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Open Source Medical Supplies

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A report on the open source maker and manufacturer response to the COVID-19 PPE crisis

Authors

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Nation of Makers
Nation of Makers supports the full range of organizations that impact makers by encouraging connections, broadly sharing resources, facilitating funding opportunities, engaging in policy development, and advocating for the maker movement.

Open Source Medical Supplies
Open Source Medical Supplies, a project of RESOLVE, informs and empowers makers, engineers, manufacturers, local organizers, experts, and institutions around the world working in their communities to meet medical supply challenges stemming from global crises.

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> The makers are my favorite people this week. Several days ago I intubated without a face shield. It was three in the morning and we had run out. There were simply more intubations than face shields and we had burned through the stash. But a patient came in and was suffocating in their own lungs and needed a breathing tube, so they got one, and they got one from me, and I did not have the proper armor. Today I stand in a room with hundreds and hundreds of face shields. They are pulled hot off the 3D printers like newspapers off a press. They are arranged on tables by volunteers who add elastic bands and attach shields to complete the ensemble. In the background the gentle hum of a dozen printers working around the clock is an echo of the thousands of engineers and designers, seamstresses and manufacturers, cooks and delivery workers and writers all contributing to the cause. Each shield is a person protected. Each volunteer is a soldier in the fight. I feel less alone.

Dr. Jason Hill
Emergency Room Physician, New York, New York, United States[1]

[1] Jason Hill, "An ER Doctor's Diary Of Three Brutal Weeks Fighting COVID-19" (BuzzFeed News, April 23, 2020), https://www.buzzfeednews.com/article/jasonhill/coronavirus-covid-19-er-doctor-diary-new-york-hospital.

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How Communities of Open Source Innovators Responded to COVID-19 Medical Supply Shortages

Summary

As COVID-19 spread around the globe in early 2020, the world experienced a concurrent medical supply chain failure that resulted in widespread shortages of personal protective equipment (PPE) and medical supplies. Existing medical supply manufacturing and distribution systems were slow to respond to the exponentially-growing global demand for supplies, leaving healthcare systems, essential service providers, and others without the supplies they needed to prevent infection. Word about these widespread shortages spread via news media and social networks and citizens around the world stepped up to design, produce, and distribute PPE and other medical supplies for their local communities.

Over the course of 8 months, an international community of makers, hackers, crafters, DIY-ers, and small-to-medium scale manufacturers were called into action by their peers, community partners, and healthcare workers. True to the "open source"[2] spirit, they shared design files and specifications, production plans, best practices, and resources. **Together they produced over 48 million units of personal protective equipment and medical supplies in 86 countries**. These emergency responders labored with little or no compensation, often receiving donations of raw materials or raising their own funds via crowdsourcing to produce supplies.

Open Source Medical Supplies (OSMS) began tallying how many supplies open source communities were producing every week, starting in March 2020, in order to capture this bottom-up response. OSMS then partnered with Nation of Makers (NoM) to issue a Community Impact Survey in Fall 2020 in order to gather comprehensive data and distill lessons learned from this open source response. The quantitative findings in this report are a combination of these two datasets and a survey that Fab Foundation sent to the Fab Lab Network. The qualitative narrative is derived from the Community Impact Survey and interviews with key individuals from within the Citizen Maker Response.

[2] "The Open Source Definition (Annotated)," Open Source Initiative, March 22, 2007, https://opensource.org/osd-annotated.

Our data indicates that the key factors that enabled diverse supply designs, large production volumes, and rapidity of the maker response include:

- Global distribution of community networks; both pre-existing and those established in the wake of pandemic response
- Widespread access to digital fabrication toolsets and an orientation towards rapid prototyping processes
- Collaboration with clinicians and medical institutions
- Vast adoption of a small number of curated online forums for free and fast information exchange
- Open source validated medical supply designs and production guides
- Hyperlocal funding support and a willingness to volunteer
- Retooled manufacturers leveraging new open source designs to scale production quickly

DESIGN | MAKE | PROTECT outlines the global issues that resulted from how our existing medical supply chain was affected by the spread of COVID-19; how citizens were compelled to respond and help their local communities as they experienced shortages; what supplies they made and how they made them; how those responses evolved over the course of the pandemic; and what can be done from a policy perspective to align, formalize and properly support a distributed volunteer manufacturing response to crises in order to build local and global resilience against future challenges.

While the OSMS Weekly Tally and Community Impact Survey results did not capture the entirety of the global open source maker response, the data does have a significant reach across the landscape of response and provides a multi-faceted view into this unique phenomenon. **DESIGN | MAKE | PROTECT** report partners focused their key insights and recommendations for a U.S. audience, though lessons may be applicable globally.

Survey Methodology

Open Source Medical Supplies (OSMS) was founded in March of 2020 to provide open source plans for makers to produce medical supplies for their local communities. Nation of Makers (NoM) is a national non-profit established in 2016 to support maker organizations (makerspaces, maker events, and other organizations that support and affiliate with the maker community) through community building, resource sharing, and advocacy. OSMS and NoM worked together to instigate, guide, and survey the open source citizen response, and then compiled their findings into this report.

From March to August 2020, OSMS manually surveyed production data on a weekly basis via self-reported "Weekly Tally" posts to its 70,000-person Facebook group.[3] Public Facebook posts were used to keep a transparent record of hundreds of respondents each week. Community members were encouraged to post weekly numbers, production locations, and group affiliations. Large reports were further verified through clarifications on the tallies, individual conversations, and photo evidence.

In September 2020, OSMS and NoM compiled a Community Impact Survey[4] to capture final production numbers and more information from the citizen responders in their online networks, with the goal of producing this report detailing their efforts. Data from a survey issued by the Fab Foundation to its network of Fab Labs throughout the U.S. and the world in Fall 2020 was additionally integrated into the dataset.

Together, these surveys represent **1,878 individuals and groups**, of which 1,336 (71.1%) are U.S.-based. The groups collectively represent a minimum of **42,000 volunteers and staff**. The responding groups are present in 86 countries and all 50 U.S. states (plus Puerto Rico and the District of Columbia). This collection of data revealed that between March and November of 2020, this distributed open source community of makers around the world produced, at minimum, 48.3 million units of medical supplies with an **estimated market value of over $271M (USD)**. Over the same period, U.S. groups alone reported over 34 million units produced and distributed, with an estimated market value of over $163M.

Due to the voluntary nature of the collected responses, the authors believe this data represents only a portion of non-traditional medical supply production—the actual count is likely much greater. As an example, this data does not include data from the JOANN chain of fabric and craft stores' Create to Give response, through which customers produced over 400 million cloth masks in the U.S. alone,[5] other maker-manufacturer networks such as

[3] Open Source COVID-19 Medical Supplies Facebook Group, accessed January 22, 2021, https://www.facebook.com/groups/opensourcecovid19medicalsupplies.
[4] "Community Impact Survey," Open Source Medical Supplies, October 16, 2020, http://osms.li/survey.
[5] "Create to Give: Donate Face Masks to Medical Personnel & More and More," JOANN, accessed January 15, 2021, https://www.joann.com/make-to-give-response/.

Formlabs, MatterHackers, and Glowforge, or other global platform connectors, such as Prusa's PPE Maker network.[6] Additionally, this report only features a small number of self-reported small-to-medium scale manufacturers who retooled some or all of their businesses and does not include the vast numbers of distilleries,[7] fashion retailers,[8] and other businesses[9] that answered the call to produce PPE and other critical supplies in the face of a crisis in traditional closed source fashions.

[6]Prusa3D, March 25, 2020, https://www.prusa3d.com/covid19/.
[7]Distilleries Producing Hand Sanitizer and Disinfectant (American Craft Spirits Association), accessed January 20, 2021, https://americancraftspirits.org/covid-19/distilleries-producing-hand-sanitizer-and-disinfectant/.
[8]Bella Webb, "The Implications of Fashion's Pivot to PPE Production" (Vogue Business, May 15, 2020), https://www.voguebusiness.com/companies/the-implications-of-fashions-pivot-to-ppe-production-covid-19.
[9] Nami Sumida, "Tracking US Manufacturers' Shift to PPE during the Coronavirus Pandemic," Supply Chain Dive, June 29, 2020, https://www.supplychaindive.com/news/us-manufacturers-ppe-coronavirus-pandemic/576665/.

The Problem

On January 11th, 2020, China reported its first death from the novel SARS-CoV-2 virus in Wuhan. By January 21st, the virus had been detected in Japan, South Korea, Thailand, and the United States.[10] By February 15th, China had placed over 760 million people under residential lockdowns of varying severities in an attempt to control the spread of the virus, thus temporarily halting production within thousands of manufacturing facilities across the country for a month or longer.[11] The U.S. began experiencing shortages of necessary medical supplies and personal protective equipment (PPE) almost immediately after Chinese manufacturing shut down. By March 18th, healthcare workers from Providence St. Joseph Hospital in Washington State were creating improvised PPE out of office supplies in conference rooms, and nurses were soliciting donations of N95s and other protective equipment through Facebook.[12]

As of mid-January, 2021, SARS-CoV-2 has infected 96.2M people worldwide and killed 2.06M. Included in those totals are 24.5M Americans who have been infected, and over 406,000 who have died from the virus. It has continued wreaking havoc across the global supply chain, and medical supplies are once again difficult to source.

Just-In-Time Global Supply Chain

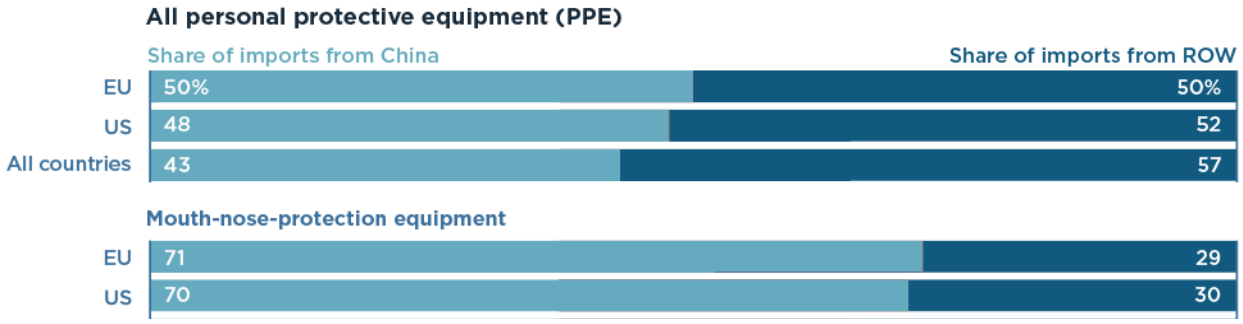
Over the past 20 years, hospitals and healthcare facilities across the United States have adopted cost-cutting, just-in-time inventory management practices that rely on fast shipping of newly-manufactured medical supplies for replenishment. According to Michael Osterholm, Director of the Center for Infectious Disease Research and Policy at the University of Minnesota, “Most if not all of the medical products or protective-device companies in this country are operating at almost full capacity. That’s the reality of today’s economy; just-in-time delivery with no surge capacity.”

This practice is fundamentally at odds with the “just-in-case” stockpiling of supplies for emergencies and is known to leave the U.S. vulnerable during epidemics and pandemics. These just-in-time inventory management practices rely on a significant percentage of medical protective equipment and supplies being manufactured abroad. As of 2018, China produced 43% of the world’s just-in-time imports of medical personal protective equipment (PPE), including face shields, protective garments, masks, and goggles. Specifically, **China provides 70% of the mouth-nose protection equipment the U.S. consumes.[13]**

[10] Derrick Bryson Taylor, “A Timeline of the Coronavirus Pandemic” (The New York Times, January 10, 2021), https://www.nytimes.com/article/coronavirus-timeline.html.
[11] Raymond Zhong and Paul Mozur, “To Tame Coronavirus, Mao-Style Social Control Blankets China” (The New York Times, February 15, 2020), https://www.nytimes.com/2020/02/15/business/china-coronavirus-lockdown.html.
[12] Ben Elgin and John Tozzi, “U.S. Hospital Workers Are Making Masks, Protective Gear From Office Supplies Amid Equipment Shortage” (Time, March 18, 2020), https://time.com/5805557/homemade-medical-face-mask-shortage/.
[13] Brown, Chad P. “COVID-19: China's Exports of Medical Supplies Provide a Ray of Hope.” PIIE Trade and Investment Policy Watch. Petersen Institute for International Economics, March 26, 2020. https://www.piie.com/blogs/trade-and-investment-policy-watch/covid-19-chinas-exports-medical-supplies-provide-ray-hope.

Figure 1: Chart comparing the percentage of personal protective equipment (PPE) in the US, EU, and other countries that is sourced from China

(ROW=Rest of World; EU=Europe, US =United States)



Source: Peterson Institute for International Economics[14]

Supply Chain Disruption

The temporary closing of Chinese manufacturing due to COVID-19 residential lockdowns created shortages of medical supplies across the globe. The U.S. experienced critical shortages of PPE and other supplies immediately and has since experienced additional shortages that correlate with surges of viral activity across different regions. This combination of factors creates preventable, recurring supply shortages that needlessly endanger healthcare workers, essential workers, and the general public throughout this pandemic. The COVID-19 pandemic has demonstrated that **these recurring yet predictable shortages are caused by the combination of our dependence on centralized offshore manufacturing, our reliance on fragile just-in-time global medical supply chains, a lack of a stockpile of critical supplies and protective equipment, and the inequitable distribution of the existing supply chain.**

A global "demand shock" of governments and healthcare systems panic-buying PPE[15] sent prices skyrocketing and turned a just-in-time industry[16] of PPE supplies with a short ordering horizon into a government-hoarding demand surge. Additionally, 80+ countries placed export restrictions on medical supplies and PPE during this surge, including China—which, at that time, produced 50% of the world's face masks.[17]

The compounding effect of the exponential spread of COVID-19 and the proportional increase in the actual monthly need for PPE multiplied the effect of panic buying stockpiles. The OECD

[14] Ibid.
[15] Jennifer Cohen and Yana van der Meulen Rodgers, "Contributing Factors to Personal Protective Equipment Shortages during the COVID-19 Pandemic," Elsevier Public Health Emergency Center (NCBI / US National Library of Medicine / National Institutes of Health, December 14, 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7531934/.
[16] Gary Gereffi, "What Does the COVID-19 Pandemic Teach Us about Global Value Chains? The Case of Medical Supplies" (Journal of International Business Policy, July 15, 2020), https://link.springer.com/article/10.1057/s42214-020-00062-w.
[17] (World Trade Organization, April 3, 2020), https://www.wto.org/english/news_e/news20_e/rese_03apr20_e.pdf.

estimates that the demand increase for surgical masks was ten times higher than the prior global production capacity.[18]

One well-known issue with widespread pandemics is their significant effect on international logistics. Once COVID-19 was declared to be a global pandemic, commercial air traffic came to a halt. Domestic U.S. airlines cut commercial flights by as much as 90% year-over-year (YoY) in the first few months.[19] This immediately impacted available air cargo capacity, as 50% of the world's air freight travels via commercial airlines. Eventually, airlines began putting freight in passenger seats or stripping seats from commercial passenger aircraft, in order to transport more cargo.[20]

Bottlenecks in exports of air cargo became so substantial at Shanghai Pudong International Airport that commercial truck drivers waited in lines for days to deliver truckloads. Parcels then waited weeks to be loaded onto aircraft and aircraft were turned away without cargo because inspections were not completed in time for scheduled departures.[21] Ocean freight, which was also disrupted at the start of the pandemic when Wuhan was quarantined, faced similar logistical issues. **The cost of shipping via ocean freight is now 300% more expensive than pre-pandemic levels, with container berths sold out for months.[22]** Manufacturers cannot currently ship new products internationally in significant volumes if they have not already purchased cargo space.[23]

A Nation Left Vulnerable

On March 4th, the Department of Health and Human Services (HHS) reported that the Strategic National Stockpile held only 1% of the face masks necessary to address a "full-blown" coronavirus pandemic. Only 12 million medical-grade N95 masks and 30 million surgical face masks were in the stockpile, but 3.5 billion were necessary.[24] **This failure to stockpile sufficient supplies, alongside hospital and faulty healthcare facility inventory practices requiring a functional and timely supply chain, meant that healthcare systems ran out of many critical medical supplies within weeks of the pandemic reaching the U.S.**

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[18] "The Face Mask Global Value Chain in the COVID-19 Outbreak: Evidence and Policy Lessons," OECD Policy Responses to Coronavirus (COVID-19) (The Organisation for Economic Co-operation and Development, May 4, 2020), http://www.oecd.org/coronavirus/policy-responses/the-face-mask-global-value-chain-in-the-covid-19-outbreak-evidence-and-policy-lessons-a4df866d/.

[19] Chris Gillis, "American to Park 80% of Domestic Capacity by May," American Shipper (FreightWaves, March 27, 2020), https://www.freightwaves.com/news/american-to-park-80-of-domestic-capacity-by-may.

[20] Eric Kulisch, "Passenger Airlines Morph into Cargo Carriers" (FreightWaves, March 27, 2020), https://www.freightwaves.com/news/passenger-airlines-morph-into-cargo-carriers.

[21] Eric Kulisch, "Deluge of Medical Cargo Cripples Shanghai Pudong Airport" (FreightWaves, May 8, 2020), https://www.freightwaves.com/news/deluge-of-medical-cargo-cripples-shanghai-pudong-airport.

[22] Stella Qiu, Shivani Singh, and Roslan Khasawneh, "Boxed out: China's Exports Pinched by Global Run on Shipping Containers," Reuters (Thomson Reuters, December 10, 2020), https://www.reuters.com/article/us-global-shipping-container/boxed-out-chinas-exports-pinched-by-global-run-on-shipping-containers-idUSKBN28K0UA.

[23] Greg Miller, "US Import Bonanza Could Extend into 2021 on 'Record' Restocking" (FreightWaves, October 2, 2020), https://www.freightwaves.com/news/us-import-bonanza-could-extend-into-2021.

[24] Jennifer Cohen and Yana van der Meulen Rodgers, "Contributing Factors to Personal Protective Equipment Shortages during the COVID-19 Pandemic," Elsevier Public Health Emergency Center (NCBI / US National Library of Medicine / National Institutes of Health, December 14, 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7531934/.

Given the extraordinarily high demand for N95 masks and the HHS-identified need for 3.5 billion of them, 3M increased its production by 42% (from 35 million to 50 million per month) between March and July 2020, but was unable to rapidly scale further due to the centralized manufacturing processes integrated into the production of this crucial item.[25] Importantly, demand during emergencies is not an automatic driver of increased production. U.S.-based surgical mask manufacturers balked at investing in production increases at the start of the COVID-19 pandemic because they had invested heavily in infrastructure during previous pandemics at significant cost. Hospitals then reverted to purchasing cheaper foreign-made masks once prior pandemics were over, and the manufacturers had to furlough employees and sell off infrastructure.[26]

Offshore manufacturing of medical supplies and protective equipment leads to potential national security issues if countries begin restricting exports or stockpiling goods to meet the demands within their own borders. In April, China introduced drastic export restrictions, and the U.S. Department of State announced that China had nationalized its medical supply manufacturers in the midst of the U.S.' first significant surge.[27] American companies were unable to import purchased, manufactured supplies from their own Chinese subsidiaries. At least 69 countries would eventually restrict or ban the export of protective equipment, medical devices, or medicines during the pandemic.[28]

Compounding the effect of Chinese export restrictions, U.S. regulators required significant inspection and certification procedures of supplies sold to US entities due, in part, to a deluge of fraudulent and counterfeit medical supplies sold throughout the U.S. Many supplies sat on loading docks for multiple weeks before the crisis lessened. These policies directly endangered healthcare and essential workers in the U.S. while they were already facing supply shortages.[29]

Dramatic Cost Increases

During supply shortages, customers capable of placing larger orders, such as primary regional hospital systems, are favored by existing manufacturers, and smaller secondary care facilities, such as nursing homes, homeless shelters, physician's offices, and others, cannot compete in

[25] M. Garside, "3M N95 Mask Production in the U.S. 2019-2020," Statista, August 6, 2020, https://www.statista.com/statistics/1110845/us-n95-mask-production-of-3m/.
[26] David Lieber, "If You Imagine That a Local Business Making Surgical Face Masks Is Working 24/7, Guess Again" (The Dallas Morning News, April 3, 2020), https://www.dallasnews.com/news/watchdog/2020/04/03/if-you-imagine-that-a-local-business-making-surgical-face-masks-is-working-247-guess-again/.
[27] Kenneth Rapoza, "China Has 'Nationalized' Its N95 Mask Makers," Forbes (Forbes Magazine, April 27, 2020), https://www.forbes.com/sites/kenrapoza/2020/04/26/china-has-nationalized-its-n95-mask-makers/?sh=7109c81644e2.
[28] Peter S Goodman et al., "A New Front for Nationalism: The Global Battle Against a Virus" (The New York Times, April 10, 2020), https://www.nytimes.com/2020/04/10/business/coronavirus-vaccine-nationalism.html.
[29] Kate O'Keeffe, Liza Lin, and Eva Xiao, "China's Export Restrictions Strand Medical Goods U.S. Needs to Fight Coronavirus, State Department Says" (The Wall Street Journal, April 16, 2020), https://www.wsj.com/articles/chinas-export-restrictions-strand-medical-goods-u-s-needs-to-fight-coronavirus-state-department-says-11587031203.

the marketplace. A survey conducted by Get Us PPE in September of 2020 reported that 80% of small U.S. facilities requesting their aid had no available stock of at least one type of PPE. N95s, disinfecting wipes, and surgical masks remained in very short supply despite manufacturers having six months to scale production.[30] Further, **markups during the pandemic drove prices up between 100% and 1,000%,** creating a shortage and distribution challenge on a global level while magnifying issues around a lack of stockpiling.

Figure 2: Cost of a 90-day supply of PPE per million healthcare workers

	90-day supply (per million workers)	Unit price			Cost $ million (per million workers)		
		Non-Pandemic	Pandemic	% Markup	Non-Pandemic	Pandemic	Savings
N95	14,050,662	$1.27	$5.90	465%	$17.80	$82.90	$65.10
Surgical masks	18,101,324	$0.05	$0.55	1100%	$1.40	$15.50	$14.10
Face shields	14,050,662	$0.50	$4.50	900%	$7.00	$63.20	$56.20
Gowns	28,101,324	$0.50	$5.00	1000%	$14.80	$147.90	$133.20
Shoe covers	28,101,324	$0.11	$0.12	109%	$3.10	$3.40	$0.30
Exam glove pairs	126,455,958	$0.04	$0.12	300%	$5.10	$15.20	$10.10

Source: *UC Berkeley Labor Center*[31]

Healthcare Workers in Peril

Healthcare workers rely on PPE to protect not only themselves but those in their communities.[32] Without adequate PPE, a healthcare worker is more likely to be exposed to infectious materials or body fluids and therefore more likely to become ill and then transmit the infection within their community.[33] With the supply chain interrupted, healthcare workers were losing their ability to safely treat patients and were resorting to measures such as reusing masks and wearing trash bags in a desperate attempt to protect themselves on the front lines.

[30] "Get Us PPE Shortage Index September 2020" (Get Us PPE), accessed January 16, 2021, https://v9b3g8f2.stackpathcdn.com/wp-content/uploads/2020/10/PPE-Shortage-Index-September-2020-Get-Us-PPE-101320.pdf.
[31] William Dow, Laura Lucia, and Kevin Lee, "Economic and Health Benefits of a PPE Stockpile," UC Berkeley Labor Center (University of California, Berkeley, August 12, 2020), https://laborcenter.berkeley.edu/economic-and-health-benefits-of-a-ppe-stockpile/.
[32] Alexandra Shaw et al., "No Patient Safety without Health Worker Safety," The Lancet (Elsevier, September 16, 2020), http://www.sciencedirect.com/science/article/pii/S0140673620319498.
[33] "We Can't (and Shouldn't) Expect Clinicians without PPE to Treat COVID-19 Patients" (Journal of Medical Ethics), accessed January 16, 2021, https://www.bmj.com/company/newsroom/we-cant-and-shouldnt-expect-clinicians-without-ppe-to-treat-covid-19-patients/.

"We have heard staff say that they have been required to use one mask for days, and that in some cases they have had to use garbage bags because there weren't enough gowns...we've also heard staff talk about how worried they are about taking the virus back home to their loved ones. Reusing a mask violates health care protocols."[34] - Robyn Grant, Director of Public Policy and Advocacy, National Consumer Voice for Quality Long-Term Care, United States

By May 20th, 2020, 87% of U.S. nurses surveyed by National Nurses United reported having to reuse single-use disposable respirators or masks with COVID-19 patients. Additionally, **27% of nurses reported having to provide care to COVID-19-positive patients without adequate PPE.**[36] UC Berkeley's Labor Center has estimated that as of August 12th, 2020, 41.7% of California's healthcare worker and essential worker COVID-19 cases could have been avoided if the state had proper amounts of PPE at the start of the pandemic.[37]

"As we sit here today, I'm still not able to get more than a few days' supply of N95 masks, and I still struggle to a certain extent with gowns. That doesn't make you sleep at night, because you're not sure when the next delivery comes."[38]
— Scott LaRue, President and CEO of ArchCare, New York, New York, United States

Images like this one of NYC hospital workers wearing trash bags as protection started to permeate news and social media feeds. *Source: New York Post*[35]

[34] Teresa Murray and Jamie Friedman, "Nursing Home Safety during COVID: PPE Shortages" (U.S. Public Interest Research Groups), accessed January 16, 2021, https://uspirg.org/feature/usp/nursing-home-safety-during-covid-ppe-shortages.
[35] Ebony Bowden, Carl Campanile, and Bruce Golding, "Worker at NYC Hospital Where Nurses Wear Trash Bags as Protection Dies from Coronavirus," New York Post, March 25, 2020, https://nypost.com/2020/03/25/worker-at-nyc-hospital-where-nurses-wear-trash-bags-as-protection-dies-from-coronavirus/.
[36] "New Survey of Nurses Provides Frontline Proof of Widespread Employer, Government Disregard for Nurse and Patient Safety, Mainly through Lack of Optimal PPE" (National Nurses United, May 20, 2020), https://www.nationalnursesunited.org/press/new-survey-results.
[37] William Dow, Laura Lucia, and Kevin Lee, "Economic and Health Benefits of a PPE Stockpile," UC Berkeley Labor Center (University of California, Berkeley, August 12, 2020), https://laborcenter.berkeley.edu/economic-and-health-benefits-of-a-ppe-stockpile/.
[38] Jordan Rau, "Nursing Homes Run Short Of COVID-19 Protective Gear As Federal Response Falters" (National Public Radio, June 11, 2020), https://www.npr.org/sections/health-shots/2020/06/11/875335588/nursing-homes-run-short-of-covid-19-protective-gear-as-federal-response-falters.

> *"The coronavirus outbreak is bending Boston's health care system, and the president of one of its top hospitals is asking for help, even from people with 3D printers. Supplies are on the "low side" at Massachusetts General Hospital, and conservation alone will not do the trick, said the hospital's president, Dr. Peter Slavin. "We have vast numbers of 3D printers in this country," he said. "The formula for producing these masks is available online for free. I would hope companies across the country would, who would have that capability, would start making masks later this afternoon."*[39] - Perry Russom, Reporter, Boston, Massachusetts, United States

A recent study by the Massachusetts General Hospital in the Lancet demonstrated that healthcare workers that reused PPE were 46% more likely to contract COVID-19, compared to those that had an adequate supply.[40] In addition to PPE for healthcare and essential workers, studies in leading medical journals conclusively determined that widespread public use of non-medical face coverings is the primary determinant of reducing COVID-19 transmission. This created a demand for hundreds of millions of non-medical face masks in the United States.[41]

As the availability of medical supplies diminished, demand signals became more public. Social media platforms and community forums started to populate with public requests for PPE from clinicians and first responders. Doctors and other healthcare workers began risking reprimand and, in some cases, their careers[42] by asking the public for help sourcing and manufacturing PPE, defying gag orders placed by their medical institutions.[43] Concerns about shortages of medical devices like ventilators also received mainstream media coverage. Governor Andrew Cuomo of New York detailed his state's experience trying to source ventilators, telling CNN's Anderson Cooper, "This state had purchased 17,000 ventilators, more than any other state in the nation, and they never got delivered. Because they were all coming from China, and 50 states are competing...we can't get any more."[44]

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[39] Perry Russom, "Mass. General 'Desperately' Needs Supplies, Even 3-D Printed Ones" (NBC10 Boston, March 20, 2020), https://www.nbcboston.com/news/coronavirus/mgh-desperately-needs-supplies-president-says/2094292/.

[40] Long H Nguyen, David A Drew, and Mark S Graham, "Risk of COVID-19 among Front-Line Health-Care Workers and the General Community: a Prospective Cohort Study," The Lancet Public Health (Science Direct, September 2020), https://www.sciencedirect.com/science/article/pii/S246826672030164X.

[41] Renyi Zhang, Yixin Li, and Annie L. Zhang, "Identifying Airborne Transmission as the Dominant Route for the Spread of COVID-19" (Proceedings of the National Academy of Sciences, June 11, 2020), https://www.pnas.org/content/117/26/14857.full.

[42] Kayleigh Skinner and Erica Hensley, "Two Mississippi Doctors Fired after Speaking out about Coronavirus Safety," Mississippi Today, April 5, 2020, https://mississippitoday.org/2020/04/05/two-mississippi-doctors-fired-after-speaking-out-about-coronavirus-safety/.

[43] Shaun Lintern, "Doctors Claim They Have Been Gagged over Protective Equipment Shortages," Digital News and Media (The Independent, March 31, 2020), https://www.independent.co.uk/news/health/coronavirus-nhs-uk-doctors-gagged-england-a9433171.html.

[44] Sarah Kliff et al., "There Aren't Enough Ventilators to Cope With the Coronavirus" (The New York Times, March 26, 2020), https://www.nytimes.com/2020/03/18/business/coronavirus-ventilator-shortage.html.

The Citizen Maker Response

As COVID-19 spread across the world, news media began describing hospital administrators making PPE out of office supplies due to widespread medical supply shortages.[45] Designers and engineers felt compelled to address the challenges that arose early in the pandemic and began voluntarily designing open source solutions that could be made by volunteer fabricators. These designers and engineers sought feedback from clinicians and other makers, pursued distribution platforms for their ideas, and quickly joined or formed online communities. These networks developed production lines, labeling and packaging procedures, and distribution efforts.

For the purposes of this report, we define these responders as **any citizen, citizen group, or small-to-medium size retooled manufacturer that produced personal protective equipment or medical supplies during the COVID-19 pandemic**, whether or not they identify with the terminology "maker", "crafter", "DIY" or other terminology typically used to describe the maker community. ***In this report, we refer to this community collectively as the Citizen Maker Response.***

Face Shields being assembled at Open Works makerspace in Baltimore, MD.
Source: Devon Rowland for OSMS

This Citizen Maker Response was comprised of commercial, community, academia, K-12 students, and hobbyist makers, tinkerers, hackers, clinicians, crafters, designers, sewists, artisans, builders, prototypers, small-batch manufacturers, DIY-enthusiasts, and others with skills and experience in electronics design, textiles, 3D printing, CNC fabrication, woodworking, metalworks, arts and crafts, and other forms of small-scale design, prototyping and fabrication. Very few of the individuals, groups, and businesses participating in this response had any experience producing medical supplies before the pandemic. **The vast majority (94%, according to survey data) volunteered their labor.**

Globally, the Citizen Maker Response produced at least 48,392,965 units of medical supplies in response to pandemic-induced supply shortages, a production output that rivals large, centralized PPE manufacturers. Of that, **U.S. maker responders manufactured at least 34,225,081 units of medical supplies with an estimated market value of over $160M**.

[45]Ben Elgin and John Tozzi, "U.S. Hospitals Make Masks From Office Supplies Amid Shortage" (Time, March 18, 2020), https://time.com/5805557/homemade-medical-face-mask-shortage/.

Pre-Existing Conditions

Over the last 15 years, significant consumer interest and rapid industry development cycles have led to dramatic price reductions in digital manufacturing equipment like 3D printers and laser cutters. Mechanical design software has become increasingly more affordable as major computer-aided design (CAD) software developers began targeting hobbyists, DIY enthusiasts, and small manufacturers. This combination of factors has led to widespread "democratization" of design and manufacturing resources that allow any hobbyist to own and operate a small, digitally-connected factory within their home.

These resources have also made their way into shared facilities for those unable to afford their own equipment. **A vast international network of thousands of makerspaces,[46] Fab Labs,[47] hackerspaces,[48] media labs,[49] and other crafting and manufacturing hubs exist to offer shared use of prototyping and digital fabrication equipment while cultivating and supporting member communities trained in design and fabrication.** These spaces typically offer a diverse assortment of materials and resources on-hand that can help bring a concept or idea to life, from sketch through design development, and have the equipment to print, build or program prototypes and final products in small-to-midsize batches.[50] ***For the purposes of this report, these spaces are all referred to as makerspaces.***

Prior to the COVID-19 pandemic, many of these makerspaces and their members were loosely connected via social media, mailing lists, and recurring events such as Maker Faire. Members often joined and participated in international online communities around their shared interests, such as 3D printing, crafting and sewing, specific fabrication-related hobbies, and manufacturing. These online communities also include tens of thousands of individuals who do not hold makerspace memberships but own personal fabrication equipment and share similar interests.

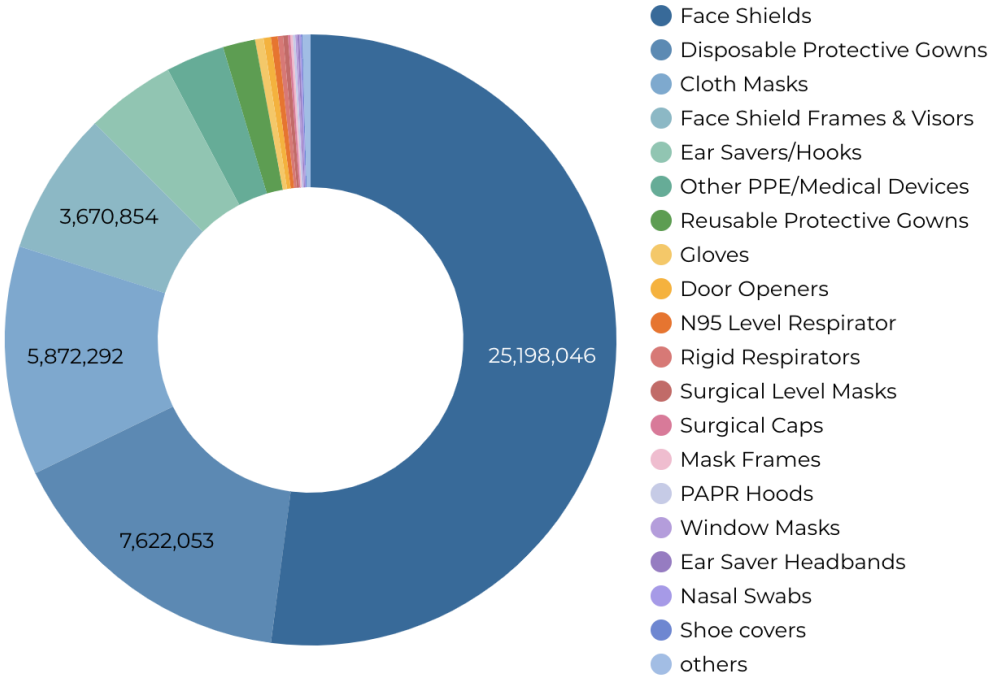
When the COVID-19 pandemic began, this pre-existing global network of makerspaces and interested individuals shared information about the pandemic and how citizen fabrication could help within a matter of hours to days—far faster than local and national governments were willing to relay such information to the public. This global network also allowed different regions and countries to prepare volunteer and production efforts before COVID-19 infections surged in their areas.

[46]Liam Grace-Flood, "Open World: 20 Databases to Help You Find Local Maker Resources," Make: Magazine, October 31, 2017, https://makezine.com/2017/11/01/open-world-20-databases-help-find-local-maker-resources/.
[47]Fab Lab Map (Fab Lab Network), accessed January 22, 2021, https://fabfoundation.org/global-community/#fablab-map.
[48]All Hackerspaces (Hackaday.io), accessed January 22, 2021, https://hackaday.io/hackerspaces.
[49] Map of Labs (Makery), accessed January 19, 2021, https://www.makery.info/en/map-labs/.
[50]Gui Cavalcanti, "Is It a Hackerspace, Makerspace, TechShop, or FabLab?," Make: Magazine, May 22, 2013, https://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs/.

Types of Supplies Produced

Makers around the globe were able to design and manufacture, from scratch, almost every type of infection-preventing PPE and a significant number of medical devices used to identify and treat COVID-19. While design and production were dominated by face shields (52.0%), disposable hospital gowns (15.8%), and cloth masks (12.2%), they also included novel devices such as ear savers that prevented N95 and surgical masks from aggravating the wearer's skin; high-performance ICU PPE such as PAPR/CAPR helmets and suits; consumables such as hand sanitizer, gloves and nasal swabs; infrastructures such as handwashing station; and complicated medical devices such as stethoscopes and ventilators.

Figure 3: Types of Supplies Produced

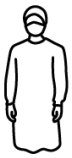


Source: OSMS Weekly Tally and OSMS/NoM Community Impact Survey combined datasets

Face Shields (25M)

Face shields proved to be an ideal product for distributed production by digital fabrication enthusiasts. Locally-manufactured face shields were a welcome additional solution for eye protection and extending the life of increasingly rare hospital-grade surgical masks and N95 respirators by preventing exterior droplet accumulation. The frame headbands could be easily 3D-printed by individuals at home, cut quickly via laser cutter, or made en masse via injection molding. The transparent plastic shields could, at the most basic level, be made from materials like office supply vinyl with scissors, and could be scaled up with laser cutting and die-cutting.

Protective Gowns (8M)



Isolation gowns, worn over clothing to protect against contamination from viral particles, were in short supply within the first few months of the pandemic. Healthcare workers expressed an urgent need to the maker community for gowns, and a number of makerspaces and production groups pivoted to manufacture them. Most isolation gowns are made by ultrasonic or thermal welding, which requires tools not typically present in most manufacturing facilities. Both makerspaces and retooled manufacturers purchased or made new infrastructure in order to produce gowns, and in large enough quantities for gowns to be the second-most produced item.

Cloth Masks (6M)

Widespread cloth mask usage in public spaces was suggested by the CDC one month into the pandemic in order to reduce community transmission. Cloth masks are used to help mitigate spread from sick individuals to healthy individuals, for covering vented filtering masks, and to protect N95 masks from viral contamination. While cloth masks rank third in the OSMS survey data, the U.S. fabric supply store chain JOANN reported that its customers manufactured 400 million masks[51] alone, suggesting a significant underreporting of the magnitude of total cloth mask production. Cloth mask production is possible in isolation, and like face shields, continues to be produced across distributed networks of makers and crafters for donation to local communities. While generally produced for non-medical environments, healthcare workers have leveraged locally produced cloth masks when disposable surgical masks have not been available, and often use them to reduce contamination of N95 filtering masks.

Other Supplies, Devices, and Services

Other types of PPE and medical supplies were also developed and produced in order to address spot shortages in specific locations. Some examples include:

- Wearable PPE, such as **shoe covers and surgical caps**, were produced by sewists when local hospitals put out calls for them.
- **Powered Air Purifying Respirators (PAPR)**, high-performance medical devices that actively filter incoming air and blow it onto wearers' faces, were repaired, reverse-engineered, or otherwise invented from scratch by a number of maker groups.
- Multiple **positive-pressure inflatable suits** were reverse-engineered and manufactured by a number of makers for specific hospital systems in need.
- Distilleries around the U.S. and world converted their ethanol production to **hand sanitizer** and other groups produced hand soap.

[51] "Create to Give: Donate Face Masks to Medical Personnel & More and More," JOANN, accessed January 18, 2021, https://www.joann.com/make-to-give-response/.

- Several types of **emergency-use ventilators** were designed and manufactured by groups across the world, with several meeting regulatory standards, including U.S. Emergency Use Authorization (EUA) standards and European Union regulations.

Some maker responders also focused specifically on repairing medical and manufacturing equipment, such as Fixit Clinic, an organization dedicated to hosting pop-up workshops that teach the value of fixing items rather than discarding them and buying something new.[52]

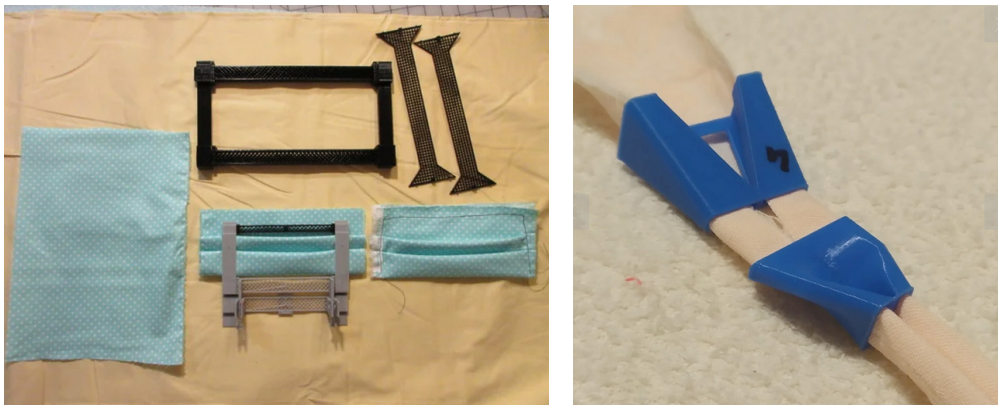
Other organizations, such as Bellingham Makerspace in Bellingham, Washington, produced over 36,000 cloth masks and 3,700 face shields and also dedicated time and resources to repairing sewing machines and sharpening scissors for community sewists in need of those services. Something Labs in San Francisco, California repaired 136 PAPR devices and fabricated 13,658 PAPR tabs.

Novel Medical Supplies

In addition to standard medical supply items, a number of new PPE types, medical supplies, and community-supportive infrastructure and tooling were invented and produced by citizen responders in response to the COVID-19 pandemic.

- **Ear savers**—thin straps with hooks or buttons that secure mask ear loops to the back of the wearer's heads—were invented in response to healthcare workers' calls for help as ear loops chafed their skin after wearing disposable masks for 12 or more hours a day.
- **Noninvasive ventilation helmets** were developed to supply pressurized oxygen to patients without having to risk esophageal or lung damage from intubation procedures.
- **Ventilator splitters** were developed so that a single ventilator could be used to support multiple patients as ventilator shortages were experienced across the world.
- **Door openers** were developed to allow people to open publicly-used doors without touching handles or other surfaces with their hands. Many also included features that would allow a user to pick up handled items, such as grocery bags, without touching them directly, thereby reducing transmission risk.
- **Handwashing stations** were developed to allow communities without access to running water to wash their hands.
- Mask variations like **windowed masks**, with transparent partitions over the mouth to allow people to read the wearer's lips as they speak, were developed for communities in need of this customization, such as the deaf and hard-of-hearing.
- Makers with 3D printers even invented community-supportive tooling like **automatic bias tape folders** and **mask pleaters** for sewists in order to improve their production output by orders of magnitude.

[52] Bill Picture, "Fixit Clinic: Saving the World One Repaired Item at a Time" (Bay Crossings, March 1, 2020), https://www.baycrossings.com/fixit-clinic-saving-the-world-one-repaired-item-at-a-time/.



Novel tools and supplies invented on public open source forums, including mask pleating jigs (left), bias tape folders (right). Source: OSMS Project Library

Additionally, the COVID-19 Challenge, launched by Challenge America and the Veterans Health Administration Innovation Ecosystem, supported by America Makes,[53] spurred the creation of over 45 innovative solutions to problems raised by healthcare workers, ranging from UV sanitizers to protective barriers to nebulizer filtration systems. (See "Crowdsourcing Innovation through Challenges").

Challenges of Making Regulated Supplies

In almost all countries, the production of medical supplies is highly controlled and regulated in order to ensure the health and safety of patients and healthcare workers. The United States, for example, categorizes medical supplies into three classes via the Food and Drug Administration (FDA), ranging from low-risk, easily-manufacturable devices like bandages (Class I) to moderate-risk items such as surgical gloves and syringes (Class II) to high-risk life-sustaining items such as pacemakers (Class III).

The FDA does not approve a manufacturer's design, so that it may be produced by anyone; rather, it inspects and approves a manufacturing facility and manufacturing process that produces the final product.[54] Obtaining FDA approval to produce Class III medical devices can take 3 to 7 years from application to approval, on average, and the costs to a manufacturer can be significant.[55]

Hospital staff in Fremont, California inspecting maker-made PPE arrivals. *Source: Anh Le*

[53]"COVID-19 Makers Challenge Rapidly Building Innovative Safety Solutions," DigitalVA (U.S. Office of Information Technology, September 16, 2020), https://www.oit.va.gov/news/article/?read=covid-19-makers-challenge-rapidly-building-innovative-safety-solutions.
[54] "Device Advice: Comprehensive Regulatory Assistance - Overview of Device Regulation," Center for Devices and Radiological Health (U.S. Food and Drug Administration, September 4, 2020), https://www.fda.gov/medical-devices/device-advice-comprehensive-regulatory-assistance/overview-device-regulation.
[55]Gail A Van Norman, "Drugs, Devices, and the FDA: Part 2: An Overview of Approval Processes: FDA Approval of Medical Devices," Journals of the American College of Cardiology (Science Direct, June 2016), https://www.sciencedirect.com/science/article/pii/S2452302X16300183.

Class I and Class II supplies and devices are generally less complex, but the time and financial commitment needed for regulatory clearances are still a significant barrier to entry for independent product developers.

Medical institutions, labor unions, and others rely on FDA standards to clarify the liability landscape and ensure adequate protection of the labor force and patients, and therefore FDA approval is typically required for every medical supply item used in hospitals. When the FDA-approved supply chain fails, medical institutions then look to the FDA for clarification on how to procure supplies. When the pandemic arrived in the U.S. in March 2020, these clarifications took the form of Emergency Use Authorizations (EUAs).[56]

Hospital gown fabrication lab at University of Washington's Center for Digital Fabrication. *Source: University of Washington Center for Digital Fabrication*

The first FDA Authorization for PPE to help fight COVID-19 was granted on April 9, 2020 (with updates on April 13, 2020), for local production of face shields.[57] This EUA clarified critical standards for production and labeling for citizen responders, requiring things like labels that indicate what materials touch the skin. The EUA also clarified that hospitals could accept face shields, as long as chosen manufacturers complied with the articulated guidance on labeling and design, opening the door for hospitals and other medical institutions to accept supplies from the maker community.

Though helpful, **by the time the face shield EUA was released, U.S. makers had already produced over 739,000 face shields without authorization, and over 3.25 million had been produced globally.** Makers took on the liability of producing these unauthorized products due to the sheer unmet need in the medical community. These face shields were designed, manufactured, and distributed by the maker community based on volunteer effort and local clinical guidance instead of centralized FDA guidance. As an example, a volunteer from Florida stated the following:

> *"We started calling the healthcare providers in our area to determine the real needs... most of them didn't want to talk to us, didn't know how to talk to us, or wouldn't even answer the call. We were fortunate to connect with a contact at Orlando Health, a local nonprofit hospital organization here in Orlando. And not only were they willing to talk to us, they had taken someone from their team who's normally on innovation*

[56] "FDA Combating COVID-19 With Medical Devices" (United States Food and Drug Administration, November 24, 2020), https://www.fda.gov/media/136702/download.
[57] Ibid.

> *projects and asked her to be the liaison. She was the perfect contact as her job is cutting through hospital bureaucracy. In the early days we were on the phone almost constantly. We built a 3D printing network with them, which included a document written for makers that clearly explained what they would accept and what they would not accept. It included links to the 3D printed models, instructions, and directions for drop off at their facility."* — Ian Cole, OSCMS Central and South Florida and Maker Effect Foundation, Miami, Florida, United States

There were a number of other challenges the Citizen Maker Response experienced which were associated with the production of regulated supplies:

- There was no pre-existing collection of open source, approved emergency medical supply designs. **Almost all open source medical supply designs were developed during the pandemic itself.**
- Most existing clinical guidance and resources were inaccessible to laymen, as medical documentation and FDA guidance are intended for professional commercial medical suppliers.
- Liability for supplies produced was extremely unclear, even though the vast majority of producers were manufacturing low-risk (Class I) supplies.
- Very few new supply designs could be sufficiently tested for efficacy, as testing labs were overwhelmed from the start of the pandemic and charged significant fees.
- Hospital supply chains are often contractually restricted to relatively few suppliers, and it is difficult for them to accept new supply sources, even if approved by the FDA via EUA.

Even with these numerous regulatory challenges, makers that pivoted to become emergency manufacturers were able to produce tens of millions of units of supplies that were primarily distributed to hospital systems and medical practitioners. These distributions were made in times of crisis, with the sheer need for supplies overriding anxiety about liability and potential litigation, and could have been much smoother had more guidance or preemptively-approved crisis designs been available.

Developing Open Source Solutions

Maker responders were determined to help their communities weather pandemic-induced shortages despite the regulatory hurdles involved in producing medical supplies. While the open source hardware movement has existed for over 15 years (due in large part to the growing popularity of consumer 3D printers), the community had generally not developed medical supply designs because there had never been a pressing need. Given the global scale of the pandemic, and the corresponding global scale of medical supply shortages, the international open source community quickly came together to rapidly design open source PPE and medical supplies in ways it never had before.

Traditional design and engineering processes are "closed source"—their outputs are considered the intellectual property of companies that pay the teams of designers and engineers. While effective and profitable over the long term, this type of development can be slow and limited, as each team working on a solution has to conduct its own user research, develop its own project requirements, iterate on designs and prototypes, and develop its own designs for specific manufacturing processes.

Two makers supervising an array of 3D printers and laser cutters in Lithuania's face shield production.
Source: Denis Vejas

By contrast, **open source design and engineering processes can happen incredibly quickly, as entire communities of hundreds of thousands of people can contribute to shared understandings of research, project requirements, designs, and manufacturing processes.** Given that all open source information and designs are public, anyone in the world can add to this body of knowledge, develop derivative designs, or manufacture supplies from existing plans without having to design their own.

Networking Problem Solvers

The first major step in the Citizen Maker Response was connecting makers around the world, and sharing as much accurate COVID-19 information as widely as possible so that makers could develop solutions. Most makers, like most people in the world, had no idea what COVID-19 was or how to fight it at the beginning of the pandemic. Makers turned to existing social media and digital networks or created new ones to determine how to help both their local communities and the world. Sharing news articles, preprint medical studies, and primary source interviews with medical practitioners trained in COVID-19 response (such as Dr. Ali Raja and Dr. Shuhan He's "Ask Me Anything" interview on Reddit) provided much-needed information on the nature of the disease and treatment protocols as this information was discovered.[58]

Open Source Medical Supplies, an author of this paper and one of the first COVID-19-specific maker response communities to form in the U.S., was launched as the Open Source COVID-19 Medical Supplies Facebook Group on March 10, 2020. On March 11th, the administrative team interviewed healthcare workers that had just been trained in COVID-19 response to determine what medical supplies were needed, shared those interviews with the group openly, and then

[58] r/Coronavirus - I'm Ali Raja, MD and Shuhan He, MD emergency physicians from Mass General Hospital/Harvard Medical School. (reddit), accessed January 17, 2021, https://www.reddit.com/r/Coronavirus/comments/flvu7k/im_ali_raja_md_and_shuhan_he_md_emergency/.

collectively began to author and curate a Medical Supply Guide to help inform the development of medical supplies necessary to fight the pandemic.[59]

The primary purpose of the guide was to provide layperson-accessible information to makers about COVID-19, as well as guidance on how to design medical supplies that met global health and regulatory standards. The first version of the guide was published on March 18, only 8 days after the start of the forum and 3.5 weeks before the FDA released any EUAs or guidance for non-traditional manufacturers. Three weeks after its formation, OSMS began actively organizing "Local Response Groups" to help makers meet demand in their communities and regions. Within one month, it had accumulated a global network of over 70,000 makers, fabricators, community organizers, and medical professionals working to meet the medical supply challenges stemming from the COVID-19 pandemic.

Nation of Makers, an author of this paper and a pre-existing network of makers that pivoted to support this pandemic response, is a national non-profit established in 2016 to support maker organizations (makerspaces, maker events, and other organizations that support and affiliate with the maker community) through community building, resource sharing, and advocacy. During the pandemic, Nation of Makers provided regular informational updates, access to resources (including funding for PPE production) and calls to action in its network of maker organizations across the U.S. and the world. Other similar pre-existing and robust maker networks included the Fab Foundation, which helps maintain a network of over 1,700 Fab Labs in 90 countries, and Make Community, the company that publishes "Make:" magazine and the worldwide Maker Faire network.

Some networks specialized in connecting certain types of responders. Just One Giant Lab, a non-profit organization started in 2018 to help provide organizational platforms for citizen science and engineering efforts, recruited tens of thousands of medical professionals, engineers, and scientists to help develop ways to fight COVID-19, ranging from PPE design to open source vaccine development. Helpful Engineering, a startup non-profit founded to help engineer solutions to the pandemic, collected over 15,000 engineers at its peak to specifically design open source PPE and medical devices.

In a nod to the Citizen Maker Response being a successful alternative to the failures of both the government (Plan A) and business (Plan B) responses to COVID-19, it was termed "Plan C" by Dale Dougherty, Make: Community President, a leader within the maker movement.[60] Beginning in mid-April of 2020, Nation of Makers Executive Director Dorothy Jones-Davis and Dougherty began hosting a free online weekly community show titled "Plan C: Live"[61] as a mechanism to share best practices and success stories broadly with the maker community. They regularly interviewed a panel of maker responders from around the world typically

[59] "Open Source COVID19 Medical Supply Guide," Open Source Medical Supplies, December 9, 2020, https://osms.li/guide.
[60] Dale Dougherty and Victor W. Hwang, "What's 'Plan C' for COVID-19?," Make: Magazine, March 25, 2020, https://makezine.com/2020/03/22/whats-plan-c-for-covid-19/.
[61] Plan C: Makers Combating Covid-19 (Make: Magazine), accessed January 23, 2021, https://makezine.com/tag/plan-c/.

grouped around a theme, with session topics that included "Developing an Open Source Ecosystem for Medical Hardware," and "Organizing within Native American Communities for Covid-19", amongst others. These sessions provided an open exchange of ideas, solutions, and dialogue that often led to international collaborations.

Additionally, a number of conferences held in the first 12 months of the pandemic gathered the Citizen Maker Response community virtually to share best practices and overcome shared community concerns. These included but were not limited to: Virtually Maker Faire (May 2020),[62] a worldwide event at which a large number of participants demonstrated pandemic response solutions, NOMCON (June 2020), the annual convening for Nation of Makers,[63] FabXLive (June 2020) hosted by Fab Foundation,[64] ENABLECON (October 2020),[65] hosted by the e-Nable Alliance, an organization with a history of mobilizing volunteers for 3D printing to supply prosthetics to those in need, the Supply Shortage Solutions Symposium (November 2020),[66] co-hosted by Field Ready and OSMS; and the Public Invention Conference (January 2021),[67] hosted by Public Invention.

Distributed and Iterative Open Source Design

Larger forums such as the Open Source COVID-19 Medical Supplies (OSCMS) Facebook group served as centralized focal points for designers and engineers to share open source designs publicly, gather feedback from a like-minded community, and distribute production plans to fabricators. Designers and engineers would typically create posts with images or plans, field questions or commentary from other designers, medical practitioners, and fabricators, and then revise designs appropriately until they were ready for release. Engagement was high; during April and May 2020, a well-performing post in the OSCMS forum might attract close to 100 comments, 1,000 reactions and over 10,000 views globally. **During peak periods, the forum might see hundreds of posts in a single day.**

[62] "Virtually Maker Faire Meet the Makers," Maker Faire, May 20, 2020, https://makerfaire.com/virtually-maker-faire-2020/meet-the-makers/.
[63] NOMCON, accessed January 24, 2021, https://www.nomcon.org/.
[64] FABxLive (Fab Lab Network), accessed January 24, 2021, https://fabxlive.fabevent.org/.
[65] E-NABLE CON (e-Nable Alliance), accessed January 23, 2021, https://enablealliance.org/enablecon/.
[66] 4S - Supply Shortage Solutions Symposium, accessed January 23, 2021, https://www.symposium.solutions/.
[67] Rachel Carp, "Summary of PubInvCon 2021: Work to Be Done," PubInv (Public Invention, January 9, 2021), https://www.pubinv.org/2021/01/19/summary-of-pubinvcon-2021-a-work-to-be-done/.

Makers sharing ideas and questions in the Open Source COVID-19 Medical Supplies Facebook group.
Source: OSCMS Facebook group

Individual project designs came from all over the world, reflecting the truly global extent of the supply chain crisis. One of the earliest designs for isolation suits and gowns came from the Manila Protective Gear Sewing Club. The Vice President of the Philippines, Leni Robredo, sent the club isolation gowns and suits that were in short supply for reverse engineering. Once engineers from the club reverse-engineered the designs, the plans were posted publicly and became one of the first suit and gown patterns posted in the OSMS Project Library.

The OSMS Project Library hosts some of the many cloth mask designs makers used, but one of the most popular patterns was developed by Iris Luckhaus,[68] a German illustrator and sewist. Luckhaus, who was fed up with cloth masks fogging up her glasses, made a small change to the

[68] John Kalil, "Sewing Change: The Iris Luckhaus Story," Open Source Medical Supplies, July 13, 2020, https://opensourcemedicalsupplies.org/sewing-change-the-iris-luckhaus-story/.

nosepiece of a standard cloth mask design that eliminated fogging. Her post went viral on the OSCMS Facebook group with incredible user engagement and over 300 shares. Since then, tens of thousands of her cloth masks have been made around the world.

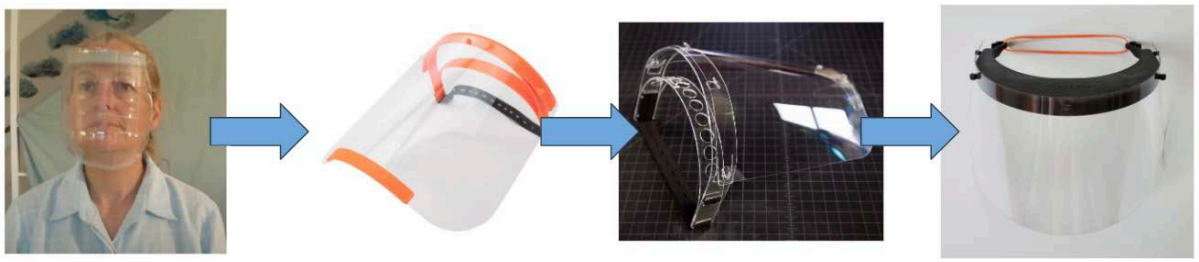
As open source designs developed, even the testing phase of these designs was facilitated through open source exchange. In the case of masks, for example, certified technical testing facilities specializing in particle filtration and fit testing became overrun with demands to test imported commercial PPE and new mask designs from pivoting domestic manufacturers. Testing was largely inaccessible for maker responders who didn't have significant financial resources.

> ***"Access to reliable, repeatable, and affordable testing for masks has remained a challenge for mask makers throughout the pandemic. Cost is prohibitive. Traditional testing of basic mask safety, efficacy, and filtration costs $3-5k per mask design and [doesn't] include validation for reuse. For FDA (510k) approval costs are typically 5-10x higher."*** — Dr. Jocelyn Songer, PhD, MakerMask, Athol, Colorado, United States

Open source efforts emerged to bridge this testing gap for the sake of the larger community. MakerMask became a trusted volunteer open source design hub, testing center, and database for the filtering efficacy of various plastics and cloths. It developed thorough documentation for at-home analog testing and performed professional analyses of commercially available mask materials.[69]

One of the earliest face shield designs came from the Prusa 3D printer manufacturing company,[70] a long-time proponent of open source designs. It has since acquired a European Union CE certification for making the shield on its printers,[71] and created instructions to help startup manufacturers acquire the certification themselves. Its initial design spawned a number of derivative open source designs, ranging from the DtM shield with forehead protection to specialized shields for other medical applications such as dentistry.

[69] MakerMask: Science-Based Mask Designs for Community Makers, accessed January 18, 2021, https://makermask.org/.
[70] Prusa3D: 3D printed face shields for medics and professionals, accessed January 18, 2021, https://www.prusa3d.com/covid19/.
[71] Josef Prusa, "How to Get a Certification for Face Shields," Prusa Printers Blog (Prusa Printers, June 2, 2020), https://blog.prusaprinters.org/how-to-get-a-certification-for-face-shields_36481/.



Our Human Planet
2-Liter Bottle Face Shield

Prusa RC1
3D-Printed Face Shield

Protohaven Proto Shield
Laser Cut Face Shield

Z-Verse Zshield Health
Injection Molded Face Shield

Evolution of face shield designs over time, starting with the Our Human Planet 2-liter soda bottle shield (left), to Prusa 3D-printed face shields (left center), to laser-cut face shields like the Protohaven Proto Shield (right center), to high volume injection molded shields like Z'Verse's Zshield. *Source: OSMS Project Library*[72]

Open source designs often reflected the designers' on-hand manufacturing capacity, and evolved as the need for supplies became more severe and manufacturing volumes had to increase. The first designs circulated for face shields could be manufactured with 2 liter soda bottles and scissors in a crisis. The next iteration of maker-manufactured face shields were designed for 3D printing, as it was one of the easiest and most accessible manufacturing processes to begin production immediately. A number of makerspaces and individual makers had 3D printers on-hand, and could begin printing right away once design files were available.

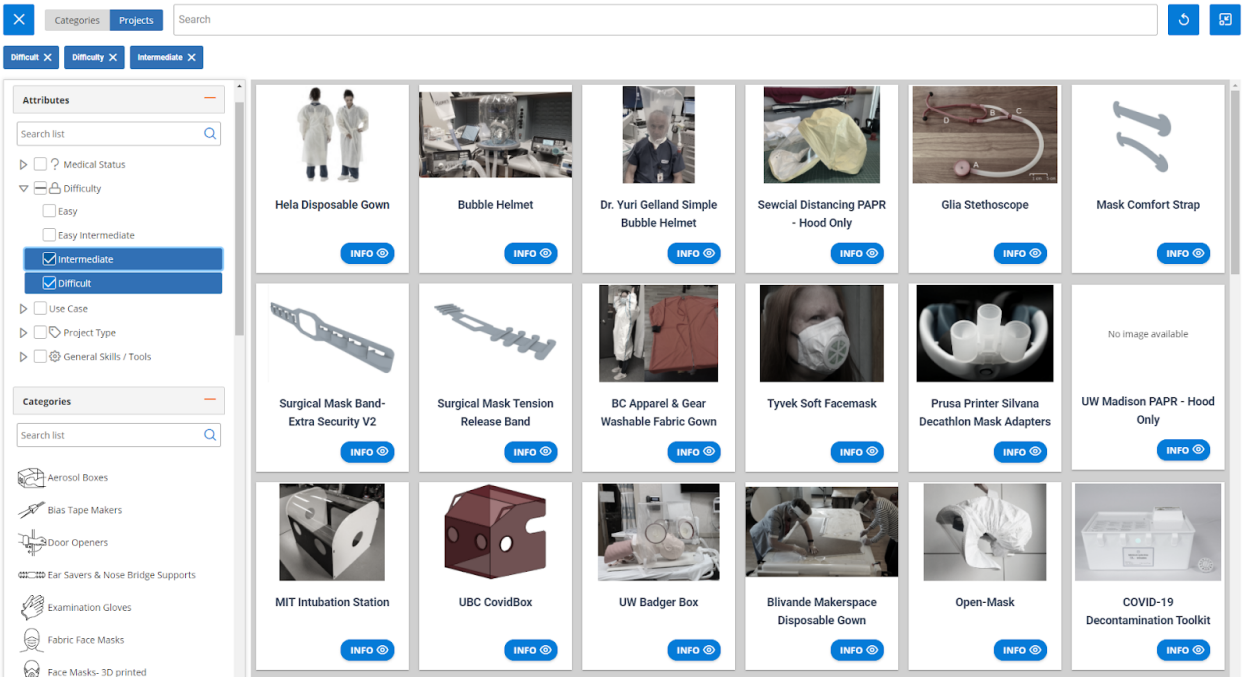
Later, face shields were designed for 2D laser cutting, which offered an order of magnitude faster production cycle over 3D printing, but is only available in dedicated manufacturing facilities or makerspaces. Ultimately, face shield designs evolved to utilize technologies such as injection molding, which could only begin after weeks of design and manufacturing of hardened tooling, but were significantly more productive than both 3D printing and laser cutting. As designers, engineers, and healthcare workers shared lessons learned in public forums, designs evolved to be cheaper, easier to manufacture, and more specific to the needs of users.

Open Source Design Repositories

As designs matured with feedback and testing, they were gathered and curated in digital design repositories. Some pre-existing open source digital repositories were populated with new designs for medical supplies, including Thingiverse's design library, the U.S. National Institute of Health's (NIH) 3D Print Exchange, Prusa's design forum,[73] and JOANN Fabrics' pattern library.[74] Other repositories were founded explicitly to host COVID-19 medical supplies, including the OSMS Project Library, which hosts over 200 unique designs across 35 medical

[72] Open Source Medical Supplies: Mask-Strap Lite, accessed January 21, 2021, https://osms.li/SeaMass.
[73] Prusa3D: 3D printed face shields for medics and professionals, accessed January 18, 2021, https://www.prusa3d.com/covid19/.
[74] "Create to Give: Donate Face Masks to Medical Personnel & More and More," JOANN, accessed January 15, 2021, https://www.joann.com/make-to-give-response/.

supply categories, and WikiFactory's ViralResponse community,[75] a platform dedicated to getting "the right products into the right hands'' during the COVID-19 supply chain disruptions.



The OSMS Project Library features hundreds of different projects across 30+ supply categories; designs were submitted from around the globe. *Source: OSMS Project Library*

These repositories vary in the type of manufacturing processes they serve and their degree of curation. Members of the public accessed designs in these repositories, often after being notified via viral social media posts in online communities that highlighted what the supplies could do for their communities, and began arranging for fabrication of these supplies for their communities. Some repositories led deliberate distributed efforts to create their own projects, such as JOANN, Prusa, and Budmen, a Syracuse, New York-based 3D printer manufacturer that released an open source face shield early in the pandemic.[76]

NIH's 3D Print Exchange, Prusa's design forum, and Thingiverse focused on designs that could be produced via 3D printer, while Joann's pattern library focused explicitly on textile goods. The OSMS Project Library and ViralResponse's community collected a variety of designs based on demand, agnostic of manufacturing process or tooling.

Existing libraries such as Thingiverse often allowed anyone to post designs for any purpose with no curation. OSMS focused on collecting designs that had been evaluated by public health officials in some capacity, and the NIH 3D Print Exchange utilized testing criteria "informed by standards from the FDA, CDC, and NIOSH, and best practices for 3D printing methods and

[75] Wikifactory: Viral Response, accessed January 18, 2020, https://viralresponse.io/.
[76] Budmen Industries: Budmen Face Shield, accessed January 21, 2021, https://budmen.com/face-shield/.

experience with medical device development."[77] Plans hosted by JOANN, Prusa and Budmen were developed by the companies themselves and were then released as open source projects.

Medical Evaluation and Collaboration

Many clinicians, hospitals, and laboratories partnered with maker responders and local manufacturers to design, prototype, test or evaluate open source PPE and medical supplies. In some cases healthcare workers and makers worked together to invent and produce new types of supplies specifically in response to the COVID-19 pandemic. These relationships were critical not only to local efforts, but to the broader response, as makers trusted healthcare workers to evaluate supply designs in the absence of state or national guidance. Healthcare workers and hospital systems were also more open to accepting maker-manufactured supplies (and makers had more faith in producing open source supplies) if they knew the designs had been evaluated or tested by other healthcare institutions.

Relationships between makers and healthcare providers varied significantly. Examples of medical-maker collaborations are described below.

Face Shields: New Use, New Design

Prior to the pandemic, face shields were infrequently used against airborne or droplet pathogens. With medical institutions facing severe shortages of N95 respirators, face shields provided barrier protection against virus droplets and prolonged the life of a single disposable N95 by days to weeks. Given this adapted purpose and the resulting high frequency of use, face shield designs required modifications to increase comfort and durability. **Rapid prototyping enabled regulatory agencies and clinicians to provide feedback on designs, and adjustments were often completed in a matter of days.**

Josef Prusa, of Czech Republic, developed one of the earliest open source face shield designs, the Prusa RC1. His design was then picked up in mid-March by Tim Prestero of the American non-profit Design That Matters (DtM) printed the Prusa RC1 shield for the Infection Control Department at the University of Washington Harborview Medical Center in Seattle.[78]

To improve protection from aerosolized virus particles, clinical staff requested a closed forehead design modification. Prestero presented a modified design with a slanted forehead visor (now called DtM-v3.1) two days later. The NIH expedited review of the DtM shield and on March 28, 2020 published the design as recommended for use in a clinical setting.[79] The regulatory

[77] NIH 3D Print Exchange (National Institutes of Health / U.S. Department of Health and Human Services), accessed January 23, 2021, https://3dprint.nih.gov/collections/covid-19-response/faqs.
[78] "Cross-Campus Effort: 3D-Printed Face Shields for Clinicians," UW Medicine Newsroom (University of Washington, April 16, 2020), https://newsroom.uw.edu/postscript/cross-campus-effort-3d-printed-face-shields-clinicians.
[79] DtM-v3.1 Face Shield PPE, 3D printable headband NO LOGO (U.S. Department of Health and Human Services / National Institutes of Health, March 31, 2020), https://3dprint.nih.gov/discover/3dpx-013359.

validation of this maker-originated design would eventually amplify production value of the device across multiple maker networks.

Protective Gowns: Tug Tests and Flying Fabric

Successful design and production of both disposable and reusable gowns was especially dependent on relationships between medical facilities and makerspaces or manufacturers. Gowns presented a unique manufacturing challenge as they required more skilled labor, specialized equipment and materials, and a longer manufacturing process compared to other PPE.

Disposable isolation gowns are made from plastic-based materials and require thermal or ultrasonic welding instead of sewing or other more-common fabrication processes. Makerspaces and retooled manufacturing facilities often had to purchase thermal and ultrasonic welders and set up assembly lines in order to produce disposable gowns. Washable fabric gowns, by comparison, require hydrophobically treated fabric to meet the minimum protection standards, and skilled sewists experienced in garment manufacturing.

Because of these requirements, gown production occurred primarily in groups able to organize centralized production lines and meet institutional approval processes. In March of 2020, Boston-area hospitals reached out to non-profit makerspace Artisan's Asylum in Somerville, Massachusetts to procure gowns, and helped guide the manufacturing and acceptance process.

> *"We researched all the ASTM, AAMI gown coverage and fabric permeability standards and found a ten-page, third-party analog test that we measured our fabric against. It was spun-bound, 35gsm material that was donated by Home Depot, the only material we could get in the beginning. There is a difference between testing raw materials and a finished gown so the hospitals told us that in the absence of testing [facilities], they were interested in the strength of the seams, the hydrophobic qualities of the fabric and how many we could possibly make.* ***Hospitals sent couriers to pick up prototypes made from everything from painters cloth to 3M sheeting and we let the hospital executives literally tug on each different prototype's seams to choose the strongest candidate.*** *Winner? Lawn fabric from Home Depot."* — Sarah Miller, Artisan's Asylum, Somerville, Massachusetts, United States

FABRIC Tempe, a fashion innovation center in Tempe, Arizona, was approached by local hospitals who "were completely out of items" and began a close partnership to meet the need,[80] and converted their manufacturing locations to accommodate FDA standards. A Dignity Health surgeon designed a gown pattern, which was tested in the in-house testing facility of Precision Fabric Group, a North Carolina fabric supplier that had previous experience with clean-room

[80] Angela Johnson, "FABRIC Ramps Up to Make PPE," F.A.B.R.I.C./LabelHorde/AZ Fashion Source/AZ Apparel Foundation (fabrictempe, March 31, 2020), https://www.fabrictempe.com/post/az-fashion-incubator-pivots-to-help-solve-ppe-shortage.

gown manufacturing.[81] Hospital administration purchased the fabric directly, thus reducing production cost, and it was flown to Tempe by the Arizona National Guard.[82]

By July 2020, FABRIC Tempe had manufactured over 80,000 FDA-approved reusable isolation gowns for both small and large healthcare facilities in Arizona.[83] At the time of publication, that number has grown to a staggering 500,000 reusable gowns.[84] FABRIC Tempe has since started a business, Reusa, for their PPE production, and, due to their prolific manufacturing, earned a visit from then-President Elect, Joe Biden, and Vice President Elect, Kamala Harris in October, 2020.

Intubation Boxes: Never Seen Before

In early 2020, with sustained shortages across PPE categories and minimal information regarding how COVID-19 spread, **clinicians themselves sought new solutions for protection when performing aerosolizing procedures.** Dr. Lai Hsien-Yung of Taiwan prototyped the first known intubation box—a simple housing made of transparent acrylic or polycarbonate that is placed around the patient during intubation.[85]

Clinicians testing an intubation box.
Source: Something Labs

News of the design spread quickly and U.S.-based hospital facilities, with the help of rapid prototyping and the maker community,[86] began testing and deploying both similar and modified designs.[87] While research suggests that some designs increase exposure to COVID-19,[88] those that incorporate design modifications such as negative pressure and active air filtration[89] or

[81] Sherri Barry of FABRIC Tempe, phone conversation with OSMS, January 15, 2021.
[82] Adam Waltz, "Dignity Health Partners with F.A.B.R.I.C. to Sew Reusable Isolation Gowns for Health Care Workers" (ABC15 News, April 14, 2020), https://www.abc15.com/news/state/dignity-health-partners-with-f-a-b-r-i-c-to-sew-reusable-isolation-gowns-for-healthcare-workers.
[83] Angela Johnson, "80,000 Medical Gowns Made!," F.A.B.R.I.C./LabelHorde/AZ Fashion Source/AZ Apparel Foundation (fabrictempe, July 20, 2020), https://www.fabrictempe.com/post/80-000-medical-gowns-made.
[84] Angela Johnson, "We've Produced 500K Medical Gowns!," F.A.B.R.I.C./LabelHorde/AZ Fashion Source/AZ Apparel Foundation (fabrictempe, January 14, 2021), https://www.fabrictempe.com/post/we-ve-produced-500k-medical-gowns.
[85] Aerosol Box Design (Dr. Hsien Yung Lai), accessed January 18, 2021, https://sites.google.com/view/aerosolbox/design.
[86] "Rutgers Supplies Hospitals With PPE to Battle COVID-19," Rutgers University, accessed January 18, 2021, https://www.rutgers.edu/news/rutgers-supplies-hospitals-ppe-battle-covid-19.
[87] "Aerosol Containment Chamber to Make COVID-19 Intubations Safer," Robert E. Fischell Institute for Biomedical Devices (University of Maryland), accessed January 23, 2021, https://fischellinstitute.umd.edu/news/story/aerosol-containment-chamber-to-make-covid19-intubations-safer.
[88] JL Begley et al., "The Aerosol Box for Intubation in Coronavirus Disease 2019 Patients: an in-Situ Simulation Crossover Study" (U.S. National Library of Medicine, June 1, 2020), https://pubmed.ncbi.nlm.nih.gov/32397008/.
[89] David M Turer, Cameron H Good, and Benjamin K Schilling, "Improved Testing and Design of Intubation Boxes During the COVID-19 Pandemic," The American College of Emergency Physicians (U.S. National Library of Medicine / National Institutes of Health, September 3, 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7470714/.

plastic drapes[90] appear to be effective at reducing exposure to aerosolized virus particles. **The original design of the intubation box, though not perfect, inspired valuable innovations that may become mainstays for clinical practice.**

Respirators & Masks: Catalysts for Collaboration

The shortage of N95 respirators was a catalyst for the maker-medical collaboration. Some of the earliest cloth mask patterns evolved as protection for existing commercial N95s, with hospitals publishing designs and requesting that community sewists drop-off finished masks at designated collection points.[91] Since it was unknown how long the N95 shortage would last, new mask designs were innovated as a stopgap, including reusable rigid respirators and non-woven polypropylene (NWPP) masks.

Clinicians and makers worked side-by-side, perhaps more so than for any other design category, to develop and test prototypes with hopes of achieving N95-level or near N95-level filtering effectiveness. The University of Southern Mississippi's 3D printing lab, Eagle Maker Hub, collaborated with Hattiesburg Clinic and Forrest General Hospital to design, test, and produce a thermoformed respirator mask shell which then had a viral filter added by medical facilities. Community sewists made fabric straps and the masks were successfully used in clinical settings.[92] The design was open sourced and supported by the Mississippi Polymer Institute (MPI).[93]

In another example of collaboration, the University of Florida anesthesiology department developed a mask made from non-woven polypropylene (NWPP) Halyard H600, which could be successfully fit-tested. Local maker Georgette Graham was engaged to sew mask prototypes and compile mask-making kits that were distributed to other sewists in the community. Finished masks were then brought back to the hospital for sterilization before use.[94] Although the design was created and tested by the anesthesiology department, the maker production network was critical for broad clinical reach.

[90] Huong Brown, David Preston, and Ravi Bhoja, "Thinking Outside the Box A Low-Cost and Pragmatic Alternative to Aerosol Boxes for Endotracheal Intubation of COVID-19 Patients," NCBI (US National Library of Medicine National Institutes of Health, May 29, 2020), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7288769/.
[91] Mask Production (Phoebe Health), accessed January 22, 2021, https://www.phoebehealth.com/patients-and-visitors/coronavirus/mask-production.
[92] Erica Hensley, "Q+A With Southern Miss' Anna Wan, Maker of 'The Hub Mask' for COVID-19 Protection" (Mississippi Today, April 14, 2020), https://mississippitoday.org/2020/04/14/qa-with-southern-miss-anna-wan-maker-of-the-hub-mask-for-covid-19-protection/.
[93] Hub Mask (Eagle Maker Hub), accessed January 22, 2021, https://www.eaglemakerhub.org/hubmask/.
[94] Leah Buletti, "UF Health Anesthesiology Team Devises Respirator Mask Made from Existing Hospital Materials" (University of Florida, March 26, 2020), https://ufhealth.org/news/2020/uf-health-anesthesiology-team-devises-respirator-mask-made-existing-hospital-materials.

Organizing for Production

Thousands of small, locally-focused groups emerged to coordinate, produce and distribute supplies for their specific regions. These existed in parallel to the large, centralized design and engineering-focused groups such as the OSCMS Facebook Group, Helpful Engineering Slack and Nation of Makers email lists. These smaller groups made use of Facebook, WhatsApp, Telegram, Reddit, Discord, Slack, existing maker forums and websites, mailing lists and other digital tools to communicate and coordinate their regional COVID-19 response.

Individuals who responded to early demand signals looked for help across their personal networks to gather other volunteers, build momentum, and acquire the resources needed to produce supplies locally. People already affiliated with makerspaces, Fab Labs, universities, colleges or K-12 schools often organized volunteer efforts within those spaces. Business owners pivoted their production lines to answer calls from local healthcare systems.

A maker keeping inventory on the face shield assembly line in Rio de Janeiro, Brazil.
Source: Marcelo Balisteri

Individuals who were not part of a pre-existing institution often formed or joined social media-based networks focused on responding locally. These networks often consisted of hundreds to thousands of individual makers or crafters with fabrication equipment in a given region such as a city, county, or state. In some cases, existing makerspaces, Fab Labs, schools, and other institutions came together to form new, cross-organizational networks.

Social media platforms provided easy ways to form, join, and share new emergency response groups across existing networks. New groups gained tremendous momentum early in the pandemic when pre-existing networks of makers migrated to new groups en masse as a result of viral social media posts. Both new and pre-existing social media channels were critical to building volunteer engagement, communicating and sharing accurate information and guidance, assigning work, and connecting to demand.

In a very short period of time, these citizen-led production initiatives evolved into demanding and complex organizational structures which required a tremendous range of expertise. The mostly-volunteer workforce in these groups devoted tremendous numbers of hours in an attempt to meet the growing demand for supplies and the increasing responsibilities of an emerging organization, which included:

- Growing and moderating community forums.
- Building collaborations to design and produce products, source materials, develop production lines and workflows, and troubleshoot scaled manufacturing.
- Organizing volunteers to make parts, assemble items, pick up or allocate materials, and sanitize, package, and label the final product.
- Organizing and coordinating regular team meetings.
- Managing workflows and orders via intake forms, spreadsheets, and Airtable[95] databases.
- Identifying and logging needs, aggregating sufficient product for distribution, coordinating product drop off, and sometimes even shipping materials or supplies.
- Raising funds to purchase materials by developing websites and crowdfunding campaigns.
- Reaching out to pre-existing and potential new partners to secure in-kind donations and monetary contributions.
- Engaging government and emergency response officials for coordination and support.
- Soliciting and responding to press inquiries to spread the word about their efforts and raise interest in the communities, which often led to future funding or materials donations.

Discussion forums similarly evolved from questions focused on design solutions to include questions about production approaches, liability, packaging, labeling, distribution and more.

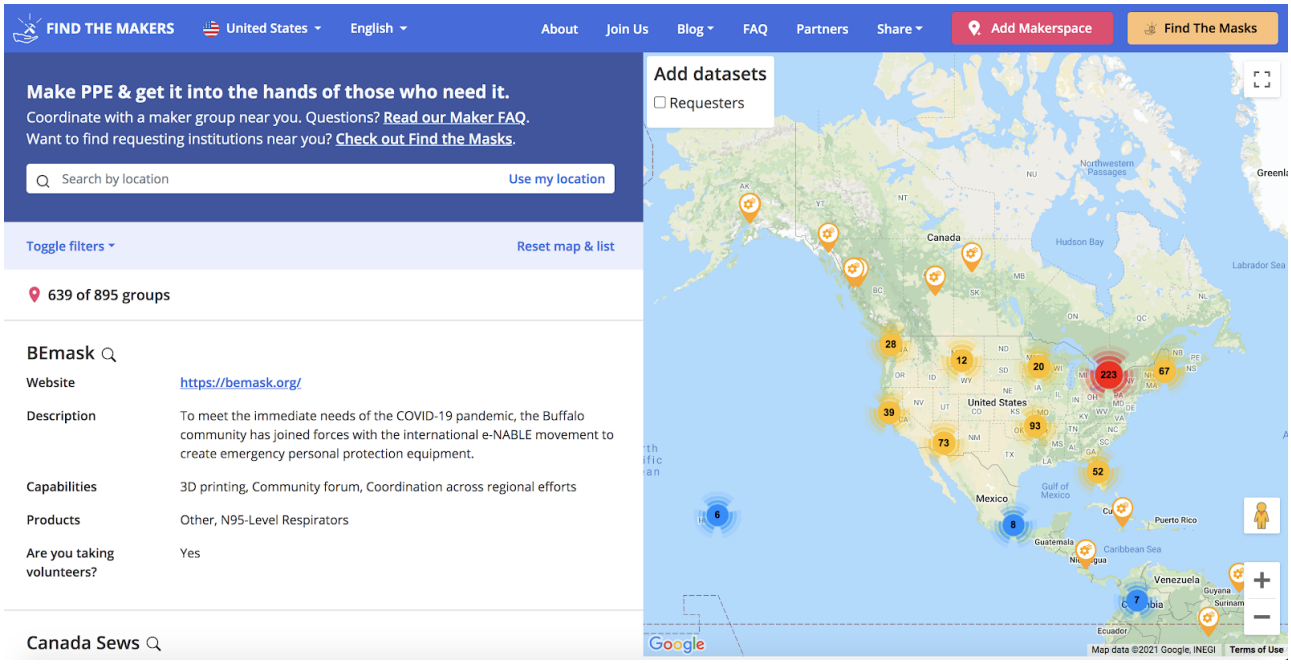
Makers producing face shields in manufacturing line style at OSMS Cape Fear, North Carolina. *Source: Kyle Horton*

On March 24, 2020 OSMS launched a registration form and "Local Response Network" for Citizen Maker Response groups in order to map the global effort and share best practices.[96] Two days later, OSMS released version 1 of the Local Response Guide, a repository of best practices for local emergency manufacturing responses.[97] On April 9, YouTube maker-influencer Destin Sandlin (Smarter Every Day) released a powerful and clear portrait of a grassroots Citizen Maker Response in Huntsville, Alabama, documenting many aspects of the distributed manufacturing and distribution effort.[98]

[95] "Airtable's Support for COVID-19 Response Efforts" (Airtable: For the Record Blog, March 16, 2020), https://blog.airtable.com/airtables-support-for-covid-19-response-efforts/.
[96] "Local Response World Map," Open Source Medical Supplies, November 13, 2020, https://opensourcemedicalsupplies.org/local-response/map.
[97] "Local Response Guide," Open Source Medical Supplies, January 19, 2021, https://opensourcemedicalsupplies.org/local-response/
[98] Destin Sandlin, Huntsville's Early Community Response to COVID-19 - Smarter Every Day 233 (YouTube, April 7, 2020), https://www.youtube.com/watch?v=sbEj7M3aZIg.

The video gained immediate traction, publicizing best practices for the Citizen Maker Response, and, at the time of publication, has accumulated over 600,000 views. These types of examples and playbooks helped small groups across the globe self-organize into effective emergency responders.

The larger organizing groups started to track and then map the Citizen Maker Response groups producing supplies, both to connect makers to each other and help healthcare workers and the public locate supply. Nation of Makers was tracking U.S. efforts, and collaborated with #FindtheMasks, a North American PPE donation match platform, to create a new layer of their map. FindTheMakers featured local production locations with an option to overlay the FindtheMasks PPE request data. Shortly thereafter, OSMS Local Response and the Fab Foundation Fab Lab networks shared their data sets with FindtheMakers, resulting in the most comprehensive view on the international Citizen Maker Response. As of publication date, 895 maker response groups and 3,865 requesting organizations have been listed on FindTheMakers, with most activity taking place during Q1-Q3 2020.



A global map for those making or searching for PPE. *Source: FindtheMakers.com*

Sourcing Raw Materials

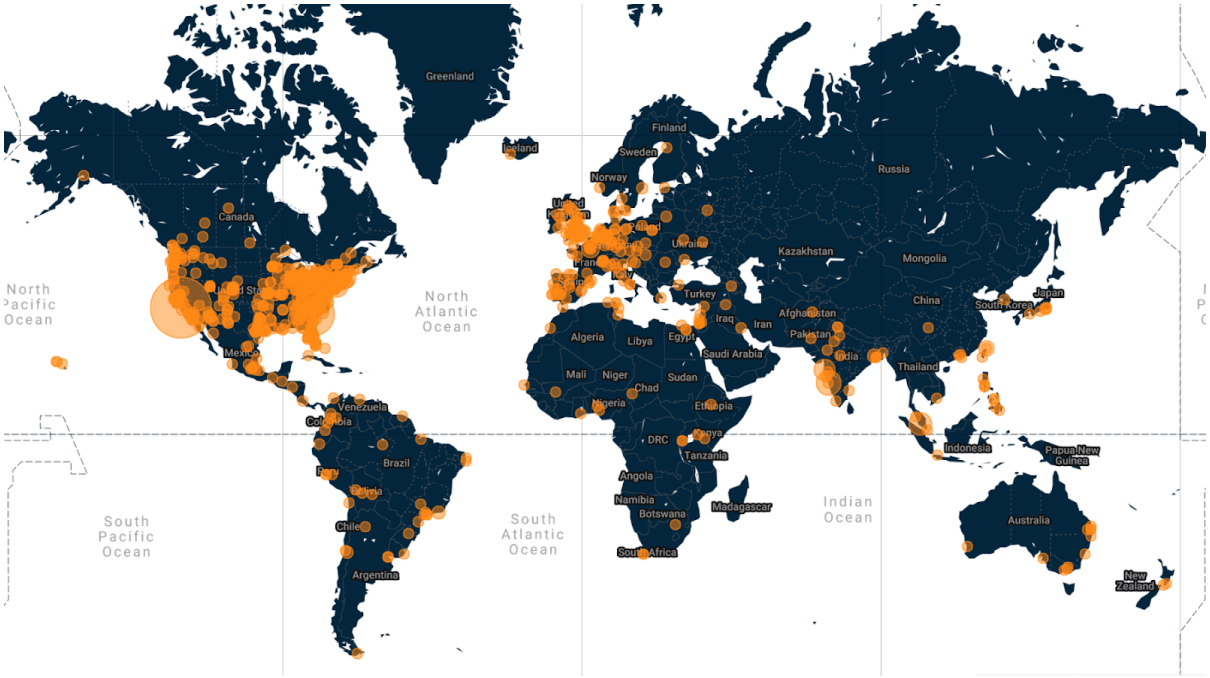
Finding the raw material sources necessary for production, such as plastic filament for 3D printing, transparent PETG plastic, fabric, elastic, and more became a costly challenge for fabricators. As supply chains dried up because so many manufacturers were making PPE

simultaneously, prices soared and inventories were depleted.[99] Several makerspaces reported having to send members out to every hardware store within driving distance in order to acquire raw materials like transparent plastic, Tyvek home wrap for isolation gowns, and more. Elastic cord and filtering material for masks became incredibly difficult and expensive to acquire.

Makers in the 70,000 member OSCMS Facebook group also found that network to be a source of raw materials. Members freely shared when a company had supplies in stock or was offering a discount to those helping with the PPE crisis. Members with extra material they could not use frequently advertised it for sale or gave it away for free if picked up locally (or sold material for the cost of shipping, if needed). In one instance in April, 2020 one member who sold elastic cord on her Etsy shop received a large overseas shipment that had been placed prior to the pandemic. She offered her elastic cord, at cost, to makers in the group. This enabled many sewists to resume their cloth mask making, which had stalled due to the lack of availability of elastic cord from commercial sources. At the time of this posting, members of the OSCMS Facebook group are still using it as a place to trade and give away raw materials for making PPE and medical supplies.

Distribution of Medical Supplies

Figure 4: Production locations of 48.3 Million pieces of maker-made PPE



Source: OSMS and NoM Community Impact Survey data

[99] Christopher Reynolds, "Manufacturers Competing for PPE Raw Materials," Inside Logistics (The Canadian Press, May 24, 2020), https://www.insidelogistics.ca/features/manufacturers-competing-for-ppe-raw-materials/.

Locating demand signals and organizing distribution was another significant scope of work for local response groups. Many community campaigns and national hubs (e.g. Get Us PPE or FindTheMasks) were created to locate and redistribute commercial products. In some instances local groups coordinated with those entities to leverage their data to deliver maker-made products where acceptable; however, the vast majority of groups relied on gathering their own local intelligence and demand requests.

> *"I learned that distribution is the most expensive and difficult thing to accomplish—manufacturing is comparatively quite easy!"* — Sam Neff, Richmond High Robotics Team 841, Richmond, California, United States

As groups matured, supply requests arrived through a variety of channels. Groups created request forms on their websites, and team members fielded requests from healthcare and essential workers posted in their social media groups and forums. Once organized and in production, many proactively reached out to procurement officers at hospitals, health care facilities, and social service agencies to discover unmet needs. Pre-existing relationships in the community continued to facilitate distribution, especially to hospitals.

> *"Most of our sales and distribution were based on personal contacts."*
> — Will Holman, Open Works/Makers Unite, Baltimore, Maryland, United States

> *"We connected with the Cleveland Clinic's innovation team and their procurement team. One of our former vice presidents who helped make think[box] possible now works at the Cleveland Clinic foundation as the chair of their Philanthropy Foundation. I knew that we needed to get connected quickly, so I reached out to her and she immediately introduced me to people pretty high up the ladder, who got things moving for us."*
> — Ian Charnas, Sears think[box], Case Western University, Cleveland, Ohio, United States

In some instances, distribution of finished products was undertaken by partner organizations. Bicycle messengers and motorcycle clubs like Dames Do Care[100] in San Francisco, California and Blood Bikers East in Dublin, Ireland[101] pitched in to deliver supplies, often to individual clinicians.

> *"We were doing drop offs at people's homes or meeting them in parking lots and handing PPE over. Not going through official channels, we weren't selling the PPE, just trying to get it to people who were desperate and who were telling us they had no other alternatives. We were getting them something to help keep them safer."*
> — Hannah House, NYCMakesPPE, New York City, New York, United States

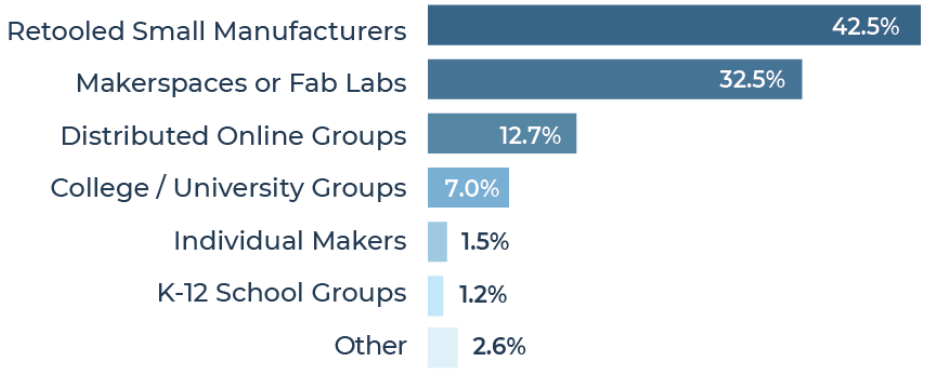
[100] Don Ford, "'Dames That Care' Women's Motorcycle Club Delivers Coronavirus PPE To Bay Area 1st Responders" (CBS San Francisco, April 7, 2020), https://sanfrancisco.cbslocal.com/2020/04/07/better-together-coronavirus-womens-motorcycle-club-delivers-ppe-first-responders/
[101] Kojii Helnwein, "Motorcycle Volunteers Fight COVID19" (Motowitch), accessed January 20, 2021, https://motowitch.com/motorcycle-volunteers-fight-covid19/.

In other scenarios, items were picked up directly by police or healthcare workers (such as in India's C-19 coalition), driven directly to facilities by volunteers (as in the case of the "Smarter Every Day" team in Huntsville, Alabama),[102] or shipped through corporate partner sponsorships, exemplified by Amazon helping the Face Shield Hub in Seattle, Washington.[103] Some developed distribution networks, pooling smaller local batches into regional distribution hubs, such as Germany's "Maker Hub" system.[104]

Who Produced Supplies

The Community Impact Survey and Fab Foundation global datasets reveal that **42.5% of items were produced by retooled small manufacturers** making medical supplies for the first time—the largest quantity of items—followed by **32.5% from makerspaces and Fab Labs** whose members worked together to produce supplies, **12.7% from distributed online groups** of individuals and organizations, **7.0% from college and university groups** whose manufacturing equipment had been repurposed, and **1.2% from K-12 school groups**.

Figure 5: Production by organization type



Source: OSMS and NoM Community Impact Survey data, Fab Foundation Survey data

[102] Pat Duggins and Will Green, "A Space Age Answer to a COVID-19 Problem in Huntsville" (Alabama Public Radio, April 28, 2020), https://www.apr.org/post/space-age-answer-covid-19-problem-huntsville.
[103] Brad Porter, "Using Prime Air's Innovation and Scale to Help Protect Medical Professionals," About Amazon (Amazon, September 23, 2020), https://www.aboutamazon.com/news/innovation-at-amazon/using-prime-airs-innovation-and-scale-to-help-protect-medical-professionals.
[104] "National Case Study: Germany's Maker Response against COVID-19," Open Source Medical Supplies, September 16, 2020, https://opensourcemedicalsupplies.org/national-maker-response-case-studies/germany/.

In the United States, an even greater percentage of total supplies produced—52.8%—was reported by retooled small manufacturers. Makerspaces and established Fab Labs produced 26.8% of the U.S. total, 8.5% came from universities or colleges, 5.9% came from distributed online groups, 1.6% came from individual makers producing supplies, and 1.1% were made by K-12 schools.

All these groups served as emergency manufacturing responders for their local communities. In many cases, these groups were first to provide medical supplies to healthcare facilities once they had run out.

Makerspaces

OSMS, NoM, and Fab Foundation data indicate that makerspaces in 54 countries participated in medical supply design and production for their local communities. Makerspaces served as critical design centers, improvised factories, coordination hubs, and distribution facilities throughout the pandemic. They responded to early requests for PPE production, designed medical supplies on-demand as institutions needed them, coordinated tens to hundreds of volunteers each, and filled gaps in the medical supply chain as they appeared throughout the early pandemic. Their inherent flexibility, production capacity, and pre-existing communications networks were critical for early and fast response across a number of axes.

Makers producing face shields in manufacturing line style at OSMS Cape Fear, North Carolina.
Source: Kyle Horton

To the extent that makerspaces serve as community centers for entrepreneurship, education, and workforce development, they often also have regional connections to other makerspaces, social service and non-profit organizations, and government officials. During the COVID-19 pandemic, **makerspaces forged new and necessary partnerships with local healthcare institutions and began serving as both improvised production facilities for medical supplies and design/prototyping facilities to create new products and improve on existing designs.**

Makers producing face shields in manufacturing line style at OSMS Cape Fear, North Carolina.
Source: Kyle Horton

One example of prototyping, production and open-source sharing was Artisan's Asylum. The Asylum was approached by several healthcare institutions in the Boston area to produce isolation gowns and other PPE that was in short supply. Their team reverse-engineered several isolation gown designs from products provided by local hospitals, identified local supplies of raw materials in hardware stores, acquired an ultrasonic welding tool from a nearby manufacturer, and arranged for over 80 volunteers to contribute to an improvised production line that manufactured 27,000 isolation gowns by the end of September 2020 with a grant from Get Us PPE.[105] The Asylum has since shared gown designs, best practices, and tips and tricks with other makerspaces to help them set up their own gown production lines across the U.S.

[105] Cristina Quinn, "A Pop-Up Business For These Times: Welcome To Gowntown," News (GBH, July 23, 2020), https://www.wgbh.org/news/local-news/2020/07/21/a-pop-up-business-for-these-times-welcome-to-gowntown.

Maker Nexus, a 501(c)3 non-profit makerspace in Santa Clara, California, was shut down by California's early quarantine and immediately began manufacturing PPE on its idle laser cutters and 3D printers. It recruited 600 members and volunteers to form both a distributed and centralized manufacturing operation. The distributed home-bound volunteer-makers shipped parts to the makerspace headquarters for assembly and distribution, which then shipped PPE to 570 organizations throughout the U.S. The Maker Nexus network produced 70,000 face shields and 5,000 cloth masks over the course of 4 months.[106]

In Durango, Colorado, the San Juan Regional Medical Center reached out to the MakerLab, a makerspace in the Powerhouse Science Center. The medical center notified MakerLab that it was running low on supplies, and MakerLab began designing and producing these necessary supplies with a network of over 160 makerspace volunteers within 7 days. MakerLab designed a variety of PPE including face shields and advanced ICU-grade supplies such as Powered Air Purifying Respirators (PAPR) and matching hoods. The design process for complex PAPR units took just 72 hours from request to prototype. The materials used in their construction were not FDA approved, so the Farmington Fire Department's biohazard and hazmat coordinator tested and approved them for local hospital use.[107] MakerLab then shared these designs with the public through the OSMS Project Library.

College & University Makerspaces

PPE and medical supplies were also produced in shuttered college and university campuses. In the case of Modesto Jr. College, in Modesto, California, the effort was spearheaded by Biology professor Dr. David Martin, who was contacted by former students working at the local hospital alerting him to the PPE shortages they faced. Following initial design work, he brought together other faculty members and students from across disciplines to improve face shield design and production.

Makers at The Powerhouse in Durango, Colorado assembling PAPR devices on emergency order for a nearby hospital. .
Source: The Powerhouse

The College gave the go-ahead and its foundation provided an initial grant of $2,000.[108] As production increased, the remainder of the costs were covered by the fabricators themselves. Recipients of the PPE included the Bay Area healthcare workers and local non-profits such

[106] "COVID Face Shield Story," COVID Shield Nexus, accessed January 18, 2021, https://www.covidshieldnexus.org/covid-faceshield-story.
[107] Jonathan Romeo, "Durango MakerLab Brings Protective Gear to Health Care Workers," Durango Herald (Durango Herald, April 4, 2020), https://durangoherald.com/articles/320352.
[108] "MJC Student and Instructors Create 3D PPE - MJC," Modesto Junior College, accessed January 21, 2021, https://www.mjc.edu/news/student3dppe.php.

as Veterans Homes of California.[109] Modesto Junior College students on hospital internships were not only protected, but also gained valuable education on the benefits of properly functioning and fitting PPE.

Case Western's SUDS (Synchronous UV Decontamination System), An open source UV mask decontamination solution for nurse stations, is now being brought to market by a medical device firm. *Source: Case Western University / Sears think[box]*

The UW-Makerspace in Madison, Wisconsin created their own open source face shield design called the Badger Shield, and partnered with Ford Motors and other large companies to produce hundreds of thousands of shields. The team also developed matching distribution software which sent Badger shields out based on urgency, location, and quantity needed. The university makerspace later designed the Badger Shield+, a face shield incorporating a cloth hood with a neck closure which offers more droplet protection than a traditional face shield, along with two other types of face shields that protect doctors wearing specialty glasses incompatible with traditional face shield designs.[110]

Engineers from Sears think[box] at Case Western Reserve University worked closely with leaders at Penn State Behrend college and product design company Nottingham Spirk to set up a face shield manufacturing line and produce approximately 150,000 easily-sterilized face shields using injection molding and die cutting. The think[box] team sold the face shields through an electronics manufacturer in western Pennsylvania at cost in order to ensure financial sustainability.

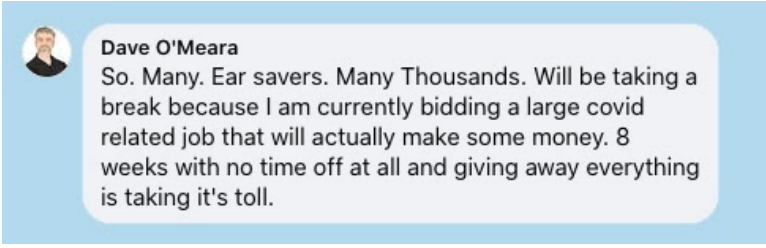
Additionally, Sears think[box] partnered with a community Fab Lab in a low income Cleveland neighborhood to laser cut 8,000 face mask kits for distribution in that neighborhood. The organization also developed a unique design for a desktop UV chamber for N95 mask sterilization that has been licensed to a manufacturer with the intention of bringing it to market.

Individual Makers

Some makers (40% of respondents surveyed by OSMS and NoM) created supplies on their own, delivering directly to their immediate communities and never joining a larger group. While these makers excelled in the production of cloth masks and face shields, they also produced a staggering number of ear savers, which are easy to print on a home 3D printer and were in high demand as many essential and healthcare workers adjusted to wearing a mask for entire work days.

[109] 2020 by Jeff Jardine in Veterans May 18 and Veterans Home of California Tags: COVID-19, "Shielding Veterans And Staff At Veterans Homes Of California Gets A Boost From Ppe-Making Modesto Junior College Group," calvetconnect.blog, May 19, 2020, https://calvetconnect.blog/2020/05/18/shielding-veterans-and-staff-at-veterans-homes-of-california-gets-a-boost-from-ppe-making-modesto-junior-college-group/.
[110] "Makerspace's Covid-19 Response," UW Makerspace, accessed January 21, 2021, https://making.engr.wisc.edu/shield/.

Without access to a centralized source for demand data in their region, individual makers reported that they struggled to discover PPE needs in their communities. Though some individual makers had success providing for frontline workers,[111] many found that hospitals and other healthcare institutions were wary of homemade supplies from unsolicited sources, so individuals often partnered with a friend or family member who was a healthcare worker and used that personal connection to donate supplies. Overall, individual makers found it easier to sell their supplies online or donate their supplies to non-medical essential workers, such as police departments, school staff, restaurant workers, and retail workers, since they did not have the pre-existing restrictions on PPE usage that healthcare facilities do.



Source: OSMS South & Central Florida Facebook Group

Some individual makers, like Dave O'Meara of Venice, Florida produced on their own but partnered up with local response groups (OSCMS - South & Central Florida, in O'Meara's case) for help with the distribution of their product. **O'Meara was one of the first makers in the OSCMS community to begin printing ear savers, and at the time of this writing has produced over 100,000.** He also curated his own collection of ear saver files that he tested and made available to the OSCMS community.[112] O'Meara worked tirelessly to help his community, dedicating his personal time and the use of his 3D printing farm, and largely covering the cost of materials.

Sewist Nicole Angell of Dahlonega, Georgia produced 2,350 cloth masks on her own, working long days for weeks at a time to produce masks for her community, and recalled the early days of the pandemic saying, "At the height (March, April, May, June) I was working 12-14 hours a day trying to cut, sew, and package fitted facemasks. When I started out my main sewing machine broke down & I couldn't get it serviced until mid-May. I hauled out a 30 year old [sewing machine] scrubbed it, oiled it and used it for six weeks." After donating some of her masks, she found commercial success by listing her masks for sale on her Etsy and Zibbet shops[113] to help cover the cost of materials for her donations.

Nicole Angell sewing face masks in Dahlonega, Georgia. *Source: Nicole Angell*

[111] Joelle Goldstein, "West Virginia Engineer Uses 3D Printer to Make Hundreds of Face Shields for Health Care Workers," PEOPLE.com, April 6, 2020, https://people.com/human-interest/west-virginia-engineer-3d-printer-face-shields-health-care-workers/.
[112] "Facebook Groups," Facebook (Facebook Groups), accessed January 21, 2021, https://www.facebook.com/groups/opensourcecovid19medicalsupplies/permalink/707658443377884.
[113] "In Every Life Some Magic Must Fall.," enchantedcraft, accessed January 21, 2021, https://enchantedcraft.zibbet.com/shop.

Nick Franklin had an idea for an ear saver design and used feedback from the OSCMS Facebook Group to help him iterate the design and work through testing. In August, 2020 his SeaMass ear saver design was finalized and the design files were published under an open-source license—free to anyone who wanted to print their own. **Franklin currently sells injection molded versions of the SeaMass ear saver on Amazon**,[114] but the files remain free for the 3D printing community through the OSMS Project Library[115] and makers can still produce and distribute them in their communities.

Source: OSCMS Facebook Group[116]

Retooled Manufacturers

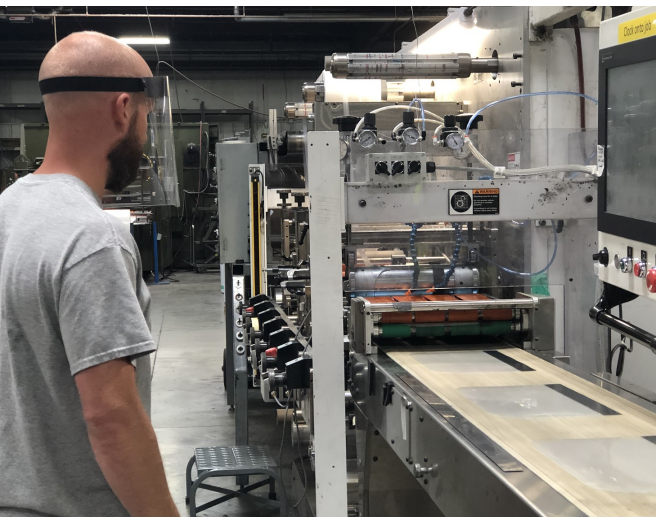
The largest source of new medical supplies outside of the traditional medical supply chain were small and mid-size manufacturing businesses that retooled existing manufacturing equipment and retrained employees to produce new supplies. These manufacturers commonly found that demand for their existing product line faltered, or that the pandemic was affecting their communities in ways they could help impact. Some state governments, hospitals, and other institutions reached out to small manufacturers, asking them to retool and produce PPE, but many simply retooled on their own.

Kaas Tailored, a 46 year old textile company in Mukilteo, Washington that specializes in furniture upholstery, is one such retooled manufacturer. In March 2020, the Providence chain of 51 hospitals requested help making PPE and within 48 hours Kaas had incorporated a subsidiary called Kaas Health and began focusing on face masks and face shield production for the community.[117] Kaas sourced its raw material from Providence, which individually approved their design for hospital use. Kaas then partnered with Nordstrom in March to produce 100,000 cloth masks for Providence,[118] set a goal to eventually produce one million masks with Nordstorm's

[114] Ear Love Mask Adjuster (20) (Amazon, n.d.), https://www.amazon.com/dp/B08FQDY3W1/.
[115] Mask-Strap Lite (Open Source Medical Supplies), accessed January 22, 2021, http://osms.li/SeaMass.
[116] Nick Franklin, "Being a Part of This Group Has Been an Incredible Experience.," Open Source COVID-19 Medical Supplies Facebook Group, August 8, 2020, https://www.facebook.com/groups/opensourcecovid19medicalsupplies/permalink/783824835761244.
[117] Purchase PPE (Kaas Tailored), accessed January 18, 2021, https://kaastailored.com/ppe/.
[118] @Nordstrom, "Last Week, We Asked You What Kind of Content You'd like to See from Us ..." (Instagram, March 24, 2020), https://www.instagram.com/.

help,[119] and was one of the first traditional manufacturers to upload open source, manufacturing-grade plans, machine instructions, and blueprints for cloth masks and face shields for other manufacturers.[120] This fast sharing of information allowed for other manufacturers to retool and use their patterns to mass produce masks.

Daniels Wood Land (DWL) in Paso Robles, California is another example. The 25-year-old company produced tree houses pre-pandemic, was considered non-essential, and had to shutter operations during the early California quarantine. The company closed its doors, laid off 54 employees, and started asking local fire department officials how they could help. The fire department provided them with an isolation gown that was in short supply, the company reverse-engineered it within 24 hours and began production.[121] Since the beginning of the pandemic, DWL has hired an 400 staff to produce and distribute over 7 million isolation gowns, and continues to produce tens of millions of gowns for federal contracts.



JBC Technologies retooled during the pandemic to produce 300,000 die-cut face shields. *Source: JBC Technologies*

In Minnesota, two companies, Frost River Trading Company and Duluth Pack, retooled after their state's quarantine began in late March and their usual canvas and leather luggage operations were shut down. The wife of the Frost River founder, Chris Benson, was an anesthesiologist and alerted him to the upcoming shortage of PPE. Both companies pivoted to produce face shields and cloth masks, producing 45,000 face shields for the St. Luke's and Essentia Health hospital systems in Duluth. Frost River produced 2,000 cloth masks a day with a team of 33 part-time sewists and Duluth Pack produced 200,000 gowns for hospitals, doctor and dental offices, and assisted living facilities.[122]

Some 3D printer manufacturers, formerly providing or curating designs for the open source hardware ecosystem as a fundamental part of their business model and value proposition, moved quickly to activate their maker communities with designs they developed. Budmen, a Syracuse, NY 3D printer manufacturer focused on artists and creatives, spent 24 hours designing a face shield on March 14, 2020. Within 24 hours, 500 people had downloaded

[119] "Working Towards Nearly 1 Million Masks," Nordstrom, accessed January 18, 2021, https://press.nordstrom.com/news-releases/news-release-details/working-towards-nearly-1-million-masks.
[120] "Manufacturing Friends," Kaas Tailored, accessed January 18, 2021, https://kaastailored.com/manufacturing-friends-update/.
[121] Brooke Martell, "Local Company Manufacturing Protective Gowns for First Responders," (KSBY, April 20, 2020), https://www.ksby.com/news/we-have-orders-for-nearly-a-million-gowns-local-company-is-manufacturing-protective-gowns-for-first-responders.
[122] Dan Kraker, "Northern Minn. Companies Step in to Help Fill PPE Shortage," MPR News (MPR News), accessed January 18, 2021, https://www.mprnews.org/story/2020/04/30/local-companies-step-in-to-fill-ppe-shortage.

their design and began printing it.[123] Over the course of the pandemic, they would manufacture over 28,000 of their Budmen face shields through their distributed network.

Small manufacturers have proven their ability to both pivot quickly and become incredibly productive in the face of the COVID-19 pandemic. Many engaged directly with healthcare and community customers that needed products, and were able to supply significant portions of the product demanded. Some shared professionally-developed designs that aligned with their specializations, which accelerated local and global response.

Distributed Manufacturing Networks

In addition to individual makers, makerspaces and small manufacturers, a new approach to manufacturing provided a significant number of supplies throughout the pandemic. Distributed manufacturing networks, organized online and often consisting of collaborative networks of companies, makerspaces, schools and/or individuals that owned fabrication equipment, sprang up across the world to provide a significant volume of PPE to their regions based on shared open-source design files.

One early and significant example of small businesses forming a distributed manufacturing network was Z-Verse, a Columbia, South Carolina-based software developer that builds distributed manufacturing software tools. In late March 2020, it began receiving calls for help from local medical institutions and government officials, and in response developed a face shield design that was freely distributed to 20 separate injection molding companies. It provided a single ordering interface to the public, and coordinated group orders and production efforts across the participating companies to manufacture and ship over 4.6 million face shields over the course of 3 months. The face shields were shipped to the U.S. Department of Veterans Affairs, the South Carolina Emergency Management Division, and local hospitals in Palmetto State.[124]

In late March and early April 2020, the Illinois PPE Network formed across the state of Illinois. DePaul University makerspace leadership organized the network, which included Northwestern University, Chicago Public Schools, Chicago Public Libraries, the Museum of Science and Industry, the Chicago Peace Fellows, and various Illinois makerspaces, libraries, and schools across the state. This network shared designs for face shields and cloth masks, and linked producers directly to donees that needed supplies. The network raised over $119,000 from private donors and corporate sponsors, and used that money to create over 100,000 face shields for 181 institutions in 3 months.[125]

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[123]Clive Thompson, "When Government Fails, Makers Come to the Rescue" (Wired, April 20, 2020), https://www.wired.com/story/when-government-fails-mask-makers-rescue/.
[124]Nic Jones, "West Columbia Company Making Millions of Face Shields for Frontline Workers" (News19 WLTX, May 15, 2020), https://www.wltx.com/article/news/health/coronavirus/west-columbia-company-making-face-shields-for-frontline-workers/101-f5873601-243f-405e-b6fb-0e861b446ebe.
[125] Personal Protective Equipment for Healthcare Workers (DePaul University), accessed January 18, 2021, https://inspire.depaul.edu/project/20592/updates/1.

A small part of the face shield batches that the M19 Collective produced, totaling more than a million shields.
Source: M19 Collective

Maker's Asylum in India rallied makerspaces throughout the country, and each makerspace housed a number of volunteers in their facilities to form months-long "COVID bubbles" within their walls.[126] It formed a country-wide group called the M19 Collective, which organized makerspaces in 42 cities to produce its face shield design and distribute the manufactured product to medical providers and facilities across India. Maker's Asylum was able to produce 135,000 face shields in its own facility, and the M19 Collective was able to produce more than 1 million face shields as a whole, within 6 weeks.[127]

Open Works, a 501(c)3 non-profit makerspace in Baltimore, Maryland, is an example of a mixed, distributed+centralized model. It gathered 388 volunteers with 3D printers through pre-existing online communication channels to print face shield frames at home. Volunteers dropped these frames at Open Works, where 28,270 face shields were assembled and later distributed within the span of 4 months.[128] The makerspace also co-authored a report on their efforts and process—perhaps the single best written documentation currently available on one makerspace's response.[129]

Several online networks of crafters and sewists formed to make cloth masks from shared open-source patterns. Relief Crafters of America, an online network that was established in 2019 to create and send crafted items for animals injured during the 2019 Australian wildfires, asked their 58,000 members to pivot their focus to cloth masks and other sewn PPE items. Members would fill out a form, commit to the production of a certain number of masks, and would receive mailing information for where to send the finished product. By July 2020, this 100% volunteer effort created over 30,000 cloth masks and distributed them to 171 facilities across the U.S.

Other examples of online networks include MakeMasks2020, which attracted a following of 747 people, raised $3,400, and managed to produce over 100,000 cloth masks across the U.S. and Canada.[130] Crafters Against COVID-19 Seattle attracted over 2,600 Facebook group members, raised $21,000, and jointly created over 97,000 cloth masks.[131] In perhaps the largest distributed crafter effort in the United States, JOANN led a nationwide effort to craft over 400M cloth masks after the CDC recommended cloth masks for use in public to combat the

[126] M-19 Initiative (Maker's Asylum), accessed January 18, 2021, https://www.makersasylum.com/m19-initiative/.
[127] National Case Study: India's Maker Response Against COVID-19 (Open Source Medical Supplies), accessed January 18, 2021, https://opensourcemedicalsupplies.org/national-maker-response-case-studies/india/.
[128] Makers Unite! Face Shield Project (Open Works, March 2020), https://www.openworksbmore.org/2020/03/makers-unite-face-shield-project/.
[129] Greater Spaces and Places, accessed January 22, 2021, https://www.greaterspacesandplaces.com/.
[130] @MakeMasks, "A Few Important Changes!," MakeMasks Facebook Group, July 20, 2020, https://www.facebook.com/MakeMasks2020/posts/16420752188151.
[131] Let's make some masks! (Crafters Against COVID-19 Seattle), accessed January 18, 2021, https://craftersagainstcovid19.org/.

COVID-19 pandemic. It distributed free open-source cloth mask patterns and kits that members of the public used to fabricate cloth masks for their communities.[132]

Something Labs is a diverse, distributed collection of healthcare workers, designers, engineers, machinists, existing manufacturers, and improvised manufacturing centers that formed in response to the PPE crisis. They have designed and produced multiple types of PPE and medical devices. As of mid-December 2020, they have collectively produced over 34,000 face shields, 64,000 PAPR cuffs, 190,000 isolation gowns, 24,000 PAPR tabs, 200 intubation boxes, 60 sneeze guards, and more. Due to their early relationships with healthcare workers, they have collectively stayed in-tune with current medical supply demands, and have been able to shift production as necessary to supplies that are most needed in their local medical community. One such niche was PAPR repair, a scope of work that evolved from an individual clinician's off-hand request to a national repair-by-mail service. Their medical partnerships allowed them to identify a need for isolation gowns that was so significant, they actually rented a centralized space to start up a production line after initially starting as a distributed, online effort. Like many Citizen Maker Response efforts, Something Labs actively worked to transfer knowledge and files to manufacturers in order to scale production. After a hand-off through a personal connection, Boston Scientific, a major medical manufacturer, went on to produce over 1M face shields that had been designed by Something Labs.[133]

Something Labs team reviewing PAPR lens replacements and units with health care workers.*Source: Something Labs*

These distributed networks demonstrate the power of volunteerism when combined with modern communication technologies. Highly populated networks coalesced using various internet-enabled communication platforms to design open source medical supplies, share those designs widely, iterate on those designs, and produce those designs in coordinated groups en masse for local communities and institutions.

Primary/Secondary (K-12) Schools

In the U.S., many primary and secondary schools shut their doors in March and April and moved to virtual learning to allow their students to finish the 2019-2020 school year at home, with the hope of keeping staff and students safe until the pandemic came to an end. By summer, it was clear that the pandemic would not end before the next school year, and with PPE still in short

[132] "Create to Give: Donate Face Masks to Medical Personnel & More and More," JOANN, accessed January 18, 2021, https://www.joann.com/make-to-give-response/.
[133] Alice Walton, "Something Labs Worked with Boston Scientific to Build 1 Million Face Shields for Donation." (Something Labs, June 4, 2020), https://www.somethinglabs.org/blog/1000000-face-shields-by-boston-scientific.

FIRST Robotics Michigan team member making masks for their "1 Million PPE Challenge.". *Source: Lisa Perez Savage*

supply for medical workers, some K-12 schools turned to the resources under their own roofs and began to manufacture PPE.

In Michigan, Gail Alpert, President of FIRST in Michigan, saw the PPE crisis looming in her state and decided to do something about it. When students learned their annual FIRST Robotics competitions were cancelled due to COVID-19, they wanted to put their time and energy back into helping fight PPE shortages within their communities. Alpert, along with longtime volunteers of FIRST in Michigan, Lisa and Eric Savage, issued a team challenge to create 1 million pieces of PPE for first responders and frontline workers.[134] These high school students already had access to tech labs within their schools, many of which had the equipment necessary to begin producing PPE.

> ***"The skills students acquire through FIRST are life-changing for both the students and for society. Nowhere was this more evident than during the Pandemic. Our teams immediately put their skills to work making PPE, using CAD to maximize the number of items that could be 3D printed at one time and separating tasks to achieve their goals while isolated."*** — Gail Alpert, President, FIRST in Michigan, Michigan, United States[135]

Word quickly spread across social media, and soon FIRST Robotics teams in neighboring states wanted to help with the challenge. The effort soon included participants from 13 states, and the FIRST in Michigan PPE challenge has produced 96,000 face shields, 2.16 million ear savers and other PPE accessories, and over 3,500 safety glasses to date, for a total of over 2.26 million items.[136]

In New Brighton, Minnesota, the KnightKrawler FIRST Robotics team started their own face shield printing effort. In less than 48 hours from initial request to running lab, the high school robotics team worked with the school district to develop a health safety plan, modified their website to create an online ordering system, and consolidated 24 3D printers from 4 schools in the district. As it was for most makers, obtaining raw materials was a major challenge. Through team relationships at 3M and Stratasys, KnightKrawler was able to secure enough plastic to cut over 30,000 clear face shields and, using their engineering skills, the high school students

[134] "FIRST in Michigan Volunteers Challenge Others to Do Good" (FIRST Inspires, April 21, 2020), https://community.firstinspires.org/first-in-michigan-volunteers-challenge-others-to-do-good.

[135] Gail Alpert, email communication to OSMS, January 22, 2021

[136] 1 Million PPE Challenge - COVID-19 Call to Action (FIRST in Michigan), accessed January 21, 2021, https://www.firstinmichigan-ppechallenge.org/. Note, only 258k were reported to by FIRST in Michigan in their OSMS/NOM Community Impact Survey response. They achieved 2.16M later in 2020.

created a custom cutting machine from robot parts, which was at the core of a student-run assembly line to cut, corner and punch the shield plastic.[137]

Running their 3D printing farm for 10 hours per day, 6 days per week, the team was able to print over 200 visors and cut hundreds of clear shields per day. Cutting shields was much quicker than printing visors, and shortly after production began the team's online ordering system was overwhelmed with over 10,000 requests. It became obvious the team could never print enough visors on their own for the large number of shields they could create. KnightKrawler reached out to other robotics teams and makers for help and, between those groups and a local plastics manufacturer, they received thousands of 3D printed and injection molded visors. This community effort allowed the team to fill their own orders for face shields, and also ship thousands of clear visor parts to other robotics teams across the U.S. who were printing visors but could not find clear plastic.

Katie Sjobeck, Programming Captain and Competition Robot Driver of the KnightCrawler FIRST Robotics Team, standing next to a spool of PET plastic sheet for face shield production. *Source: KnightKrawler FIRST Robotics*

In total, the 14 KnightKrawler teammates and their coach produced 37,000 pieces of PPE for their local and national communities. These donations were made to local hospital systems, health clinics, correctional facilities, dental offices, the local Veterans Affairs office, and police and fire stations. Once school resumed, KnightKrawler began using the remaining plastic to make large clear desk shields for speech pathologists and special education teachers to use in situations where face masks were not an option. The team's hard work and dedication to their community earned them a COVID19 Community Response award from the Minnesota Technology Association, alongside 3M and the University of Minnesota.[138]

Critical Resources for Design and Production

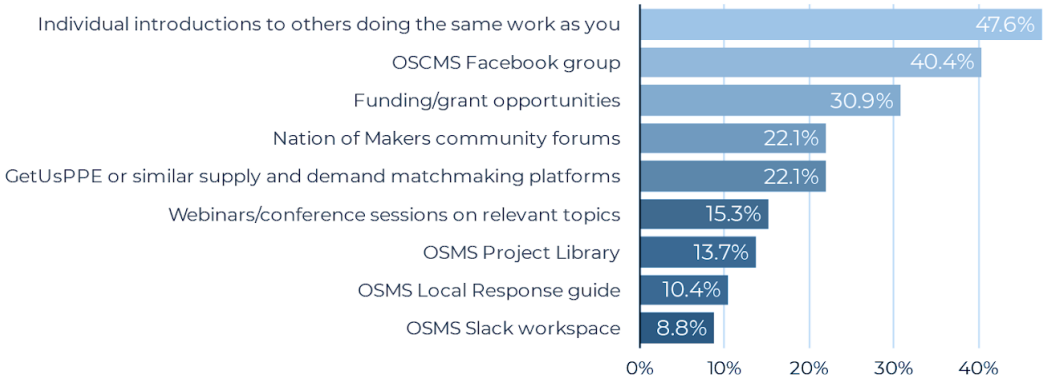
Maker responders were able to respond quickly to the need for local fabrication of medical supplies by being connected to a global network that was sharing open source plans and best practices, by having access to necessary manufacturing equipment, and by having access to or being able to build local communities of volunteers to support the efforts to provide local fabrication services.

[137] "KnightKrawler Robotics Delivers 15,000 COVID-19 Face Shields" (Youtube, June 15, 2020), https://www.youtube.com/watch?v=2_uwV3r8FKU&feature=youtu.be.
[138] KnightKrawler Robotics, accessed January 21, 2021, http://www.team2052.com.

Open Source Networks and Information

Of all makers who completed the authors' Community Impact Survey, **41.6% indicated that networking with other responding groups and individuals** was helpful (via individual introductions, certain social media groups, or other forums), and **27.7% of survey respondents listed available open-source design information as helpful** (via access to different repositories and libraries), which far exceeded the 16.5% of makers that listed some sort of access to funding and grant opportunities as being helpful.

Figure 6: Resources that all makers considered "helpful" during their emergency response, by % of respondents



Source: OSMS and NoM Community Impact Survey data

> *"[OSMS] provided a community that validated our efforts and provided important information regarding effective PPE to offer and proper ways to clean and deliver that equipment. We were able to prepare and organize weeks before the virus reached our country due to the experiences, resources, procedures, source files, etc. shared by the maker community as a whole."* — Andres Hermes, TecLab Guatemala, Guatemala

The broader community helped makers leverage the internal resources they already had access to, including manufacturing equipment, like-minded local communities willing to help. The larger networks also played a role in sourcing and securing access to raw materials.

Manufacturing Equipment

All responding individuals and groups had access to manufacturing equipment of some kind, and most groups had access to multiple types of relevant manufacturing equipment. Exactly what type of equipment any particular group owned informed what types of supplies they could produce and what production volumes they could achieve in a given time frame.

Figure 7: Manufacturing equipment utilized By the U.S. Citizen Maker Response

Manufacturing Process	% of U.S. Respondents Using Process
3D Printing	67.5%
Sewing	56.6%
Laser Cutting	39.6%
Die Cutting	11.2%
Vacuum Molding	9.8%
Injection Molding	6.9%
Die Casting	1.8%

Source: OSMS and NoM Community Impact Survey data

According to the OSMS & NoM Community Impact Survey, most responding groups had access to 3D printing and sewing machines, and just over one third had access to high-speed laser cutting. All of these processes are immediately useful prototyping and fabrication processes; given the proper plans, blueprints or patterns, simple items can be produced with little to no preparation time.

As the COVID-19 pandemic wore on, a smaller subset of responding groups were able to activate equipment that was more productive, but which required more time to design appropriate plans and produce the necessary tooling. Die cutting, vacuum molding and injection molding—used by approximately 10% or fewer groups each—are able to produce orders of magnitude more parts than 3D printing, sewing, and laser cutting, but can take weeks to set up properly.

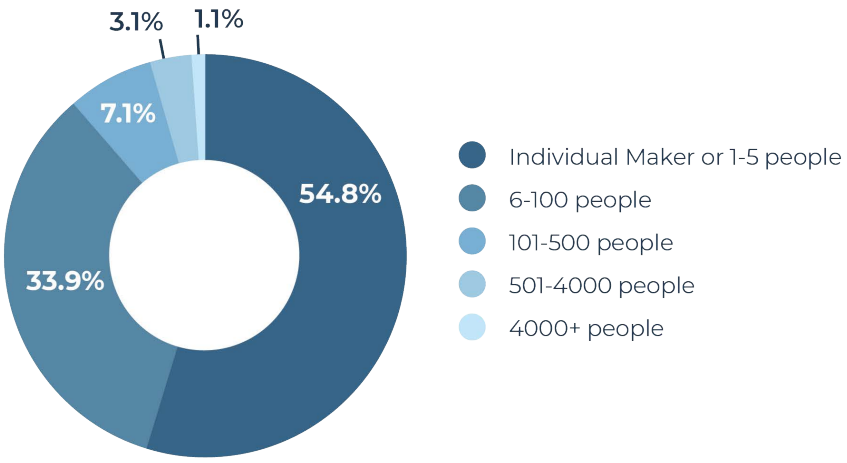
Homebound individual makers typically only had access to personal 3D printers or sewing machines, while institutions, makerspaces and manufacturers had access to more productive equipment—both in terms of the production capability of each machine and the number of machines available. In some cases, institutions like libraries, schools and universities allowed staff, students and volunteers to take manufacturing equipment (typically 3D printers) from the locked-down campuses into their homes, allowing many to have ready access to the tools and equipment needed to produce supplies. Authorities overseeing these institutions found this to be a rapid solution to the supply chain gap, while at the same time utilizing the skills of the already-trained and trusted volunteers.

People and Teamwork

Aside from connections to a global network and the manufacturing equipment itself, the most critical resources citizen responders accessed were other volunteers and paid staff members that stepped up to produce medical supplies. The Community Impact Survey data represents

the efforts of approximately 14,800 volunteers and 2,300 staff members across the U.S., and the combined efforts of those 17,100 people resulted in 18,896,082 units of medical supplies; **this represents an average production capacity of 1,105 units per person in the U.S. network**.

Figure 8: Size of organizations that responded



Source: OSMS and NoM Community Impact Survey data

Globally, just over half (54.8%) of the OSMS and NoM Community Impact Survey respondents reported they were either individual makers or that they were working in small groups of five people or fewer. Just over one third (33.9%) reported that they were medium sized groups with six to 100 people, 7.1% belonged to large groups with as many as 101-500 people, 3.1% reported up to 4,000 members in their organizations, and five groups (1.1%) reported a staggering 4,000 people or more belonging to their organization.

Numbers from U.S. Makers followed a similar pattern with 58.0% reporting they were individual makers or working in small groups of five or fewer, 32.9% reported working in medium sized groups of six to 100, 7.5% belonged to large groups of 100-500, 2.1% belonged to extra-large groups of 501-4000 members, and .80% belongs to super-sized groups of 4,000+ individuals.

Funding and Donations

While 93% of the makers producing supplies volunteered their time and labor, the raw materials to make supplies still required funding. Most responding groups sought their own funding, donations, or other kinds of support to sustain their efforts.

Sales of products to recoup costs were a secondary consideration in large part due to the emergency nature and rapidity of the response. Sorting through liability concerns, vendor paperwork, and compensation for a distributed and wide ranging labor force was too time

intensive and riddled with barriers to delivery. U.S. makerspaces in particular are largely organized as not-for-profit educational or community service entities[139]; many do not carry product liability insurance. Fundraising for donations to offset materials cost (and in some cases to provide some compensation for machine wear and tear and facility overhead) was thus a far easier and more traveled path.

Of all groups reporting, re-tooled businesses were far more likely to pivot their efforts and stand up sales (83% of all retooled manufacturers compared to 35% of makerspaces, 33% of K-12 groups, 28% of individual makers, 15% of online organized groups, and 4% of university groups).

Figure 9: Financial & material support for U.S. groups

Support Type	% of Respondents
Materials Donations	47.0%
Payment for PPE (at cost or for profit)	29.0%
Crowdfunding Campaigns	23.3%
Individual Donor or Foundation Grants	18.8%
Corporate Sponsorship	7.4%
Government Funding	2.4%

Source: OSMS and NoM Community Impact Survey data

Almost half of U.S. respondents to the OSMS & NoM Community Impact Survey (47.0%) were able to obtain materials donations from their communities, materials suppliers, or other groups within their network. Fewer than one third of all responding groups (29.0%) received direct payment for the "PPE items" they made either at-cost or for-profit; groups that did not solicit for direct payments instead relied on community crowdfunding campaigns, individual donations or staffed foundation grants, corporate sponsorship, or government funding of some kind.

3D printer filament and plastic suppliers, such as MatterHackers[140] and Keene Village Plastics[141] offered discounts on their supplies, while other industrial suppliers such as McMaster-Carr, worked directly with fabricators and those on the front lines of rapid prototyping and development.[142] Suppliers and corporations, compelled to expand their sense of civic duty

[139] Dorothy Jones-Davis et al., "2019 Survey of Makerspaces Report" (Nation of Makers, 2019), https://github.com/IttyBittyArtist/NOMANNUALSURVEY/blob/master/2019/2019-Report.pdf.
[140] MatterHackers, "COVID-19 Additive Manufacturing Response - USA," MatterHackers, accessed January 18, 2021, https://www.matterhackers.com/covid-19.
[141] Jill Bresnahan, "Keene Village Plastics Joins Nation of Makers in the Fight to Combat COVID-19" (Cision PR Web, April 30, 2020), https://www.prweb.com/releases/keene_village_plastics_joins_nation_of_makers_in_the_fight_to_combat_covid_19/prweb17082731.htm.
[142] Devin Carroll, "McMaster-Carr, Ventilator Heroes," Medical Device Products & Lifecycle Management Solutions (Velentium, November 10, 2020), https://www.velentium.com/blog/ventilator-hero-mcmaster-carr.

and corporate social responsibility to frontline workers, liberally donated supplies. Coca-Cola contributed to the production of 1.14 million face shields across multiple states, through material donations and funding for PPE production. The company worked directly with MakeItLabs in Nashua, New Hampshire to distribute transparent PET plastic to businesses and makerspaces, including academic institutions and community organizations. Additionally, Coca-Cola directly funded the production of face shields, fueling local economies.[143]

Nation of Makers served as a connector organization for limited funding provided by two key private sector funders. In April of 2020, in collaboration with Nation of Makers, the nonprofit Get Us PPE launched its first maker grant program, supporting the purchase of raw material supply to make PPE; it later expanded this program to cover the cost of labor and equipment. Get Us PPE subsequently launched the PPE for Black Lives fund, which in part supported maker efforts to produce and distribute cloth masks and face shields for Black Lives Matter protesters.[144] In response to evolving PPE needs and an unprecedented demand for gowns, in August 2020, a collaboration with Nation of Makers, Something Labs, Artisan's Asylum, and Get Us PPE launched the Maker Gown Cohort, providing seed funding and mentorship to maker groups committed to pivoting to gown production.[145] A second private sector funder that was pivotal to the support of regional PPE production hubs was Accenture, providing both funding and volunteers to support the PPE efforts of four makerspaces in Connecticut, Illinois, California, and Georgia.[146]

It is worth noting explicitly that, despite local, state, and federal governments taking responsibility for arranging emergency production and supply shipments for healthcare institutions for much of the early pandemic period, **only 2.4% of U.S. survey respondents reported having received any government funding** despite 24.2% of respondents reporting that they had created a new partnership with a governmental entity.

[143] "Face Shields to the Front Lines: Coca-Cola North America, MakersRespond Address Critical Shortage of Personal Protective Equipment" (The Coca-Cola Company, May 6, 2020), https://www.coca-colacompany.com/news/face-shields-to-the-front-lines-coca-cola-north-america-makersrespond-address-critical-shortage-of-personal-protective-equipment.
[144] Get Us PPE: The PPE for Black Lives Fund, accessed January 22, 2021, https://getusppe.org/the-ppe-for-black-lives-fund/.
[145] Rebecca Finkel, "Apply Now for the $5,000 Maker Cohort Grant" (Get Us PPE, August 28, 2020), https://getusppe.org/apply-now-for-the-5000-maker-cohort-grant.
[146] Colleen Sheehy, "We're Fast-Tracking Social Innovation" (Accenture, December 16, 2020), https://www.accenture.com/us-en/blogs/blogs-careers/were-fast-tracking-social-innovation.

The Impact of the Response

The Citizen Maker Response provided crucial supplies that helped keep healthcare and essential workers safe during the earliest, most-critical shortages of the COVID-19 pandemic. Despite needing to design medical supplies from scratch before manufacturing them, **maker responders often delivered supplies to those in need weeks to months before centralized manufacturers were able to ramp existing production up enough to make up for early shortages.** Access to maker-made supplies kept many hospitals, clinics, and essential businesses open when they would have otherwise had to shut down for lack of PPE.

As the supply chain healed and began to serve the needs of primary hospital chains that could place large bulk orders, makers quickly pivoted and provided supplies to smaller institutions like clinics, nursing homes, homeless shelters, schools, and essential businesses that had difficulty competing in the marketplace. Makers were also able to provide supplies specifically to underserved communities that had little or no access to supplies. The agility of manufacturing, speed of response, and ability to target exactly where supplies were needed most allowed makers to fill gaps in the marketplace across the country.

Where Supplies Went

Most maker-made supplies went directly to frontline workers in healthcare and under-resourced populations. U.S. respondents to the OSMS and NoM Community Impact Survey reported that 76% delivered at least once to a hospital, 72% delivered to individual medical professionals, 57% delivered to senior housing/healthcare facilities, and 54% delivered to other medical clinics such as rehabilitation centers and dentist offices. A high percentage (50%) delivered to organizations serving needs of under-resourced communities, including homeless shelters, Native American tribes, and non-profit agencies serving low income populations. 45% also reported supplying schools.

Figure 10: U.S. Distribution destinations of maker-made PPE

	Distribution	% of Respondents
1.	Hospitals	76%
2.	Individual medical professionals	72%
3.	Senior housing/healthcare facilities	57%
4.	Other medical clinics	54%
5.	Non-profit/social service agencies serving low-income populations	50%
6.	Miscellaneous essential workers	48%
7.	Schools	45%
8.	First responders	41%
9.	Other	30%
10.	Ecommerce site	8%

Source: OSMS and NoM Community Impact Survey data

In many cases these supplies made the difference between healthcare facilities and essential services remaining open or closing due to lack of PPE.

> ***"These gowns enabled this hospital to take 4 additional ICU patients today which they otherwise could not have due to PPE shortages and rationing."*** — David Rainosek, M.D., Associate Medical Director of St. Vincent Rehabilitation Hospital, Arkansas, United States

Healthcare workers expressing gratitude for maker-made PPE. Michelle Diaz of Kaiser Permanente San Francisco In a PAPR featuring a Something Labs replacement lens and cuff (left) and St. Vincent Rehabilitation Hospital, Arkansas nurses sporting protective gowns made at Future Forge makerspace. *Sources: Something Labs (left) and Dr. David Rainosek (right).*

In many cases, makers were able to identify and respond to needs from under-resourced communities that often go unnoticed or unattended by government agencies and supply chains that prefer large bulk orders. 50% of U.S. makers reported providing PPE and supplies for non-profit agencies and social services that care for low-income communities, and a number of maker efforts deliberately targeted communities that reported being unable to acquire supplies for themselves.

The U.S. Treasury Department withheld $8B in coronavirus relief funds from tribal nations across the U.S. that were earmarked, in part, for PPE and medical supplies. These funds were delayed for several months after the CARES Act was signed into law, despite the law requiring disbursal within 30 days.[147] This delay prevented tribal nations from purchasing PPE in a timely manner, which contributed significantly to the fact that the COVID-19 mortality rate is twice as high in Native American communities than in the general U.S. population.[148] Makers across the U.S., and many within the tribes themselves, began producing masks specifically for tribal communities in order to protect them from COVID-19 while the tribes waited for funding for medical supplies. Some tribal communities were able to make enough masks for everyone within their tribes, and tens of thousands of masks and other supplies have been donated by maker groups created specifically to provide for the tribal nations.[149]

Rural communities within the U.S., whose hospital systems often struggle to provide adequate care for their populations due to lack of funding and state support, often did not have the funds or purchasing power to purchase sufficient PPE at the start of the pandemic. Makers in rural communities were able to supplement these shortages of PPE, with some maker groups reporting that they met their entire hospital demand at times in more-rural states like Alabama.

Rapidity of Response

Makers and makerspaces were able to go into production immediately because they shared effective designs and learnings widely and openly, had access to large groups of volunteers already, and were already equipped for rapid prototyping manufacturing processes.

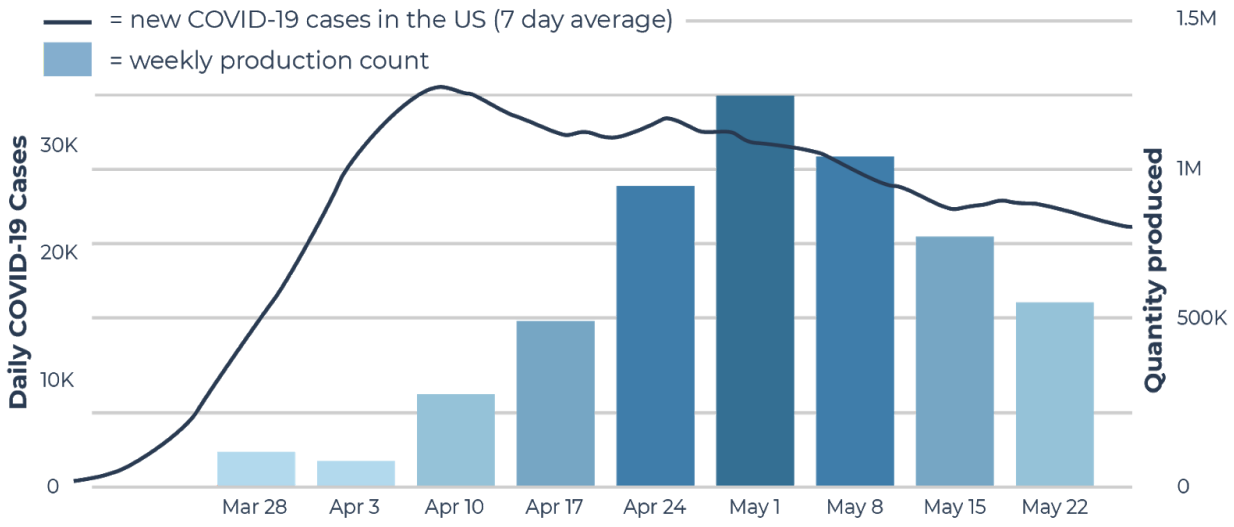
A good example of this orientation and speed of response is exemplified by a respirator valve that Italian engineer Cristian Fracassi engineered, prototyped, tested, and delivered back to the hospital within 48 hours, providing the hospital with 100 out-of-stock parts as quickly as

[147] Mark Walker and Emily Cochrane, “Native American Tribes Sue Treasury Over Stimulus Aid as They Feud Over Funding” (The New York Times, May 2, 2020), https://www.nytimes.com/2020/05/01/us/politics/coronavirus-native-american-tribes-treasury-stimulus.html.
[148] Chelsea Cirruzzo, “COVID Mortality Twice as High Among Native Americans” (U.S. News & World Report, December 10, 2020), https://www.usnews.com/news/health-news/articles/2020-12-10/covid-mortality-twice-as-high-among-native-americans-than-whites.
[149] Victoria Jaqua, “A Tradition of Creation: Celebrating Indigenous People's Day” (Open Source Medical Supplies, October 12, 2020), https://opensourcemedicalsupplies.org/we-make-something-everyday/.

humanly possible in order to keep sick patients alive.[150] David Cervantes in St. Louis, Missouri,[151] and retooled manufacturer Prent Corporation of Janesville, Wisconsin,[152] were also able to produce and deliver face shields within 48 hours of being asked. Organized Amish sewing networks made 12,000 cloth masks for Cleveland Clinic within two days[153] and consequently received orders for 140,000 more.

> *"From the time we had the fabric delivered by the National Guard to when Dignity Health received the first few hundred gowns, was about 2-3 days."* — Sherri Barry, FABRICTempe, Tempe, Arizona, United States

Figure 11: Daily coronavirus cases in the U.S. (curve) contrasted with maker-made PPE production volume ramping up in the U.S. (bars)



Source: OSMS Weekly Tally data, 91-DIVOC[154]

Rapidity of response can also be evaluated by comparing the exponential growth rate of COVID-19 cases themselves with the exponential growth of production output of the Citizen Maker Response. OSMS conducted weekly production tallies of the OSCMS Facebook Group on Fridays, and charted production totals over time. Despite the time-sink of having to invent medical supply designs from scratch and prepare assembly lines, makers were able to match

[150] Amy Feldman, "Meet The Italian Engineers 3D-Printing Respirator Parts For Free To Help Keep Coronavirus Patients Alive" (Forbes Magazine, March 19, 2020), https://www.forbes.com/sites/amyfeldman/2020/03/19/talking-with-the-italian-engineers-who-3d-printed-respirator-parts-for-hospitals-with-coronavirus-patients-for-free.
[151] "Missourians Step Up to Produce Much Needed PPE In Fight Against COVID-19" (Missouri Partnership, April 13, 2020), https://www.missouripartnership.com/missourians-step-up-to-produce-much-needed-ppe-in-fight-against-covid-19/.
[152] Matt Bechtel, "Rapid Responders" (Wiley Online Library, May 6, 2020), https://onlinelibrary.wiley.com/doi/10.1002/peng.20311.
[153] Jack Shea, "Local Business Owner Teams up with the Amish to Sew Masks and Gowns for Hospitals" (Fox8 News, April 10, 2020), https://fox8.com/news/coronavirus/local-business-owner-teams-up-with-the-amish-to-sew-masks-and-gowns-for-hospitals/.
[154] "An Interactive Visualization of the Exponential Spread of COVID-19" (91-DIVOC), accessed January 23, 2021, http://91-divoc.com/pages/covid-visualization/?chart=countries&highlight=United+%5B%E2%80%A6%5Dth&scale=linear&data=cases-daily-7&data-source=jhu&xaxis=right.

the exponential growth curve of the virus with just 2-3 weeks of lag time. Production output grew an astonishing 653% between week 1 and week 6.

Demand for the locally produced products (especially for face shields) declined quickly as larger domestic manufacturers and then later imports became available. Even the largest volume producers of face shields in the OSMS network (Z-Verse, at 4.6M total) reported that their market had evaporated by late June. Citizen Maker Response products got to the people who needed them first, but were supplanted once cheaper supplies were available, or when traditional purveyors could once again fill orders.

> *"At a time when we were feeling totally abandoned in our fight against COVID, I think the rapidity with which OSMS was able to connect us with PPE supplies was really quite pivotal... and the psychological benefit that it provided to have this equipment delivered to our doorstep by caring and compassionate and capable people in the community with 3d printers and such, to come and bring us this stuff in our time of need. I mean, that was huge."* — David Rainosek, M.D., Associate Medical Director of St. Vincent Rehabilitation Hospital, Arkansas, United States

Forbes magazine explicitly recognized the agility and speed of the Citizen Maker Response when they designated Makers as "Most Disruptive Innovator" in their year-end 2020 Technology Awards: "Before Apple and Nike turned their resources to PPE supplies, it was these hobbyists and independent 3D-printing companies that organized the resupply of frontline workers in communities across the United States facing dwindling stockpiles."[155]

Maintaining Mental Health

Aside from the role the supplies themselves played in protecting communities from COVID-19, **the act of receiving supplies from members of the public often helped supplement the mental health of healthcare and essential workers by proving community members cared about them** even when they felt abandoned by suppliers, administrators, or government officials.

> *"COVID-19 has added a huge amount of stress to the work lives of my operating room/Anesthesia staff. It is so important that staff feel safe and protected by their leader. I have received a large number of compliments, thankful that these superior face shields have been provided to us. I must, therefore, pass the thanks to you. You have provided a vital product which has allowed my staff of 40 Anesthesia providers, physicians, CRNAs, and technicians to feel SAFE."*[156] — Dean Steinberg, M.D., Vice Chair Anesthesiology, Thomas Jefferson University, Philadelphia, Pennsylvania, United States

[155] Helen A.S. Popkin, "Forbes Technology Awards 2020: Geeks Step Up When Governments Fail" (Forbes, December 26, 2020), https://www.forbes.com/sites/helenpopkin/2020/12/26/forbes-technology-awards-2020-geeks-step-up-when-governments-fail.
[156] Dean Steinberg, personal Interview by individual maker Callie Parker, n.d.

> *"To see the country rallying around to create those tools to provide the supplies is one of the most important things the country can do right now to make the front line provider know they are seen and supported through this."*[157] — Katrina Armstrong, M.D., Chief of Medicine at Massachusetts General Hospital, Boston, Massachusetts, United States

In addition to protecting the mental health of workers, **the act of making supplies preserved the mental health of makers themselves,** who found themselves better able to cope with depression and senses of helplessness brought on by quarantines, lockdowns, and the pandemic itself.

> *"Oddly, it's been some of the most special times in our lives. While everything is bittersweet with the tragedies endured, it has been an honor to serve in a way we could have never expected. We've all ended up so much different, and are so grateful for the communities that have come together over this."* — Sam Haynor, Something Labs, San Francisco, California, United States

> *"Thank you for helping me survive the spring and summer without sinking into depression. This organization gave me hope in a better world. I am working a lot of hours right now and moving. But I will be back to sewing in the not too distant future."* — Alyson Burnett Rawitch, Individual Maker, Lenexa, Kansas, United States

> *"Honestly, it was great to be involved in something with such amazing impact, but I'd be remiss if I didn't mention that making PPE every waking hour of my life kept me alive during those days, and kept my mind away from the horror that was going on around me. I learned a lot through the process about 3D printing, community organizing, and how infectious diseases spread. This was not how I had planned to spend my summer, but doing nothing was not an option."* — Norman Witte, OSCMS - Michigan, Detroit, Michigan

[157] Perry Russom, "Mass. General 'Desperately' Needs Supplies, Even 3-D Printed Ones" (NBC10 Boston, March 20, 2020), https://www.nbcboston.com/news/coronavirus/mgh-desperately-needs-supplies-president-says/2094292/.

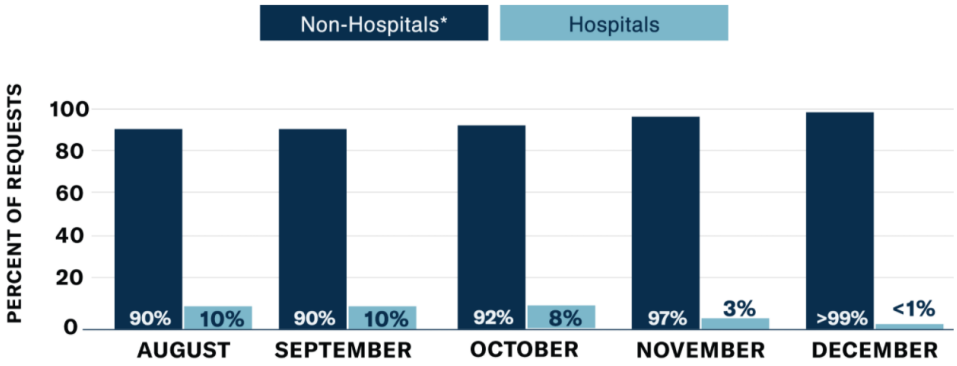
The Problem, Evolved

America is once again in the throes of a COVID-19 surge as of this writing, setting an average daily record of 3,300 deaths and 130,000 hospitalizations in the U.S. as of mid-January 2021. As cases have mounted, PPE is once again in short supply. Nurses are on strike in several hospital systems across multiple states in the U.S. due,[158] in part, to a lack of PPE.[159] FEMA and the Government Accountability Office (GAO) have reported that PPE supply chains are still strongly affected and are not expected to catch up for months,[160] and some healthcare workers across the country are still reusing soiled PPE due to a lack of supply.[161]

Unmet Demand

As centralized manufacturers have slowly increased production of medical supplies over time, shortages have hit smaller facilities that do not have the purchasing power to compete in a strained market with large minimum orders. Get Us PPE reports that unfilled U.S. supply requests are now predominantly coming from secondary care facilities like nursing homes and homeless shelters (99%+ of requests in December 2020), whereas hospitals were a more-substantial source of requests earlier in the pandemic (36% in June 2020).

Figure 12: Requests for PPE by U.S. organizations experiencing a shortage



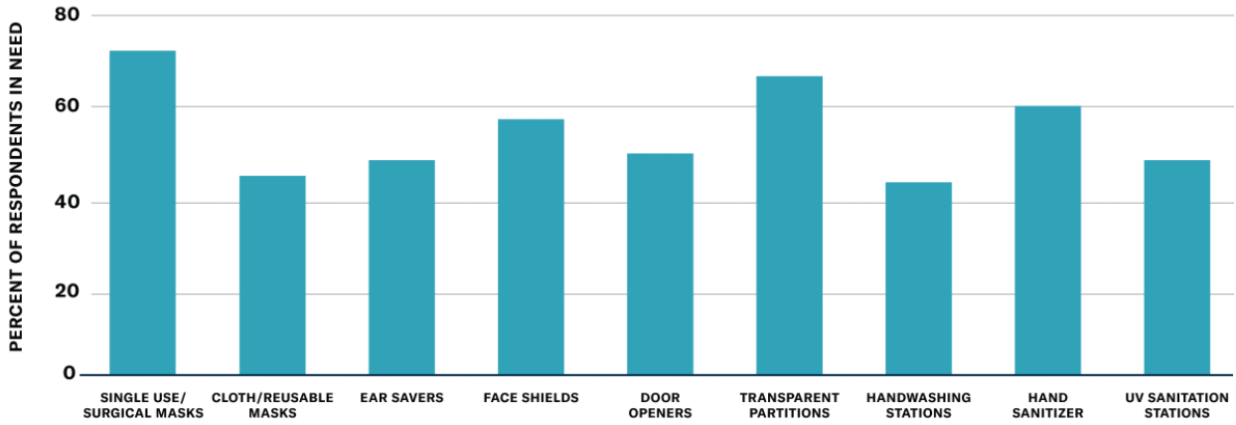
Source: Get Us PPE[162]

[158]"Nearly 800 Nurses Strike at St. Mary Medical Center in Bucks County" (6ABC News, November 18, 2020), https://6abc.com/nurse-strike-st-mary-medical-center-langhorne-pennsylvania-bucks-county-pa/8025507/.
[159] "Nurses at 2 NY Hospitals Strike Over Contract Negotiations, COVID Protection" (NBC New York, December 2, 2020), https://www.nbcnewyork.com/news/local/nurses-at-ny-hospital-to-strike-over-contract-negotiations-covid-protection/2753237/.
[160]Mary Ellen Schneider, "GAO Highlights Continued PPE Shortages in COVID-19 Report" (Regulatory Affairs Professionals Society, September 23, 2020), https://www.raps.org/news-and-articles/news-articles/2020/9/gao-highlights-continued-ppe-shortages-in-covid-19.
[161] Will Stone, "PPE Shortages Persist Nearly 9 Months Into The Coronavirus Pandemic" (National Public Radio, November 26, 2020), https://www.npr.org/2020/11/26/939286976/ppe-shortages-persist-nearly-9-months-into-the-coronavirus-pandemic.
[162] Katherine Hurley, "December PPE Shortage Index Shows Need Is Still on the Rise, Especially in Community Facilities" (Get Us PPE, January 14, 2021), https://getusppe.org/december-ppe-shortage-index-shows-need-is-on-the-rise/.

Get Us PPE estimates that, based on its current unfilled requests, **the U.S. needs an additional 87M units of PPE per week**.[163] The items in highest demand from care facilities are disinfecting wipes, nitrile gloves, and hand sanitizer, which are unfortunately not products currently created in significant quantities by the Citizen Maker Response.

Get Us PPE has also begun to track the needs of non-care facilities like schools, which report needing a much wider range of medical supplies than PPE, such as handwashing stations, hand sanitizer, transparent partitions, and cloth masks. These are products that can and have been produced locally by makers across the world.

Figure 13: Types of PPE needed by schools

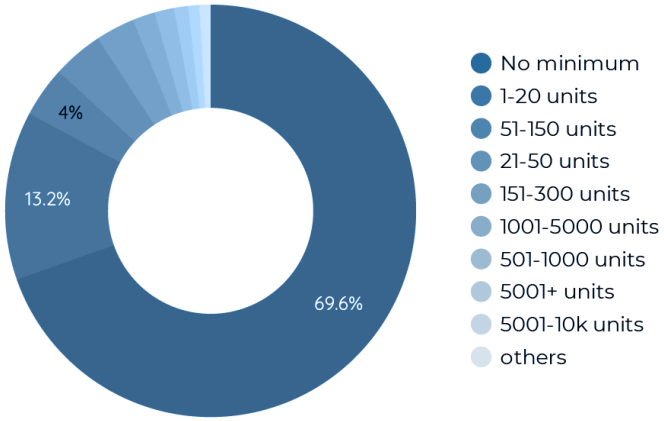


Source: Get Us PPE[164]

Makers and small manufacturers that can produce supplies are excellent fits for currently-unmet demand expressed from schools and some smaller institutions. **92.4% of U.S. makers who responded to the authors' Community Impact Survey reported minimum order quantities below 150 units per order.** Meanwhile, Get Us PPE reports that more than 99% of their requests are coming from non-hospital institutions.. **Unfortunately, this potentially-available small-scale distributed supply is disconnected from the demand of these smaller institutions**, as these institutions do not know makers have the capacity to manufacture the supplies they need.[165]

[163] Katherine Hurley, "December PPE Shortage Index Shows Need Is Still on the Rise, Especially in Community Facilities" (Get Us PPE, January 14, 2021), https://getusppe.org/december-ppe-shortage-index-shows-need-is-on-the-rise/.
[164] Ibid.
[165] Joel Rose, "Yep, Masks And Protective Gear Are Still Hard To Get - Especially For Small Buyers" (National Public Radio, August 19, 2020), https://www.npr.org/2020/08/19/903612006/yep-masks-and-protective-gear-are-still-hard-get-especially-for-small-buyers.

Figure 14: Minimum order size accepted by U.S. makers and retoolers



Source: OSMS and Nation of Makers Community Impact Survey data

Anecdotal reports of hospital PPE shortages continue to surface. On December 19, 2020, nurses in Southern California drew straws to see who would risk intubating a patient without PPE, as their hospital had run out.[166] Re-using PPE intended for single-use applications is a controversial mainstay for some facilities, with soiled N95s still in circulation[167] and rationing still occurring, almost a year after the pandemic impacted the United States.[168] To date, more than 2,900 U.S. healthcare workers have died from Covid-19, a statistic cited by U.S. Congressional members as evidence of PPE shortages.[169]

Slowed Production

As of December, 2020, 58% of U.S. survey respondents reported being "still active." 60% of those who reported being "still active" shared that production slowed due to decreased local demand from existing customers; 23.6% of makers who reported being "still active" also attributed slowing down to funding or staffing limitations.

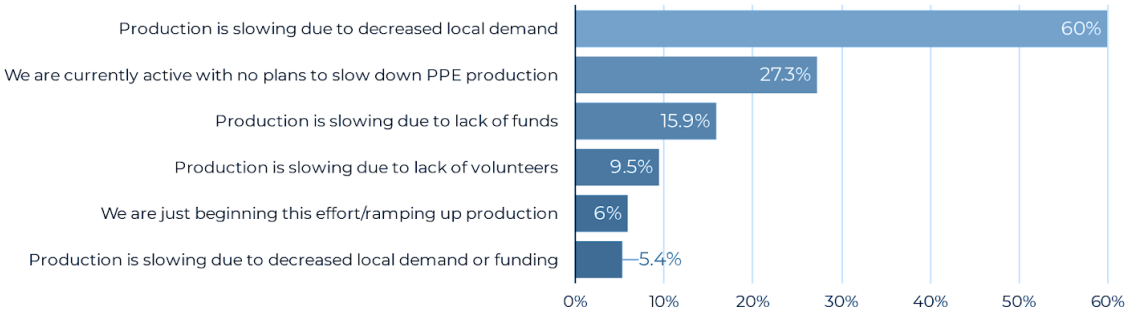
Of the "currently-inactive" groups surveyed, 91.0% report they can start production again if the need arises and/or support is provided; **the predominant issue preventing them from restarting is funding for their work.**

[166] @Kanlungan2, "Story from Filipino ICU Nurse in S. California" (Twitter, December 19, 2020), https://twitter.com/Kanlungan2/status/1340359022046707713?s=20.
[167] Pat Kane, "This Is an Actual 'Decontaminated' N95 That Albany Medical Center Gave a Nurse to Use" (Twitter, October 23, 2020), https://twitter.com/nynursesunited/status/1319767017700925447?s=20.
[168] Abraar Karan, "Have Had Private Communications from Folks about Hospitals in the US …" (Twitter, January 6, 2021), https://twitter.com/AbraarKaran/status/1346625021960216577?s=20.
[169] Christina Jewett, Melissa Bailey, and Robert Lewis, "More Than 2,900 Health Care Workers Died This Year - And the Government Barely Kept Track" (Kaiser Health, December 23, 2020), https://khn.org/news/article/more-than-2900-health-care-workers-died-this-year-and-the-government-barely-kept-track/.

The combination of domestic larger manufacturers taking over production of items such as face shields and cloth masks, plus the return of Chinese exports,[170] has undercut the market for locally produced supplies.

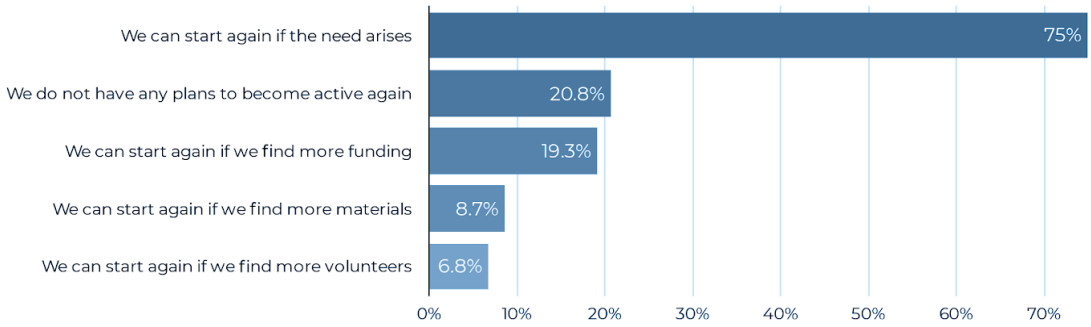
> *"The demand for USA-made gowns has dropped off the face of the earth. The fabric vendor is seeing that too. It's rippling up through the newly-formed domestic supply chain. China is flooding the market with very cheap, and I feel unsafe, gowns. If you are a for profit healthcare facility you are most likely going to go for price and buy the imported gowns. It's happening with both reusables and disposables."*
> — Sherri Barry, FABRICTempe, Tempe, Arizona, United States

Figure 15: Active U.S. Groups with reasons for continuing / slowing production



Source: OSMS and NoM Community Impact Survey data

Figure 16: Inactive U.S. Groups on potential for future production



Source: OSMS and NoM Community Impact Survey data

Though the majority of the Citizen Maker Response has either stopped or significantly slowed production of medical supplies, the vast majority reports having the ability to ramp production back up if the need arises and financial or other support is available. This network has proven its ability to provide significant surge capacity to produce supplies using open source plans, and has proven its ability to reactivate, pivot to new types of production, and scale as necessary to provide emergency supplies for local communities in dire need.

[170]"China's Exports Surge on Hot Demand for PPE, Remote Working Tech" (CNBC, December 7, 2020), https://www.cnbc.com/2020/12/07/chinas-exports-surge-on-hot-demand-for-ppe-remote-working-tech.html.

Opportunities for Policy Reform

Direct U.S. Government involvement in the Citizen Maker Response was limited. 23.7% of U.S. based survey respondents reported they had created a new relationship with some government agency through their work. But **only 2.4% received any government financial support (via grants or purchasing) for labor or supplies.**

> *"Now that we know that makerspaces can fill such a vital role... we need lawmakers to invest funds towards organizing these efforts and making sure they have the materials and support needed to ramp production back up when needed. "*
> — Craig Farrington, Factory Two, Flint, Michigan, United States

The resounding success of the Citizen Maker Response in providing for emergency innovation and manufacturing opens up two key questions for U.S. decision and policymakers:

1. How can we build on the momentum of the Citizen Maker Response to COVID-19, creating structures that integrate makers into the U.S. domestic response to crisis, and allowing makers respond to other critical challenges?
2. What specific policies and support—increased access to funding, raw materials, testing facilities, partnership with government entities—at the local, state, and federal level, can be developed to support and sustain the Citizen Maker Response?

In order to address these important questions, and to fully harness the full potential of the Citizen Maker Response, there must be coordination and support at the federal, state, and local levels. As was reinforced during the COVID-19 pandemic, each level of government carries its own decision-making and implementation power, and different levels of government also accordingly bear different resource allocation roles and responsibilities. Here we draw upon the experiences of a small number of maker groups that were positively affected by policies which enabled them to obtain the support and infrastructure to produce PPE rapidly and efficiently for their communities. In addition, we note the glaring gaps in policy that hindered a more effective response from the maker community by proposing policies that could enable an enhanced maker response in ensuing crises.

Enabling Policies

When analyzing the limited federal, state, and local policies that enabled distributed PPE production, there were a few examples of policies that worked to support the Citizen Maker Response.

Crowdsourcing Open Source Design

Founded in 2014, the NIH 3D Print Exchange is a collaborative effort led by the National Institute of Allergy and Infectious Diseases in collaboration with the Eunice Kennedy Shriver National Institute for Child Health and Human Development, and the National Library of Medicine. The Exchange "is an open, comprehensive, and interactive website for searching, browsing, downloading, and sharing biomedical 3D print files, modeling tutorials, and educational material."[171]

At the beginning of the pandemic, the Exchange released its COVID-19 Supply Chain Response as a part of the COVID 3D TRUST" (Trusted Repository for Users and Suppliers through Testing). As stated on the Exchange's website: "This collection represents a coordinated effort among the NIH/NIAID, FDA, VA, and America Makes to support the manufacturing of personal protective equipment (PPE) or other necessary medical devices that are in short supply due to the COVID-19 pandemic."[172]

The availability of a portal to submit open source 3D printed medical designs for review for clinical or community use enabled a level of validation for community-designs and allowed more widespread sharing of successful designs, including warnings against design usage that required significant refinement for safety. **Due to the maker community's desire to help however they could, the Exchange saw a 6,000% increase in unique visitors on the site on March 30, 2020** (the date the maker community was invited to supply submissions.)[173]

The NIH 3D Print Exchange is a model for government facilitation of open source design sharing, and it points to the opportunity to expand this approach beyond 3D printing and additive manufacturing to other materials and technologies.

Regulatory Accommodations for the Citizen Maker Response

Typically, personal protective equipment and medical supplies are approved by regulatory and safety agencies such as the Food and Drug Administration (FDA) and the The National Institute for Occupational Safety and Health (NIOSH) to ensure the highest levels of safety and quality control. In the absence of typical supply chain pathways, and an abundance of makers and pivoting small and medium batch manufacturers able to produce high-quality PPE and medical supplies, there was an urgent need to allow for rapid production with a relaxation of typical regulatory hurdles.

[171] About the NIH 3D Print Exchange (NIH 3D Print Exchange / U.S. Department of Health and Human Services), accessed January 18, 2021, https://3dprint.nih.gov/about.
[172] COVID 3D TRUST: Trusted Repository for Users and Suppliers through Testing (U.S. Department of Health and Human Services/ National Institutes of Health), accessed January 18, 2021, https://3dprint.nih.gov/collections/covid-19-response.
[173] Meghan McCarthy, e-mail message to Dorothy Jones-Davis, January 21, 2021.

Two federal policies enabled, and are continuing to enable, citizen production of PPE and medical supplies. Beginning in April of 2020, the FDA issued Emergency Use Authorizations (EUAs) that waive manufacturing and labeling requirements for some, but not all, PPE and medical supplies and devices.[174] As stated on the NIH 3D print exchange, "when the EUAs are lifted, manufacturers—whether industry or individuals—must cease operations if they are unable to meet those requirements."[175]

Similarly, the U.S. Department of Health & Human Services (HHS), issued the Public Readiness and Emergency Preparedness Act (PREP Act), authorizing the Secretary of HHS to issue a declaration that "provides immunity from liability (except for willful misconduct) for claims of loss caused, arising out of, relating to, or resulting from administration or use of countermeasures to diseases, threats and conditions determined by the Secretary to constitute a present, or credible risk of a future public health emergency to entities and individuals involved in the development, manufacture, testing, distribution, administration, and use of such countermeasures."[176] By removing the possible liability faced by small manufacturers and makers when producing medical supplies and PPE, these emergency manufacturers could, in good conscience, act responsibly and safely to address the significant public health needs of the U.S. during the COVID-19 pandemic.

Once published, the FDA's EUAs were critical for clarifying the landscape for both health care institutions and the Citizen Maker Response. However, the confusion experienced in the lag time (approximately 1 month) between first Citizen Maker Response and the publishing date of the EUA suggests **opportunities for improving FDA responsiveness or alternative workflows for open source regulatory pathways in crisis.**

Local Funding = Local Impacts

> ***"We advocated and convinced the City of Shreveport to designate part of their CARES Act funding for PPE production."*** — Demetrius Norman, President, NWLA Makerspace, Shreveport, Louisiana, United States

The leadership of a few cities (Baltimore, Maryland; Oakland, California; Shreveport, Louisiana), upon receiving CARES Act or other pandemic-relief funding, specifically opened funding opportunities for maker organizations producing PPE. This funding not only enabled makers to continue production efforts, but also sustained their small businesses, and compensated

[174] "Coronavirus Disease 2019 (COVID-19) Emergency Use Authorizations for Medical Devices - Personal Protective Equipment EUAs" (Center for Devices and Radiological Health / U.S. Food and Drug Administration), accessed January 18, 2021, https://www.fda.gov/medical-devices/coronavirus-disease-2019-covid-19-emergency-use-authorizations-medical-devices/personal-protective-equipment-euas.
[175] COVID-19 Response Essential Information (U.S. Department of Health and Human Services / National Institutes of Health), accessed January 22, 2021, https://3dprint.nih.gov/collections/covid-19-response/essential-info.
[176] "Declaration Under the Public Readiness and Emergency Preparedness Act for Medical Countermeasures Against COVID-19," U.S. Federal Register (U.S. Health and Human Services Department, March 17, 2020), https://www.federalregister.gov/documents/2020/03/17/2020-05484/declaration-under-the-public-readiness-and-emergency-preparedness-act-for-medical-countermeasures.

employees in the midst of one of the worst economic crises the U.S. has seen. In March of 2020, the State of Maryland announced a $5M fund to support local manufacturing by small businesses filling PPE shortages. This funding trickled down to cities in Maryland, including Baltimore, MD to the Baltimore Development Corporation's Made in Baltimore Program, where nine Baltimore manufacturers received funding to produce PPE.[177] With additional grants provided by the Baltimore Development Corporation, Open Works Makerspace was identified as a recipient of $15K in funding for PPE production. In November 2020, Ace Makerspace in Oakland, CA received $10K in CARES funding through an Oakland Arts program grant to help with "economic consequences due to COVID-19."[178] Similarly, NWLA Makerspace in Shreveport, Louisiana secured CARES Act funding from the city of Shreveport for PPE production.

The challenge for the Citizen Maker Response is how little funding reached these efforts (with survey data indicating less than 3% of respondents reported receiving any government grants or sales). Clearly, **great potential exists to increase citizen maker accessibility to emergency response allocations across local, state and federal agencies and workflows.**

State Support for Pivoting Manufacturers

A few key examples of regional collaboration on the state level to support retooling and pivoted production for manufacturers were either integrated into already existing networks, or were newly stood up during pandemic response.

State manufacturing programs to facilitate and incentivize surge manufacturing capacity during COVID-19 are a model to study as they did prove effective to stimulate production. A new report, "Strengthening Manufacturing Innovation Ecosystems Before, During, and After COVID: Lessons from Massachusetts," from MIT examines Massachusetts' efforts in detail and provides insights into opportunities for improvements.[179]

The leaders of Governor Charlie Baker and Lt. Governor Karyn Polito's Advanced Manufacturing Collaborative,[180] including Housing and Economic Development Secretary Mike Kennealy and Mike Tamasi, President and CEO of AccuRounds, established the Massachusetts Manufacturing

[177] Stephen Babcock, "These 9 Baltimore Manufacturers Received Grant Funding to Make PPE" (Technical.ly Baltimore, April 15, 2020), https://technical.ly/baltimore/2020/04/15/9-manufacturers-received-grant-funding-make-ppe-protective-gear-masks/.https://technical.ly/baltimore/2020/04/15/9-manufacturers-received-grant-funding-make-ppe-protective-gear-masks/.
[178]Oakland CARES Fund for Artists and Arts Nonprofits (Center for Cultural Innovation), accessed January 22, 2021, https://www.cciarts.org/Oakland_CARES_Fund.html.
[179] Elisabeth Reynolds, Dan Traficonte, and Anna Waldman-Brown, "Strengthening Manufacturing Innovation Ecosystems Before, During, and After COVID: Lessons from Massachusetts," Work of the Future (Massachusetts Institute of Technology, January 22, 2021), https://workofthefuture.mit.edu/research-post/strengthening-manufacturing-innovation-ecosystems-before-during-and-after-covid-lessons-from-massachusetts/.
[180] The Massachusetts Manufacturing Advantage (Manufacturing in Massachusetts), accessed January 22, 2021, https://mamanufacturing.com/see-why-ma.

Emergency Response Team: (M-ERT)[181] to organize and operationalize critical path work streams necessary for Massachusetts manufacturers to pivot their operations to produce needed materials in response to the COVID-19 pandemic. Members of the M-ERT include representatives from MIT, MIT Lincoln Labs, the Massachusetts Manufacturing Extension Partnership (MassMEP), Associated Industries of Massachusetts (AIM), other local universities, and multiple industry partners.

M-ERT identified capable manufacturers who could pivot to and ramp up PPE production. It gave the companies guidance on sourcing materials, testing products, gaining regulatory compliance and training their workforce. Commonwealth funding was also made available to some manufacturers for equipment, labor and testing.

The 50 manufacturers identified produced millions of items, including face shields, masks, gowns, sanitizer, test swabs, etc. One company has become one of the largest producers of gowns in the country.[182] The initial success of M-ERT is a result of prior state and private investments and pre-existing relationships with key stakeholders integral to the manufacturing ecosystem.

In Maryland, Governor Larry Hogan announced a $5 million incentive grant program for Maryland-based manufacturers in March 2020, called the Maryland COVID-19 Emergency Relief Manufacturing Fund, to produce PPE and critical need items: N95 and surgical masks, gowns, Tyvek suits, face shields, goggles, gloves, ventilators and thermometers. These grants could be used for costs related to capital expenses such as machinery and equipment, raw materials needed for production, and operating expenses associated with increased production. Recipients included varying sizes and types of established manufacturers, none of whom previously produced PPE.[183]

One recipient of a $100,000 Maryland COVID-19 Emergency Relief Manufacturing Fund grant, Integrated Pharma Services, was previously testing materials and new technologies for mask efficacy (to help block viruses such as coronavirus), but was without plans to manufacture them. However, when the supply chain broke down, the combination of the state grant and the company's own $200,000 capital investment enabled the actual production of masks, with initial runs of 4 million per month.[184]

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[181] MIT's COVID-19 Impact in Interactive Map (Massachusetts Institute of Technology System Design and Management), accessed January 22, 2021, https://sdm.mit.edu/view-mits-covid-19-impact-in-interactive-map.
[182] Callum Borchers, "How A Factory In Lawrence Went From Athletic Apparel To Medical Gowns" (WBUR, April 14, 2020), https://www.wbur.org/bostonomix/2020/04/14/99degrees-sports-apparel-to-medical-gowns.
[183] Karen Glenn Hood, "Maryland Commerce Awards Additional $1.6 Million in Grants to Maryland Companies Producing Personal Protective Equipment" (Maryland Economic Development Association, June 9, 2020), https://www.medamd.com/news/maryland-commerce-awards-additional-1-6-million-in-grants-to-maryland-companies-producing-personal-protective-equipment/.
[184] Steve Bohnel, "Frederick Company Ready to Manufacture Masks after $100,000 Grant from State," The Frederick News-Post, August 14, 2020, https://www.fredericknewspost.com/news/continuing_coverage/coronavirus/frederick-company-ready-to-manufacture-masks-after-100-000-grant-from-state/article_d76ac70a-ea42-56a5-b979-b414788f2fdf.html.

Crowdsourcing Innovation through Challenges

To spur rapid solutions, Challenge America and the Veterans Health Administration Innovation Ecosystem partnered with America Makes to launch the COVID-19 Maker Challenge, open to subject matter experts in engineering, manufacturing, 3D printing, infection control, industrial and experience design, emergency response, and healthcare.[185]

Participants from private industry, leading research universities, federal agencies like the VA, and nonprofits had one week to hash out solutions that could be created rapidly and cost effectively through manufacturing processes like 3D printing. Each solution had to help solve the specific issue each team was prompted with at the start of the make-a-thon and support specific frontline workers or sectors impacted by the COVID-19 crisis.

The first challenge kicked off in April and targeted first responders, the second environmental management, the third nursing home staff, the fourth in-home caregivers, and the fifth, concluding in October, disaster relief workers.

Each virtual event included the following steps: frontline workers submitted the pandemic safety issues they face to the COVID-19 Maker Challenge. These recommendations were then reviewed by an advisory panel who selected the most challenging initiatives to complete. Next, experts in engineering, manufacturing, 3D printing, infection control, sanitation, industrial and experience design were recruited to form teams who donated their time to produce the solutions. Finally, volunteers met with the workers who submitted the challenges and spent one week working with them to refine their approach before launching a 72-hour sprint to design and build working prototypes suitable for rapid manufacturing.[186]

CIS respondent HermTac, based in Dallas, Texas, earned top marks as the winner of the Innovation Experience (iEx) Design Award.[187] Their Tessellation Sanitation Station[188] uses concentrated ultraviolet light inside a box to sanitize objects in seconds.

Challenges are a proven, low-cost model for crowdsourcing maker-generated and open source solutions; the format could be leveraged more widely across more agencies to advance public sector innovation.

[185] COVID-19 Makers Challenge (Challenge America), accessed January 22, 2021, https://www.covid19makerchallenge.com/.
[186] "COVID-19 Makers Challenge Rapidly Building Innovative Safety Solutions," DigitalVA (U.S. Office of Information Technology, September 16, 2020), https://www.oit.va.gov/news/article/?read=covid-19-makers-challenge-rapidly-building-innovative-safety-solutions.
[187] Matthew Razak, "COVID-19 Maker Challenge Delivers Solutions for Veterans, VA Staff and America," VAntage Point (U.S. Department of Veterans Affairs, December 30, 2020), https://blogs.va.gov/VAntage/82801/covid-19-maker-challenge-delivers-solutions-veterans-va-staff-america/.
[188] @HERMTAC, "HermTec Tessellation Sanitation Station" (YouTube, November 28, 2020), https://www.youtube.com/watch?v=D2IwKNekQ-U.

Policy Recommendations

The 2020 COVID-19 PPE crisis has revealed a number of specific opportunities for government agencies to better integrate with and enable the Citizen Maker Response to emergencies. Below we detail our recommendations for U.S. Policy reform, although these suggestions may also be applicable and implementable in other countries. .

1. Formalize the Citizen Maker Response Network

While the focus of this report is on the Citizen Maker Response to COVID-19, the design, prototyping and production capabilities could be utilized in a wide range of response efforts, including responses to natural and man-made disasters (e.g. hurricane, flood, fire, etc.). **To plan for a greater national resilience and future disaster response, designers, prototypers, engineers, makers, local manufacturers and their facilities should be formalized, supported, funded, and leveraged as a distributed emergency innovation and manufacturing response network.**

Open Source Medical Supplies has published a memo recommending the creation of a federally defined but state-activated network of facilities and volunteers—A U.S. Prototyping and Manufacturing Reserve (USPMR)[189] or a "Maker Corps." **Such a reserve force could be activated to solve breakdowns in supply chain channels and to augment traditional emergency response services by ensuring the availability of local rapid prototyping and production facilities, plus trained staff and volunteers in times of crisis.**

A federal interagency task force should determine standards for tiered certification, with levels indicating facility capabilities, and determine the lead administrative agency. USPMR members should reflect the range of responders who are and have been critical to addressing the COVID-19 medical supply chain emergency, from independent designers to community makerspaces to medium-scale manufacturers.

Incentives to participate could include certification that enables faster access to state-allocated emergency funds during disasters; streamlined registration with the FDA as a Current Good Manufacturing Practice (CGMP) facility; and access to a USPMR aggregator program or cooperative which could market USPMR products and offer preferred contracting opportunities with state and national stockpiles, Department of Veterans Affairs (VA), etc. Read the full proposal at osms.li/dayone.

[189] Sabrina Merlo, "Building Medical Supply Chain Resilience through a U.S. Manufacturing Reserve and Digital Stockpile," Day One Project, November 17, 2020, https://www.dayoneproject.org/post/u-s-prototyping-manufacturing-reserve-u-s-digital-stockpile.

2. Fund and Incentivize the Citizen Maker Response Network

There are multiple opportunities to strengthen this ecosystem of open source innovators, whether or not an overarching reserve structure is articulated. Even with the creation of a USPMR or "Maker Corps", **incentives will be necessary to draw a robust range of qualified participants.**

Grant and capital improvement opportunities—especially for makerspaces, the central infrastructure of the Citizen Maker Response—are critical towards ensuring their capacity to respond in the future. Most unaffiliated makerspaces are key centers of learning, innovation and entrepreneurship in communities, and most exist on the edge of fiscal solvency. **Investing in makerspaces will benefit not only evergreen goals of workforce and economic development, but also any future such emergency where a rapid innovation and fabrication response is needed.**

Funding of the Citizen Maker Response Network can be achieved via variety of mechanisms:

- Providing access to a federally-funded / local-match revolving, forgivable loan funds, and/or New Markets Tax Credits that offer resources for facility capital improvements and capacity building.
- Creating grant competition opportunities to serve as a workforce development and regional emergency response training and surge production center (a paid reserve function, similar to the Civil Reserve Air Fleet (CRAF)). Community colleges are ideal locations for these manufacturing-as-emergency response regional training and testing locations.
- Investing in the creation of makerspaces in regions where there are none.
- Building channels for communication and compensation between Citizen Maker Response groups and city and state emergency response agencies. Whether or not it is accomplished through an aforementioned USPMR registry, **makerspaces and Citizen Maker Response entities (both individuals and groups) should not be invisible to government emergency response support when crisis occurs.** One mechanism by which this could occur is the integration of maker community organizations (makerspaces, maker groups, and convening organizations like Nation of Makers and Open Source Medical Supplies) into the Volunteer/Community Organizations Active in Disaster (VOAD/COAD) network, enabling activation *and support* of these organizations in disaster.

3. Create a U.S. Digital Stockpile

OSMS's Day One Project paper[190] additionally outlines a recommendation for the creation of a comprehensive library of open source medical supply "blueprints" — the U.S. Digital Stockpile.

[190] Sabrina Merlo, "Building Medical Supply Chain Resilience through a U.S. Manufacturing Reserve and Digital Stockpile," Day One Project, November 17, 2020, https://www.dayoneproject.org/post/u-s-prototyping-manufacturing-reserve-u-s-digital-stockpile.

This will be an essential resource to the success of the aforementioned USPMR. Initial scope could be limited to medical supplies and devices, and later become a full repository of disaster response designs, such as for water filters or emergency shelters. Fabrication standards from ASTM, AAMI, NIOSH, and OSHA, including technical, regulatory , and disinfection standards for raw materials (both hard and soft), prior to their use in medical device manufacturing, should be an asset of the Digital Stockpile. **The U.S. Digital Stockpile should be manufacturing-agnostic, involve a diversity of federal agencies and manufacturing institutes, include designs for low-resource environments, offer plain-language user guidance, and provide complete manufacturing requirements and testing guidance.**

4. Increase Opportunities for Crowdsourced Citizen Maker Innovation

During the COVID-19 pandemic there were limited opportunities for maker engagement and participation in design and prototyping as a part of a formal government response to COVID-19. To this end, **we recommend an expansion of Challenge programs (e.g., the VA's COVID-19 Challenge referenced earlier), as well as an expansion of other mechanisms such as hackathons** for individual knowledge bearers to transfer innovation expertise to both private and public sectors.

A successful example of the latter occurred during the 2015 Ebola outbreak, when USAID convened a group of practitioners and makers from diverse areas to crowdsource ideation via hackathon to produce the best Ebola protective suit. The best design came from a wedding dress designer, who, through her ample experience with difficult custom gowns, was able to come up with a design that was streamlined, safe, and easy to remove.[191]

An additional mechanism to harness crowdsourced innovation could occur via a federal Maker-in-Residence Fellowship program,[192] placing innovators into temporary positions within the federal, state or local government. A Maker-in-Residence placed at the National Institutes of Health or Veterans Administration, could, for example, work with additional agencies to develop the infrastructure necessary to develop the Digital Stockpile.

[191] Fiona MacDonald, "A Wedding Dress Designer Has Helped Engineer a Better Ebola Suit" (Science Alert, April 20, 2015), https://www.sciencealert.com/a-wedding-dress-designer-has-helped-engineer-a-better-ebola-suit.
[192] Dorothy Jones-Davis and Stephanie Santoso, "Enabling Federal Agencies to Tackle Complex Problems with the Help of Makers-In-Residence" (Day One Project, January 19, 2021), https://www.dayoneproject.org/post/enabling-federal-agencies-to-tackle-complex-problems-with-the-help-of-makers-in-residence.

5. Streamline Pathways with Regulators and Testing Facilities for Open Source Designs

While the FDA's EUA has enabled production of PPE by the Citizen Maker Response during COVID-19, there is currently no established formal regulatory guidance or approval pathway by which open source medical designs can be validated. **The FDA should include dedicated staff to develop approval pathways for open source supplies and devices, and provide advance coordination of Emergency Use Authorizations aligned with Digital Stockpile designs and USPMR facilities.** This new type of certification would reflect an understanding of the rigor of USPRM certification and be available to this trusted manufacturing network in times of crisis.

Currently, technical testing standards vary based on lab equipment availability and brand, which reduces end user confidence in results. **Incorporated into the new regulatory pathway involving the FDA and a USPMR should be the expectation that all testing facilities establish validation protocols and calibration tools for substantial testing equivalency, independent of geographic location.**

Additionally, a map of certified testing facilities, both independent and university-based, should be maintained as a resource in the Digital Stockpile. In times of declared crises, these facilities would operate as a distributed network with priority access for local manufacturers at little or no cost. USPMR regional hubs should have a minimum requirement to host a certified testing facility, with the understanding that testing access would be prioritized to USPMR and local Citizen Maker Response groups parallel to the signing of a Defense Production Act (DPA).[193]

Guidelines for analog testing, including particle filtration, fit, impact and permeability, should be a Digital Stockpile resource, with a requirement that USPMR regional hubs train members in this testing to guarantee ongoing program participation. Once a device is successfully tested within the USPMR network, it should be shared in real-time with other activated USPMR locations, potentially reducing regional manufacturing turnaround.

6. Ensure Access to Raw Materials for PPE Production

Consistent and affordable access to raw materials obstructed domestic pandemic response, with some imported source suppliers reporting a 500% cost increase for raw materials.[194] Many domestic raw suppliers struggled to keep up with demand, which is still affecting the woven plastics industry at the time of this writing.[195]

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[193] Defense Production Act (U.S. Federal Emergency Management Agency, November 23, 2020), https://www.fema.gov/disasters/defense-production-act.
[194] The Domino Effect: Raw Material Shortages (Salus Medical, September 1, 2020), https://www.salusmedicalrx.net/the-domino-effect-raw-material-shortages/.
[195] Richa Naidu, "Clorox Won't Have Enough Disinfecting Wipes until 2021, Its CEO Says" (Reuters, August 4, 2020), https://www.reuters.com/article/us-health-coronavirus-clorox-wipes/clorox-wont-have-enough-disinfecting-wipes-until-2021-its-ceo-says-idUSKCN2501EU.

Domestic PPE raw material manufacturers should be identified and federally contracted (similar to the SBA bidding contract system)[196] to constantly have a specified inventory available within a certain time frame. A primary distribution of this inventory to USPMR members (the Citizen Maker Response network) during declared crises would be included in the contracts.

7. Reduce the Burden of Liability

In the United States, Good Samaritan laws offer legal protection from civil lawsuits to people who voluntarily provide reasonable aid to those who are injured, ill, in danger, or otherwise incapacitated.[197] However, Good Samaritan laws only protect groups donating supplies.

As described earlier in this report, the FDA EUAs helped to clarify the liability landscape for both medical institutions and the Citizen Maker Response, but the open source community moved very quickly to respond to the gap in supplies, and critical weeks went by without sufficient guidance.

The Public Readiness and Emergency Preparedness (PREP) Act[198] enacted on March 17, 2020 supported the Citizen Maker Response by reducing fear of liability[199] or litigation[200] for their product. **The authors of this report are in support of the utilization of PREP Act issuances by the U.S. Department of Health and Human Services in future crises.**

However, **in addition to this legislation, it is important that plain language guidance be provided to increase awareness of these policies that reduce the burden of liability on the Citizen Maker Response.** For example, some makerspaces affiliated with larger entities (e.g., Colleges or Universities or corporations) reported being disincentivized or prevented from producing PPE by their insurers, thereby limiting the capacity of the Citizen Maker Response. This lack of clarity about liability supports the case for formalizing the network (i.e., the USPMR), providing a platform for knowledge sharing.

8. Facilitate New Distribution and Delivery Pipelines

The individual quantities of Citizen Maker Response-manufactured PPE are often small and unevenly distributed, creating a challenge and disincentive for large-scale distribution and

[196] SBA Contracting guide (U.S. Small Business Association), accessed January 25, 2021, https://www.sba.gov/federal-contracting/contracting-guide.
[197] Good Samaritans Law and Legal Definition (USLegal, Inc.), accessed January 24, 2021, https://definitions.uslegal.com/g/good-samaritans.
[198] Public Readiness and Emergency Preparedness (PREP) Act (U.S. Department of Health & Human Services Office of Public Health Emergency), accessed January 23, 2021, https://www.phe.gov/Preparedness/legal/prepact/Pages/default.aspx.
[199] "Are the MIT Face Shields a Substitute for Fully Tested and FDA Approved Shields?," MIT Project MANUS (Massachusetts Institute of Technology, May 1, 2020), https://project-manus.mit.edu/faq/are-the-mit-face-shields-a-complete-substitute-for-fully-tested-and-fda-approved-shields.
[200] Charles A Blanchard, Daniel A Kracov, and Vinita Kailasanath, "3D Printing and the Shifting Legal Landscape for COVID-19," Arnolds & Porter, accessed January 24, 2021, https://www.arnoldporter.com/en/perspectives/publications/2020/05/3d-printing-shifting-legal-landscape-covid19.

delivery partners to engage with these producers on an individual basis. Additionally, many of these producers do not have access to distribution and delivery partners if they are not already part of the traditional manufacturing community.

Given the emergency response nature of the Citizen Maker Response, and the lack of established networks for distribution and delivery of citizen-manufactured PPE, **it is imperative that new supply aggregators and distribution pipelines for domestic surge manufacturing are created and incentivized.**

Established private sector group purchasing organizations (GPOs)[201] could join and serve in supply chain emergencies (via the USPMR or similar manufacturing reserve effort) to aggregate and distribute quantities of supplies produced by Citizen Maker Response efforts. Alternatively, the USPMR itself could function as the supply aggregator, with FEMA, State emergency response agencies, and the U.S. National Stockpile providing demand.

9. Guarantee and Support a Domestic Market

> ***"We need to support domestic production however we can, but U.S. labor just costs more. The hospitals can't stomach that cost. They just can't. But if we could get them subsidized, I think hospitals would love to order domestically, even pay a little more for it. But they just can't pay four and five times the price."*** — David Rainosek, MD, Associate Medical Director of St. Vincent Rehabilitation Hospital, Arkansas, United States

Guaranteeing and supporting an American-Made solution for PPE and medical supplies is two-fold: requiring a willingness to pay more to fairly compensate for U.S. labor, as well as providing incentives large enough for pivoting manufacturers to justify the expense of investing in new technologies and equipment. The challenge of the U.S. market being able to offer even medium-term demand for domestic manufacturers who pivot to produce PPE is known to U.S. manufacturers. Many remember the H1N1 crisis in 2009, when manufacturers that ramped up PPE production were left without buyers when the crisis died down.[202] MIT's report points out that even with state incentives, smaller firms were reluctant to commit extensive resources to pivot to a product line that might dry up as soon as the pandemic ended: "many firms who were willing to pivot to PPE production but concerned about uncertain demand in the near future were therefore unable to find a large enough market to guarantee profitability."[203]

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[201] What Is a GPO? (Supply Chain Association), accessed January 24, 2021, https://www.supplychainassociation.org/about-us/what-is-gpo.
[202] Alexandra Berzon, Melanie Evans, and Stephanie Armour, "Miscalculation at Every Level Left U.S. Unequipped to Fight Coronavirus" (The Wall Street Journal, April 29, 2020), https://www.wsj.com/articles/miscalculation-at-every-level-left-u-s-unequipped-to-fight-coronavirus-11588170921.
[203] Elisabeth Reynolds, Anna Waldman-Brown, and Daniel Traficonte, "Strengthening Manufacturing Innovation Ecosystems Before, During, and After COVID: Lessons from Massachusetts," Work of the Future (Massachusetts Institute of Technology, January 22, 2021), https://workofthefuture.mit.edu/research-post/strengthening-manufacturing-innovation-ecosystems-before-during-and-after-covid-lessons-from-massachusetts/.

Recent news coverage of domestic N95 manufacturers who have pivoted or entered the market[204] during the COVID-19 pandemic proves the same point: domestically-produced PPE cannot compete with imports on cost.

To increase national resilience to medical supply chain disruption, the U.S. Government must offer market subsidies and/or longer-term contracts to domestic manufacturers of PPE to ensure availability of high-quality and sufficient supply in pandemics and emergencies. This could include a requirement that all PPE for the Strategic National Stockpile[205] be domestically manufactured, similar to the Berry Amendment[206] and the Buy-American Statute,[207] which promote the purchase of U.S.-made goods for military and federal agencies, respectively. The Biden Administration's "Made in All of America" Executive Order will help ensure this.[208] Other federal stockpiles, such as HHS, FEMA, and Veteran Affairs, would benefit from the same requirement, as they were depleted pre-pandemic due to 2018 tariff impositions.[209] Healthcare systems are supportive of potential regulations within the Centers for Medicare and Medicaid Services (CMS) reimbursement framework that would support domestic manufacturing.[210]

[204] "Two Guys Start a D-FW Mask Factory but Can't Catch a Break." (Dallas Morning News, January 22, 2021), https://www.dallasnews.com/news/watchdog/2021/01/22/two-guys-start-a-dfw-mask-factory-but-cant-catch-a-break-forget-made-in-texas-china-always-wins/?outputType=amp.
[205] Strategic National Stockpile (U.S. Department of Health & Human Services, Office of Public Health Emergency), accessed January 25, 2021, https://www.phe.gov/about/sns/Pages/default.aspx.
[206] "Berry Amendment (10 U.S.C. 2533a)," DPAP | Contract Policy and International Contracting (U.S. Defense Pricing and Contracting, 1994), https://www.acq.osd.mil/dpap/cpic/ic/berry_amendment_10_usc_2533a.html.
[207] "The Buy American Act" (U.S. Government Accountability Office, April 5, 1978), https://www.gao.gov/products/105519.
[208] Joseph R Biden, "Executive Order 14005 of January 25, 2021 , Ensuring the Future Is Made in All of America by All of America's Workers," Federal Register (Executive Office of the President, January 25, 2021), https://www.federalregister.gov/documents/2021/01/28/2021-02038/ensuring-the-future-is-made-in-all-of-america-by-all-of-americas-workers.
[209] Deborah Abrams Kaplan, "How Tariffs Ravaged the COVID-19 Medical Supply Chain" (Supply Chain Dive, May 27, 2020), https://www.supplychaindive.com/news/coronavirus-tariffs-trade-medical-supply-chain/578615/.
[210] Thomas M Hanna and Dana Brown, "Reimagining Personal Protective Equipment (PPE) Supply Chains" (Healthcare Anchor Network, November 18, 2020), https://democracycollaborative.org/sites/default/files/2020-11/HAN%20Reimagining%20PPE.pdf.

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Komai's Oh My!, *Madison*
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M. Eigo, *Santa Clara County* • N. Fedner, *Los Angeles*
C. Gould • J. Guillen, *Fresno* • M. Halliday • P. Hanzo, *Orange*
County • S. Haynor, *San Francisco* • S. Herbert, *Berkeley*
J. Hobson, *San Diego* • Y. Hsieh, *Orange County* • A. Kang
K. Kasner, *San Diego* • P. Kolb, *Los Angeles* • B. Kramer,
Sacramento • N. Kreglow, *Oakland* • N. Lambert-Brown,
San Diego • T. Lau, *San Diego* • L. Laubenheimer, *San Jose*
S. Leonardi, *Dixon* • W. Lin, *Arcadia* • D. Lynn • C. Malazarte,
Lawndale • T. Maughan, *Monterey Bay* • S. Maxfield
J. Menchaca, *Los Angeles* • R. Mitchell, *Carlsbad* • C. Mohr,
Santa Clara • S. Morgan, *Fresno* • S. Neff, *Richmond*
K. Panowicz, *Apple Valley* • R. Peters, *Belmont* • J. Pettit,
Los Angeles • A. Pipathsouk, *Irvine* • K. Redfield, *Rio Del Mar*
C. Reid • M. Rosenhart • M. Rosenzweig, *Los Angeles*
E. Saunders, *Burbank* • S. Schiraga, *Alameda*
A. Schwenning, *Redding* • S. Shao, *Huntington Beach*
G. Shaw, *Oakland* • P. Shuman, *Santa Maria* • B. Slakter
C. Thai, *San Diego* • K. Valentine, *San Francisco*
W. van Stam, *San Francisco* • A. Whynot, *San Diego*
S. Willats, *Felton* • C. Willis, *Culver City* • Anonymous,
Fremont • Anonymous, *Hemet* • Anonymous, *West*
Sacramento • Anonymous, *San Jose* • Anonymous, *Poway*
Anonymous, *Merced* • Anonymous, *Lakeside* • Anonymous,
Richmond • Anonymous, *San Francisco* • Anonymous,
Concord • Anonymous, *Oakland* • Anonymous, *San Jose*
Anonymous, *San Lorenzo* • Anonymous, *Sacramento*
3D Printing Friends of The Bay, *Oakland*
3DPrintMercMart, *Beaumont*
9b Apparel, *Los Angeles*
Ace Makerspace, *Oakland*
All Bay Area PPE, *Alameda*
Auntie sewing squad, *Rancho Cucamonga*
Bay Area Face Shield Supply, *Dublin*
Bay Area Medical Face Shield Emergency Production,
San Francisco
Benicia Mask Makers, *Benicia*
Berbawy Makers, *Fremont*
Bouncing Bobbin Studio, *Orange County*

United States - California (cont.)
Break the Outbreak, *Dublin*
CircuitLaunch, *Oakland*
combine.la, *Los Angeles*
Covid-19 Relief Passion Project, *Irvine*
covid-19shields.com, *Los Angeles*
CRASH Space, *Los Angeles*
CSTGRP.co, *San Diego*
Danville Fighting COVID, *Danville*
Distill my Heart Mask Project, *Oakland*
DWL Enterprises/Daniels Wood Land, *Paso Robles*
ELITE Aerospace Group, *Irvine*
Fix The Mask, *San Francisco*
Fixit Clinic
Folsom Lake College Innovation Center, *Folsom*
Hearts to Heroes, *Irvine*
Hollywood Helps Hospitals, *Los Angeles*
Individual Maker for MakeMePPE & MasksNOW, *Alameda*
Jacobs Hall, UC Berkeley, *Berkeley*
Just Tape and Converting, *Morgan Hill*
LA Face Shields, *Los Angeles*
LA Film Mask Makers, *Los Angeles*
Last Mile San Diego PPE, *San Diego*
Little Great Ideas, *San Jose*
LVLUP Learning, *Saratoga*
LVLUPed.org, *San Francisco*
Make Me PPE Bay Area, *Santa Clara*
Make Me PPE EBay, *Berkeley*
Maker Nexus, *Sunnyvale*
Matt Builds PPE, *Sunnyvale*
MatterHackers Maker Response Hub, *Lake Forest*
Modesto Jr College PPE Group, *Modesto*
Moreau Catholic High School, *Hayward*
OC3DPPE, *Orange County*
Open Source COVID Shield, *Oakland*
Open Source COVID19 Medical Supplies - San Diego, *San Diego*
Open Source COVID19 Medical Supplies - SF Bay Area, *Oakland*
Operation Make, *Irvine*
Operation Shields Up, *Rocklin*
Orange County, CA Open Source/3D Printed Medical Supplies, *Huntington Beach*
ppeSF.org, *San Francisco*
Print For The Cure, *San Diego*
Project Northern Lights AND Auntie Sewing Squad, *Oakland*
Pure Life Essentials LLC, *Carson*
Purrisima Production Effort, *Los Altos*
PWDP, *San Francisco*
Resource 19, *San Diego*
Richmond High Robotics Team 841, *Richmond*
Robots Everywhere LLC, *San Rafael*
Root Access, *Fresno*
San Diego Community Volunteers for Coronavirus Response, *San Diego*
Sausalito CA MEMM, *Sausalito*
Saving Face San Francisco, *San Francisco*
Something Labs, *San Francisco*
South Bay Masks Sewing group, *San Francisco*
StopTheBug.org, *San Francisco*
UAV Rotor King (Ear Saver Now), *Anaheim*
UMakers Makerspace
Vista Display Products, *Vlsta*

United States - Colorado
J. Brennan, *Longmont* • M. Busch • S. Capdeville, *Boulder*
J. Castle • D. Clark, *Ridgway* • R. Finnegan, *Durango* • K. Lee
K. Maxwell • F. Saplis, *Fort Collins* • W. Seltzer, *Boulder*
B. Sharpe, *Colorado Springs* • A. Walker, *Colorado Springs*
R. Warner, *Longmont* • Anonymous, *Colorado Springs*
Athena Project Arts
Chimera Investors LLC, *Erie*
Colorado Crafting for a Cause
Colorado Face Mask Warriors
Colorado Laser Technologies
Colorado Mask Crafters
Colorado Mask Makers United
Colorado Mask Project, *Durango*
Cover Up Colorado
Dena's Mask Making Army
Denver Design Incubator
Denver Mask Task Force
Greeley 3D Printing
Josephene's Inspirations
Legacy Institute of Colorado Springs
Littleton Mask Makers, Littleton
Loveland CreatorSpace, *Loveland*
Make4COVID, *Boulder*
MakerLab COVID-19 Response Team, *Durango*
Masks4Millions, *Littleton*
MasksNow
MasksNow - Eastern Region, *Eastern Region*
MasksNow - Western Region, *Northern Colorado*
MasksNow - Western Slope, *Western Slope*
Open Source COVID19 Medical Supplies - Routt/Eagle Counties, CO, *Steamboat Springs*
Operation We Can Sew
Pikes Peak Makerspace
Sew In Tune Servicing
Sew It for COVID
The Edmondson Foundation
The Holaday Family
The Powerhouse, *Durango*
Motominded LLC
Titan Robotics
United Way, *Weld County*
We Can Sew It, *Boulder*
Zay Products, *Longmont*

United States - Connecticut
C. Chapman • M. Collins, *Bristol* • M. Davis, *West Haven*
J. Esty • S. Gharlban • J. Graca • C. Knyff, *Mansfield* • A. Nichols, *Cheshire* • B. Oliver • E. Tinker, *Middlesex* • A. Tordanato, *Plantsville*
CT 3D Print Army

United States - Connecticut (cont.)
CTppeProject.com, *Danbury*
Danbury Hackerspace, *Danbury*
MakeHaven Covid-19 Response, *New Haven*
Mask Makers Unite, *Fairfield County*
Open Source COVID19 Medical Supplies - CT, *East Hampton*
OrchardWorks Magic Wands, *Stafford Springs*

United States - Delaware
C. Shannon
openPPE, *Newark*

United States - District of Columbia
L. Dyson • A. Hsieh • J. Huswit • M. Stratton • J. Wetzel

eNABLE DC
KristinaMakesPaper
Open Source COVID19 Medical Supplies - Washington DC Area

United States - Florida
C. Shannon • E. Bearden, *Pensacola* • B. Bowers, *Jacksonville* • M. Brzoska, *Vedra Beach* • M. Bucklan, *Orlando* • P. Buczynsky, *Odessa* • S. Clark, *Jacksonville*
I. Cole, *Orlando* • J. Dill, *Ponte Vedra* • M. Eaton, *Palm Coast*
S. Eiting, *Tampa* • C. Emmons, *Jacksonville* • P. Gauldin, *Pinellas Park* • N. Illasarie, *Orlando* • B. LaFerie • T. Lau, *Miami* • D. Leithauser, *New Smyrna Beach* • M. Mertz, *Tallahassee* • J. Moring, *Ocala* • T. Musolino, *Orlando*
K. Myers • D. O'Meara, *Venice* • B. Rampersand, *Brevard County* • M. Rowzie • C. Ryan, *Miami* • B. Sites • D. Turscak, *Tampa* • J. Ulrich, *Volusia County* • T. Wilk, *Orlando*
M. Yeager, *Tampa* • Anonymous, *Venice*
AD Henderson University, *Boca Raton*
Caretilt, *West Palm Beach*
CPI Medical Supply, *Edgewater*
Creative Energies Inc, *Ocala*
Feed the Hungry
Gulliver Prep, *Miami*
Hacklab, Inc., *Fort Lauderdale*
Hygienics Industries, INC. , *Miami*
Making Awesome - Emergency PPE Response, *Tallahassee*
MakerMask
Moonlighter FabLab, *Miami*
Open Source COVID19 Medical Supplies - Brevard County, *Cocoa Beach*
Open Source COVID19 Medical Supplies - Central Florida and South Florida, *Orlando*
Open Source COVID19 Medical Supplies - Sarasota/Manatee, *Bradenton*
Open Source COVID19 Medical Supplies - South Florida, *Hollywood*
Open Source COVID19 Medical Supplies - Volusia County, *Ormond Beach*
openPPE, *Newark*
Print the Curve Flat, *Riverview*
Vida Custom Designs, *Miami Lakes*
VP 3D Printing, *Venice*

United States - Georgia
B. Davis, *Dawsonville* • R. Farmer, *Atlanta* • P. Grysztar, *Columbus* • K. Hawkins, *Atlanta* • A. Lowrey, *Atlanta*
H. Martin, *Kennesaw* • J. Morris • L. Pinion, *Saint Simons Island* • V. Platacis, *Skidaway Island* • C. Staskiewicz, *Atlanta* • K. Thew, *Atlanta* • T. Thornton, *Atlanta* • B. Walker, *Wilmington Island* • S. Zeidler
ATL Seamsters, *Atlanta*
Atlanta Beats Covid, *Atlanta*
COVID19 Masks.ga, *Augusta*
CSRA Makers, *Augusta*
Enchanted Craft, *Dahlonega*
Geekspace Gwinnett, *Suwanee*
Helmet Studio LLC, *Atlanta*
Open Source COVID19 Medical Supplies - CSRA, *Augusta*
Open Source COVID19 Medical Supplies - Georgia, *Atlanta*
Sewing Masks for Area Hospitals, *Atlanta*
Stop Covid19ATL, *Atlanta*
The Mount Vernon School, *Roswell*
UDA Star Foundation, *Saint Simons Island*

United States - Hawaii
C. Grant, *Honolulu* • C. Killhour, *Maui* • B. Kuriyama, *Waianae* • M. Sahafl, *Maui* • Kahanu Ventilator Project, *Honolulu*
Maui Face Mask Project, *Maui*
Open Source COVID19 Medical Supplies - Maui, *Haiku*

United States - Idaho
G. Bentz, *Boise* • N. Hems, *Sandpoint* • T. Russo, *Cour d'Alene* • Anonymous, *Boise*
Idaho STEM Action Center, *Boise*
Palouse Open Source COVID19 Medical Supplies, *Moscow*

United States - Illinois
K. Antonakos, *Chicago* • K. Combs, *Hamilton* • S. Dembo, *Chicago* • G. Gibbs, *Hoffman Estates* • C. Guzman, *Chicago*
T. Harrison, *Chicago* • J. Hess, *Rockford* • C. Higgs, *Watson*
J. Jones, *Mokena* • L. Marshall, *Olney* • J. Murray, *Macomb*
T. Noack • D. Norman, *Pontiac* • J. Schadeck, *Chicago*
L. Staples, *Chicago* • I. Vepstas, *Chicago* • B. Walsh
N. Wegrzyn, *Chicago* • M. White'ka, *Chicago*
Anonymous, *O'Fallon*
3D Universe, LLC, *Algonquin*
Artists Resource Mobilization, *Chicago*
Central Illinois Mask & Gown Makers
Chicago Women's Hockey or Beverly Bombshells, *Chicago*
Courtnie's Cruthú, *Chicago*
Illinois Makerlab - A chapter of Makers for Covid-19, *Champaign*
Impossible Objects, *Chicago*
Macon County Covid 19 AM Response Group, *Decatur*
Makers for COVID-19, *Burr Ridge*
mHUB, *Chicago*
Open Source COVID19 Medical Supplies - Chicago, *Chicago*
Open Source COVID19 Medical Supplies - Illinois, *Chicago*
River City Labs, *Peoria*
Sew Masks for Quincy IL, *Quincy*

United States - Illinois (cont.)
SQL Server Community, *Belleville*
St. Louis Confluence FabLab
Wanger Family Fab Lab
Museum of Science and Industry Chicago, *Chicago*
West Suburban 3D Face Shield Printers, *Riverside*

United States - Indiana
A. Atkins, *Indianapolis* • N. Babin • C. Colter, *Anderson*
M. Hawkins • R. Herrold • W. Tidd, *Indianapolis*
Anonymous, *New Albany*
Cave Rover Project Laboratories
Maker Factory, *Zionsville*
Open Source COVID19 Medical Supplies - Indianapolis, *Indianapolis*
Stitched Together Indiana, *Fort Wayne*
The Workbench - Fort Wayne, *Fort Wayne*

United States - Iowa
A. Andresen, *Davenport* • L. Pare, *Des Moines* • B. Schmidt, *Des Moines* • J. Schroeder, *Des Moines*
Honeycorr, *Fairfield*
PPE Face Shields, *West Des Moines*

United States - Kansas
A. Cichowski, *Olathe* • K. Claflin, *Linwood* • L. Fox, *Anthony*
N. Grube, *Kansas City* • R. Hodapp, *Lawrence* • C. Martin, *Parsons* • A. Rawitch, *Lenexa* • P. Shults • E. Trigg, *Miami County* • Anonymous, *Olathe* • Anonymous, *Wichita*
ContourMD, *Lenexa*
FreePPEKC, *Overland Park*
Great Plains MakerSpace, *Garden City*
Kansas STEM United, *Overland Park*
Lucid Betty, *De Soto*
PPE for KC, *Kansas City*

United States - Kentucky
M. Clements • J. Gordon, *Louisville* • K. Gowan • D. Long, *Louisville* • T. Saad, *Louisville* • M. Smith, *Nebo* • R. Swain, *Hebron*
Berea Makerspace, *Berea*
Open Source COVID19 Medical Supplies - Central KY, *Lexington*

United States - Louisiana
C. Gilbert, *New Orleans* • M. Guo, *Baton Rouge* • M. Schutte, *Lake Charles*
Curious Form, *New Orleans*
Last Mile New Orleans PPE, *New Orleans*
New Orleans Open Source COVID19 Medical Supplies, *New Orleans*
NWLA Makerspace, *Shreveport*
Sew You Care, *Bossier city*
We Have Masks, Mask Makers Collective, *Slidell*

United States - Maine
T. Ackerman, *Biddeford* • E. Fraser
Haystack Mountain School of Craft, *Deer Isle*
Jonesport Shipyard, *Jonesport*
Maine Makers COVID-19 Response Group, *Biddeford*
Relief Crafters of America , *Lewiston*

United States - Maryland
B. Blevins, *Baltimore* • C. Cox • S. Czeh • T. Czeh • J. Daniels
C. Green, *Bowie* • G. Hansen, *Baltimore* • M. Kotz • S. Lalloff
J. Loupe, *Baltimore* • J. Mallo, *Howard County*
L. McMindes, *Salisbury* • A. Myers, Bethesda • K. Newman
K. Pepper, *Frostburg* • J. Powell, *Glen Burnie* • A. Schaaf
K. Schumann, *College Park* • B. Searle • K. Sessions, *Chevy Chase* • J. Stengel, *Baltimore* • Dr. N. Squires, *Montgomery County* • K. Thompson • V. Vilay, *Baltimore* • R. Willems, *Baltimore* • E. Wingren, *Baltimore* • C. Wright, *Baltimore*
Anonymous, *Frederick* • Anonymous, *New Windsor*
Annapolis Makerspace, *Annapolis*
Bullis BITlab, *Potomac*
Circuit Breaker Labs, *Capitol Heights*
Daggett Consulting LLC, *Silver Spring*
Delmarva COVID Crafters, *Salisbury*
Digital Harbor Foundation, *Baltimore*
DSA Global Partners, *Silver Spring*
Enable Alliance
Fabricationevents.com, *Jessup*
Gadget Lab LLC, *Silver Spring*
Hatch Exhibits, *Columbia*
KID Museum, *Bethesda*
Makers Unite, *Baltimore*
Maryland Thermoform and Quake Scientific, *Baltimore*
Open Source COVID-19 Medical Supplies - MD/DC/NoVA, *Baltimore*
Open Works Baltimore, *Baltimore*
Prepared for Flight, LLC, *Severn*
Route 1 Mask Match, *Hyattsville*
Station North Tool Library, *Baltimore*
The Clarice Smith Performing Arts Center Costume Shop, *College Park*
Xometry, *Gaithersburg*

United States - Massachusetts
M. Akeman, *Worcester* • M. An, *South Yarmouth*
S. Bannasch, *Shutesbury* • K. Blosser • B. Caras
A. Cardinaux, *Boston* • D. Casis • J. Cho, *Weymouth*
P. Coffey, *Lowell* • M. Cosman • B. Croteau, *Bedford*
N. Cummings, *Upton* • B. Dupree, *Auburn* • S. Edwards, *Boston* • M. etreault-Wallace, *Plymouth* • A. Ezorsky, *Somerville* • J. Fanion, *Northampton* • N. Franklin, *Framingham* • M. Graney, *Chelsea* • A. Howell, *Boston*
S. Lamothe • E. Lisa, *Boston* • M. Lovic, *Easthampton*
L. Malle-Smith, *Holyoke* • M. Mastus, *Brandon* • H. McCarthy, *Somerville* • N. Melenbrink, *Cambridge* • J. Mulready, *Boston* • T. Perez, *Rockland* • A. Ramos, *Somerville*
E. Schreiber, *Waltham* • N. Seward, *Wayland* • R. Snell, *Mathison* • D. Syrene, *Boston* • K. Toomey, *Worcester*
E. Wallace, *Martha's Vineyard* • F. Warren • D. Zackin, *Boston* Anonymous, *Upton* • Anonymous, *North Attleboro*
Anonymous, *Cambridge* • Anonymous, *Boston*
Anonymous, *Stoughton* • Anonymous, *Leominster*

United States - Massachusetts (cont.)
Artisan's Asylum, Inc., *Somerville*
Assemble Lab Fashion, *Lowell*
EarLove, *Framingham*
Eddyline Kayaks, Chinook Enterprises and Skagit Rotary.
Fab Lab Boston, *Boston*
Fab@CIC, *Boston*
Fashion Makerspace UMLAFFOA Fabric Discovery Center, *Lowell*
Fashion Makerspace, Innovation Hub, UML, *Lowell*
Harvard University - GSD, *Cambridge*
LaunchSpace Inc., *Orange*
Lena Park Fab Lab, *Boston*
Lowell Makes, *Lowell*
MakerMask.org, *Orange*
Makersyard, *Ayer*
Masks Made with Love Western MA, *Boston*
Newburyport High School, *Newburyport*
Northeast Face Shield Project, *Boston*
Pollard3Dprints, *Boston*
Pyxis Masks
South Shore Vocational Technical High School, *Hanover*
Technocopia, *Worcester*
The She, *Hopkinton*
The WorcShop, *Rochdale*
Tyr's Handcrafted, *Everett*
UML3D, *Lowell*
Worcester Face Shield Project, *Worcester*
Worcester MA Mutual Aid Face Mask Group, *Worcester*
WorcShop, *Worcester*
Zooguu, *Nahant*

United States - Michigan
A. Alba, *Wixom* • A. Amicone, *Clarkston* • L. Benages, *Plymouth* • M. Carter, *Grosse Pointe Woods* • D. Connelly, *Oakland County* • M. Crooks, *Grand Rapids* • J. Danvport, *Saugatuck* • B. DeLine • T. Diepenhorst, *Maybee* • L. Funsch, *Grand Blanc* • S. Kruszynski, *Muskegon* • C. Lientz, *Ann Arbor* A. Mandlik, *Commerce Township* • M. Marcus Y. Marie, *Lapeer* • S. Marle • R. McGarry • J. Morrison, *Frankenmuth* • K. Morrison • L. Schall, *Detroit* • K. Shamery, *Grand Rapids* • S. Siegfried, *Rochester* • V. Skier • T. Smith, *Lenawee County* • J. Trak, *Detroit* • C. Wasel, *Rockford* T. Waskiewicz, *Mt. Morris*
Anonymous, *Bay City*
3D Printing Club, *Canton*
Akervall Technologies Inc., *Saline*
Britten Safety Solutions, *Traverse City*
Detroit Sewn, Inc., *Pontiac*
Factory Two, *Flint*
Find the Helpers, *Ann Arbor*
FIRST in Michigan 1 Million PPE Challenge, *Wixom*
Maker Works, *Ann Arbor*
Masks for Marquette, *Marquette*
Open Source COVID19 Medical Supplies - MI, *Detroit*
Open Source COVID19 Medical Supplies - West Michigan
Operation Face Shield, *Ann Arbor*
Operation Face Shield Ann Arbor, *Ann Arbor*
Operation Faceshield, *Jackson*
SWMI Protective Gear Project, *Kalamazoo*
Taj Cottage

United States - Minnesota
M. Brierley • D. Domina, *Tracy* • K. Erickson, *Apple Valley* L. Hanson, *Apple Valley* • J. Hayes, *Marshall* • N. Moseman B. Rekstad, *Saint Paul* • N. Walbridge, *Duluth* • W. Wendorf, *Oak Grove* • E. Wilfreesboro, *Minneapolis* • R. Wolfe
Anonymous, *Mounds View*
BeSillyProject, *Minneapolis*
Erickson Family, *Apple Valley*
ICUshieldsMN, *St. Paul*
KnightKrawler Robotics, *New Brighton*
Minnesota Maker Collective, *Minneapolis*
Twin Cities Maker, *Minneapolis*
UMN Anderson Student Innovation Labs, *Minneapolis*
White Bear Makerspace, *White Bear Township*
Yeti 3D, *Barnesville*

United States - Mississippi
H. Graham • N. Kinney, *Hattiesburg* • S. Valentine, *Southaven*
Eagle Maker Hub, *Hattiesburg*

United States - Missouri
R. Bell, *Kansas City* • L. Christians • S. Guilick, *Cole County* S. Herin, *Wentzville* • T. Kays, *St. Louis* • B. Koke, *St. Louis* C. Palermo, *Kansas City* • S. Roca, *St. Louis* • J. Santy, *Helena* A. Scearce, *St. Louis* • A. Schwent, *St. Louis* • N. Southard J. St. Louis, *St. Louis* • B. Wahoff, *St. Louis* • Anonymous, *Moberly*
Greater St. Louis One Million Mask Drive, *St. Louis*
Hammerspace Workshop, *Kansas City*
O-STEAM, *Springfield*
Open Source COVID19 Medical Supplies - Springfield, *Springfield*
Ozarks SySTEAMic Coalition, *Springfield*
United States - Missouri (cont.)
PPE for KC, *Independence*
PPE for STL, *St. Louis*
Rural Missouri PPE

United States - Montana
Anonymous, *Helena*
406Masks, *Bozeman*
Billings Makerspace, *Billings*
Montana Ethical Hackers (MEH), *Helena*
Simms Fishing Products, *Bozeman*
spectrUM Discovery Area, *Missoula*

United States - Nebraska
A. Graham, *Randolph* • Anonymous, *Scottsbluff*
Lion's Automotive Upholstery, *Omaha*
Made New Makerspace, *Omaha*

United States - Nevada
T. Busenburg, *Las Vegas* • D. Lindstrom, *Reno*
L. McBroome • H. Shadel, *Las Vegas* • A. Yadao, *Las Vegas*
Anonymous, *Las Vegas*
Open Source COVID19 Medical Supplies - Las Vegas, *Las Vegas*
Red-Eye Net on KPRA, *Dayton*
University of Nevada Reno, *Reno*
University of Nevada, Reno - DeLaMare Library, *Reno*
WeHaveMasks, *Las Vegas*

United States - New Hampshire
A. Hamlin • L. Krupa, *Nashua* • N. Peterson, *Gilmanton*
J. Sperling, *Manchester* • Elliot Hospital, *Concord*
MakeIt Labs, *Nashua*
Makers Respond, *Nashua*
Manchester Makerspace, *Manchester*
Port City Makerspace, *Portsmouth*
Teulu Creative, *Brentwood*

United States - New Jersey
G. Alva, *Denville* • R. Dailey, *Jersey City* • N. Dzurny, *Jersey City* • C. Galesky, *Ocean County* • M. Gardner • I. Hall
D. Holmgren • K. Livingston, *Mount Holly* • C. Marietti, *Medford* • K. Pineda, *Morristown* • R. Powell K. Sanghavi-Shah G. Strac, *Vernon City* • K. Tunney
Z. Winburn • Anonymous, *Red Bank*
3D NJ SOMA, maskfordoc
DOM LLC
EyeFaceShield.com, *Ewing*
Jersey City Rapid Maker Response Group, *Jersey City*
Masks for Docs North Jersey, *Jersey City*
New Providence Face Shields, *New Providence*
Open Source COVID19 Medical Supplies - North Jersey Subgroup, *Morristown*
Open Source COVID19 Medical Supplies - Southern New Jersey, *Lacey Township*
Protect Native Elders, *Newark*
Proto Shield
OurHeroes
SOMA NJ 3D Printers Alliance, *South Orange*
TechnoChic, *Jersey City*

United States - New Mexico
J. Bare, *Rio Rancho* • K. Browning-Mezel • B. Dowd, *Los Alamos* • D. England, *Albuquerque* • B. Hartog • G. Helms, *Las Cruces* • D. Jones, *Albuquerque* • N. Paz • M. Steinkamp, *Albuquerque* • G. Valentino, *Socorro*
Air Force Research Lab
Cruces Creatives Makerspace, *Las Cruces*
Future Forge, *Silver City*
Mask Up NM
MaskCoversNM2020
MasksCoverNM.com, *Albuquerque*
New Mexico Craft Responders
New Mexico Tech, *Albuquerque*
NM Craft Responders
Open Source COVID19 Medical Supplies - New Mexico, *Albuquerque*
The Future Forge, *Silver City*

United States - New York
C. Ann, *New York City* • S. Bricker, *New York City* • R. Brome, *New York City* • K. Cheatle, *Rochester* • C. Clark, *Buffalo*
C. Connors, *Martha's Vineyard* • Z. Cowan, *Saratoga Springs* • M. Dahlquist, *Albany* • L. Daniels, *York City*
S. Davis, *New York City* • J. Dec, *New York City*
E. Decolvenaere, *New York City* • K. Estaba, *Brooklyn*
D. Flasconaro • J. Gao, *Brooklyn* • G. Harris, *Ithaca*
P. Hartmann, *New York City* • H. House, *New York City*
S. Jayaraj, *New York City* • S. Johnson, *Albany* • P. Juntunen, *Cutchogue* • T. Kuno, *New York City* • L. Leonell, *Long Island*
D. Li, *Queens* • R Logan, *New York City* • G. Lucy, *Ithaca*
S. Magilaro, *Albany* • D. Marie, *New York City* J. Mariuma, *New York City* • M. Marle, *Long Island* • C. McBride, *Rochester* • B. Medina, *Hudson Valley* • A. Metcalf, *Brooklyn*
W. Phelps, *Upstate New York* • M. Rabba, *Suffolk County*
J. Rosenkrantz, *Palenville* • S. Sage, *Rochester* • J. Sgariata, *Saratoga* • S. Shearon-Smith • R. Silberfield, *Bohemia*
J. Soderberg, *New Windsor* • B. Swart, *Buffalo* • L. Tejera, *Olean* • P. Thomas, *New York City* • M. Trevi, *New York City*
R. Weaven, *Syracuse* • E. Wells, *Tompkins County*
K. Yearsley, *West Babylon* • Anonymous, *New York City*
ArtCube Nation, *New York City*
Budmen Industries, *Syracuse*
CCLD Makerspace, *Elmira*
Open Source COVID19 - Medical Supplies #Putnam #NYS, *Carmel*
Croton Face Mask Makers, *Croton on Hudson*
Fab Lab Schenectady, *Schenectady*
Face Shields Roc, *Rochester*
FeelUSA.org
GreenGate3D, *Lake Grove*
Last Mile NYC PPE, *New York City*
LICMASKS, *New York City*
Makers for COVID-19, *Brooklyn*
Mask Crusaders, *New York City*
My 3D Printed Open Source C19 Supplies, *Martha's Vineyard*
NYC Open Source COVID19 Medical Supplies, *New York City*
NYCmakesPPE, *New York City*
Open Source COVID19 Medical Supplies - Albany, *Albany*
Open Source COVID19 Medical Supplies - Suffolk County Creators, *Suffolk County*
Open Source COVID19 Medical Supplies - Western NY, *Buffalo*
PPE - Ithaca, *Ithaca*
Regional Center for Independent Living- Rochester, *Rochester*
Open Source COVID19 Medical Supplies - Rochester, *Rochester*
Schenectady- GE Mobil Fab Lab, *Schenectady*
Sewing for Navajo Nation, *New York City*
SUNY Oneonta Theatre Department, *Oneonta*
Tech Valley Center of Gravity, *Troy*

United States - North Carolina
S. Briggs, *Charlotte* • M. Canada, *Alamance* • K. Godwin, *Wilmington* • D. Gomez • C. Grigg • L. Grubbs, *Greensboro* J. Joklik • J. Kon, *Winston Salem* • B. Lake, *Winterville* S. Lechleiter, *Salem* • J. Leonard • T. McMahon, *Asheville* J. Mitchell, *Cary* • A. Richards, *Charlotte* • J. Tarbutton, *Charlotte* • L. Taylor, *Wilmington* • J. Thielen, *Greenville*
Anonymous, *High Point*
Cape Fear OSMS, *Wilmington*
Carolina Mask Project, *Charlotte*
Carolina Textile District, *Raleigh*
Charlotte Latin Fab Lab, *Charlotte*
Charlotte MEDI, *Charlotte*
Created For Crisis, *Olivia*
MakerSpace Charlotte, *Charlotte*
Miracles in Sight, *Winston-Salem*
Mixxer Community Makerspace, *Winston-Salem*
NC Mask Warriors, *Fayetteville*
North Carolina Face Mask Warriors
Nufabrx, *Conover*
Open Source COVID19 Medical Supplies - Cape Fear, *Cape Fear*
Open Source COVID19 Medical Supplies - Raleigh, *Wake Forest*
Shield Charlotte, *Charlotte*
SplatSpace, *Durham*
Supertex, Inc., *Liberty*

United States - North Dakota
A. Bornemann
LulzBot 3D Printers, *Fargo*

United States - Ohio
N. Blake, *Middletown* • M. Burgel, *Lima* • P. Cain, *Akron* M. Casselli, *Yellow Springs* • I. Charnas, *Cleveland* • N. Clark, *Cincinnati* • A. Cullen, *Cincinnati* • D. Fischer, *Cincinnati* S. Greenberg, *Columbus* • L. Henry, *Youngstown* • L. Ielman, *Dayton* • D. Kashubeck • J. Kendall, *Cleveland* • R. Meyer T. Middleton • B. Newton, *Mentor* • K. Novak, *Parma* W. Parker, *Beavercree* • J. Patrone C. Stafford, *Springfield* M. Wharton • C. Yaeger, *Wadsworth* • Anonymous, *Cleveland* • Anonymous, *Tallmadge*
3D Printing PPE in Cincinnati, *Cincinnati*
3D Prints PPE SW Ohio, *Cincinnati*
3DCINCY, *Fairfield*
Greene County Public Library
Spark Place, *Xenia*
IATSE local 883, *Cleveland*
JBC Technologies, *Bay Village*
Lincoln Fab Lab, *Gahanna*
Lorain County Community College Super Fab Lab, *Elyria*
MasksForDocs Dayton Ohio Chapter, *Dayton*
Ohio Manufacturers Retooling and Repurposing to Create PPE, *Cleveland*
Open Source COVID19 Medical Supplies - Ashland, Ohio, *Ashland*
Open Source COVID19 Medical Supplies - Central Ohio, *Columbus*
Open Source COVID19 Medical Supplies - Ohio, *Ashland*
Schantz Maker Space, *Orrville*
Sears think[box] at Case Western Reserve University, *Cleveland*
Shields Up of Northeast Ohio, *Ashland*
The Workshop at Bounce Innovation Hub, *Akron*
Yia Yia's Sweat Shop

United States - Oklahoma
S. Caldwell, *Tulsa* • M. Desiray • J. Francis, *Tulsa* • S. Marshall, *Oklahoma City* • N. Paxton, *Oklahoma City* • M. Sohl, *Jenks* K. Williamson, *Oklahoma City* • Anonymous, *Enid*
Fab Lab Tulsa, *Tulsa*
makers4medicine.org, *Tulsa*

United States - Oregon
R. Aman, *Albany* • R. Beitz, *Salem* • E. Corral, *Portland* L. Drodrill, *Eugene* • K. Estlick, *Eugene* • M. Hathaway K. Hirsch, *Salem* • J. Lee, *Corvallis* • E. McGarvey, *Portland* R. Oprish, *Medford* • L. Own, *Albany* • S. Powell, *Portland* H. Sturgill, *Deschutes* • C. Weller, *Portland* • Anonymous, *Tigard* • Anonymous, *Hillsboro* • Anonymous, *Portland*
Anonymous, *Gearhart*
Halo Spaced, *Portland*
Makerforce, *Portland*
MakerForce PNW OSCMS, *Portland*
Oregon Institute of Technology, *Wilsonville*
Portland 3D LLC, *Portland*
REDe Print, *Portland*
River Tec company
Tier One Communications, *Tualatin*

United States - Pennsylvania
D. Cole • M. Cox • N. Eakin, *Middletown* • A. Getz, *Lehigh Valley* • K. Hedrick • C. Kilbane, *Philadelphia* • B. Kilbert, *Pittsburgh* • J. Lorah, *Paradise* • R. Lualhatl, *Philadelphia* S. Mascho, *Philadelphia* • D. Montgomery, *Pittsburgh* L. Ohliger, *Honesdale* • A. Paige, *Ebensburg* • C. Parker, *Warminster* • P. Robinson, *Pittsburgh* • S. Rosenberg, *Bensalem* • G. Salfiti, *Horsham* • J. Smith • A. Triboletti, *Chester County* • J. Ufberg, *Philadelphia* • E. Welch, *Larksville* • C. Yohe, *Pittsburgh* J. Zegley, *Lehighton* • Anonymous, *Munhall*
3D Printing Pittsburgh, *Pittsburgh*
3D Printing Club of Pittsburgh, *Apollo*
Akastex LLC, *Bensalem*
Cover Aid PHL, *Philadelphia*
HackPGH, *Pittsburgh*
IU1 Waynesburg Fab Lab, *Waynesburg*
Kohelet Yeshiva, *Philadelphia*
Luna Replicas LLC, *Philadelphia*
Makers for COVID-19: Phillymakers, *Philadelphia*
NextFab, *Philadelphia*
Open Source COVID19 Medical Supplies - Chester County, *Lincoln University*
Open Source COVID19 Medical Supplies - Philadelphia, *Philadelphia*
PPE For PA, *Phoenixville*
Protohaven, *Pittsburgh*

United States - Pennsylvania (cont.)
Sew Face Masks Philadelphia, *Philadelphia*
Swanson School of Engineering Makerspaces, University of Pittsburgh, *Pittsburgh*
TechSpark at Carnegie Mellon University, *Pittsburgh*
The Rivet at Discovery Space, *State College*
Thomas Jefferson University, Health Design Lab, *Philadelphia*
University of Pittsburgh Swanson School of Engineering, *Pittsburgh*
Wazoodle Fabrics, *Bensalem*

United States - Rhode Island
A. France, *Providence* • R. Jacobson, *Bristol* • D. McLoud, *Greenville*
C19-RI Rapid Solvers, *Providence*
United States - Rhode Island (cont.)
COVID Shields 3D, *New Providence*
Rapid Solvers, *Kingston*

United States - South Carolina
S. Cone, *Columbia* • K. Gossman, *Greenville* • K. Hall, *Spartanburg* • R. James • B. Keeter • R. Lewis, *Honea Path*
L. Matkins, *Beaufort* • K. Morris, *Columbia*
MUSC Humanitarian Cause of PPE, *Charleston*
Synergy Mill Makerspace, *Greenville*
Zverse, *West Columbia*

United States - South Dakota
W. Evans

United States - Tennessee
S. Carin, *Upper Cumberland* • J. Desmarals, *Memphis*
C. Donndelinger, *Memphis* • M. Grimm, *Knoxville* • C. Lovett
V. Mayoraz • N. Stoner, *Cookeville* • B. Ulrich, *Nashville*
Chatt Lab, *Chattanooga*
Fab Lab STEM Chattanooga, *Chattanooga*
Maker Connection, Inc., *Kingsport*
Open Source COVID19 Medical Supplies and Support - Nashville and Middle TN, Nashville
VW eLab at Red Bank, *Chattanooga*

United States - Texas
S. Andrews, *Austin* • R. Attal, *San Antonio* • A. Blurps, *Houston* • P. Byford, *League City* • R. Davidson, *Dallas*
R. Duran, *Dallas-Fort Worth* • R. Ensor, *La Vernia*
M. Hamm • K. Handschy, *Hill Country* • J. Hutchison, *Dallas-Fort Worth* • P. Kahar, *Sugar Land* • V. Keller, *Austin*
A. Kiesmit, *Dallas* • V. Kost, *Houston* • P. Magalios, *Plano*
L. McCleskey, *College Station* • D. McGrath, *Grand Prairie*
J. Miller, *Austin* • D. Morehouse, *Dallas* • J. Morris, *Dallas*
B. Murphy, *Houston* • J. Niemann, *San Antonio*
F. Patino-Atkins, *El Paso* • R. Place, *Round Rock* • A. Powell, *Dallas* • D. Root, *Tomball* • R. Rosati, *Austin* • R. Routh, *Denton* • C. Stanton, *Houston* • N. Trig, *Fort Hood*
S. Tuckker, *Houston* • R. Umberger, *Austin* • A. Vargas, *Houston* • S. Wallace, *San Antonio* • S. Warrick, *Houston*
B. Weir, *Houston* • G. West, *Tyler* • C. Wilson, *Cedar Park*
L. Wolfe, *League City* • Anonymous, *Garland* Anonymous, *Georgetown* • Anonymous, *Austin*
ACE Lab, *Cleburne*
ACME Creation Lab, *Dallas*
Atkins Art World, *El Paso*
Atxhs Covid Response, *Austin*
Corpus Christi Makers, *Corpus Christi*
Fab Lab Houston, *Houston*
Fab Lab Permian Basin, *Odessa*
Fifth Dimension Farms, *San Antonio*
HCCS Fabrication and Innovation Lab, *Stafford*
HERMTAC, *Dallas*
Houston Helpers taking on COVID-19, *Cypress*
IDEAStudio, *Houston*
Jon Hart Design, *San Antonio*
Make A Mask, *Austin*
Medical Manufacturing Alliance of South Central Texas Group, *San Antonio*
OneTwoCreate, *Tomball*
Open Source COVID19 Medical Supplies - Greater Houston, *Houston*
re:3D, Inc., *Houston*
RobotShields.com, *Greenville*
savetheears.org, *San Antonio*
Sew Makes 4 Heroes, *New Braunfels*
SRH, *Southlake*
The Humble Makers, *Humble*
Tompkins High School Robotics Team, *Katy*
University of Texas at Arlington FabLab, *Arlington*
UT Covid-19 Response, *Austin*

United States - Utah
S. Bushman • K. Call • C. Hurst • L. Petersen, *South Jordan*
J. Taylor, *Salt Lake City* • M. Thomas
Make Salt Lake, *Salt Lake City*
Salt Lake City Fighting COVID, *Salt Lake City*

United States - Vermont
Generator Makerspace, *Burlington*
Open Source COVID19 Medical Supplies - Northern New England, *Underhill*
Open Source COVID19 Medical Supplies - Vermont, *Burlington*

United States - Virginia
D. Batra, *Fairfax* • J. Blend, *Burlington* • K. Clark, *Fredericksburg* • D. Foulds, *Arlington* • S. Goodman, *Alexandria* • S. Hoffman, *Norfolk* • J. Keith • A. Kintz, *King George* • L. Lambert, *Harrisonburg* • C. Landes • J. Lareau, *Haymarket* • N. McKenzie, *Fredericksburg* • R. Mink, *Heathsville* • J. Pastore, *Warren County* • M. Peters
D. Shamblin, *Hampton Roads* • J. Silverman, *Burlington*
P. Taylor, *Gloucester* • B. Turner, *Norfolk* • C. White
S. Zuldema, *Alexandria* • Anonymous, *Troy* • Anonymous, *Harrisonburg*
ATHENA Rapid Response Innovation Lab, *Alexandria*
Future Kings, *Manassas*
Hacksburg, *Blacksburg*

United States - Virginia (cont.)
Junior League of Lynchburg, *Lynchburg*
Makersmiths Inc, *Leesburg*
Martinsville Fab Lab, *Martinsville*
Marymount eNABLE, *Arlington*
masksforcville, *Charlottesville*
Nova Labs, *Reston*
Oesh Shoes and local community, *Charlottesville*
United States - Virginia (cont.)
Open Source COVID19 Medical Supplies - Hampton Roads, *Suffolk*
PPE Sourcing/Donation for Northern Virginia Frontline Doctors, *Fairfax County*
Project Shield RVA, *Richmond*
Prusa Face Shields, *New Market*
RVA Build Forward Foundation, *Richmond*
Make It Thru Alliance, *Richmond*
The Good Works Society, *Richmond*
Vector Space, *Lynchburg*
Youth COVID-19 Relief Organization, *McLean*

United States - Washington
K. Bowie, *Seattle* • T. Clammer, *Seattle* • T. Davis, *Camano Island* • H. Doolittle, *Benton City* • C. Dougherty • J. Fevergeon, *Ellensburg* • A. Gupta, *Seattle* • J. Hall, *Vancouver* • S. Ja, *Olympia* • J. Jean, *Mukilteo* • A. Kolb, *Seattle* • V. Lonnquist, *Seattle* • J. Markestad, *Tacoma* • P. Mac, *Seattle* • P. McCurry, *Kenmore* • C. Par • T. Pham, *Seattle* • A. Pushkin, *Seattle* M. Rainville, *Seattle* • B. Rezac, *Cathlamet* • S. Sandberg, *Seattle* • K. Schultz, *Seattle* • C. Slater, *Seattle* • R. Slivka, *Seattle* • J. Smith, *Seattle* • L. Stone • A. Yan, *Seattle*
Anonymous, *Pasco* • Anonymous, *Mount Vernon*
Anonymous, *Silverale* • Anonymous, *Marysville*
Bellingham Makerspace, *Bellingham*
Chinese American Civic Association, *Seattle*
COVID19 Seattle Mask Force, *Seattle*
Happy Facemasks Tips and Tricks, *Bellingham*
Kape Consulting Manufacturing
Pacific Northwest Manufacturing, *Seattle*
Open Source COVID19 Medical Supplies - Washington State, *Olympia*
Operation Spokane Safe, *Spokane*
Paisley Duck Masked Crusaders, *Kelso*
Portland 3D Printing Lab / PNW, *Palouse*
Refugee Artisan Initiative, *Seattle*
SEA-LECT Plastics Corporation, *Everett*
Taylor Freelance, LLC, *Bellingham*
University of Washington Medical Center CREST, *Seattle*
UW Dfab, *Seattle*
Washington State 3D Face Shield Hub, *Seattle*
Whatcom mask collective, *Bellingham*
Yakima Makerspace, *Yakima*

United States - West Virginia
G. Elliott, *Fayette County* • J. Smith, *South Charleston*
Jules Enchanted Gifts, *Eastern Panhandle*
Open Source COVID19 Medical Supplies - Northern West Virginia
Open Source COVID19 Medical Supplies - Southern WV, *Fayetteville*

United States - Wisconsin
C. Becker • M. Brenner, *Milwaukee* • G. Cipriano, *Spring Valley*
C. Counard • A. Dances • E. Deering, *Racine* • L. Flunker, *Eau Claire* • A. Grimley, *Kenosha* • J. Heinz, *Milwaukee* • M. Kramer, *Menomonie* • M. Lee, *Eau Claire* • A. Maker, *Spring Valley* • S. Markee, *Superior* • K. Nairn, *Milwaukee* • D. Streeter • Anonymous, *Milwaukee* • Anonymous, *Oregon*
Chippewa Valley Makers, *Eau Claire*
David Schrubbe, *Oshkosh*
FaceShieldProject.org, *Madison*
Grainger Engineering, *Madison*
MHT Makerspace, *Medford*
Milwaukee Makerspace, *Milwaukee*
Netzer Plastics, *Medford*
Open Source COVID19 Medical Supplies - Milwaukee, *Milwaukee*
Paige Leigh Designs, *Baldwin*
UW Makerspace, *Madison*
Wisconsin Face Mask Warriors - 3D Printing, *Green Bay*

United States - Wyoming
S. Robinson, *Riverton*

Uruguay
Co-innovación UTEC, *La Coronilla*
UTEC Lab-A, *Durazno*

Venezuela
Fab Lab Caracas, *Caracas, Miranda*

Vietnam
FabLab Saigon, *Ho Chi Minh City*

Zambia
Malambo Grassroots, *Malambo*

DESIGN | MAKE | PROTECT

A report on the open source maker and manufacturer response to the COVID-19 PPE crisis

Download the full report at: osms.li/impact

OSMS Open Source Medical Supplies | NATION OF MAKERS

OSMS and NoM collected data from **1800 respondents** from **March to September 2020**. Below are the **key report findings**.

WHO

Maker organizations, re-tooled manufacturers, and networks of volunteers

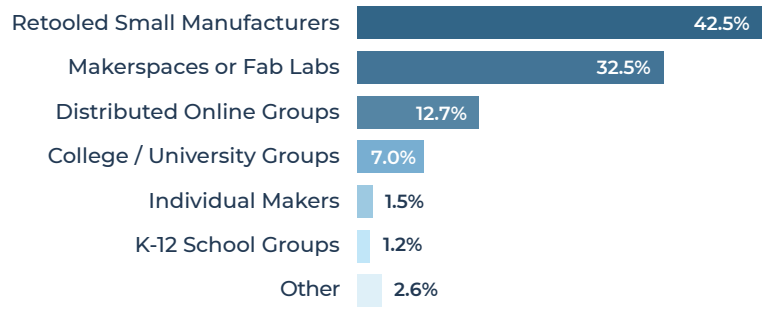
42,000+ Citizen Responders

86 Countries with Local Response Efforts

93% Volunteers

50 US States, Washington DC, and Puerto Rico

Production Per Organization Type



WHAT

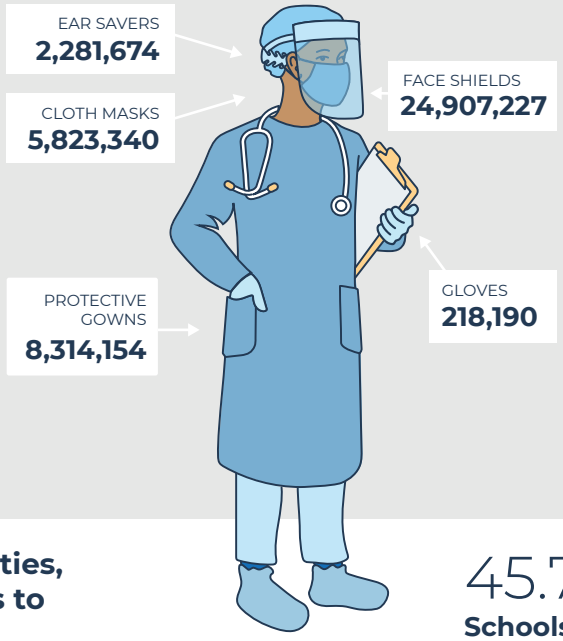
Created hundreds of new open source designs for medical supplies

200+ DESIGNS

available in the OSMS Library for **35 categories of PPE & supplies**

6,000% increase in unique visitors to the NIH 3D Print Exchange within 24 hours of engaging the maker community

Numerous medical inventions



Manufactured & delivered

OVER 48 MILLION pieces of PPE and medical supplies

worth $271 million

including critical items such as:

NASAL SWABS **45,000**

PAPR HOODS **59,289**

VENTILATOR PORTS **4,021**

WHERE

Serving their entire communities, from major hospital networks to underserved populations

Schools, non-profits, senior housing and hospitals all received PPE and medical supplies. The following percentages of makers reported distributing supplies to these recipients:

45.7% Schools

40.9% First Responders

80.4% Hospitals and medical clinics

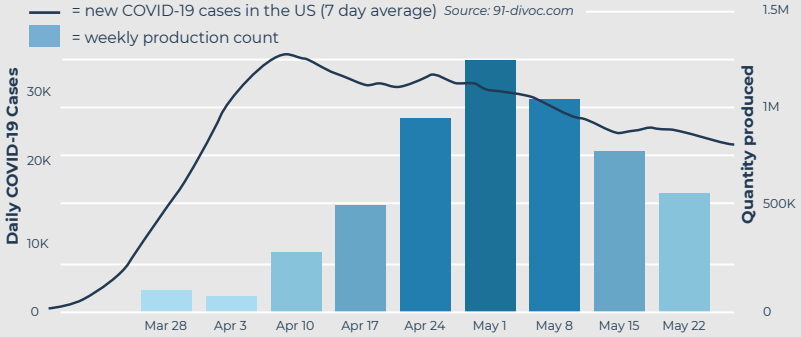
56.5% Senior Housing

43.6% Non-profit agencies serving low income populations

WHEN

Swiftly pivoting to address critical shortages

Makers are tooled for rapid prototyping — and they were indeed fast. Maximum production capacity was achieved in only six weeks; whereas traditional manufacturing took several months to reach its full production potential.



DESIGN | MAKE | PROTECT

Below are key insights about what enabled the citizen response to COVID-19 supply shortages, as well as common challenges makers and manufacturers faced.

Download the full report at: osms.li/impact

ASSETS

OPEN SOURCE INFORMATION

"We were able to prepare and organize **weeks before the virus reached our country** due to the experiences, resources, procedures, source files, etc. shared by the maker community as a whole.

Andres Hermes
TecLab, Guatemala

COMMUNITY NETWORKS

71% of respondents depended on networks, community platforms and personal introductions

"It's been fantastic **not only to share but compare and review** what people have been doing.

Sam Haynor
Something Labs,
San Francisco, CA

VETTED DESIGNS

50% of respondents made use of open source design repositories

"Without the **pre-vetted designs** AND **production instructions** we would have spent too much time reinventing the wheel and not enough time producing.

Nathaniel Fairbanks
MakeIt Labs, Nashua, NH

NEEDS

GOVERNMENT SUPPORT

Less than 3%

received any government financial support through sales or grants.

24%

reported establishing a new relationship with some level of government.

"Now that we know that makerspaces can fill such a vital role [...] **we need lawmakers to invest funds** towards organizing these efforts and making sure they have the materials and support needed to ramp production back up when needed.

Craig Farrington
Factory Two, Flint, MI

COORDINATION OF SUPPLY & DEMAND

"I learned that **distribution is the most expensive and difficult thing to accomplish** — manufacturing is comparatively quite easy!

Sam Neff
Richmond High Robotics Team 841
Richmond, CA

"Most of our sales and distribution were based on **personal contacts**.

Will Holman
Makers Unite, Baltimore, MD

CLARITY ABOUT LIABILITY

"Quite a few people felt they couldn't use their business / shop to make PPE or personally engage in PPE production **because of liability fears**.

Diana Hamann
Hollywood Helps Hospitals
Los Angeles, CA

FUNDING

63% depended on in-kind donations of materials, tools and labor.

13% of respondents listed lack of funding as their primary reason for slowing production.

"We're about to lose our shorts. We've had a good response in fundraising, however, **our costs in production and rent for the space have put us in debt to deferred rent.**

Joey Loman
Synergy Mill Makerspace, Greenville, SC

ACCESS TO TESTING

"**Cost is prohibitive.** Traditional testing of basic mask safety, efficacy, and filtration costs $3-5k per mask design and don't include validation for reuse. For FDA (510k) approval costs are typically 5-10x higher.

Dr. Jocelyn Songer
MakerMask

ABOUT THE AUTHORS

The Community Impact Report is brought to you by Open Source Medical Supplies & Nation of Makers, with additional support and data from The Fab Foundation.

Open Source Medical Supplies informs and empowers makers, engineers, manufacturers, local organizers, experts, and institutions around the world working in their communities to meet medical supply challenges stemming from global crises. **osms.li/home**

Nation of Makers supports the full range of organizations that impact makers by encouraging connections, broadly sharing resources, facilitating funding opportunities, engaging in policy development, and advocating for the maker movement. **www.nationofmakers.us**