This article has been accepted for publication in a future proceedings of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/ieem50564.2021.9672913, 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

Supply Chain Management and Resilience During Disruption. Evaluation of the Covid-19 Pandemic on the Supply of Personal Protective Equipment

Marco Cuvero[1*], Alan Pilkington[1] and David Barnes[1]
[1]Westminster Business School, University of Westminster, London, NW1 5LS, United Kingdom
*Corresponding Author: E-mail: m.cuverocalero@westminster.ac.uk

Abstract - **Covid-19 stressed supply for Personal Protective Equipment (PPE) [1]. Lean practices have traditionally been proven to support stability in most operations [2], however, the pandemic highlighted concerns regarding lean system resilience in healthcare [2], [5], [6].**

In this paper we evaluate supply chain resilience in the provision of PPE for medical staff in the United Kingdom through a content analysis of online government documents and press releases using a three-phase model: proactive, concurrent, and reactive.

We propose a framework for future work on risk management approaches seeking to mitigate the effects of pandemic style disruption resulting from our emerging themes which include the identification and appreciation of critical suppliers, the location of warehouses and distribution centers and the impact of rapid restructuring of healthcare systems.

A key recurrent theme is the need to integrate information and collaboration between government and the private sector and our data suggests that contrary to many beliefs, lean approaches are a valid tool.

Keywords - **Supply Chain Management, Lean, Resilience, Covid-19, Personal Protective Equipment**

I. INTRODUCTION

The current COVID-19 pandemic created a massive breakdown in the economy due to increased demand for products and services [4], [5]. After initial infections in Wuhan, China [7], the virus rapidly spread causing its classification as a pandemic by the World Health Organization (WHO) [2]. In response, countries began to implement lockdowns and enforce social distancing, prioritizing saving human lives but causing significant disruptions in the economy [8]. The main priority for leaders was simple: to flatten the infection curve and protect the healthcare systems capability to treat patients developing pneumonia [9].

Europe and the united states faced significant impacts due to a decline in production and sales [10] as the pandemic disrupted economical activity and social interaction [8] as the regulations restricted public gatherings [1].

A supply chain's resilience characteristics are determined by the capability of organizations to recover normal operations [12]. In this case some of the major effects included interactions occurring in global production networks (GPN) not just domestic supply [13]. Evidence suggests that supply issues hit at least 938 Fortune 1000 companies as they sourced in Wuhan, China [5], [11] and the after-effects on the demand and management of transportation was faced by at least 94% of small and medium enterprises [7], [14]. In this case, occurrences such as Covid-19 are considered disruptions affecting normal business operations [15].

One of the significant problems to address is the supply of Personal Protective Equipment (PPE) in hospitals and Intensive Care Units (ICUs). It is expected that 80% of patients who enter hospitals due to Covid-19 symptoms will only develop mild symptoms [2], however, patients who require further treatment cause significant disruption to hospital capacity and the supply of medical equipment.

Similar issues are seen not just in the number of dying patients but also on hospital staff. In May of 2020, it was estimated that 3,000 health workers had died due to Covid-19 in 79 countries [16]. A study, from the American Nurses Association, showed the scale of supply issues, citing around 45% mentioning problems in PPE shortage, while 75% were asked to reuse masks. These problems led to operation management practitioners to assess the impact of alternative supply chain strategies such as evaluating digital networks and blockchain as well as applying existing theories [17].

In this paper we examine the main themes in supply chain management resilience literature, and explore the implications on the adoption of lean apporahces. Our data comes from a content analysis conducted on official documents from the UK government and PPE suppliers. The paper is structured as follows. In section II, we discuss the literature on current resilience models and phases of disruption occurring during the pandemic. Section III oultines our research methodology and the initial insights on the processes implemented by the government and the industry during the Covid-19 pandemic. Finally, section VI provides a summary and conclusions of the research.

II. LITERATURE REVIEW

A. Supply Chain Disruption and Risk Management

Disruptions in supply are related to an organization's inability to respond to current demand [7]. Disruptions such as the Covid-19 pandemic have a low probability of occurring but a high potential cost [18]. The aim for supply chain practitioners is to reduce the costs and address employee wellbeing whilst recovering from the disruption [19]. However, pandemic decisions carry much ambiguity as companies and governmental organizations have to make decisions based on forecasts with a lack of clarity [3].

This article has been accepted for publication in a future proceedings of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/ieem50564.2021.9672913, 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

In particular, PPE provision caused by passing risk and quality checks to provide availability due to an abrupt surge of demand [20], and a reduction in manufacturing capacity [3]. Manufacturing companies changed to alternate producers in the United States and the United Kingdom to meet demand [21]. For example, the provision of ventilator parts and masks made with 3D printing [22]. Empirical data highlights the necessity to establish collaborations with third parties to supply through rush deliveries and donations [23].

The unavailability of PPE in frontline workers caused an increasing number of cases in Italy [19] and similar circumstances in the United States saw a supply of 12 million N95 masks, which was not enough [24]. On the other hand, countries such as Taiwan and South Korea organized manufacturing within weeks to cover the increased demand [24]. So governments implemented different risk management procedures and tacticts to mitigate the number of deaths and infected people. This is the aim of this project as a whole, but here we will concentrate on the early findings of our analysis of UK government data.

In general, supply chain risk management (SCRM) focuses on implementing processes to establish collaborations for supply chain risks and uncertainties [14]. The evaluation of risk is influenced by the country's initial conditions and communication abilities [8]. As such, SCRM vulnerability recommends evaluating supply chain resilience to recover and redesign the supply chain. Thus, supply chain risk is considered the event that disrupts the normal flow of materials or information through the supply chain from suppliers to customers or end-users [25].

The evaluation of risk forms part of the *initial phase of resilience* that aims to reduce potential damage and enhance the supply chain's operations to consider a potential recovery of the system and adapt to future disruptions [15]. In these cases, organizations' proficiency in recovering from disruptions reduces the supply chain risks [26]. The most important clauses for the development of innovation here management approach and access to accurate information.

B. Supply Chain Management and Resilience

The concept of resilience originated in the ecological and physiology fields [25] and is the ability to recover from a disruption [12], [18]. Disruption includes causes from natural events and disasters, terrorist attacks, problems caused by quality and accidents [1]. In particular, Covid-19 had the health sector facing problems concerning meeting technical specifications and performing diligence [25], [27]. Referring to theory, this is classified using a thre-phase model of: proactive, concurrent, and reactive [5].

Proactive is the requirement to prepare for the incoming disruption [28]: first, countries and organizations need to conduct risk management to evaluate the pandemic's effects and plan strategies to mitigate vulnerable positions. Second, preparation requires the estimated demand of PPE amid virus propagation [29], [30]. Third, the forecast needs to consider the percentage of hospitalized population during the pandemic [31]. The final phase is to invest resources and evaluate potential scenarios [10].

In the concurrent phase, the supply chain operations implement required protocols to ensure the security of health workers, maintain normal operations, and cover the demand for PPE [10]. This implementation is where governmental policies, lockdown measures and restrictions reduce infections and deaths. However, as this requires weeks before countries can start their normal operations [10], it highlights the importance of a supply chain's ability to adapt and respond to the pandemic [28].

Finally, the reactive phase involves the flexibility in the supply chain and decision-making processes required to re-start production and effectively manage inventory to cover demand [32].

Important points to consider in these pahses are information accuracy in the initial planning, potential quality and capacity problems which can lead to the unavailability of products from suppliers and other the ability to exploit flexibility to cope with failures in production [33]. It is here that lean thinking – learning how to implement processes that can adapt to situations [34] – can help design network capacity able to evolve as required [35], [36].

III. RESEARCH METHODOLOGY

We conducted a study of the actions taken by the UK to tackle the supply of protective marks during the covid-19 pandemic [37] and sought to provide initial insights on identifying research opportunities to highlight the main problems and actions required to maintain the resiliency of supply chains in the health sector. We collected data from government reports which were coded using NVivo 12. The focus of the analysis was to identify the preparations for forecasting the impact of the Covid-19 pandemic; and identify adjustments carried out to distribution centers, warehouses, logistic teams and platforms. The data gathered was coded and as well as here in investigating SCRM potential, will be used for future publications on cross country comparisons.

IV. FINDINGS

This section presents the emergent themes (identified with the resulting codes in the text) and insights from the proactive and concurrent phases of the resilience model relating specifically to PPE procurement.

A. Proactive Phase

The initial evaluation of risks in the proactive phase requires integrating systems and platforms to attain accurate information [36].

The UK evidence suggests that GPs (individual doctors) and local authorities lacked access to information on patients (thematic code: AP-BS1), and an initial increase in infections could have been reduced with data sharing between governmental and private sectors.

This article has been accepted for publication in a future proceedings of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/ieem50564.2021.9672913, 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

Second, the UK data on initial planning showed it expecting to be able to cover 79% of possible demand by the end of November and December (AP-BS2, AP-BS3) and so the response was to increase inventory over a four month period (AP-BS3). This initial aim of building inventory was based on established work on other viruses.

The theme of increased visibility in the flow of PPE inventory also emerged [38]. It was clear that over 80% of base production and acquisition of PPE was obtained from China (AP-BS3) and the pandemic caused a massive increase in demand from 10-15 million units to 70-80 million units per month (AP-V2). This is essentially what caused inventory shortages (AP-V1, AP-V2).

B. Concurrent Phase: Ability to Adapt

The initial awareness of risks in the proactive phase [39] required flexibility and evaluation of the capacity and distribution over a number of weeks [28]. The NHS's first actions considered providing support to care homes to maintain normal operations and gather relevant resources (D-IR1). Developing flexibility involved forming partnerships with SMEs and incumbents to conduct testing and link to international suppliers (D-IR2, D-IR3). This process requires establishing constant communication between specialized laboratories and NGOs such as the WHO (D-IR3). International collaborations are required to establish standardized operations to acquire billions of inventory items to tackle the pandemic (D-IR4). The inherent disruption of such change to the existing system caused major concerns for NHS staff as previously unused independent laboratories were called upon without existing routines and systems (D-IR3). Properly implemented lean approaches should not have been a barrier to these activities as effective supply requires the free flow of inventory and funding across countries and infrastructure such as airports needs to be effective [22], [40].

However, in the UK responsibility for these actions were not kept with the existing structures. The Foreign and Commonwealth Office and Defense Ministry were tasked with establishing relations with international suppliers (D-IR4) whilst the Department of Health and Social Care (DHSC) led the initiative to manage PPE. Masks were ordered weekly but the monitoring of quality was monthly (D-IR5, D-IR6). The identification of new suppliers and contract negotiation under new procedures has become a major political issue in the UK.

C. Lessons

The discussion above of the two initial phases of the resilence approach led us to consider dimensions for future work (see figure 1). An initial proposition to investigate is:

Proposition 1: SCRM can limit disruption and improve planning of critical suppliers, the location of warehouses, and distribution centers during a pandemic. The process should require the integration of information and collaboration between the government and the private sector.

V. DISCUSSION

Our theoretical discussion highlighted the importance of key organizations in supporting supply chain resilience during a time of disruption. Importantly in the proactive phase, the initial estimation of inventory can prevent the failure of the network and distribution centers, whilst lean supply chain management approaches need to be explored to improve the coordination of agile networks that align with the adaptation and responses [41], or concurrent phase of the theory.

With our proposition and model we identify research opportunities which include the exploration of physical and information systems, the evaluation of risks, and the coordination of efforts between the industry and the government [42], [43]. In this case, lean principles coud be used to show how the flow of inventory and information can be improved by coordinating teams [44]. We also highlight the imperative of close involvement of government, health sector, private industry, and the military in making the systems resilient.

Tactics resulting from our analysis of the risk evaluation data shows the prevalence of a strategy of adopting new platforms and distribution centers [45] and the evidence suggests it is necessary to increase the mandatory initial acquisitions of inventory to maintain a safe stock before increasing the demand.

Both these phases can be boosted by adopting lean practice which involves adapting production schedules and monitoring inventory throughout the supply chain [42]. This includes the capability operations to adapt to continuous disruptions [3], [43]. This is contrary to many initial claims that supply issues were directly the result of lean implementation.

VI. CONCLUSIONS AND RECOMMENDATIONS

The disruption from Covid-19 caused much discussion on the supply chain management and planning for medical items and also a call for the questioning of lean systems. By assessing both the proactive and concurrent phases of the resilience model, the evidence we have suggests weaknesses in the system performance can be attributed initially to inaccurate information about the number of infections and also that the development of the pandemic stretched the demand at the same time as the supply was restricted. This case suggests that communication is key to coordinating efforts with third parties and the health sector entities to adjust current infrastructure to boost distribution.

This article has been accepted for publication in a future proceedings of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/ieem50564.2021.9672913, 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

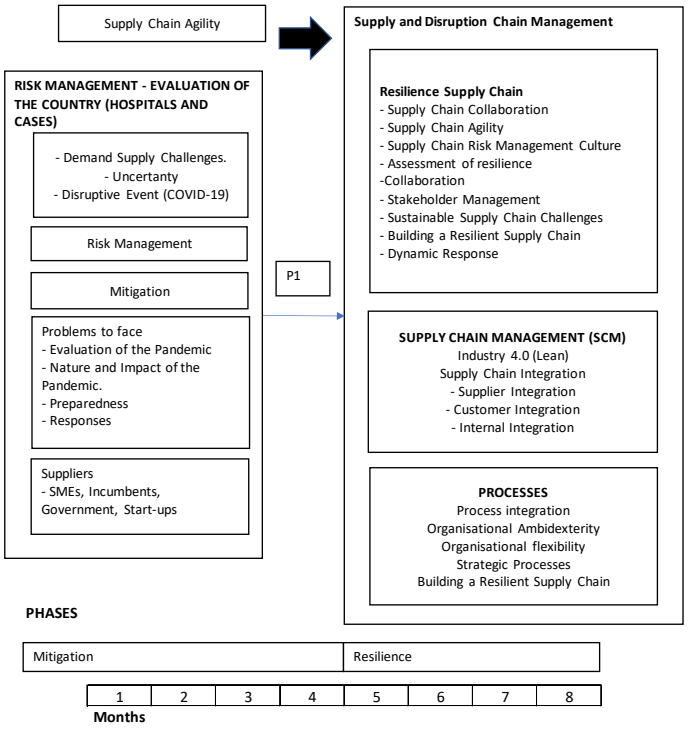

Fig. 1. Themes proposed to explore Supply Chain Management and resilience with disruption.

In the concurrent phase of the resilience model, our evidence suggests that aopting lean approaches should generate flexibility to improve performance, and that lean itself was not the cause of the system failures. Another significant theme to emerge is that extending existing networks at short notice meant that quality criteria and diligence actions were curtailed leading to problems.

Our next work is to explore discrepancies between the operations in countries compared to our UK Data and examine how disruptions to the supply of PPE was managed most effectively.

REFERENCES

[1] D. J. Ketchen and C. W. Craighead, "Research at the Intersection of Entrepreneurship, Supply Chain Management, and Strategic Management: Opportunities Highlighted by COVID-19," *J. Manage.*, vol. XX, no. X, pp. 1–12, 2020.

[2] H. Leite, C. Lindsay, and M. Kumar, "COVID-19 outbreak: implications on healthcare operations," *TQM J.*, 2020.

[3] S. Gunessee and N. Subramanian, "Ambiguity and its coping mechanisms in supply chains lessons from the Covid-19 pandemic and natural disasters," *Int. J. Oper. Prod. Manag.*, 2020.

[4] J. Blackhurst, K. S. Dunn, and C. W. Craighead, "An empirically derived framework of global supply resiliency," *J. Bus. Logist.*, vol. 32, no. 4, pp. 374–391, 2011.

[5] A. Kumar, S. Luthra, S. K. Mangla, and Y. Kazançoğlu, "COVID-19 impact on sustainable production and operations management," *Sustain. Oper. Comput.*, vol. 1, no. June, pp. 1–7, 2020.

[6] K. H. Jacobsen, "Will COVID-19 generate global preparedness?," *Lancet*, vol. 395, no. 10229, pp. 1013–1014, 2020.

[7] M. S. Kumar, D. R. D. Raut, D. V. S. Narwane, and D. B. E. Narkhede, "Applications of industry 4.0 to overcome the COVID-19 operational challenges," *Diabetes Metab. Syndr. Clin. Res. Rev.*, vol. 14, no. 5, pp. 1283–1289, 2020.

[8] S. Verma and A. Gustafsson, "Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach," *J. Bus. Res.*, vol. 118, no. June, pp. 253–261, 2020.

[9] J. Santos, "Using input-output analysis to model the impact of pandemic mitigation and suppression measures on the workforce," *Sustain. Prod. Consum.*, vol. 23, pp. 249–255, 2020.

[10] M. Rapaccini, N. Saccani, C. Kowalkowski, M. Paiola, and F. Adrodegari, "Navigating disruptive crises through service-led growth: The impact of COVID-19 on Italian manufacturing firms," *Ind. Mark. Manag.*, vol. 88, no. May, pp. 225–237, 2020.

[11] S. K. Paul and P. Chowdhury, "A production recovery plan in manufacturing supply chains for a high-demand item during COVID-19," *Int. J. Phys. Distrib. Logist. Manag.*, 2020.

[12] N. Agarwal and N. Seth, "Modeling supply chain enablers for effective resilience," 2020.

[13] J. R. Bryson and V. Vanchan, "COVID-19 and Alternative Conceptualisations of Value and Risk in GPN Research," *Tijdschr. voor Econ. en Soc. Geogr.*, vol. 111, no. 3, pp. 530–542, 2020.

[14] V. Ahlqvist, A. Norrman, and M. Jahre, "Supply Chain Risk Governance: Towards a Conceptual Multi-Level Framework," *Oper. Supply Chain Manag. Int. J.*, vol. 13, no. 4, pp. 382–395, 2020.

[15] I. Linkov *et al.*, "The case for value chain resilience," *Manag. Res. Rev.*, 2020.

[16] L. McCauley and R. Hayes, "Taking responsibility for

frontline healthcare workers," *Lancet Public Heal.*, vol. 5, no. 9, pp. e461–e462, 2020.

[17] F. Zhang, X. Wu, C. S. Tang, T. Feng, and Y. Dai, "Evolution of Operations Management Research: from Managing Flows to Building Capabilities," *Prod. Oper. Manag.*, vol. 0, no. 0, pp. 1–11, 2020.

[18] S. N. Emenike and G. Falcone, "A review on energy supply chain resilience through optimization," *Renew. Sustain. Energy Rev.*, vol. 134, no. September, p. 110088, 2020.

[19] A. Sharma, A. Adhikary, and S. B. Borah, "Covid-19′s impact on supply chain decisions: Strategic insights from NASDAQ 100 firms using Twitter data," *J. Bus. Res.*, vol. 117, no. June, pp. 443–449, 2020.

[20] A. Trautrims, M. C. Schleper, M. S. Cakir, and S. Gold, "Survival at the expense of the weakest? Managing modern slavery risks in supply chains during COVID-19," *J. Risk Res.*, vol. 0, no. 0, pp. 1–6, 2020.

[21] A. Kashyap and J. Raghuvanshi, "A preliminary study on exploring the critical success factors for developing COVID-19 preventive strategy with an economy centric approach," *Manag. Res.*, 2020.

[22] M. M. Queiroz, D. Ivanov, A. Dolgui, and S. Fosso Wamba, *Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review*, no. 0123456789. Springer US, 2020.

[23] van H. Remko, "Research opportunities for a more resilient post-COVID-19 supply chain – closing the gap between research findings and industry practice," *Int. J. Oper. Prod. Manag.*, vol. 40, no. 4, pp. 341–355, 2020.

[24] T. Dai, M. H. Zaman, W. V. Padula, and P. M. Davidson, "Supply chain failures amid Covid-19 signal a new pillar for global health preparedness," *J. Clin. Nurs.*, no. June, pp. 1–3, 2020.

[25] R. D. Tordecilla, A. A. Juan, J. R. Montoya-Torres, C. L. Quintero-Araujo, and J. Panadero, "Simulation-Optimization Methods for Designing and Assessing Resilient Supply Chain Networks under Uncertainty Scenarios: A Review," *Simul. Model. Pract. Theory*, vol. 106, no. July 2020, p. 102166, 2020.

[26] M. Rampazzo and A. Beghi, "Designing and teaching of an effective engineering continuing education course: Modeling and simulation of HVAC systems," *Comput. Appl. Eng. Educ.*, vol. 26, no. 4, pp. 739–748, 2018.

[27] A. B. Lopes de Sousa Jabbour, C. J. Chiappetta Jabbour, M. Hingley, E. L. Vilalta-Perdomo, G. Ramsden, and D. Twigg, "Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends," *Mod. Supply Chain Res. Appl.*, vol. ahead-of-p, no. ahead-of-print, 2020.

[28] A. Ali, A. Mahfouz, and A. Arisha, "Analyzing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review," *Supply Chain Manag.*, vol. 22, no. 1, pp. 16–39, 2017.

[29] D. Ivanov and A. Das, "Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: a research note," *Int. J. Integr. Supply Manag.*, vol. 13, no. 1, p. 90, 2020.

[30] J. J. Klemeš, Y. Van Fan, and P. Jiang, "The energy and environmental footprints of COVID-19 fighting measures – PPE, disinfection, supply chains," *Energy*, vol. 211, no. x, 2020.

[31] K. Govindan, H. Mina, and B. Alavi, "A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19)," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 138, no. April, p. 101967, 2020.

[32] D. Ivanov, "Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 136, no. March, p. 101922, 2020.

[33] D. Messina, A. C. Barros, A. L. Soares, and A. Matopoulos, "An information management approach for supply chain disruption recovery," *Int. J. Logist. Manag.*, vol. 31, no. 3, pp. 489–519, 2020.

[34] R. B. Handfield, G. Graham, and L. Burns, "Corona virus, tariffs, trade wars and supply chain evolutionary design," *Int. J. Oper. Prod. Manag.*, 2020.

[35] D. Ivanov and A. Dolgui, "OR-methods for coping with the ripple effect in supply chains during COVID-19 pandemic: Managerial insights and research implications.," *Int. J. Prod. Econ.*, p. 107921, 2020.

[36] D. Ivanov and A. Dolgui, "A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0," *Prod. Plan. Control*, vol. 0, no. 0, pp. 1–14, 2020.

[37] Y. Liang, "Research on Mechanism of Cluster Enterprise Innovation: A view of Co-Governance," in *2008 4TH INTERNATIONAL CONFERENCE ON WIRELESS COMMUNICATIONS, NETWORKING AND MOBILE COMPUTING, VOLS 1-31*, 2008, pp. 5786–5790.

[38] V. Jain, S. Kumar, U. Soni, and C. Chandra, "Supply chain resilience: model development and empirical analysis," *Int. J. Prod. Res.*, vol. 55, no. 22, pp. 6779–6800, 2017.

[39] U. Soni, V. Jain, and S. Kumar, "Measuring supply chain resilience using a deterministic modeling approach," *Comput. Ind. Eng.*, vol. 74, no. 1, pp. 11–25, 2014.

[40] C. Free and A. Hecimovic, "Global supply chains after COVID-19: the end of the road for neoliberal globalization?," *Accounting, Audit. Account. J.*, 2020.

[41] C. Acioli, A. Scavarda, and A. Reis, "Applying Industry 4.0 technologies in the COVID–19 sustainable chains," *Int. J. Product. Perform. Manag.*, no. 311881, 2021.

[42] D. Friday, D. A. Savage, S. A. Melnyk, N. Harrison, S. Ryan, and H. Wechtler, "A collaborative approach to maintaining optimal inventory and mitigating stockout risks during a pandemic: capabilities for enabling healthcare supply chain resilience," *J. Humanit. Logist. Supply Chain Manag.*, 2021.

[43] D. Ivanov, "Lean resilience: AURA (Active Usage of Resilience Assets) framework for post-COVID-19 supply chain management," *Int. J. Logist. Manag.*, 2021.

[44] O. McDermott, J. Antony, and J. Douglas, "Exploring the use of operational excellence methodologies in the era of COVID-19: perspectives from leading academics and practitioners," *TQM J.*, 2021.

[45] A. S. Butt, "Strategies to mitigate the impact of COVID-19 on supply chain disruptions: a multiple case analysis of buyers and distributors," *Int. J. Logist. Manag.*, no. March, 2021.