



Optimizing planning and design of COVID-19 drive-through mass vaccination clinics by simulation

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Abstract

Drive-through clinics have previously been utilized in vaccination efforts and are now being more widely adopted for COVID-19 vaccination in different parts of the world by offering many advantages including utilizing existing infrastructure, large daily throughput and enforcing social distancing by default. Successful, effective, and efficient drive-through facilities require a suitable site and keen focus on layout and process design. To demonstrate the role that high fidelity computer simulation can play in planning and design of drive-through mass vaccination clinics, we used multiple integrated discrete event simulation (DES) and agent-based modelling methods. This method using AnyLogic simulation software to aid in planning, design, and implementation of one of the largest and most successful early COVID-19 mass vaccination clinics operated by UHealth in Denver, Colorado. Simulations proved to be helpful in aiding the optimization of UHealth drive through mass vaccination clinic design and operations by exposing potential bottlenecks, overflows, and queueing, and clarifying the necessary number of supporting staff. Simulation results informed the target number of vaccinations and necessary processing times for different drive through station set ups and clinic formats. We found that modern simulation tools with advanced visual and analytical capabilities to be very useful for effective planning, design, and operations management of mass vaccination facilities.

Keywords COVID-19 · Mass Vaccination · Drive-through · Simulation · Cabana Layout · Pit-Crew Layout

1 Introduction and background

In December of 2020, the United States Food and Drug Administration approved two vaccines for emergency use to combat the novel coronavirus (COVID-19) [1]. As vaccine distribution began in earnest, the US was amidst its

highest surge in cases since the beginning of the pandemic, and the focus for health systems became how to vaccinate as many people as possible as quickly as possible in order to reduce the impacts of the COVID-19 pandemic. As part of local and regional vaccination planning, several countries turned large facilities such as sport stadiums, community centers and parking lots as sites for mass vaccination clinics [2–6]. Drive-through mass vaccination has been previously simulated and deemed a viable option for mass and rapid vaccinations [7–12].

Regardless of the type of clinic, appropriate planning and process design is essential to success. Vaccination clinic planning efforts should address the myriad complex design features, possible logistical entanglements, and anticipated challenges inherent to large-scale vaccine delivery [13–15]. Mass vaccination clinics need to have sufficient staff and space for screening, registration, vaccination, and observation [16]. Recent reports have discussed the effectiveness and feasibility of drive-through clinics [6, 17–21]. Additionally, there are numerous benefits to drive-through sites—they can reduce demand on existing facilities, accelerate the

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vaccination process, and allow patients to maintain social distancing by not exiting their cars [9, 11].

Performance of drive-through clinics can be measured by the maximum number of people that can be vaccinated and the median throughput time with a given set of financial and human resources. The goal is to maximize the number of vaccinations considering the available resources while making sure that the throughput time is kept to a minimum. Additionally, it is important to ensuring that indirect impacts such as traffic overflow and disease transmission risks remain negligible. Although the use of drive-through for mass vaccination is relatively new and only a handful of published research are available, lessons learned from the first implementations of this option, such as the ones we are reporting in this paper can provide insight and directions for public health agencies and communities intending to plan for and operate mass vaccination sites as vaccines proliferate.

We utilized simulation technology to enhance and optimize the real-world design of a mass vaccination clinic site in Denver, Colorado. This site was run by UCHealth, a large twelve-hospital health system in the Rocky Mountains. As part of its effort to stem the spread of COVID-19, UCHealth utilized a variety of vaccination clinic models, including community pop-up clinics, brick-and-mortar clinics, and a drive-through mass vaccination site. This mass vaccination clinic vaccinated 10,000 individuals over two weekend days with return four weeks later for the subsequent dose. A 1,000 individual pilot was scheduled prior to the larger full capacity vaccination dates. This event required pre-registration and individuals had the opportunity to sign consent prior to arrival on site [37].

As part of this large operation, computer simulations were used to provide the planning team with visualization and analytical tools. This illustrated possible queues with operational changes, maximum throughput and processing times and number of staff needed. Simulations allowed the planning team to assess the overall performance of the drive-through clinic under different design scenarios and options. Several models of the drive-through were simulated based on the existing protocols and pilot data collected from existing brick-and-mortar clinics. This paper will present two of the drive-through designs implemented by UCHealth and show how simulation helped evaluate these models.

2 Methodology

2.1 Simulation methods

We used a hybrid approach in developing the drive-through simulations by combining discrete event simulation (DES) and agent-based modelling methods using AnyLogic simulation software. DES is a flexible and an intuitive method

for simulating dynamic processes of complex systems. This simulation method is mostly used to assess and evaluate various strategies and operational what-if scenarios to find the most effective and efficient model. Decision makers can use DES to forecast the impacts of different decision alternatives before implementing them in the real world. DES is mostly used when field-based experiments and tests are either costly or infeasible [22]. Use of DES is very common in health care settings [23–28]. DES is ideal for simulating drive-through operations that include a road network where cars move through a number of discrete events and wait in queues to receive vaccination services.

Agent based modelling (ABM) is also gaining popularity in different fields for creating decision support systems and simulations to help decision makers with better policy and implementation choices [29–33]. ABM is used for visualizing, analyzing, and informing complex dynamic systems in public health [34]. As another bottom-up computational approach, ABM models dynamic and adaptive individual agents' behaviors (i.e., individuals, health providers, cars, etc.) and their interactions with each other and the environment based on predefined rules [35, 36]. ABM is an appropriate modelling method for drive-through simulation to treat different sections and lanes of a drive-through as agents that are connected to each other and change as one influences the behavior of the other agent.

2.2 Simulation layouts

To develop the simulations, we first created the drive-through layouts based on the sketch plans that were provided by the UCHealth planning team (Fig. 1). The predetermined drive-through mass vaccination site was the Coors Field parking lot, owned by the city's Major League Baseball (MLB) franchise, the Colorado Rockies. This site easily met most of the required criteria for a drive-through mass vaccination clinic. It had a large and long footprint, capable of accommodating at least 10 lanes of traffic with sufficient space between them and adequate space for queuing the cars. It was connected to wide streets and highways for ingress and egress. Lastly, there were two large parking lots connected to the vaccination area by a two-lane driveway that allowed for separate observation space.

We developed two different simulations based on two conceptual layouts named the “cabana” and “pit-crew” models (Fig. 2). In the “cabana” layout, cars arrived on site and were able to use one of the six available registration lanes. After completing the registration, cars move to one of the three available vaccination tents connected to their registration lane. There are four staff members in each registration station and two vaccinators in each vaccination station enabling up to four people to be registered and up to two people to be vaccinated at the same time in each lane.

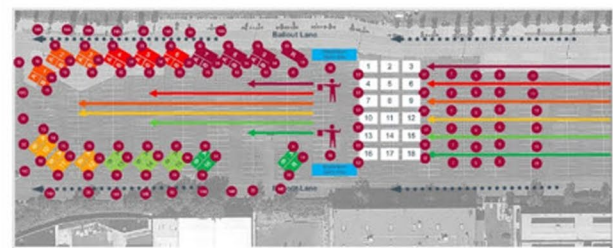
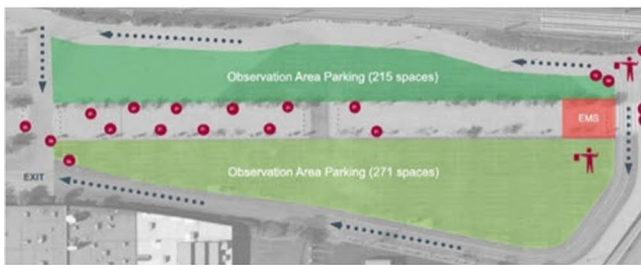


a. Overall site without observation zone



b. entrance area

c. traffic lanes



d. registration and vaccination area

e. observation area

Fig. 1 The entrance and dispatching point of the incoming traffic

In the pit-crew model, cars are dispatched to one of the eight lanes and are underwent registration and vaccination simultaneously. There were four stations in each lane that could serve patients. In this model, stations are covered by a large tent to provide staff protection from the weather and provide heat, as it was January in Denver. However, to minimize potential backlog, patients with special needs or those who required longer time are directed to outlying tents for service. In this model, all registration and vaccination stations are under the larger tent and housed most staff and support services in the same place, including pharmacy and IT.

2.3 Simulation components

We used AnyLogic (version 8.7) simulation software platform to develop the simulation models. The simulations were customized based off a more generic drive-through mass vaccination model developed by Asgary et al. [6] A combination of the *Process Modeling Library* and *Traffic Library* modules of the AnyLogic software were used. The simulations could be viewed in both 2D and 3D modes,

which provided easy understanding of the ongoing process for the UHealth operational team. A sample 3D view of the “cabana” model is shown in Fig. 3.

For both “cabana” and “pit-crew” models, we defined and used a ServiceLane agent that captures and simulates the processes in each lane. An example of the process for the “cabana” model is depicted in Fig. 4. Arriving cars are screened first (screening area), those ineligible take one of the exit lanes (carExitDriveThru) and those eligible are dispatched to one of the less busy lanes (selectServiceLane, Fig. 4a). Cars entering each service lane (beginService, Fig. 4b hereafter) were then move to the dispatched service lane (carMoveToLane) and continued to move towards the registration station (carMoveToRegistrationStation). Cars stay in the registration stations for a few seconds (registrationTime) and then move to the vaccination area (carMoveToVaccinationArea). Cars were then dispatched to one of the less busy vaccination stations that is specific to their corresponding service lane (carMoveTo_Vaccination) and stop there for a few seconds (vaccinationTime) so the driver (and the passengers, if any) would receive the vaccine after which they exit the service lane (exit). Cars exiting

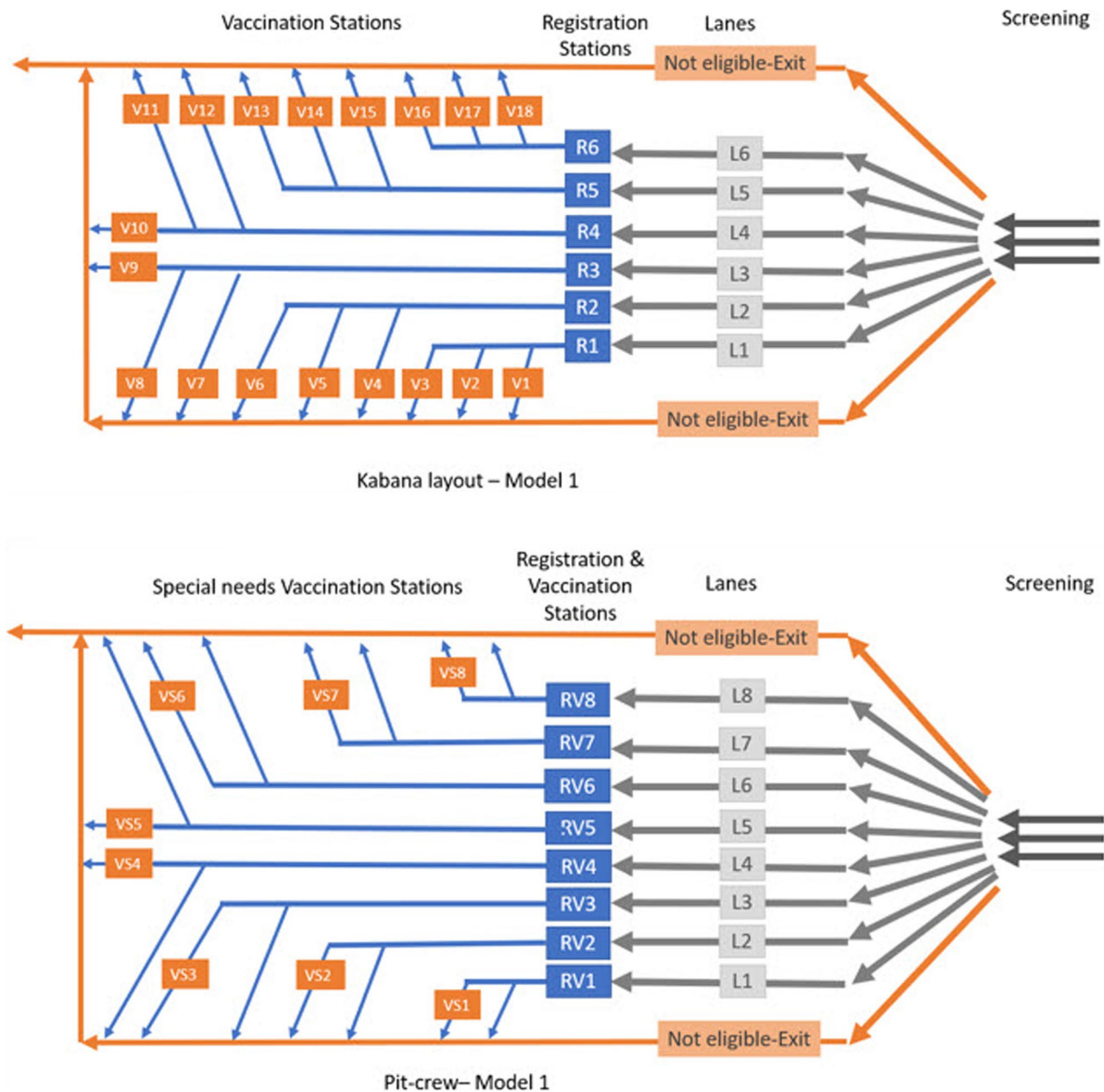


Fig. 2 Drive-through layouts tested in the study (these layouts do not include the observation area)

service lanes move towards the designated observation area (`carMoveTowardsObservation`, back to Fig. 4a again) and stay there for at least 15 min (`observationTime`) and exit the drive-through clinic (`carExitDriveThru`) thereafter. Cars exiting the drive-through are removed from the simulation. Several time measurements examined the effective service durations and wait times for each segment of this process, as well as the entire stay in the drive-through (e.g., TDS (time dataset start) and TDE (time dataset end) in Fig. 4a). Each car may carry one or more people.

3 Simulation results

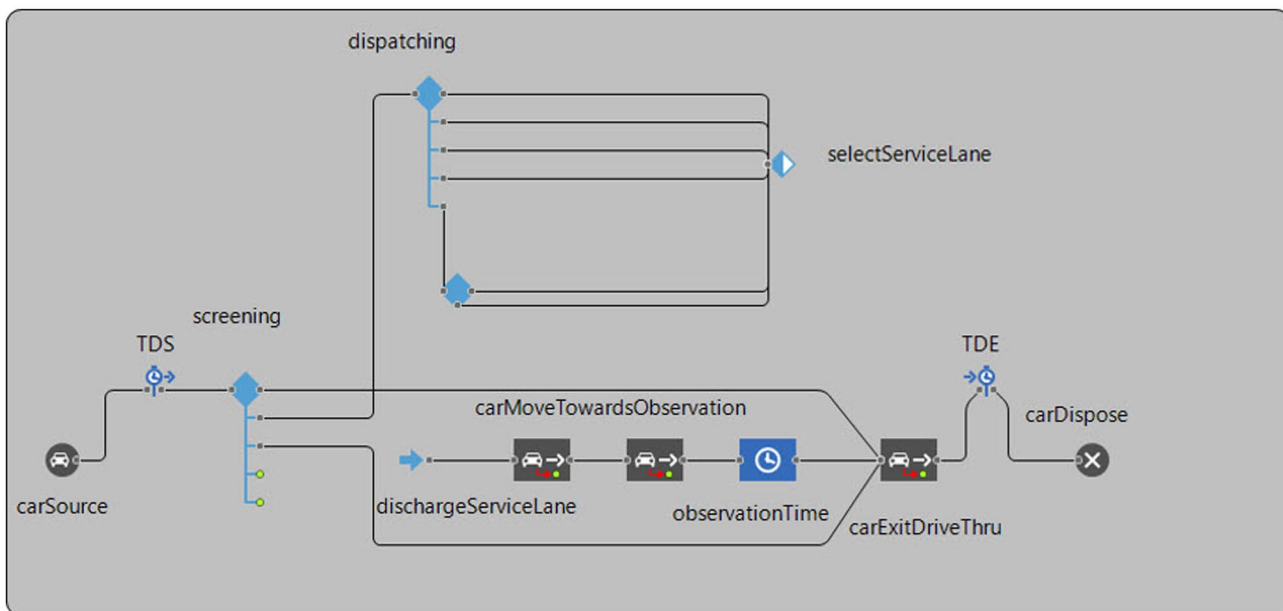
Simulation models developed for the UCHHealth drive-through were used by the planning team throughout the planning and design of each clinic. Simulations were uploaded to AnyLogic cloud platform for ease of access and use. Simulations could be run considering various input scenarios related to the number of arriving cars per hour, number of staff in registration and vaccination stations.



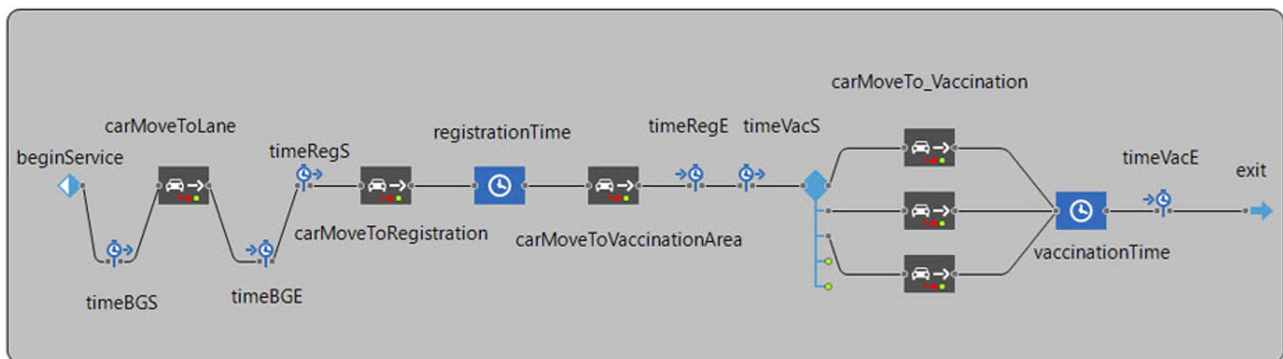
Fig. 3 Sample 3D visualization of the Cabana model

In this section, we will present some of the simulation results using the base values for different parameters of the clinics (Table 1). Registration time, vaccination time

and observation time values are based on data collected from the pilot event in pre-operation experiments. Registration and vaccination staff values were set based on the



a. Overall process



b. Service lane process

Fig. 4 The overall process of the drive-through clinic based on Cabana Model 1

Table 1 Model Parameters

Parameters	Cabana model	Pit-crew model
Registration time (seconds)	92	138
Vaccination time (seconds)	124	
Observation time (minutes)	15	15
Registration staff (per registration lane)	4	4
Vaccination staff (per each vaccination lane)	2	4
Car arrival rate (per hour)	650	650
Simulation time (minutes)	480	480

available staff for the drive-through operation. Car arrival rate was set based on the number of people pre-registered for vaccination. Simulation time was set based on one shift of operations.

3.1 Drive-through throughputs

Figure 5 shows the overall number of cars able to use the drive-through in both layouts for one realization of the simulation. Because the stochasticity of the model is minimal, random runs of the simulation does not produce significant difference. As shown here, the pit-crew model shows a slightly higher performance throughout the operation hours. After eight hours of operations with the base line parameters, about 4,480 cars exit the from the Cabana model and 4,665 cars from the pit-crew model. Although in our simulation, we allowed for different number of

passengers in each car, we use the number of cars as the performance measure because almost all cars had one person to be vaccinated.

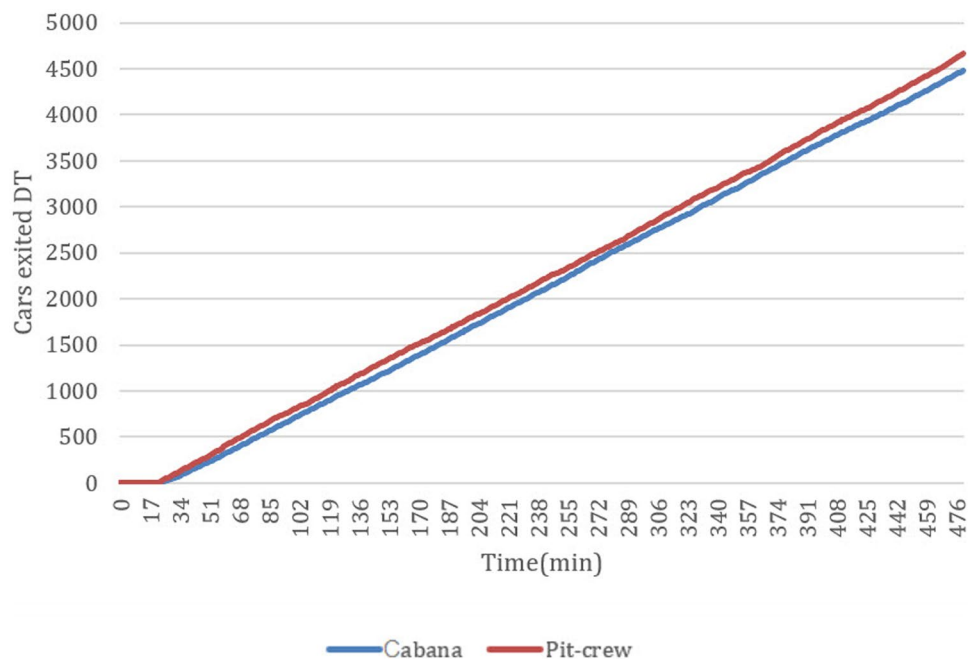
3.2 Drive-through processing time

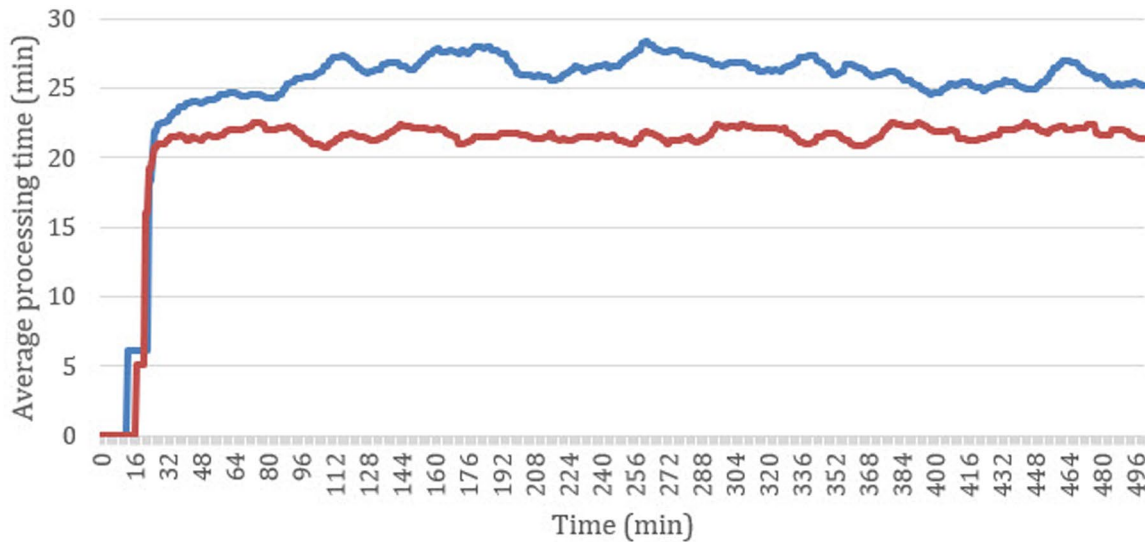
Figure 6 presents the average processing times and cumulative probability distribution for both drive-through models for eight hours of operations. The overall average processing time is 26.15 min for the Cabana model and 21.72 min for the Pit-crew model. The results show 4.43 min difference between the total average processing times in the two models.

3.3 Sensitivity analysis

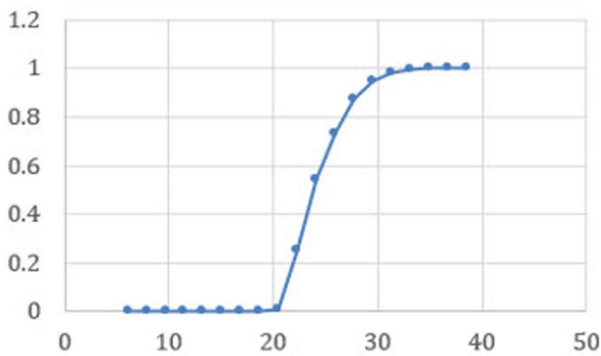
We ran sensitivity analyses of the base run to examine the effects of variations in the rate by which the cars arrive on the number of cars processed and the average processing time. Figure 7a shows the sensitivity results for the number of cars processed under different number of cars per hour. As can be seen here, in the Cabana model, as number of incoming cars increases the total number of cars processed slows down, while for the pit-crew model it continues to grow even at car arrival rates as high as 800 cars per hour. This clearly shows that the pit-crew model would allow more cars to be processed within the same amount of time. Figure 7.b projects the sensitivity analysis for different car arrival rates against average processing time. While both models provide almost similar results up to 500 cars per hour, the processing time starts to increase for the Cabana model beyond 500

Fig. 5 Cars exited drive-through for Cabana and Pit-crew models

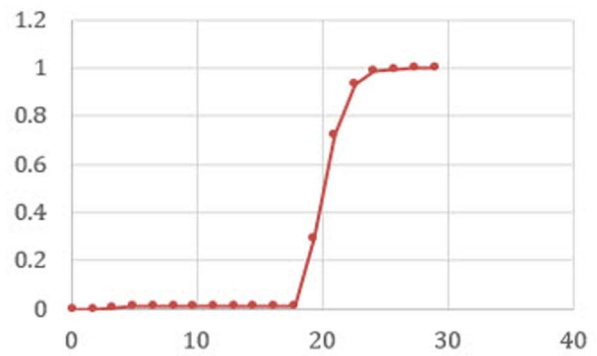




a. Average processing time



b. Cumulative probability distribution-Cabana



c. Cumulative probability distribution-pit-crew

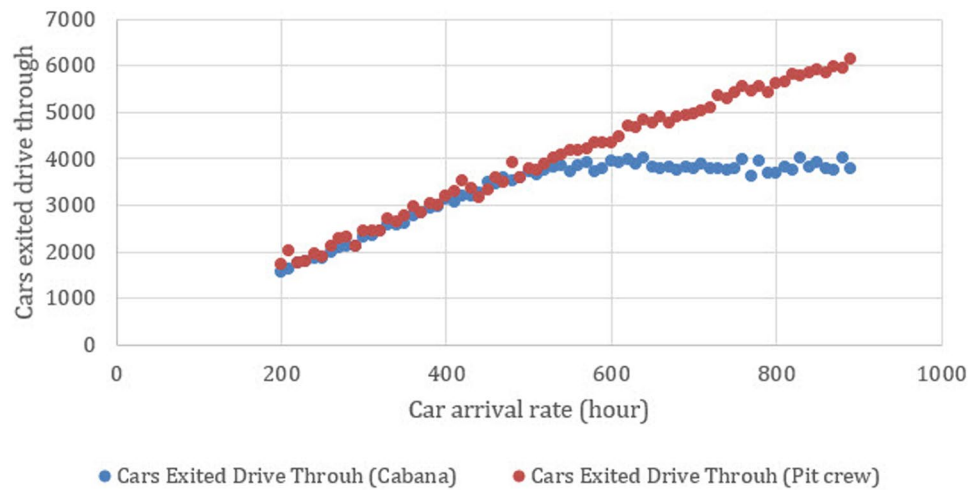
Fig. 6 Average processing time and cumulative probability distribution of the processing time in Cabana and pit-crew models

cars per hour. It implies that 500 is the max workload for registration and vaccination staff resources which are only 75% of the assigned for the Pit-crew scenario for registration and less than 25% of the assigned for the Pit crew scenario for vaccination.

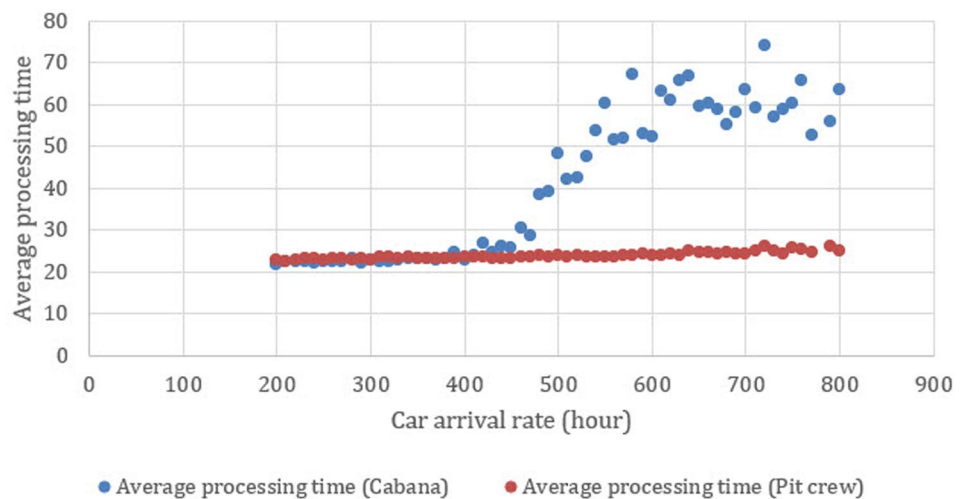
It is important to note that the major source of difference between the two models is not just the change in the layout, but the fact that the pit-crew model has 8 lanes, while the Cabana model has only 6 registration lanes. However, the simulation showed that this change in the layout could significantly enhance the drive-through performance.

Although these simulations were developed to support the planning and design of the drive through clinic, sample data collected during the operation of both types of drive through showed that the simulation output were very close to the actual operation results. The overall average simulated processing time for the Cabana model was 26.30 min and for the actual operation was 30.37. The higher processing time for the actual operation can be explained in part by the higher arrival rates during the actual operation that exceeded the 650 cars per hour. This was also confirmed by the simulation results for higher car arrival rates (Fig. 7). On the other

Fig. 7 Sensitivity analysis results



a. Car arrival rate versus Number of cars processed



b. Car arrival rate versus Average processing time

hand, the processing time of the real observed operation for the pit-crew model was lower than the simulated value (21.72). This can be explained in part by shorter combined registration and vaccination time and the fact that during the pit-crew operations observation time was reduced from 15 to 10 minutes [38].

4 Discussion

The UCHealth drive-through mass vaccination clinic utilized the simulation results for planning and design of their drive-through setting. This simulation support assisted the UCHealth team successfully implement and one of the largest and most efficient early mass vaccination clinics. By building on a generic drive-through simulation model developed previously

by the simulation team [6], the team was able to develop an individualized simulation to answer key questions on layout, resource allocation and the overall maximum throughput and possible bottlenecks in the process. Additionally, the simulation allowed the planning team to examine various scenarios and throughput models by changing input parameters without exposing patients to an experimental clinic design.

This first dose mass-vaccination clinics were held on January 30 and January 31, 2021. Although the clinic successfully met its objectives and vaccinated 10,000 individuals in two six-hour days, there were concerns raised surrounding possible winter weather for subsequent doses. In the “cabana” model, registration stations were covered by large tents, however the vaccination staff needed to deliver the vaccination to the patients outdoors and were largely exposed to the elements (Fig. 8).

Fig. 8 Cabana model of UCHealth drive-through (UCHealth, 2021)



a. Cabana drive-through operation

b. Pit-crew drive-through operation

To protect staff from cold weather, the operations team made plans to combine vaccination and registration stations the same large tent. In the “pit-crew” model, the same staff perform registration and vaccination in a single step. To make sure that it was possible to meet maximum throughput with a different layout, the simulation team developed a simulation of the proposed layout in which some experimental initial values of the parameters were used. This simulation also helped the planning team to make more adjustments to the layout considering how many cars can be processed using the pit-crew design.

However, it is important to mention that comparing the two drive through layouts based on the number of cars processed and the average processing time may not be fair to draw conclusions about which model is more effective and efficient. Other productivity measures such as average amount of resources used per client or average cost of processing each client might provide better measures for efficiency of different layouts.

Design and implementation of a large drive-through mass vaccination is complicated and requires careful attention to examine specific details. Lack of proper design and staffing may cause large queues, increasing wait times, the number of staff necessary to manage crowds, prolonging operating hours, and decreasing the performance of the clinic. These adverse outcomes related to lower efficiency all translate to increased costs for vaccine clinic operators. Simulation tools and expert knowledge should be used to optimize clinic efficiency. While conducting dry run exercises, pilot clinics, and seeking expert opinion can help predict some of these issues, modern simulation tools such as those we developed for the UCHealth drive-through clinic can provide a less expensive visual and analytical tool for planning and designing highly efficient vaccination clinics.

5 Conclusion

This paper reports the simulation of a real drive-through COVID-19 mass vaccination clinic and reported the outputs of two different potential layouts in terms of key performance indicators

including the number of cars (patients) processed and total processing time. These successful simulations in a real-world setting could help public health agencies to set up more effective and more efficient drive-through clinics. This experience also showed that modern simulation tools with advanced visual and analytical capabilities can be very useful for effective planning, design and operations management of mass vaccination facilities.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest

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