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INFORMATION SYSTEMS EDUCATION JOURNAL

Editors

Teaching Case

100 Million Doses in 100 Days: Analyzing the COVID-19 Vaccination Supply Chain

Joseph M. Woodside
joseph.m.woodside@gmail.com
Department of Business Systems and Analytics
Stetson University
DeLand, FL 32723

Abstract

With the impactful nature of the COVID-19 pandemic, this manuscript describes a teaching case for COVID-19 vaccinations to develop students' knowledge of analytics and supply chain management. The experiential learning activity is developed in the context of an undergraduate upper-level course on descriptive analytics and data visualization. The contributions of this teaching case are an experiential learning activity applied to a real-world current event and an experiential learning activity that allows students to apply and develop their course knowledge. The overall case objectives are to assess the 100 million doses in 100 days US vaccination goal capability and offer additional vaccination supply chain insights and recommendations to policymakers based on the analysis. The COVID-19 pandemic can be utilized as a real-world case study for teaching the next generation of analytics leaders and supply chain managers through an applied vaccine distribution and data analysis scenario.

Keywords: COVID-19, Data Analytics, Visual Analytics, Supply Chain Management, Experiential Learning, Teaching Case

1. INTRODUCTION AND OBJECTIVES

In the weeks before entering office in January 2021, US President Biden announced a goal of 100-150 million coronavirus (COVID-19) vaccinations, before finalizing the goal of 100 million vaccinations in the first 100 days in office (Murphy, 2021). During his first press conference on March 25, President Biden announced a new goal of 200 million vaccinations within the first 100 days or by April 29, 2021. As a note, the goal included the total number of vaccinations, both first and second shots, separate from full vaccinations. Each shot contains one dose of the vaccine, and a vial contains several doses of the vaccine varying by the manufacturer (Murphy, 2021). In addition, the comprehensive strategy outlined plans to expand the number of vaccine locations, increase resources, and make all adults in the US eligible for vaccination by May 1st (The White House, 2021).

The availability of the COVID-19 vaccine was a significant milestone, however global healthcare systems were faced with the complex task of securing, distributing, and administering the vaccines. This included ordering a sufficient number of vaccines and supplies, safely transporting to potentially thousands of locations, storing at the necessary temperatures, and end-to-end tracking to ensure integrity and quality. While other vaccines have been successfully distributed in the past, the COVID-19 vaccine was different in terms of the magnitude of scale to immediately provide the number of vaccines to all people that wished to be vaccinated, and had impacts on global health and economic wellness, requiring a fast and efficient supply chain at each stage (Foster & Liddell, 2020; CDC, 2021).

In early 2021 the US lagged other countries in vaccinations, and the increasing number of COVID-19 cases put additional pressure on policymakers to ensure vaccinations could be

distributed and administered as soon as possible (Barnhill, 2021). Potential supply chain issues included national security issues, shortages of personnel and supplies, limited coordination and capacity, vaccine damage and cold storage requirements, rural administration gaps, and misinformation. Security issues involved transfer points at each stage of the supply chain, with possible risks of theft, sabotage, and counterfeiting (Barnhill, 2021). The overall objectives for this case are to determine whether the 100 million goal will be met by May 1st and to offer insights and recommendations to improve the vaccine supply chain.

2. BACKGROUND

COVID-19 Global Supply Chain Management
COVID-19 vaccines have been developed at a significant pace, however, limitations in the global supply chain could halt this momentum and further contribute to economic losses and loss of life. At the end of 2020, the primary issue was how to deliver the vaccine efficiently and equitably to over 300 million Americans. Various supply chain management challenges included procuring raw materials, manufacturing capacity, cold storage requirements, patient preferences, social distancing requirements, 360-degree supply chain view capabilities, and advanced analytics for predicting demand (Young, Chane & Isgur, 2020; Yadav & Weintraub, 2021). The COVID-19 pandemic caused a major market shock across all industries with significant impacts and disruptions to the global supply chain, both to upstream suppliers and downstream customers with supply shortages and overages (Sherman, 2020; Woodside, 2020). The World Health Organization (WHO) declared COVID-19 a global pandemic, which spread with high velocity reaching 199 countries and territories around the world. At various points, 40% of the world population was under lockdown to reduce virus transmission, and these mass disruptions resulted in the closure of businesses and related impacts to supply chain activities (Gupta, 2020; Woodside, 2020).

As a comparison, during the 2009-2010 H1N1 pandemic, the initial consumer demand for the H1N1 vaccine exceeded supply due to an inefficient supply chain, and later many doses were returned as demand waned. To achieve COVID-19 herd immunity in the US an estimated 230 million people or 460 million doses would be required, if a two-shot dose were administered. Under ideal conditions from prior H1N1 modeling, herd immunity could have been reached in 237 days, however, due to supply chain inefficiencies and failures, herd immunity was delayed by approximately 100 days. With the COVID-19 pandemic, a similar delay may result in tens of thousands of lives lost (Young, Chane & Isgur, 2020).

Outside of the US, global vaccinations experienced several challenges, with the European Union (EU) and other countries having missed early vaccination goals by the European Commission. These goals included vaccinating 80 percent of people over the age of 80 and vaccinating 70 percent of the adult population by summer 2021. Identified causes for the delay included the delivery of millions of doses less than projected, countries pausing doses amid potential safety concerns, and countries holding onto additional doses (Deutsch and Hirsch, 2021). For example, the US had purchased more doses of vaccination than needed, and additional pressure was being applied to distribute excess vaccines globally where there was the greatest demand. Otherwise, according to US Treasury Secretary Janet Yellen, global cases could lead to increased inequality and be damaging to the US (Liptak, Atwood, & Alvarez, 2021).

Vaccine Manufacturers and Supply Chains
A successful supply chain is dependent on the relationships between suppliers and customers. Supply Chain Management (SCM) involves the planning and management of all items related to sourcing, procurement, production, logistics, and combining people, processes, and information (Sacristan-Diaz, Garrido-Vega, and Moyano-Fuentes, 2018). Supply chains flow from the upstream supplier of materials to the downstream customer distribution and are often complex and span multiple countries (Choudary, 2020). The supply chains developed by the leading vaccine manufacturers Pfizer, AstraZeneca, Moderna, Johnson & Johnson, and Novavax are described further by type, partners, manufacturing locations, price, dosing, and efficacy (Kansteiner & Sagonowsky, 2021; Terry, 2021).

Pfizer
Pfizer was the first manufacturer to receive US Food and Drug Administration (FDA) emergency use authorization (EUA) at the end of 2020. Pfizer partnered with BioNTech, Novartis, and Sanofi to increase manufacturing to produce 2 billion doses in 2021. Pfizer's US supply chain begins in St. Louis where the raw materials are made and plasmid DNA is produced. From there a site in Andover, MA produces and purifies the messenger RNA (mRNA) drug substance. After shipping the substance to Kalamazoo, MI, mRNA drug substances and materials are used to create

and transfer the vaccine into vials. Before distribution, the vials are inspected, labeled, and packaged. Similarly, Pfizer's additional sites in Belgium, Germany, and Austria, create the vaccine, fill, and packages vials. Vials must be stored in freezers and dry ice, and Global Positioning System (GPS) temperature monitors are added to the crates during shipping. The production plant in Germany is projected to produce 750 million doses annually. In addition, Sanofi who is also working on a vaccine candidate, partnered with Pfizer to produce 100 million doses for Europe in 2021 from their Frankfurt, Germany site with the first doses beginning in August 2021. Novartis is also partnering with Pfizer from their site in Stein, Switzerland to fill vials and assist with shipments of bulk mRNA at their site in Stein, Switzerland, for global distribution beginning in the 3rd quarter of 2021 (Kansteiner & Sagonowsky, 2021).

AstraZeneca

AstraZeneca set a goal of 3 billion doses delivered by the end of 2021. To achieve this goal, AstraZeneca planned production within 15 countries and 25 manufacturing locations. Within the US, AstraZeneca's vaccines are produced in Maryland by Emergent BioSolutions and filled and packaged in Ohio. In Europe, partners Halix in the Netherlands, Novasep in Belgium, and CDMO IDT Biologika in Germany are producing the vaccine, filling, and finishing. However, AstraZeneca's complex supply chain in Europe has caused a production shortfall during its initial rollout. AstraZeneca also partnered with Serum Institute of India to supply 1 billion doses internationally, and R-Pharm in Russia to supply the Commonwealth of Independent States which includes Russia, the Middle East, and the Balkans. Additional licensing has been completed with Fiocruz in Brazil and BioKangtai in China, with 150-250 million doses to be made in Mexico and Argentina in 2021 (Kansteiner & Sagonowsky, 2021).

Moderna

Moderna was the second mRNA vaccine to receive FDA emergency use authorization in December 2020. Moderna has set up 5 partners for global manufacturing and plans to deliver over 2 billion doses in the next two years, with 700 million doses in 2021 and 1.4 billion doses in 2022. Moderna collaborated with Lonza in Switzerland to scale the program and partnered with Catalent in Indiana for fill-finish to deliver 100 million doses in the US which was later expanded to 300 million doses. Moderna will produce the majority of vaccines in Massachusetts, with additional Lonza locations in New Hampshire and Switzerland. For international delivery, Moderna is working with Kuehne+Nagel a global logistics company (Kansteiner & Sagonowsky, 2021).

Johnson & Johnson

Johnson & Johnson (J&J) received FDA emergency use authorization in 2021 for their one-dose shot. J&J planned to produce 1 billion doses in 2021 with several partners including global companies Merck and Sanofi to improve supply. Partners include Leiden in the Netherlands, Emergent Biosolutions, Catalant, Aspen Pharmacare in Africa, Reig Jofre in Spain, Biological E in India, and Grand River Aseptic Manufacturing in the US and Europe. J&J develops the vaccine in several stages, through raw materials, converting these substances into batches of vaccines, and sending them to fill-finish sites for packaging and distribution (Kansteiner & Sagonowsky, 2021).

Novavax

Novavax secured a $1.6 billion Operation Warp speed deal and planned an FDA emergency use authorization in May. Novavax set a goal to generate 2 billion doses in 2021 through facilities in Maryland, Sweden, and the Czech Republic. The company has also partnered with AGC Biologies and Takeda in Japan, Biofabri in Spain, SK Bioscience in Korea, Serum Institute in India, and Polypeptide Group in Sweden. The partnerships were established to improve scale and vaccine component production at facilities in the US, Denmark, and Sweden (Kansteiner & Sagonowsky, 2021).

Supply Chain Challenges and Scenarios

There have been many challenges to successfully manufacturing and distributing the COVID-19 vaccines including last-mile delivery, temperature-controlled storage, manufacturing, organizational and regulatory coordination (Alam, Ahmed, Ali, Sarker, Kabier, & ul-Islam, 2021; Runde, Savoy, & Staguh, 2021). Actual supply chain scenarios and issues have been included below to consider for reflection, discussion, and recommendations. One of the most critical issues identified during COVID-19 manufacturing was the availability of raw materials including sodium chloride, tubing, and vials, with estimated deliveries for some materials forecasted up to 15 months (Dakin, 2021). In 2020, Pfizer announced that it was only able to ship half of the vaccines originally planned, with a decrease from 100 million to 50 million, due to supply chain constraints with raw materials (Paris, 2021). Another potential issue was the availability of personnel, requiring additional remote workers and training to support new manufacturing

processes (Dakin, 2021). Global coordination also proved problematic. In June 2021, responding to the second wave of COVID-19 and difficulty obtaining raw materials, India banned COVID-19 exports to focus on domestic vaccinations. At the time of the ban, India was the largest global manufacturer of COVID-19 vaccines, supplying both AstraZeneca and J&J. Similarly, other countries including the US imposed export bans on raw materials relating to COVID-19 production (GlobalData Healthcare, 2021). Even once manufactured, quality issues affected vaccine distribution. At the end of March 2021 J&J released information that a batch of the COVID-19 vaccine, upwards of 15 million doses produced by Emergent Biosolutions did not proceed to the fill and package vials stage as a result of a quality review (Nadeem, Anilkumar, & Adler, 2021).

3. SUPPLY CHAIN DISTRIBUTION DATASET

Your first objective is to compile a dataset with COVID-19 Vaccine Distribution Allocations by Jurisdiction. The dataset manufacturers include Moderna, Pfizer, and Janssen (J&J). The data is available in the public US Domain through the Centers for Disease Control (CDC) website data.cdc.gov. The columns in the dataset are shown in Table 1 (HHS ASPA, 2021a; HHS ASPA, 2021b; HHS ASPA, 2021c). Data should be collected through the first quarter of 2021 or the Week of Allocations on March 29, 2021. Alternatively, your instructor may provide you with an available data file. The COVID-19 vaccinations began on December 14, 2020. Shipments of the FDA-authorized COVID-19 vaccine arrive at various locations across the US. Jurisdictions receive first and second doses at the same time to optimize transportation logistics. Weekly vaccination dose allocations are posted each week on Tuesdays, and on Thursdays, states can order doses from that week's allocation of first doses. Based on the manufacturer, two weeks for Pfizer or three weeks for Moderna from the following Sunday, states can order doses from that week's allocation of second doses. Following vaccination doses ordering, shipment begins on Monday, and orders may arrive throughout the week vs. a single shipment (CDC, 2021).

Table 1: COVID-19 Vaccine Supply Chain Distribution Dataset

Column Name	Column Description	Data Type
Jurisdiction	City, State, or Territory	Text
Week of Allocations	The week that vaccines are allocated to a jurisdiction	Date & Time
1st Dose Allocations	Number of 1st dose allocations that a jurisdiction can order from	Number
2nd Dose Allocations	Number of 2nd dose allocations that a jurisdiction can order from	Number

4. SUPPLY CHAIN AND ANALYTICS EXPERIENTIAL LEARNING ACTIVITY

The experiential learning activity (ELA) can be completed through the visual analytics platform Tableau or any equivalent visual analytics platform may be utilized (Tableau, 2021). Visual supply chain analytics through graphs, charts, dashboards, and other methods can augment and enhance the decision-making processes of supply chain managers uncovering patterns and generating insights (Park, Bellamy, and Basole, 2016; IBM, 2021). The discussion questions and initial tasks are formatted similarly to prior student competition datasets (Willden, 2021). An ELA template has been provided in the Appendix following a repeatable analytics process (Woodside, 2016). The steps and objectives are listed within the template including developing a dataset, developing a set of data visualizations following best design practices, providing a summary of findings insights, and recommendations following the analysis.

Discussion Questions

Your initial task is to reflect on and answer the following discussion questions. In your discussion response, consider potential supply chain scenarios and issues, and offer additional vaccination supply chain insights and recommendations to policymakers.

1. How many total first dose and second dose vaccinations have been allocated to all states?
2. Which 3 states have the most first dose vaccinations allocated? What would you recommend for future allocations?
3. What is the total number of vaccinations distributed for the week of 2/1/21 by vaccine manufacturer?
4. Create an animation by week for the allocations by vaccine manufacturer. Are there any significant changes by week? (Tableau hint: click Format-> Animations to enable, drag Week dimension to Pages card)
5. Predict the total # First Dose Vaccinations by May 1st. Will the goals of 100 million and 200

million vaccinations be possible based on the supply chain distributions by May 1st?
6. To further connect your knowledge, what lessons were learned and how can you apply this knowledge to current or future events?

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Appendix

Appendix A: COVID-19 Vaccine Manufacturers

Manufacturer	Pfizer	AstraZeneca	Moderna	Johnson & Johnson (Janssen)	Novavax
Type	mRNA	Adenovirus-based	mRNA	Adenovirus-based	Protein-based
FDA EUA	12/11/2020	Est. Spring 2021	12/18/2020	2/27/2021	Est. Spring 2021
Key Partners	BioNTech, Novartis, Sanofi	Oxford University, Halix, Novasep, Biologika, Serum Institute, R-Pharm, Fiocruz, BioKangtai	Lonza, Catalent, Keuhne+Nagel	Leiden, Emergent Biosolutions, Catalant, Aspen Pharmacare, Reig Jofre, Biological E, Grand River Aseptic Manufacturing	AGC Biologies, Takeda, Biofabri, SK Bioscience, Serum Institute, Polypeptide Group
2021 Production Estimate	2 billion doses	3 billion doses	700 million doses	1 billion doses	2 billion doses
Manufacturing and Supply Chain Locations	US, Belgium, Germany, Austria, Switzerland	US, Netherlands, Belgium, Germany, India, Russia, Mexico, Argentina	US, Switzerland	US, Netherlands, Africa, Spain, India, Europe	US, Sweden, Czech Republic, Denmark
Dosing	2 doses, 21 days apart	2 doses, 28 days apart	2 doses, 28 days apart	1 dose	2 doses, 21 days apart
Price Charged (may vary by location/volume)	$19.50 per dose	$2.15-$5.25 per dose	$25-$37 per dose	$10 per dose	$16 per dose
Efficacy	95%	70%	95%	66%-72%	89%

Appendix B: Experiential Learning Activity Template

Experiential Learning Activity

Name

- ELA Aligned Learning Outcomes:

Learning Outcomes	
1. Written Communication	✓
2. Information Fluency	✓
3. Tools and Techniques	✓
4. Critical and Analytical Thinking	✓
5. Global Decision Making	✓
6. Ethical Reasoning	✓
7. Personal and Social Responsibility	✓
8. Integration of Learning	✓

- Employer-Valued Knowledge, Skills, and Abilities (KSAs) Gained:
    - Knowledge of Data Visualization

- Knowledge of Business Reports
- Skilled in Developing Dashboard Visualizations
- Skilled in Knowledge Delivery
- Skilled in Tableau
- Ability to analyze supply chain data to generate insights and recommendations
- Ability to select appropriate data and information visualizations

Title: CDC COVID-19 Vaccine Distributions
Description:

- Review and develop a CDC dataset
- Develop a set of data visualizations in Tableau Desktop following best design practices
- Utilize the Data Viz Story template to complete each section
- Provide an overall summary of findings, insights, and recommendations following the analysis
- Upload responses to the Learning Management System (LMS)

Data Viz Story	
Title:	
Business Opportunity	*Key story message /objectives / goal* *Outline business opportunity / problem*
Data Exploration	*Exploratory data analytics* *Data source(s)* *Data taxonomy: data types, preparation, data dictionary* *Data descriptive statistics*
Model Building and Analytics	*Explanatory data analytics* *Visual analytics* *Data mining taxonomy* *Dashboard design and visuals to support discussion questions:* *1. How many total first dose and second dose vaccinations have been allocated to all states?* *2. Which 3 states have the most first dose vaccinations allocated? What would you recommend for future allocations?* *3. What is the total number of vaccinations distributed for the week of 2/1/21 by vaccine manufacturer?* *4. Create an animation by week for the allocations by vaccine manufacturer, are there any significant changes by week? (Tableau hint: click Format-> Animations to enable, drag Week dimension to Pages card)* *5. Predict the total # First Dose Vaccinations by May 1st. Will the goals of 100 million and 200 million vaccinations be possible based on the supply chain distributions by May 1st?* *6. To further connect your knowledge, what lessons were learned and how can you apply this knowledge to current or future events?*
Operationalization and Deployment	*Potential supply chain scenarios and issues* *Proposed solution, timeline, resources, project plan* *Overall findings, supply chain insights, and recommendations to policymakers*