identified in the social network analysis (Figure 2).
(5) Measurement for k-means was based on Bregman's divergences, which were based on squared Euclidean distance.
(6) The cluster's label for $k = 5$ was based on the average centroid distance.
(7) After identifying cluster's label, the target role or predictor was set to the cluster's label. Thus, it is useful to measure the clustering performance.
(8) The training model was based on the k nearest neighbour algorithm with $k = 5$.
(9) We are testing the model using by applying the model input technique.
(10) Performance measures through accuracy, classification error, root mean square error and squared correlation.

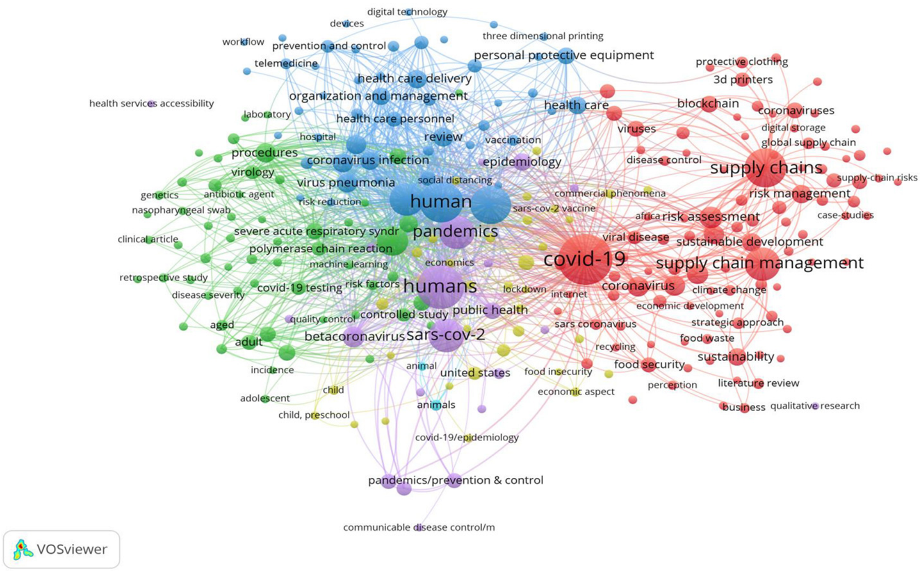
We have computed the social network analysis to measure the strength of the association between clusters. The cluster's strength depends on the weight of the edges, whereby calculating the distance between clusters. The result indicated an understanding of the closeness of each cluster (closeness) to the central cluster (centrality) and whether a certain cluster acted as a mediator or bridge to other clusters (betweenness). Table 2 shows the distance calculated for each label found after extracting the title, abstract and keywords used by authors regarding supply chain risk management, supply chain technology and supply chain mitigation strategies.

Accuracy	True cluster_1	True cluster_2	True cluster_0	Class precision
pred. cluster_1	6	0	0	100.00%
pred. cluster_2	0	5	0	100.00%
pred. cluster_0	0	2	174	98.86%
class recall	100.00%	71.43%	100.00%	
Classification error				
pred. cluster_1	6	0	0	100.00%
pred. cluster_2	0	5	0	100.00%
pred. cluster_0	0	2	174	98.86%
class recall	100.00%	71.43%	100.00%	

Root_mean_squared_error: 0.046 +/ −0.055 (micro average: 0.070 +/ −0.000)
Squared_correlation: 0.700 +/ −0.483 (micro average: 0.932)

Source: Authors' own work

Table 1.
Cluster performance



Source: Authors' own work

Figure 2.
Clustering network visualization ($n = 5$)

The degree of centrality (DC) shows the sum of weights of outbound edges from each node to all adjacent nodes. On the other hand, the DC shows the standardised index [DC divided by N-1 (non-valued nets)]. The higher the number of DC and DC', the more central the network nodes. Closeness centrality (CC) shows the distance of nodes from each other nodes. The CC' shows the standardised index (CC multiplied by N-1 minus isolates). The closer the value between CC and CC' for each node, the closer the node to the closest number obtained.

Betweenness centrality (BC) shows the role of the mediator or connector where other nodes' networks run through it. Table 2 shows that BC with a value more than 0 means that the node connects to other nodes, while 0 means that it is a standalone node or not connecting with the more extensive network. The original value shows without removing duplicate nodes to ensure that the nodes represent the real network. Modifying the network at this stage will incur a high error rate in distance calculation.

We have computed the hierarchical clustering (HCA) technique prior presented most occurrence keywords. Concerning HCA analysis, we have calculated the distance between nodes using Euclidean distance and clustered the nodes based on mean similarity. The actors or nodes are clustered together in a sequence. A more accurate representation of the network can be determined by clustering the actors.

After accomplishing the HCA analysis, we combined and removed unrelated keywords such as stop, connector and undefined keywords. Table 3 shows the highly occurring keywords with their link strength. The results show that keywords such as human, coronavirus or COVID-19, pandemic, supply chain risk, health-care policy, risk reduction, food waste and article were frequently used in the literature. According to the findings, scholars used 18 technology-related keywords and 16 method-related keywords.

Figure 3 depicts the total number of publications from 2020 to 2022, with the number of publications decreasing exponentially as the COVID-19 pandemic became endemic

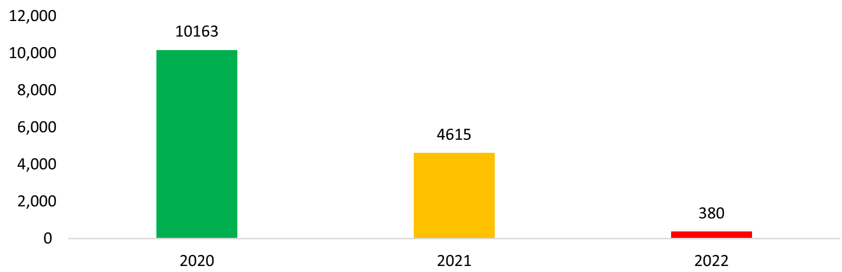
Table 2. Degree of centrality, closeness and betweenness

		Range values								
Node	Label	DC	DC'	%DC'	CC	CC'	%CC'	BC	BC'	%BC'
1–4	3D-printing	68 – 168	0.000984 – 0.002430	0.098357 – 0.151875	0.007101 – 0.012051	0.016285 – 0.027638	1.628455 – 2.763762	692 – 5394.25	0.009823 – 0.226981	0.98227 – 22.698149
5–9	Additive manufacturing	86 – 387	0.001143 – 0.005598	0.114268 – 0.559766	0.009176 – 0.013898	0.021044 – 0.031872	2.056142 – 2.765938	621 – 8009.666667	0.010526 – 0.135766	1.052614 –13.576627
10 – 18	Artificial intelligence	82 – 250	0.003616 – 0.001736	0.144642 – 0.361606	0.00593 – 0.011405	0.026156 – 0.038872	2.615607 – 3.553204	1391.083333	0.023579	2.357928
19 – 25	Blockchain technology	82 – 704	0.000463 – 0.019715	0.066536 – 1.018283	0.007981 – 0.01231	0.02477 – 0.033267	2.476974 – 3.887217	49.25 – 789.5	0.003119 – 1.131691	1.338226 – 113.169113
26 – 48	Climate change	37 – 165	0.000723 – 0.002213	0.053518 – 0.283499	0.005932 – 0.010296	0.017267 – 0.029652	1.36039 – 2.965198	0 – 1771.75	0 – 0.032884	0 – 3.288359
49 –65	Coronavirus	44 – 3709	0.000391 – 0.003558 -	0.063643 – 2.544261	0.008147 – 0.017327	0.018683 – 0.039737	1.86832 – 3.973694	0 – 21142.45833	0 – 1.012408	0 – 55.818191
66 – 84	Digitalisation	34 – 382	0.000882 – 0.001417	0.088232 – 0.500463	0.005198 – 0.014136	0.01750 – 0.031658	1.19217 – 3.241951	0 – 2	0 – 0.000034	0 – 0.00339
85 – 99	Diseases	29 – 292	0.000217 – 0.003876	0.041946 – 0.387642	0.004434 – 0.010801	0.016358 – 0.025411	1.635766 – 2.936162	0 – 336.5	0 – 0.005704	0 – 0.570378
100 –113	Epidemics	28 – 552	0.000448 – 0.002358	0.040500 – 0.798426	0.00799 – 0.015812	0.011864 – 0.036262	1.667437 – 3.626191	0 – 250	0 – 0.004238	0 – 0.423758
114 – 128	Food security	14 – 395	0.001924 – 0.002083	0.023143 – 0.571338	0.007167 – 0.012367	0.01359 – 0.032533	1.358998 – 3.310219	0 – 0.5	0 – 0.000008	0 – 0.000848
126 – 135	Globalisation	14 – 356	0.000202 – 0.001822	0.02025 – 0.514927	0.004433 – 0.013178	0.010166 – 0.029652	1.016604 – 3.022065	0 – 854.75	0 – 0.014488	0 – 1.448827
136 –168	Health issues	38 – 398	0.00055 – 0.034989	0.054964 – 0.730444	0.009664 – 0.014664	0.016399 – 0.033629	1.639939 – 3.362906	0 – 40.5	0 – 0.000686	0 – 0.068649
169 –294	Quarantine	37 – 1496	0.002502 – 0.021639	0.053518 – 0.250231	0.007552 – 0.010296	0.01639– 0.024137	1.021507 – 2.361272	0 – 208.916667	0 – 0.003541	0 – 0.35412
295 – 328	Supply chains	16 – 437	0.006321 – 0.008114	0.063643 – 1.633013	0.005394 – 0.013974	0.016361 – 0.030998	1.061354 – 3.707697	0 – 896.5	0 – 0.015196	0 – 1.519595
329 – 345	Vaccination	31 – 355	0.001027 – 0.003891	0.044839 – 1.061676	0.006272 – 0.013275	0.018644 – 0.033543	1.438328 – 3.354312	0 – 4	0 – 0.000068	0 – 0.00678

No	Keyword	Occurrences	Rank occurrences	Total link strength	Rank strength
1	Humans	313	3	4,831	1
2	Coronavirus disease 2019	265	5	4,452	2
3	Covid-19/epidemiology	557	1	4,347	3
4	Pandemic	298	4	4,121	4
5	Supply-chain risks	485	2	3,250	5
6	Health care policy	164	7	3,068	6
7	Risk reduction	177	6	1,887	7
8	Sars coronavirus	134	9	1,781	8
9	Food waste	143	8	1,449	9
10	Article	75	12	1,363	10
11	Epidemics	85	11	1,109	11
12	Sustainable development	109	10	982	12
13	Pneumonia, viral/epidemiology	51	17	916	13
14	Female	42	21	774	14
15	Public policy	52	16	737	15
16	Virus pneumonia	31	34	734	16
17	Procedures	33	29	709	17
18	Betacoronavirus	39	24	704	18
19	Diseases	43	20	668	19
20	Review	37	26	618	20
21	Priority journal	27	38	599	21
22	Infection prevention	28	37	589	22
23	Protective equipment	37	25	536	23
24	Economics	33	30	530	24
25	Organisation and management	28	36	517	25
26	Severe acute respiratory syndrome coronavirus 2	24	46	517	26
27	Disasters	33	31	511	27
28	International cooperation	43	19	499	28
29	Manufacturing sector	52	15	485	29
30	Nonhuman	22	50	451	30

Source: Authors' own work

Table 3. Top 30 keywords' occurrences and strength



Source: Authors own work

Figure 3. Total number of publications from 2020 to 2022

(post-COVID-19). Although the publication cutoff value was computed until October 2022, we discovered that the trend is downward. It was indicated for all keywords clustered, such as technology, mitigation and strategy. We computed COVID-19 as the main central node (Figure 2) and found a consistent downward trend (Figure 3). In addition, we found that the top publishers actively published COVID-19 thematic papers (Elsevier, Emerald, MDPI, Wiley and Taylor and Francis; $\mu = 36$) (Figure 4). We found the *International Journal of Environmental Research and Public Health* and the *International Journal of Logistics Research and Applications* published more on COVID-19 and its impact on supply chains. We found that the *Sustainability* journal consistently published related to the area of research, thus starring in the higher ranking (Figure 5).

Figure 6 shows the keywords related to technology. The highest technology stated in the literature was Blockchain (61 occurrences), 3D printing (42 occurrences), followed by additive manufacturing (22), which is also related to 3D printing, artificial intelligence (AI; 27) and other Industry revolution 4.0 technologies. The indicated results show methods used by scholars in their publications. The research papers on review, systematic literature review, industrial research and sensitivity analysis were high on the list. As technology related to Industry revolution 4.0 was high on the list, sensitivity analysis was expected to check the model's accuracy.

Additionally, Figure 7 shows the area of research published by scholars related to the keywords. Although the terms used are related to supply chain, technology and mitigation strategy, the highest research area was health-care policy, global supply chain and, surprisingly, climate change. It is indicated that the risk mitigation strategy in the supply chain needs to consider policy, global networks and environmental issues.

Although supply chain publications post-COVID-19 decreased, the literature shows that supply chain risk studies were increasing (Figure 8). Risk management, sustainable development and case studies were recently published concerning the keywords. Figure 9 shows the five-cluster identified in this study. Figure 9 focusses on the outer ring of the cluster, where qualitative research, 3D printing, disease control or method, health-care accessibility and digital technologies were not highly integrated into the cluster's central nodes. However, it should be the primary focus of future scholars to contribute.

5. Discussion

This paper investigated the manufacturing firm's response to mitigate the risk of COVID-19 on the global supply chain during and post-pandemic. The COVID-19 outbreak and the supply shock

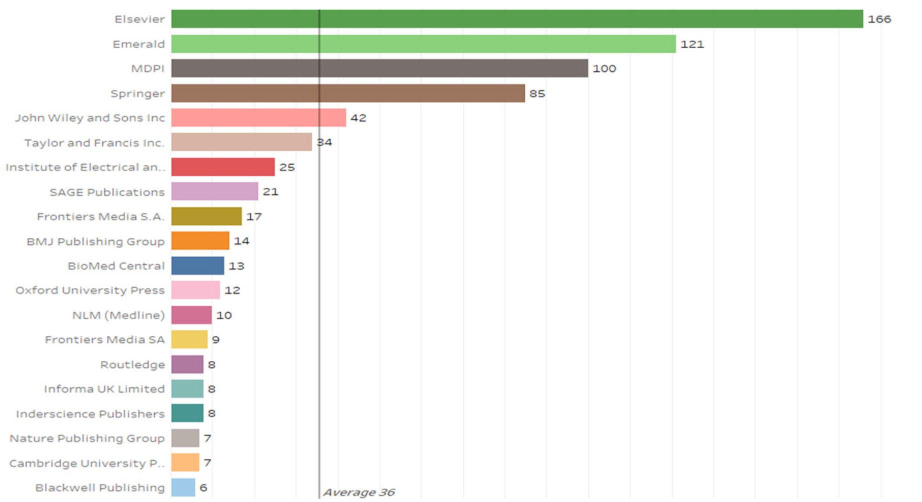
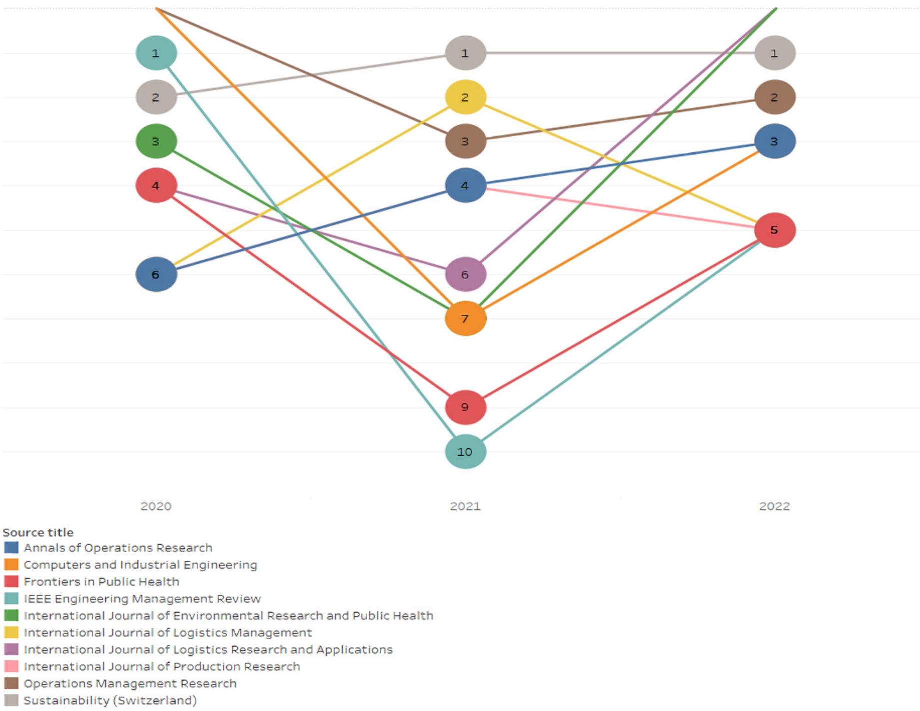


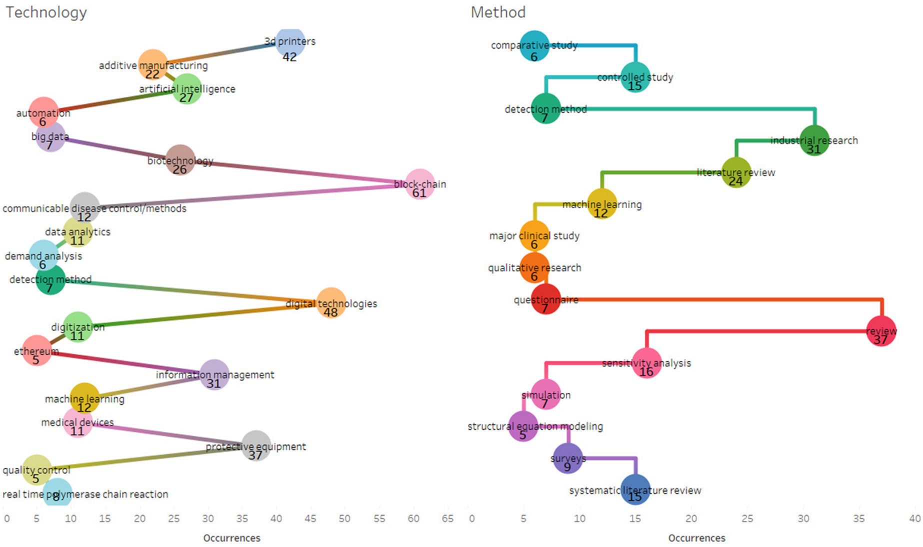
Figure 4.
Top 10 publishers

Source: Authors' own work



Source: Authors' own work

Figure 5.
Top 10 journal rank from 2020 to 2022



Source: Authors' own work

Figure 6.
Top-rank technology and method keywords

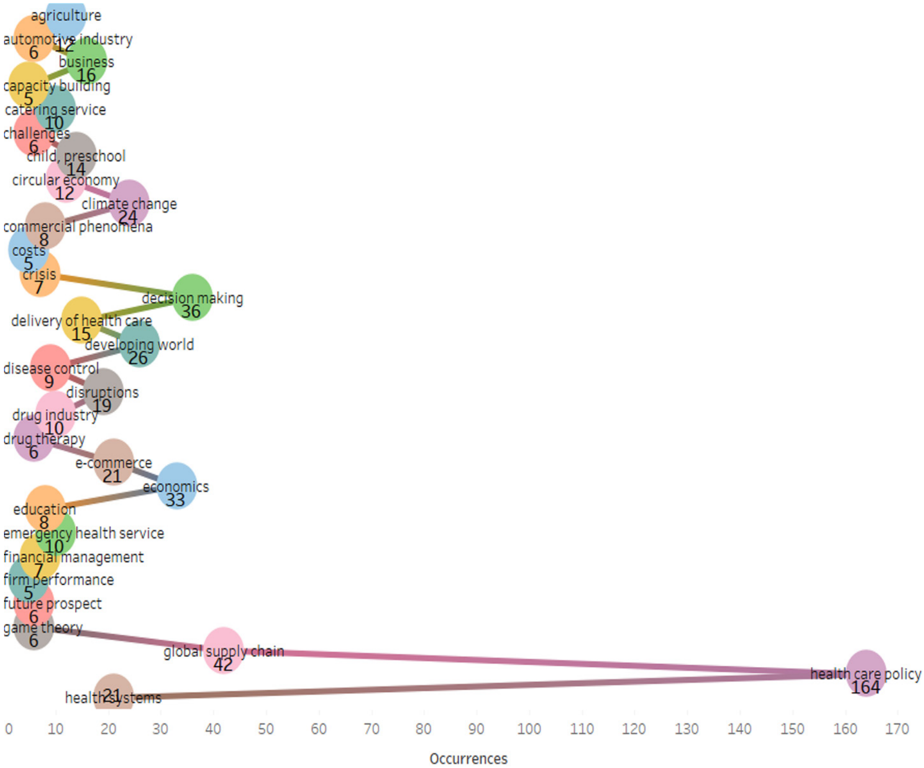


Figure 7.
Top 30 areas of research

Source: Authors' own work

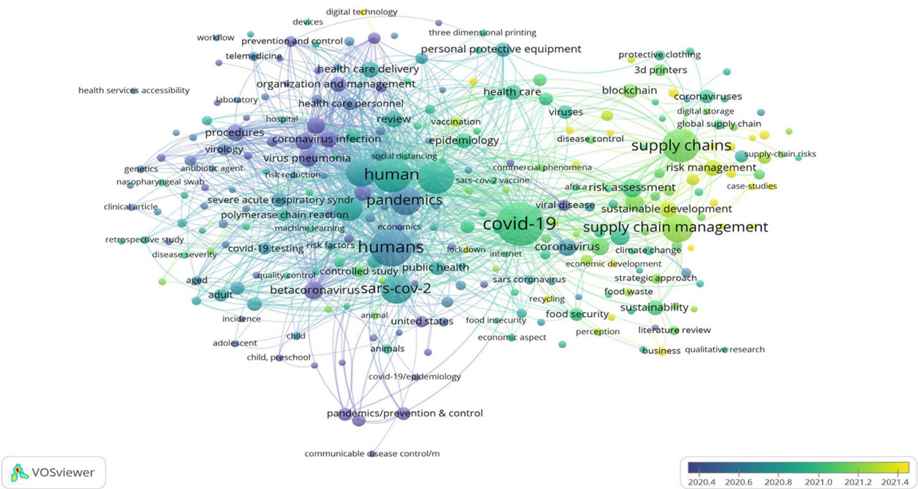
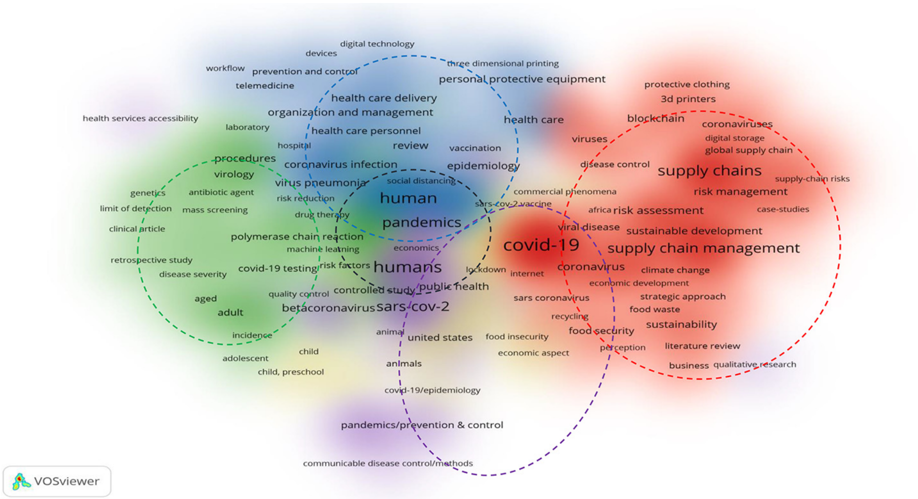


Figure 8.
Publication trend heatmap

Source: Authors' own work



Source: Authors' own work

Figure 9.
Five cluster density

that started in China led to a demand shock that followed as the global economy shut down. The COVID-19 outbreak shed light on firms' unseen vulnerabilities in designing production strategies and SCM. Firms had to deal with trade restrictions and shortages of raw materials and other products related to their business operation. However, disruption did necessarily create new challenges for supply chains but accelerated and magnified the existence of problems in supply chains. Such problems include non-resilient supply chains, weak technology adoption, low end-to-end supply chain visibility and a lack of diversity in supply chains.

In uncertain economic environments, firms are often reluctant to invest in technology improvement due to cost reasons and resistance to change (Fernando *et al.*, 2020). But during the COVID-19 pandemic, technology investments have become indispensable. The digitalisation of the supply chain has assisted firms in navigating disruptive forces and responding faster to volatile supply and demand. Blockchain is among emerging technologies to enable the global supply chain to become lighter, faster and more efficient. Authorised stakeholders can access real-time data, including manufacturers, distributors and customers. In addition, Blockchain offers real-time visibility into logistics, so stakeholders can swiftly adapt to problems as they arise.

Table 4 shows the findings of the systematic literature review in general. Risks can be divided into four stages: risk identification and risk governance. For each stage, there were several assessment tools. The finding shows that a business model is a common tool while organisations widely use technology and information system tools.

Literature screening revealed that Blockchain, AI and machine learning were among the most effective approaches to mitigate COVID-19 disruptive impacts (Figure 6). However, continuous research is still to be conducted on how different-sized firms can use technology, be it Blockchain supply chain, AI or machine learning to be relevantly effective during disruptive market environments. Technology plays a pivotal role in supporting SCM in mitigating risks during and after the COVID-19 pandemic. This result is supported by Um and Han (2021) findings that technology provides various benefits to enhance risk management practices. Technology enables improved visibility and tracking capabilities

No	Type	Assessment	Solutions
1	Risk identification	Fuzzy method	An integrated model that is more accurate in identifying risk
		Systematic literature review	Different Models to identify risk
		Machine learning	A practical approach of machine learning to understand the probability of risk factors
2	Risk assessment	Risk matrix	Predictive model
		SWOT analysis	Internal and external assessment of risks
		Failure mode and effects analysis (FMEA)	Reliability analysis of the business model
		Scenario analysis	Multiple scenarios to predict the best risk mitigation strategy
		Quantitative risk analysis	Quantitative consequence and frequency analyses
		Compliance legal framework	Compliance, regulation and policy to manage risk
3	Risk monitoring	Key risk indicators (KRIs)	Multiple indicators to monitor risk
		Dashboard	Qualitative and quantitative risk identification and reduction
		Incident reporting system	Management information system to monitor risk
		Business intelligence	Diagnostic analytics for risk identification and risk mitigation
		Vendor and customer risk Management	Business model and information system
4	Risk governance	Policies and procedure	Structured laws and regulations for organisations to minimise risks
		Risk committee	Corporate governance
		Risk framework	Theoretical framework
		Risk management software	Information system and technology-related software

Source: Authors' own work

Table 4. Type of risk and evaluation methods

through IoT and real-time tracking systems. It allows organisations to monitor goods' movement, track inventory levels and identify potential disruptions promptly. By having better visibility, supply chain managers can proactively respond to risks and take necessary actions to mitigate their impact (Al-Talib *et al.*, 2020).

Data analytics and predictive insights derived from advanced analytics, machine learning and AI offer valuable support for SCM and risk management. These technologies enable organisations to analyse vast amounts of data and identify patterns, trends and potential risks within the supply chain (Sharma *et al.*, 2020). With predictive analytics models, businesses can forecast demand, anticipate disruptions and make informed decisions to mitigate risks effectively. In addition, automation technologies such as robotics improve operational efficiency and reduce the reliance on human labour. By automating processes, organisations can minimise errors, streamline operations and maintain business continuity even during labour shortages or when adhering to social distancing measures (Butt, 2021).

Supply chain digitisation initiatives, including cloud-based platforms and digital marketplaces, foster seamless communication and collaboration among supply chain partners. These results align with Liu *et al.* (2022) findings that technologies facilitate the real-time sharing of information, data and documents, eliminating manual processes and reducing delays and errors. Digitisation enhances supply chain agility, enabling quick responses to market changes and mitigating risks associated with manual or paper-based operations. Besides that, remote collaboration and communication technologies, including collaboration tools and video conferencing, have become essential during the pandemic. These tools enable effective collaboration among supply chain professionals regardless of their physical location (Boyson, 2014). By facilitating virtual meetings, decision-making and information sharing, remote collaboration technologies ensure continuous communication and coordination, thereby mitigating risks for the supply chain in the unforeseeable future disruptions.

We found that a systematic review using a scientometric analysis of COVID-19 and the global supply chain has been useful in identifying the technologically driven strategy to develop the supply chain risk mitigation-solution framework. Our finding has extended the supply chain mitigation theory on how manufacturing firms behave during and after post-pandemic COVID-19. We argue that the supply chain mitigation theory should be explored further to examine the supply chain adaptability level to handle disruption, market demand and global networks. The firms' ability to adjust the global supply chain networks can strengthen their competitive advantage. Besides that, the technology adoption model needs to incorporate the firms' behaviour to mitigate the supply chain risk and build dynamic capabilities, especially to integrate and reconfigure the internal and external resources in a global value chain context.

Fernando *et al.* (2022) argued that the uncontrollable attack of the COVID-19 pandemic had driven manufacturing firms to incorporate the risk mitigation plan and new procedures. As a result, decision-makers must make precise and fast decisions with real-time data on supply and demand. In terms of practical implications, our study offers several guidelines to support supply chain managers to increase the flexibility to absorb disruptions due to the COVID-19 pandemic. Based on the scientometric analysis, we have proposed the supply chain risk mitigation-solution framework to overcome the unpredictable global pandemic and disruption. The practical solutions are divided into short- and long-term mitigation strategies that require data analytics technology to make decisions. Figure 10 shows the supply chain risk mitigation-solution framework.

Figure 10 shows that Blockchain is among the technologies that offer valuable solutions for mitigating risks associated with supply chain disruptions during and after the COVID-19 pandemic. By leveraging Blockchain, supply chains can enhance transparency and traceability. The immutable and transparent ledger provided by Blockchain enables stakeholders to track and verify goods' origin, movement and handling conditions (Helo and Hao, 2019). Blockchain's decentralised nature also enhances supply chain resilience by eliminating single points of failure. Even during disruptions, the distributed ledger allows uninterrupted access to information, enabling supply chain participants to make informed decisions.

Supplier management becomes more efficient as blockchain securely stores and verifies supplier credentials, certifications and compliance records, reducing the risk of engaging with unreliable suppliers. Real-time monitoring and automatic alerts on the Blockchain enable quick identification of issues, facilitating proactive risk mitigation (Liu *et al.*, 2020). Moreover, Blockchain enables secure data sharing and collaboration among supply chain partners, ensuring the confidentiality and integrity of sensitive information. Through these mechanisms, blockchain technology strengthens supply chain resilience and minimises risks during and after the COVID-19 pandemic.

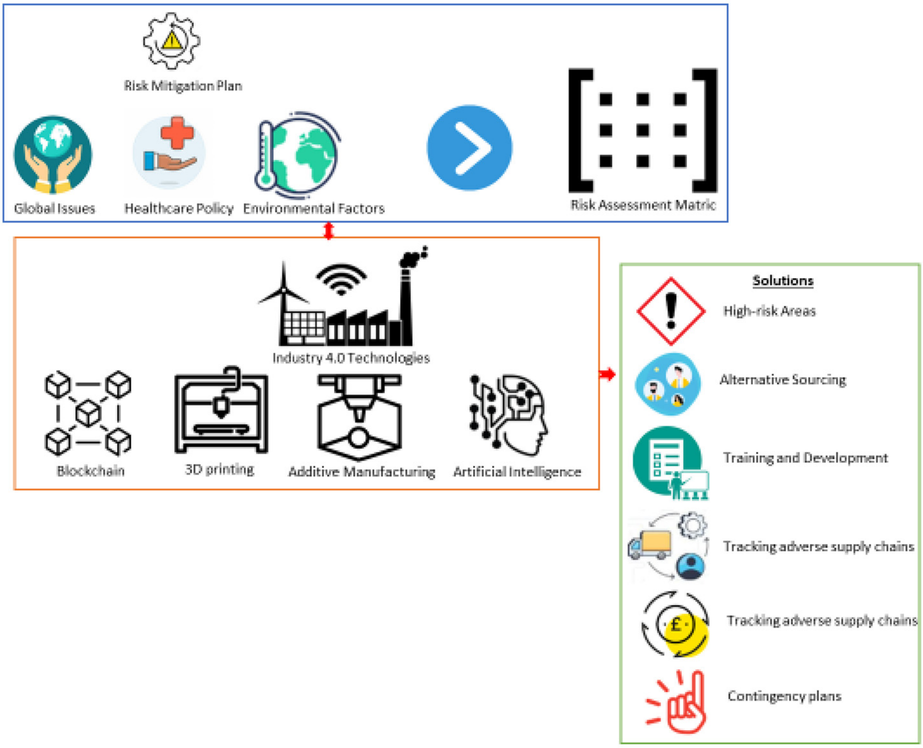


Figure 10. Supply chain risk mitigation-solution framework

Source: Authors' own work

Figure 10 shows that 3D printing, known as additive manufacturing, has emerged as a valuable solution to mitigate risks associated with supply chain disruptions during and after the COVID-19 pandemic. The results are in accordance with Nascimento *et al.* (2019) regarding the advantage of 3D printing in localised production, where parts and products can be created on-demand and closer to the point of need. This reduces reliance on global supply chains and helps avoid disruptions caused by transportation delays, border closures or shortages of materials. By enabling decentralised production, 3D printing enhances supply chain resilience and ensures a more reliable flow of essential goods. Another benefit of 3D printing is reducing dependence on traditional suppliers. With the capability to produce components and parts in-house, organisations can mitigate risks associated with supplier failures, shortages or logistical challenges (Gaustad *et al.*, 2018). Businesses can maintain operations even when external supply chains are disrupted by having the flexibility to manufacture critical items internally. It reduces the vulnerability to supply chain shocks and ensures continuity of production.

Additionally, 3D printing enables rapid prototyping and iteration of product designs. The results align with Mathias *et al.* (2019), that postulate agility allows organisations to adapt quickly to changing market demands or unforeseen disruptions. For example, if modifications are required due to supply chain constraints, 3D printing enables the swift production of updated prototypes, reducing the time needed for design iterations. It accelerates product development and enables prompt adjustments to meet evolving customer needs (Berman, 2012). Moreover, 3D printing facilitates customisation and the production of spare parts on demand. Organisations can produce specific items tailored to individual customer requirements, eliminating the need for storing and managing extensive inventories (Malik *et al.*, 2022). It reduces the risk of stockouts or obsolescence and enables efficient SCM. Furthermore, by producing spare parts as needed, organisations can ensure operational continuity and minimise the impact of supply chain disruptions.

Figure 10 also shows that integrating AI methodologies in SCM offers significant potential for mitigating risks after the COVID-19 pandemic. The application of AI-driven techniques in demand forecasting, real-time monitoring, inventory management, predictive maintenance, supply chain optimisation and supplier risk assessment empowers organisations with enhanced resilience and effective response mechanisms to navigate disruptions and maintain the continuity of supply chain operations (Belhadi *et al.*, 2021). Leveraging advanced algorithms and data analysis techniques, AI effectively enhances supply chain resilience and responsiveness. Demand forecasting and planning can be significantly improved through AI-powered algorithms that analyse comprehensive data sets encompassing market trends, consumer behaviour and external factors (Younis *et al.*, 2022). Integrating these variables enables accurate predictions of demand patterns, facilitating optimal resource allocation and inventory management to minimise the risks of shortages or surplus during disruptive events.

Real-time monitoring capabilities empowered by AI play a crucial role in detecting potential risks and disruptions within the supply chain. AI algorithms can identify anomalies and deviations by leveraging data from diverse sources, including IoT sensors and external databases (Nah and Siau, 2020). Timely detection allows for proactive risk mitigation measures, ensuring uninterrupted operations and minimising the impact of disruptions. AI-driven optimisation techniques contribute to effective inventory management by dynamically adjusting stock levels and reorder points (Wang *et al.*, 2022). By considering multiple factors such as demand fluctuations, lead times and production capacities, AI systems optimise inventory levels to mitigate the risks of stockouts or overstocking. This enables organisations to fulfil customer demands efficiently and respond promptly to disruptive events.

Furthermore, AI algorithms facilitate predictive maintenance by analysing sensor data from machinery and equipment. By identifying potential equipment failures before they occur, predictive maintenance systems powered by AI minimise unplanned downtime and mitigate disruptions caused by equipment malfunctions or breakdowns (Abedin, 2022). Supply chain optimisation, another area where AI excels, involves leveraging complex network analysis to identify the most efficient routes, optimal warehouse locations and suitable transportation modes (Baryannis *et al.*, 2018). By optimising the configuration of supply chain networks, AI techniques enhance delivery times, reduce costs and bolster overall resilience, enabling organisations to navigate disruptions with agility and adaptability. AI provides valuable support for supplier risk assessment by examining diverse data sources such as financial records and sentiment analysis from social media platforms. AI algorithms analyse these data streams to identify potential supplier risks, such as economic instability or reputational issues (Chu *et al.*, 2020). This enables organisations to proactively manage and mitigate supplier-related risks, minimising disruptions within the supply chain.

5.1 Short term solutions

We have proposed short-term supply chain risk mitigation during the pandemic and endemic situations:

5.1.1 Identifying leading suppliers in high-risk areas. We have proposed that manufacturing firms frequently investigate whether essential vendors, retailers and factories are in high-risk areas (during the pandemic and endemic situations).

5.1.2 Alternative sourcing. The manufacturing firms should identify the most vulnerable leading suppliers. The dependency on China vendors should be reduced. The mitigation plan and preparation action should be designed. The firms can design procurement strategies that focus less on China vendors. The rising inventory levels of other suppliers and market density will form a competitive advantage.

5.1.3 Training and development. Manufacturing firms should quickly react once pandemic symptoms appear. It should inform its stakeholders, especially leading vendors, about this infection's effects and impose preventive actions such as sick leave. Lost productivity attributable to the loss of some staff owing to sick leave, ill workers and site disinfection can be significantly less expensive than potential stoppages from shutting a whole factory.

5.2 Long-term solutions

Our long-terms solutions are given in the following sub-sections.

5.2.1 Tracking adverse supply chains. Techniques for tracking threats in the actual time supply chain can continue to have well-informed future developments in metropolitan lockups, policy shut-downs in industrial areas and probable transport disturbances.

5.2.2 Dual-sourcing approaches. A decrease in supplier numbers is becoming a standard for more competitive partnerships with several leading suppliers. In terms of the growing complexity of uncertainties in the supply chain, businesses may consider carrying out a competitive cost-benefit analysis to determine if it can help prevent future losses and add additional costs for procurement from different geographical locations and other suppliers.

5.2.3 Contingency plans. For example, if a factory has COVID-19, businesses should create contingency plans. In the long term, good relations with vendors or contract producers capable of transporting or producing comparable products over nearby counties or states are advised. They can be used, if appropriate, to establish new lines as quickly as possible.

6. Conclusion

Our study has achieved the research objective of how manufacturing firms behave to mitigate the risk of the first wave of coronavirus disease (COVID-19) on the global supply chain. The results can be useful in designing risk mitigation and prevention strategy during crises and endemic situations. Furthermore, the technology can assist firms in examining critical values in global value chain risk mitigation. For example, firms can use the risk assessment strategy in the global supply chain, divided into low, moderate and high-risk areas. We found that the supply chain mitigation strategy needs to incorporate Industry 4.0 technology in supply chains. In addition, firms can consider technologies such as Blockchain, AI, 3D printing and machine learning to mitigate COVID-19. We also suggested that the supply chain mitigation strategy include food security assessment, government incentives and policies, health-care systems, energy and a circular economy. We recommend that manufacturing firms design a supply chain mitigation strategy that includes Blockchain technology to monitor real-time operations and data transparency (Al-Madani *et al.*, 2022; Fernando *et al.*, 2022).

COVID-19 is an energising and significant zone for learning about its effect on supply chains. Global supply chain managers should brace themselves for a significant global impact on manufacturing. The presence of the coronavirus is already evident. In addition, the number of goods leaving China has decreased significantly because of restricted movement and complex quarantine procedures. Thus, manufacturing firms should not entirely depend on China suppliers and must have contingency plans with alternative nearest suppliers.

Regarding limitations, our proposed supply chain risk mitigation-solution framework has not incorporated the assessment matrix. Our findings must be compiled into a supply chain risk mitigation matrix that can be used to track current and future risk trends. Future research should focus on the supply chain risk mitigation matrix to better understand the various types of risk in supply chains post-COVID-19.

Concerning industrial implications, we suggest manufacturing firms need scenario planning for best responses and identifying vulnerabilities before a crisis hits. COVID-19 has had a series of impacts and has led to long-term business uncertainty. It is hard to predict when COVID-19 will disappear or when the next crisis will appear; perhaps manufacturing firms can deploy machine learning to analyse and predict the trend. Although long-term effects have not yet been fully realised, the COVID-19 epidemic also shows firms how to train their organisations to deal with significant future crises more effectively and rely on contactless technology. The readiness lies in the technology used to mitigate COVID-19.

Technology is vital in mitigating supply chain risks during and after the COVID-19 pandemic. It enhances visibility, enables data-driven decision-making, streamlines processes, facilitates communication and collaboration and strengthens supply chain resilience. Embracing these technological advancements empowers organisations to navigate uncertainties, respond to disruptions and build more robust and agile supply chains to address future challenges. For example, integrating AI methodologies in SCM offers significant potential for mitigating risks during and after the COVID-19 pandemic. Applying AI-driven techniques in demand forecasting, real-time monitoring, inventory management, predictive maintenance, supply chain optimisation and supplier risk assessment empowers organisations with enhanced resilience and effective response mechanisms to navigate disruptions and maintain the continuity of supply chain operations.

Our findings extended the literature that digitalisation should be incorporated into technology adoption to manage efficient supply chain operations and prevent unnecessary disruption. Technology such as Blockchain, AI and machine learning have been well-researched in the literature to help firms in the supply chain brace for the financial and social impacts, but less consensus on how it handles the supply chain disruption. Almost all supply chain, operations, logistics and environmental journals are concerned about COVID-19's impact on supply chains. We found that the *International Journal of Environmental Research and Public Health* and the *International Journal of Logistics Research and Applications* are actively published on COVID-19 and its impact on supply chains.

The proper supply chain risk mitigation strategy design can impact the global value chain involving multiple stakeholders contributing to a green economy (Fernando *et al.*, 2022d). Based on the findings, future studies can further focus on supply chain mitigation strategies in food security, health-care systems, government incentives and policies, energy and circular economy to mitigate COVID-19.

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