

Healthcare Supply Chain post-pandemic: What Can Be Done Better

Rose Maire Gebara

Master's Student

Department of Industrial Engineering
Lawrence Technological University
Southfield, Michigan 48075 USA
rgebara@ltu.edu

Daw Alwerfalli

Professor

Department of Mechanical Robotics and Industrial Engineering
Lawrence Technological University
Southfield, Michigan 48075 USA
dalwerfal@ltu.edu

Abstract

In 2019 the world experienced a new virus named Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) causing an illness called COVID-19 leading to a pandemic. The severe illness required a significant increase in hospitals and medical supply utilization. This highly contagious virus mandated a strict prevention of transmission among the population, first responders and medical staff with significant increase utilization of personal protective equipment (PPE). The hospital supplies were limited by the policy of just-in-time inventory, our national and states inventories were diminished by out-of-date supply in addition to a major increase demand caused shortage of PPE and medical supply. Our reliance of foreign made medical equipment, the initial decrease of the world production secondary to the worldwide mitigation efforts and diverting equipment to local health systems in the countries of origin lead to a significant brake of the medical supply chains in the United States of America. This proved to be very harmful to our effort to care for the population and added a significant burden to our healthcare budget. We reviewed the literature and summarized the lessons learned and recommended approaches to prevent similar problems when we face the next pandemic.

Keywords

Pandemic, supply chain, healthcare supply chain, covid-19, CDC, Center for Disease Control, PPE

1. Introduction

The pre-pandemic medical supply chain was not prepared for the surge in this respiratory virus even though the United States even though our Center for Disease Control (CDC) maintained the "Public Health Emergency Preparedness and Response Capabilities framework" that was updated in 2019, It set national standards for state, local, tribal, and territorial readiness. Unfortunately, when needed, A significant portion of our national and states inventories was expired. For financial reasons, hospitals used the just-in-time inventory system for medical supplies. We relied on foreign countries to produce our equipment; manufacturing of medical supply was minimal in the United States. During the pandemic our utilization of medical supply ballooned, at the same time the world production was affected by the mitigation efforts which includes quarantine. In addition, foreign countries diverted their production to their

own needs. This led to a major shortage in PPE and life saving medical equipment. This in turn allowed some greedy profiteering to overcharge for the supply they had. Our health system had no choice but to buy the equipment needed at any price which inflated our healthcare budget. The original wave of COVID 19 was so severe that it overwhelmed the health system. There was a crowding of the hospitals, increase in intensive care units (ICU) and ventilator use. Unfortunately, 352,000 people died in 2020 alone (CDC data). This was a traumatic experience to the United States; many studies tried to address the shortfall and prepare for the next pandemic. We will try to review that in this article.

1.1 Objectives

This paper looks at the causes of the medical supply chain problems during the pandemic and reviews the possible solutions to improve our response to the next pandemic that will affect us.

2. Methods

Literature search was done using the TechCat+ engine at Laurence Technological University library, PubMed and Chat GPT. Search phrases included: COVID infection rate of health workers, Pandemic PPE, pre-pandemic utilization of PPE, pandemic medical supply chain, pandemic shortage, substandard PPE in pandemic, hospital loss due to substandard PPE, cost of PPE during the beginning of COVID, medical supply post pandemic, financial damage of COVID pandemic, Increase price of PPE during the pandemic. The CDC website searching COVID 19 data and timeline, PPE wasted in the US during the pandemic. Finally, we used Google search engine to look for COVID 19 news and PPE hoarding. We selected articles containing governmental data and news articles regarding hoarding and expired PPE.

3. Results

The COVID 19 pandemic presented a significant challenge to our healthcare system. The virus was very infectious and triggered a major respiratory illness that frequently ended with respiratory failure and death. The hospitalizations spiked quickly after the illness reached the USA (Figure 1) (CDC, 2025). Within two weeks the infection rate increased from zero to almost ten people per 100,000. About 33,150 people with COVID 19 illness needed inpatient care in three weeks. The results were shortage in beds, overcrowding in the intensive care units (ICU) and shortage of ventilators (Figure 2) (French, 2022) (Sandhu P, 2022). When the pandemic hit it did not take long for the ventilator capacity to be dwarfed by the amount of COVID 19 respiratory failure cases (Sandhu P, 2022). Also, both the emergency department (ED) and ICU became overcrowded with just COVID 19 cases and stayed that way during a major part of the pandemic (Sandhu P, 2022). This delayed treatment of other medical illnesses. Ventilators are extremely important to keep patients with respiratory failure alive. Therefore, the shortage of ventilators was an essential issue for our hospitals, as a matter of fact, every country in the world was trying to get its hands on more ventilators which generated major competition and price inflation (Thai, Beleche, & Adetunji, 2025). Pre-pandemic usage of PPE was very different; it was mostly used in healthcare and industry with very few civilians using PPE. After the pandemic most citizens wanted protection and competed with hospitals. This led to further strain on the medical supply chain with a major shortage of these supplies (Cohen J, 2020).

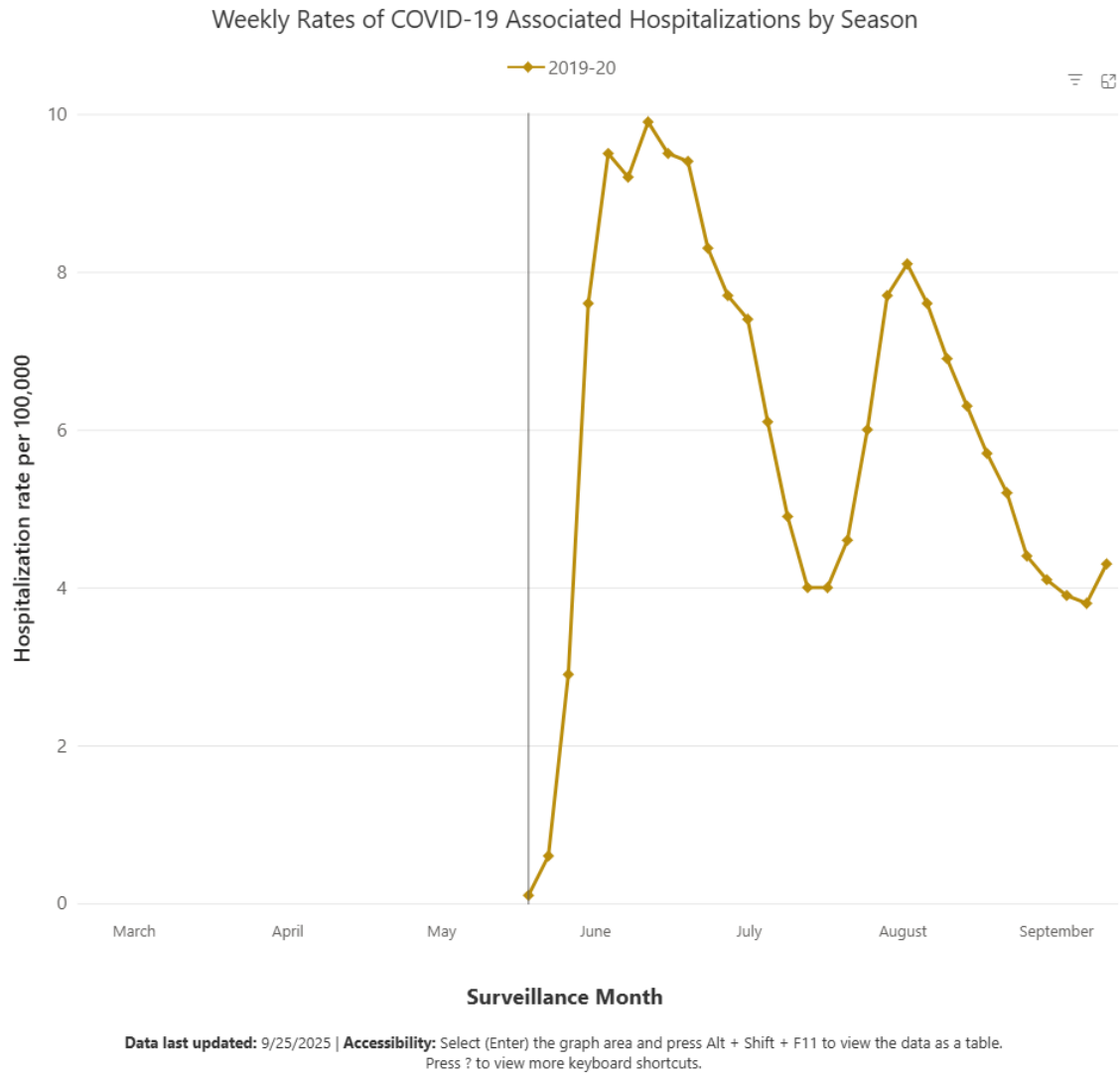


Figure 1. Weekly Rates of Covid-19 Associated Hospitalizations

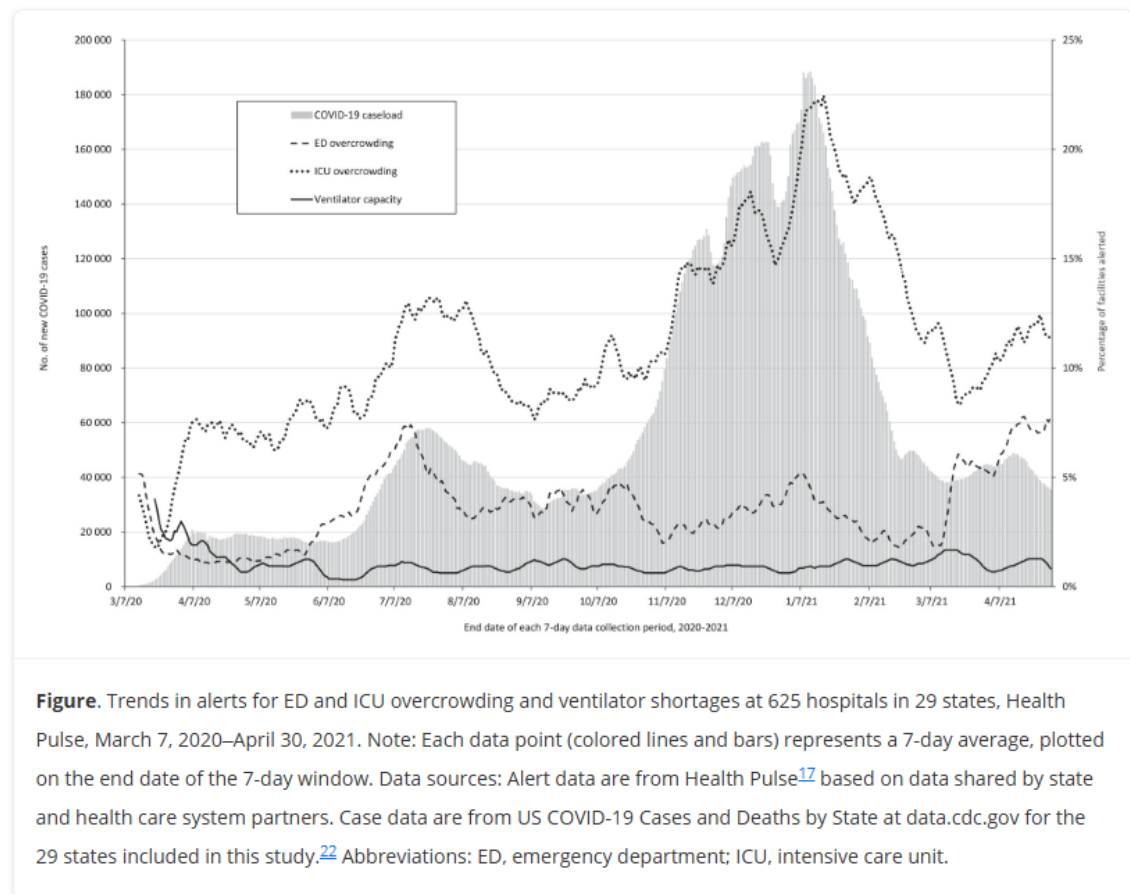


Figure 2. Covid-19 Caseload, ED overcrowding, ICU Overcrowding and Ventilator Capacity

With the shortage of PPE healthcare workers increasing got sick from the virus (Figure 3) with some of them dying (Table 1) (Burrer SL, 2020). The figure shows that the increase of COVID 19 cases in healthcare workers followed the infection trend with non-healthcare personnel. To put this in perspective there are 22 million healthcare workers making up only 14% of the American population (Laughlin, Anderson, Martinez, & Gayfield, 2021). On March 16th healthcare workers made up approximately 15% of the covid cases (Burrer SL, 2020). Which means a good number of healthcare workers were either out sick or working while sick (Linsenmeyer, et al., 2023). This led to a decrease in healthcare workers working on the front lines and some working not at their best. This could have contributed to the fatality of the virus. To combat this healthcare workers were pulled from different sectors of the healthcare system to help. There were doctors and nurses who came out of retirement to help their colleagues in the field (Farrell, 2020). They even had medical students graduate a couple months early to have more doctors on the front lines (NYU Langone Health, 2020) (Buccino, 2020).

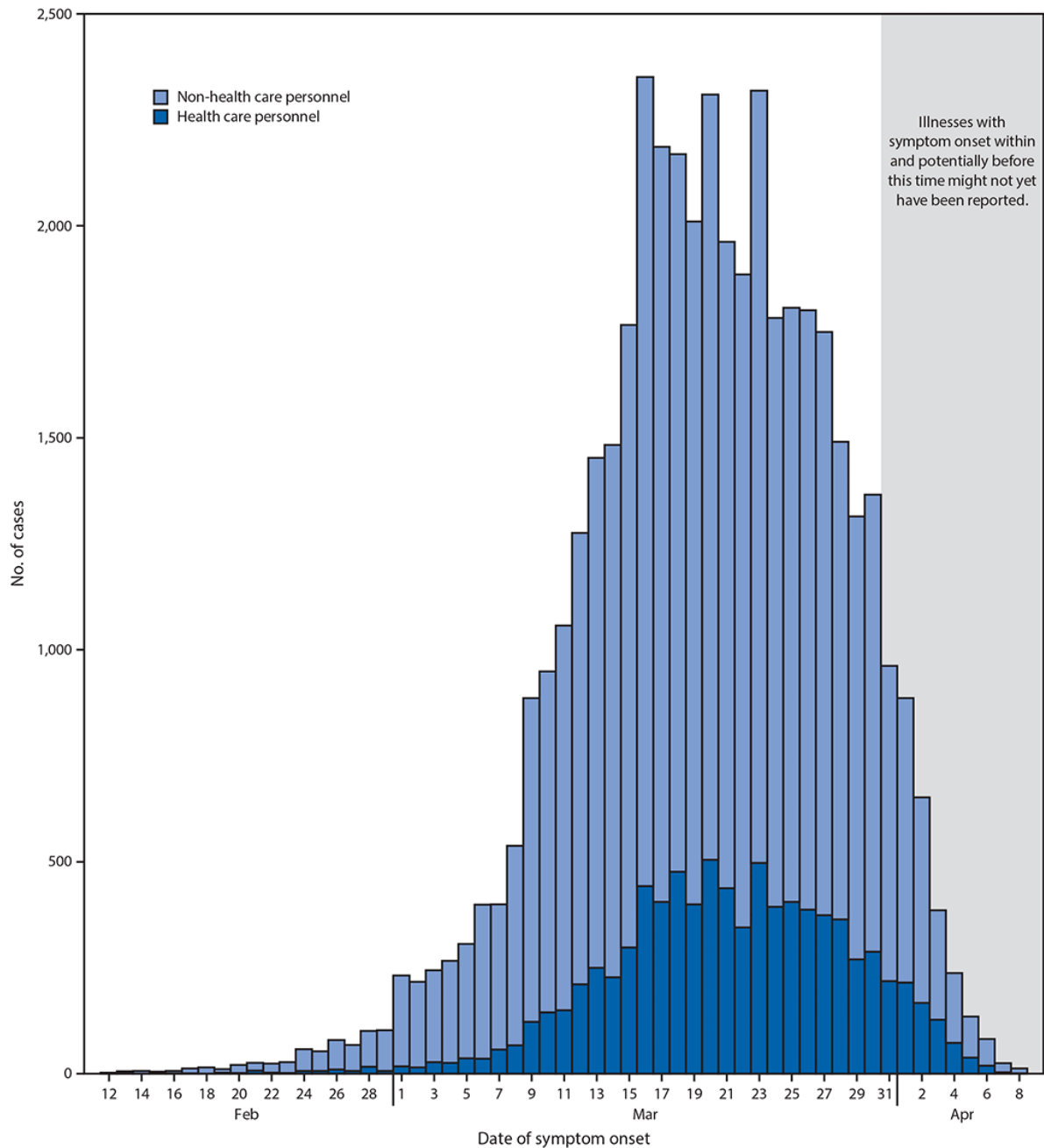


Figure 3. Daily number of COVID-19 cases, by date of symptom onset, among health care personnel and non-health care personnel (N = 43,986)*,† — United States, February 12–April 9, 2020

From the table the older healthcare workers were hit the hardest. Workers ages 55-64 had a 11.6-13.8% hospitalization rate, 3.3-7.5% ICU admission and a 0.5-1.0% death rate. The older healthcare workers 65+ years old had worse numbers. Their hospitalization rate of 19.1-22.3%, an ICU admissions rate of 6.9-16%, and a death rate of 2-4.2%. These healthcare workers are the most experienced and most likely leaders in the hospital, leading to a vacancy of medical knowledge. This led to more strain on it as there is already a healthcare worker shortage (American Hospital Association, 2021).

Table 1. Hospitalizations Intensive care unit admissions and deaths by age group among health care personnel with COVID-19 United States February 12 – April 9, 2025

Age group [†] (yrs) (no. of cases)	Outcome, no. (%)**		
	Hospitalization [‡]	ICU admission	Death
16–44 (4,898)	260 (5.3–6.4)	44 (0.9–2.2)	6 (0.1–0.3)
45–54 (1,919)	178 (9.3–11.1)	51 (2.7–6.3)	3 (0.2–0.3)
55–64 (1,620)	188 (11.6–13.8)	54 (3.3–7.5)	8 (0.5–1.0)
≥65 (508)	97 (19.1–22.3)	35 (6.9–16.0)	10 (2.0–4.2)
Total (8,945)	723 (8.1–9.7)	184 (2.1–4.9)	27 (0.3–0.6)

Abbreviation: COVID-19 = coronavirus disease 2019.

* Hospitalization status known for 7,483 (84%) patients.

[†] ICU status known for 3,739 (42%) patients.

[‡] Death outcomes known for 4,407 (49%) patients.

[†] Age status known for 8,945 (96%) patients.

** Lower bound of range = number of persons hospitalized, admitted to ICU, or who died among total in age group; upper bound of range = number of persons hospitalized, admitted to ICU, or who died among total in age group with known hospitalization status, ICU admission status, or death.

[‡] Hospitalization status includes hospitalization with or without ICU admission.

The hospitals had limited amount of PPE, and our national and states inventories were affected by a lack of maintenance, and many items were expired (Peltz & Lieb, 2023). Our available supply of PPE and other important medical supplies and equipment were used very quickly and the healthcare system started decontamination and the reuse of a single use item (Bown, 2022). Our supply chain did not keep up with the demand.

The supply chain failure in the beginning of COVID 19 was due to an over reliance of supplies from China and other countries. The United States imports 91.4% of the PPE it uses (Figure 4) (Denny, 2021). Only 8.6% of PPE is made here. The US imported a vast majority of the PPE from China at 47.2%, the starting point of the pandemic. In response to the sickness China used strategy called “Zero COVID”, a lockdown style quarantine, which shut down not only cities but factories and had a strict border control to try to internally stop the spread the illness (David J. Sencer CDC Museum, 2024). Production decreased and trading basically stopped from China as a trial to stop the spread of the disease to the US failed. The shortage began when we could not restock the supplies. Shipping delay within the United States and a lack of coordination between the federal, state and hospital system worsened the problem (Cohen J, 2020).

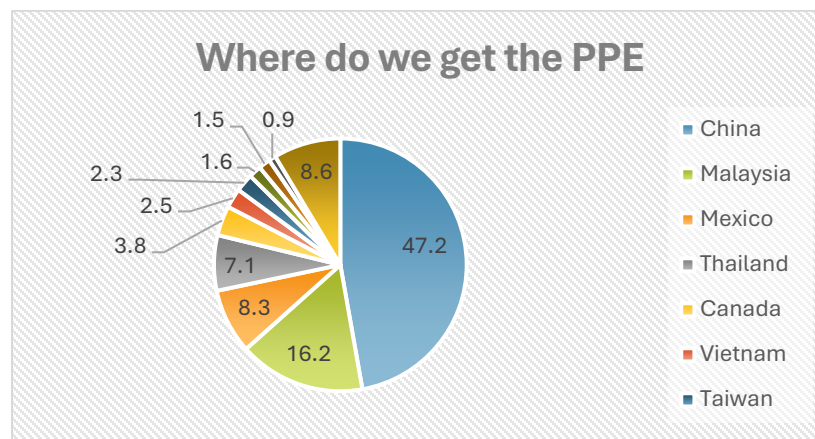


Figure 4. Where do we get PPE?

From Table 2 we can see what the shortages were in the hospitals nationwide (Thai, Beleche, & Adetunji, 2025). The shortages reflect what was needed for the COVID-19 treatment. As seen on the table, PPE was on that list. With hospitals, industry, and the public vying for PPE this is no surprise. From Figure 5 we can see that most of it comes from China (Bown, 2022). Depending on China's manufacturing industry led to the massive shortages as China shut down their manufacturing industry. When the shutdown was lifted and exports resumed the prices exploded and stayed at that level (Mena Lora A, 2021). Years of moving the US manufacturing to other countries for increased profits lead to a massive shortage of PPE which not only affected the economy but the health and lives of American citizens.

Table 2. Medical Device Shortages During the COVID-19 Pandemic

CDML		
Subfunction	Device Category	Medical Device
Airway and Respiratory Support	Tracheostomy Tubes	Tracheostomy Tubes
Airway and Respiratory Support	Mechanical Ventilators	Ventilators
Airway and Respiratory Support	Filters	Ventilator filter
Airway and Respiratory Support	Suction Tubes and Catheters	Suction Canisters
General Supportive Care	Intravenous (IV) Containers	IV bags
General Supportive Care	Beds, Stretchers, and Gurneys	Hospital beds
Liver and Kidney Support	Hemodialysis Circuit Accessories, Hemodialysis Dialysate	Continuous Venovenous Hemofiltration Cartridges, Components, Fluids
PPE	Non-Sterile PPE	Face shields
PPE	Public Use Respirators	N95
PPE	Non-Sterile PPE	Masks
Tests and Test Systems	N/A	COVID-19 Test Kits

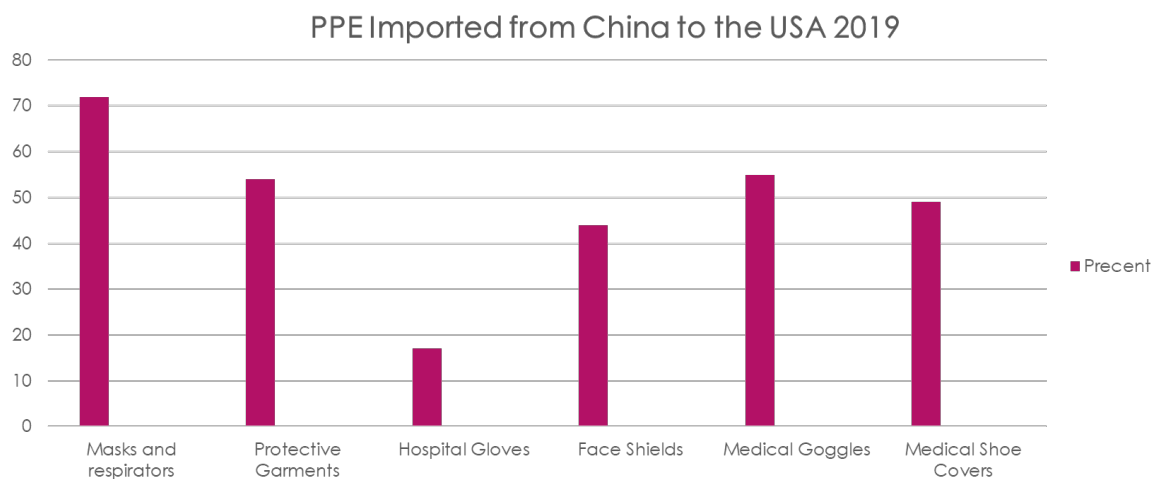


Figure 5. PPE Imported from China to the USA 2019

On April 3, 2020, the Centers for Disease Control and Prevention (CDC) issued a mask wearing guidelines and a recommendation for a wearing a mask outside of the home (David J. Sencer CDC Museum, 2024). Leading to the public, emergency workers, and companies trying to get their hands on masks, competing with hospitals workers. Other countries had the same recommendation some were even mandated. This caused more demand for PPE and with the biggest producer shutting down factories and borders caused an increase in prices (Denny, 2021). From the Fish diagram (Figure 6) we can see what contributed to the shortages (Cohen J, 2020). As we can see this is a multifaceted problem. The government was extremely unprepared for this outbreak and the lack of coordination

between the federal, state and hospital systems lead to PPE not being allocated well (Cohen J, 2020). Another problem was people hoarding supplies and buying them in bulk. There were notable cases in New York and Tennessee and selling them at an upcharge (Nicas, 2020) (Katersky, 2020).

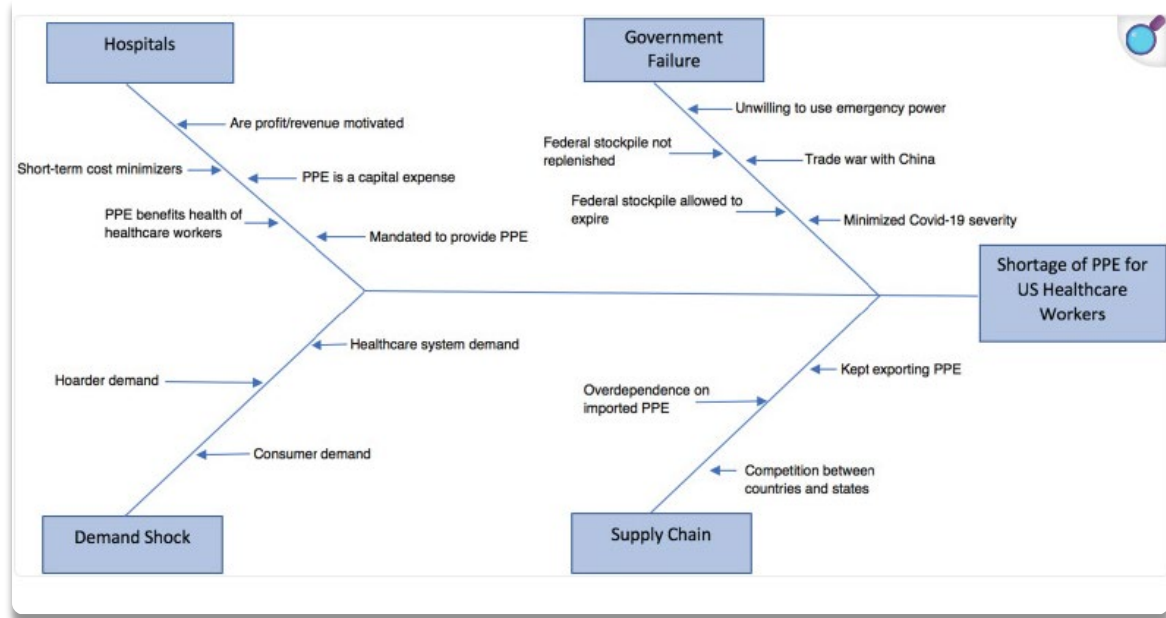


Figure 6. Fish diagram: Factors contributing to PPE Shortage

This hit the hospital system hard financially. It is estimated that US Hospitals lost about 202.6 billion dollars in the first four months of the pandemic (American Hospital Association, May). The prices of PPE skyrocketed with N95 masks increasing the highest at over seven times its normal value (Figure 7) (Mena Lora A, 2021). To limit utilization many procedures were cancelled. This not only included outpatient treatments and elective surgeries but also lifesaving surgeries (American Hospital Association, May). To help decrease absenteeism, additional support was given to staff. Front-line workers were given childcare, housing and transportation, which also helped to decrease the chance of spreading illness. There was also the cost of the COVID-19 screenings that happened before healthcare workers started work but also the treatment of workers who got infected. Major financial damages were caused by substandard or expired PPE. The UK has estimated that £8.7 billion were wasted on unusable PPE (Bawden, 2024). In the USA Maryland disposed of \$93 million of supplies while Ohio disposed of \$29 million due to the PPE being expired and or stored in correctly (Peltz & Lieb, 2023).

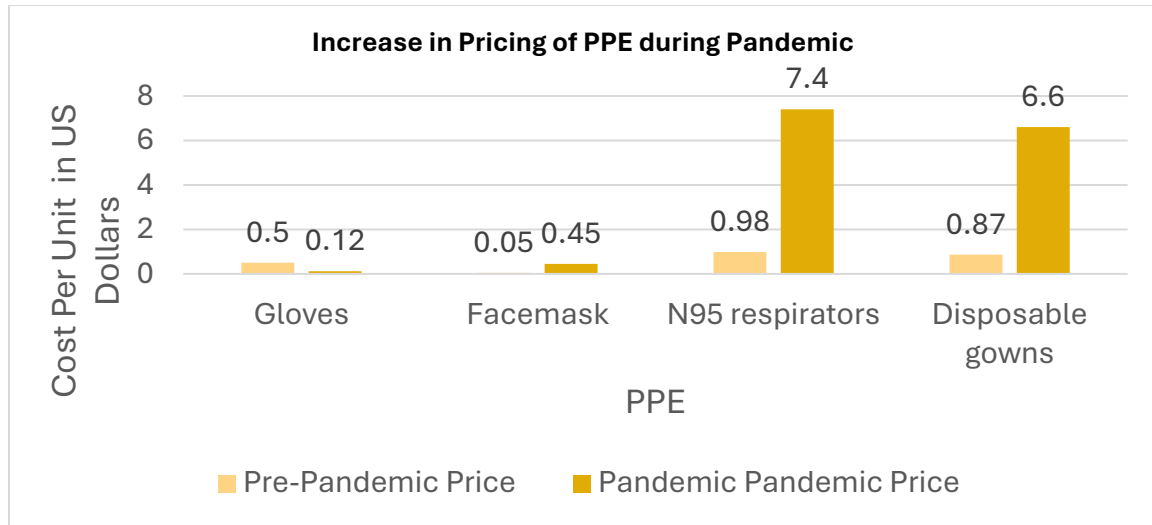


Figure 7. Increase in Pricing of PPE During the Pandemic

The increased prices and low stock resulted in healthcare workers finding creative ways to reuse PPE (Table 3) (Rowan, 2023). Instead of throwing out used masks they sanitize them. To keep up with the increasing number of patients, doctors pulled anesthesia equipment from the operating rooms, emergency transport ventilators, and continuous positive airway pressure machines. (Rowan, 2023)

Table 3. Methods or Strategies Used by Providers, Health Systems, Patients, and Manufacturers to Manage Medical Device Shortages During the COVID-19 Pandemic

Method or Strategy	Example(s)	Entities			
		Providers	Health Systems	Patients	Manufacturers
Rationing and prioritizing use or distribution of devices	Re-using or re-sterilizing PPE, and prioritization of ventilators or tracheostomy tubing are examples of rationing devices. ^{12, 20, 31, 32} Provider decisions to manage ventilator shortages grew during the COVID-19 surges due to increase in demand, with manufacturers also rationing their product by turning away new customers and focusing on existing clients. ^{9, 28}	X	X	X	X
Using unvetted, non-traditional sources, alternate suppliers	A National Pulse Survey of hospital experiences during the COVID-19 pandemic highlighted hospitals turning towards unvetted and non-traditional sources for PPE such as auto body shops. ²⁰ Rural hospitals also partnered with a local business to produce PPE. ²⁵ When patients experienced shortages in their medical devices used at home, they sought product through resources like Facebook groups. ^{7, 9, 12}	X	X	X	
Using alternative devices, components, procedures, or treatments	When physicians faced shortages of standard medical devices used for kidney replacement therapy during the COVID-19 pandemic, they turned to other, less-used methods such as peritoneal dialysis. ^{21, 33} Physicians also repurposed anesthesia equipment, emergency transport ventilators, and continuous positive airway pressure machines in lieu of full-feature ventilators to treat patients. ^{20, 34}	X	X		
Changing hospital processes/ protocol to reduce waste and patient contact	The World Gastroenterology Organization released guidance during the COVID-19 pandemic to reduce the number of staff needed during an endoscopic procedure to limit PPE usage. ³⁵	X	X		
Asking for community donation	Health systems in places like New York, Ohio, and San Francisco asked the community for PPE donations. ^{36, 37}	X	X		
Asking for help from manufacturing executives	Physicians contacted executives at a major manufacturer of dialysis fluid and equipment as a plea to send supplies to their hospital for treating patients with kidney disease affected by COVID-19. ¹³	X	X		
Centralizing distribution centers	Some rural hospitals joined together to create a centralized distribution center to reduce the impact of transportation delays and improve distribution of COVID-19 related supplies. ²⁵	X	X		
Deferring elective procedures	The Centers for Medicare and Medicaid Services (CMS) and the American College of Surgeons (ACS) recommended delaying elective procedures to combat shortages of PPE and hospital beds during the COVID-19 pandemic. ^{8, 32, 38} This led to a 91 percent reduction in elective procedures at Veterans Affairs Hospitals at the beginning of the pandemic. ³⁹	X	X		
Deploying telehealth and tele-monitoring services	Health systems implemented telehealth services and telemonitoring to limit COVID-19 exposure and PPE needs. ^{40, 41} A significant increase in telehealth visits for Medicare patients, from 1 percent to 43.5 percent, was observed at the start of the pandemic. ⁴²	X	X		
Exchanging or sharing unused PPE supplies	Some hospital systems such as those located in a rural region created partnerships for sharing and exchanging of unused PPE supplies. ²⁵	X	X		
Partnering with hospitals to bulk buy	Rural hospitals joined together to increase their collective buying power of COVID-19 related supplies. ²⁵ An increase in collective buying power can aggregate quantities and meet minimum buys to help move up in prioritization with manufacturers. ²⁵	X	X		
Re-using and/or re-sterilizing PPE	A National Pulse Survey of hospital experiences during the COVID-19 pandemic showed hospitals had to re-use and re-sterilize PPE. ²⁰ The CDC listed several methods for decontamination of PPE during a crisis and at least one equipment involving the use of a hydrogen peroxide system received emergency use authorization from the FDA. ^{40, 43}	X	X		
Using alternative PPE designs	Staff at a children's hospital in Washington D.C. partnered with academic centers to develop their own PPE when shortages arose due to COVID-19. ⁴⁴ This included portable plexiglass glass shields, face shields, breath shields, and safety goggles. ⁴⁴	X	X		
Using the national or a state stockpile	States asked for PPE from the strategic national stockpile (SNS) and some states such as California also maintained their own PPE stockpile during the COVID-19 pandemic. ^{36, 45}	X	X		

Another form of reprieve was that companies that did not manufacture medical supplies worked with the medical manufacturers to transform their factories to help decrease the shortage. Examples of this is General Motors, Ford,

Toyota and Tesla opened back up their factories to build ventilators (LaReau, 2020) (Toyota, 2020) (Tesla, 2020). Fiat Chrysler made face masks for healthcare workers and first responders (Stellantis, 2020).

This will not be the last time the medical supply chain will be affected in this way. According to Center for Global Development the next deadly pandemic will have a 47-57% chance of happening in the next 25 years (UC Davis Health, 2025). There is also a change that as America is too reliant on other countries war, tariffs and other world events can disrupt the supply chain to devastating affect especially if it is with China. This can be medicated in a couple of ways. First, we could increase manufacturing in the USA. Therefore, supplies would not be affected by trade issues, and we would have more control over the quality of supplies. To achieve that, the United States should move back the manufacturing of medical equipment or at least develop the expertise to manufacture this equipment. It should also guarantee access to the needed raw material and Infrastructure to manufacture them when necessary. We should also diversify countries of origin for equipment and raw material. One way to do so is government tax breaks. Lastly, we need to have a stockpile of PPE and other medical machinery. The national and states stockpile needs to be stored correctly in a climate-controlled unit, and those supplies should be monitored so that they are replaced when they are expired (Khouja, 2022). Local hospitals should have a stockpile as well rather than the just in time inventory. It is essential that we prepare for the next pandemic before it occurs. This will require financial commitment and political will.

References

- American Hospital Association. *Data Brief: Health Care Workforce Challenges Threaten Hospitals' Ability to Care for Patients*. Retrieved from <https://www.aha.org/system/files/media/file/2021/11/data-brief-health-care-workforce-challenges-threaten-hospitals-ability-to-care-for-patients.pdf>, 2021.
- American Hospital Association. *Hospitals and Health Systems Face Unprecedented Financial Pressures Due to COVID-19*. Retrieved from www.aha.org/guidesreports/2020-05-05-hospitals-and-health-systems-face-unprecedented-financial-pressures-due, 2020.
- Bawden, A. *UK Government Wasted Nearly £10 bn on Unused Covid PPE, Figures Show*. Retrieved from <https://www.theguardian.com/politics/2024/jan/25/uk-government-wasted-nearly-10bn-on-unused-covid-ppe-figures-show>, 2024.
- Bown. *How COVID-19 Medical Supply Shortages Led to Extraordinary Trade and Industrial Policy*. Asian Economic Policy Review, 2022.
- Buccino, N. *Rutgers University Among First in Country to Expedite Graduation of Medical Students*. Retrieved from <https://www.rutgers.edu/news/rutgers-university-among-first-country-expedite-graduation-medical-students>, 2020.
- Burrer, S. L., et al. *Characteristics of Health Care Personnel with COVID-19 — United States, February 12–April 9, 2020*. MMWR Morb Mortal Wkly Rep, 2020.
- CDC. *Covid-net*. Retrieved from <https://www.cdc.gov/covid/php/covid-net/index.html>, 2025.
- Centers for Disease Control and Prevention. *About COVID-19*. Retrieved from www.cdc.gov/covid/about/index.html, 2024.
- Cohen, J., & Rodgers, Y. *Contributing Factors to Personal Protective Equipment Shortages During the COVID-19 Pandemic*. Preventive Medicine, 2020.
- David J. Sencer CDC Museum. *COVID-19 Timeline*. Retrieved from <https://www.cdc.gov/museum/timeline/covid19.html>, 2024.
- Denny, N., et al. *Diversifying Medical Supply: Lessons from COVID-19*. Reischauer Center for East Asian Studies. Retrieved from <https://www.reischauercenter.org/reischauercenter/wp-content/uploads/Reshoring-Publication.pdf>, 2021.
- Farrell, C. *COVID-19 Draws Retired Doctors Back to Work*. Retrieved from <https://www.pbs.org/newshour/health/covid-19-draws-retired-doctors-back-to-work>, 2020.
- French, G., et al. *Impact of Hospital Strain on Excess Deaths During the COVID-19 Pandemic — United States, July 2020–July 2021*. American Journal of Transplantation, 2022.
- Katersky, A., et al. *New York Man Accused of Hoarding COVID-19 Materials for Price Gouging*. Retrieved from abcnews.go.com/US/york-man-accused-hoarding-covid-19-materials-price/story?id=70333494, 2020.
- Khouja, M., et al. *Building Viable Stockpiles of Personal Protective Equipment*. Risk, Hazards & Crisis in Public Policy, 2022.
- LaReau, J. L. *GM and Ford Deliver Last Ventilators Amid Coronavirus*. Retrieved from www.freep.com/story/money/cars/general-motors/2020/09/01/gm-and-ford-deliver-last-ventilators-amid-coronavirus/3449490001/, 2020.

- Laughlin, L., Anderson, A., Martinez, A., & Gayfield, A. *22 Million Employed in Health Care Fight Against COVID-19*. Retrieved from <https://www.census.gov/library/stories/2021/04/who-are-our-health-care-workers.html>, 2021.
- Linsenmeyer, K., Mohr, D., Gupta, K., Doshi, S., Gifford, A. L., & Charness, M. E. *Sickness Presenteeism in Healthcare Workers During the COVID-19 Pandemic: An Observational Cohort Study*. *Infection Control & Hospital Epidemiology*, 44(10), 1693–1696, 2023.
- Mena Lora, A., et al. *Cost of Personal Protective Equipment During the First Wave of COVID-19*. *Antimicrobial Stewardship & Healthcare Epidemiology*, 2021.
- Nicas, J., et al. *Sanitizer and Wipes, Now Worth Their Weight in Gold*. Retrieved from www.nytimes.com/2020/03/14/technology/coronavirus-purell-wipes-amazon-sellers.html, 2020.
- NYU Langone Health. *Early Graduation at NYU Grossman School of Medicine Sends New Doctors to Join COVID-19 Fight*. Retrieved from <https://nyulangone.org/news/early-graduation-nyu-grossman-school-medicine-sends-new-doctors-join-covid-19-fight>, 2020.
- Peltz, J., & Lieb, D. A. *States Throw Out Millions of Pandemic Materials Due to Expiration Dates, Costs of Storage*. Retrieved from <https://www.waste360.com/waste-recycling/states-throw-out-millions-of-pandemic-materials-due-to-expiration-dates-costs-of-storage>, 2023.
- Rowan, N. J. *Challenges and Future Opportunities to Unlock the Critical Supply Chain of PPE Under Emergency Use Authorization Conditions During COVID-19*. *Science of the Total Environment*, 2023.
- Sandhu, P., et al. *Emergency Department and Intensive Care Unit Overcrowding and Ventilator Shortages in US Hospitals During the COVID-19 Pandemic 2020–2021*. *Public Health Reports*, 2022.
- Stellantis. *News Release: Stellantis North America*. Retrieved from media.stellantisnorthamerica.com/newsrelease.do?id=21661&mid=1, 2020.
- Tesla. *Tesla Ventilators*. Retrieved from engage.tesla.com/articles/66-tesla-ventilators, 2020.
- Thai, L., Beleche, T., & Adetunji, O. *Understanding the Impact and Costs Associated with Medical Device Shortage During the COVID-19 Pandemic*. ASPE, Washington D.C., 2025.
- Toyota. *We Are Here for You! Toyota's Response to the COVID-19 Crisis*. Retrieved from pressroom.toyota.com/toyota-we-are-here-for-you-toyotas-response-to-the-covid-19-crisis/, 2020.
- UC Davis Health. *The Next Pandemic: COVID-19 Showed Us How We Can Fight the Next Global Outbreak*. Retrieved from <https://health.ucdavis.edu/news/headlines/the-next-pandemic-covid-19-showed-us-how-we-can-fight-the-next-global-outbreak/2025/02>, 2025

Biographies

Rose Marie Gebara received a BS in psychology at Wayne State University in 2016, a BE in mechanical engineering at Lawrence Technological University in 2021 and is working on a ME in industrial engineering at Lawrence Technological University. As an undergraduate at Lawrence Tech, she was the design and build lead for the tail for the school's SAE Aero team. She and the team went on to earn 5th place in the 2021 SAE Aero competition. Also, as an undergrad she was the president of the AIAA. She worked as a test engineer at Stellantis from 2022 to 2024. In this she tested the engine and transmission of future Stellantis and competitor vehicles, benchmarked them and then presented her findings.

Daw Alwerfalli received a BS in mechanical engineering at the University of Tripoli in 1972, A MS in textile engineering at Georgia Tech in 1978, a ME in manufacturing with honors at University of Detroit Mercy in 1981, and a PHD in Manufacturing with honors at University of Detroit Mercy in 1989. He has worked at GNOFI as a senior Manufacturing engineer in Tripoli, Libya from 1972 to 1978. He was an assistant professor in manufacturing engineering masters/doctorate degree programs at University of Tripoli from 1978 to 1979. He was a research fellow at the University of Detroit Mercy in the Manufacturing engineering masters/doctorate degree program from 1979 to 1979 to 1986. He was then a consultant in manufacturing engineering training and education at AWA from 1986 to 1990. He has done industry collaborations with Chrysler Corporations at various Chrysler plants, conducting and leading 9 research projects from 1995-2008. From 1990 to present he is a professor in the mechanical engineering department/director of Master of Engineering Management degree program, college of engineering at Lawrence Technological University. He has many publications and is currently working on many research projects. He has one US patent.