Teaching Case

Vaccination Registration – What Could Possibly Go Wrong?

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Abstract

The urgent need to administer coronavirus vaccines has led to the rapid development of various systems to manage their delivery. There have been many issues related to the effectiveness, efficiency, scalability and equity of these systems. Some of these issues are most certainly of a national and global nature, dealing with allocation of vaccine supplies, among other things. Some issues are more localized – e.g., systems that may be hard to use, systems that require technology skills and internet access, systems that do not provide an integrated view of vaccine availability, that then require the user to visit multiple web sites across many days to try to find an available appointment time. This case invites students to study a variety of different types of systems, and to analyze what design decisions made for a better or poorer end user experience. What could be done to make for a better and more equitable user experience? What factors inherent in their various organizations contributed to the design decisions made by the respective system designers?

Keywords: Scalability, coronavirus, efficacy, efficiency, equity, usability, information quality

1. INTRODUCTION

One of the authors sat down one day early in 2021 to sign his wife up for a coronavirus vaccination appointment. After providing his location and answering a long series of questions and legal disclaimers, he learned that no appointments were available through the state web site (appointments were limited due to vaccine, supply, and staff availability, and were opened only about a week at a time).

He did receive, however, a page of at least 19 links to pharmacies and health care providers who might have appointments available and was asked to click on each one individually. Many of the links led to a site that would ask for his location and eligibility (again), and then provide appointment info for a whole chain of pharmacies. He found a pharmacy nearby that had 10 appointment slots available, confirmed a time with his wife, and clicked the link to book the appointment five seconds later. By that time, all the slots were gone.

He then noted that of the 19 links, some of the major pharmacies in the area were not present. His son noted that friends had made appointments at a particular pharmacy, CVS, which was not listed by the state site. CVS had a single web site that provided appointment info

across all of their stores. They had appointments available, and he was quickly able to book one.

Now we invite you to put yourself in that scenario, and imagine that:

- You are elderly and have lost friends and family to the disease – you are desperate to get vaccinated to avoid that fate, and to be able to see friends and family again.
- You are visually impaired and have trouble using the web site.
- You do not speak the languages available on the web site.
- You do not have transportation to get you to any of the vaccination sites.
- You are physically limited and cannot readily get out of your home to get to the vaccination site.
- You do not have access to the technology or internet services in order to access the web site.

Each of these limitations makes the process of signing up for the vaccine just that much harder.

2. OVERVIEW

The emergence of the novel coronavirus and the COVID-19 disease sparked a pandemic that rapidly upended many aspects of modern life. Over the course of just a few weeks, offices and schools of all types emptied out, their activities stopped or moved to various online formats. The impact was dramatic, and the remarkably fast emergence of vaccines to prevent the disease was nearly as dramatic in terms of its perceived ability to return societies to a more "normal" status.

Numerous vaccines and treatments for the disease were in the "pipeline" at the same time as each other, with four major COVID-19 vaccine versions receiving regulatory approval in much of the Western hemisphere in late 2020 and early 2021. Early manufacturing capacity was limited, and was far less than anticipated early demand, forcing public health officials and political leaders to prioritize vaccination delivery. Some focused on first-responders and medical workers as those most at risk of contracting the disease; others prioritized the elderly and those with medical risks as well as "essential workers" whose work provided essential services to the economy – the food industry, energy, critical retail services, and infrastructure operations – water, roads, transportation, etc.

Once vaccines started to become available to the general public, the organizations delivering those vaccines needed a way to schedule appointments for those who needed them and were "qualified" based on their prioritization as described above. From this requirement grew a wide array of web-based tools to schedule appointments. These tools were built by a variety of organizations, from public health to large health-care organizations to individual volunteer groups, and ostensibly were all trying to meet the same requirements:

- to make appointments available equitably to those who met the criteria at the time,
- to not waste vaccine doses, and
- to deliver as many vaccine doses as possible, within the supply limits.

General principles of good system design are relevant to this problem, as it was critical for the signup systems to work well, to reach the right people, and to provide good quality information to both the person signing up for the vaccine, as well as to the vaccine delivery organizations and those who tracked vaccine effectiveness and side effects. Those principles are sometimes referred to as non-functional requirements, in that they define how the system works, not what the system does. Non-functional requirements might include at least the following (Mairiza, Zowghi, and Nurmuliani, 2010):

- Flexibility - Ability to readily change system behavior
- Interoperability - Ability for system to work well with multiple browsers and devices
- Scalability - Ability to readily handle changes in the amount of user activity
- Maintainability - Ability to keep the system running and to readily fix problems
- Security - Keeping information such that it is only accessible to those who are authorized to use it
- Privacy - Using information only as allowed by privacy policies, regulations, and laws
- Reliability - Ensuring that the system is always available for its intended purpose

General principles of good user interface design are appropriate to consider in evaluating the various information system approaches described below, all intended to solve some part of the same problem. Jakob Nielsen identifies ten key indicators of user interfaces for information systems (Nielsen, 2020):

- Visibility of system status - user should be able to know what is going on
- Match between system and real world - use appropriate language and style
- User control and freedom - ability to control activity in system, including stopping and easily restarting
- Consistency and standards - interface behaves similarly to other systems that the user works with
- Error prevention - user is prevented from making obvious errors
- Recognition rather than recall – do not force the user to remember things, rather make them clear and visible
- Flexibility and efficiency - interface should allow for "expert" options, as well as not requiring the user to re-enter the same information multiple times.
- Aesthetic and minimalist design - showing only required information
- Help users recognize, diagnose, and recover from errors - error messages should be clear and help the user understand how to resolve them
- Help and documentation - online help should be available if needed

Information quality is a key measure of the success of an information system. The term is used to describe various characteristics of information, including accuracy, accessibility, completeness, consistency, currency, timeliness, format, and other factors that make it available and suitable for use by organizations and individuals (Lee, Strong, Kahn, and Wang, 2002). This is critical to the vaccine signup process, as good quality information could facilitate getting the right people to the best appointment for them, at the right time.

3. DELIVERY MANAGEMENT STRUCTURE

Countries generally managed delivery of vaccines to their own citizens and other residents. Country-level guidance for how to prioritize delivery was generally shared with lower-level jurisdictions, such as states, provinces, counties, and cities, which often had the flexibility to adjust those prioritization schedules to suit their situations.

This flexibility led to differences in criteria even among neighboring states and cities. For example, public safety first responders (police, fire, etc.) and medical staff were often prioritized first, so that those most directly at risk of infection could be protected. Some regions, though, prioritized those most at risk of serious illness in the first group as well, such as the elderly or those with lung and other illnesses that make the COVID-19 disease more deadly.

Some vaccines (Pfizer, Moderna, AstraZeneca) required two doses given within a certain window of time. As such, individuals who received those vaccines had to be tracked so that they could be confirmed to get an appointment for their second dose of the same vaccine in a timely fashion. The other approved vaccine at the time, from Johnson & Johnson, required only a single dose.

Because the vaccines were early in their development and delivery, the United States and other countries undertook more proactive monitoring of vaccine side effects and risks that may not have appeared during clinical trials. It was important for every possible vaccine recipient to be registered with a system that could monitor for patient-reported side effects, and gather that information for analysis.

In mid-2020 to mid-2021, vaccination was viewed by many as a key pathway by which society could begin returning to "normal" post-pandemic life. As such, it appeared to be important to get as many people vaccinated as possible, as quickly as possible. As vaccines were approved and distribution began, a wide array of public and private organizations began the process of organizing to deliver vaccinations.

4. DELIVERY SCENARIOS

This section documents a range of different scenarios related to the first scenario (in the Introduction, above), across a variety of vaccine delivery organizations, and how their approach to scheduling vaccine appointments did or did not do as well as it could have. Each provides an opportunity to consider the various dimensions of good system design, and to analyze what went well, what did not go well, and how it might have been improved. Each also provides an opportunity to consider potential problems that still exist, and what problems may still be occurring, but at low frequencies.

States and Counties cannot agree on how to schedule vaccinations

In the early stages of vaccine delivery, states and the counties within them were frequently at odds when it came to the adoption of centralized vaccination programs. In many cases, counties

initially opted out of their state-wide program, preferring instead to continue with systems that they had already put in place.

In California, usability and control of the state's vaccine appointment website – MyTurn – were key concerns. Searching for vaccine appointments required frequent visits, and answering the same eligibility questions and legal disclaimers each time was frustrating and time consuming. Often when searching for available appointments, a provider would appear on the state website, but when a person clicked through to the provider's website, there would be no available appointments – more frustration. Many mass vaccination sites did not appear on MyTurn because they were managed by health care providers who were not connected to the MyTurn system.

The MyTurn website was built and deployed in ten days after a month of design discussions between three technology companies and two pilot counties (Douglas, 2021). As of April 2021, appointments booked on MyTurn – an average of about 100,000 per day – accounted for only 27% of the vaccinations given each day across the state (Ostrov, 2021).

Questions:

- Given the fact that there were five large organizations involved, what possible reasons can you identify for the design and implementation issues?
- What mitigations would you have put in place to reduce/eliminate them?
- How might the development timeline have contributed to the challenges with MyTurn?
- Based on this example, what general observations about system design can you make?

Scalability challenges with vaccine appointment websites

Vaccine providers - state and local health departments, pharmacies, hospitals, etc. - were under considerable time pressure to develop applications/services/websites that would allow people to look for and schedule vaccination appointments. Often, the vaccine providers would partner with software companies who would build solutions that leverage their existing systems.

Given the anticipated demand, these systems would be expected to scale to considerable volume. Unfortunately, that was not always successful. When Massachusetts expanded eligibility to residents 65 and older, their website crashed (Kail, 2021). A similar story occurred in Washington, D.C. when demand quickly overwhelmed the city's website (Barthel, Delgadillo, and Austermuhle, 2021). New York's vaccine website was flooded by newly eligible residents trying to make appointments. Even though the website displayed appointments available at a number of state-run vaccine sites, users who clicked through often landed on a page that said "Due to high volume, appointments can't be made at this time for this location. Please try again later" (Cook, 2021).

No news is often good news when it comes to vaccination appointment websites successfully meeting load demand. Instead, of course, the vaccine providers in these cases focused on delivering status updates and data on the number of shots in arms. That said, one self-reporting software vendor – Kyruus – has partnered with more than a dozen health care systems to deliver scalable online scheduling of vaccination appointments that leverage best in class cloud infrastructure. In Kyruus's case, they utilized scalable cloud services including Amazon Web Services' EC2 and Elasticsearch (Gervais, 2021). It is highly likely that other successful implementations have gone down a similar architectural path to provide the desired availability and scalability.

Questions:

- What factors may have contributed to these scalability failures?
- How do cloud service providers support scalability planning?
- Have you recently had a similar user experience – slowness, service unavailable, etc.? If so, explain it in some detail, including observations about potential design issues.
- Based on this example, what general observations about system design can you make?

A Tale of Two Vaccine Delivery Solutions

Many companies and organizations built software solutions to aid in the delivery of vaccines. Here are two contrasting systems.

Deloitte is a privately held professional services company that provides audit, tax and consulting services in 20+ industries, operates in 150 countries with more than 300,000 employees worldwide. Their 2020 revenue was $47.6 billion (Forbes, 2021).

Multi-State Partnership for Prevention, LLC (MPP) is a subsidiary of Maryland Partnership for Prevention, Inc., a nonprofit focused on improving the health status of Maryland residents through timely and appropriate vaccinations. Both organizations are led by Tiffany Tate, who says she has about 30 employees. In 2017, her nonprofit's revenue was $171,754 with expenses of $309,032 (Wintrode, 2021).

In May of 2020, the Centers for Disease Control and Prevention (CDC) signed a no-bid contract - no other companies were considered - with Deloitte for a system to schedule, track and report vaccinations. While this type of contract is not typical, the CDC chose Deloitte due to the urgent demand for a solution. Deloitte received $44 million for the project; they called their solution the Vaccine Administration Management System (VAMS). The CDC offered VAMS to states and health care providers at no cost to them (Bendix, 2021).

Building on their previous public health software solutions, MPP created PrepMod, which manages registrations, appointments, and reporting. MPP licensed and negotiated contracts for their system on a state-by-state basis; for instance, the Maryland Department of Health bought PrepMod's software for $300,000 and Colorado's contract with MPP was worth $395,000 (Wintrode, 2021).

While VAMS was offered free to states, less than ten have chosen to use it. Virginia initially adopted VAMS, then abandoned it after only a week due to website slowness and crashes along with usability issues for seniors. Idaho chose not to use VAMS because it did not meet their state's unique problems. Clinicians in Connecticut - which continued to use VAMS - said the system was frustrating due to randomly canceled appointments and periodic failures with registration (Browning, 2021; Ferguson, 2021; LaVito, 2021).

PrepMod has been used by almost thirty states and localities. However, they faced criticism as well. In Massachusetts, the registration system crashed after an increase in the numbers of those eligible for vaccination. In Allentown, Pennsylvania the health director stopped using PrepMod after an issue with appointment links being shared that caused multiple people to show up for a single appointment. Early on, California struggled with technical issues that limited people's ability to get vaccine appointments, but they continued to use PrepMod's solutions (Chen, 2021; Shalby and Gutierrez, 2021; Wintrode, 2021).

Ultimately, many states resorted to using multiple appointment scheduling systems, whether tools at the local agency level or software that better served health care providers, hospitals and pharmacies (Browning, 2021).

Questions:

- What advantages and disadvantages do these two different companies have when it comes to software development in this domain?
- Both of these companies developed software for use by government entities. Why might that have hampered their delivery of robust software?
- Is the fact that Deloitte received a no-bid contract relevant in this regard? If so, why?
- Based on this example, what general observations about system design can you make?

Volunteers to the Rescue

Given the challenges that many people faced in their attempts to schedule vaccine appointments, numerous volunteers stepped up to help. These good citizens were frequently motivated to do so when they ran into trouble trying to sign up friends and family members who were often elderly and/or lacking the requisite technologies - a smart phone or computer with internet access, etc.

While technical approaches have varied, the bulk of these systems have been websites that aggregate appointment availability from the many providers of vaccines (governmental, hospitals, pharmacies, etc.). A team in the state of Washington built a solution for an early problem - websites with locations where someone clicking through would not find any available appointments. They only listed locations where there were actually available appointments. In addition, their interface was user friendly, listing locations graphically via a map (Figure 1, Appendix).

Volunteer teams large and small came together to build and support these websites. Some of them called vaccine providers at a regular frequency to gather status on available vaccine appointments, updating their website with the information. Other teams leveraged automation – screen-scraping the web sites of vaccine providers – to achieve similar results.

Questions:

- What reasons (both technical and non-technical) would explain why the development teams responsible for the initial versions of vaccination registration systems failed to anticipate the shortcomings that prompted others to address them?
- What steps could those development teams have taken to discover issues like these ahead of time?
- Given what you now know about what the volunteers did to improve the user experience, what further enhancements to vaccination registration and appointment usability would you suggest?
- Based on this example, what general observations about system design can you make?

Managing the delivery - getting vaccines into people

While scheduling vaccination appointments proved challenging for people who needed them, there were also challenges for people trying to manage that delivery process. Delivery of large volumes of vaccines from factory to vaccination site requires a complex supply chain network, from vaccine raw materials to manufacturing supplies and capacity, to packaging materials to ultracold refrigerated shipping and storage. Vaccine shelf life was a consideration as well; dependent upon the specific vaccine and its refrigeration requirements. Then, all of the vaccines must be delivered to patients, requiring locations, syringes, staff, personal protective equipment, security, and a timely supply of patients.

In an increasingly globalized world, supply chains for many things are not isolated in one particular region of the world. Increasing manufacturing capacity in one part of the world might require obtaining biological material from another part of the world, stainless steel for making the tools to make the vaccine, and acquiring personal protective equipment for factory builders and workers from yet a third part of the world. And as the Suez Canal blockage (Fox and Thordarson, 2021) demonstrated, it is not unusual to have bumps in the supply chain.

All of this is to highlight the fact that the final scheduling of patient vaccine appointments required complex supply chains and forecasting of deliveries of the full set of supplies in time for those appointments. It required forecasting of how many shots could be delivered on a particular day, at least a few days in advance of the delivery day, to allow patients to sign up. And because the vaccines were initially scarce, demand was much greater than supply.

Once there were multiple vaccine options available, those vaccines that required two doses had to be given with the appropriate delay between doses, and the second dose had to be from the same type of vaccine. Economics then plays into the equation - since vaccines were often given without direct cost to the recipient, no-shows were not uncommon. If vaccine planners did not plan for this, they could end their day with leftover vaccines that might then go to waste (KDKA, 2021).

Questions:

- How might the vaccine appointment systems have accommodated the risk of "wasted" doses?
- What information would you expect a vaccine delivery agency to need from its appointment system to adequately plan each day's activity?
- What groups of people would you identify as being critical to vaccinate if one of the goals is to maintain the vaccine supply chain?
- Based on this example, what general observations about system design can you make?

One perspective on the Netherlands' vaccination approach

A Dutch citizen shared with the authors her personal experience related to vaccinations in the Netherlands. The respondent noted that as of April 2021, she understood that the Netherlands was only vaccinating "risk groups," including "the group of elderly above the age of 66 or people with a medical condition".

People under a doctor's care with a medical condition were sent a letter via paper mail proactively designating an appointment time and day, and where to go for the vaccination, usually their doctor or hospital treating their condition.

Health care workers were notified of vaccine availability by their employer and were asked to make appointments by phone.

People in the age-based eligibility group were notified via paper mail and asked to call a nation-wide appointment line to set an appointment at one of the vaccination facilities. After vaccination,

the recipient is expected to update their primary physician with information about their first vaccine, and the doctor is expected to contact the patient when it is time for the second dose, after which the recipient calls the national number again to get a second appointment. A subset of those invited by paper mail could make an appointment online starting in April 2021, but only if they had a digital ID (DigiD) for health care (Netherlands Government, 2021).

Other groups were notified by mail as their groups (usually by age) became eligible.

News reports later indicated that there are 38 different systems in the Netherlands that each track some portion of the vaccines delivered, and efforts were under way to collect data from those disparate systems and gather it into a centralized system managed by the Dutch government's Health Ministry.

Questions:

- How might this scenario relate to equity issues in delivery of vaccines?
- What scalability problems are likely in a system that primarily schedules appointments via phone calls?
- Why is integrating data across many different systems important?
- Why is such integration sometimes difficult to accomplish?
- Based on this example, what general observations about system design can you make?

Vaccination for the elderly and other vulnerable populations

Various segments of the U.S. population are more vulnerable to COVID-19, both in the risk of getting the disease, and in its severity. For example, the risks of hospitalization and death increase with age; in the U.S., 80% of COVID-related deaths have been in adults 65 years or older (Centers for Disease Control and Prevention, 2021). Racial and ethnic minority groups are also disproportionately affected by COVID-19, perhaps due in part to occupations and health care access. Additional disparities in environment and housing contribute to increased risks of exposure, serious illness and death (Dooling et al., 2020).

These and other groups frequently struggled with access to vaccines due to various challenges - technology (lack of internet access, computer, smart phone), language, etc. In response, health care organizations, religious organizations, civic leaders and volunteers went the extra mile to get vaccines to those most in need.

Given the devastation that COVID-19 wreaked upon the elderly and staff in long term care facilities - as of March 2021, approximately 8% of residents in these facilities had died of COVID-19 - a committee advising the Centers for Disease Control and Prevention voted to add residents of long term care facilities to the initial phase of vaccine access (The COVID Tracking Project, 2021; Weise and Weintraub, 2020). The resulting vaccination effort, led by pharmacies CVS and Walgreens, was dramatic and positive as demonstrated in Figures 2-5, Appendix.

Health care professionals, nonprofits, politicians and volunteers have taken to the streets to close the vaccine gap in vulnerable Black and Hispanic communities (Schoenfeld Walker, Sun, Avila, Pope, and Yoon, 2021). One Sunday, Dr. Karen Smith dispensed 150 vaccine doses across Raeford, North Carolina: 50 at the Freedom Chapel AME Zion Church: 71 at the town's poultry plant; and 29 at a local convenience store and gas station, where 25 shots were provided to men who self-identified as Black or Latino (Harris, 2021). Similar actions took place across the country.

Seasonal farmworkers - essential workers - are vulnerable to COVID-19 in part because they work and live in close quarters. They often work long days and do not take time off. So, good people go to them; in Connecticut, mobile clinics were set up by the Department of Agriculture, the Department of Public Health and the Department of Labor (Otte, 2021). Many other agencies across the US did similar things, sparing workers the onerous task of online registration and limiting their time away from the fields (Jordan, 2021).

Questions:

- How might vulnerable populations have been reached sooner in the process of vaccine delivery?
- What information would be required to find and arrange to vaccinate those populations?
- What information would need to be captured after vaccination?
- What information systems could support and sustain these efforts?
- Based on this example, what general observations about system design can you make?

5. FOLLOW-UP QUESTIONS

These are some follow-up questions to provoke further research and exploration. Your instructor may have other questions, and we encourage you to develop your own questions as well.

- What are the fundamental principles of system design that seem most applicable to the task of scheduling, delivering, and tracking vaccinations, and why?
- What are the fundamental principles of user experience design that seem most applicable, and why?
- What are the fundamental principles of information quality that seem most applicable, and why?
- What aspects of the COVID pandemic contributed to the difficulties described in this case?

6. FOLLOW-UP RESEARCH

We recognize that the situation with COVID-19, its vaccines, and its impact on the world, are changing even as this case is written. As such, we anticipate much new material to become available, as well as new questions to arise. As a starting point for conversation and research, please consider these questions:

- Investigate the supply chain for vaccine delivery - what information is required at the various stages to be able to accurately forecast both demand and supply?
- Consider the supply chain for what happens after the vaccine is injected - what has to happen to all the supplies, protective equipment, etc.? What information needs to be captured to track all of this?
- Thinking globally, what could developed countries have done early in the vaccination process to more equitably distribute vaccines to other parts of the world? What information would have helped make those decisions?
- What could have been done in any particular country to make the vaccine delivery process more equitable?
- What are the categories of people who could have been identified and vaccinated earlier in the process? What value is there in doing that?
- Consider the post-vaccine task of keeping track of who has been vaccinated. What are the privacy risks and tradeoffs of having a national "registry" of vaccination records, and of providing an electronic "vaccine passport" to identify those who are now "safe"?
- Information systems design has long faced tradeoffs of centralized vs. decentralized systems. What are the tradeoffs for vaccine appointment scheduling?
- What information and information systems might be leveraged to help people understand the tradeoffs between getting and not getting vaccinated?
- Visit www.vaccines.gov or your country's national vaccination information site, and assess it for system design, information quality, privacy, and other issues.
- Going forward, assuming that COVID-19 remains active in some part of the global population, and continues to mutate (much like the seasonal flu), what information systems will be needed to continue this vaccination process on an enduring basis?

7. CONCLUSIONS

For better or worse, the entire world was and is engaged in an ongoing battle with a new and virulent disease through much of 2020 and well into 2021 and beyond. Vaccine development proceeded remarkably quickly by historical standards, driven by some early fundamental work on genetic sequencing and vaccine design. Given this rapid pace, and the need to quickly deliver the vaccines as broadly as possible, organizations in many sectors engaged in developing systems to accomplish this. Some were more successful than others, and there is much to be learned about system design from studying both successes and failures.

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Appendix

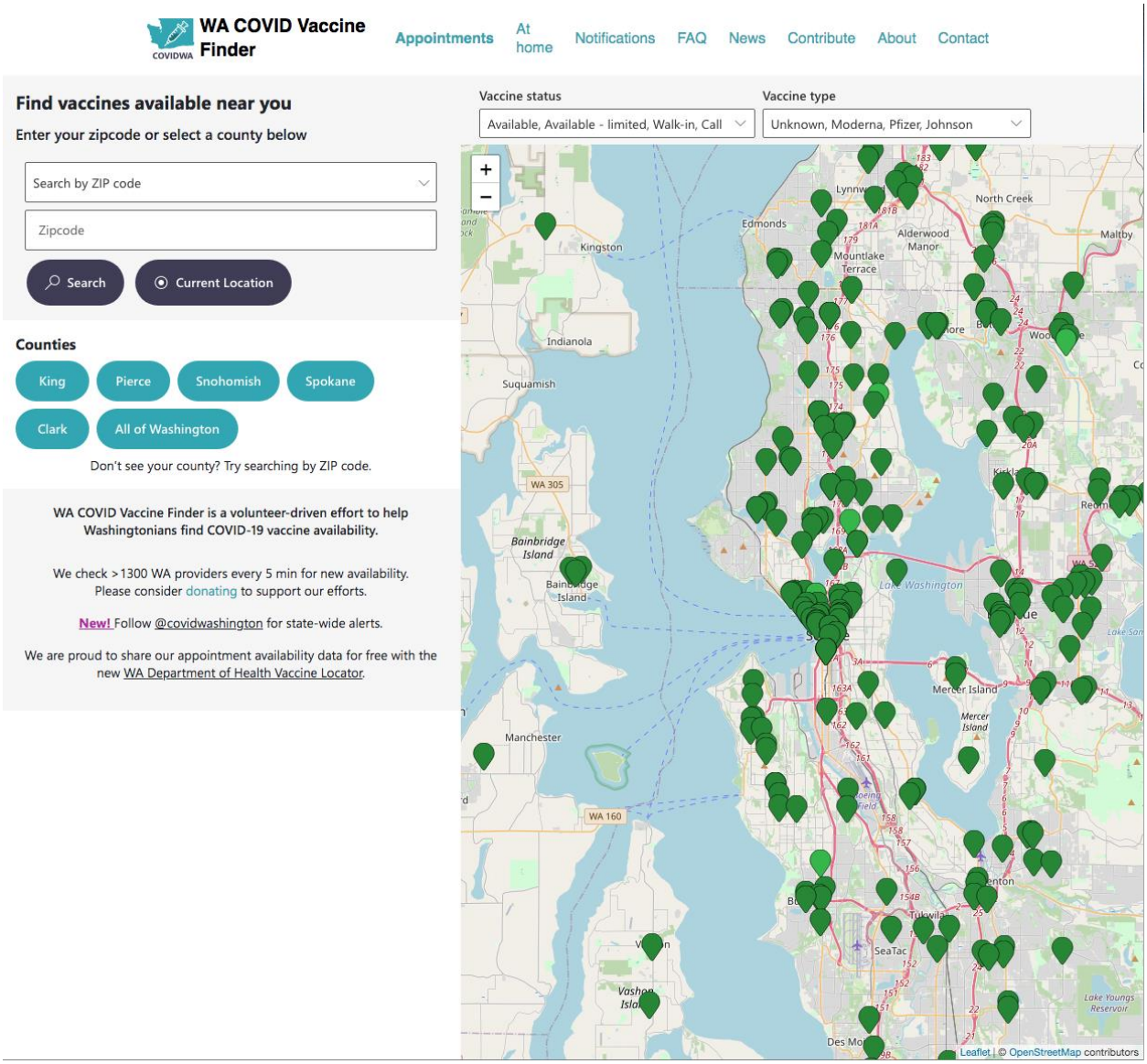

Figure 1 – Screen shot from https://www.covidwa.com/, as one example of a volunteer-run site

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Figures 2-5 are from the US CDC (Centers for Disease Control and Prevention, 2020).

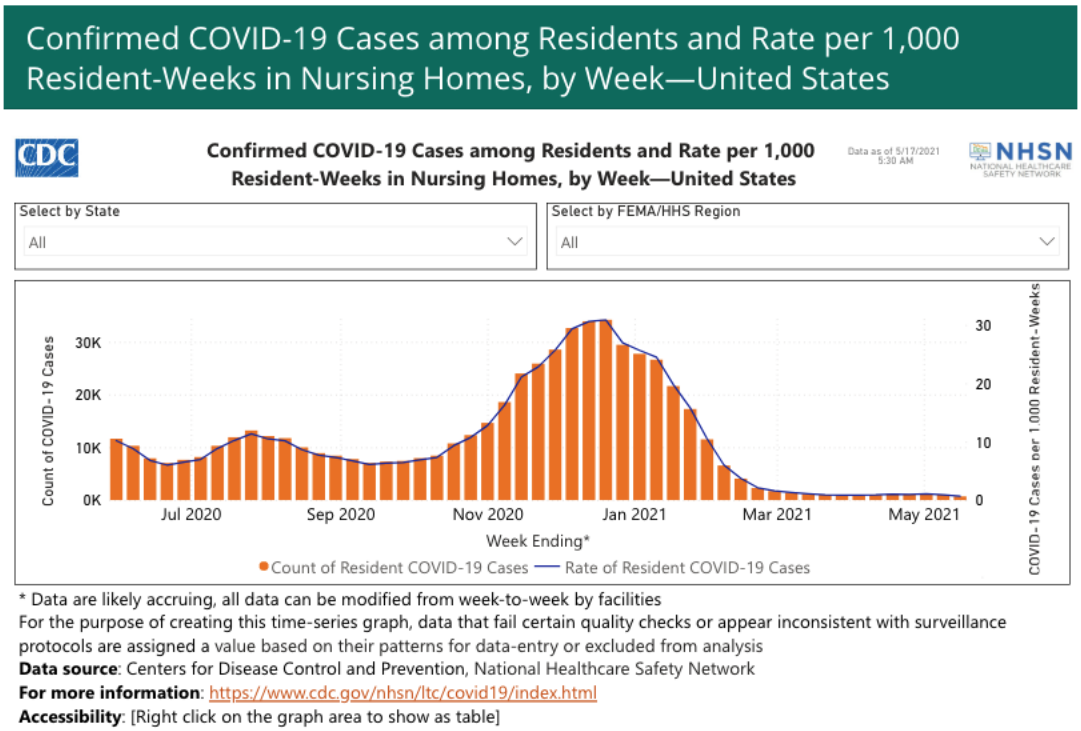

Figure 2 - COVID-19 Cases among Residents of Nursing Homes in US

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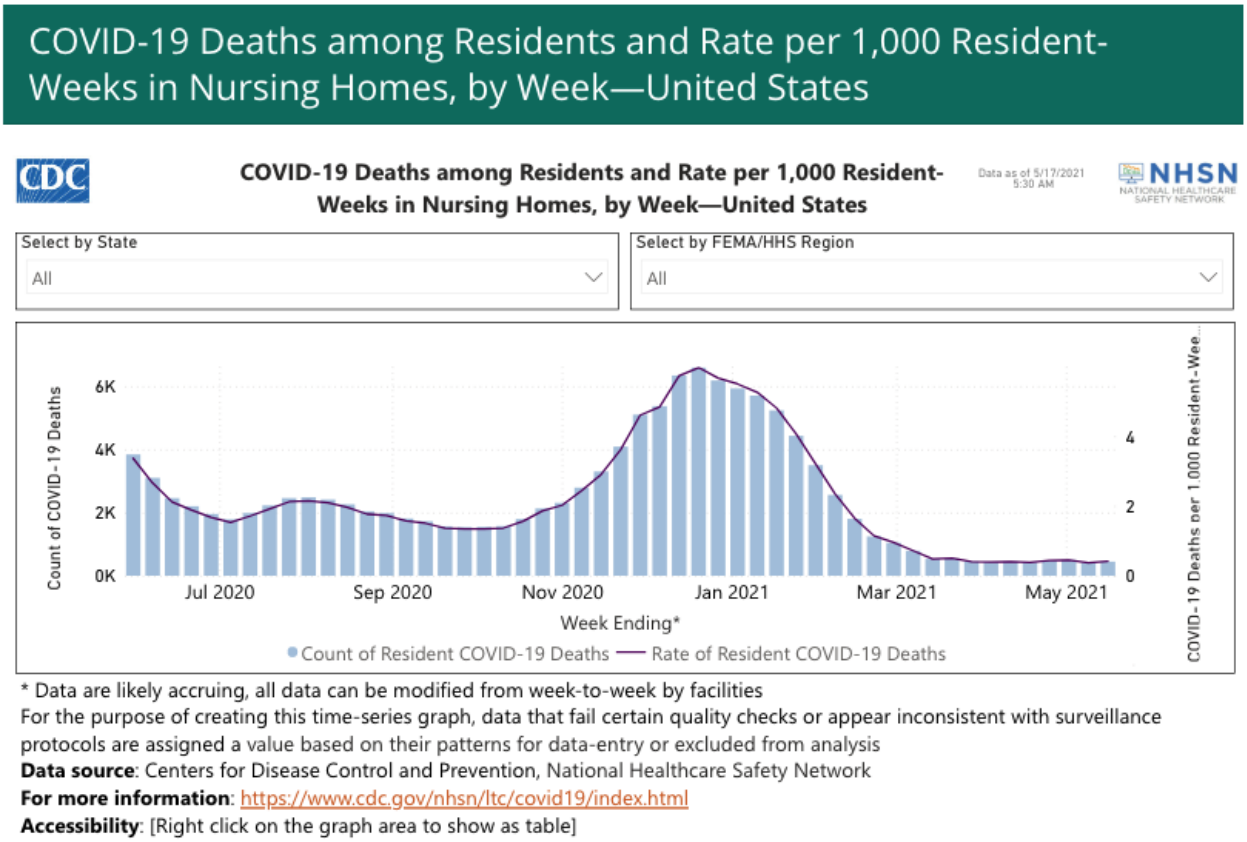

* Data are likely accruing, all data can be modified from week-to-week by facilities
For the purpose of creating this time-series graph, data that fail certain quality checks or appear inconsistent with surveillance protocols are assigned a value based on their patterns for data-entry or excluded from analysis
Data source: Centers for Disease Control and Prevention, National Healthcare Safety Network
For more information: https://www.cdc.gov/nhsn/ltc/covid19/index.html
Accessibility: [Right click on the graph area to show as table]

Figure 3 - COVID-19 Deaths among Residents of Nursing Homes in US

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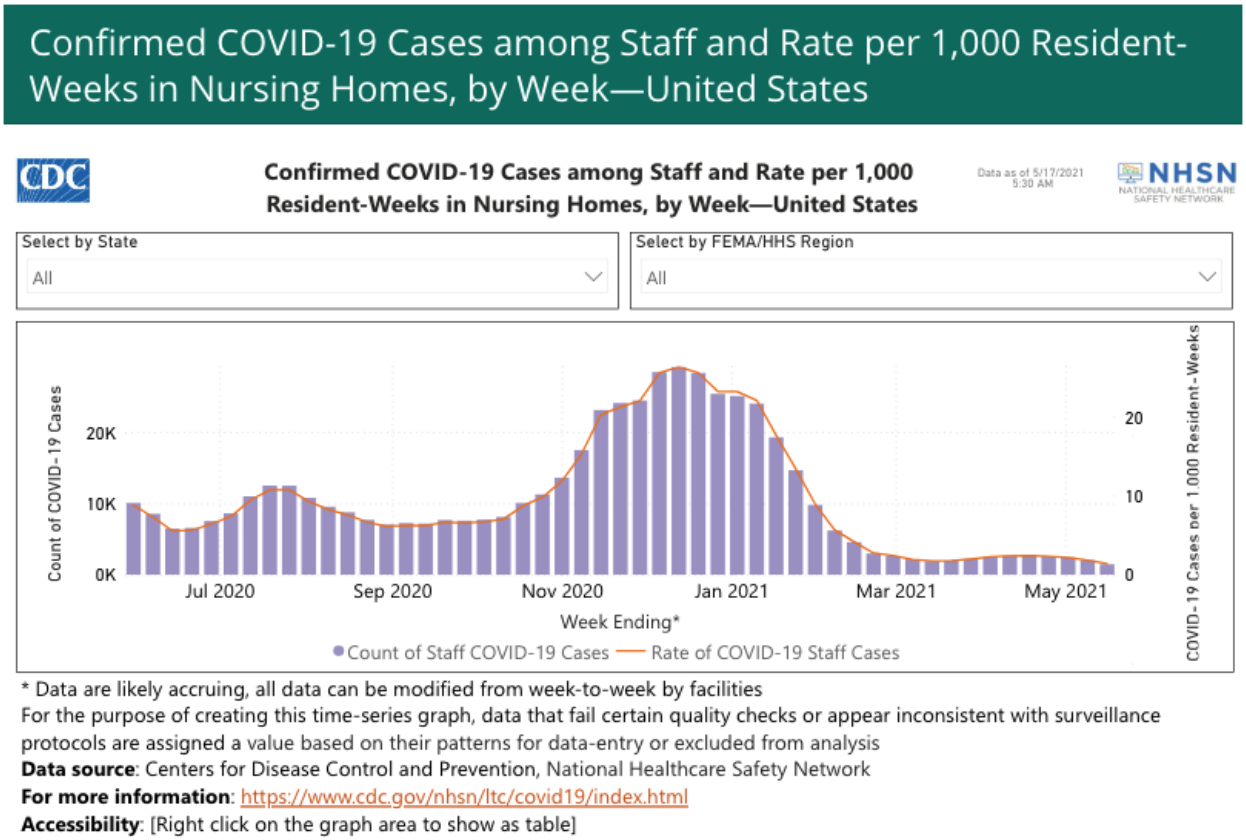

Figure 4 - COVID-19 Cases among Staff of Nursing Homes in US

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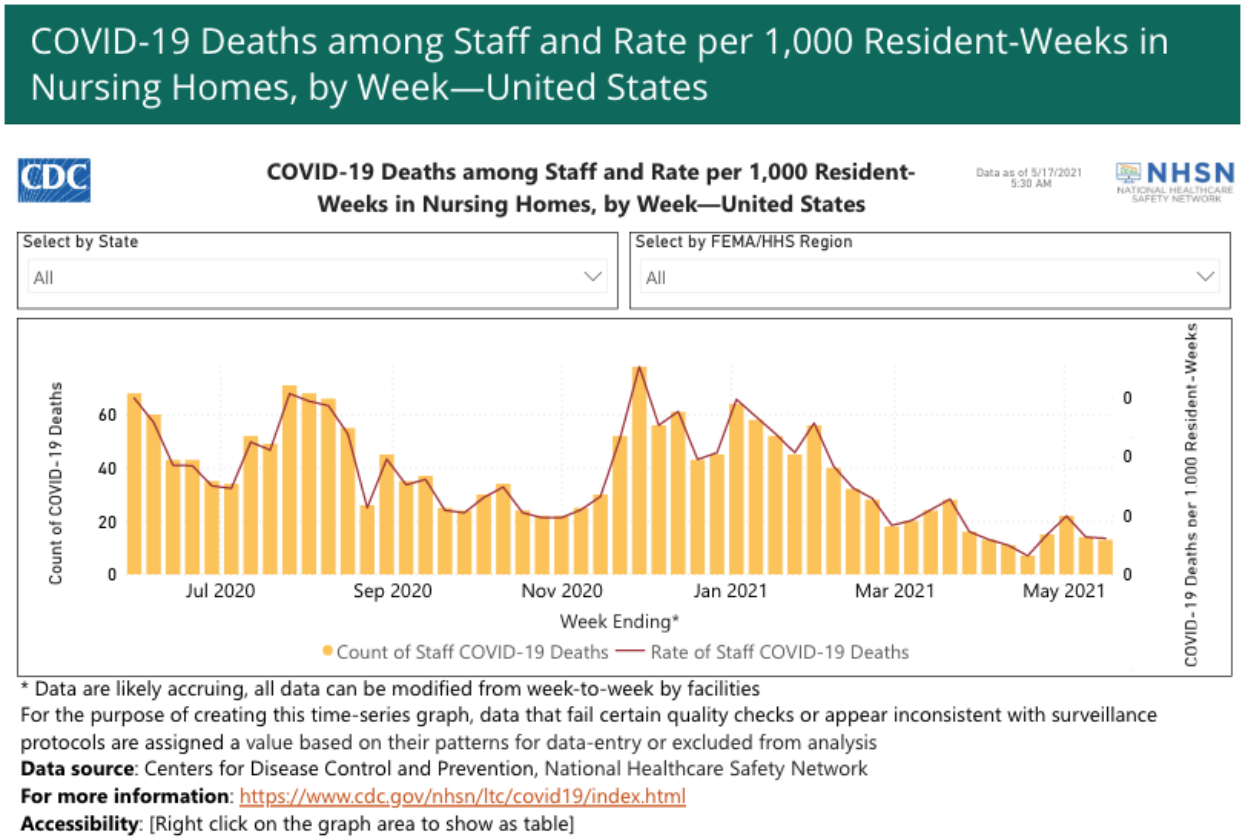

* Data are likely accruing, all data can be modified from week-to-week by facilities
For the purpose of creating this time-series graph, data that fail certain quality checks or appear inconsistent with surveillance protocols are assigned a value based on their patterns for data-entry or excluded from analysis
Data source: Centers for Disease Control and Prevention, National Healthcare Safety Network
For more information: https://www.cdc.gov/nhsn/ltc/covid19/index.html
Accessibility: [Right click on the graph area to show as table]

Figure 5 - COVID-19 Deaths among Staff of Nursing Homes in US