Supply Chain Thinking in Healthcare: Lessons and Outlooks

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Problem definition: The lessons learned over decades of supply chain management provide an opportunity for stakeholders in complex systems, such as healthcare, to understand, evaluate, and improve their complicated and often inefficient ecosystems. **Methodology:** We provide a primer on supply chain thinking in healthcare, with a focus on healthcare delivery, by following a framework that is customer-focused, systems-based, and strategically orientated, and that simultaneously considers clinical, operational, and financial dimensions. Our goal is to offer an understanding of how concepts and strategies in supply chain management can be applied and tailored to healthcare by considering the sector's unique challenges and opportunities. **Results:** After identifying key healthcare stakeholders and their interactions, we discuss the main challenges facing healthcare services from a supply chain perspective and provide examples of how various supply chain strategies are being and can be used in healthcare. **Academic/practical relevance:** The complexity in managing healthcare supply chains offers opportunities for important and impactful research avenues in key supply chain management areas such as coordination and integration (e.g., new care models), mass customization (e.g., the rise in precision medicine), and incentives (e.g., emerging reimbursement schemes), which might, in turn, provide insights relevant to traditional supply chains. We also put forward new perspectives for practice and possible research directions for the supply chain management community. **Managerial implications:** By using supply chain thinking, healthcare organizations can decrease costs and improve the quality of care by uncovering, quantifying, and addressing inefficiencies.

Key words: stakeholders in healthcare, payment methods, health technologies, care models, integrated care delivery, supply chain strategies
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1. Introduction

A supply chain (SC) is a "network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher 2016, p. 13). Supply chain management (SCM) is the "management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole" (Christopher 2016, p. 3).

Since the term was coined in the early 1980s, SCM has risen to prominence and, with decades of theoretical and practical wisdom attached to it, it is now the backbone of business. With a

marked focus on the interactions between stakeholders, the wealth of acquired SCM knowledge provides a unique opportunity to understand, evaluate, and improve complex ecosystems such as healthcare systems. This, of course, begs the question: How can we adopt well-known strategies from more traditional SCs to healthcare ecosystems? For example, how can we replicate Amazon's customer obsession in building patient- and provider-centric care delivery? How can Zara's lean and agile SCs, which satisfy their functional and innovative product needs, respectively, show us how to separate routine and complex care in hospitals? How can we extend the partnership model that enabled P&G to be a "part of Walmart" to promote integrated care through performance improvement and benefit sharing?

1.1. Supply chain thinking in healthcare: a framework

At the core of efficient and effective SCM is supply chain thinking, which includes three key aspects: a customer focus, a systems approach, and a strategic orientation (Mentzer et al. 2001). A *customer focus* ensures that the creation of customer value is the key driver of the SC's activities. A *systems approach* views the organizations in the SC as an end-to-end, integrated entity, while each individual organization's *strategic orientation* aligns the intra- and inter-firm goals and capabilities of the organization with those of the SC. Yet, as we will discuss in Section 2, healthcare faces unique challenges that sometimes deviate from the difficulties found in other ecosystems. For instance, a stark difference emerges from the fact that since their health is and their lives are potentially at stake, patients, who are the end consumers in healthcare SCs (hSCs), have distinct vulnerabilities, needs, and demands compared to customers of other goods and services. This also calls for simultaneous consideration of the clinical, operational, and financial dimensions of any healthcare research or practical initiative. That is, one can broadly conceptualize healthcare SCM (hSCM) as the adaptation of supply chain thinking within the realm of healthcare (Figure 1).

The *clinical* dimension ensures that any move from a more traditional model to an hSCM model does not diminish the safety, outcomes, or experiences provided to end users. Any action or change

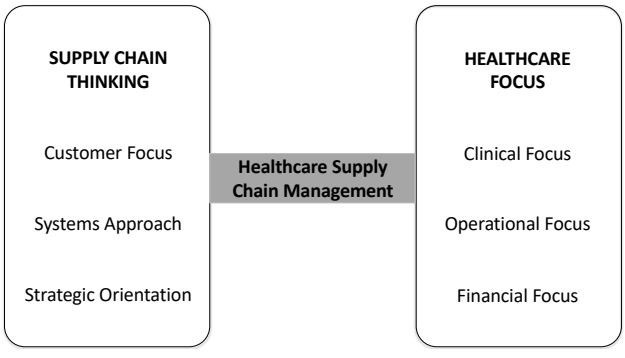

Figure 1 **Healthcare SCM requires a customer focus, a systems approach, and a strategic orientation (Mentzer et al. 2001) with simultaneous consideration of clinical, operational, and financial implications.**

within a healthcare system should be motivated and guided by the needs and requirements of patients. However, the clinical dimension does not only include individual patients but also the patient-clinician interaction, which is the principal transaction in healthcare. Therefore, whenever hSCM is adopted, it is also important to account for its consequences for clinicians' work, morale, and job satisfaction. Failing to do so can lead to burnout and reduce the most basic supply factor - clinician time (Betcheva et al. 2019, Charles 2019). The *operational* dimension comprises the technologies and care models that enable operationalization of the transformation. In considering this dimension, decision-makers must ask whether the right information and resources are in the right place and applied at the right time to ensure care is provided in the most effective and efficient way. For example, this entails determining which providers treat which patients as well as when (points of care), where (e.g., in hospitals, in outpatient clinics, at home), and how (e.g., surgery, physical therapy) treatment takes place. Finally, due consideration of the *financial* dimension ensures the cost-effectiveness of the improvement and requires creation and placement of appropriate incentives. For instance, provider reimbursement has become particularly important to the effective functioning of new care delivery models, such as accountable care organizations (ACOs). Only when a transformation creates a simultaneous win-win-win in the clinical, operational, and financial dimensions can we expect it to be successfully implemented and sustained in healthcare ecosystems.[1] Healthcare SCM can be instrumental in achieving this win-win-win.

1.2. Healthcare supply chain management: a broader view

Historically, hSCs have commonly been associated with the procurement and logistics of healthcare supplies and services. However, recent developments in healthcare render this understanding too narrow. For example, new ways of thinking, as illustrated by widespread technology adoption, a focus on integrated care delivery, and an emphasis on aligning stakeholder interests through new reimbursement schemes, have primed healthcare management for the introduction of broader SC concepts. In addition, the complexity in the interactions across healthcare stakeholders and the siloed nature of care delivery create an opportunity to understand, evaluate, and improve this inefficient ecosystem in a systematic, holistic manner. Thus, following the path of traditional SCs, which have expanded the scope of purchasing to the prevailing view of SCM (Kraljic 1983), hSCM, as we define it, has a much broader scope than the usual procurement- and logistic- focused definition.

In adopting this broader view, we define *healthcare supply chain management* as the management of people, processes, information, and finances to deliver medical products and services to

[1] Discussions in medical community highlight the importance of jointly considering these factors. For example, Berwick et al. (2008) emphasize the *triple*-aim of healthcare as enhancing clinical outcomes and user experience while controlling costs. Similarly, despite its popularity, Dartmouth Atlas (2019) has become controversial in debates for ignoring factors such as outcomes and illness severity, and only focusing on cost in their efficiency measures (Bach 2010).

consumers, in the pursuit of enhancing clinical outcomes and user experience, while controlling costs (de Vries and Huijsman 2011, Berwick et al. 2008, Betcheva et al. 2019). Within our definition, people can refer to patients, providers, purchasers, and payers while processes can include patient flow, clinical development, and blood collection and distribution. Information can take the form of diagnoses, treatment plans, patient-generated data, etc., while finances can comprise costs, payments, and reimbursements. Medical products can include pharmaceuticals, medical devices, and health aids, whereas services can encompass curative, preventive, rehabilitative, and palliative care. As the end goal of this supply chain, healthcare delivery (i.e., the provision of healthcare services including, but not limited to, the prevention, diagnosis, treatment, and management of illness) hinges on the joint efforts of and interactions between various stakeholders. Table 1 lists these stakeholders, including organizations and individuals, and Figure 2 provides a high-level representation of the interactions between stakeholders.

As the recipients of healthcare, patients, for the most part, interact exclusively with care providers: they consult with their primary care physicians, receive treatment from nurses and doctors within and outside of hospitals, and obtain prescription medications from pharmacists. To perform their duties, care providers need access to pharmaceuticals, supplies, equipment, and ancillaries. Stakeholders, such as pharmaceutical companies, medical, diagnostic, and surgical device manufacturers, and blood centers, among many others, interact with care providers (often through intermediaries such as group purchasing organizations) to ensure the provision of such products and services. Policymakers govern these interactions. For instance, the Food and Drug Administration in the US regulates the testing, manufacturing, and marketing of drugs. Interactions between

Table 1 hSC organizational and individual stakeholders (The King's Fund 2013, PhRMA 2016)

Category	Stakeholders
End consumers	Patients, patient families, and populations
Care providers	Hospitals, clinics, ambulance services, community care, social care, nursing homes, informal care, mental health, public health, dental care, physicians, nurses, technicians, managers, paramedics, dentists, psychiatrists
Intermediaries	Group purchasing organizations, pharmacy benefit managers
Pharmaceutical providers	Innovators (such as research institutes and academia), biotechnology firms, clinical trial sites, raw material suppliers, pharmaceutical manufacturers, distributors, wholesalers, pharmacies (retailers)
Equipment & ancillaries	Medical, diagnostic, and surgical devices, capital equipment, office equipment, vaccines, blood, organs
Contractors	Contract research organizations, contract manufacturing organizations, site management organizations, clinical commissioning groups
Policy makers	Governments, regulators, patent and trademark offices, quality monitors, advisory committees, lobbyists
Payers	Insurance companies, national and local governments, employers, venture capital firms, communities, nonprofit organizations, foundations and charities, patients, patient families
Support services	National Institute of Health Research, NHS Improvement, research institutes, independent and charitable think tanks, MedTech including information technology systems and electronic health records, decision support systems

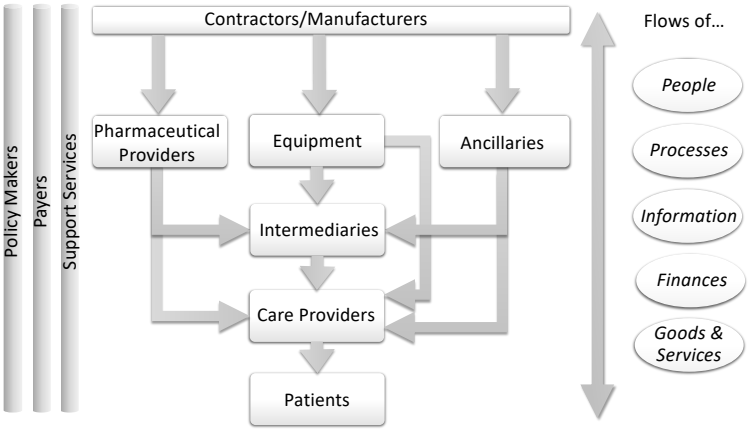

Figure 2 **A schematic of the interactions between stakeholders and the flow of people, processes, information, finances, and products and services in the hSC.**

stakeholders are facilitated by both payers (which provide finances) and support services (which provide information). That is, a multitude of different entities enable care providers to execute their functions. We can categorize these entities into various SCs (such as health services and pharmaceuticals), all of which play unique, interrelated, roles in care delivery. We refer readers to the online addendum for a categorization of hSCs and a synopsis of research for each hSC subcategory, and to Betcheva et al. (2019) for details of the main challenges and risks faced by different hSCs.

1.3. Supply chain thinking: exemplars

Numerous examples demonstrate that with SC thinking, healthcare organizations can decrease costs and improve the quality of care by uncovering, quantifying, and addressing inefficiencies. Driven by a mission to eradicate unnecessary blindness in India and to provide healthcare for all, the Aravind Eye Care System (motivated by McDonald's food assembly lines) fully aligns its delivery systems with its strategy. With a focus on patients, the utilization of a systems approach (e.g., the creation of a hub-and-spoke ecosystem through the use of telemedicine) and a strategic orientation (e.g., Aurolab, Aravind's manufacturing arm, was established to manufacture intraocular lenses at high volume in order to decrease costs), Aravind delivers cataract care in India at 1% of the cost of cataract care in the UK's national health service (NHS) (Vickers and Rosen 2011).

By combining the elective orthopedic services of five district hospitals into one high-volume excellence center, Finland's Coxa Hospital provides a one-stop shop for patients in a site purpose-built around the main patient pathways. Coxa is able to achieve high clinical (e.g., low infection and revision rates), operational (e.g., fast procedure turnaround time, high operating room utilization), and financial outcomes (cost savings passed onto consumers in the form of lower prices) as a result of standardization coupled with high volumes, information sharing (e.g., cross-organizational shared electronic health records (EHRs) and transparency of surgeon-level performance data) (Dowdeswell

and Vauramo 2009, Gov.uk 2010, Coxa 2017), and incentive mechanisms that align patients' goals with operational capabilities (such as reimbursing patients for avoidable complications).

Over the course of more than fifteen years using principles drawn from the famous Toyota Production System, the Virginia Mason Production System (VMPS) was established by Virginia Mason Health System (Virginia Mason 2019). With a focus on the entire system, the inclusion of patients and their families in the transformation, and the alignment of stakeholder expectations around Virginia Mason's shared vision have all become essential to the success of the continuously changing and learning environment of VMPS. VMPS improves quality and safety, reduces the burden of work for team members, and decreases the cost of providing care (Virginia Mason Medical Center 2010, Kenney 2011).

The benefit of SC thinking in healthcare has also been recognized in the academic literature. Recently, Dai and Tayur (2019) have argued that "the field of healthcare operations management (HOM) ... has started to look beyond point-level operational improvements and examine the interactions of multiple entities, shifting our gaze onto the healthcare ecosystem." Their paper (which uses "ecosystem" to describe what we refer to as healthcare SC) focuses on reviewing methodological tools commonly used in HOM and on classifying research problems. In contrast, we aim to provide an understanding of how broader SCM concepts and strategies can be applied and tailored to healthcare by considering the sector's unique challenges and opportunities, and we also offer guidance to practitioners and possible research directions for the hSCM community. Our goal, in other words, is to provide a primer on SC thinking in healthcare. We therefore do not present a detailed literature review; we refer readers to Keskinocak and Savva (2019) and KC et al. (2019) for thorough reviews of the healthcare operations literature from a modeling point of view and an empirical point of view, respectively.

Our paper further contributes to the existing literature by building on the work of Green (2012) and Pinker (2012). Green argues that the growing availability of operational, financial and patient data paves the way for HOM researchers to work with healthcare providers to establish evidence-based healthcare. Pinker further develops this argument by encouraging more ambitious goals and a wider range of research opportunities for HOM researchers. In this paper, we shift the focus to the *interactions* and *relationships* among a multitude of entities in healthcare ecosystems and anchor our framework in *supply chain thinking*. We broaden the scope of hSCM and advocate for further involvement of SCM scholars in the healthcare domain.

2. Challenges in healthcare delivery

Similar to traditional SCs, challenges such as variability, inflexibility, and waste (Cachon and Terwiesch 2009) are commonly observed in hSCs, making the management of these supply chains

taxing. In addition, compared to SCs in other ecosystems, management of hSCs sometimes presents unique difficulties. In Section 2.1, we give an overview of the main clinical and public health challenges. Section 2.2 outlines key operational challenges in hSCs, and in Section 2.3, we discuss financial challenges and the ways in which payment structures can lead to inefficiencies in the healthcare system. A summary of the challenges, their implications and opportunities can be found in Table 2.

2.1. Clinical and public health challenges

Different patient characteristics (e.g., health status, comorbidities, demographics and preferences), conditions (e.g., injuries, illnesses, disabilities and diseases) and situations (e.g., disease progression and the availability of resources) entail different clinical challenges. Although the array of such clinical considerations is vast, there are a few overarching areas practitioners pay particular attention to. One top priority in healthcare delivery is patient safety, arising from medicine's fundamental guiding principle of "*do no harm*." Effectiveness of care (assessed through various clinician-reported and patient-reported measures), efficiency, equitability, timeliness of care, and patient experience are also key concerns (Institute of Medicine (US) Committee on Quality of Health Care in America 2001). However, several difficulties including clinical uncertainty, medical errors, and the co-productive nature of healthcare threaten the delivery of these priorities. While we will broadly discuss some of these challenges in this section, we wish to emphasize the fact that more informed and detailed discussions are best left to healthcare experts and practitioners.

One major difficulty is uncertainty, which is to some degree is inherent in most aspects of healthcare delivery. Uncertainty can complicate and introduce variation in clinical decision making, which is already a complicated endeavor because patients have distinct journeys in which care plans may change at each encounter. As Eddy (1984) notes in his paper on healthcare uncertainty, "Whether a physician is defining a disease, making a diagnosis, selecting a procedure, observing outcomes, assessing probabilities, assigning preferences, or putting it all together, he is walking on very slippery terrain." With the intent of providing a unified, coherent concept of uncertainty in healthcare, Han et al. (2011) propose a three-dimensional taxonomy characterizing uncertainty by its fundamental sources, issues, and locus. The authors point to probability (a phenomenon's indeterminacy), ambiguity (the lack of credible, reliable or adequate information regarding a phenomenon), and complexity (difficulty in comprehending a phenomenon) as sources of uncertainty. Uncertainty can cause scientific (disease-centered uncertainties regarding diagnosis, prognosis, treatment, etc.), practical (system-centered uncertainties concerning the structures and processes of care), and personal (patient-centered psycho-social and existential uncertainties) issues. Lastly, this taxonomy describes uncertainty by its locus (existing in the minds of patients, clinicians, both, or neither).

Table 2 Clinical and public health, operational, and financial challenges in hSCs

Challenge	Description	Implications	Opportunities
1. Clinical & public health			
1.1 Uncertainty	Uncertainty in the disease definition, diagnosis, prognosis, treatment plan and outcome evaluation due to probability, ambiguity and complexity	Can complicate and introduce variation in clinical decision making	Understanding and classifying uncertainty as groundwork for effective uncertainty management strategies
1.2 Medical errors	Preventable acts occurring as a result of actions not taken or as a result of the wrong actions taken encompassing preventive, diagnostic, and surgical care and treatment as well as device, equipment, and communication errors or failures	May result in unintended consequences for the patient (e.g., adverse effects)	Can be mitigated by various operational strategies and safeguards, such as the standardization of procedures (Ramdas 2018)
1.3 Co-productive nature of healthcare	Achieving safe and effective care depends on the efforts of both patients and providers	Poor patient adherence can compromise the treatment efforts of providers and jeopardize safety and health outcomes	Better care through improved patient engagement and provider receptiveness of patient preferences
1.4 Investment trade-offs	Central trade-off between investment in upstream public health interventions associated with longer, healthier lives and spending for downstream short-term needs related to the treatment of disease (Marshall et al. 2018, Finch et al. 2018)	Although many factors that contribute to non-communicable disease are behavioral, and therefore preventable, only a small fraction of health spending (3% in OECD countries) goes towards preventive services (Gmeinder et al. 2017)	Evidence of the impact of public health interventions are limited compared to healthcare interventions
1.5 Complexity of population health	-Influenced by many health and socioeconomic factors and there can be a multidirectional and dynamic relationship between those factors -Spillover effects on others, such as family members	-Can complicate the design and evaluation of population health interventions -Effects of public health initiatives may take many years to become apparent	Studying the public health component of healthcare ecosystems would create an opportunity to deliver care at a lower cost
2. Operational			
2.1 Delegated decision making	Care providers make consumption decisions on behalf of patients, thus making the "puchasing decisions" for them as a third-party agent	Patient experience can come under threat if patient wants, preferences and expectations are not factored into care decisions	Patients should ideally be partners in designing their care processes
2.2 Third-party financing	Payers provide reimbursement for the products and services charged by providers. Patients and providers are "insulated from the price of the product or service" (wikipedia.com/health economics)	Payers are not fully privy to patients' health status (leading to adverse selection or hidden information) nor to providers' actions (leading to moral hazard or hidden action)	-Carefully designed incentive and payment mechanisms -Greater transparency between patients, providers and payers
2.3 Information asymmetry	Patients' complex needs require expert services yet patients are rarely in a position where they have complete information or the requisite knowledge to assess the quality of the service they receive	Creates a paternalistic care environment leading to potential power imbalances	Reinforced patient activation and more effective communication between patients and providers
2.4 Ambiguous and inaccurate performance measures	-Lack of patient-level cost information due to opaque cost allocations -Difficult to assess the value or utility of healthcare due to the fact that is a healthcare is a credence[i], merit[ii] and social[iii] good and health of a human being is at stake	Challenging to quantify the value of healthcare and identify quality measures that are meaningful for physicians and patients alike	-Data integration and transparency -A greater focus on delivering value (considering both outcomes and costs)
2.5 Pervasiveness of fragmented care	Siloed care and uncoordinated care delivery across organizations	-Wastes such as duplicative and non-value adding functions and inefficiencies caused by supply-driven demand -Sub-optimal patient safety and experience	Increased coordination, data integration and adoption of end-to-end applications
3. Financial			
3.1 Incentives from payment schemes	Payment methods can incentivize or disincentivize patients and providers influencing care utilization and care decisions	-Wasted resources from overtreatement, overconsultation, overdiagnosis and overprescription -Market failures such as the underuse of services and upcoding	Increased implementation of outcome- and value-based reimbursement schemes facilitated by advancement and adoption of health technologies which diminish the burden of data collection and measurement

[i] A credence good is a type of good with qualities that cannot be observed by the consumer after purchase, making it difficult to assess its utility" (investopedia.com).
[ii] A merit good is "a type of good which, when consumed, provides external benefits, although these may not be fully recognized" (economicsonline.co.uk).
[iii] A social good is a type of good whose value extends beyond the return to shareholders and benefits the wider society.

Such efforts at understanding and classifying uncertainty are building the groundwork for effective uncertainty management strategies, which are very much needed given the ongoing challenge of operating in an uncertain environment.

Medical errors, which are preventable acts encompassing preventive, diagnostic, and surgical care and treatment as well as device, equipment, and communication errors or failures, may result in unintended consequences (e.g., adverse effects) for the patient. They can occur as a result of actions not taken or as a result of the wrong actions taken (Rodziewicz and Hipskind 2019), and they pose a challenge for healthcare as they carry significant human, societal, and cost burdens. It is important to note that the incidence of medical errors can be mitigated by various operational strategies and safeguards, such as the standardization of procedures (Ramdas et al. 2018).

Another clinical challenge stems from the co-productive nature of healthcare (Andritsos and Tang 2018). Achieving safe and effective care depends on the efforts of both providers and patients. For instance, poor patient adherence can compromise the treatment efforts of providers and jeopardize safety and health outcomes. Improving patient engagement and provider receptiveness of patient preferences, as well as, bolstering more effective communication between patients and providers, could create an opportunity to deliver better care.

While the healthcare sector is focused on the treatment of disease in individuals, it simultaneously plays a central role in the domain of public health. Public health focuses on measures related to the prevention (reducing the incidence of ill health), protection (preventing the spread of communicable disease), and promotion (enabling people to lead healthier lifestyles) of health (Royal College of Nursing 2020). A closely related approach, population health, aims to improve health outcomes and reduce health inequalities across an entire population by addressing social, cultural, political, economic, commercial and environmental determinants of health (Buck et al. 2018, Lovell and Bibby 2018). An aging population, rising prevalence of chronic disease, and widening health inequalities (e.g., women living in the most-deprived 10% of areas of England are expected to live for nine fewer years than those from the least-deprived 10% and spend nineteen fewer years in good health (Buck et al. 2018)) highlight the need for effective joint functioning of healthcare delivery and public health.

A healthy population has clear economic and societal benefits. However, the main challenge associated with public health is the trade-off between investment in upstream public health interventions associated with longer, healthier lives and spending for downstream short-term needs related to the treatment of disease (Marshall et al. 2018, Finch et al. 2018). Although many factors that contribute to non-communicable disease are behavioral and therefore preventable (e.g., smoking contributes to heart and lung disease), only a small fraction of health spending (3% in OECD countries) goes towards preventive services (Gmeinder et al. 2017). One likely explanation

for this discrepancy stems from the fact that while healthcare interventions offer clear evidence of their efficacy, evidence of the impact of public health intervention is limited (Finch et al. 2018).

The intrinsic complexity of population health poses further challenges in the design of effective systems and interventions. Population health is influenced by many health and socioeconomic factors, and there can also be a multidirectional and dynamic relationship between those factors. For example, a child in good health may have a higher education potential, which results in good employment; in turn, employment and financial resources are important for good health (Marshall et al. 2018). Moreover, the effects of public health initiatives may take many years to become apparent, and interventions that affect one individual directly may have spillover effects on others, such as family members (Finch et al. 2018, Marshall et al. 2018). Studying the public health component of healthcare ecosystems would create an opportunity to deliver care at a lower cost and would lead to a better understanding and more accurate characterizations of the longer-term outcomes of care delivery.

2.2. Operational challenges

Healthcare services are characterized by a patient-provider-payer triad (Figure 3). Consequentially, there are two major differences between a traditional SC and an hSC: an hSC involves *delegated decision-making* and *third-party financing*. These differences are leading to the first two of the five major operational challenges we describe in this section.

First, given the co-productive nature of healthcare, patients, as the consumer of healthcare services, should ideally be partners in designing their care processes. Yet, patients most often do not make consumption decisions themselves. Instead, they delegate these decisions to care providers (e.g., doctors and nurses), who provide them with healthcare and make the "purchasing decisions" for them as a third-party agent.

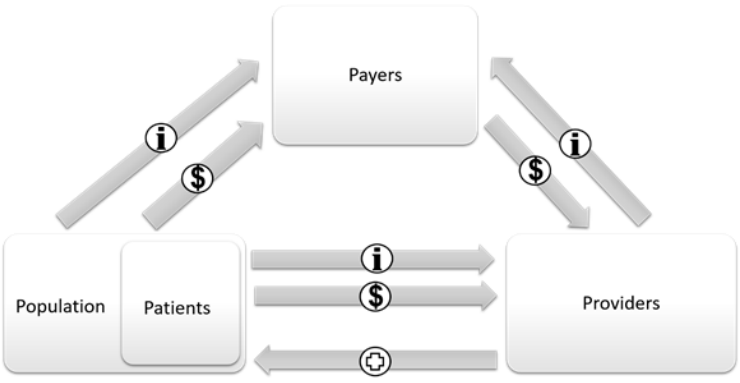

Figure 3 **The patient-provider-payer triad of healthcare. Information (i), finances ($), and healthcare services (✙) flow between entities.**

Second, in a traditional SC, the consumer pays for a given good or service. The value of the product or service can therefore usually be easily defined and measured. However, in an hSC, patients rarely pay the full price themselves. Further complicating matters, the providers are similarly "insulated from the price of the product or service" (wikipedia.com/health economics). It is the payers (e.g., insurance providers, employers, and/or the government) who largely provide reimbursement for the products and services charged by providers. Yet, the payers act with limited information, that is, without the full knowledge of patients' needs and demands (as payers are not fully privy to patients' health status, leading to adverse selection or hidden information) or of the benefits of the services provided (as payers are not fully privy to providers' actions, leading to moral hazard or hidden action).

The third challenge is partially caused by *information asymmetries* and further convoluted by the *power imbalances* in healthcare. Healthcare end consumers often have complicated needs and vulnerabilities. Yet because these patients' complex needs require expert services, patients are rarely in a position where they have complete information or the requisite knowledge to assess the quality of the service they receive[2]; this gives rise to additional information asymmetries in the triadic relationship. Furthermore, patients' vulnerabilities create a paternalistic care environment leading to potential power imbalances. Together, these matters make it difficult to meet consumers' needs and make it especially arduous to match demand with supply.

Efficient and effective SCM necessitates a clear understanding of performance measures pertaining to costs, outcomes, and quality. In healthcare, it is *challenging to quantify such performance measures*, which leads us to our fourth operational challenge. Often, accurate patient-level cost information is lacking due to inaccurate and often opaque cost allocations (Kaplan and Porter 2011). Moreover, healthcare end consumers find it difficult to assess the value or utility of the service they receive–partially due to information asymmetries (as discussed above), partially due to the fact that healthcare is a merit good[3], and partially due to the fact that the health of a human being is at stake and healthcare can therefore be a sensitive subject. It is thus challenging to identify quality measures that are meaningful for physicians and patients alike. Simply put, physicians and patients may hold very different views regarding the degree to which a provided healthcare service led to a "good" result.

Such ambiguous or disparate valuations of healthcare services jeopardize the consumer focus of hSCM. Since, according to the World Health Organization Constitution (1946), "the highest

[2] Healthcare is a credence good; in other words, it is "a type of good with qualities that cannot be observed by the consumer after purchase, making it difficult to assess its utility" (investopedia.com). Other examples of credence goods include expert services such as consulting and automobile repairs.

[3] A merit good is "a type of good which, when consumed, provides external benefits, although these may not be fully recognized" (economicsonline.co.uk). Education is another example of a merit good.

attainable standard of health" is a fundamental right of every human being (World Health Organization 2017), there are ethical concerns and thus constraints on the levers that an SC manager can use in the context of an hSC. For example, emergency departments cannot deny emergency service to any patient, independent of their insurance coverage status. In addition, since healthcare is a social good, its value extends beyond the return to shareholders, and evaluating the impact of healthcare on society as a whole further complicates the quantification of its value.

Finally, effective SCM necessitates capability alignment and (end-to-end) goal optimization across all of the organizations in an SC. Yet one of the most prominent challenges in hSCs is the *pervasiveness of fragmented care*, which results in an unrealized value in care delivery. Fragmented hSCs are burdened with wastes such as duplicative and non-value adding functions and inefficiencies caused by supply-driven demand (Burns et al. 2002). Siloed care is costly and it leads to sub-optimal patient safety and experience (Elhauge 2010, Jha et al. 2009, Stremikis et al. 2011). End-to-end goals are commonly achieved through information sharing and incentive and payment mechanisms. Yet within hSCs, "information on the value or cost added at each link is severely lacking $\cdots$ [making] meaningful knowledge sharing $\cdots$ impossible" (Burns et al. 2002). Despite the wide availability of healthcare IT systems, data integration in healthcare is limited and adoption of end-to-end applications is low. Therefore, fragmentation is a considerable impediment to SCM in healthcare systems.

2.3. Financial challenges

The operational challenges discussed in Section 2.2 complicate the development of practical and effective payment mechanisms in healthcare. Table 3 displays commonly used reimbursement methods and the main criticisms of each method.

One very common method is fee-for-service (FFS) reimbursement. Because providers are paid per service provided, FFS has been heavily criticized for incentivizing providers to overtreat, overconsult, overdiagnose and overprescribe – all leading to mismatches between true patient needs and generated demand. Christensen et al. (2017) suggest FFS schemes should only be employed in "solution shops," where resources and processes are structured to diagnose and arrive at solutions for complicated and ambiguous medical problems.

In contrast to retrospective FFS schemes, prospective bundled payments have been introduced to curtail overtreatment and wasted resources. Yet, bundled payment may lead to other types of market failures, namely the underuse of services and upcoding. To overcome these limitations, Christensen et al. (2017) recommend the use of outcome-based reimbursement schemes in situations where treatments are standardized and are carried out following a definitive diagnosis (e.g., cataract surgeries). Similarly, value-based (Porter 2009) reimbursements have been developed to improve

Table 3 Payment methods in healthcare

Payment Method	Definition	Example	Criticisms
Fee-for-service (FFS)	Providers are paid a fixed fee for each service provided	Australia's GP consultation fees under Medicare	Encourages providers to overtreat
Pay-per-diem (Bundled payment)	Providers are paid a fixed amount for each patient visit/ patient day (for inpatient services)	Hospital outpatient	Encourages providers to increase number of admissions and/or the length of stay
Case-based (Bundled payment)	Providers are paid a fixed amount for admission or discharge depending on the patient and clinical characteristics	Hospital inpatient (DRGs - diagnosis-related groups)	Encourages providers to curtail costs by utilizing less (and/or less expensive) procedures, tests and treatments and by engaging in upcoding
Population-based (Capitation)	A system of providers is paid in advance to provide a set of services for each patient enrolled	NHS Primary and Acute Care Systems (PACS)[i], US Veterans Health Administration[ii]	Encourages providers to enroll as many patients as possible, stint on care, "cherry-pick" healthier patients
Global budget	Providers are paid a fixed amount to deliver a set of services for a specified population over a defined period of time	Maryland's Global Budget Program[iii], Cambridge University Hospitals	-Encourages providers to ration services -Provides no incentive to attract more patients through improved performance
Performance-based (e.g., P4P)	Providers are paid for meeting certain performance measures	NHS Quality and Outcomes Framework [iv], Hospital Readmissions Reduction Program (HRRP)[v]	Unintended consequences of predetermined performance targets (see discussion on HRRP in Section 2.5)
Outcomes-based	Payment is linked to health indicators and outcomes (including patient-reported outcomes)	Amgen and Harvard Pilgrim's refund contract for Repatha®[vi]	The cost and difficulty of collecting timely, objective and complete data on outcomes
Value-based	Payment depends on the value (where value accounts for outcomes and costs)	Centers for Medicare and Medicaid Services Hospital Value-Based Purchasing Program[vii]	The complexity of defining, and the burden of measuring and reporting, outcome and costs

Source: Adapted from https://www.who.int/health_financing/topics/purchasing/payment-mechanisms/en/
[i] We refer the reader to NHS England (2016) for an overview of PACS.
[ii] We refer the reader to Oliver (2008) for a brief case study on the US Veterans Health Administration.
[iii] We refer the reader to Sharfstein et al. (2018) for a short discussion on global budgets in Maryland.
[iv] We refer the reader to NHS England (2018) for a review of the NHS Quality and Outcomes Framework pay-for-performance scheme.
[v] We refer the reader to James (2013) for a brief of the Medicare value-based HRRP.
[vi] We refer the reader to Amgen (2017) for a news release regarding the agreement.
[vii] We refer the reader to CMS (2017) for a fact sheet on the hospital value-based purchasing program.

clinical quality by focusing on outcomes as well as costs. Although in comparison to fixed rate payment methods like FFS, outcome- and value-based reimbursement schemes have the potential to facilitate more patient-centric healthcare, they are more difficult to implement. Outcomes and costs need to be clearly defined and agreed upon; subsequently, they need to be objectively and comprehensively measured and reported in a timely manner. (It is possible, however, that the burden of data collection and measurement may diminish over time with the advancement and adoption of health technologies such as wearable devices.)

Payment methods can incentivize or disincentivize patients as well as providers. For instance, researchers have studied the effect of cost-sharing on patient actions, such as adherence to medication (Doshi et al. 2009, Maciejewski et al. 2010) and care utilization (Trivedi et al. 2010, Lambregts and van Vliet 2018). Upon analyzing and evaluating payment methods, several key considerations emerge. A critical line of inquiry should address whether payment methods carry the right incentives for care providers and patients. Moreover, policy makers and managers should ensure that payment methods are properly matched with suitable care models. Relevant stakeholders should also establish whether they have the means (e.g., data availability) to successfully implement new reimbursement schemes.

3. Supply chain strategies in action in healthcare supply chains

SC strategies are the core of SCM. In deploying SC strategies, organizations need to consider their capabilities (e.g., capacity, flexibility, quality, speed), the features of the products and services

they offer (e.g., functionality vs. innovativeness), and the nature of supply and demand (e.g., volume, predictability). SC strategies should also align with the organizational strategy. For instance, healthcare entities whose mission is to increase access to care might pursue strategies that allow for economies of scale. There are numerous strategies used in SCM, such as integration, efficiency, responsiveness, process improvement, lean/six sigma, diversification, and outsourcing, and they are employed to match demand and supply and to manage capacity, inventory, infrastructure, etc. We proceed with a discussion of several SC strategies that are either commonly utilized in or have a high potential to be applied to healthcare. We offer examples of organizations and systems that have successfully employed these approaches to further their mission and goals, and we also highlight some of the challenges associated with certain strategies.

3.1. Coordination and integration

Coordination refers to the organization of operations and processes of multiple interdependent entities, which enables effective joint work (Erhun and Keskinocak 2011). It is typically achieved when there are mechanisms in place that allow SC partners to consider each other's constraints, actions, and objectives in order to improve collective performance. Integration takes coordination one step further. In an integrated SC, connectivity between individual organizations is increased and silos are eliminated so that the SC operates as one cohesive entity. The level of integration may vary from loosely integrated, in which participating organizations have some degree of incentive alignment, to fully integrated, under which a firm owns and manages its own SC.

Information sharing can facilitate both coordination and integration. In the retail industry, the partnership between P&G and Walmart provides a notable example of how both firms used inter-organizational information systems to their mutual benefit. Vendor managed inventory, a strategy that required Walmart to share its sales and inventory data with P&G, allowed P&G to make replenishment decisions for Walmart. This resulted in enhanced service levels and reduced inventories across the SC. Walmart's disclosure of point of sale data facilitated improved customer focus by permitting the partners to engage in better category management (Grean and Shaw 2002).

In contrast, healthcare systems tend to be far less cohesive, which is due in part to the fact that many current policies and approaches addressing performance measurement and payment reform focus on individual providers (Fisher et al. 2007). Yet, such approaches that target specific entities rather than the system as a whole risk further reinforcing fragmented patient care and discouraging coordination across providers. The lack of coordination and integration between generalist and specialist medicine and the lack of integration among social care, healthcare, and mental health hamper health outcomes, patient experience, and continuity of care.

Researchers have made multiple efforts to improve coordination and integration in care delivery. At the strategic level, Gröene and Garcia-Barbero (2001) present a theoretical framework and

discuss various models for integrated care. At the clinical level, Campbell et al. (1998) review the development of integrated care pathways for a specific clinical condition. Recently, two team-based patient-centered care models, the patient-centered medical home and perioperative surgical home, have been introduced with the goal of facilitating standardization, coordination, and transitions throughout the primary care continuum and the perioperative continuum, respectively (Hoff et al. 2012). ACOs are another possible solution to this challenge, as they integrate multiple healthcare organizations such as physicians' offices, hospitals, mental health services, and community and social care jointly into one unit. Designed as a population-level model, the underlying goal of an ACO is to improve the health of a given population by coordinating all of the population's healthcare needs, from birth to death.

While these integration initiatives focus on breaking down barriers and encouraging coordination between various healthcare providers and between healthcare and other services (e.g., community care), there is no one-size-fits-all model of integrated care. For developers of any initiative, it is critical to consider the context in which it will exist (i.e., different care settings and stakeholder perspectives) (Shaw et al. 2011). From an hSCM perspective, the particularity of context raises many interesting questions about capacity, scheduling, and contracting. For instance, within particular settings, one can consider: How can providers/services pool resources to ensure coordinated care? Which patients should flow across providers, and how and when should they do so? How should patient appointments be scheduled? A deep knowledge of the patient population is therefore necessary in order to reap the benefits of integration. Other key enablers of successful integration include rich data and an effective IT infrastructure, as well as standardized data collection protocols across organizations (Cox et al. 2016).

3.2. Standardization

Standardization, a process that ensures consistency across units, is another SC practice implemented in healthcare. Products, supplies, materials, equipment, processes, tasks, and services, among other things, can be subject to standardization, which yields multiple benefits. Since standardization removes variability, it establishes consistent quality as well as increased productivity. Goods standardization can facilitate mass production which, in turn, can enable economies of scale. Furthermore, limiting the product selection can lower inventory costs. For instance, McDonald's achieves cost savings by offering the same menu of food items globally. In combination with careful adaptations to tailor products to local tastes, the company's consistent offerings have reinforced its brand image. Similarly, Southwest Airlines attains significant efficiencies through the use of a standardized fleet. Using a single type of aircraft has allowed the company to realize savings from training and maintenance costs and through its flexibility in scheduling (as both the fleet and the staff operating the aircraft are essentially interchangeable).

In healthcare, a leading example of a system that has improved quality and access to services while also lowering costs through standardized processes is Narayana Health, a chain of multispecialty hospitals in India. To enhance the efficiency of cardiac surgery, Narayana applies a production-line approach to surgical care, which relies on minutely detailed protocols for clinical tasks and on narrowly scoped task assignments to facilitate task downshifting by preventing dangerous errors (Erhun et al. 2019). Multiple surgeries can be performed consecutively because surgeons execute the tasks that only they are qualified to perform while, concurrently, other clinicians prepare the next patient for surgery. This allows surgeons to quickly move on to the next prepped patient (Taylor et al. 2017). At Narayana, each surgeon performs 400-600 procedures a year; the average US surgeon performs 100-200 (Govindarajan and Ramamurti 2013, Erhun et al. 2019). This higher volume improves surgeon productivity and reduces costs. Another example of value obtained from standardized processes and specialization is Canada's Shouldice Hospital. For over 70 years, this Ontario hospital has maintained a singular surgical focus on inguinal hernias. While general surgeons do not perform more than 20 hernia surgeries a year, on average, Shouldice surgeons perform five to six surgeries a day (The Economist Intelligence Unit 2016). As a result of this hyper-specialization, the hospital has achieved a 99.5% success rate at a billing cost 50% less than other general hospitals in the province (The Economist Intelligence Unit 2016).

Healthcare providers have also relied on standardization in procurement. Standardized supplies and equipment lead to cost reductions stemming from volume discounts. Standardization in purchasing also eliminates the extra time and effort needed to elicit, tailor, and cater to individual preferences. For example, Seattle Children's Hospital realized savings of 20% per case in supply costs after implementing standardized preference cards for laparoscopic appendectomy (Avansino et al. 2013).

3.3. Efficiency vs. responsiveness

One popular SCM framework is Fisher's matrix (Fisher 1997), which ensures that the process used for supplying products (i.e., the SC type) is well-suited to the products' characteristics: functional products require efficient SCs whereas innovative products require responsive SCs. For example, fast fashion necessitates a responsive SC. Zara, a champion in this regard, caters to rapidly changing demand through its highly agile SC, which incorporates information integration (i.e., constant feedback between stores and designers and daily analysis of sales and customer opinions) as well as delayed differentiation production processes (e.g., the purchase of undyed fabrics to be subsequently dyed according to color trends). Moreover, Zara can also accommodate demand for its functional products through its efficient SC practices that minimize cost; for example, consumer staples such plain white t-shirts are produced in lower cost markets with long lead times.

In healthcare, the pharmaceutical SC offers several examples of supply chain efficiency. Civica Rx, a hospital-led not-for-profit generic drug company, is a good example of an efficient SC. With the goal of decreasing costs and increasing availability of generic drugs, seven healthcare systems and around 500 US hospitals have joined forces and committed to buying a fixed portion of their drug volumes from Civica Rx with a take-or-pay contract (Betz 2018). Civica Rx, in turn, has engaged in a long-term manufacturing and supply contract with Hikma, a contract manufacturer, to eliminate uncertainty in the generic drug supply and prevent drug shortages (Civica Rx 2019). Similarly, Healx, a UK biotechnology company, uses its proprietary artificial-intelligence (AI)-based tool (Healnet) to identify and repurpose existing drugs to treat rare diseases (Kavadias et al. 2016), thus providing a faster and lower-cost approach to the discovery and development of rare disease treatments – an often neglected segment of the industry.

Efficient care delivery is a hallmark of many world-renowned speciality healthcare facilities including Shouldice Hospital and Aravind Eye Care. Since these providers have a narrow surgical focus on routine procedures (inguinal hernias in the case of Shouldice and cataract surgeries in the case of Aravind), they can apply the principles of lean management and standardization to reduce costs. Conversely, non-specialized general hospitals and hospitals' emergency departments are two examples of responsive care delivery. These facilities are designed to be flexible and agile in satisfying unpredictable demand (e.g., the diagnosis and treatment of complex patients with multiple comorbidities). It is possible for healthcare organizations to take advantage of both lean and agile strategies. For instance, leagile is a hybrid SC strategy that applies either a lean or an agile approach, as is most appropriate, to different stages of the SC (Agarwal et al. 2006). Hybrid strategies have also been used in a Swedish healthcare setting, where Aronsson et al. (2011) provide illustrative examples of how patient flow in a multi-provider SC consisting of primary care, secondary care, and social services can be decomposed into several lean and agile subsystems.

A note of caution is in order when it comes to studying efficiency through hyper-specialization. While hyper-specialization in operations may result in improved patient outcomes and decreased costs, it is not always the best model when viewed in the light of a system. For one, because healthcare is burdened with reimbursement distortions. As a result and as discussed in Shactman (2005), specialty hospitals may "cherry pick" more profitable specialties as well as more profitable (i.e., less complex patients). Conversely, general hospitals that "pool" services (Section 3.4) can use revenue from their profitable specialties to cross-subsidize the unprofitable services they are required to provide. Furthermore, general hospitals can cross-subsidize care for the poor and uninsured by catering to a variety of patients. Overall, then, service line design deserves further analysis, especially through the lens of supply chain thinking.

3.4. Pooling vs. focused operations

Pooling refers to the action of redesigning areas of the SC (by aggregating demand, resources, products and capacity) to either reduce uncertainty or to hedge against uncertainty so as to mitigate its consequences (Cachon and Terwiesch 2009). Diminished demand variability allows for a lower level of safety stock. Moreover, a consolidated product inventory decreases shortage and obsolescence risk. Thus, demand and product pooling enable better inventory management. Pooling can also result in cost savings. For instance, location pooling can reduce warehousing costs while goods batching can lower transportation costs. Lastly, pooling can improve service: for example, to reduce customer wait times, some call centers pool call types rather than designating specific agents for specific customer call types.

There are many examples of pooling in different stages of the hSC. Consider, for example, procurement. At the hospital level, different specialities and departments may share the same procurement center for pharmaceuticals, supplies, and devices. Moreover, a growing number of hospitals engage in pooled procurement, routing their spending through intermediaries like group purchasing organizations. These intermediaries consolidate the purchase quantities of multiple hospitals to leverage larger purchasing volume, thus obtaining better prices than individual hospitals that purchase directly from manufacturers. In the vaccine market, UNICEF's Supply Division, the Pan American Health Organization, and the Gulf Cooperation Council Group Purchasing Program pool orders from low- and middle-income countries and procure products on their behalf (Bare 2015). Pooling is also employed for production (e.g., the use of hospital labs, X-ray machines, MRI machines, and operating rooms by different units/specialities), inventory (e.g., the use of the same warehouse by various departments of a hospital/s), and fulfillment (e.g., cross-provider use of a single, centralized appointment booking system). One emerging example of resource pooling is shared medical appointments, in which patients receive provider consultations in the presence of other patients with the same or a similar condition and which have been shown to improve outcomes and patient satisfaction while reducing waiting times and costs (Ramdas and Darzi 2017). Lastly, pooling is used in healthcare financing. A wide range of public and private agencies (such as national ministries of health, health insurance firms, and non-governmental and community-based organizations) pool funding from various sources (such as taxes, insurance contributions, and external funding) to reimburse providers for individuals' healthcare (World Health Organization 2019).

As useful as pooling can be, it may not be an ideal strategy in certain situations. Studying operational performance within a hospital, Song et al. (2015) compare a pooled queuing system to a dedicated queuing system. The authors find that a patient's average wait time and length of stay are longer when physicians are assigned patients under a pooled queuing system with a fairness

constraint compared to a dedicated queuing system with the same fairness constraint. The question of pooled versus focused service lines therefore deserves further analysis with a simultaneous consideration of clinical, operational, and financial dimensions. Other recent inquiries into the uses and limitations of pooling include studies by KC and Terwiesch (2011), Christensen et al. (2017), Jiang and Sodhi (2019), Kuntz et al. (2019) and Freeman et al. (2020).

3.5. Incentive mechanisms

The essence of a strategic orientation in SCM is aligning the intra- and inter-firm goals and capabilities with those of the SC. Incentive mechanisms are financial or non-financial measures that encourage individuals (e.g., regulators, payers, hospitals, physicians and patients) to undertake particular actions necessary for such an alignment. Disincentives and penalties, which deter individuals from performing certain actions, can also serve as alignment mechanisms.

In healthcare, to improve the distribution of human resources and match demand with supply, countries such as the US and Canada have introduced incentive programs (student stipends and loan forgiveness, as well as compensation) to encourage physicians to train and work in underserved areas (i.e., rural or remote places) (Fedyanova 2018). Physicians can also be incentivized by non-financial means such as the use of internal transparency initiatives (e.g., letting colleagues see each other's performance data motivates them to improve the patient experience (Lee 2015)).

In addition to altering physician behavior, incentive mechanisms are used to promote healthy behaviors in individuals and to emphasize prevention. For instance, many employers and insurance companies (such as UnitedHealthcare and Kaiser Permanente) offer their employees and members various fitness and wellness programs, including discounts for gym memberships and activity trackers as well as weight management, nutrition counseling, and tobacco cessation services.

At a higher level, incentive mechanisms can be employed to encourage proper management actions. In traditional SCs, incentives are often used to induce information sharing to reduce or eliminate inefficiencies like the bullwhip effect. Similar approaches have been used in healthcare, where bed blocking, caused by a lack of available ward beds, is a common source of inefficiency and one of main drivers for overcrowding in emergency departments (Bretthauer et al. 2011). Non-emergency wards also often suffer from bed blocking when elderly patients, although clinically ready to be discharged, continue to occupy hospital beds because community care and social care spaces are unavailable (Bottery et al. 2018). Bed blocking not only leads to resource misuse, but it can also prevent timely treatment. Incentivizing information sharing between upstream and downstream providers (e.g., between emergency departments and hospital wards and between hospitals and community care) can facilitate appropriate and advance planning that prevents or alleviates bed blocking. Another example of information sharing relates to hospital discharge summaries sent

to patients' primary care physicians. Since poor communication threatens patient safety and continuity of care (Boddy 2019), improving the timeliness and accuracy of discharge summaries can help ensure that primary care physicians have the information they need when they need it. This can prevent the duplication of effort (such as repeated tests) as well as enhance patient care and patient and physician experience.

Reimbursement schemes are another example of incentive mechanisms that have been used to induce appropriate treatment behavior from providers. Pay-for-performance (P4P) is a payment model that encourages healthcare providers to meet certain performance measures through the use of financial (dis)incentives (see Table 3). One notable example of P4P is the Hospital Readmissions Reduction Program (HRRP), which was implemented by the Centers for Medicare and Medicaid Services in 2002 to further the national goal of improving healthcare by linking payment to quality of care (Joynt et al. 2016). Under HRRP, hospitals with excess 30-day readmissions face payment penalties of up to 3%. The program has generated debate surrounding the extent to which it reduces readmissions: Zuckerman et al. (2016) find readmission trends consistent with hospitals responding to incentives, Zhang et al. (2016) show that HRRP's benchmarking mechanism can lead to an increase in the number of non-incentivized hospitals (which opt to pay penalties rather than reducing readmissions), and Ody et al. (2019) argue that HRRP has had no effect on readmission reduction or that its effect has been overstated. Chen and Savva (2018) suggest that the reduction in readmissions attributed to HRRP may be due in part to higher observation bed usage, while Wadhera et al. (2018) find HRRP to be associated with post-discharge mortality among patients hospitalized for heart failure and pneumonia. Andritsos and Tang (2018) show that P4P (i.e., HRRP) is more effective than fee-for-service (FFS) or bundled payment in reducing readmissions when patients' efforts are considered using a co-production model.

Another performance metric commonly targeted and investigated by regulators and researchers is patient wait times, which may result in diminished health outcomes when they are too long. Patients may also suffer other, often overlooked, consequences such as wages forgone while waiting for treatment and decreased quality of life due to increased pain and suffering (Barua et al. 2018). In their study within a public healthcare system, Guo et al. (2019) examine the impact of the reimbursement policy on social welfare, the revisit rate, and wait times. They show that when the patient pool is large, a bundled payment scheme dominates an FFS scheme in terms of higher social welfare and a lower revisit rate, but the FFS scheme prevails in terms of a shorter wait time. However, in a less-congested system, the bundled payment scheme outperforms the FFS scheme in all three measures. In a different setting, one where regulators are interested in incentivizing both cost and wait time reduction, Savva et al. (2019) examine yardstick competition in the hospital

industry. The authors present a scheme that modifies the transfer payment of the standard cost-based yardstick competition, and they show that if the regulator has prior knowledge of providers' average wait times, the scheme can significantly improve system efficiency.

These examples demonstrate how incentive mechanisms can be used to change individual and institutional behavior to improve patient outcomes and experience as well as provider performance. Yet, well-intentioned incentive mechanisms sometimes result in perverse incentives and unintended consequences (as the debate on the effectiveness of HRRP demonstrates). Thus, stakeholders (such as policy makers) should take great care to preempt any ramifications for the hSC whenever they introduce new incentive mechanisms, as well as to evaluate, assess, and amend existing mechanisms.

4. The redesign of healthcare supply chains using new care models

Numerous care models have recently been introduced in various national and regional healthcare systems. In this section, we discuss three notable trends that shift care from treatment to prevention, from hospitals and clinics to primary care and patients' homes, and from broad treatment approaches to personalized/precision medicine. These trends build on all three dimensions of hSCM. They reinforce the customer focus as they attempt to maximize patients' overall health and quality of life, and enhance treatment outcomes. In combination with new health innovations such as digital health, AI, and blockchain (Table 4), these changes are reinventing care delivery through a systems approach by becoming key drivers of integrated care models, such as ACOs and value-based healthcare. Finally, through recently introduced reimbursement schemes (Table 3), these new trends aim to align the shifting goals and priorities of stakeholders.

4.1. Shifting the focus of care from treatment to prevention

Globally, one in three adults lives with more than one chronic condition (Hajat and Stein 2018), such as arthritis, diabetes, and mental illness. Chronic diseases deteriorate individual health, reduce life expectancy, and degrade quality of life. Care for the chronically ill is also costly; in the US, chronic disease accounts for nearly 75% of aggregate healthcare spending (Raghupathi and Raghupathi 2018). Prevention is gaining traction as an essential measure in tackling this burden.

Bauer et al. (2014) describe the strategies employed by the Centers for Disease Control and Prevention (CDC) to reduce the preventable burden of chronic disease: (1) epidemiology and surveillance to monitor trends and inform programs; (2) environmental approaches that promote health and support healthy behaviors (e.g., zoning regulations that encourage walking and cycling); (3) health system interventions to improve the effective use of clinical and other preventive services (e.g., improvements in controlling high blood pressure); and (4) community resources linked to clinical services that sustain improved management of chronic conditions.

Table 4 New healthcare technologies

Technology	Role	Benefits	Challenges	Opportunities
EHRs	Decreased reliance on paper medical records	Availability of timely, more accurate, complete, and legible documentation that can be shared with patients and other clinicians[i]	Interoperability	- Standardization of records - Customization accounting for the needs of individual providers
Telemedicine	Remote delivery of healthcare services	- Increased access to underserved communities by overcoming geographical barriers[ii] - Affordability - Improved health outcomes and quality[iii]	- Reliability - Resistance to change	Properly devised incentive mechanisms and reimbursement to bolster uptake
Wearable technology	Measurement and collection of data on users' wellness, fitness, and health information	- More emphasis on self-care by enabling users to track and monitor health data - Support for healthier behavior (e.g., getting more sleep and exercise) - Engaging patients in proactively seeking medical attention based on indications from wearables - Reduced burden of monitoring[iv] - Remote monitoring by physicians to facilitate prediction and prevention of certain health conditions (e.g., hypertension)	Data security	Data generation for quantitative analysis in order to improve care and data-driven decision-making, as well as, to assist in medical advancements
Personalized medicine	Clinical interventions tailored to individual patient characteristics	More successful outcomes through an analysis of which treatments will be most effective for which patients by factoring in individuals' differences in genes, demographics, and lifestyle	- Complexity[v] - Cost (typically more expensive than conventional approaches)	- Processes to best gather, interpret, and utilize data - Value[vi] assessment of personalized medicine to drive widespread adoption
Online healthcare platforms	Forming communities of patients, professionals, or both, using information and communication technologies such as blogs, chats, and forums	- Online knowledge transfer within and among professional networks (in comparison to traditional in-person encounters such as medical conferences)[vii] - Communication across professionals caring for complex patients - Improved patient-centered care via information sharing - More knowledgeable, supported, and empowered patients, resulting in more active self-management[viii]	Accuracy of information	Improved digital health literacy for individuals, with a particular focus on assessment of information
Blockchain systems	Secure storage and distribution of pharmaceutical, clinical, patient, and billing data in distributed networks	- Better health data management allowing all pertinent providers to have access to a patient's complete medical history[ix] - Drug development based on patient data[x] - Mitigation of prescription fraud[xi], drug counterfeiting[xii], and claims and billing fraud[xiii] - Elimination of intermediaries for health information exchanges, improving SC efficiency	Lack of infrastructure and competency	Regulatory and academic support

[i] The Office of the National Coordinator for Health Information Technology (2019)

[ii] World Health Organization (2009)

[iii] For instance, the tele-ICU acts as a "second set of eyes" and allows for additional clinical support and surveillance with the intent of improving patient safety and outcomes (Goran 2010).

[iv] For example, the insertion of a continuous glucose monitor allows for glucose monitoring throughout the day and night, while reducing the number of finger-pricked checks needed.

[v] Expansion in decision algorithms and treatment options from increasing availability of information (Jameson and Longo 2015a)

[vi] Personalized medicine can also decrease costs; e.g., preventing hospitalizations resulting from adverse drug reactions.

[vii] Readers are referred to van der Eijk et al. (2013) for a discussion on the four benefits of OHCs.

[viii] Wicks et al. (2011) show respondents, part of an epilepsy OHC, reported benefits such as forming relationships with other patients, gaining a better understanding seizures and treatments.

[ix] Readers are referred to Mettler (2016) and Marr (2017). See also Gem Health Network and MedRec for two such initiatives.

[x] See HealthBank for an example of a data-trading platform.

[xi], [xii], [xiii] Readers are referred to Engelhardt (2017), del Castillo (2016), and Marr (2017), respectively.

Several remarks are in order concerning these strategies. First, in addition to facilitating epidemiology and public health surveillance, data emerging from new health information technologies can be combined with advanced analytical methodologies such as econometrics and machine learning algorithms to assess the effectiveness and efficiency of newly established care and prevention models (see Perreault et al. (2010) and Moore et al. (2010)).

Second, a vast array of organizations are naturally involved in the design and delivery of various laws, policies and environmental approaches, including governments, employers, the private and voluntary sectors, and the media, as well as health, community, and social care entities (Lovell and Bibby 2018, Alderwick et al. 2015). Supply chain thinking suggests that, to further the goal of reducing the occurrence of chronic disease, these entities need to engage in stronger collaboration (i.e., a systems approach) driven by the overarching goal of enhancing prevention (i.e., a strategic orientation). As such, process redesign may enable improvements in care delivery. For example, Thompson et al. (2018) introduce the notion of "temporal displacement of care" and show that the use of information technology and analytics can lead to value creation in the hSC (better clinical outcomes and lower cost) when early, preventive services displace later-stage, high-cost interventions for the chronically ill.

Lastly, relating to CDC strategies (3) and (4), it has been argued that since general practitioners have accumulated knowledge of, and established rapport with individual patients and their families, general practice is in a unique position to play a proactive role in emphasizing prevention and improving population health (Thorlby (2013); see, for example, the Gesundes Kinzigtal model in Germany (Hildebrandt et al. 2010)). This suggests that a shift from treatment to prevention may need to coincide with a shift from secondary care (e.g., hospitals and clinics) to primary care (e.g., general practices) and care at home, which we discuss in the following section.

4.2. Shifting care closer to patients' homes

The second emerging trend in handling the prevalence of chronic disease is that the site of care is moving closer to patients' homes. Aside from potential cost advantages, this shift may offer improvements in the quality of care and the patient experience. One model that incorporates such change is the primary and acute care system (PACS), which was recently proposed by the NHS and which aims to move care out of the hospital through the formation of a single entity responsible for delivering the full range of primary, community, mental health, and hospital services. Built on principles of patient-centricity and integrated care, PACS is a noteworthy example of supply chain thinking in healthcare. In terms of how such integrated care models should be developed, Collins (2016) points to the importance of defining how the proposed model will be governed, the organizational form it will take, and how risks will be shared.

The localization of care may also be aided by technologies such as telemedicine, wearable devices that facilitate remote monitoring, and online platforms that allow some types of care to take place in patients' homes. Examples of organizations adopting such technologies include Onduo, a Verily-Sanofi joint venture providing diabetes patients with tools, coaching, and clinical support through a virtual care program; Roche's mySugr, which enables patient-centered digital diabetes management; and 111.inc, a Chinese platform that provides online consultations and e-prescription services through a network of medical professionals, as well as online pharmacy services for retail and business customers. Online health communities (OHCs), such as PatientsLikeMe, bring together groups of patients, professionals, or a mixture of both using communication technologies like blogs, chats, and forums. Accessible primary care (e.g., general practitioners and pharmacists) and after-hours services (e.g., NHS 111, an online/telephone service for urgent medical problems), can serve as alternatives to hospitalization. Organizational processes can also enable self-care. An internationally-recognized community care model, the Buurtzorg model of care, employs teams of nurses who are responsible for a few dozen patients in a particular area, promoting continuity of care. Nurses act as health coaches by training patients and their families in self-care and, by emphasizing preventive health measures (Brindle 2017).

In addition to a rising chronic disease burden, the growing and aging population pose a major challenge. Worldwide, the population aged 65 and over is increasing faster than any other age group (United Nations 2019). Typically, elderly patients have a number of inter-related chronic health and social issues. Although a shift to prevention and to providing care closer to home may make significant strides in addressing these issues,"medicines and care pathways have been designed based on evidence from large populations and, whilst clinicians do their best to tailor this to the needs of individuals, we still have a broad spectrum approach to treatment" (Roche 2018). The clash between this broad spectrum approach and complex patient conditions points to the necessity of considering patients' unique characteristics and needs, which leads us to personalized medicine.

4.3. Shifting from broad treatment to personalized/precision medicine

Personalized medicine is a broad term that refers to a departure from one-size-fits-all, population-based strategies to tailored interventions centered on individuals. The narrower term precision medicine is typically used to refer to treatments targeted to the needs of individual patients on the basis of "-omics" (e.g., genomics, proteomics) data (Ayer and Chen 2018). Personalized medicine promises more successful outcomes through determining which treatments will be most effective for which patients by factoring in individual differences in genes, demographics, and lifestyle (Jameson and Longo 2015a,b) as well as through improved patient assessment, diagnosis, and prognosis (Hamburg and Collin 2010). Moreover, with the use of diagnostic technologies, personalized medicine

can play a role in prevention by detecting ill health before symptoms appear, paving the way for preventive interventions that are similarly personalized.

One supply chain strategy that may grow in importance for healthcare is mass customization[4], which combines flexibility (allowing firms to provide customers with individualized, custom-made products and services) with low unit costs achieved through mass production (Minvielle 2018). Mass customization will allow healthcare organizations to respond to both the growing number of chronically ill patients who require a sophisticated combination of long term care and to patients, who are becoming more vocal in expressing their demands, preferences, and expectations. Such a strategy would facilitate increased attention to patient-centric care (that seeks to treat the patient rather than the disease) and the growing focus on improving the quality of care and patient experience. Mass customization can lead to quality improvement by enhancing outcomes and patient satisfaction (e.g., through tailoring clinical decision making to individuals' needs). Furthermore, identification of the most appropriate treatment, in addition to personalized follow-up and better patient adherence, can lead to cost savings from unnecessary treatments/actions.

Another fundamental aspect of customized care, one which has also been facilitated by advances in technology, is categorizing patients. Healthcare organizations and researchers can now segment large patient populations into smaller groups based on characteristics such as genetic profile (Harvey 2016). Moreover, Volpp et al. (2018) note that defining behavioral phenotypes and expressed patterns of behaviors (from clinical data as well as everyday monitoring via wearable devices and social media footprints) can give providers a systematic approach to identify which patients to target for which interventions. The authors suggest that such improved patient targeting can help the healthcare sector derive more value from currently available treatments instead of spending more to develop new medical technologies. For instance, behavioral, social and environmental data can be used to determine approaches that facilitate better adherence to existing efficacious treatments.

AI is another technology that is being used to successfully apply and advance personalized medicine, with the NHS being one case in point. The UK government has announced plans to allocate £250 million for a national AI lab, in addition to offering five million people a free personalized health report based on their DNA (Neville 2019). For more information on the application of AI, we refer readers to a recent Roche report outlining a long-term framework of how advances in digital technologies, genomic profiling and machine learning can revolutionize personalized healthcare,

[4] Mass customization has been employed in various industries including auto manufacturing (customers can choose vehicle attributes such as the engine size and interior), apparel (products come in various patterns and colors), and the PC industry (the most well-known example being Dell, where customers can select the desired processor, storage, etc.). Minvielle et al. (2014) develop a framework for managing customization in healthcare. On a broad level, the key factors of the framework relate to categorizing patients, the technical and human factors in the service delivery (i.e., ensuring the necessary IT, developing provider service skills, and improving patient self-management), and assessment (i.e., whether the service met patients' needs and was financially sustainable).

from the patient journey to wider population health (Roche 2018); to Roden et al. (2008), who develop a de-identified DNA biobank linked to an electronic medical record system with the intent of discovering genotype-phenotype relationships that can enable personalized medicine; and to Yu et al. (2016), who use machine learning methods to predict the prognosis of lung cancer patients, thereby advancing precision oncology.

5. Research opportunities and concluding remarks

It is our hope that this paper provides readers with a better understanding and appreciation of the importance of hSCM, which we broadly define as the management of people, processes, information, and finances to deliver medical products and services to consumers. As described in Section 2, a number of factors, including information asymmetries, ambiguous and disparate valuations of healthcare, lack of accurate costing information, perverse incentives resulting from payment structures, and siloed services, make the adoption of hSCM an onerous task. Although healthcare systems can make strides in improving their operations through applying the various lessons learned over decades of SCM and SC thinking, hSCM will only yield significant value if tools, strategies, and approaches are tailored or created to address the challenges and opportunities unique to healthcare.

Integration is key for healthcare moving forward, both within the healthcare sector and across social and community care and public health. These sectors impact one another; for example, the healthcare sector faces delayed transfers of care due to inadequate community care, individuals with unmet social needs may end up relying more heavily on primary and secondary care, and all sectors exert "gravitational pull" on each other's workforce. Models that address these issues through integration and collaboration should be a topic of interest for practitioners and researchers, who may ask questions like: What is smart integration? From a systems perspective, which providers should provide which services, and when? Consequently, how should their processes be aligned? How can information technologies (such as the flagging systems used in Toronto's Mount Sinai Hospital, which allow primary care, home care, emergency, and inpatient care providers to effectively communicate geriatrics patients' needs (Mount Sinai Hospital 2011)) improve inter-professional, collaborative care for complex patients? Should providers be incentivized and rewarded for collaboration? If so, how should the risks and benefits be shared? At a higher level, how should primary, secondary, tertiary, community, and social care organizations be reorganized, individually and collectively? And in addition to engaging with these questions, any potential healthcare model needs to incorporate the impact of behavioral aspects such as patient engagement and provider receptiveness of patient preferences on the clinical, operational, and financial dimensions of care.

One key point we can take away from this overview of SC thinking in healthcare is that a better understanding of the value of preventive models closer to home is essential for healthcare delivery.

More evidence quantifying the spillover and longitudinal effects of public health initiatives is needed to address the investment challenge for prevention discussed in discussed in Section 2.1. For insights into this new area of research, we refer the reader to Marshall et al. (2018) for a description of The Social and Economic Value of Health research program funded by the Health Foundation, which will examine the complex, multidirectional relationship between individual health and socioeconomic factors using innovative statistical methods and varied data sources (notably, genetic data). In addition, the cost impacts, workforce consequences, and the social impacts on patients and carers resulting from the reorganization of care delivery should be studied. Such redesign also raises other questions. How can we use online, reliable resources and telemedicine to enable easy access to care? How can we carefully integrate these resources with more traditional care delivery methods while avoiding unintended consequences? (For instance, Bavafa et al. (2018) show that "e-visits" trigger more primary care office visits, which come at the expense of fewer new patients accepted by physicians.) How can we design incentive mechanisms and payments (such as the Gesundes Kinzigtal model) that encourage early prevention rather than remaining passive until treatment is necessary? Such shifts in care require identifying the susceptible patients early on; therefore, how can we use data and predictive modeling as an integral part of the design of care delivery models?

The proliferation of EHRs, health technologies, and online healthcare platforms have generated large amounts of data. The surge in data availability, in conjunction with growing computer power, has allowed healthcare analytics tools, such as AI and machine learning, to play an expanding role in the advancement of healthcare. For example, machine learning is now used to inform diagnosis (Miotto et al. 2018), make predictions (Finlay 2018), develop prescriptive treatment algorithms (Champagne et al. 2018, Jameson and Longo 2015a), reduce readmissions (Liu et al. 2018, Queenan et al. 2019), and objectively evaluate physicians (Foster et al. 2018) (see Guha and Kumar (2018) for an overview of how big data analytics has been applied in the healthcare domain and for a roadmap of future research). Moreover, health information exchanges, facilitated by technologies like blockchain (Babich and Hilary 2019), may lead to more efficient hSCs by minimizing transaction costs and wastes (e.g., fraud, counterfeits).

There are, however, concerns regarding the accuracy and security of data, as well as the feasibility, cost, interoperability, and operational complexity of new ITs. Complexity can also hinder the adoption of various trends in healthcare, such as personalized/precision medicine. Moreover, as the availability of data and healthcare analytics capabilities both increase, hSC members (such as clinicians) are faced with an expansion in decision algorithms (e.g., treatment options) (Jameson and Longo 2015a), which amplifies the uncertainty challenge facing healthcare. To manage this complexity, stakeholders will need to establish best practices for gathering, interpreting, and utilizing data. Improving data interpretability, in particular, can facilitate the development of effective

strategies for managing uncertainty. Therefore, we encourage researchers to consider questions such as: How can stakeholders make use of data to advance health; which methodologies, tools, and data should be applied, and to which contexts? Which stakeholders, and what actions, play a role in ensuring data protection? (e.g., Should patients own and control their own health data and records?) How can data be optimally integrated across systems and stakeholders in the hSC and which processes need to be put in place to establish this? How can we best enable adoption of new technologies and approaches and overcome resistance to change? Accordingly, how can the value that new technologies create for hSCs be determined, measured, and shared?

In this paper, we have taken a high-level view to discuss how supply chain thinking (Figure 1) provides an opportunity for healthcare to understand, evaluate, and improve its complicated and often inefficient ecosystem. A more focused view of healthcare supply chains may lead to opportunities to adapt or develop supply chain frameworks from other domains for the healthcare context. For example, frameworks such as the supply chain operations references (SCOR) model may be adapted to concentrate on the evaluation of particular hSCs, such as pharmaceutical supply chains. Additionally, in Tables 3 and 4, we present many challenges and opportunities for payment mechanisms and healthcare technologies, respectively, and in an online addendum we offer a categorization of hSCs and a synopsis of research for each hSC subcategory. The challenges, opportunities, and references we provide may spur potential ideas for future research.

The complexities and inefficiencies found in hSCs put hSCM in a leading position to improve the provision of healthcare. It is only when an improvement initiative concurrently satisfies the clinical, operational, and financial dimensions, that we expect to see hSCM offer considerable value. Meeting this requirement may prove to be a rewarding (but by no means easy) feat, making hSCM a promising field for researchers, practitioners, and policymakers. We believe that the complexity in managing hSCs offers opportunities for important and impactful research avenues involving key SC strategies such as coordination and integration (e.g., new care models), mass customization (e.g., the rise in precision medicine), and incentives (e.g., emerging reimbursement schemes).

"There is a change in the air," Roy Lilley wrote on his popular healthcare blog nhsManagers.net on September 10, 2019. He offers a slightly cautious take on how SCM can be used in healthcare, emphasizing the extraordinarily complex and challenging environment of care delivery. We believe that the hSCM framework described in this paper can contribute to the future success of healthcare delivery. More importantly, new research in line with supply chain thinking will advance healthcare management and expose research opportunities, which might not only help address inefficiencies we observe in healthcare delivery but also provide insights relevant to traditional supply chains.

6. Epilogue: COVID-19 pandemic and healthcare supply chains

As we were wrapping up this paper, global SCs[5], including healthcare SCs, have been thrown into disarray and scrutiny by an infectious respiratory disease called COVID-19. The disease, which is believed to have started in Wuhan (China) in November 2019, has quickly spread to other parts of the world and was declared a pandemic by the World Health Organization on March 11, 2020. Countries around the world have responded to the disease with varying degrees of actions, ranging from social distancing to quarantines and lockdowns. As of April 25, less than six months after the first case was confirmed, more than 2.9 million cases have been reported across the world, with over 202,500 resulting in death (https://www.worldometers.info/coronavirus/). There are still a lot of unknowns about the origin, progression, infectivity, and treatment of the disease, as well as what the next 12 to 18 months will bring. Vaccinations against the disease are currently under development but none are yet approved, and it may take many months for a vaccine to be rolled out to market.

In spite of earlier epidemics, such as Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS) and H1N1 influenza, as well as various calls over the years regarding the possibility and the crippling impact of such a future pandemic, global hSCs were caught underprepared by the COVID-19 pandemic. COVID-19 created a surge demand in medical SCs, increasing the need for infrastructure (e.g., hospital beds, ICU beds, and ventilators), workforce (e.g., doctors, nurses and carers), and supplies (e.g., oxygen). National and regional health systems are competing for limited resources such as face masks, medications, personal protective equipment (PPE), medical equipment, and test kits. On the supply side, global SCs are experiencing difficulties in the production and distribution of such items, with delivery times growing longer (Bloomberg 2020). Despite some countries relaxing their restrictions, production facilities are not working at full capacity. Transportation disruptions complicate the delivery of products across regions and countries. Worse still, competition for logistics is exacerbated by many people now relying on online shopping due to movement restrictions. Shortages are further complicated by national and international regulations on PPE and test kits. For instance, many suppliers and buyers are

[5] The occurrence of global SC disruptions and failures is not new. For example, the 2011 Tohoku earthquake and the tsunami that followed disrupted semiconductor, high-technology, and automotive SCs, in some cases leading to plant closures of up to six months. Geographical concentration of SCs made it challenging for many semiconductor companies to cope with the disruption (Schorpp et al. 2020). When Boeing launched the production of its 787 Dreamliner in 2007, the company promised to do it in record time. However, Boeing's issues in managing their SC led to a launch delayed by a number of years (Tang et al. 2009). In 1995, Apple faced high customer interest for its new Power Macs, but could not satisfy demand due to limited inventory, which ultimately resulted in an order backlog reaching $1 billion at one point. As a result of deploying the incorrect SC strategy, Apple lost its market position (Digest 2006). Healthcare executives should therefore be aware of such deficiencies in SCM, which provide significant learning opportunities to curtail the potential of falling into similar pitfalls.

waiting for national (such as FDA) and international (such as CE) certification for newly developed products so that they may be able to produce and distribute them.

To create much needed capacity, governments and healthcare organizations have been learning from each other to develop and promote prevention strategies which "flatten the curve" - that is, reduce the speed of disease spread (Cyranoski 2020, Mattiuzzi and Lippi 2020) while researchers have sprung into action to develop models to support intervention decisions (Kaplan 2020, Imperial College London 2020). In the UK, the NHS quickly reacted to the increase and anticipated increase in demand by undertaking multiple measures, such as canceling non-urgent surgeries and discharging all hospital inpatients who are medically fit to leave (NHS England and NHS Improvement 2020). The government called out to car manufacturers to produce at least 20,000 ventilators. With ventilators, regular patient beds can be repurposed so that patients can receive respiratory support outside of ICUs (e.g., hospital wards or even nursing homes). In order to increase the capacity of medical staff and better control for the potential workforce reduction due to COVID-19 infections (especially given the lack of sufficient and quality PPE), recently retired professionals were called back to work and some final year medical students have been allowed early registration so that they can join the hospital workforce. Strategies for the sourcing of PPE for health personnel warrants mention. A call by the Journal of the American Medical Association for ideas addressing the impending PPE shortage received over 100,000 views and generated more than 250 comments. Livingston et al. (2020) summarize the proposed strategies which include the reuse of PPE, importing PPE from international suppliers, reclaiming PPE from other industries, repurposing items into PPE, rationing the allocation via regional coordination, reducing patient contact through various measures, canceling non-essential services which require PPE, among many others.

Despite these reactive actions, there were also several missteps in the early phases of the pandemic. The number of infections and deaths in many countries could have been scaled down through appropriate interventions such as broad testing of symptomatic and asymptomatic populations, better contact tracing and isolation of susceptible patients, earlier social distancing and lockdown measures, protecting health professionals through access to PPE, increased coordination between healthcare delivery, public health, community care and social care; and by coordinating and commencing planning and procurement activities much earlier. These steps would have shifted the focus from treatment to prevention, and would have more effectively flattened the curve. In a sense, hSCs suffered from a common ailment in traditional SCs, where managers are more successful in their reactive planning rather than their proactive planning. Careful planning reduces the need for dire reactive actions. For example, measures such as calling retired healthcare workers back to the workforce have been met with both praise and some criticism. With proper planning, the course of

action would have been more effective if returning workers were ensured adequate PPE. The need for former workers could have been curtailed had there been proper and timely workforce planning.

Yet, as is the case with any major disruption, COVID-19 has created opportunities for innovation in hSCs and has started to advance the adoption of new care models discussed in Section 4. Given the difficulty of controlling the disease without effective treatments and a vaccine, pharmaceutical and biotech companies have ramped up development efforts. Universities and research labs are using technologies, such as 3D-printing and AI, to help produce supplies and assist in triage and supply allocation decisions, while companies have used users' location data to shed light on responses to policies. The pandemic is triggering and accelerating the implementation of telemedicine, which not only brings treatment and care closer to patients' homes, but also increases service efficiency by pooling remote resources. Moreover, telemedicine safeguards patients and medical staff from infection. In the UK, over 80% of primary care patients are now being managed through digital care. Researchers have already started thinking about how AI can be used to measure "an individual's clinical risk of suffering severe outcomes" to guide personalized care and resource allocation, if not for COVID-19, for future pandemics (Evgeniou et al. 2020).

The COVID-19 pandemic has reminded us the importance of being adaptive in our approach in the application of supply chain thinking and provides many opportunities for the future of hSCM. As health systems around the world emerge from the pandemic, hSCs will need to consider the follow-on consequences such as the toll on mental health (in particular that of frontline workers) and effects of cancellations to non-essential services. The COVID-19 crisis calls for the formulation of long term, contingency plans and supply chain thinking in hSCs.

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