INSE- 691 Topics in Information Systems Engineering

Project Report

On

Decrease in Wait time for COVID-19 Vaccination using Simulation and Modeling

Submitted to:

Professor Dr. Anjali Awasthi

Submitted By:

Student Name	Student ID
Keerthi Sanna Reddy	40159954
Nithish Reddy Yalaka	40164619
Sisinder Reddy Valmiki	40186128
Venu Babu Podila	40159998
Chakri Gorantla	40165176

Faculty of Engineering and Computer Science
Expectations of Originality

This form sets out the requirements for originality for work submitted by students in the Faculty of Engineering and Computer Science. Submissions such as assignments, lab reports, project reports, computer programs and take-home exams must conform to the requirements stated on this form and to the Academic Code of Conduct. The course outline may stipulate additional requirements for the course.

1. Your submissions must be your own original work. Group submissions must be the original work of the students in the group.
2. Direct quotations must not exceed 5% of the content of a report, must be enclosed in quotation marks, and must be attributed to the source by a numerical reference citation[1]. Note that engineering reports rarely contain direct quotations.
3. Material paraphrased or taken from a source must be attributed to the source by a numerical reference citation.
4. Text that is inserted from a web site must be enclosed in quotation marks and attributed to the web site by numerical reference citation.
5. Drawings, diagrams, photos, maps or other visual material taken from a source must be attributed to that source by a numerical reference citation.
6. No part of any assignment, lab report or project report submitted for this course can be submitted for any other course.
7. In preparing your submissions, the work of other past or present students cannot be consulted, used, copied, paraphrased or relied upon in any manner whatsoever.
8. Your submissions must consist entirely of your own or your group's ideas, observations, calculations, information and conclusions, except for statements attributed to sources by numerical citation.
9. Your submissions cannot be edited or revised by any other student.
10. For lab reports, the data must be obtained from your own or your lab group's experimental work.
11. For software, the code must be composed by you or by the group submitting the work, except for code that is attributed to its sources by numerical reference.

You must write one of the following statements on each piece of work that you submit:
For individual work: **"I certify that this submission is my original work and meets the Faculty's Expectations of Originality",** with your signature, I.D. #, and the date.
For group work: **"We certify that this submission is the original work of members of the group and meets the Faculty's Expectations of Originality",** with the signatures and I.D. #s of all the team members and the date.

A signed copy of this form must be submitted to the instructor at the beginning of the semester in each course. I certify that I have read the requirements set out on this form, and that I am aware of these requirements. I certify that all the work I will submit for this course will comply with these requirements and with additional requirements stated [illegible]utline.

Course Number: Inse 691 Instructor: Dr.Anjali Awasthi
Name: ____________ I.D. # ____________
Signature: ____________ Date: ____________

[1] Rules for reference citation can be found in "Form and Style" by Patrich MacDonagh and Jack Bordan, fourth edition, May, 2000, available at http://www.encs.concordia.ca/scs/Forms/Form&Style.pdf.

Approved by the ENCS Faculty Council February 10, 2012

Keerthi Sanna Reddy	Chakri Gorantla	Nithish Reddy Yalaka	Sisinder Reddy Valmiki	Venu Babu Podila
40159954	40165176	40164619	40186128	40159998

Table of Contents

1. Introduction

COVID-19 an infectious disease that has affected and wiped almost 9.3% of the world and turned everything into a totally new place to live in. people have struggled and are still battling against covid to protect them from this deadly disease. It has been almost 2 years since this all started in the first place. People still need to be very preventive since there is no cure for this disease. The only thing that can help people to withstand these rising cases is take precautions like maintaining social distances, always wearing mask, and sanitizing the hands whenever you get into contact with new people and surfaces. Other than this the next thing that can help us to survive is Vaccine. With wide research and continuous vaccination many countries have found vaccine for Covid but there aren't many doses that can be sufficient for the whole world. This started panic situation in public and made them rush towards vaccination centers. This increased the number of people at vaccination centers and increased the wait time.

Figure1 People waiting for vaccination at Vaccination center

So, to fix the issue of the waiting time we come up with the simulation-based model that significantly reduces the wait time of the people. We tried making changes to existing models and made tried optimizing the wait times at vaccination centers. We tried to do this by collecting real time data from few of the biggest vaccination centers in Montreal and gathered information to sort out the necessary data which can be useful for simulation and developed a few simulation models using simulation software's.

2. Problem Statement

Metrics will be determined in the system, such as the number of people visiting the vaccination center, the average time spent per person, the average wait time at each resource, and the average service time required to finish the dose. Person's arrival time and service time are used as input for the simulation. We will analyze the vaccination process and provide the necessary suggestions based on the simulation results. In addition, we will use different technologies available to simulate the model.

3. Simulation Models

We will simulate the model and analyze the results with the help of following simulation models.

- Arena Simulation Model for Discrete event simulation
- Vensim Simulation Model
- Monte Carlo MS-Excel

3.1 Discrete Event Simulation- Arena

Since our model has multiple events, different processes and changes will occur in the system at a specific time, so we chose the discrete event simulation. This is the best because we can observe the system at a micro level. Our model is inherently random, because people arrive at the vaccination center at random.

3.2 Input Modelling and Data Collection

The input parameters are the person arrival rate and the service rate of the vaccination process. The arrival rate is the number of people who arrive at the vaccination center in one day and the service rate is the time it takes for the hospital administrator to complete the vaccination process.

3.2.1 Assumptions

1. The vaccination center does not operate 24/7.
2. There can be only 300 to 400 members that can be vaccinated per day.
3. Some persons may not be allowed into the vaccination center if they have any kind of symptoms.
4. The person will be standing in the queue for his turn of the dose.
5. When a person is done with the dose, he/she leave the system.
6. Same vaccine that he/she took for the first dose are not available.
7. The minimum service time for a person is 2 mins, and the maximum is 4 mins.

We considered the vaccination center in Montreal, which runs 12 hours a day and collects people's arrival data by observing the center.

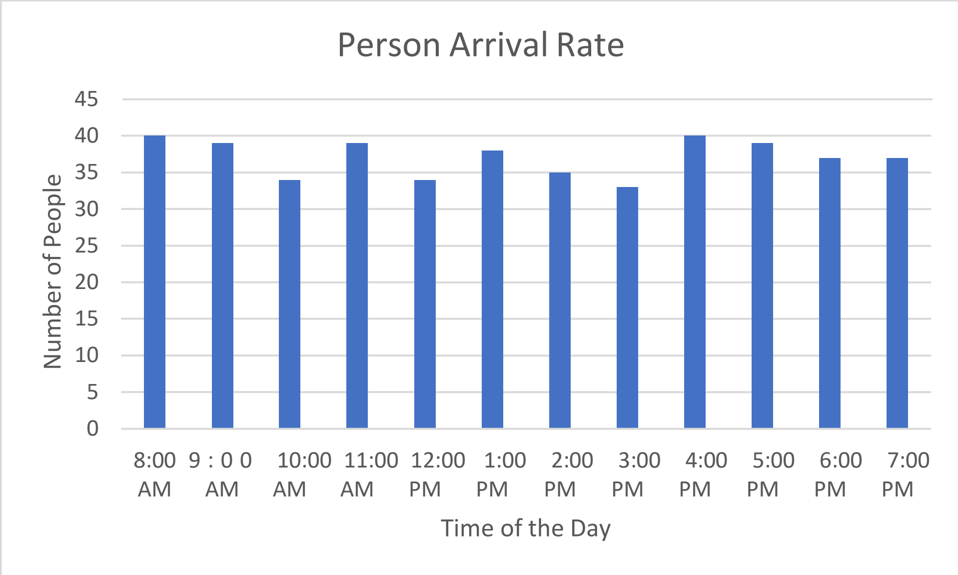


Figure2 Data representation for Person Arrival Rate

For service rate at vaccination center, we considered it is the whole time taken by the vaccination center to complete the vaccination process i.e., time taken by receptionist, time taken by the nurse and the time taken for giving the dose and marking the dose number with a proper ID so that it will be used as a proof of vaccination for future purpose.

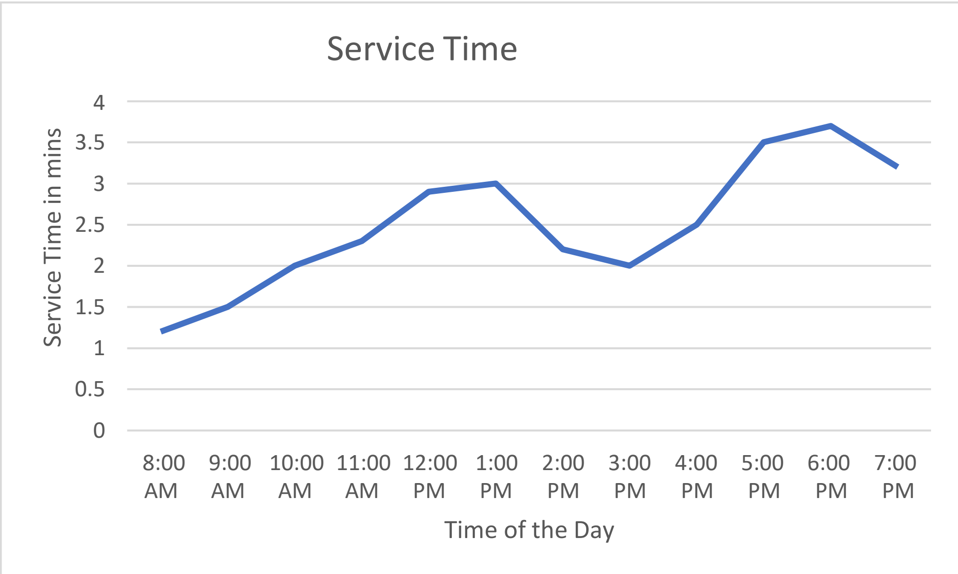


Figure3 Data representation for Person service Rate

3.2.2 Parameter's estimation and Goodness of fit vaccination

In this, we use arena software for discrete event simulation. It also suggests the best statistical model to see which fits best with the data obtained. In arena there is an input analyzer which is used to analyze the data and uses its data to estimate the best fit for vaccinations.

In this we are using Chi-square vaccination, Kolmogorov–Smirnov vaccination to evaluate the fitness of the data. For this reason, the raw data values of arrival and service rates (in minutes) are recorded in the vaccination file. For our input data, we recommend using the Beta distribution.

Chi-Square test:

Here, Chi-square test is used for assessing goodness of fit data. The level of significance is 0.05 . We are considering a sample of 300 people and considering how long will be their wait time till the complete procedure of their vaccination. We divided working hours of the vaccination for every 2 hours is 37, 40, 35 and 36. We are expecting result around 10%, 12%, 9% and 11% respectively.

Null hypothesis: Expected data is true and valid

Alternative hypothesis: Expected numbers of people inflow is false.

Pearson's Chi-square goodness of fit Calculation:

Total number of people observed over a day for vaccination: 300

Ei = Total * percentage expected

E1= 40

E2= 48

E3= 36

E4 = 44

X2 =∑ [(Oi-Ei)2/Ei]

= ∑ [((37-40)2/40) + ((40-48)2/48) + ((35-36)2/36) + ((36-44)2/44))

= 2.036

From the significance level α =0.05, and Degrees of freedom 3 we get the critical value as X2 = 7.81 from table of X2 Vs p-values.

Since our value of X2 is 2.03 which is less than the critical value of 7.81, our null hypothesis is true and is accepted Since the difference between the expected and the observed value is very small.

Kolmogorov-Smirnov test:

KS test was used to compare our data with distribution, and it gives us with any significant difference between the distribution and sample data. How good it is, to fit the sampledistribution as it follows the theoretical distribution is known by performing the vaccination. Unknowncumulative distribution holds true with theoretical distribution is assumed to be null hypothesis and the opposite is our alternate hypothesis. With 0.05 significance, we do not have sufficient evidence to reject the hypothesis. The difference is calculated using the statistic D with the greatest difference between the Fs(X) and Ft(X). Based on calculations the maximum wait time is found to be 2.39 for the whole observations, which when compared with the p-value- D table from the supreme value for 0.05 significance and a sample of 30, Kolmogorov quartile is 1.69, lesser than that from the value. Since the assumed sample is to be 30 from t score table, we have value of 1.69, this varies if sample n is greater than 30 as we go for z scores with mean, standard deviation values. So, it is said that the null hypothesis can be accepted as the value isgreater than that from quartile.

D statistic = Sup| Fs(X) – FT(X) |

Comparison between the unknown cumulative distribution and theoretical distribution hold true and hence the data is also said to be a good fit as per Kolmogorov-Simonov vaccination.

3.2.3 Arena Simulation for Arrival Rate

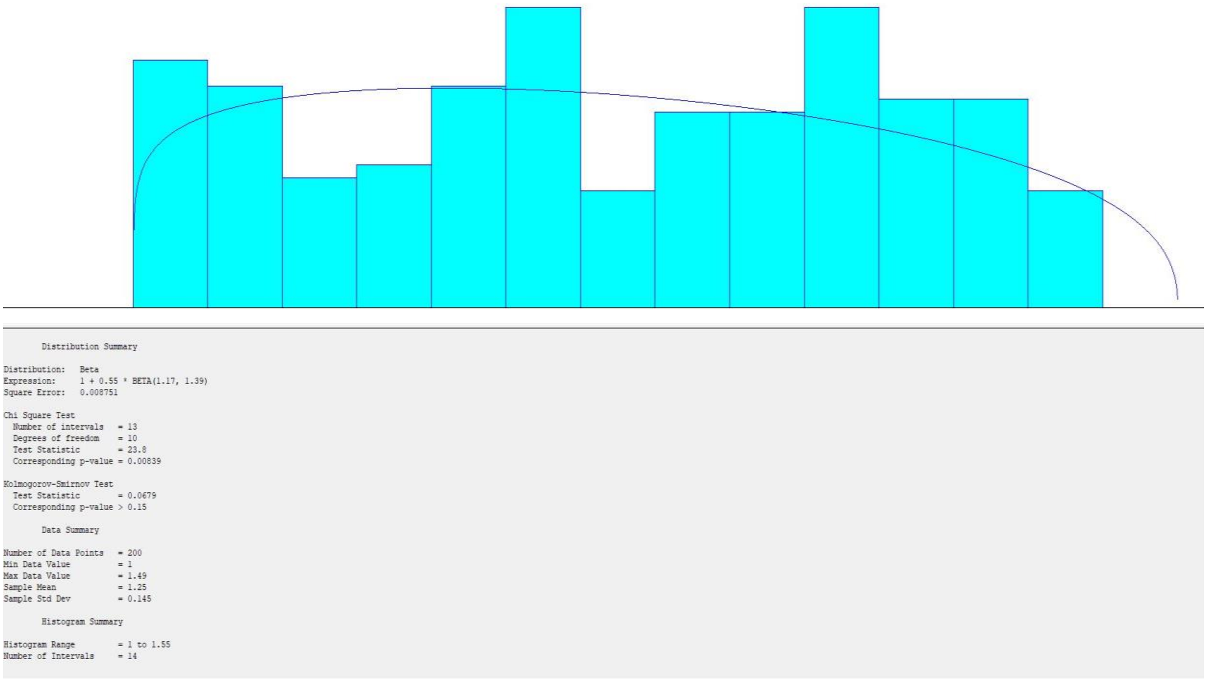


Fig: Data representation for Patient Arrival Rate in Arena

3.2.4 Arena Simulation for Service Rate

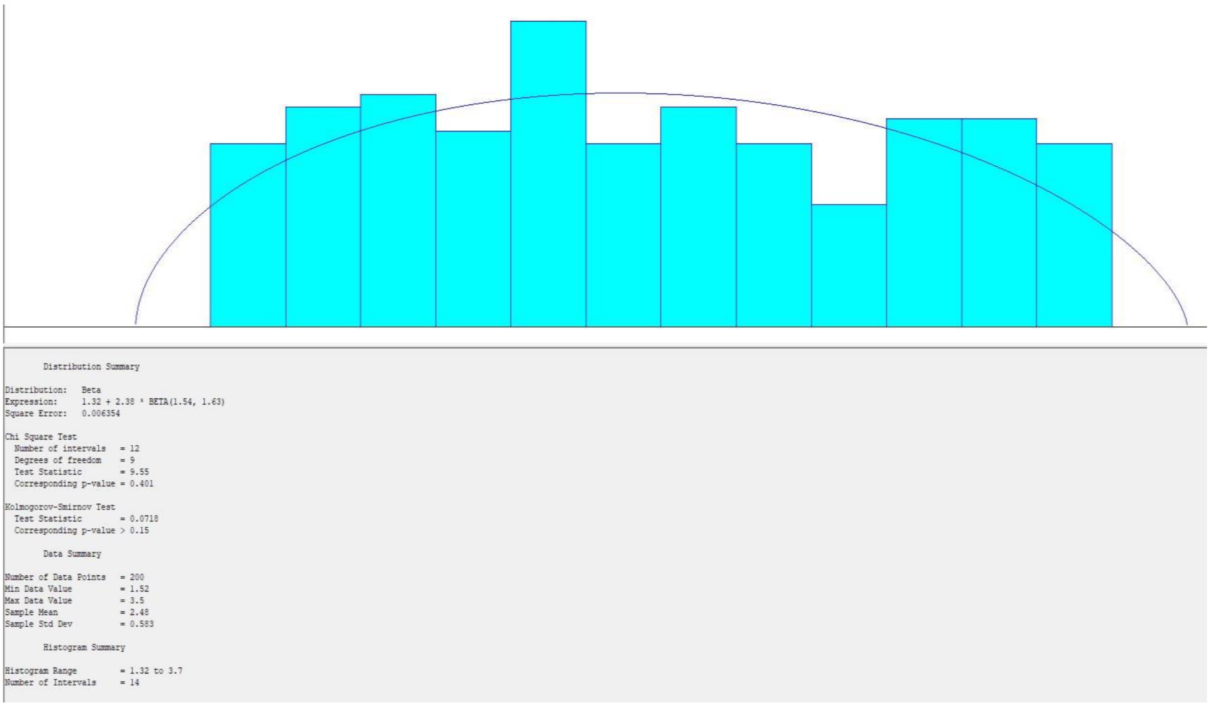


Fig: Data representation for Patient Service Rate in Arena

3.3 Model Design

Our model is stochastic because patients arrive at the vaccination center at random. Furthermore, because the state of the system changes in response to events, it is classified as a discrete model. Arena Simulation is being used for discrete occurrences in this case.
Entities: Patients
Queues: Sanitize hands, Reception Counter, Collect patient details, Vaccination counters.
Resources: Receptionist, Health official, Nurse, Sanitizer, Table, Laptop, Printer, Vaccination Kits
Events: Arrival, Exit

3.3.1 System with One Counter

We considered the Montreal's busiest vaccination clinics. In the current vaccination method, the patient will arrive and then undergo sanitization to ensure that he is virus-free on the outside. The receptionist will complete the questionnaire with each individual and determine whether they are eligible for vaccination. If the person is not eligible, he will be asked to leave the vaccination center because immunization is not necessary for him, and if he is, he will queue to meet the health official who will collect his insurance and mailing information. After that person will join the queue for the vaccination and the nurse will do the required. In specified intervals of the entire process, the person will go for sanitization multiple times.
Because just one server or resource is used for each event in the existing version, the waiting time in this model will be longer. The patient must spend a significant amount of time in line, and there are little resources available to meet the demand.

3.3.1.1 Process Map for Exiting System – Single Counter Waiting time

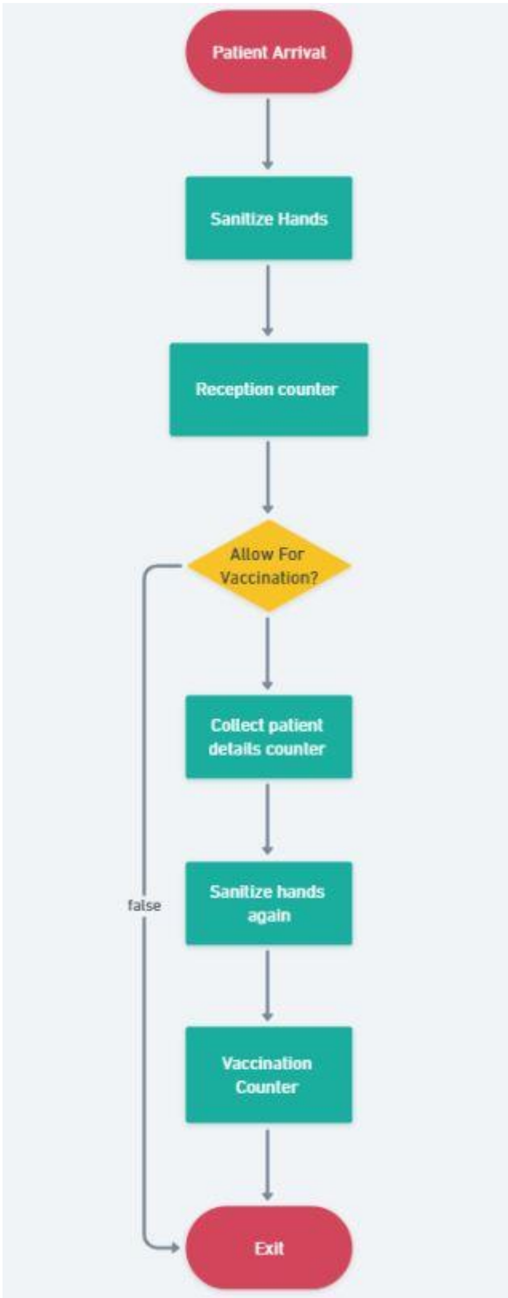


Fig: Process Map for Existing System

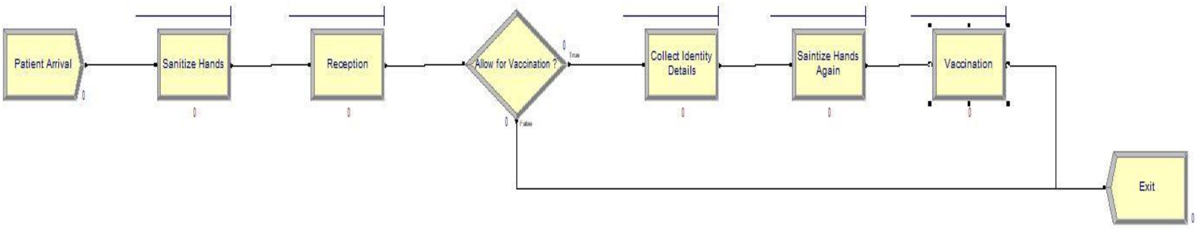


Fig: Process Map for Existing System in Arena

3.3.2 The Proposed model – Double counter

We have increased the counters at each model queue in the system we propose. When a patient first enters the vaccination center, he or she will be escorted to one of the several reception counters to complete a questionnaire. If he or she is eligible for vaccination, he or she will be referred to the nearest health official counter to provide personal information. Finally, he will be permitted to travel to one of the available vaccine counters, where a Nurse will perform the necessary procedures. The person must leave the immunization center if he is not eligible for vaccination. During the vaccination process, the individual must also sanitize their hands several times.

With the addition of more counters, the wait time in this process model has been considerably reduced. In addition, the service time has been enhanced, and the vaccination process can now accommodate a larger number of patients.

3.3.2.1 Model Setup

1) Run Setup in Arena

The simulation is performed on a 24-hour clock assuming it runs for 12 hours starting from 8AM –8 PM. Total of 20 days were replicated to measure the accuracy. We have taken the average of 400 patients everyday who visit the vaccination clinics.

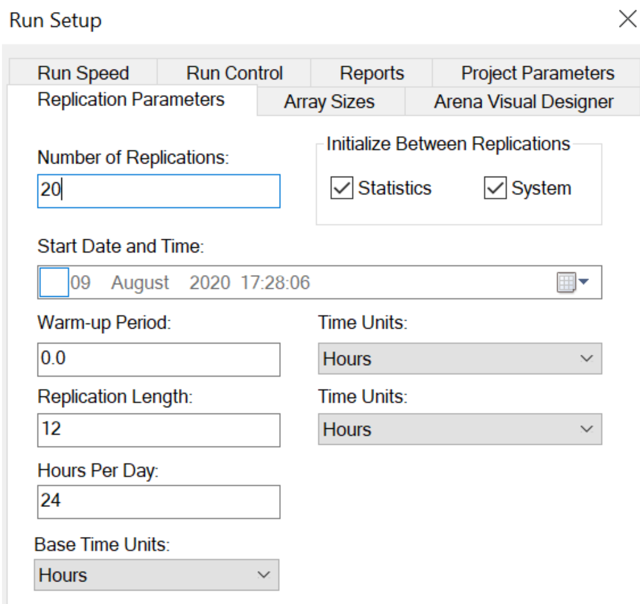


Fig: Simulation Run setup in Arena

2) Queues in Reception Counter, Consultation, Vaccination.

The time taken at each counter to avail the service is given in the process. A resource such as receptionist, Health official, Nurse has been captured by the patient and is released once he/she avails the service. To achieve this process 'Seize Delay Release' was chosen as the action.

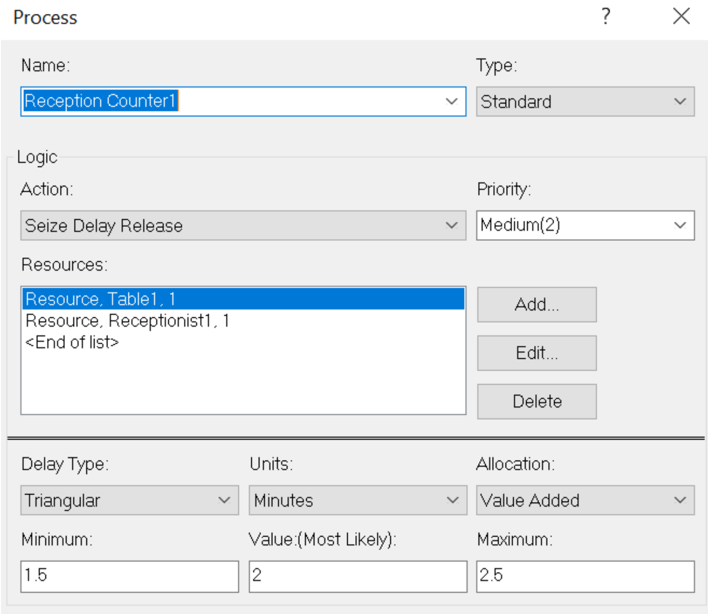


Fig: Reception Queue setup in Arena

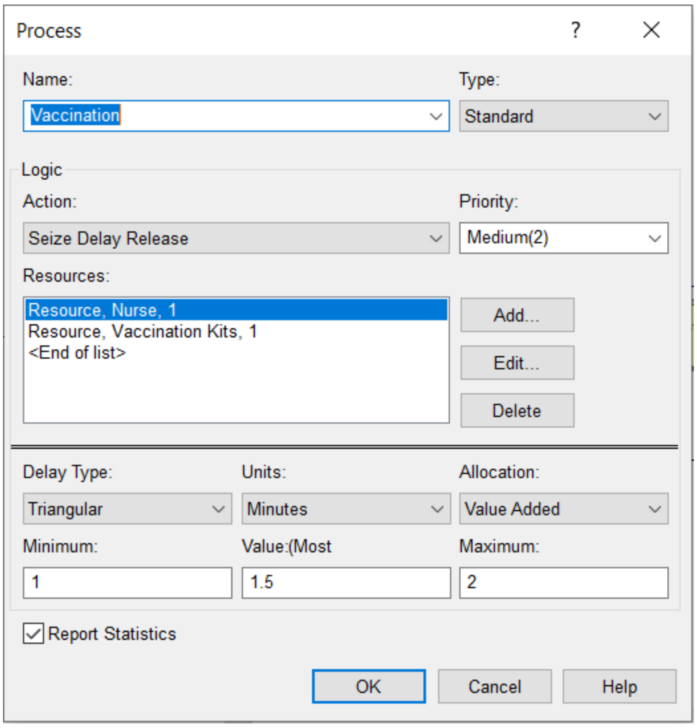


Fig: Vaccination Queue setup in Arena

3) Decision making.

The decision process whether a person is eligible for vaccination or not is given as 90% eligible which is a true case. For other decision-making processes at respective counter direction given as 50%.

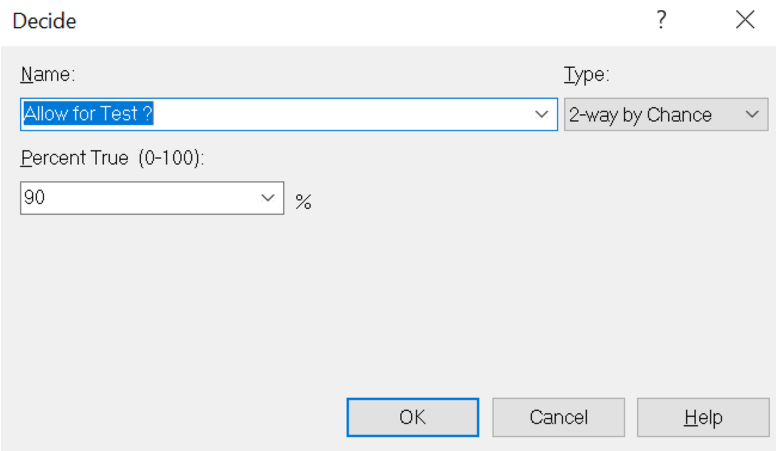


Fig: Vaccination eligibility decision setup in Arena

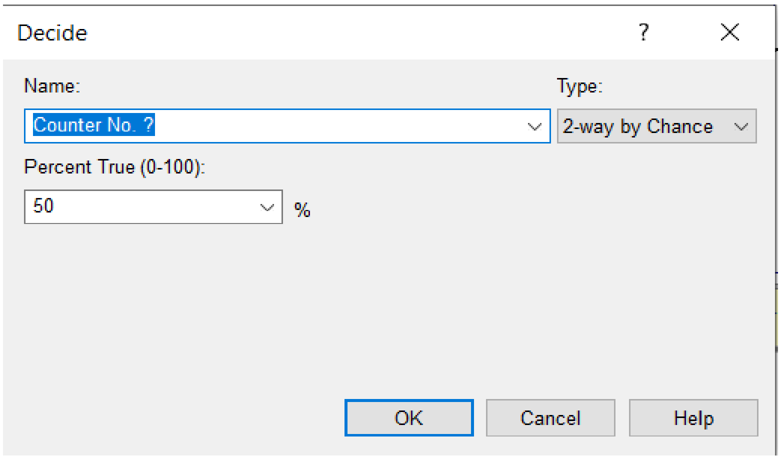


Fig: Vaccine collection Counter decision setup in Arena

4) The below Entities were created in the implemented system.

	Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Minimum	Value	Maximum	Report Statistics
1	Vaccination counter 1	Standard	Seize Delay Release	Medium(2)	2 rows	Triangular	Minutes	Value Added	1	1.5	2	☑
2	Vaccination counter 2	Standard	Seize Delay Release	Medium(2)	2 rows	Triangular	Minutes	Value Added	1	1.5	2	☑
3	Reception Counter1	Standard	Seize Delay Release	Medium(2)	2 rows	Triangular	Minutes	Value Added	1.5	2	2.5	☑
4	Reception Counter2	Standard	Seize Delay Release	Medium(2)	2 rows	Triangular	Minutes	Value Added	1.5	2	2.5	☑
5	Collect Patient Details Counter 2	Standard	Seize Delay Release	Medium(2)	3 rows	Triangular	Minutes	Value Added	1.5	2	3	☑
6	Sanitize Hands	Standard	Seize Delay Release	Medium(2)	1 rows	Constant	Seconds	Value Added	5	10	1.5	☑
7	Sanitize Hands Again	Standard	Seize Delay Release	Medium(2)	1 rows	Constant	Seconds	Value Added	5	10	1.5	☑
8	Collect Patient Details Counter 1	Standard	Seize Delay Release	Medium(2)	3 rows	Triangular	Minutes	Value Added	1.5	2	3	☑

Fig: Entity table for double counter implementation

	Name	Type	Percent True
1	Allow for Vaccination ?	2-way by Chance	90
2	Counter No. ?	2-way by Chance	50
3	Reception Counter ?	2-way by Chance	50
4	Details Collection Counter ?	2-way by Chance	50

Fig: Decision making table for double counter implementation

3.3.2.2 Process Map for Proposed System – Multiple Counter Waiting time

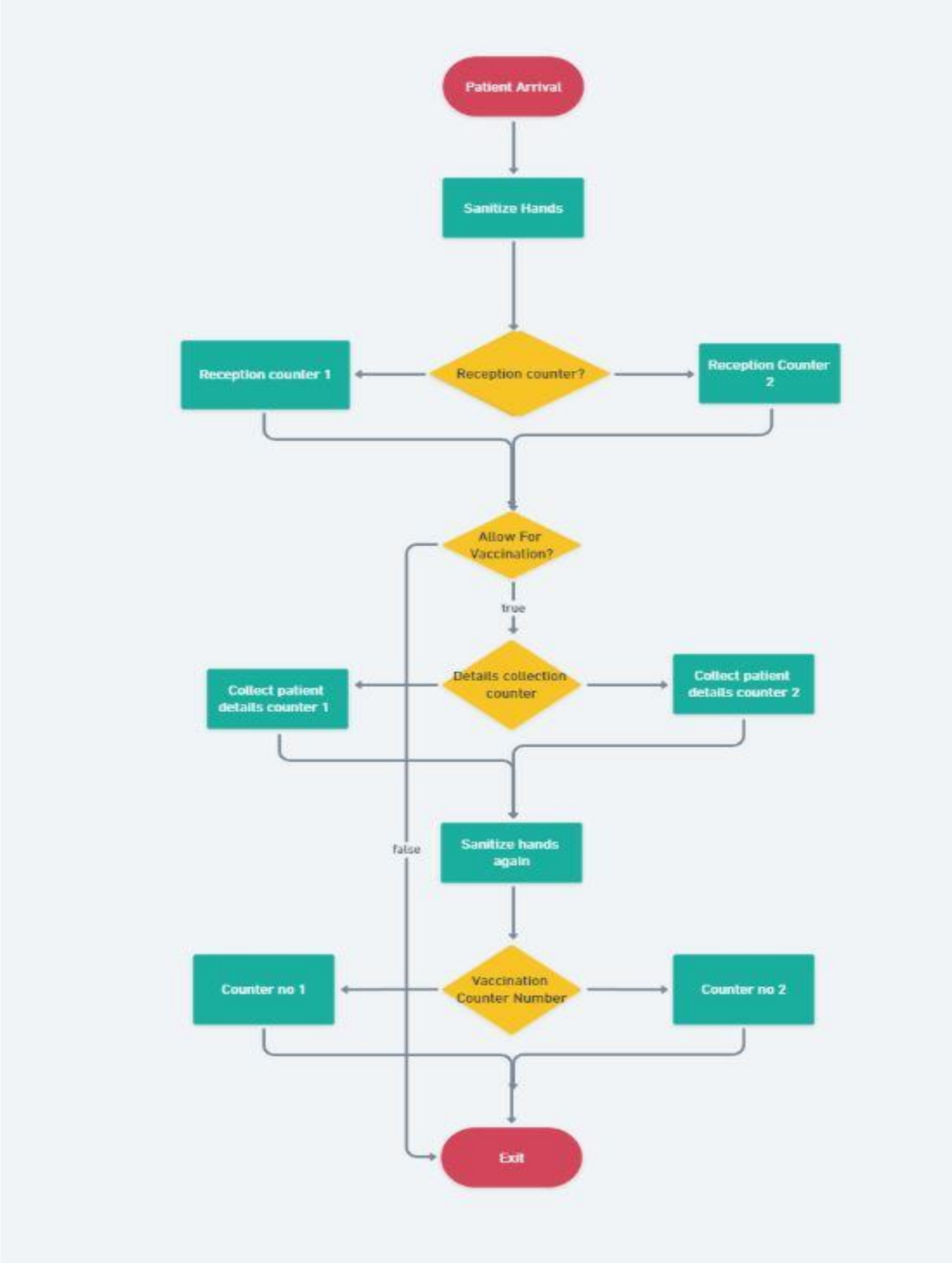
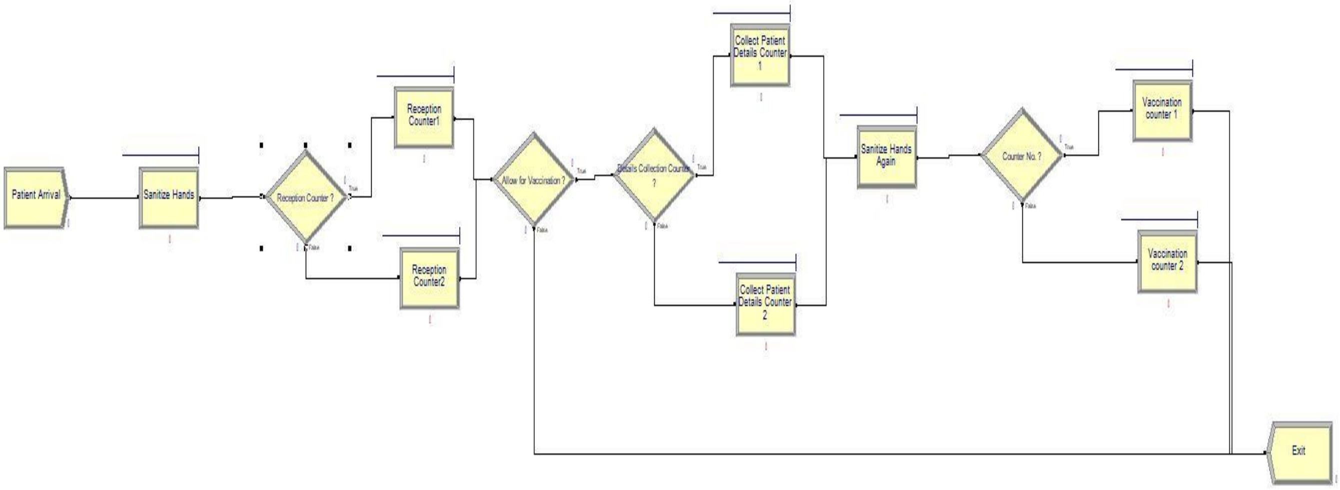


Fig: Process Map for Existing System



Process map for multiple counters in Arena

3.4 Output Analysis

The simulation is done on 24-hour clock starting from 8 AM to 8 PM as the vaccination centre will be opened for 12 hours a day. The model is replicated for 20 days to get the accurate results. The units are considered in hours. Upon running the model simulation, the following results were depicted for both Existing and Implemented model.

The results for the existing system are as follows.

3.4.1 Existing System Results – Arena reports

The reports overview of the existing system is showed below:

22:11:18 Category Overview August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	200

Performance Indicators for Existing System in Arena

22:11:18 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.08722118	0.00	0.08596373	0.0900	0.02840293	0.1218

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.3041	0.10	0.1585	0.5866	0.00	1.3669

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.3914	0.10	0.2457	0.6731	0.03168868	1.4580

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Patient	200.00	0.00	200.00	200.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Patient	200.00	0.00	200.00	200.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	6.5227	1.71	4.0958	11.2181	0.00	44.0000

Results for each entity in Arena reports

22:11:18 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Collect Identity Details.Queue	0.01401499	0.00	0.00627835	0.02173566	0.00	0.1179
Reception.Queue	0.2927	0.10	0.1437	0.5691	0.00	1.3430
Saintize Hands Again.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Sanitize Hands.Queue	0.00013779	0.00	0.00007849	0.00019331	0.00	0.00481177
Vaccination.Queue	0.00003594	0.00	0.00000458	0.00009017	0.00	0.00463839

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Collect Identity Details.Queue	0.1881	0.04	0.08214178	0.2880	0.00	4.0000
Reception.Queue	4.8782	1.69	2.3943	9.4849	0.00	40.0000
Saintize Hands Again.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Sanitize Hands.Queue	0.00229648	0.00	0.00130822	0.00322178	0.00	2.0000
Vaccination.Queue	0.00048445	0.00	0.00005998	0.00123990	0.00	1.0000

Results for each Queue in Arena reports

Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Laptop	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Nurse	0.3329	0.01	0.3246	0.3546	0.00	1.0000
Printer	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Receptionist	0.5551	0.00	0.5508	0.5611	0.00	1.0000
Sanitizer	0.04629630	0.00	0.04629630	0.04629630	0.00	1.0000
Sanitizer2	0.03712963	0.00	0.03634259	0.03958333	0.00	1.0000
Table	0.5551	0.00	0.5508	0.5611	0.00	1.0000
Vaccination Kits	0.3329	0.01	0.3246	0.3546	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Laptop	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Nurse	0.3329	0.01	0.3246	0.3546	0.00	1.0000
Printer	0.4823	0.01	0.4725	0.5059	0.00	1.0000
Receptionist	0.5551	0.00	0.5508	0.5611	0.00	1.0000
Sanitizer	0.04629630	0.00	0.04629630	0.04629630	0.00	1.0000
Sanitizer2	0.03712963	0.00	0.03634259	0.03958333	0.00	1.0000
Table	0.5551	0.00	0.5508	0.5611	0.00	1.0000
Vaccination Kits	0.3329	0.01	0.3246	0.3546	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Laptop	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Nurse	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Printer	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Receptionist	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Sanitizer	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Sanitizer2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Table	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Vaccination Kits	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

22:11:18 **Category Overview** August 16, 2021

Values Across All Replications

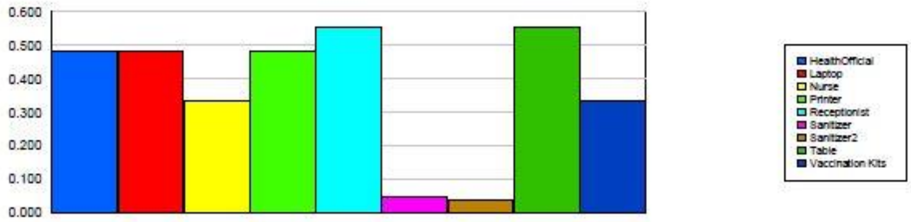
Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
HealthOfficial	0.4823	0.01	0.4725	0.5059
Laptop	0.4823	0.01	0.4725	0.5059
Nurse	0.3329	0.01	0.3246	0.3546
Printer	0.4823	0.01	0.4725	0.5059
Receptionist	0.5551	0.00	0.5508	0.5611
Sanitizer	0.04629630	0.00	0.04629630	0.04629630
Sanitizer2	0.03712963	0.00	0.03634259	0.03958333
Table	0.5551	0.00	0.5508	0.5611
Vaccination Kits	0.3329	0.01	0.3246	0.3546



22:11:18 **Category Overview** August 16, 2021

Values Across All Replications

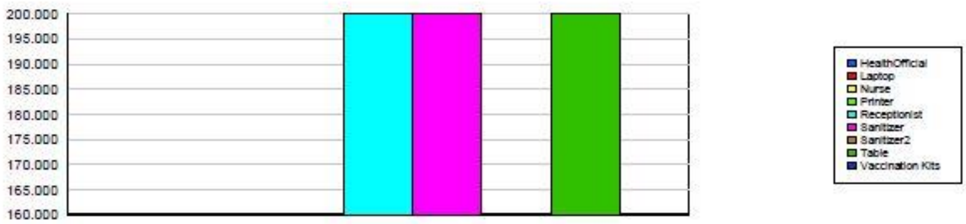
Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
HealthOfficial	160.40	3.15	157.00	171.00
Laptop	160.40	3.15	157.00	171.00
Nurse	160.40	3.15	157.00	171.00
Printer	160.40	3.15	157.00	171.00
Receptionist	200.00	0.00	200.00	200.00
Sanitizer	200.00	0.00	200.00	200.00
Sanitizer2	160.40	3.15	157.00	171.00
Table	200.00	0.00	200.00	200.00
Vaccination Kits	160.40	3.15	157.00	171.00



Averages of the resource Usages in Arena reports

3.4.2 Implemented System Results – Arena Models

Now, these are the results for the proposed model with multiple counters:

22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Key Performance Indicators

System	Average
Number Out	400

Performance Indicators for Implemented system in Arena

22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.0935	0.00	0.0918	0.0953	0.02864453	0.1210

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.4613	0.13	0.2441	0.7352	0.00	1.5317

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	0.5547	0.13	0.3359	0.8291	0.03035218	1.6288

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Patient	400.00	0.00	400.00	400.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Patient	400.00	0.00	400.00	400.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Patient	18.4916	4.21	11.1961	27.6372	0.00	75.0000

Entity performance result for implemented model

22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Collect Patient Details Counter 1.Queue	0.1088	0.05	0.04785139	0.2425	0.00	0.5778
Collect Patient Details Counter 2.Queue	0.1333	0.09	0.03067299	0.4391	0.00	0.7552
Reception Counter1.Queue	0.2864	0.10	0.1217	0.5678	0.00	0.8742
Reception Counter2.Queue	0.3865	0.14	0.1094	0.6567	0.00	1.0523
Sanitize Hands Again.Queue	0.00009795	0.00	0.00004598	0.00016334	0.00	0.00276662
Sanitize Hands.Queue	0.00194209	0.00	0.00177446	0.00214278	0.00	0.01822136
Vaccination counter 1.Queue	0.00813157	0.00	0.00494023	0.01182243	0.00	0.08840064
Vaccination counter 2.Queue	0.00780317	0.00	0.00623647	0.00949038	0.00	0.06741631

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Collect Patient Details Counter 1.Queue	1.6635	0.73	0.6779	3.8596	0.00	15.0000
Collect Patient Details Counter 2.Queue	2.1023	1.52	0.4243	7.4640	0.00	22.0000
Reception Counter1.Queue	4.6762	1.62	2.0389	9.1788	0.00	28.0000
Reception Counter2.Queue	6.6271	2.51	1.7782	11.3829	0.00	31.0000
Sanitize Hands Again.Queue	0.00294474	0.00	0.00133348	0.00494097	0.00	1.0000
Sanitize Hands.Queue	0.06473620	0.00	0.05914854	0.07142598	0.00	7.0000
Vaccination counter 1.Queue	0.1236	0.03	0.06833989	0.1837	0.00	4.0000
Vaccination counter 2.Queue	0.1162	0.01	0.0934	0.1378	0.00	3.0000

Queue waiting time at each counter for the implemented models in Arena

22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
HealthOfficial2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Laptop1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
Laptop2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Nurse1	0.3760	0.01	0.3491	0.4034	0.00	1.0000
Nurse2	0.3699	0.01	0.3438	0.4046	0.00	1.0000
Printer1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
Printer2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Receptionist1	0.5481	0.02	0.5266	0.5989	0.00	1.0000
Receptionist2	0.5626	0.02	0.5036	0.5854	0.00	1.0000
Sanitizer1	0.0926	0.00	0.0926	0.0926	0.00	1.0000
Sanitizer2	0.08326389	0.00	0.08055556	0.08541667	0.00	1.0000
Table1	0.5481	0.02	0.5266	0.5989	0.00	1.0000
Table2	0.5626	0.02	0.5036	0.5854	0.00	1.0000
VaccinationKits1	0.3760	0.01	0.3491	0.4034	0.00	1.0000
VaccinationKits2	0.3699	0.01	0.3438	0.4046	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
HealthOfficial2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Laptop1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
Laptop2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Nurse1	0.3760	0.01	0.3491	0.4034	0.00	1.0000
Nurse2	0.3699	0.01	0.3438	0.4046	0.00	1.0000
Printer1	0.5423	0.02	0.4753	0.5873	0.00	1.0000
Printer2	0.5402	0.03	0.4801	0.6144	0.00	1.0000
Receptionist1	0.5481	0.02	0.5266	0.5989	0.00	1.0000
Receptionist2	0.5626	0.02	0.5036	0.5854	0.00	1.0000
Sanitizer1	0.0926	0.00	0.0926	0.0926	0.00	1.0000
Sanitizer2	0.08326389	0.00	0.08055556	0.08541667	0.00	1.0000
Table1	0.5481	0.02	0.5266	0.5989	0.00	1.0000
Table2	0.5626	0.02	0.5036	0.5854	0.00	1.0000
VaccinationKits1	0.3760	0.01	0.3491	0.4034	0.00	1.0000
VaccinationKits2	0.3699	0.01	0.3438	0.4046	0.00	1.0000

22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HealthOfficial1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
HealthOfficial2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Laptop1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Laptop2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Nurse1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Nurse2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Printer1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Printer2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Receptionist1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Receptionist2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Sanitizer1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Sanitizer2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Table1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Table2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
VaccinationKits1	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
VaccinationKits2	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

Average Usage of resources for implemented model- Arena

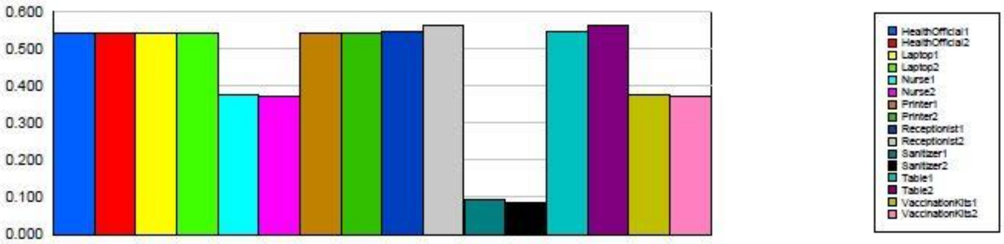
Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
HealthOfficial1	0.5423	0.02	0.4753	0.5873
HealthOfficial2	0.5402	0.03	0.4801	0.6144
Laptop1	0.5423	0.02	0.4753	0.5873
Laptop2	0.5402	0.03	0.4801	0.6144
Nurse1	0.3760	0.01	0.3491	0.4034
Nurse2	0.3699	0.01	0.3438	0.4046
Printer1	0.5423	0.02	0.4753	0.5873
Printer2	0.5402	0.03	0.4801	0.6144
Receptionist1	0.5481	0.02	0.5266	0.5989
Receptionist2	0.5626	0.02	0.5036	0.5854
Sanitizer1	0.0926	0.00	0.0926	0.0926
Sanitizer2	0.08326389	0.00	0.08055556	0.08541667
Table1	0.5481	0.02	0.5266	0.5989
Table2	0.5626	0.02	0.5036	0.5854
VaccinationKits1	0.3760	0.01	0.3491	0.4034
VaccinationKits2	0.3699	0.01	0.3438	0.4046



22:32:58 **Category Overview** August 16, 2021

Values Across All Replications

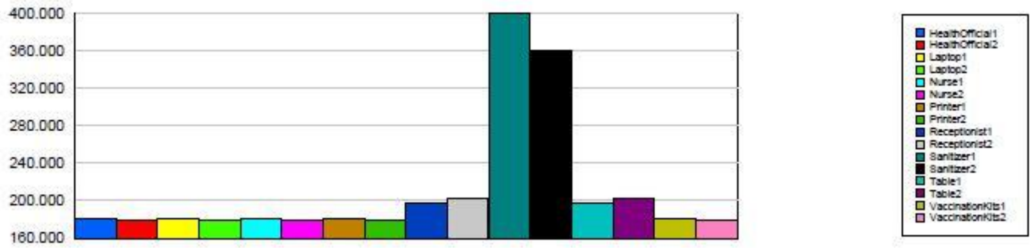
Unnamed Project

Replications: 10 Time Units: Hours

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
HealthOfficial1	180.40	7.83	156.00	193.00
HealthOfficial2	179.30	9.17	162.00	204.00
Laptop1	180.40	7.83	156.00	193.00
Laptop2	179.30	9.17	162.00	204.00
Nurse1	180.80	6.16	166.00	195.00
Nurse2	178.90	5.76	168.00	194.00
Printer1	180.40	7.83	156.00	193.00
Printer2	179.30	9.17	162.00	204.00
Receptionist1	197.20	6.01	189.00	217.00
Receptionist2	202.80	6.01	183.00	211.00
Sanitizer1	400.00	0.00	400.00	400.00
Sanitizer2	359.70	4.38	348.00	369.00
Table1	197.20	6.01	189.00	217.00
Table2	202.80	6.01	183.00	211.00
VaccinationKits1	180.80	6.16	166.00	195.00
VaccinationKits2	178.90	5.76	168.00	194.00



Observations:

The average customer wait time has decreased from 0.46 to 0.035, and the average total time spent by each patient has decreased from 0.83 to 0.29. The maximum total time spent by each patient is reduced from 2.6 to 0.7, and simulation units are measured in hours. The model that we designed has more resources, and the number of patients served per day appears to have increased in the implemented model.

3.5 Verification and Validation:

3.5.1 Verification

The model met the system requirements and could operate effectively with better results during the implementation stage; therefore, verification was done using simulation approaches. Static and dynamic testing techniques are the two types of verification techniques.

Static testing:

Static testing verifies how well the system would operate with the established technique based just on model specification. We can say that our implemented model of increasing the number of counters in dealing with patients and dedicating a count of patients to treat for each hour would show good results in reducing the waiting time for patients/people who come to be vaccinated, which in either way reduces the exposure and risk. In our situation, additional counters, appointments, and a specific number of testing workers are used to meet the criteria for the model at any moment in all possible conditions.

Dynamic testing:

Simulation approaches are used in dynamic testing to verify the model and check behavior in real time. We are confident in declaring that the model is proven for many scenarios because of the advantage of collecting more precise information via simulation techniques. More scenario-based realistic testing was conducted as a single counter and a double counter with various data sets to calculate the average wait time, with good findings. Because our simulation testing is a methodology-based approach to reducing wait time rather than product development, we employed a scenario and model execution to ensure that the system worked as intended. We've gotten outputs in such a manner that the parameters involved have a stronger impact in lowering the waiting or vaccinating time, just like a real-time system, with various values of patients coming in at different hours and varying the counters to manage, just like a real-time system. At the verification step, meeting specifications when dealing with model implementation is desirable, and our model meets the intended specification of vaccinating a given number of people.

3.5.2 Validation

Validating our model is to determine that our data which we have provided meets with real world representation and the changes in input have significant bearing over our output. We have used hypothesis testing in determining that our observed data and expected data are good enough in proceeding with the simulation. We also conclude that our model is valid with two other valid vaccination techniques namely degenerate tests and event validity.

Degenerate test:

Degeneracy of model behavior is tested with changes in input values and few other modifications in the parameters. There will be decrease in queue, for people to get vaccinated when the service time is less when compared to the longer arrival time. In our case when people visit the vaccination center the arrival times longer than usual then there would be a few people in queue as service time is also reduced than arrival time.

Event validity:

Our model is said to be valid in case of event validity as the event occurrences are way like the real-world scenarios as the events dealing with model are true and valid. Patient arrival times and vaccinating times along with details identification counters and vaccines are all the real-world scenario and as patient wait time reduction simulation model deals with the service times and arrival times.

Along with the above two techniques one strong validation model of hypothesis testing in assessing the data to proceed further was also done in making it to have hypothesis of data and model being used would be true at all possible scenarios.

4. Monte Carlo Simulation - MS-Excel

Monte Carlo Simulations are used to model the possibility of different outcomes in a process that cannot be easily predicted due to the presence of random variables. It is also termed as a mathematical technique that is used to calculate the risk of a system by qualitative analysis anddecision making. Monte Carlo Simulation is used to analyze systems in various fields like Healthcare, Finance, Engineering and Supply Chain, etc. In the process of simulation for predicting the risk of a system, we face a lot of uncertain variables that make our study difficultto complete. These situations can be addressed by Monte Carlo Simulation modeling by just replacing an uncertainty variable with a single average number, and it is proven that the simulation has yielded better solutions and results.

We decided to choose Monte Carlo simulation to analyze and predict the possible waiting andservice times of the patients arriving for a COVID testing center to give their samples. We haveconsidered an existing system with our assumptions by looking at a testing site and come up with a proposed solution to reduce the waiting and service times and provide quick service.

Parameters to be considered for designing a Simulation Model -

Arrival Rate – The number of patients arriving for testing to the COVID testing center in at specified intervals.

Maximum Capacity in Queue – The maximum number of patients can be waiting in the queue.

Arrival Process –Decide the arrival process of the patients, can be at scheduled arrivals or at random times.

Service Pattern – The pattern in which each patient goes through the process and exit the testingcenter. Based on these patterns, we can derive the Average service time per each patient and the number of patients served every minute or hour.

4.1 Monte Carlo - Model Description

Our Team's intention is to design a simulation model to determine the waiting time and service times for registered citizensvisiting a COVID-19 vaccination center with an existing system(Montreal-based) and then demonstrate a new effective and efficient possible solution after evaluating the outcomes. In the current system, registered people while going to a vaccination center, they go through a set of predefined exercises like exchanging the old mask with a new one, sanitizing their hands and bags, consultation with service desk by providing their identity and then consulting the health department and then finally getting the vaccination shot, wait for 5 minutes, and then exit the vaccination center. At each action, the citizens will spend few minutes of time and then advance to the laterstages. The arrival rate and service time at each stage are the demanding specification to be described practically while simulating the model.
Monte Carlo Simulation is an advanced mathematical simulation model, in our case we are considering the distributions that are applicable for arrival rate and service patterns. For arrival rate we are using Poisson Distribution, which is used to describe the distribution of rare events in a large population.

Arrival Rate – Poisson Distribution Service

Times – Exponential DistributionQueue

Capacity – No Limit

The uniform distribution is a probability distribution model that describes the time between the events that has constant probability. The events occur rate is independent and continuous at a constant rate in this uniform distribution. In Monte Carlo model, the system also has the service pattern at each process is continuous and independent of each other with a consistent service time. So, we are determined to move forward with uniform distribution for service times.

Poisson distribution is a discrete probability distribution that gives the number of registered citizens visiting the COVID-19 vaccination center over a given period, given the average number of citizens visit over that period. Based on the requirement to satisfy the problem statement we must assume that the arrival rate of patients is random, we felt Poisson distribution is the perfect apt for our model.

4.2 Monte Carlo - Input Analysis

Based on our recent research, we are considering that a COVID-19 vaccination center will serve an average of 300 registrations per day and the vaccination center will be open for 8 hours

Analysis of Arrival rate	
Average number of citizens vaccinated daily	300 registered citizens
No of working hours per day	08 hours
No of registered citizens arrived in an hour	37.5 per hour
Nor of registered citizens arrived in a minute	0.625 per minute
Average minutes per arrival	1.4

Analysis of Service rate	
Citizens vaccinated per hour	30 per hour
Citizens vaccinated per minute	0.57
Average minutes per one citizen	3.8 minutes

Total Service Time = Sum of Service Times (Sanitization, validity of Identification, Consultation, Vaccination shot)

Process	**Service Times**
Sanitization	10 seconds
Validity of Identification	1.5 minutes
Consultation	2 minutes
Vaccination Shot	< 1 minute
Total Average	4 minutes/patient

The service waiting times doesn't include the queue waiting times of each citizen takes to startthe process. The output of the Monte Carlo simulation model will demonstrate the Average waiting time of citizens spent in the queue to complete their service.

Process	Service Times
Sanitization	Receptionist will provide the sanitary mask and sanitizer to the applicants
Validity of Identification	Officer will check the registration details, health card and passport verification
Consultation	Doctor will ask your recent health condition and provide suggestions on after effects
Vaccination Shot	Nurse will perform the vaccination shot on left hand and ask them to take the precuations
Total Average	4 minutes/patient

4.3 Existing System

4.3.1 Simulation Model – Single Booth

In this model, the vaccination center will only have 1 check-in booth, 1 Identity validation booth, and 1 vaccination booth. The patient arrived at the center will have to go through the entire process sequentially and have exit after getting the vaccination shot by the nurse.

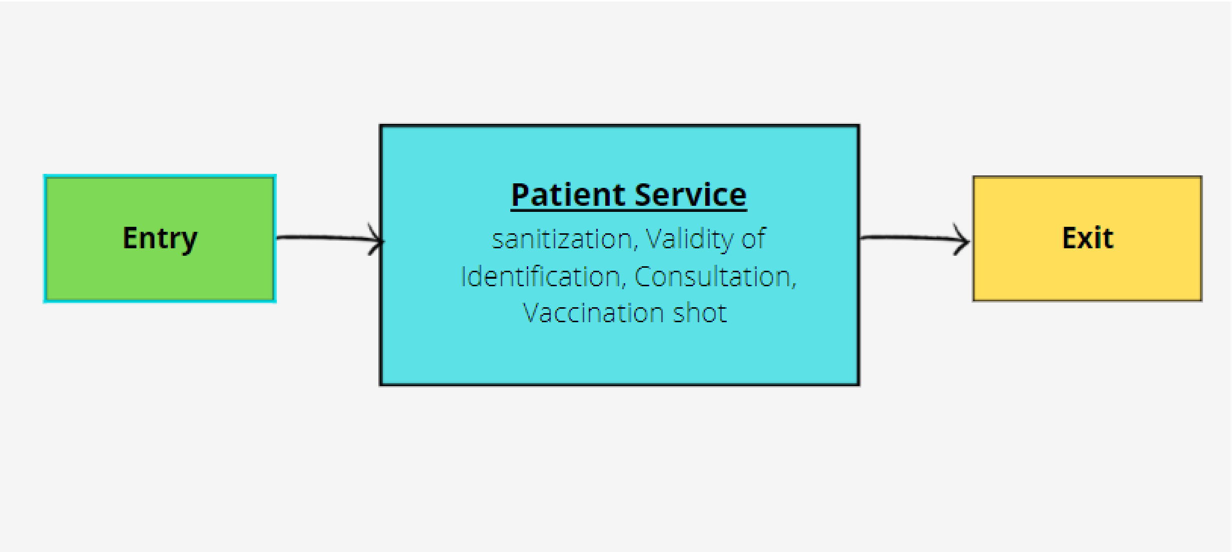


Fig: Representation of the process using the flow diagram

Registered Citizen vs Total Service Time

The graph below depicts the total service time taken for each registration. Looking at the graph itis clearly demonstrated that service varying at a range of 3 to 7 minutes

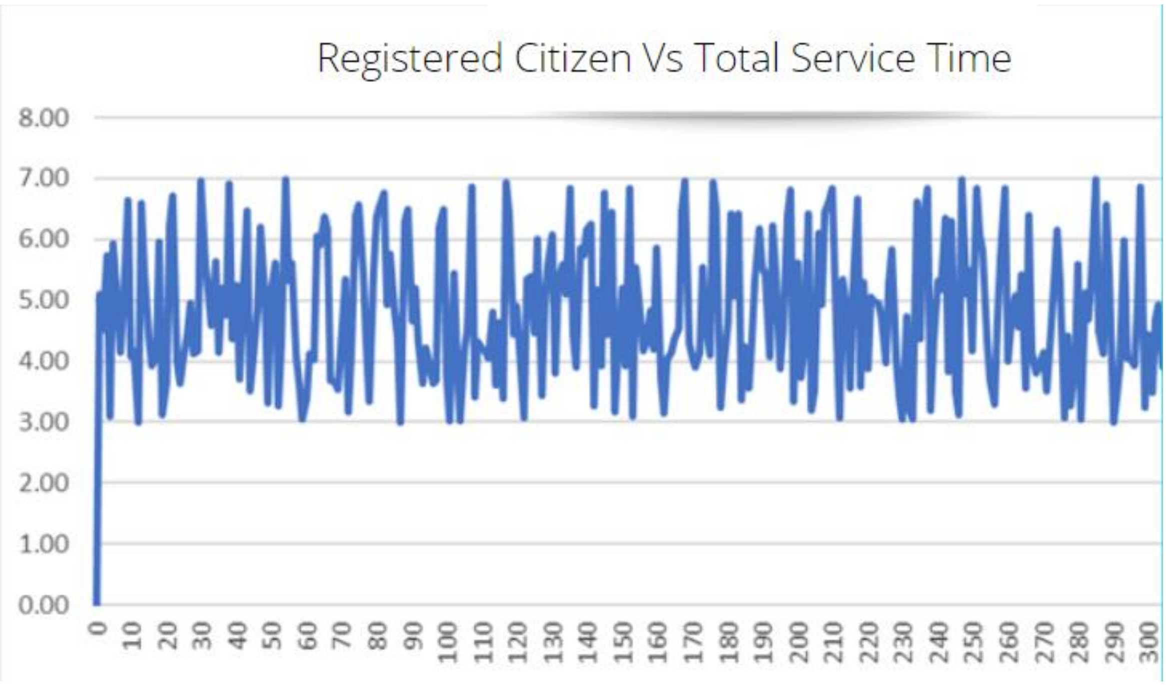


Fig: Citizen Service Rate

Registered Citizen vs Wait Time

The graph below indicates the amount of time each registered citizen must wait to get vaccination shot. From the graph it is demonstrated that the wait time are rising exponentially because of the wait in very long queues.

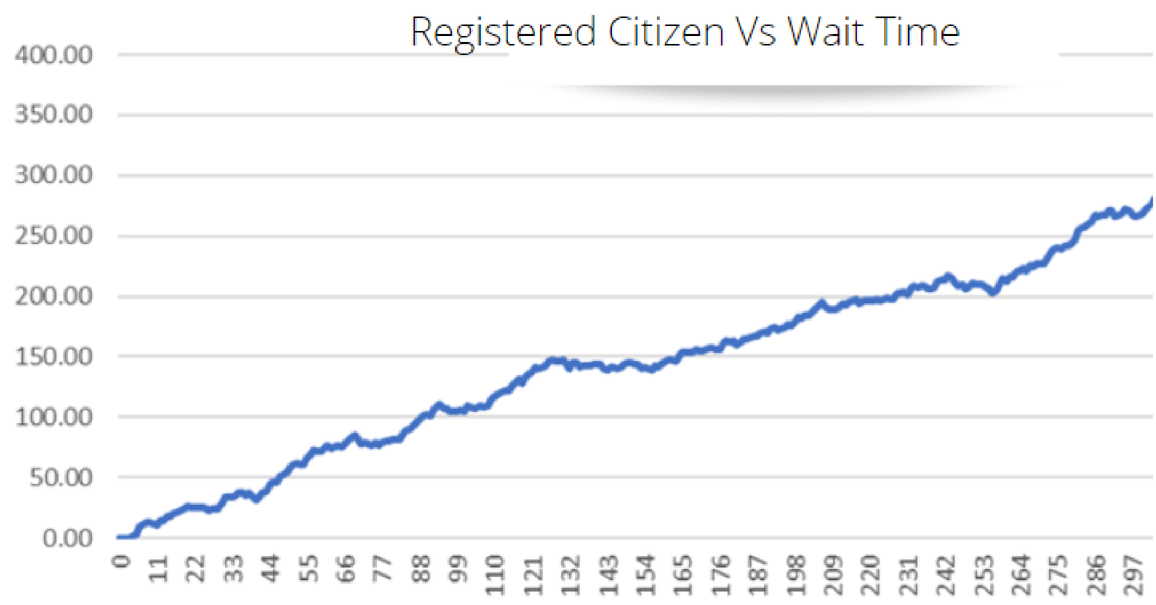
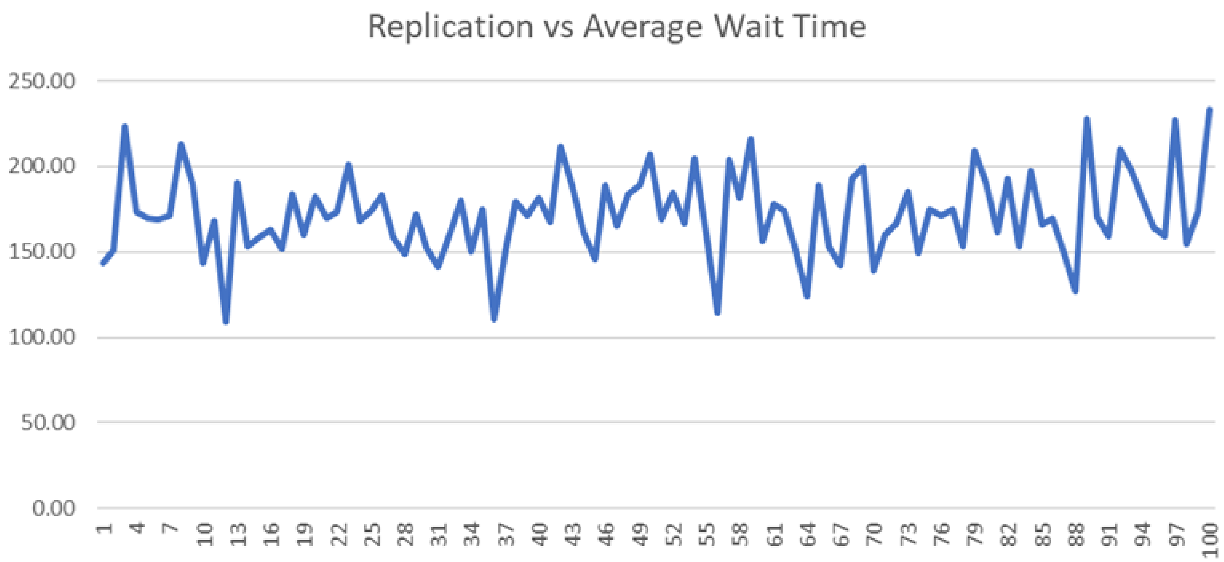


Fig: Citizen wait time because of long queues

Replication vs Average Wait Time:

The below graph represents the average wait time taken by all the registered citizens in various replications. The below graph is plotted for 100 replications.



Registered Citizen	Time between Arrivals	Arrival Time of the citizen	Validation of Identity	Service start	Total Service Time	Service Time End	Wait Time
0	0	0	0	0	0	0	0
1	0	0	1	0	3.69	3.69	0.00
2	1	1	1	3.69	5.87	9.56	2.69
3	2	3	1	9.56	6.14	15.70	6.56
4	1	4	1	15.70	3.53	19.23	11.70
5	2	6	1	19.23	6.35	25.58	13.23
6	1	7	1	25.58	3.76	29.34	18.58
7	4	11	1	29.34	6.75	36.09	18.34
8	0	11	1	36.09	4.98	41.07	25.09
9	2	13	1	41.07	3.31	44.38	28.07
10	3	16	0	44.38	3.00	47.38	28.38
11	2	18	1	47.38	3.44	50.82	29.38
12	2	20	0	50.82	3.00	53.82	30.82
13	0	20	1	53.82	5.38	59.20	33.82
14	2	22	1	59.20	4.44	63.64	37.20
15	2	24	1	63.64	6.69	70.33	39.64
16	3	27	1	70.33	5.33	75.66	43.33
17	1	28	1	75.66	5.65	81.31	47.66

Arrival Distribution - Poisson	
Average arrivals/Hr	37.5
Average arrivals/Min	0.625
Average mins/Arrival	1.4
Service Distribution - Uniform	
Citizens Vaccinated /Hr	30
Citizens Vaccinated /Min	0.57
Average Mins/Patient	3.80
Based on 1 Replication	
Average Wait Time	656.2
Max Wait Time	1331.36
Based on 100 Replication	
Average Wait Time	645.20
Max Wait Time	692.87

Arrival Rate Distribution Table		
Cumulative Probability	Cumulative Probability Lookup	# Mins Between Arrival
0.246596964	0	0
0.591832713	0.246596964	1
0.833497738	0.591832713	2
0.94627475	0.833497738	3
0.985746704	0.94627475	4
0.996798851	0.985746704	5
0.999377685	0.996798851	6
0.999893452	0.999377685	7
0.999983711	0.999893452	8
0.999997752	0.999983711	9
0.999999717	0.999997752	10
0.999999967	0.999999717	11
0.999999997	0.999999967	12
1	0.999999997	13
1	1	14
1	1	15
1	1	16

Run #	Average Wait Time
1	656.21
2	671.02
3	628.98
4	636.17
5	628.75
6	640.82
7	663.24
8	634.52
9	635.54
10	630.32
11	658.14
12	606.47
13	664.16
14	650.49
15	644.34
16	633.83
17	653.50
18	634.67

Fig: Simulation Model for Single counter-Monte Carlo

4.4 Implemented System

4.4.1 Improvised Simulation Model – Two Booth's

Registered Citizen vs Total Service Time

The graph below indicates that the total service time taken for each citizen. By viewing at the graph, itis observed that the service fluctuating at a range of 3.5 to 7.0 minutes.

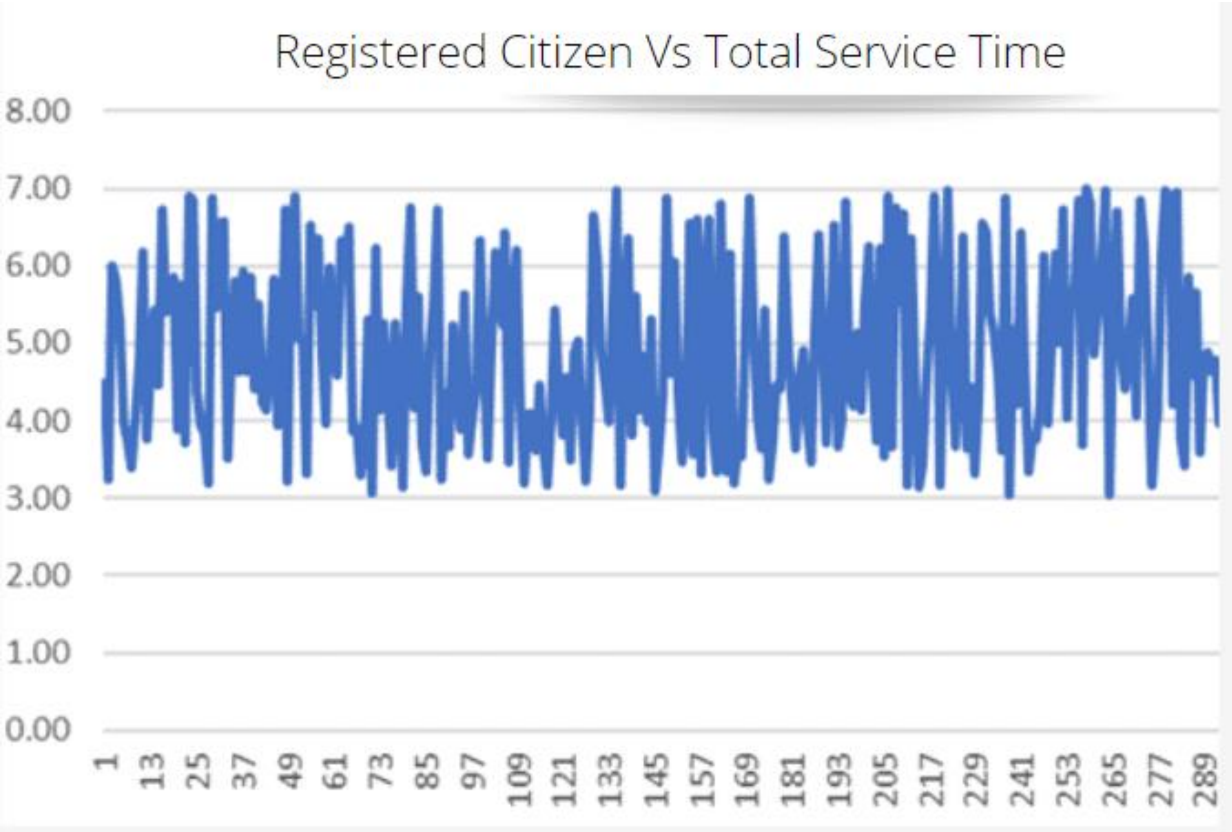


Fig: Citizen Service Rate

Registered Citizen vs Wait time

The graph below indicates the extent number of times each registered citizen must wait to get a vaccination shot. From the below graph it is recognized that the wait time is rising exponentially due to the long waitingqueues. However, the wait times has been reduced to 55-60 % when compared to the single booth in the first place.

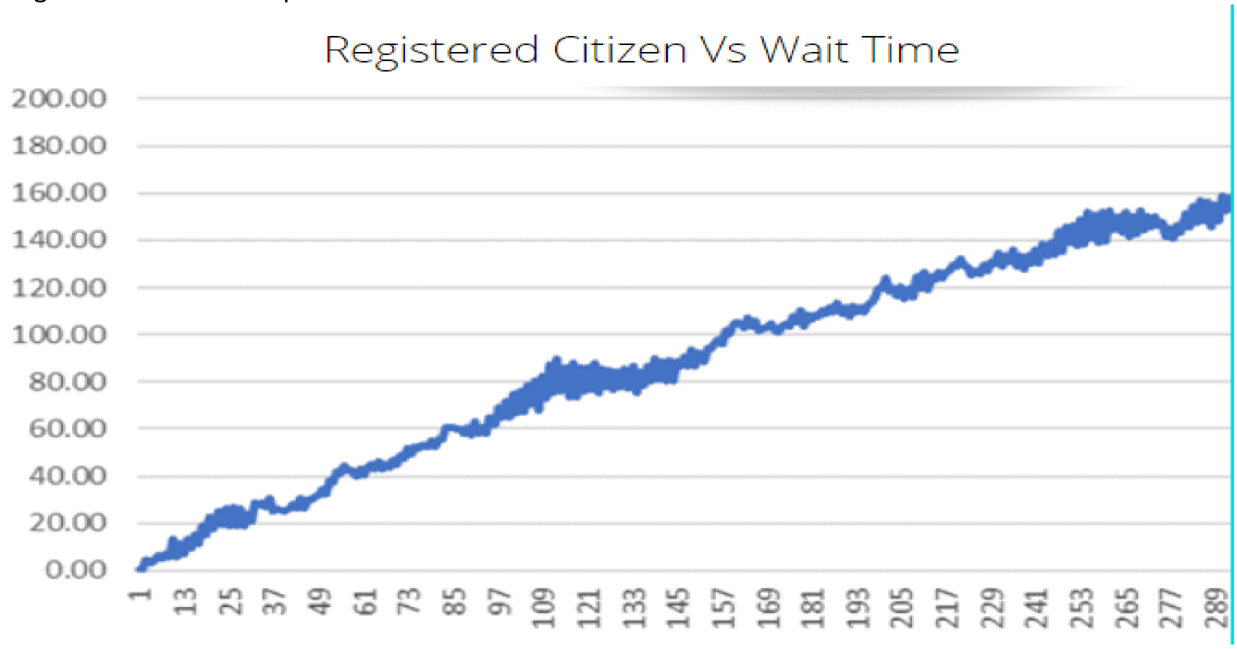
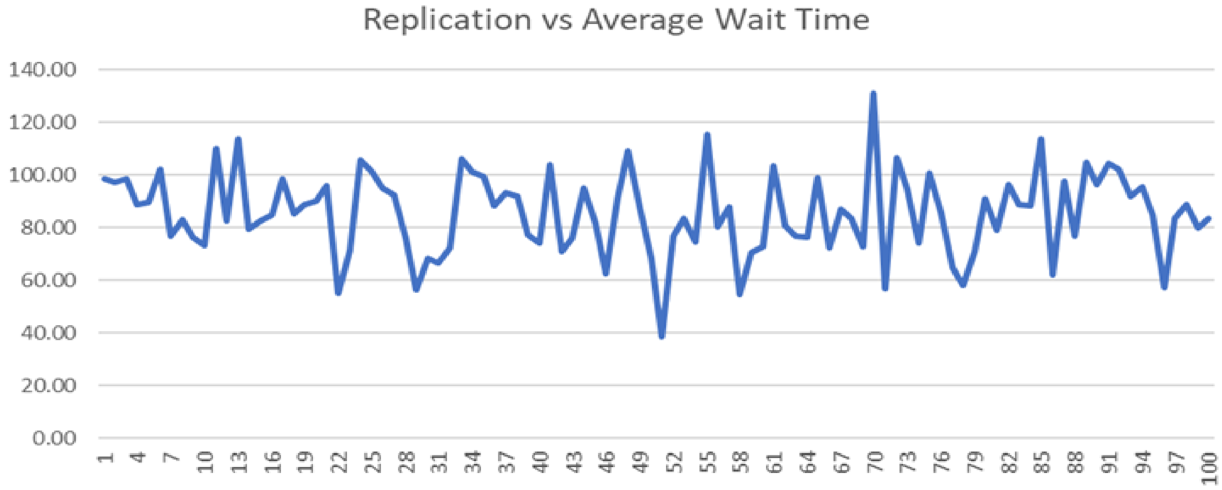


Fig: Citizen wait time because of long queues

Replication vs Average Wait Time

The below graph shows the average waiting time taken by all the patients in different replications. The graph is plotted for 100 replications. The average waiting time for 100 replications was observed to be 85 minutes.



Registered Citizen	Time between Arrivals	Arrival Time of citizens	Validation of Identity	Booth#	Booth #1 Start Time	Booth #1 Total Service Time	Booth #1 End Time	Booth #2 Start Time	Booth #2 Total Service Time	Booth #2 End Time	Wait Time
0	0	0	0	0	0.00	0	0	0	0.00	0	0
1	1	1	0	1	1.00	3.00	4.00				0.00
2	3	4	1	2				4.00	4.74	8.74	0.00
3	1	5	1	1	5.00	4.34	9.34				0.00
4	1	6	1	2				8.74	3.85	12.59	2.74
5	1	7	1	1	9.34	6.45	15.80				2.34
6	0	7	1	2				12.59	5.96	18.55	5.59
7	1	8	1	1	15.80	3.43	19.23				7.80
8	1	9	1	2				18.55	3.66	22.21	9.55
9	0	9	0	1	19.23	3.00	22.23				10.23
10	1	10	1	2				22.21	6.76	28.97	12.21
11	2	12	1	1	22.23	6.36	28.59				10.23
12	1	13	1	2				28.97	6.62	35.59	15.97
13	0	13	1	1	28.59	4.30	32.89				15.59
14	0	13	1	2				35.59	3.80	39.39	22.59
15	1	14	1	1	32.89	6.65	39.54				18.89
16	0	14	1	2				39.39	3.42	42.81	25.39

Arrival Distribution - Poisson	
Average arrivals/Hr	37.5
Average arrivals/Min	0.625
Average mins/Arrival	1.4
Service Distribution - Uniform	
Patients Tested/Hr	30
Patients Tested/Min	0.57
Average Mins/Patient	3.80
Based on 1 Replication	
Average Wait Time	196.8
Max Wait Time	420.14
Based on 100 Replication	
Average Wait Time	185.42
Max Wait Time	222.24

Arrival Rate Distribution Table: Cumulative Probability	Cumulative Probability Lookup	# Mins Between Arrival
0.246596964	0	0
0.591832713	0.246596964	1
0.833497738	0.591832713	2
0.94627475	0.833497738	3
0.985746704	0.94627475	4
0.996798851	0.985746704	5
0.999377685	0.996798851	6
0.999893452	0.999377685	7
0.999983711	0.999893452	8
0.999997752	0.999983711	9
0.999999717	0.999997752	10
0.999999967	0.999999717	11
0.999999997	0.999999967	12
1	0.999999997	13
1	1	14
1	1	15
1	1	16

Run #	Average Wait Time
1	196.78
2	215.61
3	176.78
4	177.56
5	185.44
6	181.04
7	165.09
8	202.06
9	193.50
10	179.27
11	201.42
12	190.08
13	175.96
14	172.34
15	173.63
16	180.44
17	187.59

Fig: Implementation of proposed model with Two Booth's - Excel

4.4.2 Improvised Simulation Model with Constant Arrival – Two Booth's(scheduled Arrival)

Registered Citizen # vs Total Service Time

The graph below depicts the total service time taken for each patient. Looking at the graph itis observed that service varying at a range of 3.5 to 6.5 minutes.

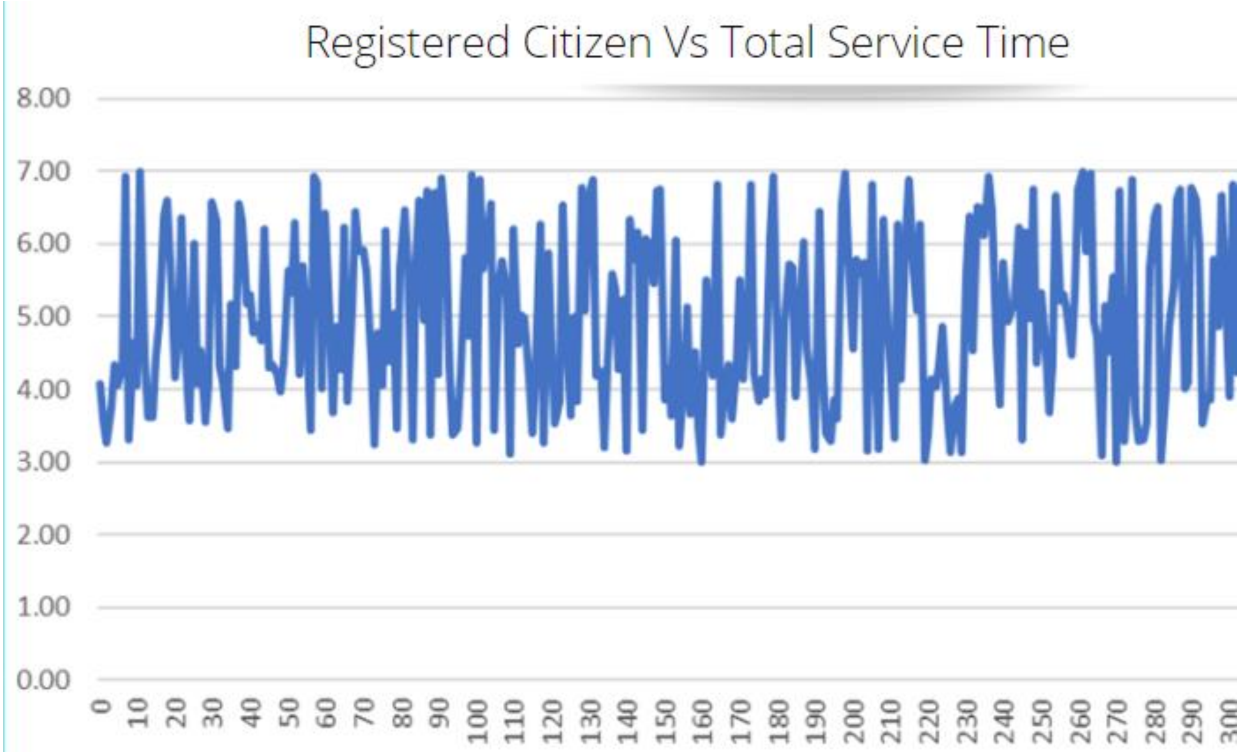


Fig: Citizen Service Rate

Registered Citizen vs Wait time

The graph below illustrates the amount of time each citizen must wait to get the vaccination shot. From the graph it is demonstrated that the wait time are rising exponentially but the maximum and average waiting times are comparatively very less than the previous versions

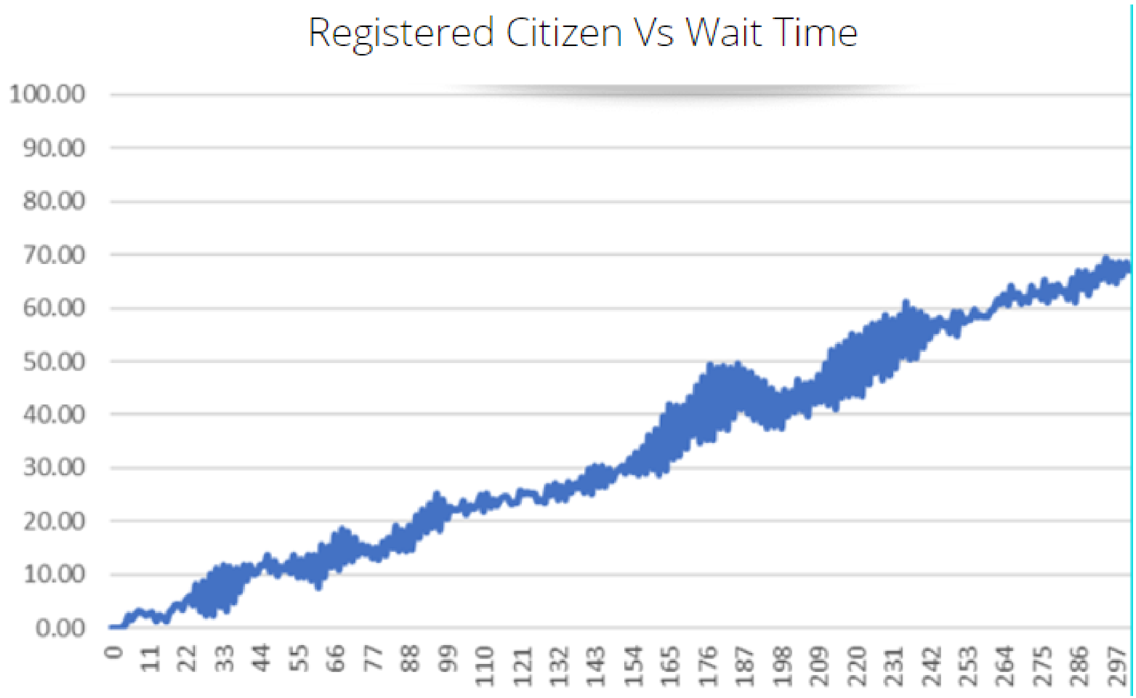


Fig: Citizen wait time because of long queues

Replication vs Average Wait Time

The below graph shows the average waiting time taken by all the patients in different replications. The graph is plotted for 100 replications. The average waiting time for 100 replications was observed to be 30 minutes.

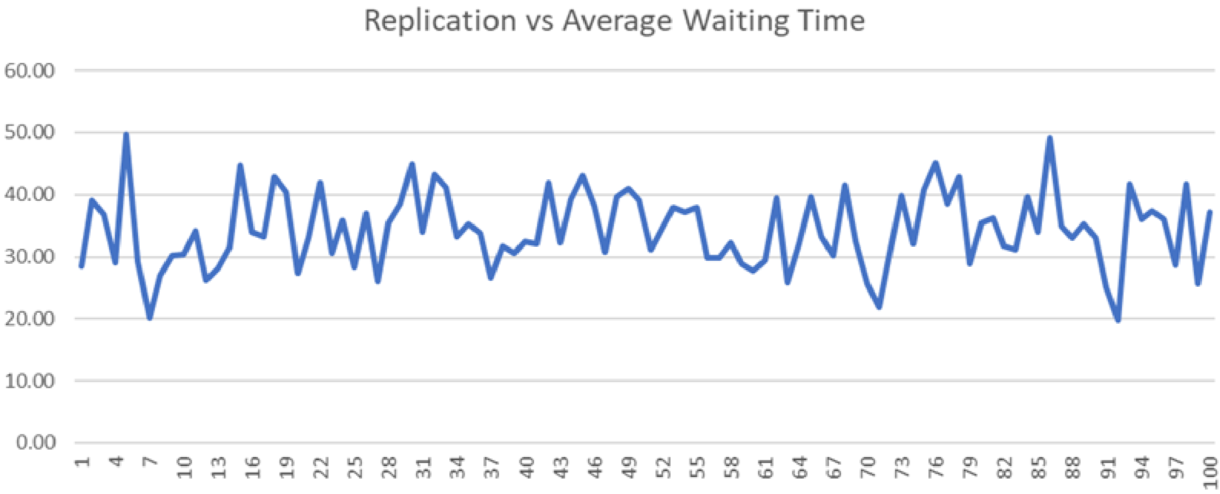


Fig: Citizen average wait times based on number of replications

Registered Citizen	Time between Arrivals (Schedule Arrival)	Arrival Time of citizens	Validation of Identity	Booth#	Booth #1 Start Time	Booth #1 Total Service Time	Booth #1 End Time	Booth #2 Start Time	Booth #2 Total Service Time	Booth #2 End Time	Wait Time
0	0	0	0	0	0.00	0	0	0	0.00	0	0
1	2.25	2.25	0	1	2.25	4.16	6.41				0.00
2	2.25	4.5	1	2				4.50	3.82	8.32	0.00
3	2.25	6.75	1	1	6.75	3.42	10.17				0.00
4	2.25	9	1	2				9.00	5.08	14.08	0.00
5	2.25	11.25	1	1	11.25	4.25	15.50				0.00
6	2.25	13.5	1	2				14.08	3.53	17.62	0.58
7	2.25	15.75	1	1	15.75	6.11	21.86				0.00
8	2.25	18	1	2				18.00	5.78	23.78	0.00
9	2.25	20.25	0	1	21.86	4.43	26.29				1.61
10	2.25	22.5	1	2				23.78	6.44	30.22	1.28
11	2.25	24.75	1	1	26.29	6.69	32.98				1.54
12	2.25	27	1	2				30.22	3.44	33.66	3.22
13	2.25	29.25	1	1	32.98	3.88	36.87				3.73
14	2.25	31.5	1	2				33.66	4.25	37.91	2.16
15	2.25	33.75	1	1	36.87	5.87	42.74				3.12
16	2.25	36	1	2				37.91	5.51	43.42	1.91
17	2.25	38.25	1	1	42.74	5.52	48.26				4.49
18	2.25	40.5	1	2				43.42	4.63	48.04	2.92
19	2.25	42.75	1	1	48.26	6.46	54.71				5.51
20	2.25	45	1	2				48.04	4.08	52.12	3.04

Arrival Distribution - Poisson	
Average arrivals/Hr	37.5
Average arrivals/Min	0.625
Average mins/Arrival	1.4
Service Distribution - Uniform	
Patients Tested/Hr	30
Patients Tested/Min	0.57
Average Mins/Patient	3.80
Based on 1 Replication	
Average Wait Time	30.3
Max Wait Time	65.20
Based on 100 Replication	
Average Wait Time	26.72
Max Wait Time	40.36
Service Distribution - Exponential for Patient not Allowed for Testing	
Average Mins/Patient	1.50

Run #	Average Wait Time
1	30.33
2	30.01
3	23.31
4	20.05
5	26.32
6	21.78
7	26.80
8	23.66
9	26.99
10	27.80
11	19.26
12	40.36
13	23.61
14	31.45
15	31.58
16	32.95
17	30.39
18	24.93
19	19.42
20	37.33
21	29.31

Fig: Implementation of enhanced and proposed model with Two Booth's – Uniform Arrival Rate – Excel

4.5 Output Analysis

We have computed the margin of error for confidence interval of 90% and achieved the lower and upper limits of the wait times for every model. Please find the particulars of calculations and observations in the below tables

Single Booth - 100 Replications	
Mean of the wait times	169.7
Standard Deviation of wait times	28.88
No of Count of Replications	100
Square root of count of replications	10
T-score scaling factor	1.98
Margin of Error - (t-score(standard deviation/square root of count))	5.73

Confidence Interval 90% - Lower Limit	164.00
Confidence Interval 90% -Upper Limit	175.46

Two Booth's - 100 Replications	
Mean of the wait times	87.3
Standard Deviation of wait times	17.51
No of Count of Replications	100
Square root of count of replications	10
T-score scaling factor	1.98
Margin of Error - (t-score(standard deviation/square root of count))	3.47
Confidence Interval 90% - Lower Limit	83.79
Confidence Interval 90% -Upper Limit	90.74

Two Booth's - Constant Arrival - 100 Replications	
Mean of the wait times	35.4
Standard Deviation of wait times	5.46
Count of Replications	100
Square root of count of replications	10
T-score scaling factor	1.98
Margin of Error - (t-score(standard deviation/square root of count))	1.08
Confidence Interval 90% - Lower Limit	34.32
Confidence Interval 90% -Upper Limit	36.49

Based on the calculations and inspections through this model.

- For single Booth the wait time is in the range of 154 to 185 minutes
- For two Booth's model the wait time is in the range of 75 to 95 minutes
- For two Booth's model with constant arrival rate the wait time is in the range of 31 to 39 minutes

4.6 Verification and Validation

Verification

- In our simulation model, we have taken input parameters as assumptions based on Montreal based vaccination center.
- We have started developing the simulation model with conservative details in the beginning and then we added additional specifics after confirming the model we proposed was accurate.

- We did an analysis by collecting the transitional test results retrieved by the simulation model and compared both the outcomes obtained with real-time handy calculations.
- In our Static Testing, wait time increases with the decrease in staff members or increase in registrations and wait time decreases with decrease in registrations or increase in staff.
- In Dynamic Testing, we have used the Random function in order randomize and vary the input data in real-time. We have verified the relation between input and output validations.
- Simulation model is accomplished with variety of input scenarios and understood if the variation in the output is acceptable.

Validation

- Sensitivity Analysis was performed on the model by changing and inputs and observed the parameters that are affected because of the input change.
- Followed confidence interval approach and calculated the 90% confidence interval to find the margin of error and obtain the exact outcomes.

All our analysis performed by doing verification and validation are proved to be accurate fromthe results. By this, we are confident that the model we developed matches with the actual system and any changes suggested to this model to improve the waiting times will also have effect on the actual system

5. Vensim – Simulation

5.1 Decrease in wait time using Vensim – Simulation

Vensim is a simulation software developed by Ventana Systems. It primarily supports continuous simulation (system dynamics), with some discrete event and agent-based modeling capabilities, and also provides a graphical modeling interface with stock and flow and causal loop diagrams, on top of a text-based system of equations in a declarative programming language. Vensim can be used to solve a variety of problems. There are several example applications at our corporate website, in the resources, and of course in the models that come with Vensim. Still, that is only a small sample of things that can be done, and the applications of Vensim are as follows:

- Work education mismatch.
- New C-roads and world climate simulators.
- Integrated sustainable development goals planning model.
- Energy policy simulator.
- Game change Rio.

5.2 Casual Loop diagram

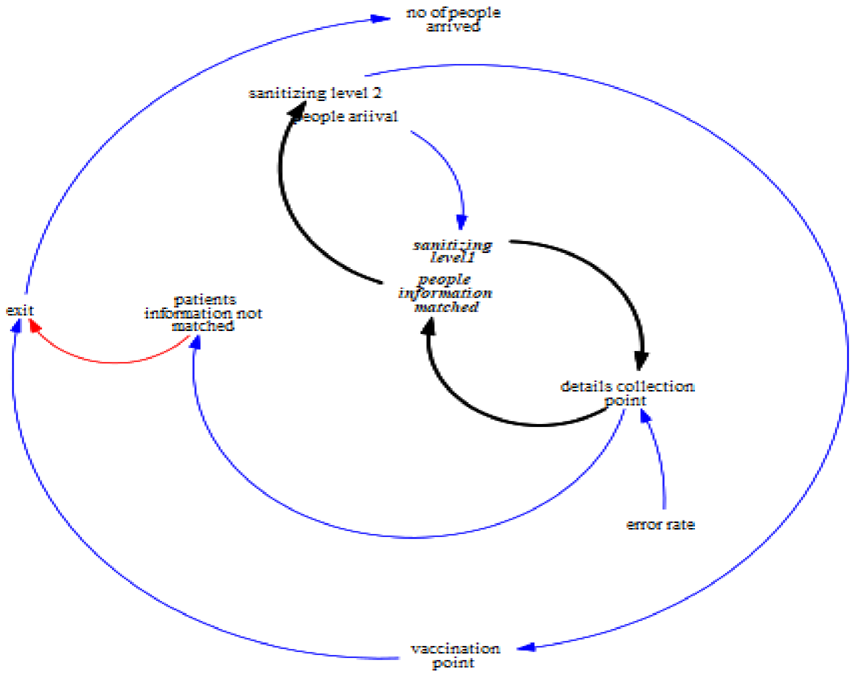


Fig: causal loop diagram of covid19 wait time

Causal diagram that aids in visualizing how different variables in a system are causally interrelated. The diagram consists of a set of words and arrows. Causal loop diagrams are accompanied by a narrative that describes the causally closed situation the CLD describes. Closed loops, or causal feedback loops, in the diagram, are very important features of CLDs.

5.2.1 Execution of Casual Loop diagram

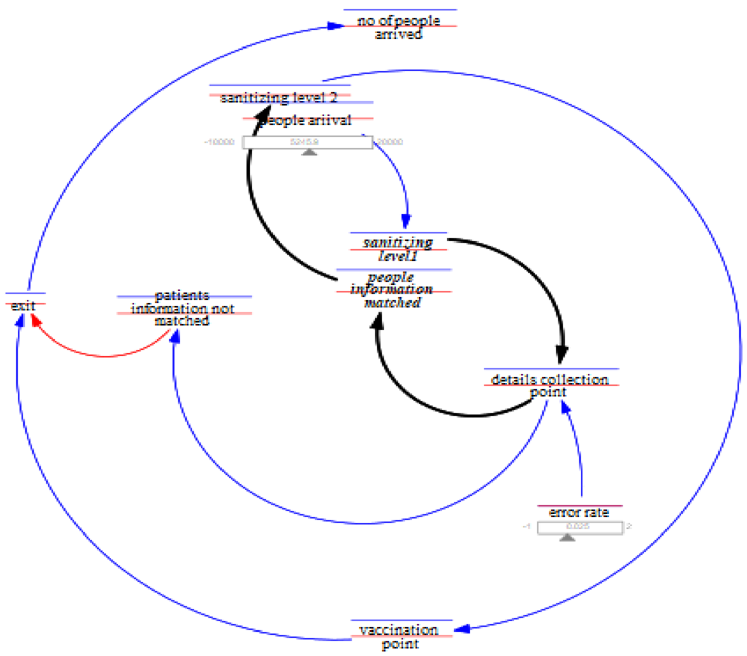
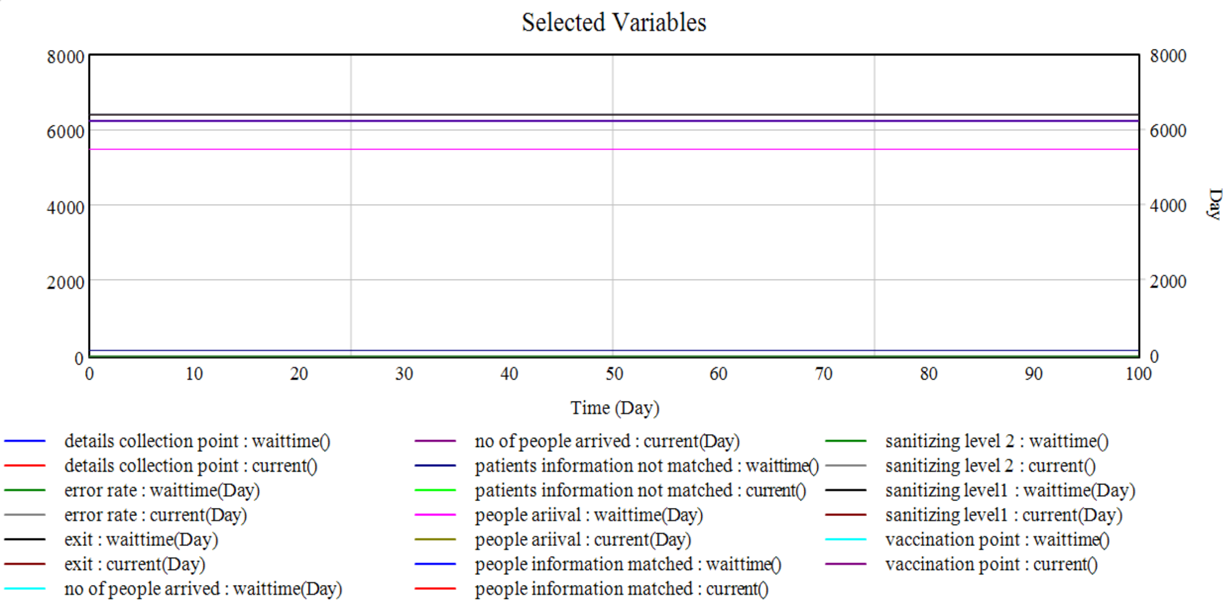


Fig: execution of causal loop diagram

In the execution part of reducing the wait time at vaccination center we fixed the error rate as 0.025 according to the normal error rate of Quebec government. and we have used different variables like people arrived, sanitizing level, error rate, details collection point, people with correct information, people with wrong information and exit. In this people information matched refers to the one who have booked a slot for vaccine and arrived the correct place for vaccination and patient information not matched refers to any one of the data is wrong may be arrived to another location for vaccine or not booked the appointment.

5.2.2 Casual Loop diagram Output

In obtaining output for the above causal loop, we have inserted formulas according to the performance and arrangement of blocks and values are given to the input which will range from 1000 to 20000 per day. Through vaccinating a huge number per day requires many other factors like staff and equipment, here we have just used the value for testing, and we also compared the practical values of vaccinating people with theoretical values which matched exactly. The graphs obtained by performing the operations are below which are with different variables and colors.



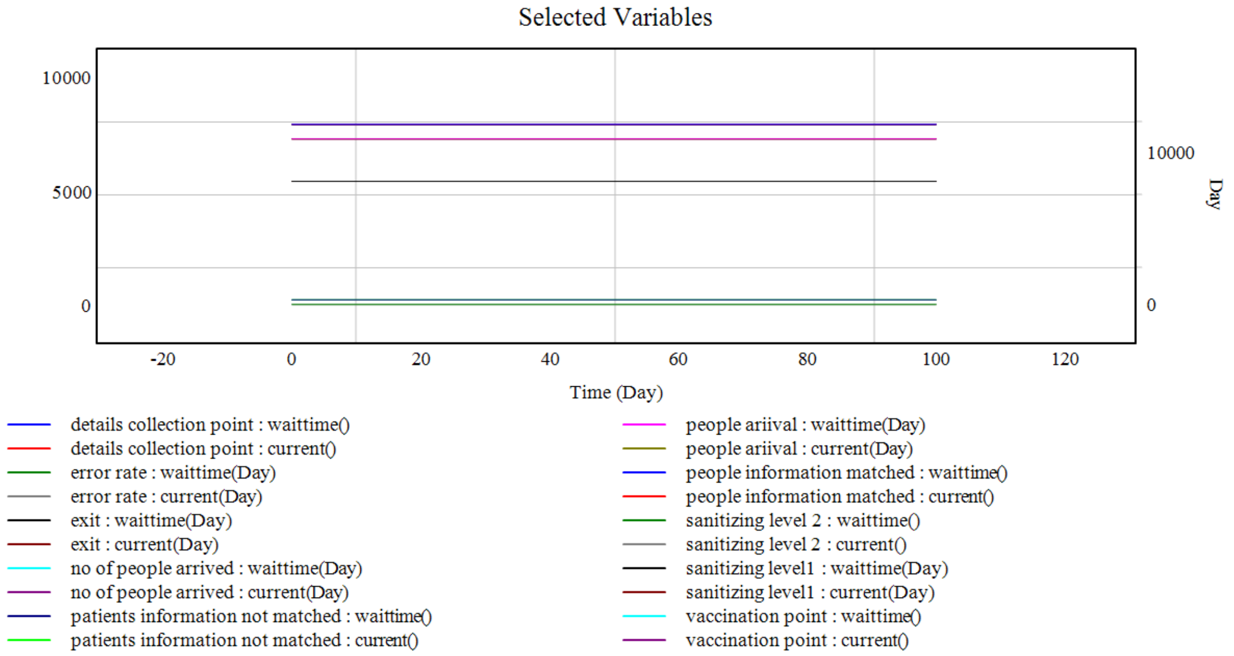
Graph: output for specific set of inputs

5.3 Verification and Validation

Verification which means identifying the truth, correctness and a process if validating the output multiple times to cross check whether we are getting same results after many trails. After multiple performance we can say it is running efficiently and validation is the specific approach of fulfilling requirements of the system by meeting predefined format attributes with other output criteria and evaluating whether the outputs are sufficient with meeting the user expectations by structuring accordingly.

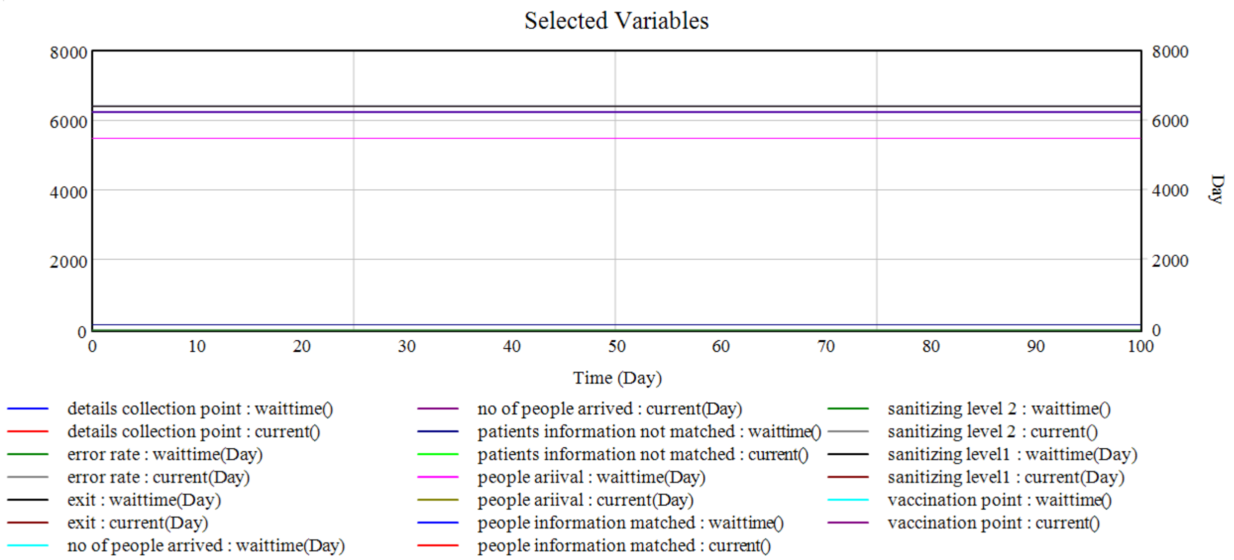
Designing and simulation of reducing waiting of covid19 wait time is a needed thing in this pandemic and the result of the above simulation shows that the error rate is very low and can be vaccinated in great percentage without spreading the infection.

Trail 1:



Graph: out plot of vaccinated people per day trails 1

Trail 2:



Graph: out plot of vaccinated people trails 2

5.4 Documentation for the executable flow

(01) details collection point=
sanitizing level1-(error rate*sanitizing level1)
Units: **undefined**

(02) error rate=
0.025
Units: Day

(03) exit=
patients information not matched+vaccination point
Units: Day

(04) FINAL TIME = 100
Units: Day
The final time for the simulation.

(05) INITIAL TIME = 0
Units: Day
The initial time for the simulation.

(06) no of people arrived=
exit
Units: Day

(07) patients information not matched=
details collection point/39
Units: **undefined**

(08) people arrival=
2500
Units: Day

(09) people information matched=
details collection point
Units: **undefined**

(10) sanitizing level 2=
people information matched
Units: **undefined**

(11) sanitizing level1=
people ariival
Units: Day

(12) SAVEPER =
TIME STEP
Units: Day [0,?]
The frequency with which output is stored.

(13) TIME STEP = 0.5
Units: Day [0,?]

The time step for the simulation.

(14) vaccination point=
sanitizing level 2
Units: **undefined**

6. Conclusion

We have successfully implemented the current utilized system of the COVID-19 vaccination center and analyzed the problems in the current system and proposed a new system that rectifies the complication. Two different simulation models were developed and simulated to understand the system, the first one is using Arena Simulation software for discrete event simulation and the other is Monte Carlo Simulation using Microsoft Excel. We have also analyzed the outcomes via Vensim simulation through casual loop diagram and the executable flow. We have evaluated the simulation outcomes achieved from the above models and documented our observations. We have proved that our simulation is realistic through the verification and validation aspects and all the outcomes are practical and credible.

7. References

[1] Course Material, INSE 691 - Dr. Anjali Awasthi.

[2] Vensim Simulation – Lecture-9, https://moodle.concordia.ca/moodle/mod/folder/view.php?id=2773682

[3] Monte Carlo simulation – Lecture-7 , https://moodle.concordia.ca/moodle/mod/folder/view.php?id=2773647

[4] Arena Simulation – Lecture -6 & 8, https://moodle.concordia.ca/moodle/mod/folder/view.php?id=2770716

[5] Verification and Validation, https://moodle.concordia.ca/moodle/mod/folder/view.php?id=2764424

[6] Bixi Transport Geography, https://www.google.com/url?sa=t&source=web&rct=j&url=https://tram.mcgill.ca/Research/Publications/Bixi_transport_geography.pdf&ved=2ahUKEwjH0vfg-bbyAhXFl-AKHV6UDWsQFnoECAQQAQ&usg=AOvVaw3nwlaOtCm8TW2xyT9uEUiN

[7] Bixi case study, https://www.google.com/url?sa=t&source=web&rct=j&url=https://toolsofchange.com/userfiles/BIXI%2520Case%2520Study(1).pdf&ved=2ahUKEwj3-t77-bbyAhXHTd8KHSM0DdoQFnoECAQQAQ&usg=AOvVaw3ihv8hsTDHTVo-EmjQOq5g

[8] Monte Carlo Simulation-YouTube, https://youtu.be/7ESK5SaP-bc

[9] Simulation with Arena, https://pdfs.semanticscholar.org/5b22/64de5cbdb2eb3a397786c41b30bdba9bef2f.pdf

[10] Monte Carlo Simulation – IBM, https://www.ibm.com/cloud/learn/monte-

carlo-
simulation#:~:text=Monte%20Carlo%20Simulation%2C%20also%20known,outcomes%20of%20an%20uncertain%20event

[11] Arena Tutorial, https://shamsulsarip.files.wordpress.com/2015/07/arena-tutorial.pdf

[12] Using Arena Input Analyzer, http://salimian.webersedu.com/courses/IEGR410N/pdf/Using_Arena_Input_Analyzer.pdf

[13] Net Logo web, http://www.netlogoweb.org/launch#http://ccl.northwestern.edu/netlogo/models/models/Sample%20Models/Social%20Science/Economics/Unverified/Cash%20Flow.nlogo