Process Improvement of COVID-19 Vaccination System by utilizing Queuing Theory and ProModel Simulator on Vaccination Facilities in Metro Manila

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Abstract

Providing timely and equitable access to vaccines against COVID-19 for all people in developing countries presents enormous struggles. Thus, the study aims to improve the process of the vaccination system in the facilities by utilizing the queuing theory and Promodel process simulator to provide the best possible "what if's" and create a model that can obtain a much precise and functional process layout, sought to address the challenges upon the rollout of the vaccine. The results show the massive difference between the two layouts; the current system by the government can only produce 2,821 vaccinated patients, having an average time of 198 minutes, 29 seconds in the system, and an average time of 68 minutes, 22 seconds in operation. The proposed layout obtained 17,085 vaccinated patients, having an average time of 85 minutes, 12 seconds in the system, and obtaining an average time of 39 minutes, 15 seconds in operation. Both have eight work hours and can be implemented to any size of facilities, with 17-27 health workers. The proposed layout provides a much better process flow and time-saving to minimize exposure to risks and provide a safe facility and foresee the remarkable stories of human resilience, ingenuity, and creativity.

Keywords
Queuing Theory, ProModel, Process Simulator, Vaccination Process System, Vaccine Rollout.

1. Introduction

A year since the COVID-19 has officially declared a pandemic and has been tremendously challenging, but behind this are remarkable stories of human resilience, ingenuity, and creativity. Nobody could foresee the changes that the COVID-19 pandemic would bring, yet its effects spread like wildfire over just a few short months. While everyone is on their move to limiting the spread of the virus, there are people behind those white coats who spend their whole time figuring out a vaccine to end its spread. Everyone can agree that the vaccine is treated as an antigen or a synthetic substitute and serves antibodies to provide immunity to the body. Nevertheless, its effectiveness goes down to various factors, and one of the most significant factors of people being safe and away from the virus is its distribution. March 1 of 2021, the Philippines began lawfully distributing the first dose of COVID-19 vaccines; however, because of the massive needs of every affected country, the vaccine is on a limited resource. The vaccination campaign has taken off with the use of various modalities. The Philippine government has decided to prioritize the vaccination process as a temporary solution in distributing the vaccine and controlling the virus's spread. The government's system onto the distribution indicates the eligible categories to be prioritized for receiving the vaccines with the understanding and awareness that many people and other categories will stay in line for a couple of months and might continue risking their lives because of the exposure. The prioritization of the first batch will be given to the prioritize people who serve the country and help stop the spread of the virus. These are (1) the workers in frontline health services. Next is (2) all senior citizens, (3) Persons with Comorbidities, (4) Frontline personnel in essential sectors, including uniformed personnel, and lastly, (5) Indigent People. These are prioritized since they have a higher risk of exposure while on duty, allowing them to continue fulfilling their duties and services in the public and private sectors. Vulnerable groups such as the elderly and the indigent population are also prioritized, guided by the principle of equity from the DOH (DOH, 2021).

Since the pandemic's beginning last March of 2020, there have been 1,649,341 confirmed cases, 76,063 active cases, 1,544,443 recovered patients, and 28,835 coronavirus-related deaths in the country as of August 7. COVID-19 vaccination in the Philippines started in March 2021, and the country aims to vaccinate 58 million people by the end of the year. As of August 5, 2021, the Philippines has administered at least 23,199,187 doses of COVID vaccines so far, which is 10.7% of the country's population. As of August 3, 2021, about 12,058,320 already received the first dose of vaccine, and 9,825,420 had completed the second dose; roughly 9.9 % of the country's population are completely vaccinated. Since the rollout of the vaccines, the country's average distribution was about 550,543 doses administered each day (WHO, 2021). Metro Manila has a population of 14 million and has an 8,592,233 target population to be vaccinated. The Metro Manila alone has approximately 2,839,432 fully vaccinated citizens, which is 33.05% of the population. About 4,603,756 had their first dose, having thousands of converted vaccination facilities such as primary and secondary schools, universities, institutes, and even malls. The local government unit of Manila also established last June 25 the Manila COVID-19 Field Hospital that serves as a facility for mild to moderate COVID-19 patients. Factors such as shortage of vaccines and the allocated budget of the government. The system of the vaccination process is the main problem that needed to be addressed. In ensuring if the health protocols are being employed to the vaccination site properly and the time consumption of patients in the site produces many risks being exposed to other people they never knew if that person is positive in the virus or not, which is alarming. Efforts to contribute to an inevitable change are a must.

1.1 Objectives

The general objective of this study is to improve the process and steps of the vaccination system in the facilities. Utilizing the queuing theory and promodel process simulator to obtain a much precise and functional process layout sought to address and resolve the challenges upon the rollout of the vaccine and focus on the following specific objectives.

- Reduce the time consuming of a patient getting the vaccine and their exposure to other people and places.
- Maximize the capacity of people getting the vaccine.
- Providing a more systematic and flexible process in any scale of facilities and those converted as vaccination facilities.
- Maintaining the social distancing and other health and safety protocols.
- Use in preference to lack of equipment, health workers, and volunteers in some facilities.
- Help the Government and health authorities keep everything in place, organized objectives, and convince people to get vaccinated.

2. Literature Review

Utilizing Queuing System

Queuing theory is defined as a branch of knowledge in operation research that concerns the analysis of queues when a customer or patient arrives at a service center and shall queue in a line to get some service. The theory pays attention to how organizations can serve many customers who demand quality services and a queue of customers or patients waiting to be served. A queuing network embodies the operational components of the patient stream in a clinic, with the clinical units being the hubs of the organization; patients are the clients, while beds, clinical staff, and clinical gear are the workers (Hamdan et al., 2017). Studies in response to the pandemic have been on the run for quite a while. According to Ferreira M.A. (2018) study, the queuing system is a hypothesis perfectly admissible in this kind of phenomenon since they have great geographic spread. It is considered the mean arrival rate for the pandemic period as the constant rate. The study establishes a model "the pandemic Period" where $M|G|\infty$ queue busy period length distribution can be applied to the period study. The results are remarkable for easiness and require only the knowledge of the infectious rate λ, the mean sickness time α, and the sickness time variance. The other results are more complex and demand the goodness of fit test for the distributions indicated to the sickness times.

In the study of Zimmerman S., Rutherford A.R., et al. (2020), the importance of mathematical modeling needed critical care resource capacity during the COVID-19 Pandemic has been recognized. This study used the queuing system to establish a model that might support ventilator capacity planning during the first wave of the COVID-19 Pandemic in British Columbia (BC), Canada. The study's framework is accomplishing an Erlang loss model, which incorporates COVID-19 case projections. The researchers implemented their model using discrete event simulation to forecast ventilator utilization. The resulting prediction was when capacity would be reached and the rate at which patients would be unable to access a ventilator. The prediction of reduced transmission is averted about 50 deathless per day by ensuring the capacity of the ventilator.

Optimization of Promodel Process Simulation

ProModel is a Windows-based system that features a user-friendly graphical interface and object-oriented modeling constructs that reduce programming. In order to make the most immeasurable decisions, the simulation or system must include three key parameters. One of the primary and most essential employments of simulations is for optimization. Simulation optimization can be characterized as the way toward finding the best result info variable qualities from among all potential outcomes without unequivocally evaluating each possibility (Ahmad 2017).

Establishing a straightforward process to collect and report simulation outcomes has never been more important for staff and patient safety to reduce preventable harm. According to the study of Dube M., Kaba, A., Cronin T., et al. (2020), healthcare resources have been strained to previously unforeseeable limits due to the COVID-19 pandemic of 2020. The rate at which the COVID-19 pandemic has emerged in Canada may prevent healthcare sectors in urban and rural settings from having an opportunity for healthcare teams to participate in just-in-time in situ simulation-based learning before a potential surge of COVID-19 patients. The researcher's approach and infrastructure have enabled Canada's organizational learnings and the ability to theme and categorize a mass volume of simulation outcome data, primarily from acute care settings, to help all sectors further anticipate and plan. Since their research aims to share the unique features and advantages of using a centralized provincial simulation response team, preparedness using learning and systems integration methods.

On the study of Eastman B., Meaney C., Przedborski M., et al. (2021), they have developed a mathematical study of the impact of social behavior on the pandemic in the province of Ontario. Following the variable transmission rate, the model can predict the second wave of occurrence using current infection data and disease-specific traits. The study results are found effectively from the reproduction number. Thus the course of the pandemic is found to be sensitive to the adherence to public health policies, which illustrates the need for vigilance as the economy continues to reopen.

Vaccination System Flow

Vaccines are among the safest and effective public health interventions to prevent severe disease and death. Therefore, the government encourages its people to be vaccinated. However, due to the lack of funds in buying enough vaccines for the citizens, the government decided to prioritize first all the front liners in order for them to be protected against the virus while serving and helping the government stop the spread of the virus. It is essential to have a system flow, especially when the vaccines are limited. According to the World Health Organization (WHO) Strategic Advisory Group of Experts (SAGE), together with the recommendations of independent bodies of experts, including the Interim National Immunization Technical Advisory Group (iNITAG) and the Technical Advisory Group (TAG), having a prioritization framework for COVID-19 vaccination and a vaccination Plan formulated strategies and contingencies are needed to ensure the equitable distribution of vaccine products for all Filipinos and focused objectives of maximizing the doses and time of the patient going out of their homes (WHO, 2020).

Priority Queuing Discipline (PQD)

In most medical care settings, except if an arrangement framework is set up, the line discipline is either earliest in, earliest out or a bunch of patient classes that have various needs as in a crisis office, which treats patients with perilous wounds before others (Fomundam and Herrmann, 2007). The control depicts how the patients are served after a line has been framed (Johnson, 2008). The standard orders are First Come First Served (FCFS), Last Come First Served (LCFS), and Random Selection Service (RSS).

Factors Affecting the Vaccine Rollout

One of the government's problems facing this pandemic is the factors influencing the vaccine rollout. One of these is the people's hesitancy to get a jab of the vaccine because it is ineffective, and maybe it can cause them to be positive in the virus. Second is the brand preference where the vaccine is manufactured. People are more careful when it comes to the brand because it all has a different level of effectiveness, so people tend to pick which one is the most effective for them to be safe from the virus. The third factor is that the availability of vaccines; because of their production and demands all over the world, and those countries who can buy vaccines are put at the front of the line for them to be first who received, so third world countries like the Philippines will take much longer time in waiting for it. Fourth is probably the strategic plans upon the vaccination process set by the government. The current layout that the government and facilities are using takes much more of the patients waiting time than the operation itself, which can lead to various problems such as too much exposure of people, the social distancing can also be misguided, and following other protocols might not be followed by the other patients.

3. Methods

The study's methodology involves using the ProModel Process Simulator to determine the best system flow of the vaccination, evaluate methods being used, survey design, different processes of gathering data, and the respondents engaging in the study. It explains the methods used and how the researchers can get the ideas contained in the previous chapter and enhance the research, gather data, collect the related information, and design the design used in this study. The tool used for designing the facility layout is the ProModel Process Simulator software. Using the software, the researcher created various process flow models and ran the simulation process. The results of determining the most desirable model are compared to the baseline, which is the current process flow of the vaccination. In designing using Promodel, there is a sequence of steps that are to be followed. Queuing theory is also used to analyze quantitative data obtained during the gathering mathematically. The queuing theory provides different formulas to see the average time of the flow of vaccination presented within the study. The numbers acquired will determine the effectiveness of the vaccination queuing system.

Mathematical Expressions and Symbols

The following formulas were used in analyzing quantitative data

Legend:

ʎ - Average number of arrivals entering the system per unit time
L - Average number of customers present in the queuing system
μ - Average service rate
W - Average time a customer spends in the system
Wq - Average time a customer spends in line
Ws - Average time a customer spends in service

Queuing formulas:

a. L_s - the average number of customers in the system

$$L_s = \frac{\lambda}{\mu - \lambda} \quad (1)$$

b. W_s - the average time a customer spends in the system

$$W_s = \frac{1}{\mu - \lambda} \quad (2)$$

c. L_q - the average number of customers waiting in the queue

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} \quad (3)$$

d. W_q - the average time a customer spends waiting in the queue

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} \quad (4)$$

e. ρ - the utilization factor for the system

$$\rho = \frac{\lambda}{\mu} \quad (5)$$

f. P_0 - the probability of 0 units in the system

$$P_0 = 1 - \frac{\lambda}{\mu} \quad (6)$$

g. $P_{n>k}$ - the probability of more than k units in the system, where n is the number of units in the system

$$P_{n>k} = \left(\frac{\lambda}{\mu}\right)^k \quad (7)$$

4. Data Collection

The data obtained by the researchers are acquired through observation and on-hand experience. From 40 people who are vaccinated, for the time being, it helped the study to gain manageable information. The observation process allows researchers to obtain data needed to analyze the vaccination system flow and see the implementation's effectiveness. This study aims to use qualitative methods as well as quantitative methods to be able to help analyze the proposed topic. Using measurable research questions, such as descriptive and comparative questions, enables the researchers to use data and statistics to obtain a precise observation and compare the time occurrence with the time consumed with the other patient.

The topic's layout process will start upon the arrival of the patient in that facility to finish all the activities regarding the vaccination process. On-hand interviews and experience were the basis for determining the time spent in the current facilities system implemented by the LGU's and the Government. This study limits its coverage to the activities that need to accomplish in those facilities. It does not include the whole vaccination process, from registration to getting the second vaccine shot.

5. Results and Discussion

5.1 Determining the Time in System with and without Waiting Time of the Current System.

The Table 1 shows the 40 participants that fall in various categories given by the government, the priority to be vaccinated is (A1) the workers in frontline health services. Next are (A2) all senior citizens, (A3) Persons with Comorbidities, (A4) Frontline personnel in essential sectors, including uniformed personnel, and lastly, (A5) Indigent People. The researchers can determine the average time in the system and the operations of people in different categories.

Table 1. Result of Time in System and Operation of each category

Steps	**Average Time in the System**									
	A1		**A2**		**A3**		**A4**		**A5**	
	w/ waiting time (mins)	w/out waiting time (mins)	w/ waiting time (mins)	w/out waiting time (mins)	w/ waiting time (mins)	w/out waiting time (mins)	w/ waiting time (mins)	w/out waiting time (mins)	w/ waiting time (mins)	w/out waiting time (mins)
Registration	45	5	15	5	15	5	20	5	20	5
Filling out forms	15	5	10	5	10	5	10	5	10	5
Checking of Requirements	15	10	15	10	20	5	15	5	15	5
Getting the patient's vitals (BP/temp/pulse rate)	15	5	10	5	10	5	15	5	15	5
Vaccination	20	5	15	5	15	5	20	5	20	5
Status Monitoring and Consultation	45	30	30	30	30	30	45	30	45	30
Final Orientation and guidelines for side effects	15	5	15	5	15	5	15	5	15	5

Overall Average Time in the Operation	**155**	**65**	**150**	**65**	**115**	**60**	**140**	**60**	**140**	**60**

5.2 Baseline of the Current Vaccination System Installed by the Government

Using the Promodel Process Simulator utilizing an optimization design to quickly and accurately create a system is the best suited for these problems. It develops simulation-based predictive and prescriptive analytic software for process improvement enabling organizations to make better decisions. The government is currently in the initial phase of vaccine rollout, and the vaccination system layout is from the LGU's or the health workers. The Layout of the current vaccination system is composed of processes that enable the health worker to separate the patients based on their comorbidities and prioritization. This process consumes much time waiting or queueing because of adequate equipment, waiting booths, and vaccines. This process layout can also be why people get a virus because of exposure to many people and risk in the facility.

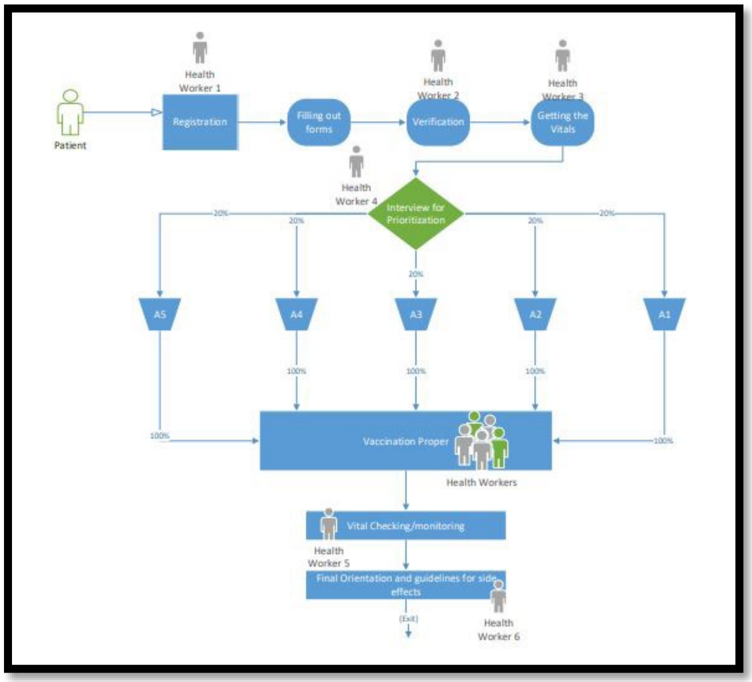

Figure 1. Current Process Layout of Vaccination System implemented by the Government

Figure 1 is the current layout that the LGU's and Health facility follows, in a small hall or converted vaccination-covered court for some areas in Manila. Having limited volunteers and health workers, people often wait longer than the schedule they have received upon the registration for the vaccination. With 19 or fewer health workers assigned to some areas, because of limited resources and the capacity to maximize the time, vaccines, and people getting vaccinated, those workers tend to work overtime, and people have a longer exposure time. The workers are distributed according to the needs of the service. As the patient arrives, it will go to the screening process where they will fill up a form, verify, and obtain the vitals if suitable for getting the shot. Then they will proceed to the interview about the comorbidities and segregate according to the category set by the government. After those things, the vaccination proper is on queue, after that another round of vital check and observation for quite minutes and then orientation, and they are good to go.

5.3 Numerical Results

Analysis of Simulation Result of the Current System

The result of the baseline or the current system is determined after the simulation of the given layout having a work time or simulation time of 8 hours according to the maximum work hours of a particular worker. It shows the results of the following:

Table 2. Summary of the Simulation results of the Current System

Average Time in System	Average Time in Operation	Total Patients
198 minutes & 29 seconds	68 minutes & 22 seconds	2,821

The Table 2 shows the summarized average time in a system with 198 minutes and 29 seconds of waiting for the queue. The average time in operation is 68 minutes and 22 seconds, and this is obtained by subtracting the waiting time offered by the system. As for the total exits having 2,821 patients, these successful patients can finish the vaccination program within the given time.

Table 3. Summary of Entity States Result of Current System

Patients Entity State	% Results
Average Time Moving logically	12.39 %
In Operation the whole time	34.40 %
Average Time Waiting	10.34 %

Table 3 shows the resulting entity states of the current vaccination system implemented by the government, which contains the percentage of patients in the queue; 12.39% of the patients are moving according to logic, which means that they are moving accordingly with the process installed. 10.34% of the overall population has waited for a while. 34.40% have been in a continuous operation.

5.4 Proposed Vaccination Process System to the vaccination facilities

The present undertaking will enable the country to be resourceful and use the vaccines available right now. For it to be deployed, a proper vaccination process system is needed to be prioritized. With the analysis from the current system, the researchers can determine a time-saving and effective process for the current vaccination program by the government. With the use of the ProModel Process simulator, the layout is appropriately imposed. Upon the arrival of the scheduled patient to be vaccinated, it will proceed directly into the screening process, where they will fill up forms and get registered. Based on their schedule, patients will get verified and then proceed to the assigned booth based on their prioritization and assigned vaccination area. After getting the vaccine shots, patients will be directed to the holding area. Health workers will observe another round of vital checking while proceeding to the orientation, where a video presentation will play, informing the patients about the guidelines and proper direction after getting the vaccine to know what to do if they feel something wrong with them after being vaccinated.

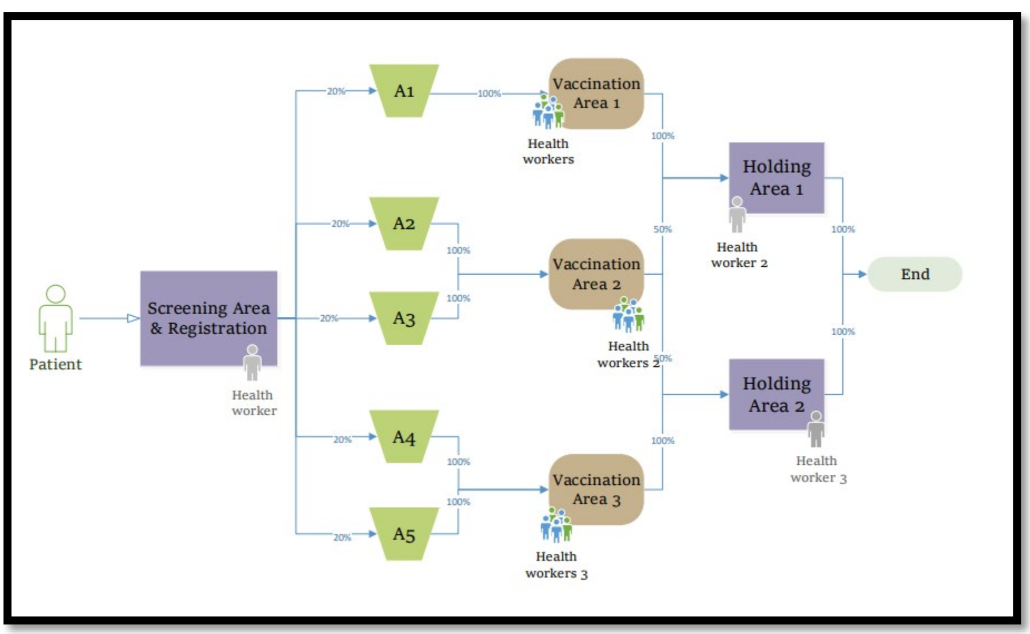

Figure 2. Proposed Layout of Prioritizing Vaccination System

Figure 2. given above is the proposed simulation layout for the proposed vaccination system. It is an organized chart built to ensure the safety of the people and maximize the number of people vaccinated. The layout has a capacity of 19-25 health workers or volunteers to help and assist the patients. In this layout, the objective is to maximize the time and lessen the patient's waiting time. As the patient set foot at the facility, the proposal layout offers no waiting time to lessen the exposure. The patient will directly go to the screening area, and the registration, about 2-3 health workers are to assist the patients. The next station would be the verification for each assigned prioritization. Patients then will proceed to the vaccination area where 5-7 health workers are assigned. In the holding area, around 3-4 health workers are assigned to accommodate the patients and observe any problems after the process.

5.5 Analysis of Simulation Result of the Proposed Layout System

The result of the baseline or the current system is determined after the simulation of the given layout having a work time or simulation time of 8 hours which is according to the maximum work hours of a particular worker. It shows the results of the following:

Table 4. Summary of the Simulation results of the Proposed System Layout

Average Time in System	**Average Time in Operation**	**Total exits**
85 minutes 12 seconds	39 minutes 15 seconds	17,085

Table 4 shows the summarized average time in a system that has 85 minutes and 12 seconds of spending time or waiting for the queue. The average time in Operation has an average time of 39 minutes 15 seconds, and this is obtained by subtracting the waiting time offered by the system. As for the total exits having 17,085 patients, these successful patients can finish the vaccination program within the given time.

Table 5. Summary of Entity States Result of the Proposed System Layout

Patients Entity State	**% Results**
Average Time Moving logically	4.70 %
In Operation the whole time	45.99 %
Average Time Waiting	0

Table 5. shows the resulting entity states of the current vaccination system implemented by the government, which contains the percentage of patients in the queue; 4.70% of the patients are moving according to logic, which means that they are moving accordingly with the process installed and staying in one station or step. 45.99 % have been in a continuous operation, and no people are waiting or blocking the system.

5.6 Results Comparison between the Two Layout

With the ProModel Process Simulator, the researchers can determine the difference between the two-layout model by having a total of 8 hours of working time spent by the workers on both layouts. Having 19-23 health workers to the current and 17-25 health workers to the proposed, the results of acquired time in both system and operation are being shown.

Table 6. Summary of Comparison to the Results of the Two System Layout

	Current System Layout	Proposed System Layout	Percentage difference
Average Time in System minutes/seconds)	198 mins & 29 secs	85 mins & 12 secs	79.86 %
Average Time in Operation (minutes/seconds)	68 mins & 22 secs	39 mins & 15 secs	54.15 %
Total patients Accommodated	2,821	17,085	143.31 %

Table 6 shows the resulting difference between the two layouts, where the Proposed system layout has much difference from the current system layout. The proposed layout average time in the system has a 79.86 % difference from the current. Suggesting that the proposed has the lesser time a patient spends in the process. In the time in operation, the proposed layout has a percentage difference of 54.15%, suggesting that the proposed layout has a lesser time in the operation, which means less exposure to other people. Lastly, the total patients accommodated, the proposed layout obtain about 143.31% difference from the current system layout implemented by the government.

6. Conclusion

Providing timely and equitable access to vaccines against COVID-19 for all people in developing countries presents enormous struggles. In addressing these challenges, much can be learned from past approaches in dealing with health crises; such challenges include overcoming barriers to the availability of the vaccines, cost, local production, and logistics and infrastructure upon the rollout. The application of queuing theory, simulator software can help determine the best possible "what if's" and create a model that can accurately predict and create precise results, such as the given comparison between the current vaccination system implemented by the government and the proposed prioritization system layout using simulation model and software. It also shows the massive difference between the two layouts; the current system by the government can only produce a total of 2,821 patients that got vaccinated for eight full hours, having an average of 198 minutes and 22 seconds in the system. An average of 68 minutes and 22 seconds in operation—as for the proposed layout, obtaining a total of 17,085 patients that can be vaccinated for eight full hours, having an average of 85 minutes and 12 seconds in the system, and obtaining an average of 39 minutes and 15 seconds in operation. This proposed layout can also be helpful and effective upon having enough health care workers, following the schedule, and not delaying the whole process for the safety of everyone. This layout can be applied to any facility, having 17-25 health workers; this number of patients being vaccinated per day is possible.

Based on the findings presented, the researchers have recommended optimizing the proposed layout. It provides a much better process flow and time saving to minimize exposure to risks and provide a safe facility. The researchers also recommend that the government implement the vaccination better to convince people to get vaccinated. The researchers also look forward to considering these options when the mass vaccination has been provided. Furthermore, future researchers can use this Promodel to engage themselves in this kind of system to be more familiarized with the process and how Promodel works in real life. Therefore, understanding the best way to present the system's process flow and minimize the exposure of risk and provide a safe facility.

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