33rd European Modeling & Simulation Symposium
18th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0029 ISBN 978-88-85741-57-7 © 2021 The Authors.
doi: 10.46354/i3m.2021.emss.036

Discrete event simulation of a drive-through COVID-19 mass vaccination model: senior population prioritization strategies

Anastasia Angelopoulou[1,*] and Sonipriya Paul[1]

[1]Columbus State University, 4225 University Avenue, Columbus, GA, 31907, USA

[*]Corresponding author. Email address: angelopoulou_anastasia@columbusstate.edu

Abstract

The COVID-19 pandemic has disrupted the normal operations of countries around the world, which applied different containment and mitigation policies, such as mask-wearing, social distancing, quarantine, and lockdowns, to limit the spread of the virus. More recent mitigation efforts include vaccination strategies, since various vaccines have been authorized for emergency use for the prevention of COVID-19. In fact, vaccination is one of the best proactive mitigation strategies against the virus spread. Mass vaccination strategies have been undertaken by multiple research and development teams in the past when the public needed to be vaccinated on a large scale due to a pandemic, such as the seasonal flu or H1N1. Drive through vaccination, in particular, is more convenient and safer than walk-in vaccinations in clinics due the nature of the contagious virus. In this paper, we present the implementation of a discrete event simulation model of a drive through clinic for mass vaccinations of patients, while prioritizing the senior population. The simulation output is examined in terms of average waiting time in the queue to get vaccinated, number of patients getting vaccinated per week, and utilization of the medical resources. The results are expected to provide insights into the allocation of medical resources across lanes and prioritization strategies for the senior population to achieve higher vaccination rates, while reducing the waiting time in queue.

Keywords: Discrete Event Simulation; COVID-19; Mass Vaccination; Senior Population; Waiting time.

1. Introduction

The World Health Organization (WHO) declared the rapidly spreading COVID-19 outbreak a pandemic on Wednesday, March 11, 2020. Countries around the world have been applying different containment and mitigation policies, such as mask-wearing, social distancing, quarantine, and lockdowns, to limit the virus spread. Moreover, researchers and medical experts have been working to create vaccine solutions to reduce the spread of the virus.

Vaccination is one of the best proactive mitigation strategies against the virus spread. Another important precautionary measure to protect from the virus is social distancing. However, it is difficult to maintain social distancing in walk-in vaccination centers. Patients, who may have been exposed to or infected by the virus, may come in contact with non-COVID19 patients and lead to increased numbers of infections. Thus, drive-through vaccination efforts have been explored as a safer alternative to minimize contact among individuals getting vaccinated and to lower the risk of virus transmission (Reid, 2010). Mass vaccination drive-through strategies, in particular, have been undertaken by multiple research and development teams in past pandemics, such as the seasonal flu or H1N1, when the public needed to be vaccinated on a large scale (Rega et al., 2010; Rambiah et al., 2010).

Simulation modeling is a useful decision support tool that can assist in designing, refining, planning, and implementing a drive-through mass vaccination clinic. This work presents the implementation of a discrete event simulation model of a drive through clinic for mass vaccinations of patients. The simulation output is examined in terms of average waiting time in the queue to get vaccinated, number of patients getting vaccinated per week, and utilization of the medical resources. The results are expected to provide insights on the allocation of medical resources across vaccination lanes and prioritization strategies for the senior population to achieve higher vaccination rates, while reducing the waiting time in queue.

The remainder of the paper is organized as follows: Section 2 provides a brief description of the literature on the mass vaccination topic as well as recent research projects and their outcomes. Section 3 describes the model development, while Section 4 discusses the results and findings of this research. Finally, Section 5 summarizes the main conclusions of the research along with limitations and directions for future work.

2. State of the art

Mass vaccination strategies are common during pandemics when trying to control infectious diseases. Drive-through mass vaccination is one of the methods used in the past and proposed during the COVID-19 pandemic due to the nature of the communicable disease. According to research findings from the investigation of virus transmissions in indoor spaces (Shen et al., 2020), it can be concluded that individuals are more likely to infect others or become infected with COVID-19 in an indoor space, such as a hospital or clinic, while waiting for hours to get vaccinated. Therefore, in the case of COVID-19, drive-through vaccination sites and clinics are particularly important because people wait in their own vehicles, thus limiting the virus transmission compared to walk-in clinics (Weiss et al., 2010).

Past studies have confirmed that drive-through mass vaccination efforts can be an efficient approach for safe and rapid vaccinations during a pandemic (Reid 2010; Wiggers et al., 2011; Gupta et al., 2013). During the H1N1 outbreak, the Louisville Metro Public Health and Wellness department provided the H1N1 vaccine via the world's largest drive-through clinic. A simulation model was used in designing and implementing the drive-through vaccination clinic (van de Kracht & Heragu, 2020).

In the case of COVID-19, modeling and simulation efforts have also taken place to provide suggestions and help with the proper planning and execution of mass vaccinations. More specifically, researchers have found that, with reasonable processing time and negligible carbon monoxide exposure, drive-through is a feasible and effective alternative to traditional walk-in clinics as they provide faster vaccination under lower disease transmission risks (Asgary et al., 2020; Asgary et al., 2021). Moreover, drive-through facilities with more dispensing lanes can provide higher throughput and prevent traffic overflow onto neighboring streets.

The aim of our research is to implement a discrete event simulation model of a rapid drive-through mass vaccination clinic, while investigating different prioritization strategies for the senior population. The simulation output is examined in terms of average waiting time in the queue to get vaccinated, number of patients getting vaccinated per week (throughput), and utilization of the medical resources. The average time to complete the vaccination consent process as well as the overall time spent in the system are also recorded. The model can be used to investigate the allocation strategies of medical resources across lanes that are necessary to increase the vaccination rates and reduce the waiting times in the queue, while prioritizing the senior population. The vaccination rate, which is the number of people getting vaccinated over a period of time (or throughput) is one of the most important metrics that will capture the effectiveness of the drive-through mass vaccination clinic over the walk-in clinic.

3. Discrete Event Simulation Model

Simulation modeling is an effective way to test different options, assess the outcomes, and take informed decisions when designing, planning, and implementing a COVID-19 mass vaccination drive through clinic. This work uses the Arena simulation software for the development of a pilot DES model that captures the operations of a COVID-19 mass vaccination drive-through clinic. The model can be used to examine different number of lanes and medical resources to achieve higher throughput and lower waiting times.

3.1. Study Design

The simulation model was implemented using the Discrete Event Simulation (DES) method. At the beginning of the simulation, the patients move to the consent counters, where they are handed out a consent form and are asked to fill it. Depending on whether they sign the consent form or not, they are directed to the vaccination lanes or they leave the clinic. If all the queues, have reached capacity, the patients leave the clinic. Otherwise, they move to one of the vaccination lanes. The patients that are directed to the vaccination lanes choose the lane with the lowest number of cars in the queue. In addition, the patients that are older than 65 years old are directed to a priority lane dedicated to the senior population. Once the vaccination lane is selected, the patients receive the vaccine or wait in the queue to get vaccinated, if another vaccination takes place at that time. After the patient is vaccinated, he/she leaves the drive-through clinic.

3.2. Discrete Event Simulation Model Setup

Before simulating the model, the model parameters need to be setup. Figure 1 shows the DES process flow logic of the mass vaccination drive-through clinic.

The input data for the arrival frequencies, rates, consent handout and sign-in times, and vaccination processing times are adopted from past and recent studies on H1N1 and COVID-19 drive-through vaccination clinic simulations (Gupta et al., 2013; Asgary et al., 2020; Wood et al., 2021). The percentage of the population that is older than 65 years old is adopted by a Statista Research Department study and census data in the United States for our simulation study. Table 1 summarizes the data used as input in our simulation model.

Table 1. Input data of DES simulation model.

Parameter	Value	Source
Arrival Schedule	Approximately 5 cars per hour with up to 10 cars per hour arriving around rush hour (12pm)	-
Senior population (older than 65 years)	16.9%	(Statista Research Department, 2021)
Group size	DISC(0.267, 1, 0.672, 2, 0.878, 3, 0.975, 4, 0.996, 5, 1, 6)	(Gupta et al., 2013)
Consent handout	Gamma(4.7, 2.3)	(Gupta et al., 2013)
Consent fill-in	Gamma(4.3, 28)	(Gupta et al., 2013)
Consent percentage	Set to 75% for 12 hours	-
Vaccination time	Gamma(2.4, 70.5)	(Gupta et al., 2013

Patients are generated based on an arrival schedule per 12 hours. Arrivals are assumed independent of one another, and patients are served in the order of arrival in the queue. The group size per vehicle ranges from one to six, with frequencies 0.267, 0.405, 0.206, 0.097, 0.021, and 0.004 respectively (Gupta et al., 2013).

After arrival, the patients move to the consent form process. The consent service times for hand-out and fill-in are modeled using the gamma distribution with parameters (alpha, beta) as (4.7, 2.3) and (4.3, 28) seconds, respectively (Gupta et al., 2013). half of those. We set up two thirds (75%) of the scheduled patients to sign the consent form.

Once the consent form is signed, if the capacity of all queues has reached the limit (25 cars per lane), the patients are assumed to be rescheduled for another day and leave the clinic without getting vaccinated. If there is an empty spot, the vaccination process takes place with service time Gamma(2.4, 70.5) seconds (Gupta et al., 2013). The senior population is directed to the senior vaccination lane, while the rest of the patients to one of the regular vaccination lanes. Initially, the clinic is staffed with two receptionists that administer the consent forms and three doctors and nurses assigned to each of the vaccination lanes (two regular lanes and one senior lane). Different scenarios are then simulated for the allocation of medical resources across lanes and prioritization strategies for the senior population. After the vaccination process is completed, the patients leave the system.

The simulation of the drive-through clinic has been set up to operate 12 hours a day for a length of a week. Statistics are recorded for patients that completed the vaccination as well as for the medical staff. To guarantee stochasticity in our model, the number of replications is set to 20.

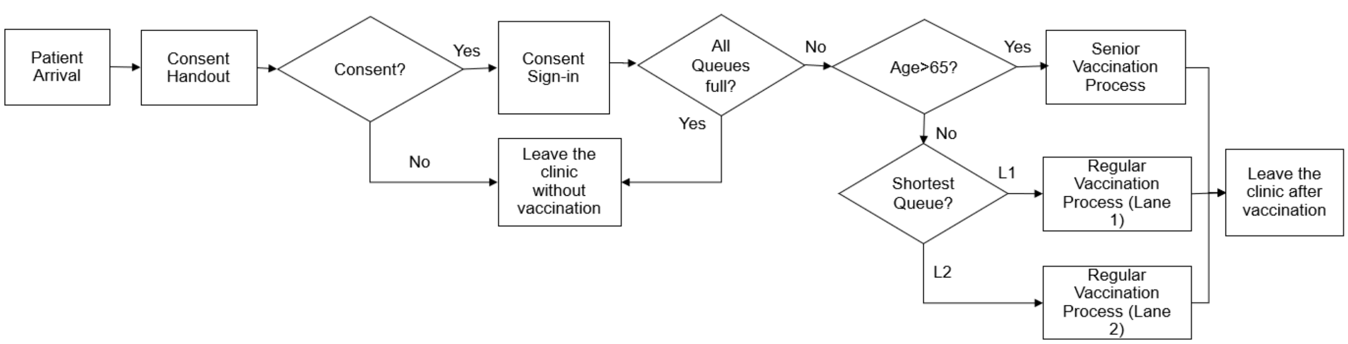

Figure 1. DES process flow logic of the mass vaccination drive-through clinic.

4. Results and Discussion

This section describes the different scenarios that were conducted to improve the system's performance. The scenarios involve different allocations of medical resources across lanes and prioritization strategies for the senior population.

Scenario 1: Two medical staff serve only the regular vaccination lane and a third medical resource to serve the senior population

In this scenario, one of three available doctors and nurses is assigned to the senior lane and only serves the senior population in this lane. The results for this scenario are summarized in Table 2.

Table 2. Results for simulation Scenario 1.

Parameter	Value	Units
Average Wait Time in Regular Lane 1	3.47	minutes
Average Wait Time in Regular Lane 2	6.58	minutes
Average Wait Time in Senior Lane	0.56	minutes
Average Wait Time in Consent Fill-In Queue	3.96	minutes
Average Utilization of Regular Lane Resource	80.8%	-
Average Utilization of Senior Lane Resource	32.8%	-
Average Wait Time	9.75	minutes
Throughput		-
Total Time in System (Regular)	17.32	minutes
Total Time in System (Senior)	13.39	minutes
Average Total Time in System	16.66	minutes

Scenario 2: One medical resource serves the senior population but can serve the regular vaccination lane along with the two other medical staff, if the senior lane is empty

In this scenario, the doctor or nurse who is assigned to the senior lane can serve other patients, if no patients are waiting in the senior lane. To implement this, we used a resource set and applied the Preferred Order selection rule when seizing a resource. The results for this scenario are summarized in Table 3.

Table 3. Results for simulation Scenario 2.

Parameter	Value	Units
Average Wait Time in Regular Lane 1	0.13	minutes
Average Wait Time in Regular Lane 2	0.96	minutes
Average Wait Time in Senior Lane	1.31	minutes
Average Wait Time in Consent Fill-In Queue	3.96	minutes
Average Utilization of Regular Lane Resource	63%	-
Average Utilization of Senior Lane Resource	66%	-
Average Wait Time	7.15	minutes
Throughput	4,622	-
Total Time in System (Regular)	13.04	minutes
Total Time in System (Senior)	14.22	minutes
Average Total Time in System	13.24	minutes

Scenario 3: The three medical resources can serve any lane but priority is given to the senior population

In this scenario, the three doctors and nurses serve any lane with priority to the senior population. To implement this, we used two resource sets and applied the Preferred Order selection rule when seizing a resource. The results for this scenario are summarized in Table 4.

Table 4. Results for simulation Scenario 3.

Parameter	Value	Units
Average Wait Time in Regular Lane 1	0.17	minutes
Average Wait Time in Regular Lane 2	0.73	minutes
Average Wait Time in Senior Lane	0.11	minutes
Average Wait Time in Consent Fill-In Queue	4.17	minutes
Average Utilization of Regular Lane Resource	67%	-
Average Utilization of Senior Lane Resource	60%	-
Average Wait Time	7.31	minutes
Throughput	4.652	-
Total Time in System (Regular)	13.35	minutes
Total Time in System (Senior)	13.46	minutes
Average Total Time in System	13.37	minutes

To identify the "best" scenario among the three scenarios, we used Arena Process Analyzer. The best scenarios for Total Time in System (TIS) are highlighted in red and illustrated in Figures 2(a)-(c).

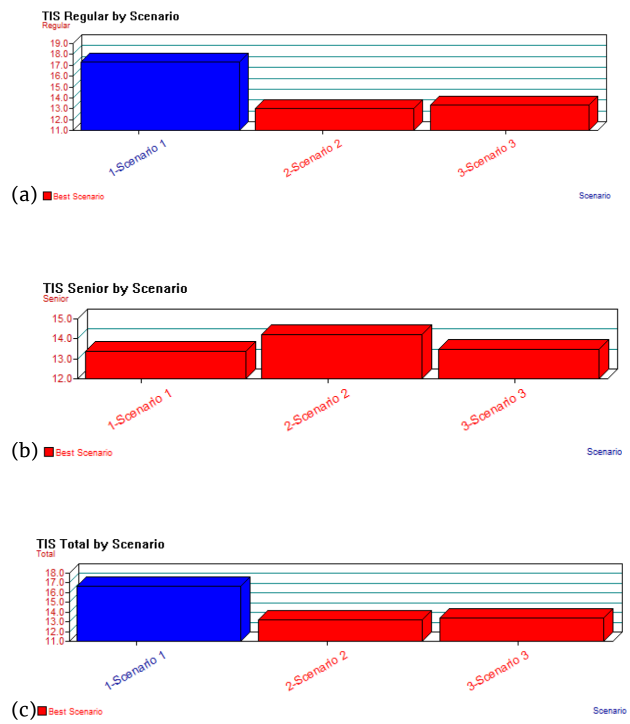

Figure 2. Best scenarios in terms of TIS for (a) regular patients, (b) senior patients, and (c) all patients

The results indicate that scenarios 2 and 3 are better than scenario 1 in terms of total time in system for the patients. Moreover, scenario 3 is the best in terms of average waiting time in each lane, as depicted in Figure 3.

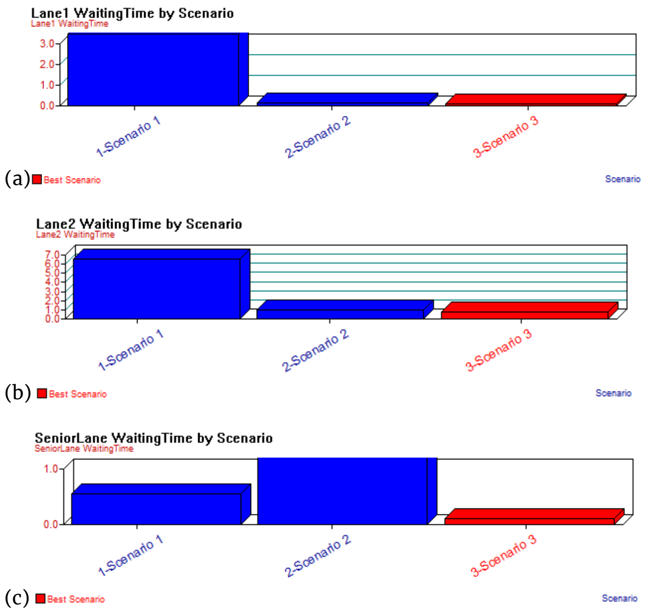

Figure 3. Best scenarios in terms of waiting time for (a) regular patients in lane 1, (b) regular patients in lane 2, and (c) senior patients

Therefore, we recommend scenario 3 that allocates the medical staff to any lane but prioritizes seniors. This scenario would provide the lowest waiting time in queue, lowest total time in system, and higher vaccination rate.

5. Conclusions

This paper presented the implementation of a DES simulation for mass vaccination for prioritizing the senior population. The model was used to investigate different medical staff allocation scenarios and prioritization of senior patients who are over 65 years old.

Three different scenarios were compared in terms of waiting time in the queue to get vaccinated, total time in system, and throughput for regular and senior patients as well as all the patients. The recommended configuration is the allocation of doctors and nurses to any vaccination lanes while prioritizing the senior patients.

It should be noted that additional considerations must be taken into account when interpreting the simulation results. For example, facilities are assumed to be staffed with the appropriately skilled personnel, including immunization, nursing, logistics, and security, among others. Moreover, weather conditions and traffic in neighboring streets are assumed to be normal and no overflow is present. Attention must be paid to the safety and security issues related to the traffic, the drivers' behaviors, and extreme weather conditions. Hence, large drive-through clinics may need to be supported by local emergency services such as police, fire, and paramedics (Asgary et al., 2010).

Future work will investigate the development of a hybrid model combining the DES and Agent-based modeling (ABM) paradigms. The hybrid model will be explored as an approach to capture the patient and medical staff behavior and other traffic- and weather-related patterns during the consent and vaccination processes in a more realistic manner (Mykoniatis, 2015; Mykoniatis and Angelopoulou 2020).

References

Asgary, A., Najafabadi, M. M., Karsseboom, R., & Wu, J. (2020, December). A drive-through simulation tool for mass vaccination during COVID-19 pandemic. In *Healthcare* (Vol. 8, No. 4, p. 469). Multidisciplinary Digital Publishing Institute.

Asgary, A., Valtchev, S. Z., Chen, M., Najafabadi, M. M., & Wu, J. (2021). Artificial Intelligence Model of Drive-Through Vaccination Simulation. *International journal of environmental research and public health*, *18*(1), 268.

Gupta, A., Evans, G. W., & Heragu, S. S. (2013). Simulation and optimization modeling for drive-through mass vaccination–A generalized approach. *Simulation modelling practice and theory*, *37*, 99-106.

Mykoniatis, K. (2015). A Generic Framework For Multi-Method Modeling and Simulation of Complex Systems Using Discrete Event, System Dynamics and Agent Based Approaches.

Mykoniatis, K., & Angelopoulou, A. (2020). A modeling framework for the application of multi-paradigm simulation methods. SIMULATION, 96(1), 55-73.

Rambhia, K. J., Watson, M., Sell, T. K., Waldhorn, R., & Toner, E. (2010). Mass vaccination for the 2009 H1N1 pandemic: approaches, challenges, and recommendations. *Biosecurity and bioterrorism: biodefense strategy, practice, and science*, *8*(4), 321-330.

Reid, D. E. (2010). *What are the Efficiencies of a Mass Vaccination Drive-through Clinic Compared to a Walk-in Clinic?*. National Fire Academy.

Rega, P., Bork, C., Chen, Y., Woodson, D., Hogue, P., & Batten, S. (2010). Using an H1N1 vaccination drive-through to introduce healthcare students and their faculty to disaster medicine. *American journal of disaster medicine*, *5*(2), 129-136.

Shen, Y., Li, C., Dong, H., Wang, Z., Martinez, L., Sun, Z.,... & Xu, G. (2020). Community outbreak investigation of SARS-CoV-2 transmission among bus riders in eastern China. *JAMA internal medicine*, *180*(12), 1665-1671.

Statista Research Department (2021). U.S. - seniors as a percentage of the population 1950-2050. Online. Available at https://www.statista.com/statistics/241488/population-of-the-us-by-sex-and-age/ [Accessed on

April 6, 2021]

van de Kracht, T., & Heragu, S. S. (2020). Lessons from Modeling and Running the World's Largest Drive-Through Mass Vaccination Clinic. *INFORMS Journal on Applied Analytics*.

Weiss, E. A., Ngo, J., Gilbert, G. H., & Quinn, J. V. (2010). Drive-through medicine: a novel proposal for rapid evaluation of patients during an influenza pandemic. *Annals of emergency medicine*, *55*(3), 268-273.

Wiggers, J., van de Kracht, T., Gupta, A., & Heragu, S. S. (2011). Design and Analysis of a Simulation Model for Drive-Through Mass Vaccination. In *IIE Annual Conference. Proceedings* (p. 1). Institute of Industrial and Systems Engineers (IISE).

Wood, R. M., Moss, S. J., Murch, B. J., Davies, C., & Vasilakis, C. (2021). Improving COVID-19 vaccination centre operation through computer modelling and simulation. *medRxiv*.