

Supply Chains and COVID-19 Vaccines: How Fast Can We Reach Herd Immunity?

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The COVID-19 epidemic continues to disrupt global society, but the advent of available vaccines in the Winter of 2021 meant that a return to some form of pre-pandemic “normal life” could be possible. With the supply disruptions and shortages through 2021 and 2022, the ability to both manufacture and distribute these remains important, especially with the rise of new variants and sub-variants that can evade earlier vaccines. US vaccine delivery strategies show the need to balance between focusing on delivery efficiency and delivery equity. Urban centers can focus on delivering mass numbers of vaccines quickly as these areas are often the epicenters for early stages of a pandemic, but rural areas need to focus on delivery equity over efficiency with sparsely-populated areas. Additional lessons include means to deal with vaccine-hesitant populations. This paper investigates how these changes can be implemented and the effect of current vaccine delivery with lessons for future pandemic preparation.

Keywords: supply chain management, Covid-19, vaccines, pandemic, herd immunity, vaccine delivery, disruptions

INTRODUCTION

On February 10, 2021, the Biden administration announced it had procured enough doses of Covid-19 vaccine to inoculate every American by mid-July 2021 (Chowdury, 2021). However, officials cautioned that the country may return to a pre-pandemic “normal” only by Christmas or Fall 2021 at the earliest (Flaherty, 2021). At the same time, vaccination sites nationwide were running out of vaccines. Cities like New York and Los Angeles were vaccinating people quickly but supply could not keep up with demand (Smith et. al, 2021). Better news arrived on March 11, 2021 with an announcement that Biden would direct all states to have all Americans able to be vaccinated by May 1, 76 days earlier than the February statement. This accompanied news that Americans could gather in groups worry-free by mid-summer if everything went well (White House Remarks, 2021).

This was tempered by the news that newer variants of the virus including the Delta Variant were showing up in numerous US states. Increasing cases and hospitalizations from Delta dashed hopes for a return to normal by summer 2021. The variant spread faster, reproduced far more inside an infected person, and took less time to reach detectable levels (Baisheng et. al, 2021). The Omicron Variant in Winter 2021 restarted much of the concern from Delta, so the United States was starting over again. This pattern seems

to be repeating once again with the rise of Delta sub-variants and their ability to evade previously vaccinated individuals (this author can personally attest to that, having caught COVID both during the winter 2021-22 wave and again in June 2022).

As of July 2022 the Center for Disease Control states that approximately 67% of all Americans have gotten fully vaccinated against COVID-19 (at least two doses), and approximately 78.5% received at least one dose of the vaccine. Depending on the state the total percentage of citizens with two vaccinations and at least one booster ranges from a low of 28.1% to a high of 65.2% (Center for Disease Control, 2022). Numerous factors are behind the different rates by state, including various forms of vaccine hesitancy. To reach the percentages needed for herd immunity the country has to address these causes; simply having the vaccines is not enough if they are not administered to everyone that needs them.

Key strategies for making herd immunity through vaccines work lie with managing supply chains and monitoring the forecasts for vaccine deliveries. An overarching problem with creating this is that creating the vaccines available is a manufacturing issue while delivering the shots into arms is a service issue. By monitoring the variables related to how fast organizations can get shots into arms and streamlining those variables that act as chokepoints, the administration could maintain and even slim down the forecast dates for hitting the percentage needed for herd immunity. Given the passage of time since vaccine efforts began in 2020, there is an abundance of data to sift through to find best practices for these variables.

DEFINING HERD IMMUNITY

Herd immunity can be defined as “resistance to the spread of an infectious disease within populations based on pre-existing immunity of a proportion of individuals because of either previous infection or vaccination.” Articles published early in the pandemic assumed that herd immunity would function as a result of the virus’s R0 number. In April 2020 Syal estimated COVID-19’s R0 at anywhere from 2 to 3, meaning that 50 -- 66% of the population would need to be either infected and recovered or vaccinated to reach herd immunity (Syal, 2021).

The Delta Variant’s arrival in 2021 led to reappraisals of the virus’s R0 number. Ying and Rocklov reviewed five international studies estimating the basic reproductive number for the Delta Variant; the numbers ranged from 3.2 to 8, with a mean of 5.08 (Ying, Rocklov, 2021). Based on their numbers, that would require anywhere from 67% to 87.5% vaccination to reach herd immunity, with their mean requiring approximately 80%. These estimates were in line with Biden administration officials estimating the percentage needed to be 70% -- 85% of the country’s population (White House, 2021).

The greater infection rate from Omicron skewed these numbers upward and continued to do so as Omicron sub-variants appeared through 2022; due to the contagiousness of the new variants, it is estimated that 94% of the population must be immune to interrupt transition and prevent greater spread of the virus (Mayo Clinic, 2022). Even back in 2021 Dr. Anthony Fauci stated that the herd immunity percentage needed would be similar to measles (approximately 90%), and by the time the new Omicron variants were dominant in summer 2022 he doubted that the ever-changing variants and fading immune response in the face of those same new variants would allow the country to reach what the paper defines as “herd immunity” (National Press Foundation, 2022).

Number of Vaccines Required

Syal’s initial estimate would require anywhere from approximately 164 million to 218.6 million Americans to receive complete Covid vaccinations (a total number of 328 million to 437.3 million shots assuming all shots were a two-dose regimen without counting later booster shots). The high-end R0 number of Ying and Rocklov’s study would require approximately 287 million Americans to be vaccinated that would in turn require 574 million doses of the vaccine. For this paper (taking into account the latest sub-variants of Omicron) we assume the need to achieve at least a 90% vaccination rate to achieve herd immunity, so to reach herd immunity with the current US population, we require 590.4 million vaccine doses manufactured and the logistical capacity to get two doses into the arms of 295.2 million people.

FACTORS TO SUCCESS

The first part of the formula should focus on how quickly supply chains can be utilized to produce the required doses. To reach 90% vaccination, we must estimate how fast manufacturers can assemble 590.4 million doses. Additional research focused purely on the manufacturing factor can be done using a multi-factor regression analysis, taking into account variables such as the materials needed and available production facilities for the vaccines. This may include bringing production facilities and manufacturing capacity back into the United States from overseas, but evidence shows this is easier said than done and may not be as beneficial as one may think.

The second part of the formula focuses on how quickly we can get those vaccines into the arms of Americans. This second part relies on rendering services to consumers and so will need to be calculated using a separate set of equations. Here the questions revolve around how best to manage the various “service package(s)” that factor into getting the vaccine doses into the arms of waiting Americans. This includes managing the supply chain to provide the maximum number of vaccines quickly and equitably across the entire country.

This equitability includes getting vaccines to marginalized populations that will be critical to slowing and ending the pandemic. It will also include reaching out to vaccine-hesitant/vaccine-resistant populations and persuading them to take the shots too. Experience in 2021 showed some large and critical demographic resistant to the COVID vaccines, so our strategy must include ways to bring them in and increase the number of immunized Americans.

Changes Since the First Draft

The first draft of this paper in April 2021, when rising vaccination levels came with predictions of herd immunity by late summer 2021. However, stalling vaccination rates and the rise of the Delta Variant and now the Omicron Variant and sub-variants proved those predictions wrong. As of July 2022 the first part of the equation is dealt with in the United States and now the second factor is the one of most concern. It may seem prudent to ignore the first factor now, but these blueprints for success are still relevant for COVID-19 globally and for future pandemics. Indeed, with the spreading Monkeypox virus in the US, we are seeing vaccine shortages and government response failures not dissimilar to those seen in the early days of COVID vaccination campaigns (Andrews, 2022).

As seen with the 2022 rise in Monkeypox cases, in a globalized world the question of the next pandemic is not a matter of *if* but a matter of *when*; John Barry stated that pandemics have occurred throughout human history and that this will only continue as humanity becomes more interconnected. In the 20th century, there were three pandemics and as of now two in the 21st century, there is no uncertainty that another virus will strike us in the foreseeable future (Barry, 2004). The lessons learned in creating this record of how best to utilize supply lines could prove vital in dealing with any future pandemic. Knowing how to use resources efficiently and equitably in such a short amount of time could save more lives in the future and prevent much of the chaos and confusion we saw these past two years.

PRODUCING THE VACCINE

To reach herd immunity there are two options. The first is reaching immunity through exposure to the virus, which Syal mentioned in April 2020 when the virus was still relatively new and little-understood. As of January 2022 The second option mentioned by Syal was the prospect of vaccinations, though there was no vaccine at the time and little hope for one within the year (Syal, 2020). The availability of actual vaccines in December 2020 gave hope for herd immunity through means other than exposure.

As of July 2022 there is likely a suitable mix of immunity gained both through vaccination and viral exposure that Americans would likely be at herd immunity percentages. However, as noted earlier in the paper, COVID may be beyond our ability to gain “herd immunity” because of its ability to quickly evolve into new subvariants (National Press Foundation, 2022). For the purposes of the paper, though, we will still

assume sufficient vaccine production could get us to herd immunity for purposes of preparation for future pandemic responses.

Creating Domestic Vaccine Production

The United States has a manufacturing advantage compared to Canada and Mexico since it has facilities that can produce vaccines (Kitroeff, Abi-Habib, Kanno-Youngs, Tankersley, 2021). While it can produce the doses domestically, that is not the same as having all the ingredients necessary to do so. Reliance on the efficiencies of a globalized supply chain means the materials needed to produce said vaccines may not be available domestically and would be subject to broken trade routes and other international problems.

One of the biggest political threats noted by government officials, particularly Republicans during 2020 and 2021, was that much of the pharmaceutical production capacity the US relied on was located in the People's Republic of China. According to these arguments, if the Chinese decided to conduct a trade war during this or a future pandemic US medical workers and facilities would be without the personal protective equipment (PPE) and other materials needed to function safely. This equipment is defined as "equipment worn to minimize exposure to hazards that cause serious workplace injuries and illnesses [that] may result from contact with...workplace hazards" and includes gloves, facemasks, respirators, coveralls, body suits, and other items needed by healthcare workers dealing with COVID-19 (Occupational Safety and Health Administration, 2022).

The bipartisan solution offered at the time was to bring back the manufacturing capacity throughout the entire supply line to the United States for "national security." This response was not limited to the United States. Willy Shih noted that the United States, the European Union, Japan, and China have all started work on in-shoring production on vital industries like semiconductors and other "strategic materials" that would otherwise be imported from abroad (Shih, 2022). COVID was the initial system shock that started these conversations, but since the initial outbreaks in 2020 other issues like the war in Ukraine and tensions in Taiwan have reinforced this idea to secure resources and production capacity at home.

It is easy to say we should shift our supply chains back to an entirely domestic capacity in the name of national security and resilience but it is much harder to do in practice, particularly in a highly globalized economy. As noted by Shih, shortages during the pandemic are due to fundamental shifts in global manufacturing that will be hard to reverse. Due to specialization of labor and "complex interdependencies" of multi-tier suppliers for major firms, he argues that replacing any one component in our current supply chains for these industries will be extremely difficult (Shih, 2020).

Shih argued it would be possible to shift back to domestic production, but the time and effort involved would be immense for both countries and companies. He noted that it took China at least 20 years to build the base necessary to supply the specialized components necessary for domestic manufacture of electronics, chemicals, auto parts, and other ingredients (Shih, 2020). Additional problems would arise from the increased costs necessary to domestic production, particularly in the United States. Customers would still demand low prices they are accustomed to while stakeholders would demand efficient production and capital usage.

Alternatives to Completely In-Shoring Production

In place of completely in-shoring production Shih argued for other concrete steps that organizations could take to secure their supply chains in case of future shocks. This includes diversifying sources for components and materials, keeping levels of strategic inventory reserves when available, planning workarounds for logistic bottlenecks in your supply chains, and reconsidering capacity-planning for strategic commodities like medical supplies and equipment (Shih, 2020).

A middle-of-the-road strategy Shih noted was keeping supply chains international but focused on "balancing of production capacity and consumption within geographic trade blocs" such as the United States keeping international supply chains but focusing critical resources and production around the US, Mexico, Canada, and portions of Central America. Likewise, Shih suggested a similar trading bloc built around the European Union and North Africa that would combine the former's production capacity with

the latter's low-cost labor (Shih, 2022). Both options would keep some benefits from a globalized economy and competitive advantage while securing resources and production capacity closer to home.

Each option above comes with an inherent risk that runs contrary to current operational management prerogatives. Maintaining a strategic inventory reserve would be inefficient and run the risk of stockpiles becoming obsolete, while diversifying supply chain sources for materials could create additional inefficiencies with multiple producers unable to operate with economies of scale due to decentralization of production. However, these inefficiencies during normal times are what is needed during a supply disruption like the COVID-19 pandemic. In that scenario strategic reserves are there to cushion falling supply and handle potentially increased demand while the diversified manufacturing and material sources would prevent severe problems like relying on a single country for your production materials.

Pooling Resources of Competitors

If competing firms are able to cooperate and pool their respective supply chains they can produce vaccines far faster than they could working in competition. A good example of this is the cooperation between Johnson & Johnson and rival Merck in 2021. The Biden administration touted the move as a step to producing enough vaccines for every American, but they also noted the extra time needed to upgrade plants to necessary safety standards and bringing the additional manufacturing capacity online (Rowland et. al., 2021). Problems with the Johnson and Johnson and AstraZeneca vaccine side effects also showcase how focusing on operational efficiency could run into problems with shortening the time needed to generate enough vaccine supply.

Pooling resources is another strategy that could be used at the federal level when choosing where to send vaccines. States are not necessarily competitors in this scenario, but limited supplies will be available when new vaccines and other treatments are first available. In 2020 the Trump administration initially let states lead the charge with procuring supplies but later switched their approach to have the federal government taking the lead in procuring supplies then directing shipments to states (the Biden administration continued this approach). Both approaches were criticized; letting individual states manage procurement led to complaints over inflated prices amid competition while the federal government buying up supplies in bulk led to complaints of states unable to get limited supplies since they were already bought up (Flaherty and Pezenik, 2022).

Conflicts With Previously-Accepted Strategies

Shih noted that performance indicators tracked by managers motivated them to size operations with minimal surplus capacity and maintain as close to 100% productivity as often as possible to avoid excess costs (Shih, 2020). Minimizing this excess capacity while maximizing capital efficiency may be important for the bottom line when it comes to outside analysts and organizational shareholders, but in this scenario this strategy runs counter to the goal of maximizing the amount of vaccines available in the shortest amount of time.

The conflicting interests here return to the central question asked in the paper: what are the quickest ways we can reach herd immunity? To build up the necessary supply manufacturers would be going against the operating goals of "normal" times since the response needed during the pandemic would demand massive output and production capacity that would be largely unneeded during regular business periods. The pandemic revealed many weaknesses in supply chains that would exacerbate these problems during the pandemic, but once life returns to normal many of the pre-pandemic concerns will likely come back into focus (Shih, 2020).

This all means that the shifts in supply chains and the focus on domestic manufacturing over the consumer demand for lower prices from outsourced production may disappear when we return to a world more closely like the one that existed before COVID-19. However, both Shih and Barry warn against treating pandemics as one-off disruptions, arguing that this is the best time for organizations and countries to strengthen their supply chains against these weaknesses to prepare for the next systemic disruption (Shih, 2020). Indeed, the rash of news in 2022 involving Monkeypox reinforces their point that these changes should not be temporary but rather a permanent shift in how we treat our supply chains.

GETTING SHOTS INTO ARMS

We face another major hurdle once we have the number of vaccines available to inoculate the entire US population. How do we get the vaccines from manufacturing facilities out to every US state and territory and then transport them to population centers and into the arm of every US citizen able to receive a vaccine? In addition, how do we ensure that as many vaccines are given out as quickly as possible in these vaccination centers? Finally, how do we overcome the vaccine hesitancy and even denial that exists in significant portions of the US population?

In dealing with vaccinations, the formula used for services revolves around a server's maximum number of customers they can process in a given amount of time, μ and the total number of customers arriving in that same amount of time, λ . The greater the capacity the organization has to process customers and provide services, the greater the number of customers able to be served in shorter amounts of time. Adding more personnel able to process consumers or creating efficiencies in staff to increase the number of consumers they can process will increase the total number of customers served. It is critical to increase both factors to increase the maximum amount of persons vaccinated per day to reach herd immunity faster. However, there are some concerns about the country's limitations in maximizing both factors, including logistics, vaccine hesitancy/denial, and personnel needed.

Facility Capacity - High Population Areas

A primary concern for minimizing the time needed to reach herd immunity is securing facilities that process large amounts of vaccine recipients, put shots into arms, and then discharge them in a reasonable amount of time. Given the recommended fifteen minute post-shot waiting period, these facilities would also need sufficient space to let individuals remain while others in line got their shots. Because of the wait, this would negate using something like the drive-through mass COVID testing centers. Instead, large sports stadiums and concert arenas become a good option for mass vaccinations.

Large stadiums are a good solution both for those wanting to deliver the vaccinations and for those that own the stadiums. Governments and public health agencies want a place to deliver large numbers of vaccinations as quickly as possible and the venue owners want to be able to open these buildings to business after being closed during the early COVID pandemic. To this end the Biden administration made an effort early in 2021 to open more federally-run mass vaccination centers to maximize the amount of vaccinations given, noting in an April release that FEMA was launching 21 sites in communities that would be able to administer a total of 79,000 shots per day at full capacity (White House FACT SHEET, 2021).

Facility Capacity - Low Population Areas

In that same release the White House noted the goal of having enough community pharmacies able to deliver vaccines so that 90% of Americans would be no more than five miles from a vaccination site (White House FACT SHEET, 2021). This is more inefficient than mass vaccination sites but it takes into account time needed by suburban and rural populations to drive, park, and then walk into the mass vaccination sites. The efficiency with the increased number of pharmacies able to deliver vaccines (up to 40,000) would be in lowering the time constraints for anyone getting a vaccine.

Here the supply chain concern is not delivering the vaccines to the local centers as much as making it easier for anyone wanting a vaccine to get one. Local community centers and churches can address issues of equity and provide quicker options for people unable to travel to the mass vaccination centers. This can also apply to marginalized populations in some areas, particularly residents that might be undocumented. Some states prioritize legal residents first, but if the goal is to get as many individuals vaccinated as quickly as possible, it may need to prioritize whoever can show up to a vaccination site (Henderson, 2021).

Even with that promise, there would still be 10% of Americans that would have to drive longer than five miles to reach a vaccination site. The United States has a sizeable logistical problem with getting vaccines to everyone because of the country's size. Tightly-packed urban areas will benefit from mass vaccination sites, but there are large rural areas where people are spread out and would have to drive potentially for hours to reach a mass vaccination site. In areas like Arkansas there are several urban centers

in the central and northwest parts of the state with some smaller communities scattered along the major highways. The rest of the state consists of small rural communities without the pharmacies in other more-populated areas that can get the vaccines to people who need them.

In these disparate communities the best option may be mobile vaccination clinics that can transport vaccination personnel and equipment to those rural communities that otherwise might miss out on COVID vaccines. Multiple states created mobile vaccine clinics to do this, putting them together to reach vulnerable communities who can't attend clinics in person (Wingo, 2021). This would not create efficiencies in either of the service factors, but the mobile clinics will ensure equity in vaccine access. The most important part of reaching herd immunity is not getting it out the fastest but getting it to everyone who needs it. Mobile clinics may be inefficient but they are critical in ensuring that states can reach the numbers needed for herd immunity. However, to make these work we will need another key factor in guaranteeing quick vaccine access to everyone: the personnel needed to actually put shots into arms.

Personnel Capacity

The supply chains of vaccine and transport to waiting medical facilities will do no good if there are not personnel able to actually put the shots into the arms of those waiting. Anna Nagurney argued that the COVID pandemic has done more than anything to reveal that without what she calls “the human element” much of our supply chain and delivery system simply cannot function. Noting headlines from throughout the pandemic, without people in the supply chain, grocery stores would have bare shelves, produce would be rotting untouched in fields, manufacturing plants would have no operators to run equipment, and, most importantly for the vaccine equation, shots would go unused because there were not enough medical professional to deliver them (Nagurney, 2021).

This is on top of an already-existing numbers problem facing the United States with fewer doctors and nurses needed for a growing elderly population. In the near term the country will need to expand the vaccine-administering capability as quickly as possible while also taking advantage of only qualified medical personnel. With segments of the population quick to pick up and disseminate any faults in the vaccine delivery system the government will need to keep the familiar pace of acting quickly but cautious to avoid potential mishaps. To that end governments have been working on activating additional personnel that have the necessary training to deliver vaccines but with requisite medical training. In particular, they are looking to recruit personnel from existing medical professionals and students, ensuring that they will have the medical training necessary to deliver vaccinations without worrying about major mishaps.

Actions Taken Regarding Vaccine Personnel

One of the Biden administration's moves in March 2021 was an executive order to “expand COVID-19 Vaccinator Eligibility to Additional Classes of Medical Professionals and Healthcare Students” through an amendment to the Public Readiness and Emergency Preparedness (PREP) Act. It allowed additional current and retired healthcare professionals to be eligible vaccinators, including paramedics, EMTs, dentists, respiratory therapists, and veterinarians. It also authorized medical students in any of the eligible healthcare professions “with proper training and professional supervision” to serve as vaccinators too.

This comes alongside orders allowing reciprocity recognizing state licenses for healthcare workers, allowing them to work across state lines and surge workers for vaccinations and COVID cases. The same order also ordered several thousand federal personnel to be deployed for the same purpose (White House FACT SHEET, 2021). The administration approached the personnel issue as recommended by rapidly expanding the pool of eligible vaccinators but cautious to avoid potential mishaps from unqualified personnel.

Several similar moves appeared at the state level as well. In March 2021 a bill was filed in Wisconsin to allow dentists to administer COVID-19 vaccine, joining 20 other states that had expanded eligibility, noting there were about 3,500 dentists that would be affected (Associated Press, 2021). Additional personnel would be helpful in efforts to reach smaller communities that might otherwise miss out on vaccination efforts. As mentioned in the section on facility capacity, newly-eligible vaccinators in smaller

communities could work with churches and other community groups to expand access to vaccines that marginalized groups might not otherwise have (Henderson, 2021).

With the new variants and the reality that we may never reach a “herd immunity” with COVID like we have for measles, numerous experts are advocating we treat COVID like we do the seasonal flu. In that case the vaccine personnel capacity would be more in line with our current capability; earlier drafts focused on the mass buildup in the early stages of the pandemic, but once COVID becomes endemic like the flu the need for massive vaccine delivery capacity will not be as critical. Rather than a quick rollout COVID shots could be given over several months at local pharmacies alongside the annual flu shots.

WHAT STEPS CAN WE TAKE?

After examining the evidence, there are several concrete steps that we can take to speed up how soon we can get to herd immunity. Between the moves to secure the vaccine manufacturing supply lines and those to get as many shots into arms in as short a time as possible, the current COVID pandemic gives us several concrete steps to shorten this pandemic and ease the strain of any future one. Governments should be stockpiling this advice and integrating it into their future plans. With the emerging problem of Monkeypox we are already seeing headlines noting that the same failures done in the early days of COVID are occurring all over again with this new outbreak.

Vaccine Manufacturing

The ability to quickly manufacture vaccines will remain paramount in any future pandemic. Companies and governments should know that the disruptions caused by COVID-19 are not a bug but a feature of our globalized and interconnected economy. Just-in-time strategies that minimize strategic reserves and prefer minimal reserves for greater efficiencies/cost savings work great when disruptions don’t occur. However, in an age of increasing extreme weather events, regional wars, political tensions in Europe and Asia, natural disasters, and global pandemics, this business strategy will only lead to future supply chain disruptions and potential disaster.

Securing Manufacturing Capacity

The first priority should be on securing the ability to manufacture the vaccines necessary to reach herd immunity. Companies and governments should follow Shih’s recommendations of diversifying sources, building in strategic reserves in case of major disruptions, creating workarounds for logistical bottlenecks, and creating plans for emergency capacity buildup. Each of these steps plays a role in reducing the impact of future disruptions on supply chains. Even though the inefficiencies created by holding these reserves and source diversifications will add to the bottom line financially, the cost of maintaining these “inefficiencies” will pay off when the next major supply chain disruption hits and they can weather the storm.

In-Shoring Supply Chains and Alternatives

Governments could also encourage businesses to bring back supply chains to purely domestic production for materials considered national security priorities. As Shih mentioned this could be done, but governments must be willing to invest the time and money into making this possible. The current system developed over years and created labor specializations in that same time in certain areas that became entrenched, and developing similar industries domestically may likewise take years or even decades.

A country looking at a shorter-term fix to pandemic supply line disruptions should look to the advice on protecting supply lines mentioned in the previous paragraph. However, a country looking for a longer-term solution and wanting to bring back production of national security-related resources could definitely opt to bring business back into their own country. The one thing to remember about bringing back the domestic production though is that the investments will be immense and the results will not be felt immediately. For democracies like the United States, that alone may make the latter option unfeasible minus a unified and bipartisan effort akin the Cold War-era Space Race.

As noted before, a less resource-intensive option would be to invest in regional trading blocs that have some of the advantages of pre-COVID globalization while also moving critical production capacity closer to the home country. This would also be capital-intensive and long-term, particularly since managers and investors may be keen on concentrating production capabilities in a single region (Shih, 2022). However, organizations would benefit from shorter distances involved with the logistics (and that may also mean lower costs involved). Bottlenecks and congestion are still likely to occur, but keeping production capacity closer to home and in friendly, politically stable territory reduces the likelihood of mass disruptions like those from 2020 to 2022.

Vaccine Manufacturing

Ensuring a rapid and equitable distribution of those same vaccines will also take an immense effort, but here countries and organizations will have to contend with the twin goals of rapid deployment while also ensuring equitable distribution of the available vaccines. Rapid deployment will be easier in urban centers and areas with more concentrated populations in general; there you will have both facilities and personnel able to concentrate their efforts to vaccinate as many people as possible in as quick a time as possible.

That will also rely on having the supply available. If companies decide not to take the advice mentioned above and secure their supply chains, we may face a situation similar to the one faced by the United States in early 2021. Getting all the vaccines needed to be manufactured means nothing if governments and companies don't work to have the personnel and facilities in place to administer those shots once manufactured and delivered. This will also have to account for differences in getting those vaccines shipped to urban and rural areas nationwide.

An additional question arises with this surge in manufacturing: what do we do with this manufacturing capacity once that number is reached? One of this country's competitive advantages versus Canada and Mexico is our aforementioned ability to manufacture the vaccines here instead of buying them from companies abroad as Canada and Mexico had to do (Kitroeff et. al., 2021). This ability to streamline supply chains to adapt to the pandemic and maximize our production capacity serves an important diplomatic focus.

Once the country has the vaccines it needs to reach herd immunity, it can ship vaccines abroad to neighboring countries and regions to help them reach herd immunity faster too. The Biden administration did exactly this, shipping millions of doses abroad to fight COVID in other countries (White House, 2021). Helping other countries reach herd immunity will help relieve stress in the globalized supply chain and also reduce chances of dangerous variants arising in countries with lower vaccination rates; as noted in the many sources, the fact that much of the developing world is still unvaccinated means more fertile ground for new COVID variants to emerge. It is often framed in terms of humanitarian help, but there is an important economic benefit to it as well.

Distribution in Urban Areas

As described in the section on facility capacity, large population centers with massive arenas and stadiums are great places to assemble mass vaccination centers for quick and continuous administration. These are great starting points for a quick beginning; the areas will have great transportation capacity and can handle massive crowds coming in for vaccines (and the massive deliveries needed to provide the service components). Cities can also provide transportation for those unable to travel to the sites themselves, as some cities have already started using public transportation. However, these same cities would also need to launch information campaigns to let everyone know about these options (Ewald, 2021). In this situation the most important goal is getting the maximum number of vaccinations given as quickly as possible. Urban areas were the first to feel the COVID-19 outbreak in 2020, so they would be a logical first place to start with vaccinations.

Distribution in Rural Areas

To reach the country's far-flung areas, we would need programs to deliver vaccines to rural areas and those populations that might otherwise hesitate taking the vaccines. Here we get into the equity side of this

equation; focusing only on the urban areas would ensure an efficient delivery of as many vaccines as quickly as possible, but it would not meet the need for an equitable distribution to ensure access for everyone. The Biden Administration's plan to use local pharmacies and healthcare workers to guarantee 90 percent of Americans a vaccine within 5 miles is a great start for this type of program. Mobile vaccine clinics could be used for those still outside of that area; these may not be nearly as efficient as the mass vaccination centers but ensure equitable access to the vaccinations.

Distribution Personnel

However, both of these approaches will come to naught if they do not have the personnel necessary to put shots into arms. As mentioned by Nagurney the human element is often overlooked in supply chain management. Governments are already working to ease this logistical chokepoint with the measures already mentioned. Opening eligibility to all qualified medical personnel and students creates a greater pool of manpower to work the mass vaccination centers and smaller clinics. With enough of these people the mass vaccination centers can run 24 hours a day; this creates cost inefficiencies but much like with Shih's supply chain recommendations, the ability to scale up our capacity during a pandemic is worth the cost of inefficiencies endured during normal times.

Expanding the number of medical personnel eligible to administer vaccines means that doctors and students at the local level can often persuade people and families to get the vaccine that might otherwise hesitate or refuse (Keith, 2021). Reaching the numbers needed for herd immunity will require vaccinating most American adults. Not only does this local touch help reach Americans that otherwise couldn't get the vaccine, it may also reach Americans that otherwise wouldn't get the vaccine at all. With the threat of potential mandates requiring vaccines under threat of losing employment, this kind of outreach will be critical to ensuring the supply lines and personnel maintaining them stay effective.

All Pieces Work in Concert

All of these pieces will have to work together in concert to achieve herd immunity. If one of them cannot work, the entire vaccination campaign could be jeopardized. Without the necessary vaccines the vaccination centers will sit empty, and without the facilities necessary to quickly get shots into arms vaccine delivery speed will be greatly stunted. Without the eligible personnel, you get facilities filled with vaccines but long lines as Americans wait for shots delivered by small, overworked staff members. Governments and companies will need to work together to ensure each of these pieces are successful, keeping in mind that the next pandemic is inevitable and one day it will arrive. It will be best for everyone if we have the plans in place to scale up vaccinations as quickly as possible. If we don't we could face another era of lockdowns and social isolation, and no one wants to go through that again.

2022 UPDATE: IS REACHING HERD IMMUNITY EVEN POSSIBLE?

When first creating the outline for this paper we assumed by the end of the semester the US would rapidly be approaching herd immunity; if nothing else we might be reaching the 50% threshold Sayr hoped would be the bare minimum. However, as of July 2022, approximately 66% of Americans have received both doses, while over 78% have received at least one dose. After a high point of April 10, 2021 with 4.6 million vaccines delivered the reported doses delivered each day and the 7-day trend began to fall. Now supply has outstripped demand, leading to appointment times going unfilled at vaccination sites. There are reasons to believe we may not reach the numbers needed for herd immunity.

The Delta and Omicron variants further complicated this, leading to multiple booster shots to help with falling vaccine effectiveness. With the outbreak of the Omicron sub-variants in spring and summer 2022, the idea of ever reaching herd immunity is regarded as increasingly impossible (if it ever was in the first place). As of 2022 there is no longer talk of full vaccination with only two shots; now there are calls for one or even two booster shots to keep vaccines effective, especially with newer variants that can evade prior vaccine doses. The original paper's premise that two shots would be enough appears to have failed; in light of this we ask what issues are complicating US vaccination rates and other strategies that may lead

to some form of pre-pandemic “normality.” Herd immunity for COVID may be impossible but some of the strategies noted earlier could be rectified for future pandemics in light of the new reality.

Vaccine Hesitancy

A primary reason cited through 2021 for falling vaccination rates is “vaccine hesitancy” but this covers many reasons from different groups. When the vaccine push began the largest concern was over minority communities. There were concerns these groups would be resistant to getting the vaccine because of past histories of medical abuse and experimentation (Simama, 2020) but a survey in December 2020 gave a much more nuanced and concerning picture of who was leery of getting a COVID vaccine.

Jagdish Khubchandani’s survey of 1,878 individuals highlighted how prevalent vaccine hesitancy was across a broad spectrum of US citizens (though a larger percentage were degree holders than the average US individual). Even though 79 percent of those surveyed were likely to get a vaccine the other 21% were either likely or opposed to getting a vaccine (Khubchandani, Sharma, Price, Wiblishauser, Sharma, Webb, 2020), which is troubling if herd immunity depends on 80% of the population getting one. It’s especially jarring as evidence arises that the percentage needed for true herd immunity is even higher than 80 percent; Dr. Fauci recently noted that herd immunity for COVID-19 may need to look more like measles-level herd immunity that is around 90 percent (White House, 2020).

Hesitancy Based on “Culture War”

Khubchandani found among the surveyed that vaccine hesitancy was larger among groups that were minorities (perhaps related to the reasons already mentioned) but also those who lived in rural areas, those who identified as Republicans, and those with lower income and education. While the study noted that some of these groups could be explained by lower awareness, health literacy, and cost-based concerns, political affiliation stood out among the strongest vaccine hesitancy predictors (Khubchandani et. al., 2020). Due to the previous administration’s turning of public health measures like masks into political “culture war” issues vaccines became another front in that war.

As 2021 continued this group’s vaccine hesitancy became the most concerning one for health professionals. Whether through religious faith, a wariness of science, or the broader political “culture war,” vaccine hesitancy in the white conservative evangelical community could be a major hurdle to reaching herd immunity. The group’s size is considerable; approximately 41 million adults are classified as white evangelicals, making them nearly 12.5% of the country’s population (Dias, Graham, 2021). Whitehead and Perry argued that the number was higher than 20% of the US adult population (Whitehead, Perry, 2020). If vaccination needs to reach 90% to reach herd immunity it will be critical to get members of this group to get the vaccine and bump up the national numbers.

Countering “Culture War” Hesitancy

It will be important to counter misinformation spreading through this and other groups, and part of the way this could be done is through the methods discussed in the section on facility capacity. Corcoran et. al argued correctly that understanding the hesitancy based on political and religious influences is critical to informing public health interventions and increasing rates of COVID-19 vaccine uptake (Corcoran et. al, 2021). Tamara Keith’s article mentioned earlier could be a first step in this direction. Getting churches and local communities involved in vaccine distribution and administration can introduce individuals to trusted friends and family members willing to get the vaccine. National messages may not convince them as well as one from trusted friends, doctors, and other community members (Keith, 2021).

In a highly-polarized environment such outreach messages may be difficult to achieve. As of late 2021 surveys found that 95% of Christian Evangelical leaders planned to get vaccinated but this did not equal advocacy (Reeves, 2021). Advocates and opponents to vaccination are there, but most so far say nothing on the issue. With fewer vaccinated people across the “Bible Belt” of the US, experts see these figures staying quiet as a missed opportunity to boost vaccination rates (Reeves, 2021). This reluctance is part of the broader “culture war” hesitancy where politics and religion are intertwined. With vaccines seen as a personal choice and with vaccines interconnected with inflamed political tensions, local messaging from

pastors and community leaders remains a critical but sometimes missing piece of getting parts of the country closer to herd immunity.

Was Herd Immunity for COVID Ever Possible?

With these challenges facing our race to reach herd immunity, some question if that scenario is already beyond our capability. With Anthony Fauci quoted saying we may need to hit closer to 90% rather than the initial estimates of 50% -- 67%, especially in light of the newer, more infectious variants, the job of vaccinating enough people to get that percentage seems harder than ever (McNeil, Jr., 2021). As of December 2021 75% of COVID-19 deaths in the US are individuals 65 and older, about 1 in 100 (Bosman, Harmon, Sun, 2021). Even if we cannot reach that herd immunity, having large portions of the population vaccinated can still help slow the spread of the virus, especially those at-risk populations like the elderly.

The onset of the newer, more infectious variants in 2022 seemed to be the final nail in the coffin for the idea that we could reach herd immunity against COVID-19. Even though the number of exposed individuals and vaccinated individuals likely reached the 80-90% range needed for what we thought would be herd immunity, the Omicron sub-variants proved able to evade immune defenses and vaccine protections. While some argue that the pandemic is already starting to become an endemic like the flu, others note that an endemic phase is one without “surprises” like the new COVID sub-variants that keep appearing (Florida et. al., 2022). For now the emphasis should be on implementing the vaccine recommendations in this paper in countries with few vaccinated individuals and little to no vaccine delivery capacity. The fewer individuals that are vulnerable to COVID strains, the faster we will get to the endemic phase.

Beyond this we can use the lessons learned from this pandemic to prepare for the next one. When the next major virus shows up governments can use successful steps during the COVID pandemic to reach herd immunity quicker and slow the disease down better than this time. In that case it would do well to examine countries that were able to quickly reach herd immunity levels of vaccination. In the COVID pandemic Portugal is often cited as one of the success cases with vaccinations and for comparison with the United States.

US Rates Compared to Portugal

The country of Portugal started in a similar situation to European countries short on vaccine supplies, but the country’s population quickly accepted vaccination as the best way out of the crisis, and soon vaccine rates went up. While the country had similar surges to the United States, the numbers in Portugal were much lower even when adjusting for the difference in population (Scott, 2021). It is important to see where the two countries diverged in vaccination strategies and how the Portuguese managed to reach potential herd immunity percentages while the US is still struggling to reach 65%.

It is worth noting that Portugal already had one of the highest vaccine coverage rates among European countries, partially attributable to the country’s relatively recent embrace of national vaccination campaigns in 1965 (Fonsec, Pereira, and Barros, 2021). The country also treated the pandemic like a wartime situation, with a single individual acting as the point person for the pandemic response. Admiral Gouveia e Melo often appeared in his combat uniform when updating the country on the pandemic response to avoid political polarization. Critics point to the country’s history of dictatorships and culture afraid to question authority, but the unified approach helped drive up vaccination rates when other western countries were stalling (Santora and Minder, 2021).

Portugal managed to achieve higher vaccination results, but “herd immunity” as we defined it in this paper remains elusive. With low rates in the country’s former African colonies, there are still concerns of new variants coming in, so Gouveia e Melo argues that the approach is still unfinished. He stated that the efforts to vaccinate are only over once everyone around the world is vaccinated, otherwise there is always a chance a new strain arrives and we have to start all over again (Harlan and Alberti, 2021).

CONCLUDING THOUGHTS

Using the lessons learned in supply chain management, both in vaccine manufacture and distribution will be crucial to solving the next crisis before it reaches the current level of COVID-19. Between diversifying supply sources and building in strategic reserves for vaccine production to moves necessary to disseminate as many vaccines to as many people as possible as possible, each of these lessons will play a role in tamping down our next pandemic.

It is critical to secure worldwide supply chains to manufacture and supply vaccines and other protective measures to fight the next pandemic, even if the strategies needed are counterintuitive to pre-pandemic theories and best practices for operations management. Many of those strategies will take years to implement, meaning that focusing purely on short-term gains could lead to repeating this process in a few years or decades when the next global pandemic arrives.

Personnel are another critical piece of blunting the impact of the pandemic and getting closer to herd immunity. The individuals administering vaccines are often the most important element in getting the vaccine-hesitant to agree to get their shots and great efforts should be made to promote information and strategies to convince the vaccine-hesitant. It is a difficult process, particularly in a hyper-polarized society like the current United States, but it will be necessary to reach herd immunity or at least some form of pre-pandemic normality.

Like Portugal's approach to vaccination, any future effort should strive to be apolitical. In a hyper-polarized country an easy way to derail pandemic protection measures is to link politics to it. Efforts should be made to strip politics out of fighting the disease, but like in-shoring vaccine production it is easier said than done. If a political party sees an advantage in politicizing vaccination and prevention measures it can be hard to counter this approach, particularly with our current almost-tribal form of politics. Like with approaching the vaccine-hesitant, much effort should be made in how to make any future pandemic prevention or mitigation free of political tension.

As noted in the most recent paper updates, herd immunity is likely out of our reach with COVID and all its variants and sub-variants. While the vaccination plans and strategies here were initially developed to reach herd immunity, those same strategies can be used to reach populations in countries that have not been able to mount effective vaccination strategies. Utilizing the best practices noted here would speed up future efforts to ramp up global vaccination efforts and speed up the timeline to turn this from a pandemic into an endemic like the seasonal flue. Herd immunity may be impossible but these strategies can still mitigate the worst of COVID's effects.

The most important part is that we learn from our current mistakes and try to prevent them in the future; if we ignore the lessons learned during the pandemic, we will likely be doomed to repeat them all over again.

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