

A collaborative approach to maintaining optimal inventory and mitigating stockout risks during a pandemic: capabilities for enabling health-care supply chain resilience

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Abstract

Purpose – Inventory management systems in health-care supply chains (HCSC) have been pushed to breaking point by the COVID-19 pandemic. Unanticipated demand shocks due to stockpiling of medical supplies caused stockouts, and the stockouts triggered systematic supply chain (SC) disruptions inconceivable for risk managers working individually with limited information about the pandemic. The purpose of this paper is to respond to calls from the United Nations (UN) and World Health Organization (WHO) for coordinated global action by proposing a research agenda based on a review of current knowledge and knowledge gaps on the role of collaboration in HCSCs in maintaining optimal stock levels and reinforcing resilience against stockout disruptions during pandemics.

Design/methodology/approach – A systematic review was conducted, and a total of 752 articles were analyzed.

Findings – Collaborative planning, forecasting and replenishment practices are under-researched in the HCSC literature. Similarly, a fragmented application of extant SC collaborative risk management capabilities undermines efforts to enhance resilience against systematic disruptions from medical stockouts. The paucity of HCSC articles in humanitarian logistics and SC journals indicates a need for more research interlinking two interdependent yet critical fields in responding to pandemics.

Research limitations/implications – Although based on an exhaustive search of academic articles addressing HCSCs, there is a possibility of having overlooked other studies due to search variations in language controls, differences in publication cycle time and database search engines.

Originality/value – The paper relies on COVID-19's uniqueness to highlight the limitations in optimization and individualistic approaches to managing medical inventory and stockout risks in HCSCs. The paper proposes a shift from a fragmented to holistic application of relevant collaboration practices and capabilities to enhance the resilience of HCSCs against stockout ripple effects during future pandemics. The study propositions and suggestion for an SC learning curve provide an interdisciplinary research agenda to trigger early preparation of a coordinated HCSC and humanitarian logistics response to future pandemics.

Keywords Collaborative forecasting planning replenishment, Supply chain collaborative risk management, Supply chain resilience, Supply chain uncertainty, Risk perception, Healthcare supply chains, COVID-19 pandemic, Supply chain learning curve

Paper type Research paper



1. Introduction

Health-care supply chain (HCSC) management has attracted increasing attention among scholars, practitioners and governments (e.g. *Kwon et al., 2016; Kwon and Kim, 2018*). While

effective supply chain (SC) management has critical implications for most industries, HCSC disruption can jeopardize patient safety and overall health quality (e.g. [Clauson et al., 2018](#)). Events such as the COVID-19 pandemic serve to make this issue more urgent and visible (e.g. [Ivanov, 2020a](#); [Ivanov and Das, 2020](#); [Queiroz et al., 2020](#)). The global context of the COVID-19 pandemic has spawned a nascent research cluster focused on the implications of COVID-19 for SCs. *Inter alia*, these studies focused, for instance, on resilience (e.g. [Ivanov, 2020b](#); [Ivanov and Das, 2020](#); [Ivanov and Dolgui, 2020a, b](#)), decision support ([Govindan et al., 2020](#); [Currie et al., 2020](#)) or production recovery plans (e.g. [Paul and Chowdhury, 2020](#)). However, there is limited attention on the criticality of maintaining optimal medical stock levels in HCSCs.

As the COVID-19 pandemic impact escalated, unprecedented uncertainty and risk surrounding availability, access and affordability of medical supplies lead to panic buying and stockpiling of medical supplies, creating unanticipated demand shocks, stockouts and systematic disruptions of HCSCs. For humanitarian logistics, private business and governments, medical stockouts escalated the challenges of delivering medical relief and increasing life or death risks for COVID-19 patients and their communities ([Mack, 2020](#); [Besiou and Van Wassenhove, 2020](#); [Schiffing et al., 2020](#); [Wagner et al., 2020](#)).

Most research on managing medical stocks was undertaken outside a pandemic context, and so highlight inventory management techniques that minimize cost, maximize profit, and generally optimize HCSCs through stochastic and periodic reviews, approximation of inventory control via simulation or radio frequency identification (RFID), or vendor-managed inventory (VMI) plans ([Franco and Alfonso-Lizarazo, 2017](#); [Jabbarzadeh et al., 2019](#); [Saha and Ray, 2019](#); [da Conceição et al., 2020](#)). However, in a pandemic context, optimized lean inventory systems are counterintuitive as governments, health-care and relief organizations individually grapple with clogged inventory processes. The need for ensuring global accessibility to optimal medical stocks during pandemics supersedes costs, profits and other performance optimization objectives. Businesses, humanitarian logistics organizations and governments cannot not function under an inventory-stressed global HCSC network.

Stockout risks could be reduced if effective medicine management followed a collaborative process between key stakeholders. Collaborative decision-making has been advocated in pharmaceutical SCs in relation to inventory review periods (e.g. [Nematollahi et al., 2018](#)) and coordination among third- and fourth-party logistics (4PL) service providers. While research on optimal medicine stocks focuses on uncertain lead times and demands, it does so in a context where uncertainty and risk probabilities can be estimated (e.g. [Kumar and Kumar, 2018](#)).

Drawing from the [van der Laan's et al. \(2016\)](#) model of demand forecasting for humanitarian logistics, limited knowledge of pandemics adds to stock management problems. In both humanitarian logistics and HCSC demand forecasting and order planning, there is a lack of data and metrics for performance measurement, limited quality control for medical purchases and time-consuming and error-prone SCs ([van der Laan et al., 2016](#)). The preference to overestimate medical stock forecasts in humanitarian logistics contradicts the aim of commercial SCs to “radically reduce inventories and expenses while improving customer service” ([Panahifar et al., 2015](#), p. 839). The negative effects of conflicting HCSC inventory management objectives are exacerbated by the lack of collaborative planning, forecasting and replenishment (CPFR) practices in the health-care sector ([Panahifar et al., 2015](#)).

Furthermore, medical stockouts during the COVID-19 pandemic resulted in systematic SC disruptions where it was not possible to mitigate risk with firm-level techniques because idiosyncratic responses cannot consider negative SC externalities from interconnectivity and interdependences inherent in an HCSC. Unlike well-known frequent inventory risks, medicine stockouts caused by pandemics can be categorized as *low-frequency-high-impact*

risks, whose disruption impact is worsened by the sensitivity of lean, interconnected and interdependent inventory management processes. The lack of a coherent and integrated logistics strategy, and constrained logistics components like transportation and distribution infrastructure, procurement processes, closed international borders and insufficient human resources have an even greater impact on the resilience of an HCSC during a pandemic (Thompson, 2015).

Some reviews in HCSC research highlight the effectiveness of SC collaboration in managing counterfeits, drug shortages and enabling resilience (Machado *et al.*, 2018; Nematollahi *et al.*, 2018; Lima *et al.*, 2018; Milne-Ives *et al.*, 2020). Additionally, there is related knowledge about agility and resilience as main determinants of humanitarian SC performance and competitiveness (e.g. Altay *et al.*, 2018; Carvalho *et al.*, 2012; Dubey *et al.*, 2020). While collaboration is identified as a key strategy in responding to pandemics and improving overall SC performance (Russo, 2012; Moshtari, 2016; Dubey *et al.*, 2019), the potential of SC collaborative risk management (SCCRM) capabilities to enhance the resilience of HCSC against systematic stockout disruptions during a global pandemic is yet to be considered.

The ineffectiveness of conventionally optimized inventory (quantity of stock able to meet demand between two order processing and delivery cycles) and risk management techniques could be explained by the failure to adjust for information asymmetry, radical changes in behavior and perception of uncertainty and risk (Hajmohammad and Vachon, 2016; Chan *et al.*, 2020). Behavioral economics approaches to decision-making under uncertainty indicate that COVID-19 is unique (grey swan) in comparison to natural calamities (e.g. Akkermans and Van Wassenhove, 2018; da Silva *et al.*, 2020). Accordingly, general optimization techniques are bound to fail due to limited information about the pandemic and unpredictable change in purchasing behavior. The ineffectiveness of individualistic responses to HCSC management were recognized by the United Nations (UN) and World Health Organization (WHO) in their calls for coordinated global actions against the pandemic (Djalante *et al.*, 2020). At the time of writing this paper, COVID-19 vaccines were being rolled out for the first time, and it appears that countries are opting for individual national stockpiles, contrary to the pleas for coordination from the UN and WHO.

Thus, the two research questions that guide this systematic literature review are:

- RQ1. What collaborative practices are employed to maintain optimal stock in an HCSC during a pandemic?
- RQ2. What SCCRM capabilities are employed to enhance the resilience of an HCSC against systematic disruptions from medical stockouts during a pandemic?

To address the research questions and propose a research agenda, this paper reviews the HCSC literature on the current state of knowledge and knowledge gaps related to collaboration in maintaining optimal stock levels and reinforcing resilience against stockout disruptions during the COVID-19 pandemic.

The study makes the following contributions. Within the COVID-19 context, we propose a re-examination of the CPFMR model assumptions by introducing new assumptions on perception of uncertainty and risk drawn from behavioral economics and the risk homeostasis theory (RHT) (Wilde, 1998). In line with the relational view theory (RVT), and based on the argument that fragmented applications of relational capabilities undermine the synergistic benefits of collaboration initiatives (Dyer and Singh, 1998), we propose a holistic application of collaboration capabilities to reinforce resilience against stockout ripple effects. We view collaboration as a strategic approach for achieving optimal medical stocks and enabling the resilience of HCSCs against medical stockout risks. Pandemics are a unique

research opportunity with insights on the limitations of idiosyncratic approaches, which insights provide building blocks on which to advance a coordinated response in the preparation for future pandemics. We propose a multi-level interdisciplinary research agenda for advancing a collaborative response to pandemics similar to COVID-19.

For practitioners, this study highlights the importance of aligning objectives and strategy between leading organizations in preparing coordinated responses to future pandemics. This includes pointing out the disconnects in strategies between the WHO Framework for Health Emergency and Disaster Risk Management and the UN Office of Disaster Risk Reduction (Djalante *et al.*, 2020). The paper offers a solution on how interdependent sectors (government, humanitarian logistics and HCSC) can work together.

The paper proceeds with an overview of the systematic literature review method, followed by presentation and discussion of results, directions for future research, contributions to theory and implications for practitioners. Lastly, we offer collaboration lessons from COVID-19 and concluding remarks.

2. Method

To answer the research questions, a systematic literature review was conducted following methodological guidelines from Denyer and Tranfield (2009). Similar to other recent reviews in the field of SC management (e.g. Machado *et al.*, 2020; Pournader *et al.*, 2020; Wijewickrama *et al.*, 2020), we searched for relevant literature in Scopus, Web of Science, ProQuest and Ebsco Databases using the following keywords in the title, abstract or keywords: “healthcare supply chain” OR “health-care supply chain” OR “health care supply chain” OR “pharmaceuticals supply chain” OR “medicine supply chain” OR “telehealth supply chain” OR “telehealth care supply chain” OR “telemedicine supply chain” OR “hospital supply chain” OR “medical supply chain”. This initial search process was limited to peer-reviewed articles and reviews published in English and resulted in 1,547 articles.

The initial 1,547 articles were further reduced to 752 articles. The excluded articles were composed of 710 duplicates or publications incorrectly indexed as articles (no identified authors or journals) and 85 articles with abstracts without a clear link to SCs and health care. We found that Articles addressing HCSCs are scattered across several journal specializations, although journals with the most articles were in *Supply Change Management and Health* (Table 1). Despite SC journals individually containing the highest number of articles, overall, the majority of articles were published in health care, information communication technologies and science and engineering journals. There was only one article in the *Humanitarian Logistics* journal about HCSC management, indicating a likely disconnect in two interdependent yet critical functions key to building a coordinated response to pandemics.

The objective of this review of HCSC literature is to provide a thematic analysis of collaboration concepts in the literature, highlight their application in HCSCs, and propose a research agenda. The intention is not to redefine CPFR or SCCRM, although interested readers may refer to Min and Yu (2008), Panahifar *et al.* (2015), Friday *et al.* (2018) and Tang (2006). Because the concepts are already defined, albeit outside the context of a pandemic, they need not be redefined but rather need to be re-examined. We do this by isolating, analyzing and tabulating relevant data from the selected articles and then aggregate common ideas based on a thematic approach.

In carrying out the review, we followed the approach of structuring codes associated with the research questions to assign articles to one of two primary dimensions: CPFR (*collaborative planning, collaborative forecasting, collaborative replenishment*); SCCRM (*risk information sharing, joint decision-making, risk and benefit sharing, process integration,*

Table 1.
Journals with the most
articles in HCSC
management

Health journals	Count	Supply chain/Management journals	Count
International Journal of Pharmaceutical and Healthcare Mark	14	International Journal of Supply Chain Management	13
American Journal of Health-System Pharmacy	13	International Journal of Logistics Systems and Management	10
Operations Research for Health Care	9	International Journal of Production Economics	9
Pharmaceutical Technology	7	Journal of Cleaner Production	8
		Supply Chain Management – an International Journal	8
		Production and Operations Management	7
		Supply Chain Forum	7

collaborative performance systems and standardization of procedures). The codes were then checked to eliminate inconsistencies and increase the internal validity and credibility of the data (Elliott *et al.*, 1999; Turner *et al.*, 2008). Reconfigured data and themes were presented as qualitative data using graphs and tabulations to facilitate interpretation, discussion and verification by future researchers. Analyses of the findings are presented below.

3. Analysis and discussion

3.1 Publication trend

Articles published on HCSC span a 26-year publication period from 1994 to 2020 (Figure 1). Prior to 1999, interest in HCSCs was limited but increased steeply after 2004 and 2009. Among the 752 articles on HCSC, those mentioning collaboration in HCSC accounted for 22.5%, those with a focus on pandemics were 4% and those mentioning resilience in HCSC were 1.5%. The number of articles addressing collaboration across all (including inventory management and stockout disruptions) functions in HCSC management is considerably higher than articles on pandemics and resilience; however, interest in pandemics has increased since 2015 and will no doubt increase substantially after 2020, the year of COVID-19. Furthermore, we anticipate a spike in publications addressing the importance of collaboration during pandemics because of: failure of individualistic inventory management approaches to ensure access to optimal

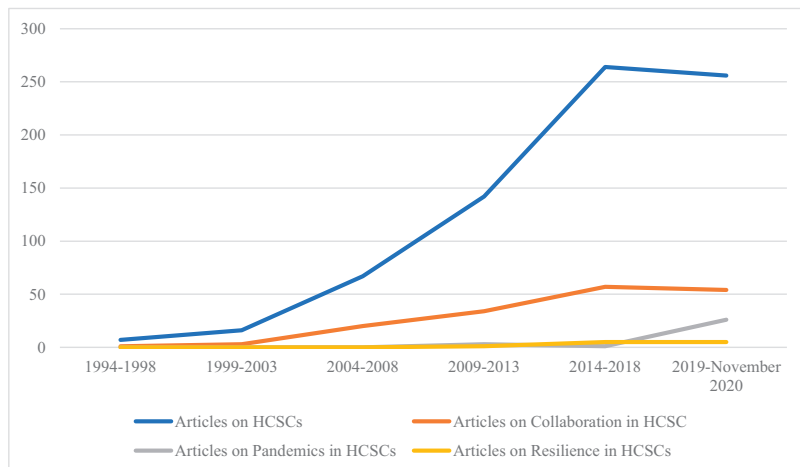


Figure 1.
Publication trend –
comparing articles
addressing
collaboration in HCSCs
(1994–2020)

medical stocks; limitations of individualistic (firm level) SC risk management (SCRM) approaches; and calls from the UN and WHO for coordinated global action to combat the COVID-19 pandemic impact. While collaboration is identified as a key strategy to enhance resilience against the pandemic impact, we found little HCSC research linking collaboration to resilience. This omission is even more critical in the context of a pandemic, and this needs to be addressed.

From a practice perspective, acceptance of SC collaboration practices may be much slower because of conflicting objectives among businesses, humanitarian organizations and government. For example, due to issues relating to intellectual property on flu vaccines in pharmaceuticals, pharmaceutical SCs are more likely to seek profit maximization objectives to achieve self-interests (Nematollahi *et al.*, 2018). Overall, further research on collaboration across government, humanitarian and the private sector will help better understand how to jointly prepare HCSCs to be more resilient to medical stockout ripple effects during future pandemics.

3.2 Collaborative planning, forecasting and replenishment practices in health-care supply chain management

To address RQ1 concerning the collaborative practices for stock maintenance in HCSCs, we examined references to planning, forecasting and replenishment. Collaborative planning practice is identified in 2% of the 752 articles (Table 2), while an additional 4% focus on generic planning, e.g. closed-loop planning (forward and return flows). Rather than collaborative planning, individual firm-level planning is more common because it aligns with profit maximization objectives in a highly competitive health-care industry (e.g. VanVactor, 2017; Chen *et al.*, 2013; Jabbarzadeh *et al.*, 2019). In relation to forecasting, there were only four articles addressing the collaborative forecasting practice, including coordination of material ordering (Iannone *et al.*, 2015), indicating a higher preference for individualistic forecasting (15 articles). The articles on collaborative forecasting of demand for medicine highlight a problem with individualistic forecasting, further complicated by different and dynamic health policies across private actors and government (Hoffman *et al.*, 2008; Orenstein and Nardi, 2014).

Similarly, there were only four articles dealing with collaborative replenishment practices compared to eight articles on general replenishment practices. However, individual or firm level practices of inventory control and replenishment are identified as ineffective under pandemic conditions because of the likelihood that support functions such as transport for just in time (JIT) replenishments and other optimization functions are disabled or constrained

CPFR dimension	Frequency	Exemplar research	Other dimensions	Frequency	Exemplar research
Collaborative planning	15	Kwon and Kim (2018), Amaro <i>et al.</i> (2007), VanVactor (2011)	Planning	33	VanVactor (2017), Chen <i>et al.</i> (2013), Jabbarzadeh <i>et al.</i> (2019)
Collaborative forecasting	4	Iannone <i>et al.</i> (2015), Kiely (2004)	Forecasting	15	Miori <i>et al.</i> (2011), Orenstein and Nardi (2014), Varghese <i>et al.</i> (2012)
Collaborative replenishment	4	Baboli <i>et al.</i> (2011), Parsa <i>et al.</i> (2017)	Replenishment	8	Franco and Alfonso-Lizarazo (2020), Çakıcı (2020)

Table 2. CPFR in HCSC management

(Baboli *et al.*, 2011). Overall, among the articles referring to CPFR practices, all but two dealt with only one of the three practices. The exceptions are Kwon and Kim (2018) and Moosivand *et al.* (2019), which contain two of the three CPFR practices. No article dealt with all three practices in crisis or pandemic context, which is surprising, given that the application of one practice without the others limits the efficacy of all three practices.

Even prior to COVID-19, the analyses indicates that medical inventory planning and control were critical problems for medicine logistics and SCs (Viegas *et al.*, 2019), and that CPFR practices increase both inventory management, financial and operational firm performance (Hill *et al.*, 2018). However, the absence of any pandemic related research dealing with the three practices concurrently urgently needs to be addressed in an HCSC because failure to do so will result in systematic disruptions that undermine independent relief interventions.

The criticality of reserve stock levels to all industries is well documented and reliant on better information, lean operations and better coordination to reduce the reserves. Yet, the COVID-19 positive demand shock has no precedent in terms of information and geographical scope in an era of the internet of things (IoT). With a globally interconnected medical inventory system relying on IoT technologies comes the disadvantage of limited responsiveness to immediate localized hospital demand because the systems take longer to add capacity from global SCs. Adding capacity is more difficult when there is panic buying under a constrained transport function and with limited collaboration among HCSC actors.

3.3 Supply chain collaborative risk management capabilities in health-care supply chain research

To address RQ2 concerning the collaborative risk management capabilities used in HCSCs to enhance resilience against stock out risks, we examined references to six SCCRM capabilities: process integration, standardization of procedures, joint decision-making, risk information sharing, risk and benefit sharing, and collaborative performance systems. We searched articles for references to the six SCCRM capabilities as well as general collaborative practices across other supply change function. There were 29 references to SCCRM capabilities compared to 94 references on general collaboration practices across other SC functions. Table 3 lists the comparison. This section discusses the findings in terms of each SCCRM capability and how it has been applied in HCSC literature.

The first SCCRM capability, process integration, is contained in 11/752 articles, which is the highest number of articles. The capability is used to address a range of subjects in HCSCs, including cyber threats due to external risks and dependencies, and the forward and product returns planning level of SC optimization (e.g. Wirth, 2018; Amaro *et al.*, 2007; Dixit *et al.*, 2019). The second capability, standardization of procedures, is addressed in 11/752 articles, and applied in HCSC functions such as procurement in hospitals where there are challenges in standardizing of processes to increase mutual gains among collaborating partners (Klein, 2015). It is also used to show how combinations of complexity and uncertainty create a chaotic environment with different and conflicting objectives defying traditional optimization objectives (Cox and Boyd, 2018). Various terminologies are used in referring to standardization of procedure, such as centralization of medicine procurement process (Liao and Chen, 2013).

The third capability, risk information sharing is used in three articles, while other articles focus on the importance of general information sharing to improve traceability or SC performance (Cullen and Taylor, 2009; Papert *et al.*, 2016; Martinelly *et al.*, 2017). The fourth capability, joint decision-making, is also identified in three articles. Narayana *et al.* (2014) highlight the importance of stakeholder analysis and address complex risks from overstocking and flooding markets with medicine. Enyinda (2018) suggests the use of a multi-criteria decision-making approach to model enterprise risk management for pharmaceuticals. Conventional decision-making is more popular, with its traditional focus

Table 3. SCCRM capabilities in HCSC literature

SCCRM capabilities	Frequency	Exemplar research	Related capabilities	Frequency	Exemplar research
Process integration	11	Wirth (2018), Amaro <i>et al.</i> (2007), Dixit <i>et al.</i> (2019)			
Standardization of procedures	11	Klein (2015), Cox and Boyd (2018), Liao and Chen (2013)			
Risk information sharing	3	Kim <i>et al.</i> (2012), Papalexi <i>et al.</i> (2016), Afshan and Sindhuja (2015)	Information sharing	21	Cullen and Taylor (2009), Papert <i>et al.</i> (2016), Martinelly <i>et al.</i> (2017)
Joint decision-making	3	Narayana <i>et al.</i> (2014), Bailey <i>et al.</i> (2013), Enyinda (2018)	Decision making	16	Fenies <i>et al.</i> (2006), Jabbarzadeh <i>et al.</i> (2019), Priyan and Mala (2020), Bhakoo and Chan (2011)
Risk benefit sharing	1	Papalexi <i>et al.</i> (2016)	Profit allocation /sharing	11	Tan <i>et al.</i> (2020), Drosatos and Kaldoudi (2019), Zhang <i>et al.</i> (2013)
Collaborative performance systems			Collaboration and performance	46	Kwon and Kim (2018), Mandal and Jha (2018), Iannone <i>et al.</i> (2015)

on optimization decisions incorporating decision makers' risk attitudes to address demand uncertainties under conditions of limited information (Jabbarzadeh *et al.*, 2019; Priyan and Mala, 2020). The fifth capability, risk and benefit sharing, was mentioned in only one article (Papalexi *et al.*, 2016). The article highlights the importance of both risk and benefit sharing, while several other articles refer to only one side of the capability, usually the benefit such as profit sharing to mitigate sourcing risks among partnering firms (Zhang *et al.*, 2013). Sharing blockchain technology is viewed as a benefit because it is a unifying platform for sharing patient data inaccessible due to the siloed architecture (Drosatos and Kaldoudi, 2019; Tan *et al.*, 2020). The final capability, collaborative performance systems, was not identified at all; however, there were 46 articles relating collaboration and HCSC performance. Collaborative performance systems are related to HCSC performance indicators such as material orders, demand forecasts and how quality care and cost of care suffer when there is a disconnection between suppliers and manufacturer SC alliances (Kwon and Kim, 2018).

Overall, the application of SCCRM capabilities is fragmented, with few or any dealing with more than one or two capabilities. HCSC actors appear to prefer non-collaborative approaches to managing systematic disruptions caused by medical stockouts. While the fragmented application of SCCRM capabilities is suboptimal, the 46 articles linking collaboration and performance is a positive sign of growing interest in developing collaboration capabilities in HCSCs.

4. Agenda for future research

The COVID-19 pandemic illustrates the inability of current inventory management approaches to maintain optimal medical stock levels and how the idiosyncratic firm-level

SCRM techniques are limited in their ability to mitigate systematic SC disruptions. As such, the uniqueness of pandemics presents a research opportunity to re-examine underlying assumptions on how an SC collaborative platform could reinforce current individual inventory management techniques while improving resilience against systematic SC disruptions caused by medical stockouts. Similar to [Brandon-Jones et al. \(2014\)](#), the following two models and propositions for future research are based on the assumption that current medical stock decisions following inventory optimization objectives are constrained by limited knowledge (known-unknown state of knowledge) about pandemics, as they are counterintuitive in a COVID-19 context. The section proceeds with a proposed model for collaborative practices in planning, forecasting and replenishment, followed by a model for SC collaborative risk management capabilities, and finally, the suggestion that an SC learning curve is urgently required.

4.1 The effect of a change in perception of uncertainty and risk on collaborative planning, forecasting and replenishment practices and optimal medical stock during a pandemic

The COVID-19 pandemic introduces new perceptions of uncertainty and risk yet to be addressed by inventory management research outside of cost minimization, profit maximization and overall HCSC optimization ([Franco and Alfonso-Lizarazo, 2017](#); [Jabbarzadeh et al., 2019](#); [Saha and Ray, 2019](#); [da Conceição et al., 2020](#)). Consistent with [Townsend et al. \(2018\)](#), both industry and scholarly attempts to stretch uncertainty boundaries to cover growing unknowns increase the tendency for risk managers and researchers to conflate uncertainty with risk. The result is a knowledge problem (labelling COVID-19 as a Black Swan) that threatens the ability to identify, distinguish and model value-enhancing decisions under different uncertainty conditions from other forms of ignorance/unknowingness such as ambiguity, equivocality and complexity. Failure to differentiate uncertainty conditions during COVID-19 led to a reliance on ineffective forecasting and replenishment models designed to achieve other objectives inappropriate to pandemic conditions ([Tang, 2006](#)). Current models are not adjusted for demand shocks caused by radical changes in perceptions of uncertainty and risk during a pandemic. Upon realizing the constraints with individualistic responses at the peak of the pandemic, the calls for a collaborative approach as the key strategy for accessing available medical stocks came a little too late.

What was missing? Conventional demand forecasting techniques in HCSCs do not provide for changes in consumption behavior unique to a pandemic. Their limitations are exacerbated by misconceptions of firm-level SC uncertainty and risk ([Townsend et al., 2018](#); [Vilko et al., 2014](#)), leading to suboptimal estimations of medical items. Studies addressing decision-making on stock levels in cases of uncertain demand fall short in explicitly addressing the variation in stock due to planning, forecasting and replenishing across different levels of an SC uncertainty continuum ([Popović, 1987](#)). Understanding pandemic effects requires broadening an inventory management decision system to capture the effect of a change in perceptions of uncertainty and risk among end-user behavior and decision-making in situations when estimates of uncertainty and risk probabilities cannot be estimated.

Unlike idiosyncratic operationalization of inventory management techniques, CPFR practices provide a platform that enables a more accurate prediction of medicine demand under uncertainty than general demand forecasting models employed by individual organizations. There are three steps to achieving such a platform. Collaborative planning is the first step to developing collaboration terms/conditions for a CPFR model. It requires developing front-end agreements and business plans, the lack of which has significant negative consequences on HCSC performance ([Panahifar et al., 2015](#)). Studies addressing collaborative planning focus on model-based decision support systems, trust and information sharing as key antecedents for collaborative planning's ability to improve HCSC performance ([Petersen et al., 2005](#); [Ramanathan and Gunasekaran, 2014](#); [Stadtler, 2009](#)). Collaborative

planning is, therefore, fundamental to collaboration in forecasting and inventory replenishment.

The second step is collaborative forecasting to synchronize service demand forecasts between suppliers and customers; however, greater understanding of how it can be implemented in HCSCs is required (Panahifar *et al.*, 2015). Collaborative forecasting increases the accuracy in forecasting and reduces bullwhip effects and improves HCSC performance even in times of complex communication. Research stresses the importance of participatory decision-making and inter-organization relationships over technology in reinforcing the effectiveness of collaborative forecasting (Kahn *et al.*, 2006; McCarthy and Golicic, 2002).

The third step is collaborative replenishment to facilitate inventory management across all SC stages. This step includes order processing and fulfillment based on sales and collaborative demand forecasts for commercial and humanitarian logistics organizations, respectively. Unlike prior replenishment techniques such as VMI and continuous replenishment, collaborative replenishment relies on collaborative transport management to facilitate integration of procurement forecasts and logistics demands (Chen and Chen, 2009). The likely potential achieved from a concurrent deployment of all CPFR practices during future pandemics leads to the first proposition for future research:

Proposition 1. CPFR practices enable HCSCs to maintain optimal medical stock levels during a pandemic.

Despite some evidence from the review in support of the above proposition, it is not clear whether the proposition will hold in a pandemic context, where demand and supply factors and related uncertainty and risks are unknown. For example, current assumptions based on economic order quantities in relation to total holding and ordering costs did not hold during the pandemic because the focus is on optimization of inventory processes, not access to medical supplies (Dewi *et al.*, 2020). Furthermore, contrary to private sector optimization assumptions, governments and relief agencies prefer to maintain larger medicine stock levels in HCSCs based on estimates of uncertain lead times and demand and exogenous factors influencing consumption and order forecasting accuracy (Kumar and Kumar, 2018; van der Laan *et al.*, 2016). However, the ability of conventional demand forecasting models is undermined by factors unique to pandemics such as: closing international borders, shutting down support functions in transport and logistics infrastructure, concern for safety of logistics staff, remote working, increased vulnerability to HCSC cybersecurity threats and decision blocking due to limited collaboration among firms and governments responding to the pandemic. A reinforcement of relational capabilities, in line with current SC digitalization maturity and advanced physical internet platforms, would improve the chances of determining optimal medical inventory levels during a pandemic. The blessing and curse of modern technology (digitalization and the IoT technologies) is that instant access to global information on pandemic news enables early preparation (early warning), while the same technologies increase the visibility of medical stockouts, hence triggering panic and the need to stockpile.

On an uncertainty continuum, the COVID-19 pandemic is identified as procedural uncertainty: a situation where the decision maker is constrained by computational and cognitive capabilities in being able to accurately define the risk event due to limited knowledge and the complexity of the pandemic (Vilko *et al.*, 2014). Factors and causalities in procedural uncertainty are not known, and system operability and malfunctions are recognized but incomprehensible as an economic crisis (Vilko *et al.*, 2014). This issue is evidenced in the drastic changes in action and behavior across governments, consumers and SCs during COVID-19. The changes were driven by radical shifts in estimations of uncertainty and risks relating to medical stockouts in the early and peak stages following the

declaration of COVID-19 as a global pandemic. The above discussion leads to the second proposition:

Proposition 2. Overestimation of perceived uncertainty during a pandemic undermines the ability of CPFR practices to determine/maintain optimal medical inventory stock levels.

Risk perception guides probability estimations in stock decisions outside a certain decision-making environment. Risk perception is a subjective judgement the public makes based on the estimate of the severity (harm or loss) of risk events. "Better to err on the side of caution" best describes the public's perception of the COVID-19 risk/disruption impact. Understanding the factors influencing the public's subjective risk perception is key to identifying how individuals and organizations prepare and respond to pandemic outbreaks (Blum *et al.*, 2014). These factors include: scope of event, controllability, awareness, voluntariness, trust in authorities, geographic and temporal proximity to the event, personal impact and experience and individual and national demographic characteristics (Blum *et al.*, 2014). These factors and underlying decision-making biases may undermine assumptions of rationality and optimization under pandemic conditions (Bazerman and Moore, 2017). This leads to the third proposition for future research:

Proposition 3. Overestimation of perceived risk during a pandemic undermines the ability of CPFR practices to determine/maintain optimal medical stock levels.

The three propositions on CPFR practices in the HCSC form the basis of a proposed holistic model (Figure 2) on how collaboration enhances inventory management during crises like pandemics by minimizing medical supply stockouts.

The propositions in Figure 2 present a multidisciplinary approach encompassing assumptions from behavioral economics and SC management and are grounded in RHT. Panic buying and stockpiling behavior can be viewed relatively as rational or irrational. From a behavioral economics view, scarcity buying behavior is rational behavior based on limited knowledge and/or opportunity, summed up in the phrase, "let's buy now because it might not be available in the future". The four conditions required for panic to occur are: victims perceive an immediate threat of entrapment, the escape routes appear to be rapidly closing, flight seems the only way to survive and no one is available to help (Heide, 2004). These conditions existed under the COVID-19 pandemic to greater or lesser extents. Re-examining these assumptions consistent with CPFR practices in a pandemic context could provide new insights on how to maintain optimal medical stocks in the future.

The propositions are further grounded in RHT. The theory can be used to explain perceptions of uncertainty and risk among COVID-19-impacted communities. The RHT argues that the expected costs and benefits of risky behavior alternatives compared to the expected costs and benefits of safe behavior alternatives potentially explains panic buying and stockpiling of medical items during the COVID-19 pandemic (Wilde, 1982b, 1998). Because decisions made during a pandemic are driven by the health and safety needs of impacted communities above any needs for utility or profit maximization, the RHT has particular relevance to testing the propositions in the model in Figure 2. The following section develops further propositions on collaborative capabilities for mitigating systematic HCSC disruptions resulting from medical stock outs during a pandemic.

4.2 The effect of a change in perception of uncertain and risk on collaboration and health-care supply chain resilience against stockout systematic disruptions during a pandemic

Failure to maintain optimal medical stock levels leads to systematic HCSC disruptions that cannot be contained by conventional firm-level SCRM techniques such as postponement,

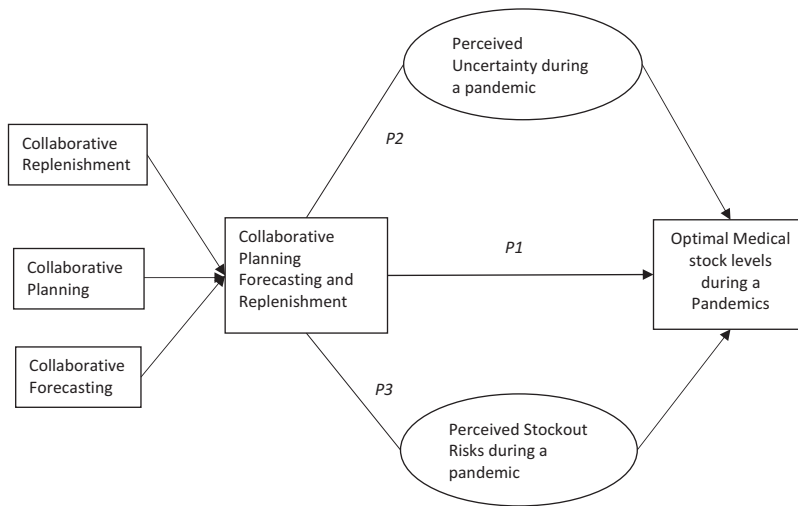


Figure 2.
Moderating effect of changes in perception of uncertainty and risk during a pandemic

hedging and avoidance (Manuj and Mentzer, 2008). Limitations of conventional SCRM techniques are exacerbated during pandemics due to limited collaboration among pharmaceutical SC actors (Nematollahi *et al.*, 2018). Additional limitations include: being more reactive than proactive, application of a narrow foci centered on risk identification and mitigation and a limited ability to increase HCSC resilience against systematic disruptions (Christopher and Peck, 2004; Jüttner and Maklan, 2011). Sá *et al.* (2019) and Xu *et al.* (2020) call for a more holistic view to enhance SC resilience against SC risk propagation such as: stockout ripple effects, spill-over effects, cascading effects or bullwhip effects on HCSCs and across other industrial sectors. The ripple effects from medical stockouts permeate, migrate and, at times, transform at different nodes in HCSCs, leading to incomprehensible devastation that cannot be managed using individualistic SCRM techniques (Tukamuhabwa *et al.*, 2017). Clearly, firm-level SCRM techniques are unable to respond to demand shocks, sporadic instability, disturbances and resulting systematic disruptions from medical stockouts during a pandemic (Friday *et al.*, 2018; Ramezani and Camarinha-Matos, 2020). This section presents further three propositions that form the basis of a model of how collaboration can be used to enhance resilience against systematic disruptions caused by medical stockouts.

The limited literature directly addressing resilience in HCSC indicates an important oversight that requires addressing through the broader development of SCCRM capabilities (Lawrence *et al.*, 2020; Salehi *et al.*, 2020; Zhu *et al.*, 2020). Developing SCCRM capabilities will enable HCSCs to go beyond risk identification and mitigation by individual firms, toward enabling resilience against systematic disruptions based on interfirm collaboration. Thus, we propose a greater focus on SCCRM as an interactive process based on mutual commitment between firms with a common objective to join effort and mitigate HCSC risks and disruptions through co-development of strategic relational capabilities and sharing of resources (Friday *et al.*, 2018). A shift in SCRM objectives toward collaborative risk management and resilience reinforces the proactiveness, reactivity and adaptability potential of HCSCs to address systematic disruptions and spill-over effects regardless of source or geolocation of a medical stockout, time of occurrence or point of impact (Grötsch *et al.*, 2013; Pettit *et al.*, 2010).

The results in Table 3 indicate the application of SC collaboration capabilities to increase resilience is not new, given studies highlighting additional value on SC processes when inter-

organizational relationships are optimized, or in solving demand planning and forecasting problems (van der Laan *et al.*, 2016). Because SCCRM research is in its infancy, it is fragmented. A holistic application of capabilities to enhance HCSC resilience against systematic disruptions created by medical stockouts is required (Blackhurst *et al.*, 2011; Scholten and Schilder, 2015; Wieland and Wallenburg, 2013). The discussion leads to Proposition 4 below:

Proposition 4. SCCRM capabilities increase the resilience of HCSCs against medical stockout disruptions and the resulting ripple effects.

Perception of uncertainty and risk surrounding the availability, access, affordability, and replenishment of medical supplies can be influenced by several factors, including existing relationships among HCSC actors, and differences in institutional environments across pandemic impacted countries (Dyer and Singh, 1998). Managers have a short timeframe to develop relational factors such as trust when faced with a need to provide emergency relief during a pandemic. Thus, SCCRM capabilities between critical functions like HCSCs and humanitarian logistics organizations should be developed in advance to address the likely cognitive impairment or bias in decision making (overestimating uncertainty and risk during a pandemic), and to overcome the challenges relating to, the long period required to establish collaboration antecedents: trust, commitment, power and governance mechanisms (Blomqvist and Levy, 2006; Grötsch *et al.*, 2013; Morgan and Hunt, 1994; Nyaga *et al.*, 2010; Yeung *et al.*, 2009).

Proposition 5. Overestimation of perceived uncertainty during a pandemic undermines the ability of SCCRM capabilities to increase resilience against systematic disruptions from medical stockouts.

Proposition 6. Overestimation of perceived risk during a pandemic undermines the ability of SCCRM capabilities to increase resilience against systematic disruptions from medical stockouts.

The three propositions on SCCRM capabilities in HCSC form the basis of a proposed holistic model (Figure 3) on how collaboration enhances resilience against systematic SC disruptions caused by medical stockouts during crises like pandemics. According to Relational View Theory, a holistic application of SCCRM offers an alternative for HCSCs to build synergies and resources using unique combinations unachievable by firms working in isolation: knowledge sharing routines, complementary resource endowment, relation-specific assets and effective governance (Dyer and Singh, 1998). Empirical testing of the SCCRM and resilience framework in Figure 3 could follow a reflective as opposed to formative model, to allow the ascertainment of which collaboration capabilities form the SCCRM model (Hair *et al.*, 2016). The SCCRM capability's potential to increase resilience is embedded in its ability to: increase visibility regarding the identity, location, status, and variations in stock and information flows transiting HCSCs; preventing demand amplification (bullwhip effect); minimizing uncertainties and opportunistic behavior by reducing information asymmetry (Chen *et al.*, 2013; Ellram and Hendrick, 1995; Li *et al.*, 2015).

Below are brief explanations on how the six SCCRM capabilities in Figure 3 reinforce resilience against systematic SC disruptions. Risk information sharing is the exchange of data relevant for enabling the monitoring of inventory management processes and making timely interventions against potential stock disruptions, and spillovers. Risk information sharing reinforces resilience by increasing visibility regarding the identity, location and status of medical inventory flows transiting HCSCs and pre-empting demand amplification (Friday *et al.*, 2018). The joint decision-making capability mitigates ripple effects from inventory variations by increasing visibility in the inventory planning process, and pre-empting amplified small degrees

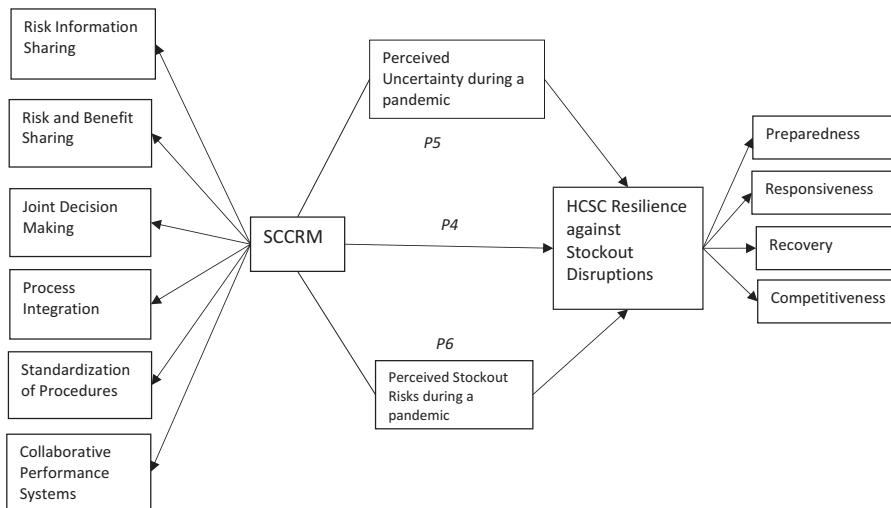


Figure 3.
The moderating effect
of perceived
uncertainty and risk
during a pandemic

of stock errors among individual firm decision-making processes (Hale and Moberg, 2005; Ozkan and Karabacak, 2010; Wilding, 1998). The risk and benefit sharing capability requires firms to develop formal policies and agreements to share stockout liability and benefits from joint efforts and further contribution to SCCRM by enabling apportionment of the stockout risk burden in a way that reduces the disruption impact on individual firms. The process integration capability mitigates HCSC disruptions by smoothening out inventory process flows, safety stock conflicting objectives, and risk information asymmetry (Wagner and Neshat, 2010). The collaborative performance systems capability comprises of jointly developed key performance indicators (KPIs) and metrics that monitor stock variations in sensitive processes such as safety stock levels and informs participating firms about latent stockout risks arising from individual performance variations. According to Wang (2011), the accuracy of collaborative forecasting can be improved through establishment of standardization in medical stock variation handling processes (Grote *et al.*, 2009; Jayaraman *et al.*, 2008). The standardisation capability assists in gathering, analyzing and assessing control information of potential risk triggers that could materialize into systematic disruptions (Heckmann *et al.*, 2015).

Challenges of collaborative approaches to build resilience during a pandemic point to the need for addressing fears on consequence of increased visibility across collaborating HCSC partners: fears over disintermediation of the HCSC; the need to protect a supplier from outside intervention; decision blocking, malicious intent (SC cyberattacks); and incompatible performance criteria (Wichmann *et al.*, 2020). Behavioral uncertainty has a significant negative effect on SCCRM antecedents such as trust and commitment (Chao *et al.*, 2013). Consistent with van der Laan *et al.* (2016), exogenous COVID-19 factors disrupting inventory stock levels are beyond the control of individual organizations and play a role in how perception of uncertainty and risk are interpreted.

Lastly, the limited research on resilience in HCSCs (Figure 1) indicates a research gap that can be addressed by borrowing from the existing body of knowledge on SC resilience elements: readiness, responsiveness, recovery and competitiveness (Hohenstein *et al.*, 2015; Han *et al.*, 2020). We hope that our conceptualization of HCSC resilience in Figure 3 will direct research in both commercial HCSCs and humanitarian logistics towards examining and advancing the Sendai Framework for Disaster Risk Reduction (SFDRR) (Jahre, 2017; Pearson and Pelling, 2015). We argue that while readiness, responsiveness and recovery form the common dimensions of resilience, it is just as important to plan beyond not just bouncing

back to the former stable state after recovering from a pandemic, but to adapt to new positions fitting the alternative environment post a pandemic. SC actors that survive the pandemic need to adapt and seize opportunities likely to open after a supplies market disruption: new demand and supply markets, access to resources. *Competitiveness* captures the adaptation element (learning and transformation) of resilience to enable HCSCs to reconfigure resources and processes to maintain a former stable form and transition to a better state with consideration of prevailing business opportunities after a disruption (Buvik and Grønhaug, 2000; Li *et al.*, 2015; Kochan and Nowicki, 2018).

4.3 Supply chain learning curve

In addition to the suggested six propositions as platforms for future research, the COVID-19 experience provides a unique opportunity to develop a HCSC learning curve for more sustainable and resilient responses to global emergencies. The SC learning curve should be able to differentiate between our response to a pandemic (less frequent, high global impact) and epidemics, natural and manmade calamities and disasters (frequent and impact a specific community, country or region) (Govindan *et al.*, 2020; Queiroz *et al.*, 2020). A combination of ongoing pandemics (HIV, COVID-19) illuminates a new perspective that reinterprets HCSCs as a social–ecological system, with structures and processes that are fluid and interwoven with political–economic and planetary phenomena (Wieland, 2020). As such, individualistic and deterministic views based on simulation and optimization that largely characterize HCSC management are no longer sufficient to address contemporary challenges in the future: objectivity, rationality, optimization, controllability (Currie *et al.*, 2020). Failure to anticipate the radical change in behavior and perception of risk following the COVID-19 pandemic (Chan *et al.*, 2020) signals the importance in learning from our experiences with medical stock optimization practices or the failure of individualistic risk management technics to enhance resilience against systematic HCSC disruptions caused by medical stock outs.

Like disaster and emergency management agencies, organizational and state barriers prevent SC actors/agents responding to the COVID-19 pandemic from learning from each other. This is because of differences in resources, objectives and variations in learning experiences across private and public sectors, non-governmental organizations (NGOs), developing and developed economies. As such, the focus on individualism and optimization objectives undermines our ability to develop and document a learning culture, or the achievement double-loop learning among stakeholders, to ensure we do not repeat mistakes during future pandemics (Thompson, 2012). For example, we learned from the COVID-19 experience that last-minute attempts to implement CPFR practices or deployment of SCCRM capabilities to increase resilience against stockout disruptions at the peak of a pandemic is counter intuitive. Furthermore, knowledge from countries impacted by previous epidemics and pandemics such as Ebola (Liberia, Sierra Leone, Guinea and Uganda) was not properly leveraged in determining an effective global response to COVID-19 disruptions due to lack of accurate documentation in developing countries (Maxmen, 2020).

Thus, there is a need to create, acquire, interpret, share and retain knowledge about why current inventory optimization and SCRM practices failed, and what needs to be done to overcome barriers concerning cognitive biases embedded in individualistic values, belief systems, and optimization technics, to enable the modification of a collaborative behavioral response to new pandemics. Researchers can draw from learning curves in general knowledge management, technology advancement and environmental impact (Bergesen and Suh, 2016; Yadav *et al.*, 2020), to develop an HCSC learning curve highlighting the global response the COVID-19 pandemic. Different phases of the HCSC learning curve can also be generated by reviewing what Wei *et al.* (2012) refer to as sensitive and rational periods, rational and forgotten periods before, during and after the COVID-19 pandemic.

5. Implications for practitioners

Our study responds to the WHO and UN call for a coordinated global response to COVID-19 pandemic by proposing a holistic application CPFR practices to enable HCSCs maintain optimal medical stock levels during future pandemics. To mitigate any potential systematic disruptions due to medical stockouts, this paper suggests an early development of SCCRM capabilities to enhance resilience against systematic disruptions due to stockouts. The proposed collaborative approaches are adjusted to address future pandemic contexts by taking into consideration the change in perception of uncertainty and risk when making stock or consumption decisions with limited information about the pandemic.

Additionally, propositions discussed in this paper contribute toward bridging the disconnection between interdependent commercial HCSCs, government, NGOs and humanitarian logistics SCs key to a coordinated global response to future pandemics. For example, it is through early development SCCRM capabilities that misalignments undermining the response to pandemics (COVID-19) between leading organizations can be reconciled: lack of strategic response in the WHO Framework on Health Emergency and Disaster Risk Management and UN Office on Disaster Risk Reduction (Djalante *et al.*, 2020).

For commercial HCSCs, building resilient HCSCs through collaboration with key suppliers using models adjusted for drastic changes in perception of uncertainty and risk perspectives could facilitate better prediction and maintenance of optimal medical stock levels during future pandemics. It is anticipated that the paper's propositions will shift medical inventory management perceptions toward adjusting cost, profit and optimization stock models to capture behavioral economics aspects on perceptions of uncertainty and risk during pandemics and extreme disaster emergency situations.

5.1 Concluding remarks

The question is not whether the world will experience another pandemic or similar crisis in HCSCs, but rather a question of when. Motivated by the calls from the UN and WHO for a coordinated global response to the COVID-19 pandemic, the focus of our paper is collaboration in HCSCs. The study relies on insights from the pre-pandemic literature to demonstrate that current inventory optimization objectives are inappropriate for HCSC under pandemic conditions. Access to medicine, neither profit nor cost reduction, must be the objective of HCSC optimization in such situations. We propose that collaborative practices in planning, forecasting and replenishment as well collaborative capabilities in SCRM are obvious means to optimizing HCSCs for access. We generate two models based on three propositions each on how a collaborative approach could maintain optimal medical stocks and reinforce the resilience of HCSCs during future pandemics. Underlying our models is the assumption that fragmented approaches to collaboration practices and risk management capabilities limit the synergistic benefits that potentially arise from more holistic approaches. The propositions and models are relevant to both HCSCs and disaster-relief agencies requiring medical supplies. We further suggest that SC scholars begin documenting an HCSC learning curve based on the COVID-19 pandemic experience to ensure mistakes are not repeated, and future actions are informed by past experience.

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