Using COVID-19 Data on Vaccine Shipments and Wastage to Inform Modeling and Decision-making

Leila Hajibabai[1], Ali Hajbabaie[1], Julie Swann[1], and Dan Vergano[2]
[1] North Carolina State University, [2] Buzzfeed News

Abstract

Since the start of the COVID-19 pandemic, disruptions have been experienced in many supply chains, particularly in personal protective equipment, testing kits, and even essential household goods. Effective vaccines to protect against COVID-19 were approved for emergency use in the U.S. in late 2020, which led to one of the most extensive vaccination campaigns in history. We continuously collect data on vaccine allocation, shipment and distribution, administration, and inventory in the U.S., covering the entire vaccination campaign. In this article, we describe some datasets that we collaborated to obtain. We are publishing the data and making them freely available to researchers, media organizations, and other stakeholders so that others may use the data to develop insights about the distribution and wastage of vaccines during the current pandemic or to provide an informed future pandemic response. This article gives an overview of vaccine distribution logistics in the U.S., describes the data we obtain, outlines how they may be accessed and used by others, and describes some high-level analyses demonstrating some aspects of the data (for data collected during 01/01/2021 – 03/31/2021). This article also provides directions for future research using the collected data. Our goal is two-fold: (i) We would like the data to be used in many creative ways to inform the current and future pandemic response. (ii) We also want to inspire other researchers to make their data publicly available in a timely manner.

Keywords: COVID-19, Vaccine Distribution, Vaccine Wastage, Data Analytics

1. Introduction

Effective vaccines to protect against COVID-19 were first approved for emergency use in the U.S. in December 2020. With an increase in the supply, vaccines have been distributed to states in phases through various channels, including hospitals, pharmacies, nursing homes, public health departments, and mass vaccination sites in an effort to vaccinate as much of the population as possible to reduce morbidity and mortality. Large-scale distribution and administration of vaccines over a short period, particularly under extraordinary cold storage requirements, is a complex logistical problem.

This paper aims to provide information on collecting time-sensitive data on COVID-19 vaccine distribution and wastage from the Centers for Disease Control and Prevention (CDC), containing the record of every vaccine shipment to providers in the U.S. from January 2021 to March 2021. The data can be analyzed to understand how distribution decisions are made across different states, which distribution network structure is used within a state, what types of providers are available, among others. This paper summarizes the collected data, outlines how to use them, suggests some types of analysis that could be done with the data, and describes how to access the data. Collecting and archiving time-sensitive data on the vaccination effort in the U.S. will assist researchers and interested parties in studying the distribution challenges and enable a more efficient response to future pandemics or natural or man-made disasters. In addition, a high-level analysis on vaccine distribution will be provided and followed by concluding remarks and directions for future research using the collected data.

2. Description of COVID-19 Vaccination System in the U.S.

In the U.S., the federal government has allocated limited supplies of COVID-19 vaccines to three main types of vaccine awardees, including jurisdictions, federal programs, and federal entities. Jurisdictions include states, territories, freely associated states, tribes, or local entities. Federal programs include Federal Retail Pharmacy Program, Health Resources and Services Administration's (HRSA) Federally Qualified Community Health Center Program, Federal Emergency Management Agency (FEMA) Community Vaccination Center (CVC) Pilot Site and Mobile Vaccination Program, and Federal Dialysis Center Program. Federal Entities include the Bureau of Prisons, Department of Defense, Indian Health Service, and Veterans Health Administration, each receiving its own vaccine allocation (1). Pharmacies and other retailers (e.g., CVS, Walgreens, COSTCO, and Walmart) may also receive vaccines from jurisdictions. The CDC publishes vaccine allocation and shipment to jurisdictions. Therefore, the number of vaccines shipped to Illinois, as an example, is available; however, data on shipment to awardees is only available through the data that we are collecting.

After allocation, a jurisdiction places vaccine orders in the Vaccine Tracking System (VTrckS) to be shipped to specific locations within the jurisdiction (2,3). Doses of Pfizer-BioNTech (Pfizer) are shipped from a location in Michigan. Moderna and later Johnson & Johnson (Janssen) are shipped through distribution centers managed by McKesson Inc., a company specializing in distributing pharmaceuticals and other medical supplies.

Once vaccines arrive at a location, they can be administered at the same location in most cases; however, a secondary distribution may occur in some instances (e.g., in North Dakota, as described in their planning document, or from commercial pharmacies to individual locations). Shipments of Pfizer range in size from approximately 1,000 to 5,000 doses (4), while shipments of Moderna and Janssen are 100 doses or more. The cold chain requirements for each vaccine are outlined in publicly available documents, e.g., initially in the CDC interim planning documents (4), then press releases from companies (5–7). Initially, a vial of Pfizer contained five doses but later expanded to six; Moderna initially contained five but later expanded to ten (4), eleven, and fifteen; Janssen included five doses (8).

Vaccine doses are stored until used in most cases. At any point in time, estimates of vaccine inventory may be obtained by pairing the shipment dataset with data on vaccine administrations. In a few cases, wastage occurred, e.g., due to breakage, disruption of the cold chain requirements, and/or because vaccine vials were opened but not used in their entirety.

The CDC authorized the Pfizer vaccine for emergency use on December 11, 2020, Moderna on December 18, 2020, and Janssen on February 27, 2021 (9). Shipments are handled by commercial operators, including Fed-Ex and UPS. Auxiliary supplies (e.g., syringes, gloves, vaccination cards) for all vaccines are shipped from the McKesson distribution centers. The number of doses allocated during the first months of distribution was primarily pro-rata according to the population in the jurisdiction. Our understanding is that the CDC has used estimates of the population from the 2019 American Community Survey data (10) for the allocation to jurisdictions. Alaska was one exception, where the logistics of allocated weekly vaccines would have been more expensive than distributing fewer, larger shipments. Allocations are made weekly on Mondays for all vaccine types, as shown by the CDC's publicly available allocation data (11).

3. U.S. Vaccination Data Landscape

The paper's main contribution is to provide a unique and detailed dataset that can be used to inform analyses of the COVID-19 vaccination campaign to improve decision-making in the current and future pandemics. The dataset presented in this paper provides detailed daily vaccine shipment information to vaccine providers for each U.S. state and territory. This section summarizes datasets related to the COVID-19 response, especially those that could be linked to our data to facilitate further analyses. The overall landscape of the vaccination data is shown in Table 1. There are many datasets in the U.S. containing various elements of COVID-19 testing and vaccination data, including (a) allocation of vaccine, (b) administration of vaccine, (c) distribution (shipment) of vaccine, (d) wastage of vaccine doses, (e) vaccine distribution and administration guidelines, (f) individual state plans for vaccine distribution, and (g) vaccine inventory (estimated). In addition, researchers may be interested in datasets such as (h) summary of state eligibility over time, (i) media summary of appointment systems used by states, (j) summary of policies at schools or colleges, (k) Google COVID-19 community mobility reports, (l) Safegraph mobility, (m) COVID-19 surveillance of cases, (n) COVID-19 test positivity, (o) COVID-19 hospitalization, and (p) COVID-19 tracking.

Table 1. Examples of COVID-19 vaccination and testing data in the U.S.

Dataset	**Source**
a. Allocation of vaccine	The weekly vaccine allocations to health jurisdictions and federal entities are available to download from the CDC (11). The dataset summarizes aggregate doses allocated to a jurisdiction such as a state or local health department and specific large cities. The allocation is available to those entities for ordering.
b. Administration of vaccine	Data on vaccine administration can be acquired through the CDC, individual state health department websites, or summaries by the New York Times. Publicly available data are aggregated, e.g., at the county, state, or national level, and it indicates the number of doses administered by a particular date. Some states, such as North Carolina, provide more detailed data, e.g., weekly county-level data (12). Some states, such as South Carolina, include provider information in administration data (13). Some information is available by age or race-ethnicity, although the availability of the latter varies by state.
c. Distribution (shipment) of vaccine	Detailed data such as shipments to specific locations are not generally provided publicly. A rare exception is South Carolina, where a state website provides some snapshots of shipments at some points in time (13). The dataset described in this paper provides distribution data, including shipments to specific locations over time. This paper makes this data publicly available.
d. Wastage of vaccine doses	The dataset described in this paper provides wastage data of doses for all jurisdictions that report it.
e. Vaccine distribution and administration guidelines	Initial guidance to states on vaccine distribution, administration, and reporting can be found in the CDC's COVID-19 Vaccination Program Interim Playbook for Jurisdiction Operations (4,14).
f. Individual state plans for distribution	Some state plans for vaccine distribution are publically available. States were asked to submit initial plans for vaccine distribution in October 2020. Note that some states posted their plans publicly but removed them over time. A summary list is available (15).
g. Inventory of vaccine (estimated)	The available vaccine inventory by state can be estimated by combining allocation, distribution, and wastage data (16).

Dataset	Source
h. Summary of state eligibility for vaccine over time	The summary of state vaccination eligibility is publicly available. The dataset indicates the eligibility of different population groups in each state over time (17). The accuracy may not be 100%, so researchers are encouraged to check details for a particular state of interest.
i. Summary of vaccine appointment systems used by states	The vaccine appointment summary is publicly available. The summary is compiled by media on how to get COVID-19 vaccine in each state, including whether a state has a centralized appointment system, waitlist, call center, or others (18).
j. Summary of policies at schools or colleges	Some policies can be obtained from the schools' or colleges' websites. Various websites track schools (by state and county) or universities on their mask and vaccine requirements (19–21).
k. Google COVID-19 community mobility reports	The mobility reports are available on Google (22). The dataset shows how travel patterns in the U.S., different states, or different counties changed due to the COVID-19 pandemic(22).
l. Safegraph mobility	The safegraph mobility dataset is available online (23). The dataset shows traveler behavior at the census block level, similar to Google COVID-19 community mobility reports. It also provides origin-destination data and can be acquired by special request.
m. COVID-19 surveillance	The surveillance data of COVID-19, including reported positive cases, can be obtained from the CDC (24,25).
n. COVID-19 test positivity	The percentage of positive tests for each state and nationally over time can be obtained from the Johns Hopkins University portal (26).
o. COVID-19 hospitalization	The hospitalization data can be acquired from HHS that compiles summary data on hospitalization utilization at the facility level (27). The CDC provides more detailed information on hospitalizations for 14 states in the COVID-NET weekly (28).
p. COVID-19 tracking	The COVID-19 tracking data can be obtained from The Atlantic (29).

The CDC summarizes several vaccination datasets on a webpage (30). Furthermore, USA Today has provided an info-graphic explaining vaccination system components in the U.S. (3) along with their interrelationships. The system components are listed in Table 2. It includes (1) State Immunization Information Systems (IIS), (2) Vaccination Administration Management System (VAMS), (3) VaccineFinder, (4) The CDC's Vaccine Tracking System (VTrckS), (5) IZ Gateway and Clearing House, (6) COVID-19 Data Lake, and (7) Tiberius, as described in the table.

Table 2. Examples of COVID-19 vaccination and testing data in the U.S.

Dataset	Description
1. IIS	It stores patient immunization information in each state or major city. De-identified data are reported to a federal data lake.

Dataset	Description
2. VAMS	It is a portal used by clinics or jurisdictions to help manage vaccines from arrival at a clinic until the administration.
3. VaccineFinder	It is a public website to find providers of COVID-19 vaccines. It may not reflect whether a vaccine is currently available at that location.
4. VTrckS	It is a vaccine ordering and management system for vaccine awardees and providers.
5. IZ Gateway and Clearing House	It provides a system for connecting and sharing immunization information for IISs, federal agencies, and private partners.
6. COVID-19 Data Lake	It includes all patient immunization record data submitted by states.
7. Tiberius	It is a COVID-19 vaccination tracking system available for the CDC and awardees.

4. Vaccine Distribution and Wastage Data Description

The vaccine allocation data are currently publicly available with frequent updates, e.g., weekly. We are downloading this data and storing it on the GitHub site (31,32) Harvard Dataverse (33) for researchers. We partnered with a media organization to obtain vaccine shipment data from CDC by submitting Freedom Of Information Act (FOIA) requests. As we receive additional datasets of this type, we will add them to the storage on GitHub and Harvaer Dataverse.

The shipment data include fields such as (a) provider name and address, (b) vaccine awardee, (c) vaccine manufacturer, (d) vaccine expiration date, (e) vaccine ship date, and (f) number of doses shipped. The current shipment dataset does not include the date of vaccine arrival; however, it can be estimated based on the provider's location as the origin of the shipment is known. The data can also be used to see changes over time, such as when a winter storm caused delays for FedEx and UPS (34). The existing shipment dataset has more than 633,000 records. More than 293,000 records correspond to vaccine shipments, and more than 339,000 records account for vaccine supply shipments such as dry ice kits, administration kits, and mixing kits.

The vaccine wastage data include the date and number of vaccine doses wasted, vaccine awardee, and vaccine type. This dataset is obtained from the CDC and includes records from

January 1, 2021, to March 31, 2021. The dataset will be updated as we obtain more data. The wastage dataset has 1,200 records.

Table 2 shows different data fields included in our dataset and their descriptions. Researchers can access both datasets and metadata through GitHub (31,32) and Harvard Dataverse (33). Note that there is no restriction on reporting or generating analytical results associated with the data. The storage site will be continuously updated.

Table 3. Description of data fields available in the vaccine shipment and wastage datasets

Dataset	Data Field	Description
Vaccine Shipment	PROVIDER_NAME	Name of provider who administers vaccines
	STREET_SHP	Street address of the provider
	STREET2_SHP	Apartment, suite, unit, etc. of the provider; This field may be blank if the information is not reported
	CITY_SHP	City of the provider
	STATE_SHP	State of the provider
	ZIPCODE_SHP	Zip code of the provider
	PROVIDER_STATUS	Provider status: active, inactive, pending, or suspended
	AWARDEE	The name of vaccine awardee: states/territories and non-state/territories
	NDC	National drug code; is a unique code used to identify and report drugs
	NDC_DESCRIPTION	Description of NDC showing vaccine type, packaging, etc.
	VAX_MANUFACTURER	Vaccine manufacturer
	LOT_NUMBER	Lot number can be used to determine the expiration date
	LOT_EXPIRATION_DATE	Expiration date of the shipped lot; If shows 2069, the expiration date is not reported; the Lot number should be entered in resources (35,36) to determine the expiration date.
	ORDER_SHIPPED_DATE	Shipment date of the lot
	DOSES_SHIPPED	Number of doses included in the shipment
	LAST_REFRESH_DATE	Date the data was last updated
	ORDER_NUMBER	Order number
	ORDER_LINE_NUMBER	Order line number
Vaccine Wastage	AWARDEE	Name of vaccine awardee: states/territories and non-state/territories
	NDC_DESCRIPTION	Description of NDC showing vaccine type, packaging, etc.
	WASTAGE_SUBMITTED_DATE	Date that the vaccine wastage was reported
	TotalDoses	Total number of doses wasted during the reporting period

5. High-level analysis

Vaccine shipment and wastage datasets can be used to conduct different high-level and detailed analyses to understand how the vaccination supply chain has performed. In this section, a few examples of high-level analyses are presented.

5.1. Distribution of vaccine providers

Vaccines are shipped to 47,188 destinations, each representing a unique provider distributed across the U.S. states and territories. Figure 1 shows the average population per provider in each state/territory and the average number of doses shipped to each provider in each state/territory from January to April 2021. On average, each provider is responsible for a population of 9,618 with a minimum population of 2,723 and a maximum of 51,433 based on the state/territory population. In this period, an average of 6,126 doses is shipped to each provider in the U.S., with a minimum of 1,416 doses in the Virgin Islands and a maximum of 47,260 in the Northern Mariana Islands. Note that data on providers, unique shipping destinations, and locations in each state or territory are available through the dataset that we are providing. These data are not otherwise available publicly.

The awardees with a large value for population per unique shipment destination should be noted. Several territories such as American Samoa and Guam likely received a small number of shipments to their distant island, with a secondary distribution locally. West Virginia did not participate in the federal long-term care pharmacy program (37). While the vaccine allocated to each awardee during this time was generally according to population size, the exact ordering and shipment dates also depended on policies and processes within that awardee. Some states also used a centralized warehouse or hub for distribution, so the shipment data may show fewer shipments by destination.

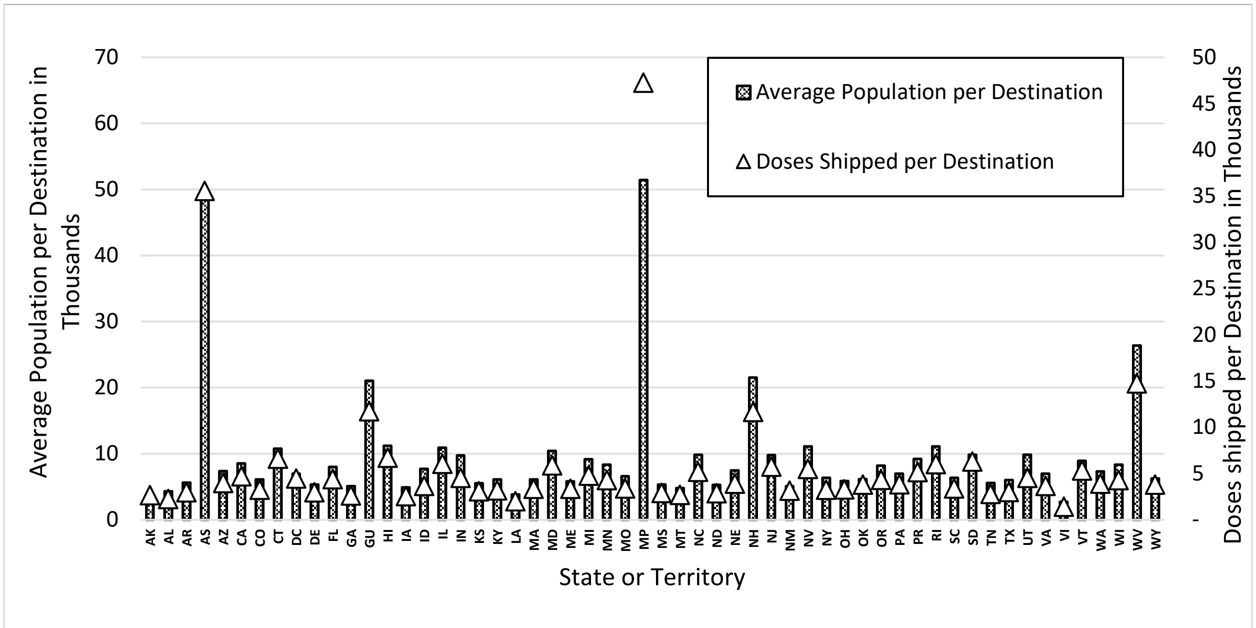

Figure 1. Average population and doses shipped per destination in each state/territory

Figure 2 shows the total number of doses (in millions) shipped to each state or territory from each vaccine manufacturer between 01/01/2021 and 03/31/2021 (publicly available). Additionally, the state population (publicly available in (38)) is shown on the primary vertical axis, and the number of unique vaccine shipment destinations (not publicly available) in each state is shown on the secondary vertical axis. In general, the total shipped vaccines are proportional to the state/territory population. In addition, the number of unique destinations in each state or territory follows their population. Note that the population of California and Texas are not shown on the graph to improve the readability.

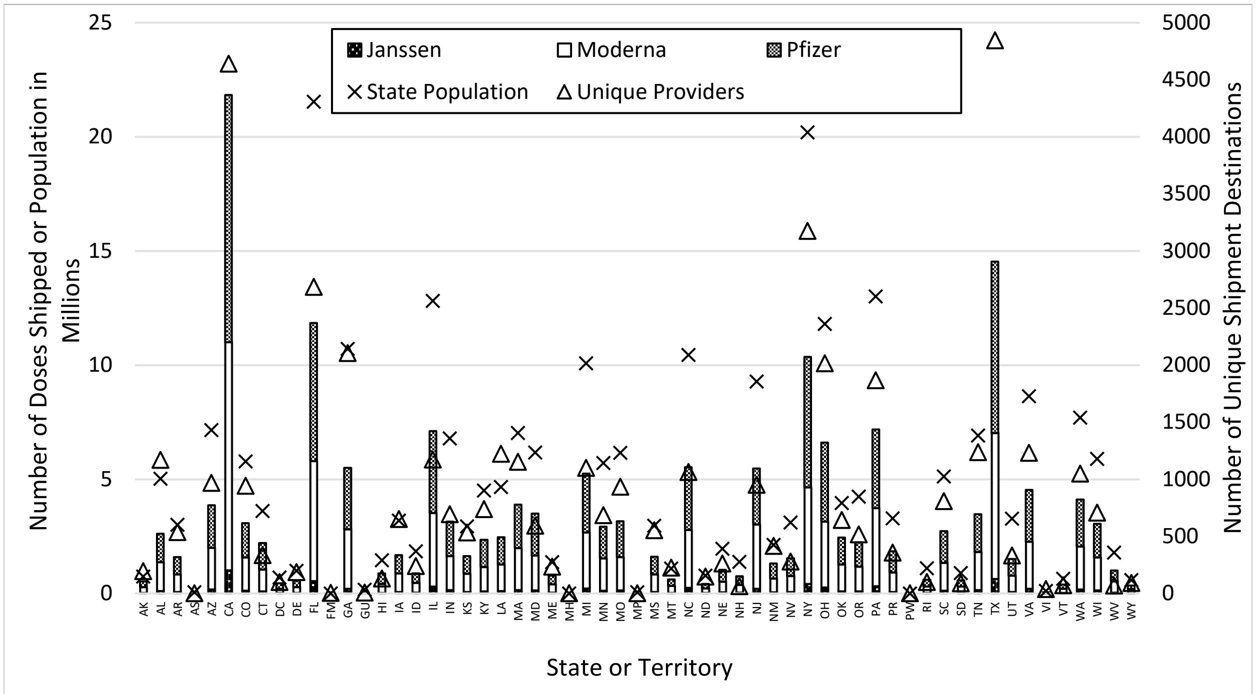

Figure 2. Total number of doses shipped to each state and the number of unique providers: 01/01/2021 – 03/31/2021

While the shipment to jurisdiction data are publicly available, shipment to awardee data are only available through the data we are collecting. Figure 3 shows the total number of vaccine doses from each manufacturer shipped to non-state/territory awardees. Vaccines shipped to a non-state awardee, e.g., Bureau of Prisons, are not counted in those shipped to the state (as an awardee) where the awardee is located. CVS and Walgreens are the two largest non-state/territory awardees in this period. The pie chart in Figure 3 shows the distribution of the total number of shipped doses among different awardees. Around 76% of vaccine doses were shipped to state or territory awardees, 11% were shipped to either CVS or Walgreens, and the remaining 13% of doses to all other awardees.

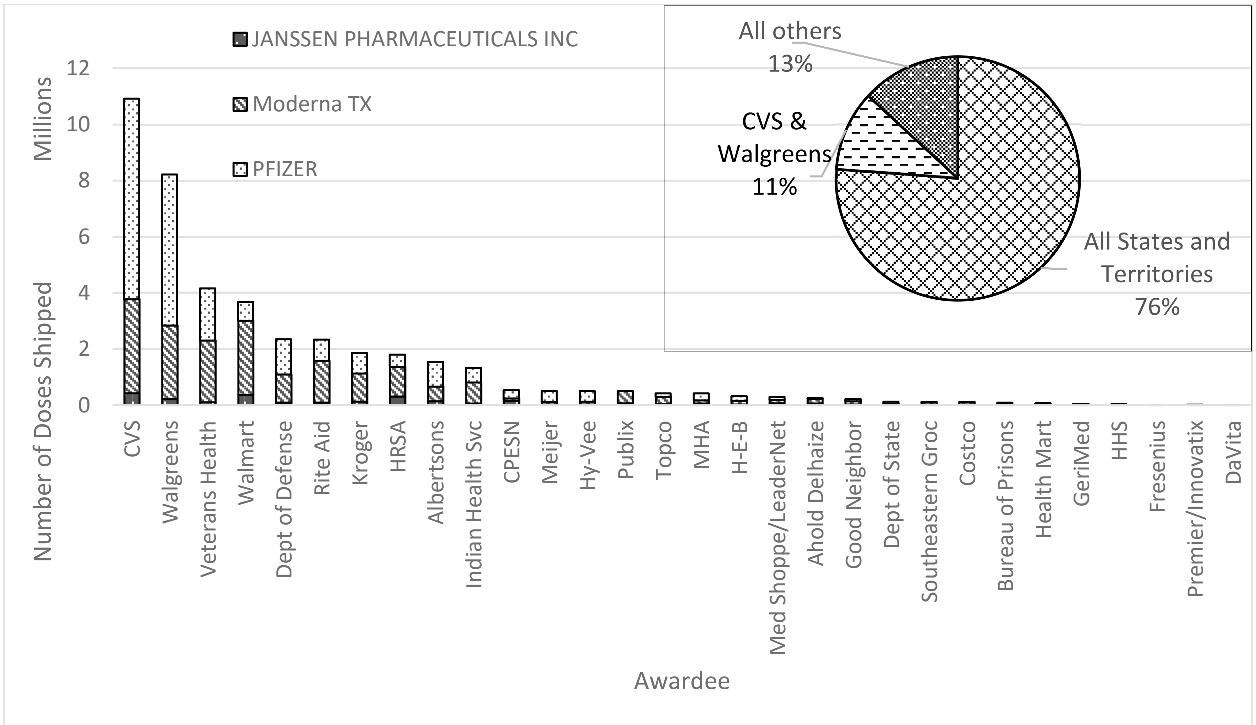

Figure 3. Number of doses shipped to non-state/territory awardees

The shipment data are only available through the dataset presented here. The data show that California, Texas, CVS, Florida, and Walgreens were the top five vaccine awardees that have received 31.6% of total doses in the U.S. Furthermore, CVS, Walgreens, Walmart, Rite Aid, and Kroger are the top five pharmacy/grocery stores that have received 15% of total vaccine doses shipped in the 01/01/2021 – 03/31/2021 period. It is also worthwhile to note that around 45% of total doses were shipped to 10 awardees among a total of 92 awardees.

5.2. Number of doses shipped over time

While the number of doses allocated and shipped to each jurisdiction is publicly available (11), the number of doses shipped to a specific provider, retail pharmacy, zip code, city, or county is not. Our shipment data are very detailed: they show the number of doses shipped to each vaccine provider from each manufacturer over time. Therefore, when combined with the administration data, they can provide the inventory of vaccines at each provider. For instance, Figure 4 shows the number of doses shipped to a hospital in Raleigh, NC. We have combined all three vaccine types in the figure. The data can be further aggregated at different levels to show, for example, the number of vaccines shipped to all hospitals in a city, county, or state; to different CVS stores in a city; to an entire state; or to all recipients in the U.S.

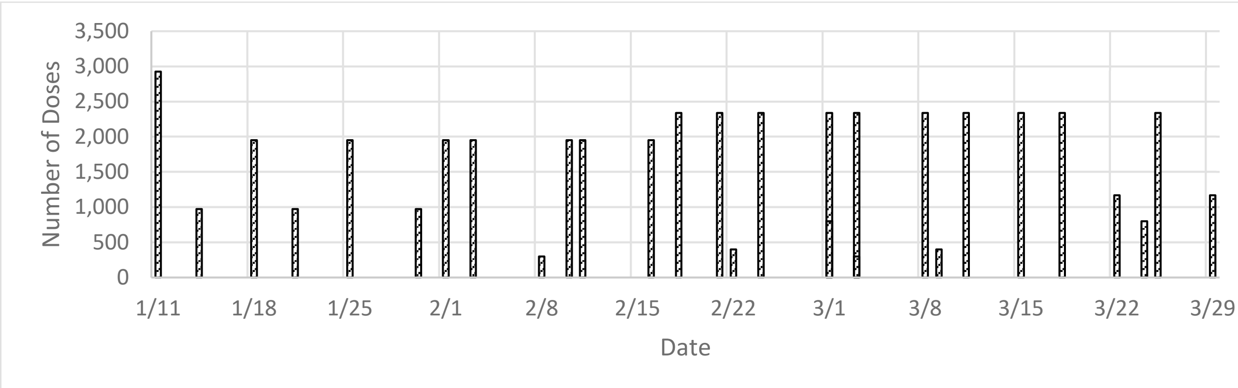

Figure 4. Doses of vaccines shipped to a hospital in Raleigh, NC

For example, Figure 5 shows the number of vaccine doses shipped to ZIP code 27607 in Raleigh, NC, where the hospital is located. While there is a significant variation in the number of doses shipped from one day to another, the average number of shipped doses varies between 1,000 and 3,000, as shown by the seven-day average trend-line. This type of analysis could be expanded to examine geographical access to vaccines over time using the shipment destinations with population data (39).

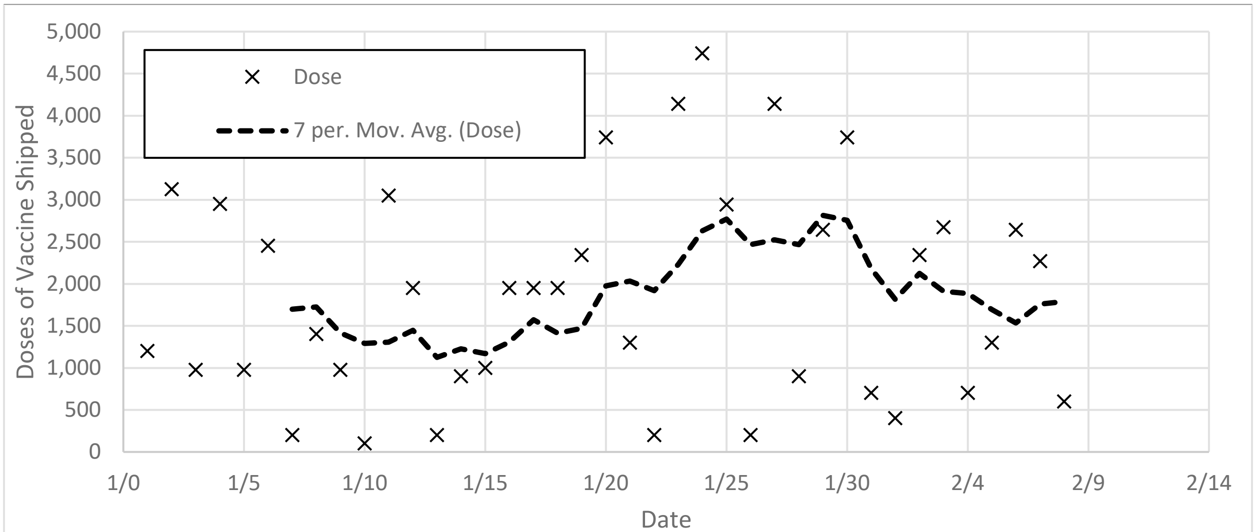

Figure 5. Doses of vaccine shipped to Zip code 27607 in Raleigh, NC containing the hospital shown in Figure 4

As another example, Figure 6 shows the seven-day moving average of the number of doses shipped to California, Texas, and Illinois in the 01/01/2021 – 03/31/2021 period each day. These states are selected to present states with significant populations in the west, south, and Midwest regions. The average number of doses shipped to Illinois follows a steady level, which was the case for many states in Midwest. On the other hand, the seven-day moving average of the number of doses shipped to California and Texas fluctuates over time and shows a significant drop during mid-February. That time period corresponds to a large storm (34). This trend indicates that the shipments were delayed in anticipation of the storm and resumed soon after.

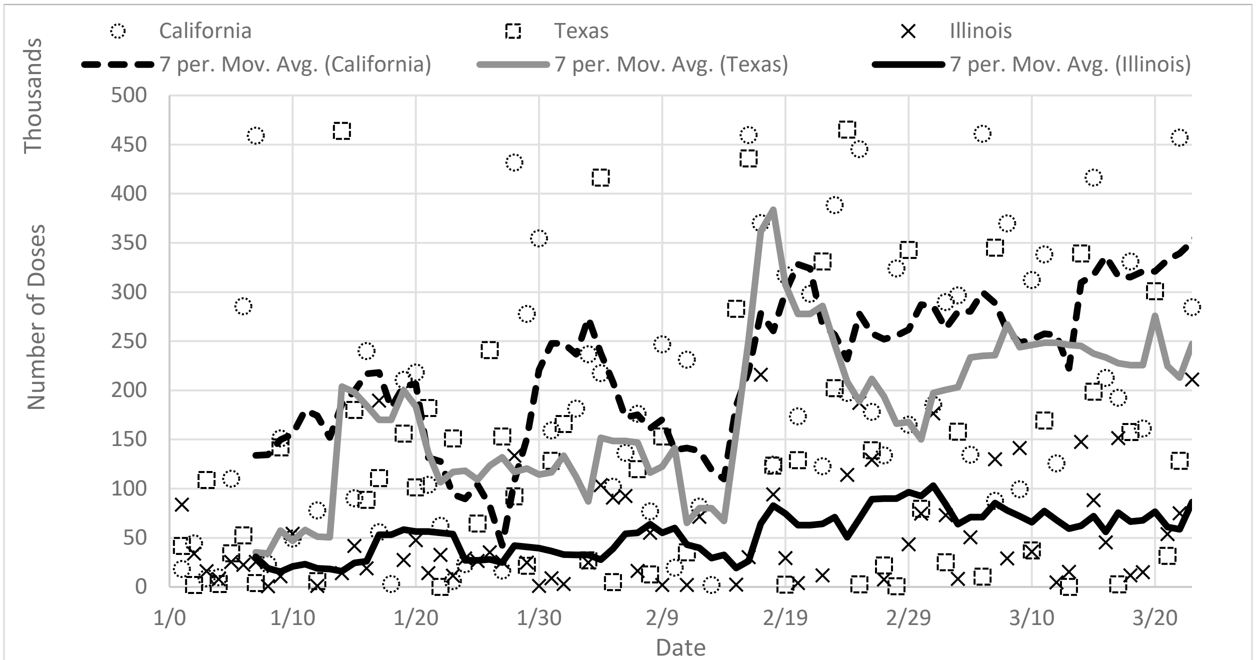

Figure 6. Number of doses shipped over time to CA, TX, and IL

As another example, Figure 7 shows the seven-day moving average of the number of doses shipped to CVS, Walgreens, and Walmart over the same period. The number of doses shipped to CVS and Walgreens follows the same levels except for two periods in late January and late March, where the number of doses shipped to CVS was significantly more than those shipped to Walgreens. Shipment of doses to Walmart started in mid-January and was much lower than the other two awardees until the first week of February and then followed the same levels.

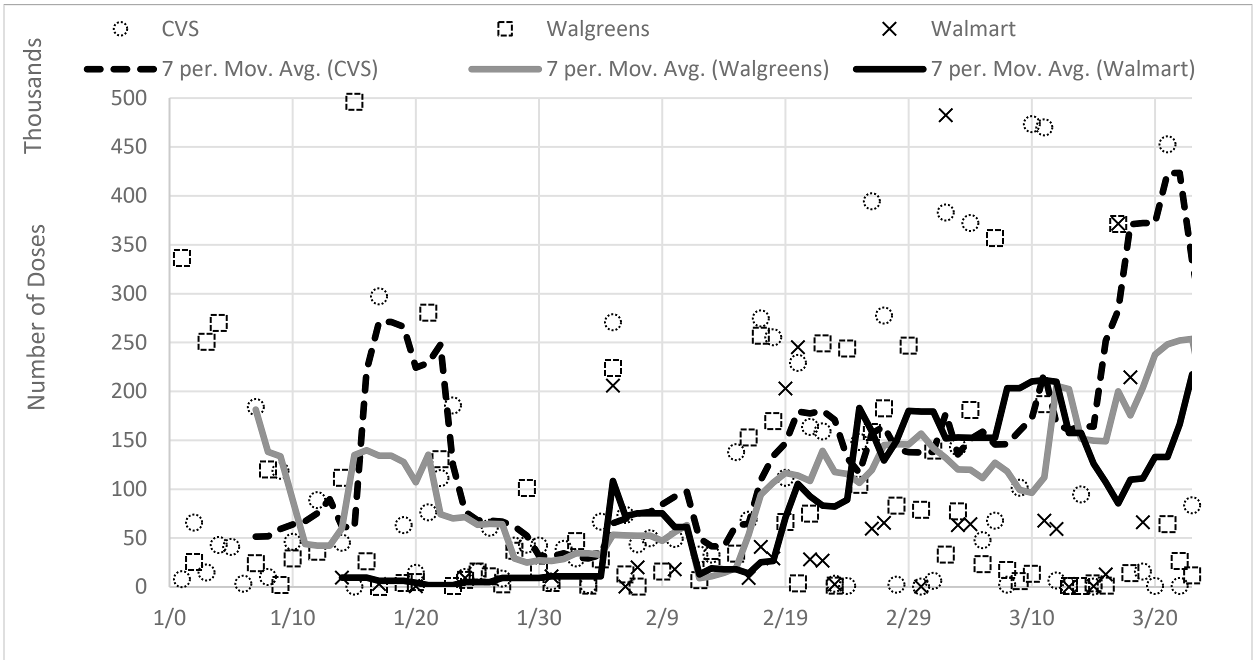

Figure 7. Number of doses shipped over time to CVS, Walgreens, and Walmart

Finally, Figure 8 shows the seven-day moving average of the number of vaccine doses shipped to the Department of Veterans Affairs, Department of Defense, and Bureau of Prisons. In general, these data were not available during the vaccine rollout, e.g., to state jurisdictions.

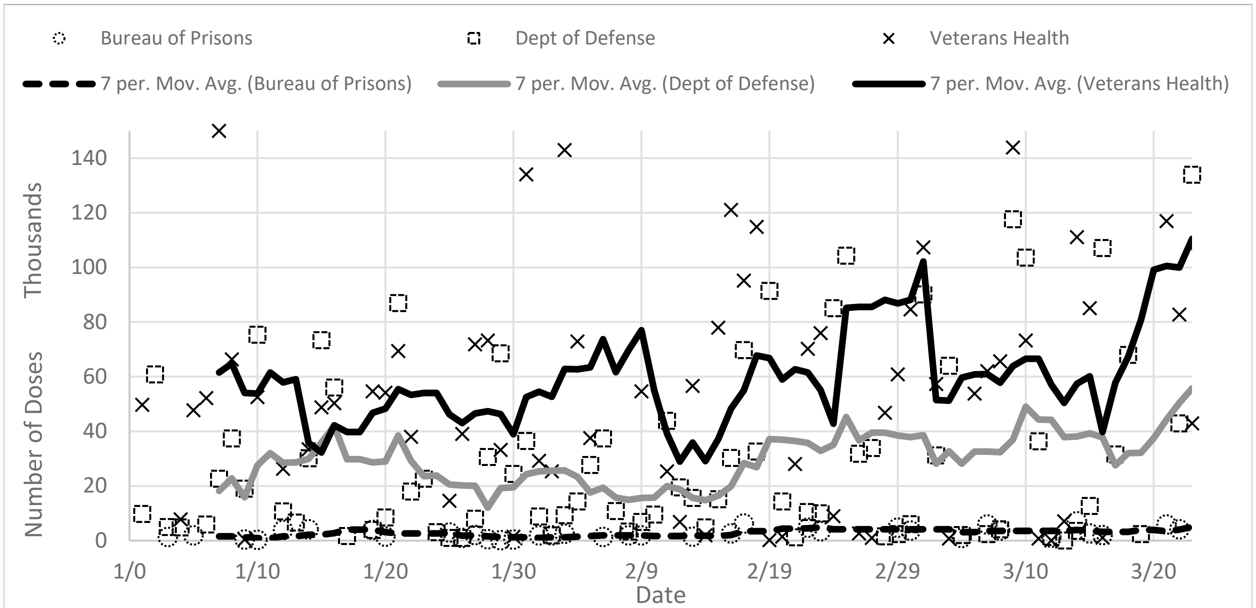

Figure 8. Number of doses shipped over time to the Department of Veterans Affairs, Department of Defense, and Bureau of Prisons

5.3. Vaccine wastage

This section summarizes the vaccine wastage dataset and some relevant sample analyses. The wastage data show the number of doses wasted at each awardee every day. Note that 34 out of 92 awardees have not reported vaccine wastage data. Therefore, the numbers here need to be interpreted cautiously. In addition, the data do not include provider-level details. Such elements can be publicly available through the data we are collecting. Some high-level findings follow. Within the 01/01/2021 – 03/31/2021 period, a total of 179.7 million vaccine doses were shipped, and 182.8 thousand doses were reported as spoiled, which translates to a 0.102% wastage. Note that 0.0241% of Janssen vaccines, 0.0867% of Moderna vaccines, and 0.1221% of Pfizer vaccines were wasted; see Figure 9 (a). This observation is as expected as the Janssen vaccine does not require storage at a cold temperature while the Moderna and Pfizer vaccines do. It is also worth noting that there are many reasons for wastage (8), which are not related to cold chain requirements, such as unused doses after a vial has been opened for administration. Figure 9 (b) and (c) show vaccine wastage at each state/territory and non-state/territory awardee, respectively. Note that awardees with the highest vaccine wastage are shown, given 34 awardees have not reported wastage.

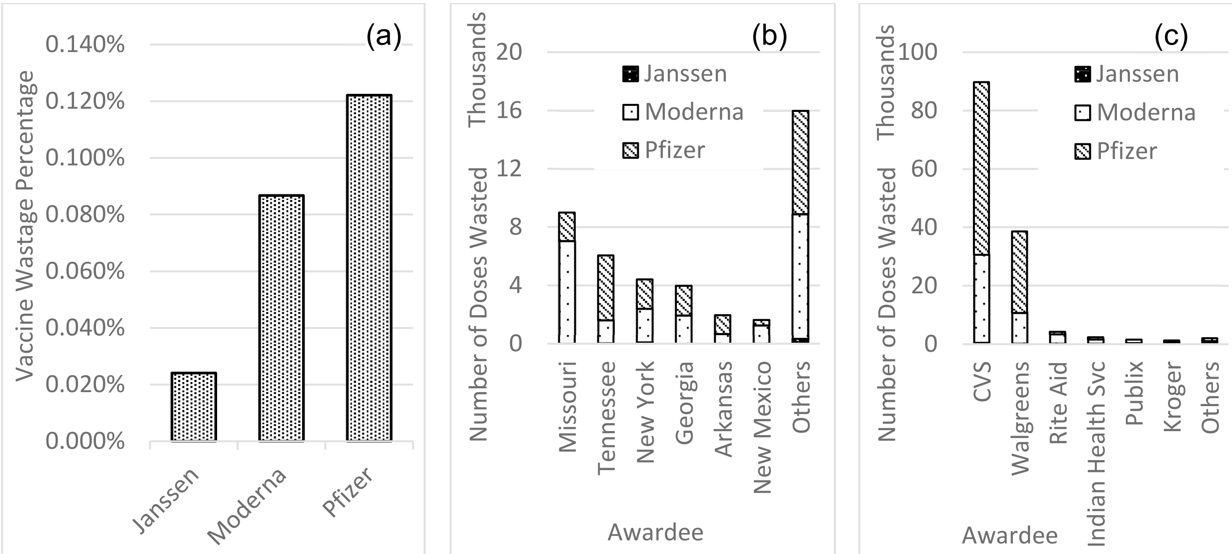

Figure 9. (a) Vaccine wastage with respect to the doses shipped; (b) Number of vaccines wasted at each state/territory awardee; (c) Number of vaccines wasted at each non-state/territory awardee

The highest number of doses spoiled was at CVS and Walgreens; however, note that they have received a considerable number of doses. Six awardees recorded around 83% of wasted vaccines, and the remaining 52 awardees recorded 17% wastage. Figure 10 shows vaccine wastage distribution among different awardee types.

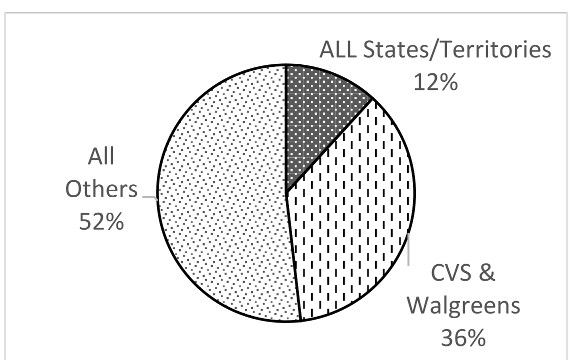

Figure 10. Vaccine wastage distribution

Figure 11 shows the percentage of vaccine spoiled at each awardee with respect to the number of vaccine doses shipped to them. For example, 1.7% of Moderna vaccine doses were wasted in the Virgin Islands, as shown in Figure 11(a). At CVS, 0.1% of Janssen, 0.9% of Moderna, and 0.83% of Pfizer vaccines were wasted, see Figure 11(b). Further analysis of this type of data can reveal patterns, such as relationships with the size of the vial, time period of viability after reaching room temperature, minimum shipment size, and wastage during the start-up of a new vaccine.

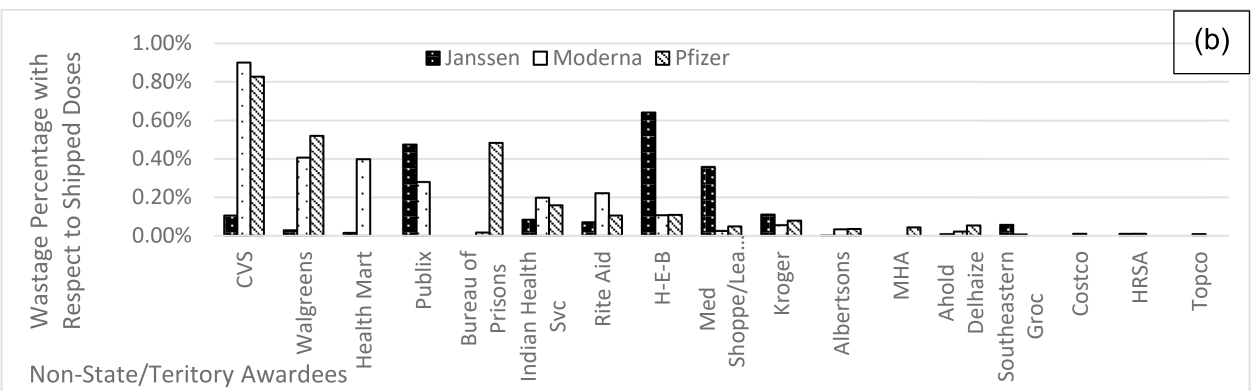

Figure 11. Vaccine wastage to shipment percentage for different awardees: (a) state/territory, (b) non-state/territory

Figure 12 shows the total number of doses shipped by all three manufacturers (on the primary vertical axis) and the total number of doses wasted (on the secondary vertical axis) over time. Note that both axes follow a logarithmic scale. It can be observed that with an increase in the total number of doses shipped, especially after the third week of February, the number of wasted vaccines increases. The trend continues until the last week of March, where a sharp increase in the total number of doses wasted is observed. Further analysis can provide insights on why the wastage occurred, e.g., based on inventory, shipments, demand, or specific programs. Note that the change in shipments in February was not reflected by a similar change in wastage.

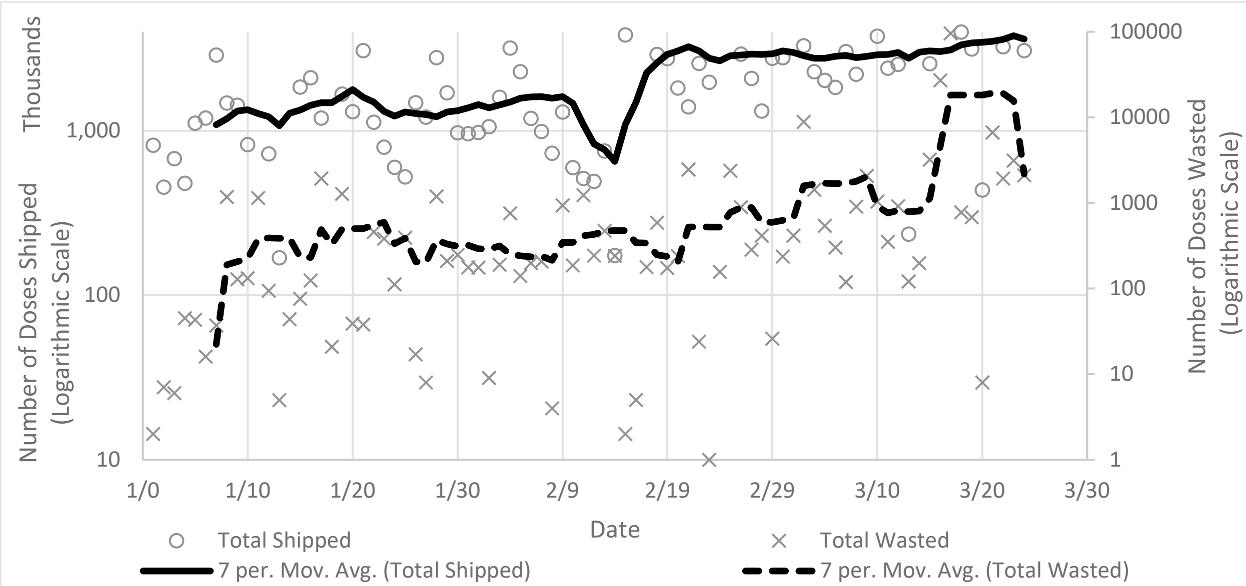

Figure 12. Number of doses shipped and spoiled over time.

6. Conclusion and Future Research

This paper introduces a dataset that is being collected on COVID-19 vaccine distribution in the U.S. and made available to researchers. The data collection effort currently includes shipment location data from January 1, 2021, up to March 31, 2021, with a total of 633,000 records, which are in Excel files, and more will be added to the repository as it becomes available. We describe other datasets related to the COVID-19 pandemic response, which may be combined for additional insights.

A series of high-level analyses are performed based on the collected shipment data. The analysis shows that the vaccine doses and the number of vaccine providers in this period are approximately distributed pro rata according to each state's population. Around 76% of doses are shipped to states and territories, 11% shipped to CVS and Walgreens, and the rest shipped to all other vaccine awardees. A significant jump in the number of shipped doses is observed in the third week of February, sustained throughout the study period. As expected, a higher percentage of Pfizer and Moderna vaccines are wasted. Around 36% of wasted vaccines are spoiled at only two awardees; however, it should be noted that not all awardees have reported their wastage data yet.

The collected data can serve as a building block for many future studies on large-scale, time-window constrained, and capacity-restricted logistical problems. Some future directions are listed here: For instance, daily vaccine distribution data will allow researchers to estimate lead times and potentially predict vaccine availability dates at each vaccination site. Across the data sets described in this paper, a complete picture of the supply chain can be obtained, e.g., the time between allocation and ordering and shipment, the time between shipment and administration of a vaccine, inventory over time, and some aspects of geographical access.

We can estimate the demand and waste accordingly and make recommendations to seamlessly schedule patients and reduce wastage. Additionally, we can incorporate the lead times and other performance measures into stochastic models that establish relationships between resource availability and vaccination capacity and estimate vaccination wait times at different sites. Furthermore, methodologies can be developed for vaccine location and allocation analyses as well as similar large-scale supply chain and emergency response logistics. Such scientific investigations will help further understand the processes and identify the contributing factors that adversely affect the efficiency of vaccination efforts.

This dataset may also be used to explore whether assumptions made in transportation and supply chain models are accurate. For example, in public health (unlike many private industry settings), it may not be possible to determine which customers should be served from which distribution centers. This is particularly relevant for distribution in cities such as Chicago and New York, which received separate allocations. Still, some of their residents may have received vaccines at other locations, or some of their doses may have been used to satisfy the demand of non-residents. This is particularly important if each awardee is assessed based on the doses given per population. Additionally, many interpretations have been made over the vaccination rates in areas based on the social vulnerability of the location (40) or based on income levels. However, at least some of those differences may be realized due to administering vaccines to non-residents. Our data can help demonstrate the extent to which that occurred. On the other hand, private industry is often driven by concerns of efficiency (e.g., cost or speed) or even effectiveness (i.e., giving the right product to the right customer at the right time). For public health, equity is also important. The data, especially when paired with the vaccine administration data by age or race/ethnicity, can help researchers understand the relative trade-offs among those objectives and how shipments corresponded to policy. Other datasets described in the paper could be used to understand the link between pooled waiting lists and time until administration, compared to decentralized waiting lists and appointment times.

The data that we are making available could help understand what distribution systems were associated with higher immunization uptake, as was done for the H1N1 pandemic and vaccine distribution (41,42). We hypothesize that there was not just one or even two systems that were predetermined to be best. Rather, we theorize that the dataset will indicate that several effective types of distribution systems exist and that leadership within the system had a significant impact on the final outcomes. Additionally, decisions during an emergency are often made when significant uncertainty remains, e.g., in demand, supply, or other aspects. One area that may be fruitful is to use the data to understand how jurisdictions or other entities could learn from decisions over time and the extent to which that learning seemed to occur over time during the period studied.

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