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Blurry vision: Supply chain visibility for personal protective equipment during COVID-19

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Abstract

We explore supply chain visibility challenges in the context of our contemporary COVID pandemic, and offer insights, models and potential solutions to remove barriers to clear supply chain visibility. In this paper, we describe how visibility and velocity are the two key attributes that are required to enabling critical decision-making accuracy which will in turn increase the ability of local, state and federal healthcare and public health decision-makers to respond to shifts in the U.S. system. We describe the problems in current systems due to the lack of visibility of material in global supply chains, which in turn leads to problems such as the lack of PPE that occurred during the COVID pandemic. We conclude with recommendations on how to render inventory more visible for the future.

1. You can’t manage what you can’t see

In any crisis decision speed and accuracy can be the difference between recovering versus relapse and repeat (Handfield and Linton, 2017). This is especially important when faced with a fast-moving situation when events are changing hourly and rapid updates must be shared quickly between team members. In such cases, real-time visibility to field events based on eyewitness encounters are essential for battlefield tactics, as poignantly described by General Stanley McChrystal in his book “Team of Teams”. So how can policy-makers make sound decisions without sound information in the face of a crisis like the COVID pandemic? How can they gain sound information if their vision is blurred?

Readers are likely keenly aware of the term “Personal Protective Equipment” or PPE, especially as it applies to the fight against COVID-19. Healthcare and supply chain personnel and systems have been struggling under the strain of insufficient available stock since the pandemic began. While everyone was aware of the shortage during the early months of the pandemic, not many people are aware that this shortage was never really solved, and that shortages are worse than ever in the summer of 2020. You may also be wondering how there can be so many disparate story lines regarding PPE coming from federal and local government administrations, agencies, hospitals and front-line medical workers, who really have no visibility to where healthcare supplies are in the supply chain.

This issue is pervasive to all countries, not just the United States, and has begun to produce nationalistic policies to restrict exports when questions arise as to how much inventory resides in stockpiles. Examples include the EU’s move to restrict exports of the AstraZeneca vaccine, or China’s restrictions on exports of healthcare goods required to support healthcare workers in the US. These are desperate measures taken by governments who are pressured by citizens, demanding answers as to the status of critical healthcare supplies in the supply chain. They ignore the bigger issue facing governments in the face of a crisis like COVID: the lack of a global stewardship for combating the virus, which is a global crisis that requires a global healthcare policy approach. We explore one of the root causes of this problem, which is that healthcare systems in general have exceedingly poor data tracking and inventory management tracking capabilities (Handfield et al., 2019; Schneller and Smeltzer, 2006)). Many healthcare procurement departments buy their supplies

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through third party distributors, who are often selected based on the lowest cost. They also maintain as little inventory as possible, relying on just-in-time weekly deliveries from these distributors. Consequentially, many of these distributors rely on suppliers in low cost countries like China (masks and gowns), Vietnam and Indonesia (gloves), and other Asian countries (ventilators). When a global crisis shut down exports from these countries in March 2020, healthcare systems were brought to their knees.

2. The protective personal equipment (PPE) crisis

The authors became deeply involved in the US federal supply chain task force efforts that occurred early in the pandemic, and observed that the supply of PPE necessary to combat COVID for the near, intermediate and long haul was woefully insufficient. The protective personal equipment most in demand includes face protection (goggles, shields, N95 respirators, surgical masks etc.), body protection (gowns, coveralls, aprons etc.) and hand protection (gloves and sanitizer). Despite our early insights into this issue and our early warnings, we still have not solved the issue. Reporting by Andrew Jacobs of the New York Times shows that nursing home and professional medical associations like the Good Samaritan Society, American Medical Association and National Nurses United report medical practitioners at all levels feeling chronic levels of PPE scarcity. Many of these agencies report having to reuse disposable masks and gloves, and with calls for reporting of shortages to be diverted to the White House, the likelihood of further shortages is becoming potentially hidden and elevated. Practitioners admit that, though the FDA has provided emergency use authorization for ultraviolet PPE decontamination, using decontamination procedures on disposable items is not ideal. Dr. Susan Bailey of the American Medical Association is quoted in Jacobs’ article pointing to the frustration in the government’s early focus on ventilators when there was, and is, an ongoing need for PPE. Again, our team pointed this out early in the pandemic but there seemed to be a momentum around certain items that was not easy to shift.

On July 8th, 2020, a consortium of medical agencies sent a letter to the U.S. Vice President Mike Pence requesting the names of the individuals responsible for overseeing supply chain for testing and PPE as well as visibility into the supply allocation at the state level. These authors emphasized that:

Since our members were first able to start testing for COVID-19 they have experienced significant difficulty acquiring the supplies—test kits, nasopharyngeal and mid-turbinate swabs, transport media, and personal protective equipment (PPE)—needed to perform COVID-19 testing. Without proper testing supplies and PPE, our members continue to struggle to meet the demand for COVID-19 testing and help track its spread across our communities. At times, our members have even received faulty or unusable equipment, including swabs from the Strategic National Stockpile, which has further impeded our work to combat this pandemic.

This letter was signed by the American Association of Bioanalysts, the American Association for Clinical Chemistry, the American Medical Technologists, the American Society for Microbiology, the Association of Public Health Laboratories, the Association for Molecular Pathology, the College of American Pathologists and the National Independent Laboratory Association.

How is it that five months into the pandemic medical personnel still did not have a good handle on PPE in the United States and around the world? How can our government healthcare agencies not know in an instant what is needed and what is on hand? What contributes to this blindness in the system that links raw materials to manufacturers, distributors to private corporations and public agencies, medical logistics systems to the medical professional in need?

To answer these questions, we turned to the natural sciences to inform a model that can help explain the nature of this “blurry vision”, (a metaphor that refers to our inability to see what is happening in our healthcare supply chain). We offer a metaphor and associated nomenclatures from which to view and describe the various types of supply chain stock in the healthcare supply chain (including not just PPE, but others as well). Inventory resides in ranges that exist in either the visible spectrum of the supply chain, or hidden within that spectrum for various reasons discussed below. We offer this model in the hopes that it may offer insight into how and why we have so many disparate stories surrounding the availability of PPE during this pandemic.

3. A word on methodology

As noted earlier, the authors became almost involuntarily engaged on the front lines of the COVID PPE shortage in March 2020, and remained engaged through June of 2020. We were asked to serve in a variety of roles within the Department of Defense Joint Acquisition Task Force, providing market intelligence and analysis for supply of PPE, N95 masks, gowns and gloves, ventilators, testing kits, and other key materials. Our engagement led us to have hundreds of conversations with individuals in different US federal agencies (DoD, FEMA, DHS, Strategic National Stockpile, DLA, GSA), state agencies (NASPO, GRA), private sector companies (manufacturers of pharmaceuticals, textiles, medical devices, distributors), universities and hospitals (UNC, WakeMed, National Hospital Association), as well as other subject matter experts. Collectively our team had over a hundred years of experience in working in healthcare and acquisition, and relied on and brought to bear our industry knowledge and current experiences to develop insights into what happened, what went wrong, and how to fix it.

This type of research is best described as “engaged scholarship” (Touboulic et al., 2020), which seeks to cross the chasm between theory and practice. A critical requirement in this case is reflexivity, which requires consider of a multiplicity of perspectives as well as past and future actions and may often create some tension (Touboulic et al., 2020). As consultants to the Joint Acquisition Task Force, we were called into meetings to help provide an objective view of what was happening, but also were called on to share our supply chain expertise, as many of the members of these committees were not trained in acquisition or logistics. We were also able to observe how small private sector companies interacted with a broad initiative focused on locating PPE (Harland et al., 2019), and witnessed firsthand how ineffective large federal agencies were at conducting market intelligence and acquisition without a reliance on standard bidding procedures. In this situation, the government failed to recognize that PPE was simply impossible to find, since the entire world was seeking to find it, and it was a supplier’s market. The ad hoc methods that arose in this case, as well as the lack of visibility to existing supplies, created a treacherous situation for healthcare workers that was never quite resolved in 2020.

4. The claims and contradictions

In 2020, the US federal government and the President largely dismissed claims of a PPE shortage, despite the evidence to the contrary. On April 26, President Trump deemed PPE shortages “fake news”. On May 4, he publicly disagreed with the president of the American Association

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3 https://www.nytimes.com/2020/07/08/health/coronavirus-masks-ppe.doc.html.

4 https://www.politico.com/news/2020/04/26/trump-ppe-fake-news.s-207523,
of Nurse Practitioners, who in a visit to the White House noted that PPE had sporadic supply, stating “I have heard we have tremendous supply to almost all places, tremendous supply.” On July 20, the American Federal of Teachers ran a public advertisement in response to President Trump’s press conference comment “Something’s going on. Where are the masks going? Are they going out the back door?” In the ad, several different nurses respond, with one saying, “President Trump suggested that nurses like me are possibly stealing masks.” Some members of Congress have finally admitted that the PPE situation was dire throughout the pandemic. At a virtual Congressional hearing in mid-2020, Illinois Gov. JB Pritzker criticized the federal government for leaving it up to states to compete for personal protective equipment, or PPE, saying, “in the midst of a global pandemic, states were forced to play some sort of sick ‘Hunger Games’ game show to save the lives of our people.”

Putting aside the rhetorical comments from political wings, there exists significant evidence to suggest that the PPE shortage was real, and that acute care facilities, continue to be very dangerous places to be for healthcare workers due to shortages. Consider the following summary published by the National Healthcare Safety Network (NHSN) recorded on June 10, 2020. (Some may not know that the NHSN is part of the Centers for Disease Control (CDC), and is the nation’s most widely used healthcare-associated infection tracking system for utilization of healthcare facilities). NHSN provides facilities, states, regions, and the nation with data needed to identify problem areas, measure progress of prevention efforts, and ultimately eliminate healthcare-associated infections.

Here is what the statistics shows:

- Acute-care national estimate of number of inpatients with COVID-19: 75,257 (this may be at a plateau over the past week or so)
- Acute-care, national crude percentages:
  - 8% of inpatients have COVID-19 (crude percent) (down from about 22% at peak)
  - 15% of COVID-19 inpatients are on a ventilator (crude percent) (had been quite consistent at about 18% but seems to be dropping over the past 1–2 weeks)
  - 18% of in-use ventilators are occupied by COVID-19 patients (crude percent) (down from peak of 45% in early April)
  - 18% of facilities have more than 80% of their ICU beds filled (crude percent) (has been consistent at 17–18% throughout)
  - 40% reporting facilities are reporting not able to obtain N95 masks (a figure that has not changed significantly over the past few weeks)

The PPE shortages were also pervasive in every region of the world, including South America, Europe, the Middle East, and Asia. Several characteristics of the PPE supply chain were the root cause of these shortages. First, no country was prepared for the closing of international boarders during COVID, which immediately shut down international shipments. Since more than 80% of PPE is produced in China, this caused significant shortfalls globally. A second reason is that there are few international standards when it comes to critical healthcare supplies like PPE, ventilators, etc. Different government agencies are responsible for setting such standards, and there is often disagreement (even within Europe, standards are exceedingly difficult to come by). This renders the ability to track supplies globally difficult, and prevents transparency in sharing inventory levels across global healthcare agencies.

Despite PPE shortages, government agencies were slow to respond, and were fearful of admitting indeed that a problem existed. For instance, FEMA guidelines advocated that hospitals reach out to their state emergency office, and before reaching out to FEMA, explore alternatives for re-using PPE, explore all use reduction strategies, and provide justification for the shortage and the timeline it is needed for. (State offices were typically unable to get masks either). In essence, this emergency response government resource is doing everything possible to avoid having to provide masks – because they don’t have any in stock (essentially). For weeks prior to April, nurses and other employees at Veterans Affairs hospitals have said they were working with inadequate protective gear. VA officials denied it. Finally on April 25, 2020, Richard Stone, executive in charge of the sprawling Veterans Health Administration, reluctantly admitted that he had been forced to move to “austerity” levels at some hospitals, and that the four week supply of masks was almost gone. A large survey at that time indicated that 47 institutions in Massachusetts, half had less than a week’s supply of N95 masks left, with another 23% having none at all. In California, of 120 institutions, 41% had a week or less left of N95 masks, and 12% had none left. In Florida, of 50 institutions, 40% had a week or less left of N95 masks, and 24% had none at all. In the UK, a scandal emerged over the government denying the opportunity to join a medical supplies consortium being run out of the EU, andstranding many hospital workers with shortages of PPE.

In effect, there is a significant disparity between the claims of government leaders about adequate PPE that do not reflect the truth “on the front lines”. This is mystifying – why would government healthcare agencies not admit there is a shortage of materials? Why would this be the case? Has this become a political issue, or is there a legitimate belief that there is enough PPE to go around in the minds of these government officials?

In this paper, we offer another perspective – which is based on the flawed nature of how information flows in the healthcare supply chain (Handfield et al., 2019). It may be that the level of visibility to inventory and to shortages in PPE is so disparate when viewed from the vantage of the government, vs. the vantage point of healthcare workers, that two different reports on current state of healthcare material shortages are emerging, and what to do about it.

Another important perspective is the nature of the demand for PPE. In this case, many different industries and countries all had a concurrent and massive sudden demand for PPE in 2020 and throughout 2021. In this case, what occurred were disparate, overlapping networks of supply demand, which put pressure on a limited and small set of manufacturers, all being asked to serve multiple supply chains. This set of circumstances was entirely different from the way that the SCM community has conceived traditional supply chains to be. Under normal circumstances, network governance occurs through well-defined, normalized channels. But this was something entirely different.

Network governance is defined as involving

“a select, persistent, and structured set of autonomous firms (as well as nonprofit agencies) engaged in creating products or services based on implicit and open-ended contracts to adapt to environmental

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5 https://www.forbes.com/sites/mattperez/2020/05/06/president-trump-disagrees-with-nurse-who-says-ppe-supplies-have-been-sporadic/#77301d862a75
6 https://www.nbcnews.com/politics/meet-the-press/blog/meet-the-press-blog-latest-news-analysis-data-driving-political-discussion-9888541/nr/cdr1183416
7 https://www.cdc.gov/nhsn/index.html
8 https://www.cdc.gov/nhsn/covid19/report-14day-change.html
9 https://www.fema.gov/news-release/2020/04/22/coronavirus-covid-19-pandemic-addressing-ppe-needs-non-healthcare-setting.
10 https://www.fema.gov/news-release/2020/04/22/coronavirus-covid-19-pandemic-addressing-ppe-needs-non-healthcare-setting.
11 https://www.washingtonpost.com/politics/va-health-chief-acknowledges-a-shortage-of-protective-gear-for-its-hospital-workers/2020/04/24/4c1bd5e-84bf-11ea-ae26-989cfce1c7_story.html.
12 https://time.com/5823983/coronavirus-ppe-shortage/.
13 https://www.theguardian.com/politics/2020/apr/22/uk-government-accused-of-cover-up-over-eu-scheme-to-buy-ppe.
contingencies and to coordinate and safeguard exchanges. These contracts are socially—not legally—binding (Jones et al., 1997, p. 914).

The general theory of network governance would contend that the demand uncertainties surrounding PPE and other COVID-19 supply issues should result in stronger network ties (Jones et al., 1997). However, since this environment also involves high supply uncertainty and multiple overlapping networks, the network governance that one would hope to see has not manifested, despite otherwise theoretically favorable conditions. This lack of governance is due in large part to the lack of structural embeddedness available at the start of the pandemic and that has not matured during the pandemic. This lack of embeddedness may be the result of competing interests and the massive size and complexity of the potential network in an environment of high supply uncertainties (Jones et al., 1997).

Without embeddedness, information cannot diffuse properly across network boundaries. In a moment of global contingency (i.e. pandemic) we needed strong leadership and agile strategies to increase structural embeddedness across a global network of entities that may see themselves as rivals but, in truth, be highly interdependent. But pandemics of this size pose significant challenges to the social mechanisms that traditionally resolve exchange issues and increase network governance. Restricted access, macro-cultures, collective sanctions and reputation are all conditions that can increase network governance exchange effectiveness. What we needed perhaps was a “host” to coordinate this potpourri of different governance mechanisms, (not so much a “hero” to save the day). What we observed was that in times of unexpected, global emergency there is little chance that restricted access and macro-culture coordination can be scaled to meet the need, and there is insufficient time to establish collective sanctions and reputational consequences to safeguard exchanges between all interested parties. Without a well-defined system of network governance and information exchange, entities develop varying vantage points of a global supply chain and there is less incentive to share information across boundaries. In the worst cases, there is an increased incentive to share misinformation to increase myopic benefits. We have personally witnessed this effect and offer a model that pulls from natural science to explain potential variations in supply chain insight when network governance is lacking and myopic strategies take over.

4.1. The vantage point

We recently introduced the concept of a new Supply Chain Commons post COVID-19 coupled with the concept of Orbital Market Intelligence (Biltgen and Ryan, 2016; Handfield et al., 2020). We proposed the need for a formalized interface between the public and private sectors, and developed a framework that builds a commons that relies on five components: 1) governance and direction under a centralized federal center to direct appropriate information sharing and activity between major government agencies; 2) technology for creation of visibility into material, 3) capabilities required to create category strategies, market intelligence, and risk management, 4) regulatory changes to establish new forms of federal contracting and 5) equity and ethical considerations to support decision making around the distribution of goods and services. Visibility is a key component of this new commons concept. To increase visibility, we need increased intelligence. For that we turn to our concept of Orbital Market Intelligence.

Supply chains and markets can be viewed as having informational attributes that can be viewed in the aggregate or at discrete, finite levels. We can ‘zoom in’ or ‘zoom out’ of a supply chain. They can also be viewed along a temporal dimensional attribute. We recently adapted the concept of Space-based Persistent Surveillance taken from Activity-based Intelligence Principles and Applications (Biltgen and Ryan, 2016). This concept recognizes that there are bodies of observation that can be so vast that a single point of view could never adequately surveil the entire surface and provide targeted details at the same time. In such cases, teams rely on a suite of sensors deployed at various orbital regimes in order to maximize intelligence collection and optimize the use of finite exploratory resources. In the case of space, that body of observation is the earth’s surface. In a global supply chain that body of observation is also the supply chain networks contained therein. But even with the high ground, persistence, rapid revisit rates and tracking, the supply chain’s visible spectrum can become murky or even invisible given the form of screening that takes place for various reasons. We explore the reasons these screenings occur in a detailed discussion of our PPE Supply Chain Spectrum model.

5. A supply chain spectrum for PPE

In the natural sciences the electromagnetic spectrum refers to the

![Fig. 1. Supply chain spectrum for ppe during COVID-19.](image-url)
Table 1
Types of hidden stock within the PPE supply chain spectrum.

| Hidden Stock Type | External Screen | Reason                                                                 | Potential root causes |
|-------------------|-----------------|----------------------------------------------------------------------|-----------------------|
| Ghost stock       | Political motivation | Re-election, reputation, optimistic speculations, career-building, public pressure to provide rapid updates | Bureaucrats measured on hospital availability |
| Safety stock       | Hoarding         | Risk mitigation, capitalist focus, poor demand forecasting capabilities              | Medical workers and administrators protecting their personal or organizational interests and safety |
| Blocked stock      | Distribution barriers | Tariffs, blockades, poor logistics, lack of global independence in the supply chain, prohibitive price gouging | Customs agents, brokers and other agents |
| Invisible stock    | Fog of war and/or poor tracking and monitoring systems. | Unprecedented global need, inadequate command and control, years of failure to invest in people, systems and processes to monitor supply chain risks | Buffers, lead time settings in MRP systems, outdated hospital systems, FEMA, DHS, Wholesalers motivated by profit, poor governance |

The entire range of light that exists, from radio waves to gamma rays. Most of this light is invisible to us and we must use other means of measuring or ‘seeing’ it. Similar to the all-to-common iceberg analogy in business, the visible portion of the light spectrum is only a sliver of what is all around us, present yet not perceived. Our Supply Chain Spectrum for PPE (Fig. 1) employs the spectrum as a useful metaphor for depicting the current level of visibility into healthcare materials within the supply chain. Scientific theories of the universe are constantly at odds with one another, and we continually look at ways to uncover the unknown or unseen. Supply chains are no different, except, in our case, the unknown and unseen can cause panic if they remain unexplored. Our model offers a first-of-its-kind ontology for researchers to consider for exploring supply chain visibility that is generalizable beyond COVID-19 supplies, healthcare or even global crises. However, it is one that is especially needed given our current state.

The model represents the differing degrees of visibility that supply chain managers, end users, policymakers, agencies and other stakeholders have into the available stock for any medical item(s), (in our case PPE). In a perfect world all stakeholders have full visibility into system-wide inventory supply levels that match precisely to their accessible stock. A portion of this stock can be considered “Accessible”, (e.g. it can be acquired and shipped to an approved buyer who needs the material). However, a number of External Screens exist that hide the true quantity of stock in the system, (such that the accessible stock is much less than the Full Stock Spectrum for critical items like PPE that is available in the system). This places the supplies and service into one of two ranges: the visible (e.g. accessible) and the hidden, (which in turn can be broken down into Ghost, Blocked, Safety, and Invisible stock).

Further explanation of this spectrum model follows.

In our experience, working on the COVID-19 supply chain task force, as well as our external observations of medical systems, businesses, public agencies and suppliers we have noted five primary types of external screens that prevent the full spectrum of PPE stock from reaching the visible range of our spectrum (shown in Table 1). These include: 1) Fog of war, 2) Poor tracking and monitoring systems, 3) Hoarding behaviors, 4) Distribution barriers and 5) Political motivations. In turn, these screens can place more portions of the full spectrum into the hidden range in the form of four main types of hidden stock: 1) Ghost stock, 2) Safety stock, 3) Blocked stock, or 4) Invisible stock. These screens, or “filters”, distort the true level of inventory that exists in the system, and are a function of the individual rationale and bias of the individuals who are at different levels of distance to the source of information.

We observe ghost stock as those PPE items that are claimed to be available for use, but such claims are either mistaken, exaggerated or false for political motivations. Members of the government at all levels have an incentive to provide the most optimistic position during a time of crisis. Sometimes a positive spin on the unknown is a calculated risk worth taking for those entrusted with leading us through a bad situation. Similarly, at lower levels of the government where officials are appointed versus elected, it behooves them to provide the most publicly acceptable answer.

We were aware of safety stock early on in our fight against COVID-based healthcare shortages. It was apparent that certain hospitals and medical systems were hoarding PPE for “just-in-case” scenarios. State level procurement was occurring independently and leading to hoarding and gaps throughout the country, often with major states (e.g. New York, California, Illinois) getting priority and less populated or lower-funded states (e.g. Wyoming, New Mexico, North Dakota) being left out. We observe that this occurred because some combination of factors was driving states and medical centers to mitigate the risk of being underprepared to accept and treat patients. This was occurring either for purely financial reasons, or due to an inability of states to forecast the demand for PPE, or some combination of the two.

Blocked stock was also an early observation for our team and much of the world. We knew early on that China and other countries were our primary suppliers of PPE and that they intended to curb or stop the distribution of these needed items when COVID hit their country. Efforts were made by the administration to access this blocked stock during Operation Air Bridge, but those results have been less than adequate for meeting our domestic PPE supply needs. The reliance on suppliers that are primarily overseas and beholden to the export policies and priorities of other nations led to significant shortages.

Invisible stock can occur for a couple of reasons. One of the most common that is often seen in military situations is what we call the “Fog of War”. The authors began working early on with teams from various agencies in early March, and observed first-hand the volume of disparate communication and coordination that occurred between public agencies, a lack of acquisition and planning capability that was apparent within these organizations, high levels of reactionary planning, and interventionist strategies (e.g. universities stepping in to rapidly produce face masks using 3D printing) seeking to fill the gap for whatever category of material was in short supply on any given day. Agencies at the federal level were competing with one another over decision-rights and ownership of issues. Further, poor supply chain tracking and monitoring was not a random crisis, it was considered “business as usual”.

We also observed significant challenges within the operational systems used to manage the Strategic National Stockpile and hospital supply systems. This included the early depletion of the SNS in February, an inability to replenish these supplies in a timely manner, a lack of clear barcoding systems (or other modern inventory management systems) to allow tracking and tracing of material in the supply chain, use of manual processes prone to human error, an inability to detect expiration dates on key supplies and equipment, and a singular lack of federal level market intelligence and supply chain transparency. These problems were often undetected, unannounced, and never properly audited and reviewed, so that they in all likelihood exist today. This is frustrating if we consider that we are not yet in a second wave of the pandemic, but are likely still in the first.14

14 “Not the last pandemic: Investing now to reimagine public-health systems”, McKinsey, July 2020. [https://www.mckinsey.com/~/media/Industries/Public%20Sector/Our%20Insights/Not%20the%20last%20pandemic%20Investing%20now%20to%20reimagine%20public%20health%20systems/Not-the-last-pandemic-Investing-now-to-reimagine-public-health-systems-F.pdf]
6. Shedding some light (how do we see more clearly)

In order to see the full spectrum of PPE supplies available to us and discern those that are not truly available to us (e.g. ghost stock) we need to embrace a PPE sourcing strategy that seeks to enhance supply chain immunity over resilience. We believe that five key attributes of an immune national supply chain system in general and specifically for PPE include being flexible, traceable and transparent, persistent and responsive, globally independent and equitable (Schneller et al., 2000). These attributes reflect the lessons learned and responses that would have created a very different picture based of the COVID-19 experience we are currently facing. The critical characteristics associated with each of these attributes are shown in Table 2, as well as the investments that will be required to create them. But these attributes will require significant changes in the way we manage national supply chains, and a new governance structure for a supply chain transparency that will allow us to oversee and direct activity between the public and private sector.

McCrystal’s book “Team of Teams” (2015) explains the idea that true openness, trust, and transparency is not just important, but in fact was the foundational component in the battle against Al Qaeda in Iraq. Faced by an adaptable and networked enemy, the general and his team explored why traditional organizations aren’t adaptable to change. The four fundamental elements that allowed McCrystal’s (2015) “Team of Teams” concept included 1) transparency to ensure common understanding and awareness, 2) changing personal behaviors to establish trust and foster collaboration, 3) creation of a shared context to enable decentralization and empowerment of individuals to act, and 4) creating a broader environment of leadership instead of micromanaging. To address the challenges that exist in the healthcare supply chain, we evoke a similar set of requirements, noting that a transparent system in healthcare that promotes flexibility, transparency, responsiveness, and immune national supply chain system in general and specifically for PPE include being flexible, traceable and transparent, persistent and responsive, globally independent and equitable (Schneller et al., 2000). These attributes reflect the lessons learned and responses that would have created a very different picture based of the COVID-19 experience we are currently facing. The critical characteristics associated with each of these attributes are shown in Table 2, as well as the investments that will be required to create them. But these attributes will require significant changes in the way we manage national supply chains, and a new governance structure for a supply chain transparency that will allow us to oversee and direct activity between the public and private sector.

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Table 2
Requirements for robust healthcare response SUPPLY CHAIN.

| Requirements for An Agile Supply Chain Response to Emergencies | Description |
|-------------------------------------------------------------|-------------|
| Flexible                                                   | A key component of a future state supply chain response is the ability to withstand different requirements that need to be pulled together. This requires advanced planning, effective category intelligence, and strategic sourcing plans for every key need that might arise in an emergency. A Pandemic Planning Team responsible for managing healthcare system-wide should be appointed at a federal level, with state-level pandemic teams that have local authority, but report in to a national level with updates on inventory, demand, and consumption levels. Given the rapidly shifting nature of demand and consumption of the pandemic, real-time planning is needed using tools such as war-gaming situations/simulations, and capacity planning that span both domestic and global sources. Requirements should embed industry standards to create maximum flexibility and increase alternatives in the event of need. This is the opposite of stockpiling of items, but rather involves contractual requirements and effective supplier development to ensure availability of supplies. |
| Traceable and Transparent                                  | Contractual requirements must be supplemented by inventory visibility systems, as well as blockchain transaction channels. A blockchain creates a trusted network of suppliers, through a private and secure technology network, that allows instantaneous ordering, payment, and notification of receipt. A missing component of the supply chain during COVID-19 was the inability to track where products were coming from, where they were being sent, and who was receiving them. The hoarding that is occurring can be prevented by inventory visibility systems, that employ barcode and QR code tracking of material through the supply chain, through a trusted network of distributors and manufacturers. Consumption of supplies should also be tracked, so that supply allocation decisions can be made in real-time based on daily or even hourly updates on what is happening vs. self-reporting demand that can contribute heavily to further opacity in the system. Traceability and transparency can reduce the risk of profiteering, counterfeiting and quality degradation in critical supply chains as well. Blockchain and visibility are critical features not a nice to have for the future strategic national stockpile (SNS) and should be used by all healthcare logistics functions |
| Persistent and Responsive                                  | A national response system must be decisive and efficient in making decisions, based on data provided by the visibility system. They must also be persistently prepared and informed of supply chain risks and opportunities through robust market intelligence to avoid the inefficiencies and costs (financial and human) of ramping up supply chain awareness. A leadership team cannot manage what they cannot see – and so there must be clear channels of communication to review data by the experts who are best positioned to understand and derive meaning from it. Data on inventory levels, material capacity, materials in transit, consumption levels at hospitals, and unexpected disruptions need to be available in real-time, consumed by a persistently prepared team of decision-makers using a sensible governance structure deployed rapidly by senior leadership. This new form of governance to manage the SNS, the allocation of material to states, counties, and cities, and the buy-in of the states to adhere to this national policy may require some legislation to approved and stand-up ahead of time. The governance structure must also have explicit criteria and triggers that are enabled to respond to force majeure in the future. |
| Globally Independent                                       | Inde Independence is a key attribute for creating supply chain protection. There are several components of an SNS that cannot be sourced domestically 100%, as it may not be practical or even possible. Outsourcing of manufacturing capabilities in North America has been on-going for more than 20 years. The goal should be to maintain domestic sources where it makes sense, to support national security, and create a global network of trusted suppliers who are willing to become part of the blockchain/visibility network. This can facilitate an understanding of the full risk picture, promote securing national needs first with a “cold eye” on global impacts. Early warning is the key, to early action, which can prevent shortages and capacity problems from occurring if one is too late to the game. The idea is not, however, to remove global supplies from the field, as this is not only impossible for certain categories of material but may be detrimental to overall supply chain risk. For example, it may be in our best interest to source nonwoven materials for PPE domestically given our recent challenges in supply distribution and quality control for masks, however we would not want a policy so isolating that it could prohibit global access to the best available vaccine. |
| Equitable                                                   | During a pandemic the demand for materials can come from many different kinds of organizations, at different times with claims of the common goods. We have seen large integrated delivery systems, individual hospitals (in and outside of these systems), government delivery systems including military and VA, prisons, nursing and senior residential facilities and rural hospitals and clinics all seeking products. Importantly, all have had access or lack of access to different sources, especially traditional distributors and group purchasing organizations. The “alternative market” that has emerged during COVID-19, consisting principally of suppliers with personal contacts in Asia or Central America that were not part of the every-day PPE production system, targeted many of these provider organizations. An equitable system will be responsive to need as opposed to demand and be guided by a set of ethical principles that facilitate triage and distribution and are not subject to behaviors that threaten the evolving commons. To have an equitable system requires input from the various provider organizations regarding demand on their systems – but also focuses on preparedness (just in case) – which, if credible, may well prevent hoarding of supplies at some locations, while other hospitals are starved of supplies. (This is also a major challenge, as we observed hospitals that were loath to share any type of information on their internal material stocks). This equitable feature speaks directly to the necessity for the development of a commons with agreed-upon rules for its utilization |
Advising the entire SNS 2.0 revamp project with our larger group of research partners.

8. Conclusion

If transparency and visibility are indeed caveats for success, hospitals’ age-old strategy of hoarding material cannot be allowed to occur and will require regulatory changes. There will also need to be significant changes in federal contracting guidelines, to allow the Data Management and Prevention teams in our proposed governance model to create bills of agreement with vetted and audited suppliers, to ensure their capability to replenish the strategic national stockpile (SNS). The SNS itself will require on-site management, to drive appropriate turning of inventory and avoid large lot buying and large concurrent expiration dates for large parts of its contents, (which occurred in January 2020 right before COVID hit). These changes will require a different set of capabilities, which will mean working with qualified supply management professionals who experience and knowledge in applying the tools of category management, strategic sourcing, contracting, specifications, statements of work, supply market research, and inventory management (Chick and Handfield, 2014). Our supply chain spectrum model can be generalized to all forms of supplies and services impacting the global response to COVID-19 and other common requirements. Stock levels and capacity data can be misrepresented, misunderstood and miscommunicated for a variety of reasons. This early work provides an ontology for discussing these common manifestations of conflicting information. It allows managers, researchers, policy makers and the public to more fully understand the rationale for conflicting information during a time of national concern. It is not all smoke and mirrors, it is not all opportunist or fraudulent vendors. It is some of that and more. We believe that further research is needed to measure and discern the types of supply chain screens and spectral differences to advance our world understanding of the unknown. While our framework is not complete in all of its detail, we believe it sets out a useful framework upon which to construct a national pandemic response policy in our federal government and clear our blurry vision.

Author contribution

The authors contributed equally to all portions of conceptualizing and writing this paper.

Declaration of competing interest

The authors have no conflicts of interest with any parties noted in this paper.

References

Bilgen, P., Ryan, S., 2016. Activity Based Intelligence: Principles and Applications. Artech House, Norwood.
Chick, G., Handfield, R., 2014. Procurement’s Value Proposition. Kogan-Page, London.
Handfield, R., Linton, T., 2017. The LIVING Supply Chain: the Evolving Imperative of Operating in Real Time. Wiley.
Handfield, R., Murthy, S., Venkatsraman, J., 2019. Do prices vary with purchase volumes in healthcare contracts? J. Strat. Contract. Negotiation 1–30. April.
Handfield, Finkenstadt, Schneller, Godfrey, Guiotto, 2020. A commons for a supply chain in the post-COVID-19 era: the case for a reformed strategic national stockpile. Milbank Q. 1–33. https://doi.org/10.1111/1468-0009.12485, 2020.
Harland, C., Telgen, J., Caliender, G., Grimm, R., Patrucco, A., 2019. Implementing government policy in supply chains: an international crossproduction study of public procurement. J. Supply Chain Manag. 55 (2), 6–25.
Jones, C., Hesterly, W.S., Borgatti, S.P., 1997. A general theory of network governance: exchange conditions and social mechanisms. Acad. Manag. Rev. 22 (4), 911–945.
McPherson, S., Collins, T., Silverman, D., Fussell, C., 2015. Team of Teams: New Rules of Engagement for a Complex World. Harper Collins.
Schneller, A., Smelzer, L., 2006. Strategic Management of the Healthcare Supply Chain. Jossey-Bass, New York.
Touboulce, A., McCarthy, L., Matthews, L., 2020. Re-imagining supply chain challenges through critical engaged research. J. Supply Chain Manag. 56 (2), 36–51.