The Emerging Features of Healthcare Supply Chain Resilience: Learning from a Pandemic

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Abstract

The COVID-19 pandemic exposed significant fragilities in the configuration of global healthcare supply chains. This was felt acutely by citizens, patients and healthcare workers across Canada. As demand for critical medical products surged in Canada, and globally, provincial healthcare supply chain teams worked to rapidly stabilize their supply chains. These efforts indicate the emerging features of healthcare supply chain resilience. Results suggest that there are five emerging features: (1) redundancy of supply inventory; (2) diversification of suppliers across geographies; (3) maturity of digital infrastructure to create transparency; (4) proactivity; and (5) equity of distribution to protect the lives of all.

Introduction

The COVID-19 pandemic has exposed significant fragilities in the configuration of global healthcare supply chains. Driven by the exigencies of cost containment, health systems in Canada had – prior to the COVID-19 pandemic – come to rely on lengthy, lean and undiversified supply chains for the provision of their critical medical products. Seeking the lowest possible price points, manufacturing capacity in Canada was offshored, and supply chains were greatly lengthened. However, the more these supply chains were lengthened, the more brittle – or prone to disruption – they became. It was this situation of systemic fragility that characterized the pre-pandemic healthcare supply chain situation in Canada. As the pandemic unfolded across Canada, provincial healthcare supply chain teams and health system leadership worked to reconfigure their supply chains in order to address both the shortage of and the surge in demand for critical products. Drawing on empirical evidence gathered through a Canadian Institutes of Health Research (CIHR)–funded research project called, "Development of an Implementation Framework to Advance Provincial and National Health System Supply Chain Management of the COVID-19 Pandemic," (CIHR Ref. VR5 172669), the purpose of this paper is to document the emerging evidence of features of healthcare supply chain resilience in Canada.

The solutions implemented by healthcare supply chain teams to address supply shortages were often provisional or designed as quick remedies to immediate pressures to manage supply shortages. However, it is our contention that these provisional remedies were not simply *ad hoc* solutions to a "once in a lifetime" crisis, but also often indices of the necessary features of healthcare supply chain resilience. By shining a light on the cruciality of healthcare supply chain functioning for care delivery, the COVID-19 pandemic incentivized healthcare supply chain teams and health system leaders to rapidly implement solutions to structural fragilities that would have otherwise remained unaddressed. It is, therefore, possible to

extract from these short-term solutions some of the features of long-term healthcare supply chain resilience. Our research draws on the experiences and recommendations of healthcare supply chain teams and leaders to define evidence-informed features of healthcare supply chain resilience.

Although provisional, then, these emerging features of resilience both highlight some of the successes in Canada's healthcare supply chain response during the COVID-19 pandemic and provide a vision of what a resilient healthcare supply chain could look like in Canada in the post-pandemic future. In this paper, we propose five emerging features of healthcare supply chain resilience from our qualitative analysis that can serve as waymarks on the road map to a resilient health supply chain in Canada: (1) redundancy of supply inventory; (2) diversification of suppliers across geographies; (3) maturity of digital infrastructure to create transparency; (4) proactivity; and (5) equity of distribution to protect the lives of all. These features will be discussed under three organizing headings: (1) emerging resilience in supply sourcing and procurement; (2) emerging resilience in data and digital infrastructure; and (3) emerging resilience in supply management and distribution.

Literature Review

Health supply chain resilience is bound together with health protection, the quality and safety of care environments and the capacity to deliver patient care. Health supply chain strategy and quality healthcare must be thought of as highly interdependent dimensions of healthcare systems that are critical to the system's capacity to deliver patient care within safe working environments. The health supply chain encompasses the network of relationships from the acquisition of the raw materials required to enable product manufacturing to the distribution of products to health systems so as to enable delivery of patient care by clinician teams. A disruption at any stage of this process – to any entity in this network of relationships – would constitute a supply chain disruption and indicate a point of supply chain fragility.

Supply chain resilience has been identified as a crucial component of supply chain risk management (Ponomarov and Holcomb 2009). A recent body of research is dedicated to the understanding of supply chain resilience as the ability to respond to and recover from disruptions. Disruptions can take place due to natural occurrences (e.g., hurricanes, pandemics) or due to internal failures (e.g., a failure to carry an adequate inventory of products) or a failure to procure raw materials for product manufacturing, resulting in shortages that compromise healthcare delivery (Ponomarov and Holcomb 2009). While there is currently no consensus in the literature regarding the definition of supply chain resilience (Golan et al. 2020), a commonly used definition is the "adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function" (Ponomarov and Holcomb 2009: 131). In the health sector, this refers to the capacity of health supply chain teams to ensure that should a disruption occur (Mandal 2017), products, equipment and supplies are available to enable clinician teams to deliver medically necessary care to patients within safe work environments. Research relating supply chain resilience specifically to health systems is early in its development and will require more in-depth study and evidence to fully understand the unique role and function of the supply chain in the health sector. Only a small fraction of the current supply chain literature provides insight into the unique context of the healthcare sector; those that do, limit their focus to specific product groups such as pharmaceuticals (Golan et al. 2020).

The importance of supply chain capacity to ensure that critical health products reach healthcare organizations is imperative, given its direct impact on human life (Aldrighetti et al. 2019; Mandal 2017); as Aldrighetti et al. (2019) noted, "in the context of HSCs [healthcare supply chains], such disruptions can potentially have devastating effects because human lives are on the table" (p. 82). Given this unique interface between the clinical and the logistical, a resilient health supply chain must be underpinned and motivated by the same ethos of care that informs and organizes the broader healthcare system. Due to the unique identity of the healthcare supply chain, the economic concerns and incentives that inform and organize non-healthcare supply chains may, if translated into a healthcare supply chain context, have negative impacts on care delivery. For example, a resilient health supply chain must contain redundancy as disruptions to the health supply chain may mean disruptions to delivery of care. For this reason, Aldrighetti et al. (2019) suggested that "recovery policies in this particular sector [health supply chain] need to consider not only costs but also the service levels that must maintain a level of 100%, as human life is the final customer" (p. 82).

The reshoring or re-localizing of supply chains has emerged as a disputed locus of post-pandemic strategies for healthcare supply chain resilience. Broadly speaking, the question of the merit or not of supply chain localization has been framed as a question of cost versus resilience. A 2020 report from the Organisation for Economic Co-operation and Development (OECD) on the face mask global value chain has stressed that there are multiple inputs involved in the production of face masks. Specifically, they emphasize that the non-woven fabric manufactured from electret melt-blown polypropylene – which constitutes the middle filtering layer of a face mask – represents a significant bottleneck in the face mask supply chain (OECD 2020). According to this same report, the specialized heavy machinery involved in the production of polypropylene electret

melt-blown non-woven fabrics (such as "hoppers, extruders and melt spinning systems") distinguishes the production of electret non-woven fabric from standard polypropylene non-woven fabrics. Only a limited number of companies possess this specialized machinery and produce electret non-woven fabric, which limits the existing manufacturing base from increasing supply and complicates the ability of companies to pivot to manufacturing face masks (OECD 2020). The OECD report contends that it is shortages of this fabric, and not an inability to manufacture face masks at the assembly stage, that represents a bottleneck or point of fragility in this particular supply chain. The OECD (2020) report suggests that, in the early phases of the pandemic, the demand for face masks may have been 10 times higher than world production capacity.

Other proposals have suggested that state-owned manufacturing may be an important component of disaster mitigation.

A core policy implication of the OECD analysis of the evidence of the face mask global value chain is that it would be "excessively costly" for countries to develop healthcare supply chain self-sufficiency (Arriola et al. 2020). However, a report by the Canada Standards Association (CSA) Group identifies "a need and an opportunity for Canada to develop its own pandemic products and associated standards to improve national security via a sovereign supply of essential resources" (Hancock-Howard et al. 2021: 8). The CSA report articulates a very different policy implication to that of the OECD report. They argue that "sustained policy efforts are needed to ensure that procurement from Canadian manufacturers becomes a key priority in the health care sector" (Hancock-Howard et al. 2021: 30). Other proposals have suggested that state-owned manufacturing may be an important component of disaster mitigation (Simpson 2020). The basic thematic tension, then, emerging from the current literature on healthcare supply chain resilience, especially in the context of supply chain localization, or the creation of a domestic manufacturing capacity, is the tension between security (understood as supply chain resilience) and cost-effectiveness.

And yet, in much the same way as the term *supply chain* has come to function as a catch-all for a diverse set of functions, products, services and stakeholders, supply chain resilience has been understood monolithically as though the measure of resilience in one sector is immediately applicable in another. Such monolithic, "one-size-fits-all" approaches to and understandings of supply chain resilience often elide the existential stakes of *healthcare* supply chain resilience (Aldrighetti et al. [2019] quoted earlier, with their emphasis on the need for healthcare supply chains to maintain a 100% service level, being a notable exception). To prescind from a consideration of these existential stakes is to fail to adequately articulate the context in which considerations of healthcare supply chain resilience must take place. Accordingly, it is our contention that health supply chain resilience requires its own definition in order to reflect and highlight the uniqueness of the health supply chain and the profound ways in which it directly affects and bears on human life and care for this life. Because of the significant dearth of scholarly literature on the health supply chain, most attempts to consider the healthcare supply chain rely on the assumption of the more or less direct translatability of the evidence and processes associated with other business sectors – for example, the automotive supply chain. However, as Jean De Vries and Robbert Huijsman explained:

> From a supply chain management perspective, however, our body of knowledge regarding the health care sector still seems to be rather fragmented. Although many health care organisations have recognized the importance of adopting supply chain management practices, the application of techniques, methods and best practices originally developed in an industrial setting clearly is often problematic. Without doubt, the complexity of the technologies being used, the existence of multiple stakeholders, a dynamic internal and external environment and distinctive characteristics of health service operations often impede a straightforward application of industrial-oriented supply chain management practices. (de Vries and Huijsman 2011: 159)

As the COVID-19 pandemic has made very clear, the health supply chain has a bearing on the well-being of patients and healthcare workers and on care delivery (Snowdon and Saunders 2021), given that its processes are associated with both the safety of front-line workforces and the health and safety of patients in the healthcare system. The significance of the healthcare supply chain is highlighted by the COVID-19 pandemic, which brings forward the critical role of the capacity of the health supply chain in supporting the effective management of workplace safety risk mitigation to reduce the risk of outbreaks. Inadequate protection for high-risk populations (e.g., such as the elderly in long-term care settings) and the lack of personal protective equipment (PPE) available for care teams in all settings (e.g., hospitals, home care, emergency medical services, long-term care) has posed a significant risk to the safety of the health workforce and Canadian citizens.

Furthermore, scarcity of supply of critical products led to the implementation of conservation and allocation strategies by distributors, group purchasing agencies and health systems, which resulted in tremendous workforce anxiety and influenced the modification of infection prevention and control procedures (Snowdon and Saunders 2021). These

modifications were informed by supply inventory, rather than precautionary principles designed to prevent infection, with the intent of conserving the supply of critical products (Snowdon and Saunders 2021). That "[PPE] guidelines had been tailored to fit the stockpile" (Foster and Neville 2020) – i.e., that supply availability and not scientific evidence of best practice was shaping guidelines for which PPE to use in which circumstances – was a global concern. Importantly, the ability of health systems to deliver vaccinations to protect populations from becoming infected with the SARS-CoV-2 virus has directly depended upon the availability of critical supplies, such as PPE for staff and patients, lab testing supplies (e.g., syringes) and ventilators, in addition to the vaccine itself.

Therefore, the healthcare supply chain differs from other supply chains because delays or shortages of critical health supplies can mean the difference between infection, illness or even death and the safe and effective delivery of care. It is with the existential significance of the healthcare supply chain in mind that this paper proposes a new definition of healthcare supply chain resilience, a definition that emphasizes the uniqueness of the healthcare supply chain relative to industrial supply chains. Healthcare supply chain resilience is as follows: the capacity of a healthcare supply chain to support, without interruption or decrease in service level during a crisis, the healthcare system in the delivery of safe and effective healthcare services to populations health systems are mandated to serve.

We have previously reported on the characteristics of a fragile health supply chain that were highlighted by the COVID-19 pandemic response in Canadian health systems (Snowdon et al. 2021). These characteristics of fragility left the health system vulnerable, contributing to a significant loss of life and heightened risk of infection. If the COVID-19 pandemic brings into view the fragility of our current healthcare supply chain, then it also brings forward the crucial relationship between health supply chain resilience and its influence on health system outcomes. The purpose of this paper is to highlight the essential characteristics of a resilient health supply chain that can inform a new health supply chain strategy – a strategy organized toward the realization of a resilient health supply chain across Canada. The features of health supply chain resilience that are advanced in this paper are informed by the themes and findings of a COVID-19 rapid research project, which gathered data across seven participating provincial health systems.

Methodology

This paper features emerging findings from an ongoing COVID-19 Rapid Research Funding Opportunity called, "Development of an Implementation Framework to Advance Provincial and National Health System Supply Chain Management of the COVID-19 Pandemic." A variety of sources were relied upon to inform this empirical study. Secondary data sources included government websites, media resources, reports, academic literature and grey literature. Findings emerging from analyses of secondary data. Semi-structured interviews were conducted to elicit the perspectives and experiences of key informants from each participating province – British Columbia, Alberta, Manitoba, Ontario, Quebec, Nova Scotia and Newfoundland and Labrador. Theoretical sampling was used to identify participants who represented varied perspectives and expertise in each provincial health system. Key stakeholders interviewed included supply chain teams, procurement teams, senior health system leaders, physicians, clinician teams and leaders from public health, long-term care, hospitals, residential care, government, distributors and group purchasing organizations. A total of 152 cross-provincial qualitative interviews were included in the analyses.

Interviews were audio recorded, transcribed verbatim and analyzed using the NVivo Transcription software. Qualitative data analysis was completed using inductive content analysis to generate new knowledge grounded in participant data (Elo and Kyngas 2008). Interview transcripts were reviewed repeatedly and then coded and organized into smaller, more manageable segments. The coding scheme was designed using a systematic and analytic procedure to create a map of conceptual categories, with definitions and exemplars for each code and category (Hsieh and Shannon 2005). Themes were identified that linked the meanings of these conceptual categories. Content analysis was iterative, such that coded transcripts were revisited repeatedly as new insights surfaced during data collection and analysis. The findings reported in the following section represent experiences and perspectives from the first two waves of the COVID-19 pandemic.

Findings: The Emerging Features of Resilience in Healthcare Supply Chains

Emerging resilience in supply sourcing and procurement: Redundancy and diversification

Creation of critical supply redundancy

During the first wave of the COVID-19 pandemic, provinces across Canada found that they lacked sufficiently robust stockpiles of critical medical supplies. Prior to the pandemic, "leanness" and "efficiency" had become the central organizing concepts of healthcare supply management. The vision of supply management made possible through the lenses of leanness and efficiency was one in which costs would be minimized and efficiency increased through the elimination of supply redundancy or the maintenance of additional stock. Based on this understanding of supply management, inventories were replenished just as soon as that replenishment

became necessary – a lean methodology antithetical to stockpiling. In the province of Newfoundland and Labrador, a pandemic stockpile of supplies – created in the wake of the H1N1 pandemic – was abandoned due to cost-saving pressures. One regional health authority in Newfoundland and Labrador purchased "500,000 N95 masks, a million procedure masks, 15 million gloves and one million isolation gowns" (Cowan 2020). However, in September 2016, after deciding that this product could not be consumed at a regular usage rate, the supply was left to expire (without being replenished) and was later discarded (Cowan 2020). In the words of a healthcare union leader in Newfoundland and Labrador:

> It became very clear at the beginning of the pandemic that we did not have supply, and we did not have a stockpile. We learned, maybe, a week into the pandemic that the stockpile we thought we had, about five years ago, had expired, and it was all thrown away and not used. So, we had no stockpile and that created a lot of anxiety.

The absence of sufficiently robust stockpiles of critical medical supplies – whether because they were abandoned due to cost-saving pressures or were mismanaged – was a common feature of Canada's healthcare supply landscape prior to the onset of the pandemic (Snowdon and Saunders 2022a, 2022b; Snowdon and Wright 2022).

As the pandemic progressed, traditional supply chains were de-stabilized and the demand for life-saving products, such as PPE, increased dramatically. Many provincial health systems found themselves ill-equipped to meet this surge in demand due to global supply shortages. To redress this, provincial healthcare supply chain teams and health system leadership worked to generate the very thing that leanness initiatives had attempted to curtail: supply redundancy. The generation of this redundancy necessitated both the acquisition of supplies in excess of their utilization and the creation of the warehousing capacity necessary to house these supplies. Newfoundland and Labrador and Nova Scotia acquired this emergency warehousing capacity and began to create stockpiles, using COVID-19 "burn rates" (or the consumption rates of products during the pandemic) to discern how many supplies to procure. These provinces worked to create pandemic stockpiles that would house up to approximately six months' worth of supplies at a COVID-19 burn rate (Snowdon and Saunders 2022a, 2020b).

A supply chain leader described that the need for redundancy of critical supplies (e.g., a pandemic stockpile) was one of the crucial lessons learned from the pandemic:

> If we had a pandemic supply, if we were managing that appropriately and accordingly [] people wouldn't be in this position right [now]. So, in my eyes, that is the solution, having a pandemic warehouse and having some management around it, obviously, because products in a pandemic warehouse will expire, so there is some work that would have to be done to keep that managed. But I think that's definitely a need or requirement. Our normal streams of accessing PPE are never normally an issue for us. Our supply chain model was never normally an issue for us, but in these circumstances [] it will impact some of those streams, and I think the only way around it is to be better prepared for it in terms of having a pandemic warehouse full of available PPE for when these circumstances do happen.

Healthcare supply chain leaders also noted that, contrary to the prevailing wisdom that lean methodologies generate cost savings, the possession of a pandemic stockpile would have ultimately proven to be more fiscally prudent for their respective provinces:

> It would have cost us around $15 million I think if we [would] have done this in advance. It would cost us $87 million because we didn't. Like we bought everything at ×5 or ×10 [the cost], and so the cost of being prepared is much less than the cost of not being prepared.

> I really think we need to look at how supply chain can impact how we deliver services globally. So, we really need business continuance. We need to look at it differently. We need to look at our sourcing strategies. We need to get value, but every bit of money that we saved over the past five years – we just spent it all.

Put otherwise, "just-in-case" supply management – in which excess supplies are kept on hand – would not only have fostered supply chain resilience, helping to ensure an uninterrupted and safe delivery of care, it would have also been more cost-effective for health systems.

By working to create these pandemic stockpiles, healthcare supply chains teams in Canada generated supply redundancy as a protective measure to ensure that product availability was able to support health systems in the safe and effective delivery of patient care. Redundancy as an emerging feature of healthcare supply chain resilience indicates that a post-pandemic supply chain strategy should weigh the benefits of long-term sustainability over short-term cost savings. Lean or "just-in-time" methodologies risk brittleness and fragility; redundancy should be the watchword of a strategy for healthcare supply chain resilience focused on "just-in-case" supply management. The Canadian supply chain experience during the COVID-19

pandemic suggests that a careful re-evaluation of the place of redundancy in supply management may be necessary to redress the systemic fragilities engendered by the just-in-time supply chain inventory management and logistical models that were incentivized by cost-reduction policies prior to the onset of the pandemic.

Health system supplier diversification

In a previous publication, we indicated how reliance on product sourcing from single geographies or limited supply sources was a feature of healthcare supply chain fragility (Snowdon et al. 2021). The same economic motives that eliminated redundancy also drove health systems (or their vendor communities/purchasing organizations) to privilege single geographies or jurisdictions for the provision of their supplies. In particular, geographies or jurisdictions whose labour practices allowed for the cheap production of products at low price points were commonly sought out. Supply sources in this way became *undiversified*. At the same time, manufacturing capacity in Canada was outsourced and offshored as domestic companies could not compete with low labour cost environments. During the pandemic, these traditional supply channels were de-stabilized, and healthcare supply chain teams found that they had to rapidly diversify their sources of supply. In many provinces, this diversification entailed the creation of a domestic manufacturing capacity for critical supplies, or the *re-localization* of this manufacturing capacity (Metge and Islam 2022; Snowdon and Saunders 2022a, 2022b).

In one province, robust collaboration with their academic community and a taskforce of local business leaders very quickly developed the manufacturing capacity for critical PPE products, including surgical masks, face shields and medical gowns (Snowdon and Saunders 2022b). Much of this local manufacturing capacity emerged through the retooling or repurposing of already existing industries. For example, a local mattress factory was retooled to create face shields, and an industrial sewing guild produced face masks. A medical technology start-up partnered with the largest health authority to use 3D-printing technology to manufacture components of Health Canada–approved face shields (Snowdon and Saunders 2022b). Likewise, in another province, the retooling of a local garment-manufacturing company enabled the production of medical gowns (Snowdon and Saunders 2022a).

By diversifying and re-localizing their healthcare supply chains, provinces were able to address the surge in demand for critical supplies in their provinces to varying degrees. Reflecting on their diversification efforts, a government leader stated:

> We've really come to [a point where] we need a diversified mix [of supply sources]. We can't put all of our eggs in one basket. That's not a solution for us, so we see a domestic line as imperative going forward, frankly.

Diversification, especially as manifest in the cultivation of local manufacturing capacity, is another emerging feature of healthcare supply chain resilience in Canada. Diversified, local healthcare supply chains are perhaps the indices of a post-pandemic health supply chain landscape that is not wholly dependent on lean and lengthy global supply chains.

Emerging resilience in data and digital infrastructure: Transparency of supply chain processes and proactive approaches to supply management

Maturing digital and data supply chain infrastructure to create transparency and visibility

Robust data and digital infrastructure are crucial for leaders of healthcare supply chains and health systems to have visibility of the availability and location of supplies and to track the use of and demand for products such as PPE. During the pandemic, many health systems leaders found themselves lacking this visibility; they were, as one leader put it, "flying blind" (Snowdon and Forest 2021). For example, healthcare supply chain teams would often not have "line of sight" to product inventories on patient care units; these products were not visible to supply chain teams and therefore could not easily be included in considerations of supply availability. More critically still, supply chain teams could not readily track the rate at which these critical products were being consumed (or formulate their "burn rate") in order to determine the urgency of supply replenishment.

Without this visibility to product inventories and a real-time understanding of burn rate, supply chain teams were at times hampered in their ability to ascertain supply needs. In order to redress this lack of visibility, many provinces found that they had to manually count supplies (Snowdon et al. 2021; Snowdon and Saunders 2022a, 2022b; Snowdon and Wright 2022). With very little line of slight to their product inventories, especially at the unit level, some provinces took to *clawing back* their supplies from hospital shelves and to storing these supplies in centralized warehouses. They could then allocate these supplies from centralized warehouses to more closely monitor inventory volumes and control product utilization rates in order to preserve inventory for as long as possible. Under these allocation regimes, product ordering patterns became a surrogate for utilization rates. A lack of robust data and digital infrastructure, then, stymied supply chain efforts to support a healthcare system in the safe and effective delivery of care. Accordingly, many provinces moved to quickly advance their data and digital infrastructure in order

to more adequately respond to the demands of the pandemic by advancing digital infrastructure to create this visibility to their product inventories.

Health supply chain teams were able to aggregate their multiple inventory management systems through the creation of a dashboard. This was described by a healthcare supply chain leader:

> We had to get [the centre's name] to build us dashboards that download information out of the four systems and dashboards in terms of what we had, what we had to order [and] where it was. And then, I mean, we were moving stuff, still moving stuff around; if we [had] one area short, we could look at another area and move it from [there] to [the] area [where we were short].

Although most health systems across Canada lack a mature and interoperable traceability infrastructure, this digital supply chain maturation effort nevertheless indicates an incipient feature of supply chain resilience.

Proactive response strategies informed by modelling and analytics

Emerging resilience in data and digital infrastructure could also be observed during the pandemic in the increased use of data modelling and analytics to facilitate greater organization and inform supply procurement strategies. These analytic tools allowed health supply chain teams to forecast demand. Instead of reacting to supply shortages, supply chain teams were able to anticipate need and proactively manage product supplies by identifying the risk of supply shortages. In a previous paper, we identified *reactivity* as a key characteristic of a fragile healthcare supply chain:

> A reactive health supply chain mobilizes resources *in the wake* of an acute surge event or supply interruption; it does not anticipate, or plan for, such events and is unable to proactively mobilize resources to ensure that supplies, products, medications and equipment are available when and where they are most needed. (Snowdon et al. 2021: 42)

Analytics and modelling enables a *proactive* healthcare supply chain, one which anticipates shortages and procures and mobilizes resources prior to a surge in demand. During the pandemic, supply chain teams were able to avoid the kind of supply shortages that would put at risk effective care delivery or the implementation of public health measures to contain spread of the virus. Digital tools such as dashboards made it possible to develop predictive models, described in the following quotation:

> The dashboard was a big help for us, and the centre came on with that dashboard in the very early days to help us understand the usage and monitor by facility. Also, our predictive analytics team that's been doing some of the modelling for the province [has] also been helping us have a look at our PPE usage and digging into some of those numbers. And we've been working with professors to help us work on a predictive analytical model.

A number of provinces developed analytic models that could incorporate the requirements for public health measures or changes in protocols (changes that would require use of PPE to mitigate risks of spread). These models enabled supply chain teams to procure supplies in advance of the implementation of these policies or changes in protocol. In this way, supply chain decisions were proactive to enable preparation for implementation of public health protocols. This digitally enabled proactive supply chain strategy was described by a healthcare supply chain leader:

> [E]arly on, I'd say back in late February, we integrated with an analytics team within Nova Scotia Health, and we were doing modelling right from early days and adding additional layers into the model, additional demand, channels and scenarios. We essentially had modelled out some of the most likely scenarios that could take place to understand how to prepare for these eventualities. Something we kind of felt would be the case and we definitely observed [that it] was the case that decisions [got] made either because of what's possible or regardless of what's possible. And some decisions were being held back because clinicians or leaders didn't believe they could actually execute the thing that they wanted to do, so they would not be doing the thing [that] they really wanted to do because they didn't think the supply could support that protocol that they wanted to implement. In other cases we would get two days' notice of a protocol change that would have traumatic impacts, so we learned early that it was important to model on the eventualities and be prepared in advance.

The same supply chain leader went on to describe how this need to be prepared in advance shaped their procurement strategy; informed by their modelling efforts, they proactively procured supplies in anticipation of increased demand:

> So, when we model our requirements, we model them under circumstances where[in] protocols that don't even exist could possibly exist. … [L]ooking at what

> other jurisdictions have done around the world, we ask ourselves a question: "What if we did that here even if it's not potentially on the radar here, just in case at some point our leadership decides [that] they would like to do that too?" And so, we are still scanning the environment. We are still including demand in our modelling, which then feeds our procurement strategy for things that are currently not taking place here to try to anticipate and be ready. And for N95s as the example, we continue to and have been procuring well above the quantity [than] our current conditions or any reasonably foreseeable set of circumstances would predict we'd require. We are still trying to always not be, I guess, a challenge from an implementation perspective.

The development of modelling and analytics capacity enabled a proactive healthcare supply chain strategy, one which supported care delivery and policy implementation. This proactive, data-driven approach is another emerging feature in healthcare supply chain resilience.

Emerging resilience in supply management and distribution: Equity

Equitable, person-centred supply management

If healthcare supply chain resilience is understood as the ability to support the healthcare system in the delivery of care, then healthcare supply chain function must be understood in a significantly expansive way such that it encompasses the entirety of the healthcare system. Put differently, a lack of equity in the distribution of supplies would indicate fragility in the healthcare supply chain. In Canada, the current configuration of healthcare supply chains – closely tethered to the hospital system (with just-in-time supply management and logistics, in which critical supplies are overwhelmingly stored in hospital settings) – meant that long-term care facilities had difficulty accessing critical supplies. An initially hospital-centric approach to supply distribution exacerbated this already uneven health supply landscape. This contributed to devastating outcomes for vulnerable populations in many Canadian provinces (Snowdon and Wright 2022; Snowdon and Saunders 2022a). Healthcare settings on the periphery of the established healthcare supply chain system, such as long-term care, often suffered most.

Accordingly, another critical incipient feature of supply chain resilience in the Canadian healthcare supply chain landscape was a move toward the greater integration of traditionally peripheral care settings into the healthcare supply chain system. In provinces such as Newfoundland and Labrador, long-term care (LTC) was much more closely tethered to the healthcare system, and critical products and supplies were very equitably distributed to all care settings as described by a health system and supply chain leader:

> We were about two weeks in, and then we started supplying the personal care homes, the private homes. We started supplying them with PPE about two weeks into the event.

In one province that initially adopted a hospital-centric approach to supply distribution (Snowdon and Saunders 2022a), a transformation of their healthcare supply chain mandate and infrastructure took place such that greater supply equity across all settings was made possible. In the words of a healthcare supply chain leader:

> We had everything in place by March to be able to serve PPE to the entire province, no matter who you were. And that was all just driven by the belief that there's nobody else for people to turn to, so we just accepted the responsibility at the beginning that we would be responsible. I guess [we had] a strong sense of ownership and responsibility for the welfare of everyone as a supply chain function. [P]eople don't know what you do; finance doesn't know anything about what you're doing. Nobody knows what you're doing. So as a supply chain expert, you know what has to be done, and so just do it and don't wait to be told, and I think that that was a big part of our success.

Healthcare supply chain teams developed a supply management strategy that assumed responsibility for the welfare of everyone as a prioritized supply chain function. This comprehensive approach aligns with the definition of healthcare supply chain resilience advanced in this paper. Importantly, this sense of responsibility coincided with the development of the data and digital infrastructural and material – logistical capacity to enable equity across all care settings. That is, a shift in supply management strategy – one which emphasized greater equity through the integration of healthcare supply chain peripheral care settings – came in tandem with the cultivation of the material infrastructure to enable this strategy. This transformation was described by a healthcare supply chain leader:

> We just assumed we have to care for everyone. So, I took the approach before I was even in the role I'm in now, that we weren't going to lock the doors; [that] if LTC was going to be running out of N95s, we [were] not going to put chains on the doors of our hospital and prevent them from having things. We assumed that we would work together, even before structures were in place that caused us to work together. We just

> assumed that it would be all for one and one for all, so to speak. And so we immediately started planning that way. We built a warehouse that could support the entire province. We got infrastructure and IT technology so that we could serve any customer regardless of whether they were private sector or public sector through a common technology platform, which would have been previously impossible with our normal ERP system. So we built all the underlying enablement.

Predictive modelling capacity was a necessary requirement to fulfil the goal of equitable supply chain distribution as described by the same supply chain leader quoted earlier:

> [We were supplying] everybody, even [the] private sector. So we'[d] give PPE to dentists, we'[d] give it to family doctors, we [would] give PPE to anyone in the province, and we are able to do that. [W]e've modelled [for] every single demand channel in the province, whether you're a bus driver or a nurse in homecare environments; we have calculated how much PPE you need, and we have modelled all of it, and feel comfortable that under full pressure from every channel all turned on at the same time, we have enough supplies.

Equity as a hallmark of emerging healthcare supply chain resilience indicates a reconfiguration of healthcare supply management. If fragility was a by-product of supply management strategies that focused on cost-efficiency and savings (such as just-in-time models), resilience entails supply management strategies that can ensure equitable distribution of supplies. In important ways, then, this key feature of resilience recapitulates and crystallizes the features discussed earlier. Redundancy, diversification, maturity and proactivity are all the hallmarks of a healthcare supply chain strategy that is equitable and person-centred and that *possesses the conditions or material resources required to distribute supplies in an equitable manner* to support safe and effective delivery of healthcare. A resilient healthcare supply chain, a supply chain that assumes care for everyone as a supply chain function, is an equitable and person-centred healthcare supply chain.

Conclusion

Healthcare supply chains are indissolubly wedded to patients' care delivery across health systems. The COVID-19 pandemic exposed the fragility of these supply chains. The shattering of traditional and brittle supply chains was felt across Canadian health systems and touched the lives of healthcare workers, patients and citizens. Yet, the healthcare supply chain story in Canada during the COVID-19 pandemic was not just a story of brittleness and breaking: it was also a story of incipient resilience – of a hard-won resilience achieved through the efforts of healthcare supply chain teams and their respective health system leaders. In this paper, we have attempted to isolate and surface the emerging features of resilience contained in the Canadian healthcare supply chain experience:

1. *Emerging resilience in supply sourcing and procurement:*
   - redundancy of supply inventory
   - diversification of suppliers across geographies
2. *Emerging resilience in data and digital infrastructure:*
   - maturity of digital infrastructure to create transparency
   - proactive, data-driven decision making
3. *Emerging resilience in supply management and distribution:*
   - equity of distribution to protect the lives of all

Honouring the experiences of healthcare supply chain teams and front-line healthcare workers may require a radical reconfiguration of the conceptual and practical approaches to supply chain that were dominant in the pre-pandemic world. Evidence of emerging resilience, then, can inform supply chain strategies to advance healthcare supply chain resilience for the post-pandemic future. Put otherwise, it is these emerging features of healthcare supply chain–specific resilience that can function as lodestars for a post-pandemic digital health and medical supply ecosystem. HQ

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