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IDENTIFYING SOURCES OF COVID19 PANDEMIC SUPPLY CHAIN FRAGILITY

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Abstract

Supply chain management is in the industrial engineering management and operations management disciplines. It involves product procurement of raw materials, production, storage, distribution, wholesales, and retail sales. The COVID19 pandemic has the added challenge of healthcare service operations management. This paper is a bibliometric study of the COVID19 supply chain fragility problem. In February 2021, the United States' President called for a review of the pandemic related supply chain for vaccines, personal protective equipment (PPE), medical equipment such as ventilators, and food. This study involves a search for references published between January 1, 2020 and April 30, 2021. It reveals that food was a primary topic among 82 publications rather than vaccines. Also, reasons cited for America's supply chain fragility include America's dependence on products produced in other countries such as China; these countries' own pandemic induced supply chain challenges; and US trade restrictions on such products enacted prior to the COVID19 outbreak. Engineering management strategies were mentioned in 60% of the publications and are summarized in the Conclusions and Implications for Managers are provided.

Keywords

COVID19, COVID-19 vaccine, supply chain management, supply chain disruption, supply chain fragility, engineering management, operations management, pandemic food, China manufacturing, semiconductor chips, disaster relief, infectious diseases

Introduction

The following introduction sets the stage for explaining events that led to the current global COVID19 supply chain fragility problem. In order to suppress the outbreak of COVID19, the World Health Organization (WHO) escalated the threat levels and alarmed the general public against inaction. WHO recommended lockdowns, quarantines, testing, contact tracing, isolation, mask wearing and school closures (WHO, 2020b). Disruptions to the global supply chain dominated the news. The Institute for Supply Management (ISM) reported that 95% of US businesses experienced supply chain disruptions (ISM, 2020). This research is relevant to the engineering and business disciplines of operations and supply chain management. The purpose of this study is to make sense of the news stories. A bibliometric review of publications between January 1, 2020 and April 30, 2020 was conducted. This paper describes the key findings related to vaccine, personal protective equipment (PPE), medical equipment (such as ventilators), food and semiconductors. The goal was to provide a comprehensive overview of the COVID19 global supply chain in our interconnected world. This study concludes with conclusions based on the findings and recommendations which serve to improve supply chain management of future outbreaks and disasters requiring relief such as COVID19.

In July 2020, Patrick Vallance, Chief Scientific Advisor stated that "mistakes were made" (Triggle, 2021). Max Boot, Senior Fellow of the Council on Foreign Relations called the handling of resources by the USA, the richest country in the world, a failure (CNN, 2020). There are bottlenecks across the entire global supply chain: raw materials, manufacturing, human capital, regulations, and geopolitics.

By late July 2020, 25 vaccines were in clinical trials (Goodman & Carmichael, 2020). Vaccine production is very complex. There is a need for heightened quality control (Tin, 2021). Nathalie Moll of the EFPIA stated that while there is a need for increased manufacturing, the production requires security and efficiency; and substantial training to increase capacity (EFPIA, 2021). In 2020, the President made little use of the Defense Production Act's broad authority to compel US manufacturers to make equipment needed to combat COVID19 (LeBlanc, 2020). Vaccine equity is a concern. Those closer to vaccine manufacturing will get vaccines first in the developed world (Irwin, 2021). Countries such as the UK, Israel, US and Canada are better prepared because they made orders with pharmaceutical manufacturers earlier (Twohey, Collins, & Thomas, 2020). Canada secured vaccines in an amount five times their population (Hegarty, 2020). Accessibility to poorer countries is a concern (BBC, 2020b; WHO, 2021).

By December 2020, hospitals in London were running out of space and beds (Campbell & Davis, 2020). The virus is pushing Japan's medical system to a breaking point. By May 2021, 17,000 people were waiting to be hospitalized (McCurry, 2021). Yet, very early on in Wuhan, China built a hospital in just 10 days (BBC, 2020a). Why aren't other countries following China's lead?

In January 2021, the WHO criticized the EU over export controls related to Astra Zeneca. The EU took issue with Astra Zeneca over delivery shortfalls. The export controls would give the EU powers to deny vaccine exports if a company has not honored existing contracts with the EU. Vaccine companies would need to apply for export permission before supplying doses outside of the EU. This was in the wake of an EU raid which uncovered 29 million doses of Astra Zeneca vaccine planned for export (Lee, 2021; Pickston, Frater, & Fox, 2021).

Vaccine distribution is a big problem in rural country sides and urban area. COVAX is an attempt at the equitable distribution of vaccines. According to Richard Hatchett, the CEO of the Coalition for Epidemic Preparedness and Innovation, COVAX is to deliver 2 billion vaccines to developing countries by the end of 2021 (Wei, 2021). In February 2021, the Director of the U.S. National Institute of Allergy and Infectious Diseases (NIAID) and the Chief Medical Advisor to the President, called for the mobilization of FEMA and the military to help with vaccine distribution in the USA (Farmer, 2021; McPhillips, 2021). Some poor nations have no roads or money for vaccine distribution. Vaccine spoilage is also issue (Farmer, 2021).

Vaccine rollout in Africa is sluggish (Hegarty, 2020). Africa imports 99% of their vaccines. WHO wants drug patents waived (WHO, 2021). In February 2021, Hannah Ryder, CEO of Development Reimagined stated that African countries need manufacturers' intellectual property rights so that they can manufacture vaccines in their own countries. Although Africa gets help from China and COVAX, there is a desire for the nation to become more self-reliant. This will require the development of manufacturing locations and training (Xinhua, 2021). John Nkengasong, Director of Cameroon's CDC echoes the sentiment that it is critical for Africa to produce their own vaccines. By May 2021, the US President declared support for waiving intellectual property rights for COVID19 vaccines (Bowman, 2021; Junfeng, 2021). However, Germany opposes patent waivers, and the World Trade Organization (WTO) is advocating for a negotiated compromise. There is a need to protect the global supply chains and to do technology transfer (David, 2021; Rigo, 2021). Another perspective against patent waivers favors simply helping lower-income countries purchase vaccines (Koujianou Goldberg, 2021).

Hatchett stated that some vaccines are being shipped and are just sitting in warehouses. Better planning is needed to prevent delays. Refrigeration requirements of some vaccines are a challenge. Countries need to determine how much they need, when they need it, what kind of vaccine they want and how to get employees trained (Wei, 2021). Vaccine hesitancy by government leadership and reluctant use runs counter to the short shelf life (Bender, 2021). In the COVID19 global supply chain, 'information' and should be viewed as a product in and of itself. Addressing misinformation and the dissemination of accurate information throughout the supply chain has been a concern throughout the pandemic (Abrams, 2021; OECD, 2020; Tozzi, 2020; WHO, 2020a). With regard to marketing, propaganda and messaging, there were mixed messages that the general public did not really understand.

Vaccine hesitancy and distrust contribute to supply chain disruptions. When vaccines go unused, it will be difficult to reach herd immunity. The hesitancy and distrust among marginalized groups results from some hearing that hospitals will insert chips under their skin, alter their DNA or inject them with virus (BBC Radio, 2021; Roberts, 2019). The COVID19 pandemic amplifies marginalized populations' history of distrust of the healthcare system and pre-existing health inequalities. Researcher Tolu Oni states that "[i]t is critical that we adopt an equity lens" (Lathbridge, 2021).

Large health systems can build up equipment supplies via preexisting contracts, but small clinics are struggling to get enough vaccines and supplies (Harris, 2021). Existing supply chains need to be strengthened. Existing health care providers have already made the investments to build trust among local residents. So, they need to be identified and supported by government agencies (Lathbridge, 2021). There is also vaccine inequity in the USA. For example, in the Mississippi Delta hospitals are 20 miles way from impoverished residents. When residents have little advanced notice of vaccine appointments, they cannot make the arrangements to take time off work. Many residents have unreliable internet service. The clinics have an insufficient supply of COVID19 vaccine supplies (Harris, 2021). Vaccination through the federal government's pharmacy program with companies like CVS and Walgreens were delayed. And the algorithm for distributing vaccines based on states' populations has not been consistent (Stribling, 2021). The potential of this type of supply chain disruption should have been anticipated and addressed in a disaster emergency management plan.

Further, the pandemic has resulted in an increase in online sales, meetings, educational courses, games, and social media use. Vaccine websites have high numbers of visitors. There is also an increase in contactless AI technology such as drones and CCTV (for surveillance and body temperature checks) and robotics used to serve people. There are also digital algorithms being used to prioritize, order and schedule categories of people to get

vaccinated (Stribling, 2021). Thus, the pandemic has highlighted the importance of our digital economy and technology (McKinsey, 2020).

Method

The research method used is a systematic bibliometric literature review. This is descriptive, micro-level bibliometric study required Excel spreadsheet modeling, data cleaning and data analysis. Since 1929, bibliometric studies have been well regarded technical forms of literature reviews. These studies use statistical analysis to obtain information on the number of documents issued such as trends and scientific gaps (Glanzel, 2003; de Oliveira, et al., 2019). The key is the technical term ‘metrics’ in the word bibliometrics. Bibliometrics is a standard tool of science policy and research management (Glanzel, 2003); and can certainly be used for engineering management policy and research management.

The Cochrane Method is regarded as the leading systematic review strategy in health research such as clinical trials (McGowan et al., 2016). Systematic reviews differ from traditional narrative reviews because systematic reviews require the use of a pre-planned standard format and scientific method. In a traditional review, the researchers would generally look for research papers that support or not support the researchers’ hypotheses. To obtain an unbiased review, there is a clearly specified method of identifying, selecting, validating and including publications so that it is clear, transparent, recordable and reproducible. The process of searching for and selecting publications must be well documented and made transparent. Using their Cochrane Handbook for Systematic Reviews, the first step in this systematic review was to develop a protocol which outlined the steps for doing the review based on the Cochrane Method (Cochrane Collaboration, 2011). The protocol included data collection, screening the results, abstracting data, appraising the risk of bias, synthesizing the findings, and interpreting the results.

Hypotheses Development

This study aimed to answer what publications on supply chain disruption or fragility were addressing. Three hypotheses were tested with this systematic review:

Hypothesis 1 - COVID19 related vaccine production supply chain disruptions is the most frequently discussed topic and concern.

Besides the aforementioned issues with the vaccine rollout, South Korea needs vaccines (Cha, 2021; Kim, 2021; Yoon, 2021); and the semiconductor chip industry is concerned about the fate of chip manufacturing if Taiwan does not get vaccines (Crawford, Wu, & Marlow, 2021). Vaccines and chips are interdependent. In Taiwan, there was concern about the fate of vaccines if there are no chips because the lack of vaccines led to a surge in virus cases and then a lockdown. With only 1% of the Taiwanese population vaccinated, this disrupted chip production. Jaguar and Kia had to shut down plant operations due to semiconductor chip shortages (Canadian Press, 2021; Hughes, 2021; Jones 2021; Lea, 2021; Eastern Eye, 2021, Tovey, 2021; Eunsoo, 2021). This is relevant to engineering management because safeguarding production lines and supply chains is an industrial engineering operations manager’s job. Because of these concerns, there are recommendations to reshore plants closer to each other to shorten supply chains and reduce lead times (Cushman & Wakefield, 2020).

Hypothesis 2 - China is blamed for COVID19 related supply chain disruptions.

The US had 40% of the world’s manufacturing in the 1950s. The US was followed by Europe and Japan. With increased globalization, since the 1970s, China has been receiving offshore production opportunities from developed countries. China has the top position in electronic components for telecom, high-tech, computers and automotive manufacturing according to the 2020 Manufacturing Risk Index (MRI) rankings. The US is in second place (Cushman & Wakefield, 2020). Chinese industries are tested and protected by government contracts and subsidies which has helped Asia become the world’s manufacturing hub (Pham, 2017). Thus, when there are supply chain disruptions, it is hypothesized that China will be blamed. This is relevant to engineering managers who may be contemplating whether to reshore production.

Hypothesis 3 - Engineering management strategies are not mentioned as solutions to resolve the COVID19 related supply chain disruptions.

Communities of practice are comprised of practitioners with shared expertise and a desire to interact regularly to learn how to improve what they do (Wenger, 1998, p. 2). These are learning communities that are cultivated through shared

practice (Wenger, McDermott, & Snyder, 2002). It is important for academics to spend time with and interact with business practitioners (Nobel, 2016). Yet, there is a gap between academics and practitioners. Are our research and lessons of value to people facing real world problems? One of the reasons for the perceived disconnect is a purported gap between academic rigor and practitioner relevance (Bartunek & Rynes, 2014). Given this issue, it is hypothesized that publications in the literature review would not discuss textbook, academic engineering management strategies as solutions to the supply chain fragility problem.

Data Sources

In this bibliometric systematic review, a comprehensive list of phenomenon-specific search keywords was created. Keywords were selected using the Cochrane Collaboration recommended PICO strategy. The benefit of using the PICO strategy is to ensure well formulated research questions (Cochrane Collaboration, 2011). In PICO, research questions are broken down into concepts which include the research Population, Interventions, Comparisons and research Outcomes. The setting and population in the following research questions for this study are related to COVID19 supply chain management.

P = Populations engaged in supply chain management during the COVID19 pandemic

I = Interventions such as the use of engineering management strategies

C = Comparison of analyses of engineering management and other strategies

O = Outcomes including strengths and challenges

We attempt to identify all studies that are related to supply chain disruption by searching terms based on the PICO framework. These parameters were translated into the following general Boolean format that a database could understand: (Population OR synonym1 OR synonym2) AND (Strategies1 OR synonym1 OR synonym2) AND (Outcome1 OR synonym1 OR synonym2). Thus, the initial search for the research questions would utilize the keywords that correspond to the PICO criteria. The Boolean search used to identify full text publications was broadly:

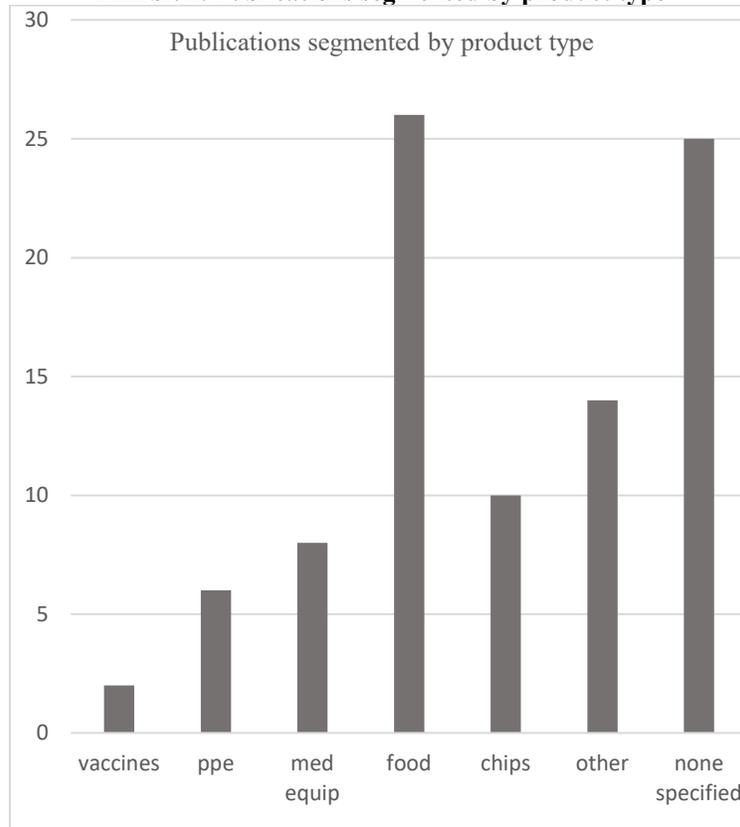
COVID AND (“supply chain disruption” OR “supply chain fragility”) BUT NOT “earnings call”.

The method typically requires use of peer reviewed academic publications. In this study, the goal is to access what is available to practitioners. So, the types of publications included peer reviewed journal articles, magazines, newspapers and press releases. Thus, the search strategy was conducted in *EBSCO's Academic Search Complete, Business Source Complete, Newspaper Source Plus and News wires*. To record all of this data for the systematic review and meta-analysis, the PRISMA method of transparent reporting was used. PRISMA was used to ensure a high-quality rigorous review (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). The goal is to capture the most comprehensive set of articles that specifically addressed the issues targeted by the research questions.

The search was rerun and documented. The goal was to create an optimal search strategy in order to retrieve useful citations. There was a total of 167 publications. Duplicates and irrelevant publications were eliminated. To be included in the systematic literature review, each study had to address at least one of the three (3) research questions. This was the inclusion-exclusion criteria. Eighty-two (82) publications were selected for inclusion in the study are listed in Appendix 1. In February 2021, the United States' President called for a review of the pandemic related supply chain for vaccines, personal protective equipment (PPE), medical equipment such as ventilators, and food. Therefore, each publication was read and coded for relevance to vaccine production, PPE's, medical devices, semiconductor chips, other products, no product specified, whether China was blamed for disruptions, and whether engineering management strategies were mentioned as solutions. Following the PRISMA Model, data was added to a table which included the data that a reference was found and the source of the data. The title of each publication, publication outlet and findings were noted.

Results

See Exhibit 1. Most of the publications did not specify a particular product and discussed supply chain disruptions more generally. When products were mentioned, food was discussed more frequently than vaccines. Thus, Hypothesis 1 was not supported. However, one reason that publications mentioning vaccine supplies are lower than food security is that COVID19 vaccines were not on the market until August 2020.

Exhibit 1. Publications segmented by product type

China was blamed for supply chain disruptions in 17 of the 82 publications (21%). While this is not an overwhelming percentage of the publications in support of Hypothesis 2, this finding offers evidence that China has been blamed. The reasons why China was blamed included: (1) the US China trade war and tariffs; (2) the concentration of manufacturing in China; (3) how China's lockdown thwarted manufacturing in China; and (4) China stopped reduced purchases from exporters.

Also note that engineering management strategies were mentioned in 49 of the 82 publications (60%). Thus, Hypothesis 3 is not supported. Five engineering operations management topics prevailed: (1) strategic sourcing; (2) supply chain strategy; (3) inventory management; (4) digital data collection and analytics; and (5) transportation logistics. The engineering management strategies that were mentioned related to how consumers could not get a hold of food and toiletries because manufacturers simply could not produce items quickly enough. Thus, companies needed to pivot quickly and find more efficient and effective business models (Bhakta, 2020).

Conclusions

This research has policy implications for engineering managers. Operations managers are being forced to make decision that defy long term supply chain strategies. Operations managers need a fundamental understanding of sourcing, production, inventory management, and logistics (ERP Advisors Group, 2020). They also need to review their risk management practices and contracts terms for liability arising from delays and for their ability to ship substitutes when products are not available (McGrath, 2020).

Manufacturing Locations

Knowing the reasons why engineering operations managers blame China for supply chain disruptions during times of crises like the COVID19 pandemic can help them decide where to strategically locate their manufacturing operations. This is particularly true for the US China trade war and tariffs reason. With respect to the heavy concentration of manufacturing in China, engineering managers should take this into consideration regarding disaster risk reduction. In times of crises like the COVID19 pandemic, when China had to lockdown, it adversely impacted their manufacturing and the disruption reverberated throughout global supply chains. Instead, perhaps companies should diversify the locations of their manufacturing operations (FitchSolutions, 2020b). Pre-pandemic, supply chain

diversification was not a priority. But, with the COVID19 pandemic and trade wars, companies are reassessing their supply chains (Krawcke, 2021). Companies need to contrast the cost and efficiency benefits offered by globalized supply chains against more robust, expensive domestic supply chains. Domestic supply chains with smaller local suppliers can be risky if their workers get sick during an outbreak like COVID19 (Moyo, 2020). Another consideration is that generally, products that travel longer distances before reaching their final point of sale have more fragile supply chains (Mahajan, 2020). Companies should consider reshoring plants closer to each other to shorten supply chains. QIMA, a provider of supply chain solutions, reported that some companies are near shoring to Latin and South America (Brown, 2020).

Strategic Sourcing

During the COVID19 pandemic, with speed and agility, companies have needed to source new buyers, suppliers, and partners (Bhakta, 2020; de Matos, 2020); new multimodal transportation modes; new carriers, and new technology (Cassidy, 2021b). Price is not the only decision. Companies are urged to look at other suppliers in low-cost countries to move the origin outside China and look at countries where customs and border duties are not going to be applied. They should also leverage free trade agreements (Krawcke, 2021). Operations managers need logistics capacity assessments that include mapping local and international players in the supply chain, their roles, their responsibilities, and their capacities such as warehousing and supplies, and their reputation for having community trust (Koliousis, 2021). Companies can benefit from cloud-based applications that match supply with demand (PR Newswire, 2020b); and social networking to help buyers and sellers build collaborative partnering relationships (PR Newswire, 2020e).

Lean Manufacturing and JIT Fulfillment

The logistical planning for demand during this pandemic proves to be more complex than planning for demand after a weather driven or terrorist disaster (Barlow, 2020). Production operations managers experienced extended transportation time which signals the need to revise the supply chain strategy. This is true of the Just in Time (JIT) fulfillment strategy. They can prolong the JIT idea within the system and analyze possibilities to configure supply chains based on local suppliers (Marzantowicz, 2020). In particular, the auto industry is centered on JIT and lean manufacturing. Supply chains that were designed to be lean are now fatter (Cassidy, 2021b). However, for original equipment manufacturers, a move away from JIT is not likely because of the cost, size, and weight of components such as engines. To move away from JIT would likely increase capital expenditures (Braden, 2020).

Inventory Management

The need for having safety and buffer stock was discussed. “Safety stock is no longer a bad thing” because of increased carrying costs. Operations managers must weigh the increased carrying costs against the potential cost of a stock out (Cassidy, 2021b). Due to boost in sales with more people staying home, Domino’s pizza expanded its inventory to head off potential supply chain disruptions (Times, 2020). Enterprise Resource Planning (ERP) systems are necessary to predict inventory fluctuations (ERP Advisors Group, 2020). Operations managers need better forecasting of customer demand, order volumes and transportation volumes to keep shippers from getting caught with a lot of inventory on hand (Cassidy, 2021b). During COVID19, manufacturers have faced shocks to supply. They need access to tracking information regarding the routing of their shipments and repositioning of their inventory (Koliousis, 2021).

Digital Data Collection and Analytics

Some companies had to pivot to online sales. Some faced operational challenges such as complying with COVID restrictions like social distancing; unavailable workers due to lockdowns and illness; scarce raw materials; and/or machine failures due to increased production (Dar, 2020). When rethinking inventory holding practices and sourcing, data is needed for supply chain resilience (Saghiri and Bourlakis, 2021). In addition, the pandemic shed light on the need for more integrated supply chain planning software that accommodates when decisions are made and how; at what level of data granularity are decisions made; and how often decisions must be made. Integrated software needs to also consider how data is generated and what the data availability to employees should be (Van Hove, 2020).

Some had to improve their ERP data analytics and sales and operations management. For example, the US Veteran’s Administration quickly realized how antiquated their systems were for tracking medical supplies. They are now planning to modernize their system by 2027 (GAO, 2020). Interestingly, Josh Buchanan, Director of Supply Chain Design and Innovation at Walmart stated that his team refreshes their supply chain modeling annually. But, with the pandemic, they plan to accelerate the frequency and speed of their supply chain modeling, network design, and examination of worse case scenarios. Much can be learned from China because they have technology and processes that can be implemented faster. For example, they have “the ability to onboard an associate in under 24 hours as well as start-up a warehouse management system in a matter of days, as opposed to weeks or months, to get

a new distribution center operational” (McTaggart, 2020). With digital platforms, reduced document handling and reduced data entry can increase speed (de Matos, 2020; Cassidy, 2020d). Having a digital command center with supplier surveillance analytics and the ability to monitor data in real time enables managers to take immediate action to pre-stock critical supplies (Barlow, 2020). Further, warehouses need to be automated as well. Online orders require more logistical work such as individual picking, packaging, and shipping (ResearchandMarkets.com, 2020e).

Transportation Logistics

To alleviate delivery shortfalls, there is a need for better planning to prevent delays. For example, during the COVID19 pandemic, shipment delays caused Peloton to lose sales to competitors (Cassidy, 2021b). Shippers have had to rethink how they procure freight transportation, i.e., how they put their freight lanes and business out for bid. Traditional practices focused on prices from shipping analysts and trucking executives. Rather than arms-length bidding, more collaborative bidding has been needed (Cassidy, 2020a). Multi-modal transportation optimization is also needed. This has been a goal for shippers for decades. Optimization will enhance speed in finding new freight lanes and new transportation modes (Cassidy, 2020a; Cassidy, 2020e).

Implications for Engineering Managers

Supply chain management is in the industrial engineering management discipline. In Hypotheses 3 it is hypothesized that engineering management strategies would not be mentioned as solutions to resolve the COVID19 supply chain disruptions. However, as mentioned in the results, it was found that engineering management strategies were mentioned in 60% of the papers included in this bibliometric study. This is promising and important to know. This sheds light on the notion that more engineering management scholars should take on the role of ‘scholar practitioner’ and cultivate a community of practice focused on reducing supply chain disruptions in times of disasters like the COVID19 pandemic. In addition, since food security was more frequently discussed than vaccines, to reduce supply chain fragility, engineering management scholar practitioners can perhaps begin with knowledge sharing focused on the food supply chain. The COVID19 virus is the source of supply chain disruption. Thus, logically, knowledge sharing related to vaccination distribution and supply chain employees’ safety are other areas for engineering managers to concentrate their efforts on.

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