Quantitative Comparison of the Three Vaccination Centers in the Philippines: An Assessment for the Optimum Practices Using Queueing Theory

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Abstract

The recent COVID - 19 outbreak began in China and has nearly infected every country and is considered the most recent health public problem of worldwide significance. As the spread of the virus intensifies, COVID - 19 vaccination has been recognized and licensed. However, there is no information to guide the administration of these sites as there is no directly comparable experience. With this, dedicated vaccination sites and their process optimization are vital in reaching the goal. Hence, this paper focused on studying and evaluating three vaccination sites of Rizal, Cavite, and Quezon City, in the Philippines. Based on the data gathered, the researchers identified and assessed the process and system of each of the vaccination sites among the three locations and used the queuing theory. In eight hours of the vaccination program, the results show that the vaccination site in Quezon City yields the most productive system yet the highest total cost, which is a relevant result having 57 patients, four servers, and taking 3.18 minutes each in the whole process. Along with the findings of this study, the government will be able to better plan and operate COVID - 19 vaccination centers that are efficient and cost-effective.

Keywords
Best Practices, Comparing, COVID-19, Queuing Theory, Vaccination Sites

1. Introduction

In December 2019, a coronavirus disease outbreak (COVID-19) was identified in Wuhan, China, and eventually spread over the world, becoming a worldwide pandemic according to the study done by Zhu, Wei, and Niu, (2020). The World Health Organization (WHO) has declared a new terminology for the new coronavirus epidemic disease as 2019-nCoV, that is COVID-19 as explained by Lai, et al. (2020). According to studies, the virus can be transmitted from one person with only a fourteen-day incubation time (Zheng, 2020). Moreover, cough, fever, and shortness of breath are symptoms that can be spread through direct contact with an infected individual through coughing, sneezing, respiratory droplets, or aerosols. (Shereen et al., 2020). Since January 2020, SARS-CoV-2, the virus that causes COVID-19, has caused almost 98 million confirmed cases and 2.2 million deaths as stated by Fraser (2020). Furthermore, studies revealed that the pandemic can be mitigated and controlled by practicing social distancing, wearing masks, and an effective vaccine (Sharma et al., 2020). Vaccines against covid 19 have been recognized and licensed as a successful prophylactic method for infection control and prevention after being tested in clinical trials and proving that they significantly reduce the risk of acquiring the virus. A vaccinologist at the Fred Hutchinson Cancer Research Center in Seattle, Washington stated that a vaccine that is highly effective at preventing people from acquiring the infection in the first place would help to reduce transmission (Hospital et al., 2021). The claim was backed up by a COVID-funded study in the United States which stated that due to enhanced vaccination coverage, covid-19 cases and deaths have declined substantially since their peak in early January 2021 (Christie et al., 2021).

In the Philippines, only 10.3 million people, or 9.3% of the 110 million people have been completely vaccinated, far from what the government aims to immunize which constitutes 70 million people or 63.64% of the population as reported by Jazeera, (2021) & Pilar, (2021). The number of new illnesses recorded each day has risen dramatically,

with more than 17,100 infections reported daily. Infections with covid -19 are at an all-time high in the Philippines, with 17,166 new infections reported every day, the highest daily average ever. The country has experienced 2,304,192 illnesses and 36,018 coronavirus-related deaths since the outbreak began. Provinces like Rizal and Cavite have exceeded Metro Manila as the region with the highest risk of Covid-19. According to the provincial government of Cavite, the province has 64,718 confirmed covid -19 cases, with 6,654 active cases, 1,690 deaths, 56,374 recoveries and there are 74,476 fully vaccinated residents in the province and still needs about 5 million vaccine doses to protect its residents against Covid-19. Similarly, the province of Rizal has accounted for 56,466 confirmed cases, with 1,564 deaths, and is too far from adequately vaccinating 70 % of the population with 43,833 fully vaccinated. Correspondingly, Quezon City has been identified as the city with the highest number of coronavirus cases with 150,740 confirmed cases, 1,384 deaths, and 1,324,740 fully vaccinated residents constituting 77.93% of the 1.7 million target population. Data shows that 41,247,552 doses of covid vaccines so far have been administered in the country, about 18.7% of the country's population still far from achieving herd immunity according to the Department of Health (2021). According to the Presidential Adviser on Peace Process, there is a good probability that our economy will recover and we will be able to prevent a surge in cases if we can achieve herd immunity by vaccinating up to 70% of the inhabitants in these areas. With this in mind, optimization of vaccination sites is vital in reaching the goal based on Atienza and Villegas (2021).

Schaffer et al. (2017) stated that vaccination sites deal directly with people's lives as it is one of the promising solutions to counter the pandemic. However, Vuorinen, V. et al. (2020), shows that standing in queues, for prolonged periods and less than 2 meters distance puts people at a substantially higher risk of spreading or catching the virus. In these conditions, the virus appears to spread more quickly through respiratory droplets or aerosols than by just walking on the street. With this in mind, improving system performance is a top priority. System performance can be improved by increasing server utilization and decreasing waiting times. A study conducted in Southwest England by Wood, R. et al. (2021) demonstrated the value of queue modeling in supporting operational planning at COVID-19 vaccination centers used to inform the configuration of two major regional vaccination centers. Furthermore, Hanly M. et al. (2021) conducted a study in Australia to improve the distribution of vaccines, using queue network models to estimate the capacity of vaccination sites based on assumptions about appointment schedules, service times, and available staff numbers. Queueing Theory according to Fomundam et al. (2007) is an approach to minimize the cost through the minimization of inefficiencies and delays in the system. It minimizes the time that the patients have to wait and maximizes the utilization of the servers or resources. In addition, Forman et al., (2021) coined that it is very helpful for determining how to operate a queueing system in the most effective way since providing too much service capacity to operate the system involves excessive costs and additional work for the medical front liners but not providing enough service results in excessive waiting of people and all its unfortunate consequences. This will aid in finding an appropriate balance between the cost of service and the amount of waiting.

1.1 Objectives

With the growing transmission of the virus and the fact that no study has been undertaken to guide the administration of vaccination sites, the country's population is still far from achieving herd immunity. This paper aims to assess the three vaccination sites in the Philippines using Queuing Theory and demonstrate the value of Queuing Theory using Excel Solver, which is beneficial in determining the most efficient way to operate a queueing system. The paper will also evaluate the best practices of the three vaccination sites, and the findings of this study will guide the government to better plan and optimize the COVID-19 vaccination centers that are efficient and cost-effective.

2. Literature Review

In December 2019, a coronavirus disease outbreak (COVID-19) was identified in Wuhan, China, and eventually spread over the world, becoming a worldwide pandemic [1]. The World Health Organization (WHO) has declared a new terminology for the new coronavirus epidemic disease as 2019-nCoV, that is COVID-19. The virus itself has been renamed from 2019-nCoV to severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) [2]. COVID-19 has been shown in studies to be transmissible from human to human, with an incubation period of only fourteen days. Cough, fever, and shortness of breath are symptoms that can be spread through direct contact with an infected individual through coughing, sneezing, respiratory droplets, or aerosols [3] [4]. Adults, children, and persons with underlying medical disorders are the most sensitive to it, affecting people of all ages [5]. The virus underlying the COVID-19 disease, SARS-CoV-2, has caused over 98 million confirmed cases and 2.2 million deaths since January 2020 [6]. In the Philippines, the number of new illnesses recorded each day has soared, with over 20,705 infections

reported daily. COVID-19 infections in the Philippines are at an all-time high, with 22,366 new infections reported per day, the highest daily average ever recorded. As of September 2021, the country has seen 2,227,367 confirmed cases and 35,145 coronavirus-related deaths [7]. Since the disease can be transmitted from human to human, almost every country where the disease has been reported has undertaken considerable control and mitigation measures [8]. It is anticipated that the COVID-19 pandemic can be controlled using social distancing, masks, new antiviral drugs, and an effective vaccine [9].

Vaccination against COVID-19 has been recognized and licensed as a successful prophylactic method for infection control and prevention after being tested in clinical trials and proving that they significantly reduce the risk of acquiring the virus [10]. The amount of research among medical students suggests that the necessity of vaccination, in general, seems to be well. Due to various indication-specific vaccination recommendations and widely differing perceptions of the dangers of distinct vaccine-preventable diseases, it is reasonable to infer that the importance of vaccination should be examined by immunization [1]. Vaccine distribution campaigns are taking place across the country, and communities are grappling with how to distribute limited resources in a fair and effective manner. Effective vaccination is one part of effective, comprehensive control of the pandemic [2]. In the current situation, the incomplete vaccinations of people lead to an increased risk of infections [3]. These vaccines against infectious agents have been developed and widely used, and this has been a breakthrough in medical science [4]. Vaccination, according to health professionals, is a critical instrument in bringing the pandemic to an end. However, many Filipinos are doubtful, and vaccination rates remain dangerously low [5]. In the Philippines, there are allotted vaccination centers/sites in every province, but not everybody got their first dose of vaccines. Aside from the lack of vaccines [6], the slow and painful process of getting the vaccines to the Philippines [7]. Mass vaccination is the most promising but the most difficult option since it necessitates the safety and effective delivery of millions of vaccine doses in the shortest amount of time while also minimizing health disparities [11]. The goal of mass vaccination is to hasten the control of the COVID-19 virus by proliferating vaccination coverage and establishing immunity levels required to achieve international mortality reduction goals [12]. The initiation of herd immunity by mass vaccination has been a very successful strategy in preventing the spread of many infectious diseases. It works through achieving a threshold immunity at the population level where it can cut the transmission of infectious disease through vaccination. If the virus's basic reproduction number (R0) is three, one infected individual infects three additional individuals. A. A threshold value of 67% is believed to be sufficient for acquiring herd immunity against SARS-CoV-2. According to this estimate, a single-dose vaccination would require 5.3 billion doses, while a multi-dose vaccine would require 12–16 billion doses. Therefore, protecting the most vulnerable population groups, such as individuals with immunodeficiencies due to underlying medical health issues, and protecting most, if not all, the population in a given geographical area for a certain time interval. Hence, vaccination is one of the most promising solutions or counter-pandemic measures to COVID-19 [1][2][3].

In the Philippines, only 10.3 million people or 9.3% of the 110 million people have been completely vaccinated. The government wants to immunize up to 70 million people or 63.64% of the population to achieve herd immunity through mass vaccination. According to Carlito G. Galvez Jr the Presidential Adviser on Peace Process, “There is a good probability that our economy will recover and we will prevent a surge in cases if we can achieve herd immunity by vaccinating up to 70% of the inhabitants in these areas,” he said. He also added, the government has set up 5,000 vaccination sites capable of administering 100 shots each day, which is a critical need for achieving herd immunity. He said that herd immunity may be achieved as early as September or October if the vaccination pace can be increased to a daily rate of 8,000 to 10,000 shots [4][5][6].

Provinces like Rizal and Cavite have exceeded Metro Manila as the region with the highest risk of Covid-19 [1]. According to an interview with CNN Philippines, to address the continuous rising of COVID-19 cases, Cavite will be taking advantage of being an industrial hub where they coordinate with companies to establish more vaccination centers [2]. Since two of the vaccination sites in Cavite were temporarily closed down due to the surge in COVID-19 cases in the province, 18 medical staff tested positive for COVID-19 [3]. In accordance with the suspension of vaccination drive in two different sites, Imus City, Cavite launched a new inoculation site for local residents who are suffering from coronavirus symptoms [4]. According to the provincial government of Cavite, there are only 500,000 fully vaccinated residents in the province and still needs about 5 million vaccine doses to protect its residents against Covid-19 [2]. According to the Province Governor of Rizal, it is far too far to adequately vaccinate 70 % of the population. The vaccination in Antipolo Rizal has the capacity to vaccinate 12,000 doses a day but the national government only gave 7,200 doses [1]. As of June 22, 2021, the total number who got the 1st dose in Antipolo Rizal is 49,294 and 20,700 for the 2nd dose [2]. Due to the lack of vaccines, Antipolo City halted the distribution of the first

dose of covid-19 vaccines where A1 to A4 categories were given priority [3]. Also, the city government disallowed the walk-ins for vaccination in order to lessen the transmission of the disease, only those who have the confirmation schedule via text of Antipolo City can be vaccinated during the said date given [4]. To continuously serve and give prioritize to the residents of Antipolo City, the province conducting a three-day mobile vaccination rollout where residents and workers in Antipolo can now be vaccinated against COVID-19 through the COVID-19 Mobile Vaccination program of the city government dubbed as "Antipolo Bakuna Caravan-COVID-19 Mobile Vaccination." The said program will operate in different barangays in Antipolo City [5].

As the more infectious Delta variant of the virus threatens the country, independent group Octa Research reported a significant rise of COVID-19 infections in Metro Manila particularly in Quezon City. Octa also noted that 13 of 17 local government units in Metro Manila are considered "high-risk" areas. During the fourteen-day extended community quarantine in Metro Manila, the Quezon City administration regulated about a quarter of a million COVID-19 vaccine doses. On August 6 to 20, through their program named QCProtektodo Vaccination, they managed to give shots for a total of 493, 000 doses under priority groups such as A1 to A5 [1]. The Quezon City Government has reserved P1B from its 2021 spending plan for the purchase of COVID 19 antibodies. The regional government has joined forces with AstraZeneca to give an underlying 750,000 dosages of the immunization. It will focus on its 10,000 wellbeing laborers, 300,000 senior residents, 20,000 grown-up people with handicaps, and other need areas suggested by the DOH [2]. As a component of its objective to immunize 1.7 million people, the Quezon City government explicitly designated its first Johnson and Johnson's Janssen immunization supply to the senior residents of District 2 in a one-day rollout in the area. Out of the six locales, District 2 is the most thickly populated, made out of five barangays with a populace of 738,000, as indicated by the most recent information of the Philippine Statistics Authority [3]. To supplement its consistently developing antibody program, the Quezon City government dispatched another immunization enrollment gateway. QC Vax Easy will be a city-helped enrollment framework that is planned to expand the current enlistment cycles of the QCProtektodo Vaccination Program. City Administrator Michael Alimurung said that this will assist with tending to the worries of numerous QCitizens who are having issues enrolling in the program [4]. The Quezon City government said it is looking to immunize 267,000 understudies from 12 to 17 years old as it plans to carry out the immunization for minors. In a press statement, the neighborhood government said its QC Task Force Vax is organizing with private and state-funded schools in the city to enroll the number of selected understudies for this scholarly year [5]. Quezon City Mayor Joy Belmonte explained that the neighborhood government isn't permitting walk-ins in its immunization destinations. Belmonte denied reports that stroll-in game plans were permitted in some immunization destinations in the city which prompted an enormous deluge of individuals [6].

According to WHO, providing an excessive amount of service capacity to operate the system results in higher costs and more work for the medical frontlines. However, failing to provide adequate service results in long lines of people and all of the negative effects that come with it. For individuals attending a COVID-19 vaccination center, several key activities may be expected. Following arrival, the individual would register and confirm their details and online registration. They would then be clinically assessed to ensure suitability for the vaccine. Then they would be vaccinated and possibly follow some observation period, as required for the particular vaccine and they would exit the site. Standing in queues, for prolonged periods and less than 2 meters distance puts people at a substantially higher risk of spreading or catching the virus. In these conditions, the virus appears to spread more quickly through respiratory droplets or aerosols than by just walking on the street [6]. Thus, in this perspective, researchers understand the need for an analysis to be carried out.

3. Methods

This chapter presents the research design, setting, data collection and analysis, and the methodologies used in the study. This also presents the Industrial Engineering Tools such as flowcharts and queueing theory that will be used by the researchers in analyzing the gathered data and other discussions that are needed on different approaches of methodology and procedure of the process that will be done in the course of study.

3.1 Research Design

The research focused on the application of Queuing Theory to the current situation within the vaccination sites in the Philippines. Specifically, the vaccination sites in Antipolo, Cavite, and Quezon City will benefit primarily from this plan of action. The approach utilized in this research is descriptive. Descriptive research will help the researchers to gather needed information and present it using IE tools to interpret it.

4. Data Collection

A quantitative approach was utilized to find the essential data from various individuals in order to complete the study. This covered the information on the residents in the Philippines' three vaccination sites given their current situations, as well as the factors that influenced the vaccine distribution for individuals to acquire herd immunity. The researchers were able to obtain video of the entire vaccination process among residents of Antipolo, Cavite, and Quezon City last September 15,16, and 17, 2021 accordingly. The researchers needed this information to assess and analyze the likely conclusions and best solutions for the government to better plan and optimize the COVID-19 vaccination centers with efficiency and cost-effectiveness.

4.1 Process Flow for Vaccination Site

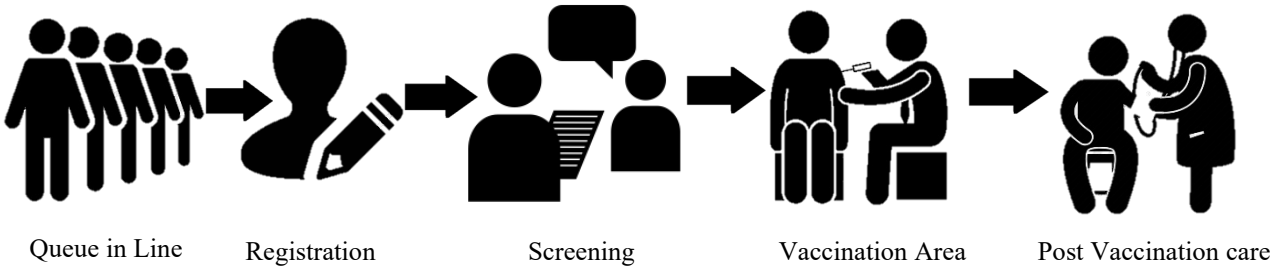

Figure 4.1.1 Process flow of vaccination sites

Figure 4.1.1 shows the overall process flow within the vaccination site. It starts with the queue in line then followed by the registration using the pen and paper approach, prior to the screening, and then assistance will be provided towards the vaccination area where the available doctors are present to administer COVID-19 shots. Post-vaccination care will be provided to examine the presentation of any side effects to those people under the A3 and A4 categories.

4.2 Process of Data Collection

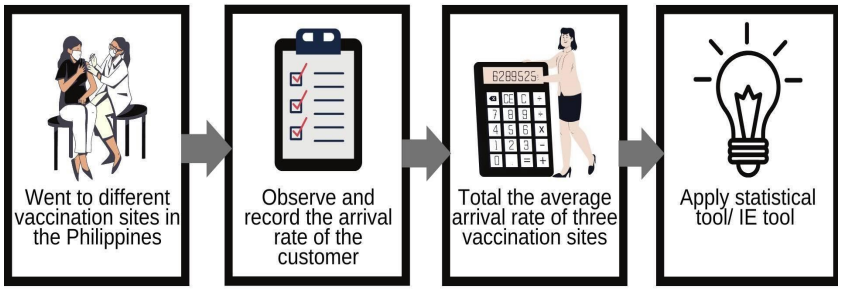

Figure 4.2.1 Process of data collection

Figure 4.2.1 above shows the process of how the researchers gathered the data from the three vaccination sites in the Philippines. The researchers went to the vaccination sites to observe and take a video of the whole process of getting the COVID-19 shot. After obtaining the primary sources of data, the arrival rate and service rate of the residents were recorded using a time and motion study. After getting the average arrival and service rate within the three vaccination sites, the researchers applied a statistical and Industrial Engineering tool.

4.3 Sources of data and Sampling Techniques

The sources of data were obtained through observation in the vaccination sites of Antipolo, Cavite, and Quezon City, in the Philippines. The video clips were taken during a scheduled vaccination and were used as a primary source for analyzing and assessing the process and system of each vaccination site. Moreover, the researchers gathered related information about each vaccination site through articles and were used as secondary sources to determine the differences and similarities of the said vaccination sites.

Due to the pandemic restrictions, the sources of data were chosen in a nonprobability or nonrandom sampling, where the researchers used judgment, selective, or subjective method sampling, called purposive sampling. After acquiring adequate knowledge about the purpose of the study, the researchers aim to assess all the subset of people as participants of the study.

The vaccination sites in Quezon City were administering 200,000 shots in a span of 2 weeks under the A1 to A5 priority groups while in Cavite, the supply given to the province is based on its capability of vaccinating 4,000 per day. Moreover, vaccinating at least 15,000 residents a day once Covid-19 vaccines are available is the target in Antipolo City. Data collection was carried out within the time frame of the eight-hour period of the vaccination program.

4.3.1 Queuing Theory

Queuing is a pervasive occurrence that happens daily in stores, airports, train stations, and call centers. Queuing theory is a statistical model of this common phenomenon. Three factors define the most basic queue: the rate at which people join the line, the service time, and the number of servers [13]. By modeling the queueing process and understanding the balance between these components, queueing theory gives a technique to optimize this experience for both the user and the server. Arrival and service times are represented as stochastic processes in queueing models. The goal is to predict queue characteristics such as average waiting time and queue lengths given a certain number of servers or to estimate the number of servers required to maintain average waiting times at a specified level given probable service times and arrivals.

4.4 Data Analysis Method

The primary data was gathered through on-site observation and visual inspection based on a video clip in the three vaccination sites that were chosen. The average interarrival rate of sources of data, average time spent in the queue waiting for service, the average number of people waiting on the line for service, the average number of people in the system, service time, and a total number of vaccinated per day on these three sites were carefully worked out and analyzed using mathematical and queuing models. Additionally, the researchers also obtained the mean as well as the standard deviation for each site and observed the process of giving vaccines from the start until the finish of service by using Time and Motion Study then compared to find out the most efficient and productive vaccination sites among the three.

4.4.1 Excel Solver

Figure 4.4.1.1 Excel Solver logo

The researchers used a spreadsheet to analyze the necessary data. As shown in Figure 4.4.1.1, the Excel Solver was used as a spreadsheet queuing simulation engine that was developed to simplify or eliminate the difficult programming required to simulate a queue spreadsheet. The data from the observation such that the arrival time, service time, and the number of servers were entered, and the simulation was performed to provide the results needed for this study. Various improved models of queueing theory are widely used to solve problems. A study conducted by Akuamoah, S.W., et al., provides an analysis and decision-making strategy for perfecting the theory of hospital queueing and improving the efficiency of medical services. Thus, the researchers will utilize the Microsoft Excel Solver in the course of this study to assess the process and system of each of the vaccination sites among the three locations.

5. Results and Discussion

This section provides the result of the sources gathered by the researchers, the data was analyzed and interpreted in this chapter. Each source was evaluated and interpreted in the context of the study's problem.

5.1 Numerical Results

In this paper Poisson probability distribution for the arrival and exponential probability distribution for the service, the rate is assumed to fit in the model where several servers are involved in the service provision of vaccination sites utilizing first come first (FCFS) served queue discipline. It is represented as M/M/s where "s" stands for the number of servers.

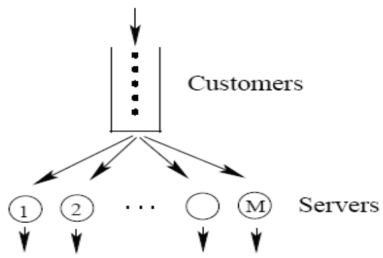

Figure 5.1.1.1 Illustration of multiple channel service system in a vaccination site

The mathematical study of waiting lines, or queues, is known as queuing theory. Arriving at the back of the queue, waiting in the queue is basically a storage operation, and being serviced at the front of the queue can all be mathematically analyzed using this theory as shown in Figure 5.1.1.1. The theory allows for the derivation and calculation of a variety of performance metrics, including the average queue or system wait time, the expected number of people waiting or receiving service, and the likelihood of encountering the system in various states, such as empty, full, having an available server, or having to wait a certain amount of time to be served as listed in Table 5.1.1. Telecommunications, traffic engineering, computing, and the design of factories, stores, offices, getting your vaccine done and hospitals are just a few of the disciplines where queueing theory is used.

Table 5.1.1 Equations based on multiple server – queue system (M/M/s)

	Equation
Average arrival rate (λ)	$\lambda = \frac{1}{average\ arrival\ time}$
Average service rate (μ)	$\mu = \frac{1}{average\ service\ time}$
Utilization factor for the system (ρ)	$\rho = \frac{\lambda}{\mu}$
The probability that there are zero people (P_0)	$P_0 = \frac{1}{\left[\sum_{n=0}^{M-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{M!}\left(\frac{\lambda}{\mu}\right)^M \frac{M\mu}{M\mu - \lambda}}$ for $M\mu > \lambda$
The average number of people or units in the system (*Ls*)	$Ls = \frac{\lambda\mu(\lambda/\mu)^M}{(M-1)!(M\mu-\lambda)^2} P_0 + \frac{\lambda}{\mu}$
The average time a unit spends in the waiting line and being serviced (*Ws*)	$Ws = \frac{\mu(\lambda/\mu)^M}{(M-1)!(M\mu-\lambda)^2} P_0 + \frac{1}{\mu} = \frac{L_s}{\lambda}$
The average number of people or units in line waiting for service (*Lq*)	$Lq = L_s - \frac{\lambda}{\mu}$
The average time a person or unit spends in the queue waiting for service (*Wq*)	$Wq = W_s - \frac{1}{\mu} = \frac{L_q}{\lambda}$

Notations:
λ = average arrival rate
μ = average service rate at each channel

L = Expected number of customers in the system, including those being served (the symbol L comes from Line Length)
Lq = Expected number of customers in the queue, which excludes customers being served
W = Expected waiting for time in the system (includes service time) for an individual customer (the symbol W comes from Waiting time)
Wq = Expected waiting time in the queue (excludes service time) for an individual customer
r = Utilization factor, the time that equipment is in use/total time that it could be in use.

5.2 Descriptive Statistic of Three Vaccination Sites in the Philippines

Table 5.2.2 Mean and standard deviation of vaccination process

Process:	Vaccination Sites		
	Antipolo Rizal	Cavite	Quezon City
Step 1: Queue in Line	43.95	91.02	31.22
Step 2: Registration	10.47	1440.00	12.15
Step 3: Screening	45.00	360.93	15.27
Step 4: Vaccination Area	25.28	25.35	20.85
Step 5: Post Vaccination Area	70.00	212.17	81.23
Total time in minutes	38.94	425.89	32.14
Mean	22.49	581.14	28.38
Standard dev	38.94	425.89	32.14

Table 5.2.2 shows the five (5) processes of the vaccination sites in the Philippines; the units that are used in this table are in minutes, also the mean and standard deviation of each site including Antipolo City, Cavite, and Quezon City are also presented. Antipolo Rizal has a mean of 22.49 minutes and a standard deviation of 38.94 minutes, Cavite has 581.14 minutes and 425.89 minutes, and Quezon City has 28.38 minutes and 32.13 minutes respectively. The researchers identify that Quezon City has the fastest way on how to administer covid 19 vaccines based on the result in the table above. The mean of each vaccination site represents all of the values in the data set in minutes, and the standard deviation is a measure of how dispersed the data is in relation to the mean; a low standard deviation indicates that data is clustered around the mean, while a high standard deviation indicates that data is spread out.

5.3 Mean Arrival Rate and Service Rate of Quezon City using Excel Solver

Table 5.3.1 Average arrival rate and service rate of three vaccination sites

	Average		
	Antipolo City	Cavite City	Quezon City
Arrival Rate (l)	12	11	18
Service Rate (m)	15	12	19
Number of Server (s)	3	3	4

Table 5.3.1 shows the average arrival rate and service rate of three vaccination sites, Antipolo City has an arrival rate of 12 and service rate of 15 with 3 servers, Cavite has 11, 12, and 3, while Quezon City has 18, 19, and 4 respectively. An arrival rate is the number of arrivals per unit time usually per hour or day, the researchers focus per hour only due to Covid -19 restriction, and a service rate is the number of customers served per unit time at the place of service in a vaccination area. In relation to vaccination sites, arrival rate and service rate in queueing analysis have been used in healthcare facilities where patients walk in with/without appointments, this analysis allows the government to identify the possible problem to create an action to reduce the patient wait time, the large screens in the waiting areas can be used effectively to ease the waiting time stress. The automated patient routing will significantly reduce the wait time and improve service delivery time.

Table 5.3.2 M/M/s simulation results of Excel Solver assuming Poisson arrivals and exponential service times

Results						
	Antipolo City		Cavite		Quezon City	
L =	0.818920916		0.94892267		0.952654939	
L_q =	0.018920916		0.032256004		0.005286518	
		minutes		minutes		minutes
W =	0.06824341	4.09460458	0.086265697	5.17594184	0.052925274	3.17551646
W_q =	0.001576743	0.09460458	0.002932364	0.17594184	0.000293695	0.01762173
ρ =	0.266666667		0.305555556		0.236842105	

Table 5.3.2 shows the simulation results of the Excel Solver and the findings of the study shows that the busiest vaccination site is in Cavite with a utilization factor of 30.56% and 1.92 expected number of patients in the vaccination line per minute, followed by Antipolo and Quezon City with 1.14 and 0.32, respectively. With this arrangement, the average proportion of time that each server was busy or the service utilization factor (ρ) is found to be highest in Cavite, followed by 26.67% in Antipolo City and 23.68% in Quezon City, reflecting the productivity of their vaccination systems. Despite being the lowest with utilization, Quezon City bears the most number of the expected number of patients in the vaccination process with 57.16 per minute yet the lowest time in the expected time of waiting in the whole vaccination process with 3.18 minutes and 0.02 minutes expected time of waiting in the vaccination line followed by 0.09 and 0.18 minutes in Antipolo and Cavite, respectively. With this being said, Quezon City is considered to be the most productive among the two vaccination sites in the Philippines even if it counted as the least in terms of the utilization factor in multiple server – queue systems (M/M/S). Also, Quezon City which was observed by the researchers with the best practices between Antipolo and Cavite for planning the vaccination considering all the COVID -19 guidelines.

5.4 Economic Analysis of the Three Vaccination Sites

Table 5.4.1 Economic analysis of three vaccination sites

Economic Analysis:			
	Antipolo City	Cavite City	Quezon City
Cs =	$21.55	$18.62	$25.98
Cw =	$1.06	$1.06	$1.06
Cost of Service	$64.64	$55.87	$103.90
Cost of Waiting	$0.87	$1.01	$1.13
Total Cost	$65.51	$56.88	$105.03

Assumptions:
The staff on the server are registered nurses.
Cs = Cost of server based on supply and labor cost
Cw = Cost of waiting based on labor cost (patient in the queue)

The evaluation results of the costs in economic analysis of the three vaccination sites were shown in Table 5.4.1, where the vaccination site in Quezon City entails the highest total cost of service with 105.03 US dollars. The waiting cost in Antipolo City is equivalent to 1.06 US dollars, the same as the cost of waiting in Cavite and Quezon City, in view of the minimum wage rate of 8.49 US dollars in the Philippines. All the while, the cost of the server for providing the service was computed considering six staff in the service, with two staff per server; the daily minimum wage of staff required, ideally registered nurses; and the food allowance for the period of eight hours, whereas in Antipolo City, the result shows 21.55 US dollars and in Cavite and Quezon City, 18.62 and 25.98 US dollars respectively. The vaccination site in Quezon City has the highest total cost, which is a relevant result considering having the most significant number of patients arriving and being vaccinated per hour (See Table 5.3.1 of the Results) among the three vaccinations sites mentioned.

5.5 Proposed Improvements

Based on the result, the proposed improvements for the vaccination centers to have four (4) servers with a server utilization of 30.56%. With four (4) servers, the people spend 3.17 minutes waiting in the system before proceeding to the step-by-step process of testing and receiving the vaccination. Also, the total number of people is relatively low as compared with the total number of people waiting in the systems when the number of servers is three (3). Based on the results, even though having four (4) servers on each vaccination center has a higher service cost and waiting time, it is efficient and productive and can accommodate more people to be vaccinated per day.

To fully achieve and identify the best practice vaccination center, the researchers would recommend to the future researchers to broaden their scope in comparing the vaccination centers in the Philippines. Comparing the vaccination centers in high-risk areas is one best example. According to Tomacruz (2021) in Metro Manila, Central Luzon, Metro Cebu, Metro Davao, Cagayan de Oro, and CALABARZON is reaching an earlier target of vaccinating 70% of residents and considering the greatest number of Covid-19 cases and the greatest number of people who need to be vaccinated. In addition, observe the entire process and document the number of people arriving in the vaccination centers for at least 8 hours in a day to be more accurate in the result.

5.6 Implication

This study can be beneficial to local governments to set up vaccination sites in their communities and give them information on how to operate a vaccination program effectively. According to the literature review, vaccination sites immediately affect people's lives and are one of the most promising options for combating the pandemic. Expanding vaccination capacity and supporting practices that provide optimal vaccination would help the Philippines attain its mass vaccination objectives. Other vaccination delivery methods include modifying vaccines. Drive-through mass testing sites should be considered as well. Mass vaccination is also expected to be achieved through a combination of expanded mass vaccination sites and expanded in-home vaccination.

The researchers would like to imply to future researchers to consider the locale of the study, a large number of sources of data is needed for the reliability and validity of the result. Future researchers can ponder the vaccination sites in Luzon, Visayas, and Mindanao to differentiate the results of this current study since this study is only focused on three vaccination sites in Luzon, specifically in Antipolo City, Cavite, and Quezon City.

Moreover, the findings of this study can be used to plan and optimize operations by utilizing the queuing theory. This theory also addresses both the mathematical and social factors of waiting lines in daily life. Queuing theory has the potential to generate excellent results in a wide range of engineering disciplines, including health care, production, communication, construction, and a variety of other sectors.

5.7 Limitation of the Study

This study focuses on the three Covid-19 vaccination centers in the Philippines which are Antipolo City, Cavite, and Quezon City. The three Covid-19 vaccination centers were observed to gather data. Considering the study was not applied to use surveys to gather data, the researchers will make use of sources to accumulate data. However, due to the pandemic, the researchers are not allowed to stay and observe in the centers on the entire day of vaccination. Taking video was utilized by the researchers to capture the entire process of vaccination to be the source of data, yet it was tough to count the people arriving in the vaccination centers by observing through video. The utilization of Queueing Theory to identify the best practice among three vaccination centers.

6. Conclusion

The findings of the study have shown that Quezon City in the National Capital Region has an average of 28.38 minutes with a standard deviation of 32.13 minutes (See Table 5.2.2 of the Results) in the whole vaccination process with the lowest waiting time in the system for each patient given an average of 3.18 minutes (See Table 5.3.1 of the Results). However, it has the highest total cost, which is a significant outcome given that it has the most patients arriving and being vaccinated every hour (See Table 5.4.1 of the Results) compared to the two (2) stated vaccination sites which are in Naic, Cavite and Antipolo, Rizal. This determines that Quezon City has the most efficient vaccination program and has the fastest process in terms of giving or administering vaccines, followed by the city of Antipolo in Rizal and Naic in the province of Cavite, despite the fact that it has the lowest utilization factor where Cavite has the lead reflecting its productivity. Moreover, the researchers identified that one of the vaccination sites in Cavite has the

longest waiting time in distributing forms and has the busiest servers. It was observed that the signing up of names and administration of forms were in different stages, thus making it very slow and time-consuming. Also, there was a lack of nurses doing the job, and the process was confusing and messed up due to prolonged hours of waiting. The researchers concluded that it is inefficient and has the most inappropriate process in giving vaccines. Moreover, as having four (4) servers to every vaccination site increases service costs and waiting time, it is more efficient and productive and can enable more individuals to get vaccinated in a day. With this, this research is intended for local governments to establish vaccination sites in local communities and provide information on how to administer an effective vaccination program in achieving herd immunity by mass vaccination being a very successful strategy in preventing the spread of many infectious diseases, like COVID-19 as it works through achieving a threshold immunity at the population level where cutting the transmission of the virus is obtained through vaccination.

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