# Vaccination Queueing System Simulation

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# INTRODUCTION

***Infectious disease***, in medicine is defined as a process caused by an agent, often a type of microorganism, that impairs a person's health.

In many cases, infectious disease can be spread from person to person, either directly (e.g., via skin contact) or indirectly (e.g., via contaminated food or water).

***Epidemics in History***

- Plague in 14th Century Europe killed 25 million.
- Aztecs lost half of 3.5 million to smallpox.
- 20 million people in influenza epidemic of 1919.

***Diseases at Present***

- 1 million deaths per year due to malaria
- 1 million deaths per year due to measles
- 2 million deaths per year due to tuberculosis
- 3 million deaths per year due to HIV
- About 3 million deaths from the beginning of the COVID-19 pandemics

- Infectious diseases remain a leading cause of morbidity and mortality worldwide, with HIV, tuberculosis and malaria estimated to cause 10% of all deaths each year.

- In the recent years, new pathogens emerged and to cause epidemics or pandemics:

➢ SARS epidemic in 2003;
➢ the swine flu pandemic in 2009;
➢ MERS CoV in 2013;
➢ Zika in 2016;
➢ SARS-CoV-2 (COVID-19) in 2020.

- The coronavirus pandemic (Covid-19) is the biggest world crisis in the world in the last tens of years.
- The number of infected is growing daily, so today there are about 225 million infected people since the beginning of the pandemic in March 2020.

- The latest virus that unfortunately humankind has heard of appeared in December 2019 in Wuhan, Hubei Province of China.

- As a result of the tragic death cases that occurred because of the COVID-19 virus, The World Health Organization (WHO) announced COVID-19 pandemic on 12 March 2020, when 125600 confirmed cases were reported from 118 countries and regions from all over the world.

- Due to the fast progression of COVID-19, The World Health Organization was determined to recommend governments to take drastic measures for slowing down the propagation of this new disease known as COVID-19 and flattering the epidemiology curve down to the lowest treatment capacity of the health system in each country.

## *History of Epidemiology*

- Hippocrates’s On the Epidemics (circa 400 BC)
- John Graunt’s Natural and Political Observations made upon the Bills of Mortality (1662)
- Louis Pasteur and Robert Koch (middle 1800’s)

- Many infectious diseases in populations can be described by appropriate mathematical models which offer different ways for simulation and predictions. The mathematical modelling is crucial for understanding of the infectious diseases spread at the individual and population levels.

# Vaccination

Looking back at the past 100 years of medical advances in the prevention and treatment of disease, vaccination is the miracle of modern medicine. In the past 50 years, evidence suggests it has saved more lives worldwide than any other medical product or procedure.

To bring the COVID-19 pandemic under control and substantially reduce hospitalization, morbidity, and mortality rates, and in the meantime reopen the economy, a large portion of susceptible people should receive the vaccine to become immune to the virus in a short period of time.

Rapid mass vaccination should be implemented to minimize further human and economic impacts.

# Vaccination

Such a large-scale implementation of the COVID-19 vaccine could be among the most challenging public health actions of the decade. From a preparation and planning point of view, this translates into many local mass vaccination sites in each city and town that offer immunization services.

Since the ultimate goal of the vaccine process is to immunize the population against SARS-CoV-2, the success of vaccine development, production, and distribution very much depends on timely and efficient dispensing which requires extraordinary advance planning and preparation at different levels.

This paper introduces a simulation tool developed for the design and operation of mass vaccination facilities.

The tool is developed using a hybrid approach and by integrating discrete event and agent-based modeling methods.

The simulation tool enables users to estimate how many people may be vaccinated and how many staff are needed to run such facilities efficiently under different setups and configurations.

The simulation can help public health planners and decision makers to evaluate and understand the repercussions of their mass vaccination plans using (e.g., different number of lanes, different number of personnel, different processing times that represent different processes).

## Why is this Kind of Model Needed?

Mass vaccination of COVID-19 will not only need to use the existing and traditional points of dispensing facilities such as clinics, pharmacies, schools, workplaces, nursing homes, pharmacies, and places of worships, but also requires the creation of new and innovative vaccination approaches.

This is mainly because the use of some of the above listed facilities and settings may be inefficient or unsafe for immunization during a deadly infectious disease.

Because of that, is created vaccination model for planning of the total vaccination process: the number of the involved medical staff, the size of the space where the vaccination will be done, the organization of the process for continuous vaccination of the population without waiting, keeping the distance etc.

## Description of the Model

The created model provide simulation of the vaccination process.
The model is created in AnyLogic: Simulation Modelling Software.

Every client in the vaccination process passes through the following phases:

- Check-in;
- Receiving a vaccine;
- Rest for 15 minutes after vaccination;
- Check-out and exit;

In this model, the clients are generating from the source, and they form Poisson process i.e., the times between arriving of successive clients are exponential distributed.
After generating, they are going in the waiting queue, which can be chosen with different length and different priority for serving. Here, FIFO (First In First Out) model is considered.

## Description of the Model

If there enough places in the waiting queue the client is waiting, otherwise he will be removed from the system, until the free space in the queue will be provided.

After waiting in the queue, the client goes at the checkpoint. It is assumed that the service time of the checkpoint is uniformly distributed, equal to the mathematical expectation of 3.5 minutes, i.e., is assumed that each client will be able to check in a time interval of [2,5].

The second phase is vaccination. It is assumed that the service time of the vaccination point is uniformly distributed, equal to the mathematical expectation of 3.5 minutes, i.e., is assumed that each client will be vaccinated at a time interval of [2,5].

The next phase is the rest phase, which is very important for the patients with reactions from the vaccine. Here, the reactions can be recorded, and the medical staff can respond appropriately.

The service time at this phase is assumed to have a triangular distribution with mathematical expectation of 10 minutes.

After passing this phase, the client leaves the vaccination place.

# Used Elements in the Model

- Source
- Time of Arriving
- Waiting queue

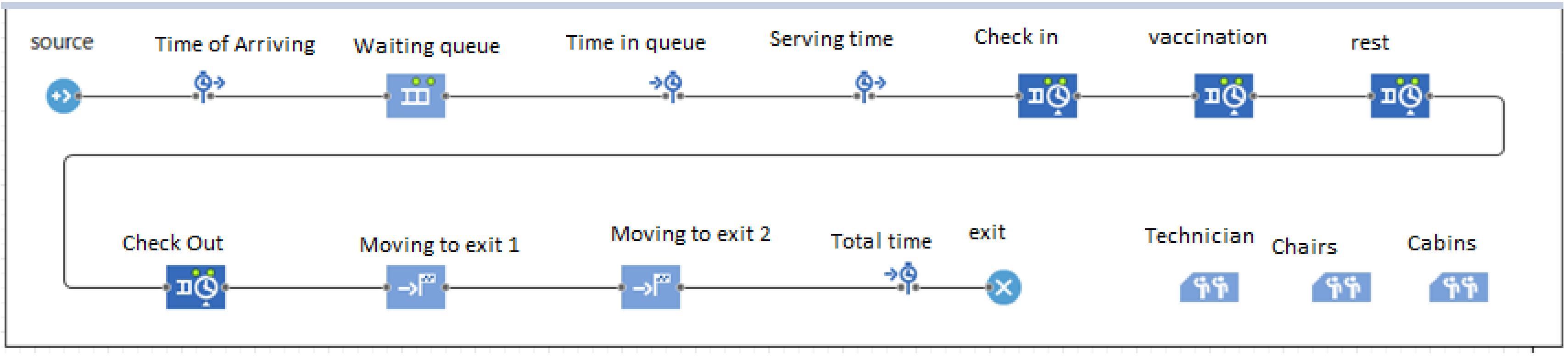
- Time in the queue
- Service time

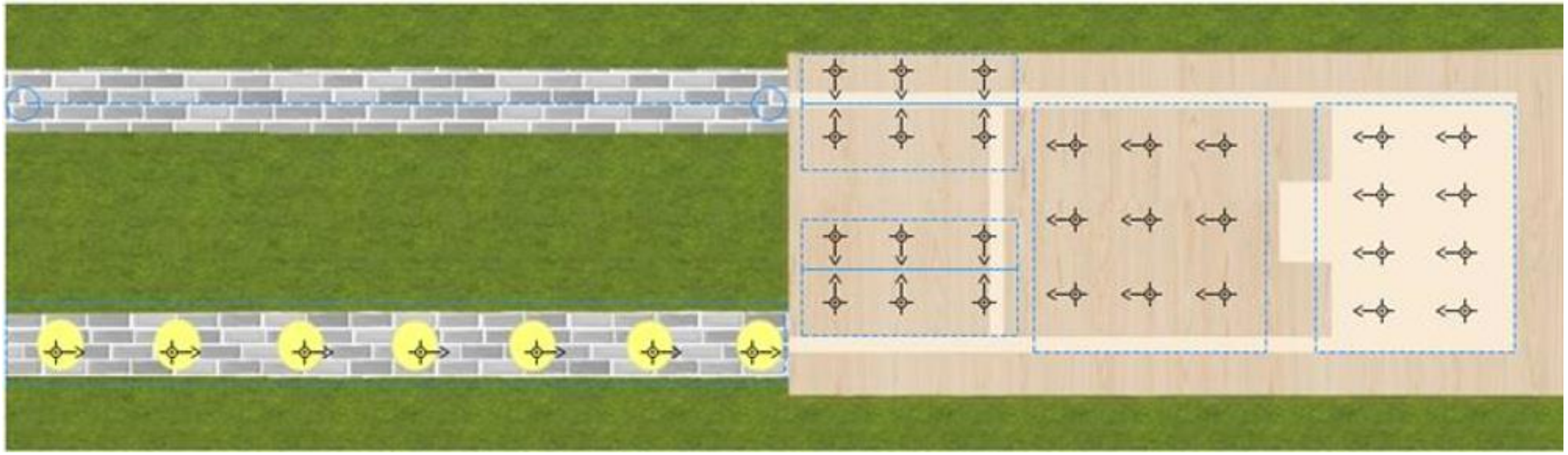
- Check in
- Vaccination
- Rest

- Check out
- Moving to the exit

- Total time in the system
- Moving to the exit

- Technician
- Cabins
- Chairs


source
Time of Arriving
Waiting queue
Time in queue
Serving time
Check in
vaccination
rest
Check Out
Moving to exit 1
Moving to exit 2
Total time
exit
Technician
Chairs
Cabins



## Simulation

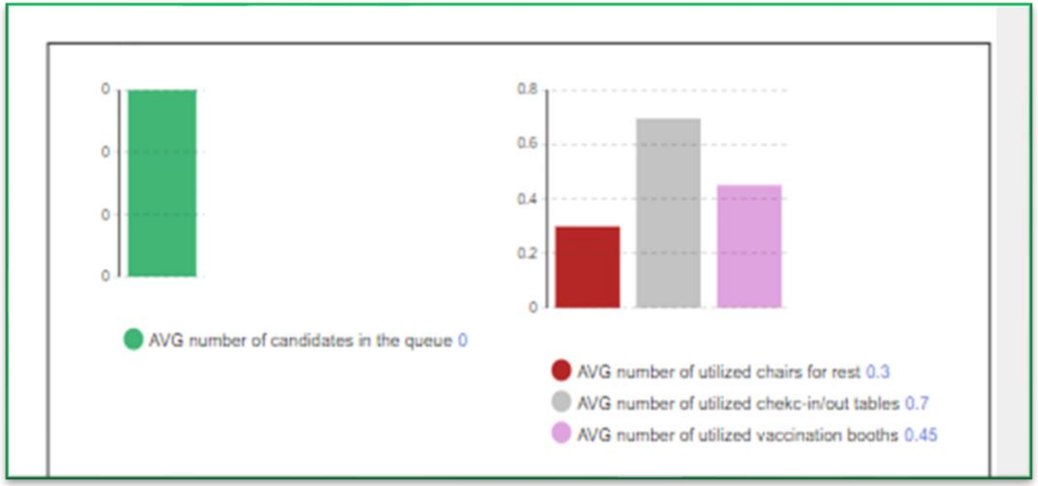
The simulation of the model is done in AnyLogic. We are assuming that the clients' arrival rate is 35 clients per hour, waiting queue length is 7 clients, the number of cabins is 4, the number of chairs is 20, the number of the check in points is 3, and the number of check out points is 3.

In order to analyze the model, we determine the average time in the queue and the average staying time in the system.

The simulation provides **graphics of stochastic processes related to the time spent in the queue and the total staying time in the system**.

The simulation also determines the **average time spent in the queue** and the **time spent in the whole system**.

## Simulations

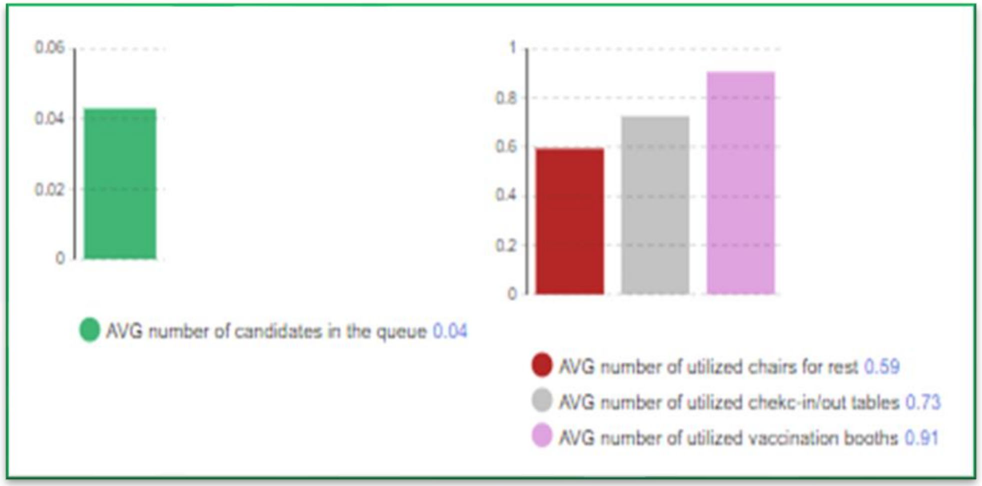


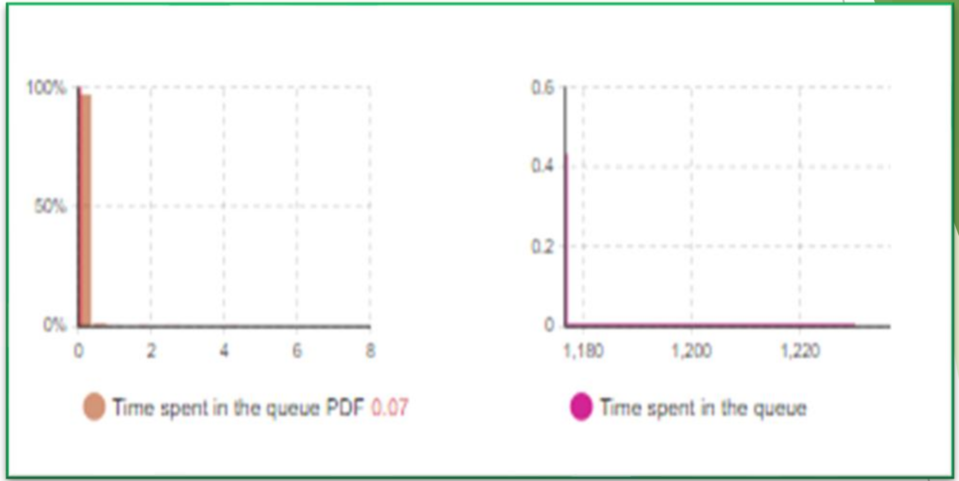



These graphics are for 1000 clients in the vaccination system. The average number of busy vaccine cabins is 0.46 (46%), the average number of chairs for resting is 0.3 (30%) and the average number of busy check-in and check-out stations is 0.71 (71%).

Clients' arrival rate is 35 clients per hour. 4 vaccination cabins are in used, 20 chairs for rest, 3 check in points and 3 check out points.

## Simulations



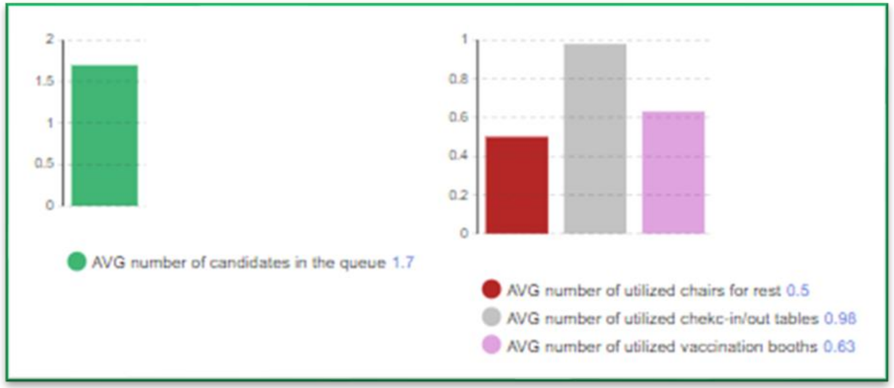



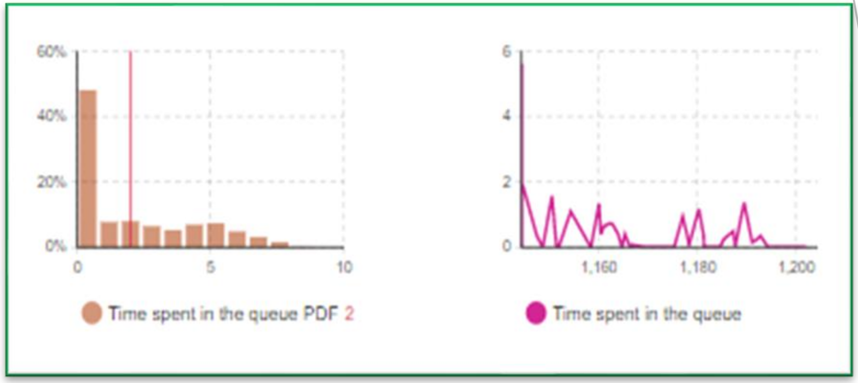


In this case, the simulations show that the model work more optimally, since the occupancy rate of vaccination cabins is already increased at 91%, and the occupancy of the chairs at 59%.

Because of the low strain of the 4 vaccination cabins, we are considering the case with 35 clients per hour, with the decreased number of the vaccination cabins to 2 are in used, 10 chairs for rest, 3 check in points and 3 check out points.

# Simulations



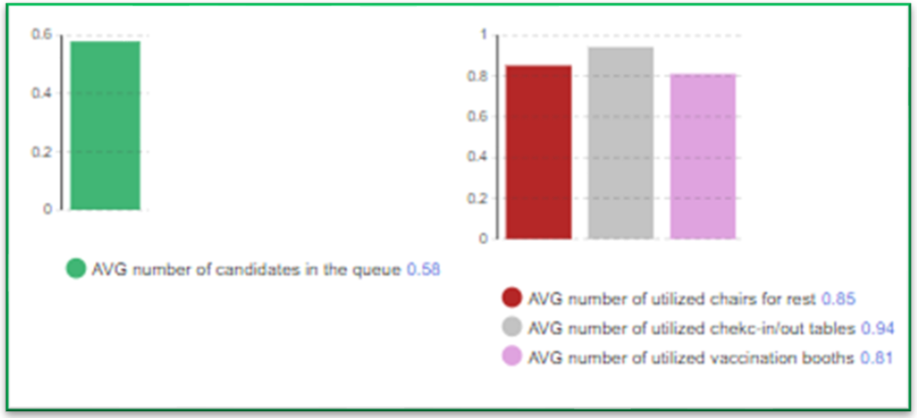



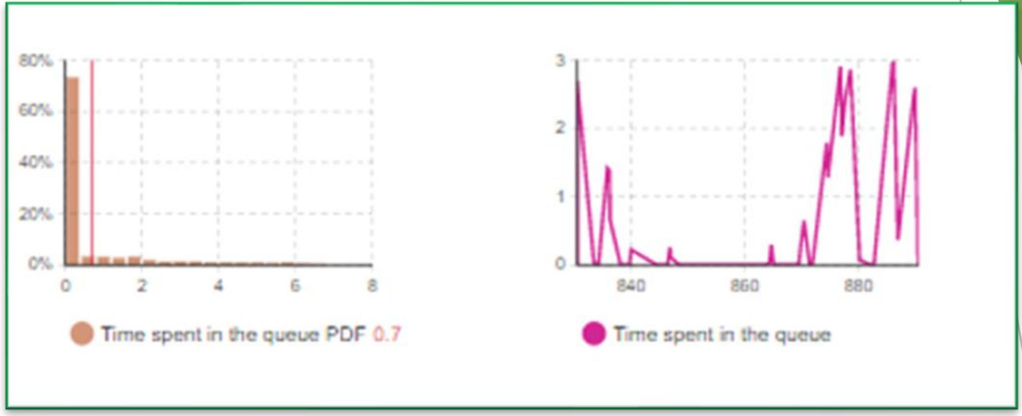


The number of clients in the queue is 1.7, the average waiting time in the queue is 2 minutes and the average time in the system is 29.09. There are no significant changes in the total time spent in the system and in the queue. Also, there are no significant changes in the average number of the used resources.

We are considering the case with 50 clients per hour, with 4 vaccination cabins, 20 chairs for rest, 3 check in points and 3 check out points.

## Simulations





In this case, the model works more optimally, since the occupancy of the vaccination cabins is 81%, and of the occupied chairs is 85%.

We are considering the case with 50 clients per hour, with 3 vaccination cabins, 10 chairs for rest, 3 check in points and 3 check out points.

## Conclusion

The model presented in the paper describes the real vaccination situation. It can be used as a model for well organizing of the vaccination process, because the simulations provide good results for the needed medical staff and resources depending on the rate of clients' arrivals.

It shows where and how to take actions in order to have optimal use of the total system of vaccination.

It is demonstrated how data generated from a simulation can be used
to develop a new and better predictive machine learning model for vaccination clinics.

The model can be used to obtain quick predictions of the number of people to be vaccinated and the average time it takes for vaccination under various parameter settings. The results show promising outcomes in applying this method in other aspects of pandemic management.
Most of these simulations have the potential to be further enhanced and turned into artificial intelligence models that can help end users and policy makers to assess the impacts of various policy options.

# Thank You for Your Attention