Queuing Theory: A Case Study in Analyzing the Vaccination Service in Quezon City

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Abstract

COVID-19 vaccines are being developed by a number of research and development teams across the world, but the distribution of the vaccines to different cities in the Philippines became a common problem. This research aims to determine the different factors in the vaccination rates. This study focuses on the queuing system to improve the service of vaccination in Quezon City that had been observed within a parameter of arrival time, waiting time in queue and time of service of the vaccine. The researchers gathered data through direct time study. Using a watch and timer, the data was collected from each procedure. For a duration of 1 hour, all the information is manually recorded for the three factors of this study. The Data using M/M/1 Queuing Model resulted in the slowest Average Time in the System is Step 4, Monitoring. For the Average Waiting Time, Step 1 has the slowest time. For the Average Service Time, Step 4 is the slowest system. For the Probability of No Person in the system, Step 1 and 3 has the highest percentage and for the Probability of Busy Server, Step 2 and 4 denotes the highest percentage.

Keywords:
Queuing Theory, COVID-19, Vaccination Service

1. Introduction

1.1 Background of the Study
The COVID-19 pandemic has thrown children's and their families' lives into disarray all around the world. According to Professor José Manuel Barroso, Gavi Board Chair (2021), nobody is safe until everybody is safe in the midst of a Pandemic. So, right from the start of this worldwide disaster, it was evident that each individual doesn't only need vaccines, but that everyone requires a lot of them. Much more than producers and distribution systems had been able to produce and distribute to individuals prior to the epidemic. The enormous and urgent issue of satisfying this worldwide demand has generated vast ethical and legal dilemmas that every individual must resolve not only to stop this outbreak, but also to guarantee that every person is better prepared for the next. COVID-19 vaccines are being developed by a number of research and development teams across the world, but the distribution of the vaccines to different cities in the Philippines became a common problem that led the citizens to high risk of exposure in crowded areas and disordering Social Distancing and Safety Protocols, due to following the guidelines in the vaccination area at first, then filling up registration forms for contact tracing, then staying in line and waiting for their turn, and other centers interviews their registrants. This one common problem could use Queuing Theory to improve the service of vaccination.

Queuing theory is a mathematical study of queueing systems or waiting lines and how lines are formed-- how they operate and malfunction. It is a model that is built in order to anticipate queue lengths and waiting periods. The congestion and factors in a process are utilized to generate more improved and cost-efficient systems and services. Queuing Theory is mostly used in a wide range of business and operation management in order to enhance total customer service shortfalls, assess and optimize business objectives, scheduling, and inventory.

1.2 Current Issues Related to the Topic

Social Distancing
One of the most important rules the country's Inter-Agency Task Force (IATF) implemented to prevent the spread of COVID-19 was the Social Distancing, this is a physical distance or no-physical greeting with a person. This has caused every citizen to limit themselves in going outside their houses, attending gatherings and masses, doing outdoor activities and exercises.

According to the article stated by the Manila Reuters last November 2, 2019, President Duterte enacted the Filipino citizens to retain a meter distance of 1 to 2 meters to reduce COVID-19 infections. Social distancing is a requirement that needs to be maintained and to be followed even up to this day.

1.2.b Safety Protocols
According to the guidelines of the IATF on Section 3 rule #16, every individual is mandated to wear face masks and face shields as one of the safety protocols. During the pandemic, washing of hands properly also became viral on social media as a form of encouragement to prevent the spread of the virus. Other safety protocols such as, practicing sneezing and coughing into bent elbows and using of alcohol and hand sanitizer are also observed.

1.2.c Exposure to Crowded Areas
According to the Centers for Disease Control and Prevention (CDC), they recommend an avoidance of large gatherings and exposure to crowded areas such as concerts, parties, weddings, family gatherings, eating at a restaurant, going to malls, waiting in line, etc. The said events cause a high risk of being exposed to the COVID-19 and other types of viruses. Physical distancing and following safety protocols are highly advised.

1.3 The Research Gap
When the COVID-19 happened last 2019, everyone wasn't prepared to face the pandemic, not even the government of the country. There were no vaccines produced globally back then. But according to the World Health Organization (2021), the first mass vaccination program was implemented last year, December 2020. Therefore, there is no sufficient studies and research that are available yet to be a basis of this research study.

1.4 Objectives
This research aims to determine the different factors in the vaccination rates. The specific objectives of this study are as follows: (a) To assess the queuing lines of each step on the vaccination center. (b) To implement the Steady State Equation. (c) To determine which Step process has the longest time in the system.

1.5 Scope and Limitation
This study focuses on the queuing system to improve the service of vaccination in Quezon City that had been observed within a parameter of arrival time, waiting time in queue and time of service of the vaccine. The study was conducted in July 2021 within a period of 1 hour in the vaccination site. The researchers only recorded at peak hour of the actual queuing lines. In addition, the vaccines that arrived at the site were from a new batch. The actual data has been gathered from a vaccination center in Sangandaan, Quezon City and would not generalize all the vaccination centers in Quezon City.

Although the data will be on hand, there are some unavoidable limitations as such COVID-19 vaccination was only conducted this year as pandemic takes worldwide.

1.6 Significance of the Study
The importance of this study is that the researchers can provide an adequate solution providing the vaccination site a better and improved queuing system. It can address the issue of long waiting lines and can minimize the time of waiting and intervals in line. This research can serve as basis for improvement of queuing in vaccination sites

2. Literature Review
The goal of this literature review is to give the reader a broad overview of the models, ideas, and discussions utilized in this study so that they may better understand the variables and terms utilized. This would also provide further

discussion about acquired methods of analyzing and how we conclude the results with the aims to improve vaccination service of vaccination.

2.1 Methods and Parameters

The data that would be recorded for the peak hour would only represent a specific queue at that moment. Even the off-peak recorded data, would only refer to the current recorded time. According to (Manuel et.al, 2014), Poisson distribution would estimate the inter-arrival and inter-service time of the recorded data. And Monte-Carlo Simulation would bridge the gap for reliability of queues in the future. The simulation that would be randomized could be used as the general state of the system. Their research proved the parameters of waiting time, service time and arrival rate could be treated through simulation. And the simulation can help the improvement of the queuing system. According to (Kimani et.al, 2014), Monte Carlo Simulation aided to predict the specific number for queues. Their research on predicting the number of patients in an ongoing queue helped solved the capacity limit of their rooms for improvement. Due to their modeling and Markov chain application, the rooms for each department can increase based on the ratio of room availability to patients.

2.2 Queuing Theory Model

Queues, or "waiting in line," are a common social phenomenon that aids organizations and service providers in maintaining order (Narayan Bhat, 2015). Queuing ensures that all customers have an equal chance of receiving services by distributing them in a sequential order. The Queueing Theory is exemplified by all perceivable systems with queueing features. Fundamentals of Queuing Systems explains how to calculate probability and statistics for a wide range of queueing systems. The subject matter is ageless, and the book will never go out of print. Infinite and finite arriving populations, single and many service facilities, and infinite, finite, and no waits are all part of the systems.

The customer, whether human or not, is the unit that is requesting assistance in this context. The device that delivers service is known as the server. Customers and servers are generic words that are utilized regardless of the actual context (Narayan Bhat, 2015). This form of transactions or relationships occur in several ways, such as communication, manufacturing, vehicle services or medical treatment procedures.

The systems in question are referred to as the continuous-service M/M/1 queueing system. The continuous-service M/M/1 system differs from the normal system in that the server is never idle since it is constantly serving. We suppose that there are two categories of consumers in this system to display the aforementioned characteristic (Chew, 2019). The typical M/M/1 system is a queuing system with a single server that distributes interarrival and service times separately and exponentially. When consumers are present in the system, the server serves them one by one in the typical M/M/1 manner. When no consumers are present in the system, the server becomes idle.

A quantitative characterization of the underlying processes is necessary for a quantitative evaluation of a queueing system in a common queueing system. In many cases, six basic characteristics are sufficient to characterize a system: Customers' arrival and service patterns, the number of servers and service channels, system capacity, queue discipline, and the number of service stages (Shortle et al, 2018).

2.3 The People's Research Gap

Based on (Asgary et.al, 2020), as different countries are focused on mass vaccination, the layout and distribution process would be more difficult. For the rapid and safe immunization of the people, their research helped predict the vaccination process. They simulated mass vaccination and created different models. But in this study of the vaccination center in Quezon City, more reliable and accurate data would be obtained. Actual on-queues waiting, and service time would be recorded.

3. Methodology

3.1 Conceptual Framework

This research aims to interpret its data through several processes in order to achieve the objective output. In this section of the paper, the conceptual framework will describe and provide an overview of how the data will be handled for this research. The researchers used several techniques to acquire adequate data for further interpretation. The intended method for this study and the process that the data will undergo in figure 1 are as follows.

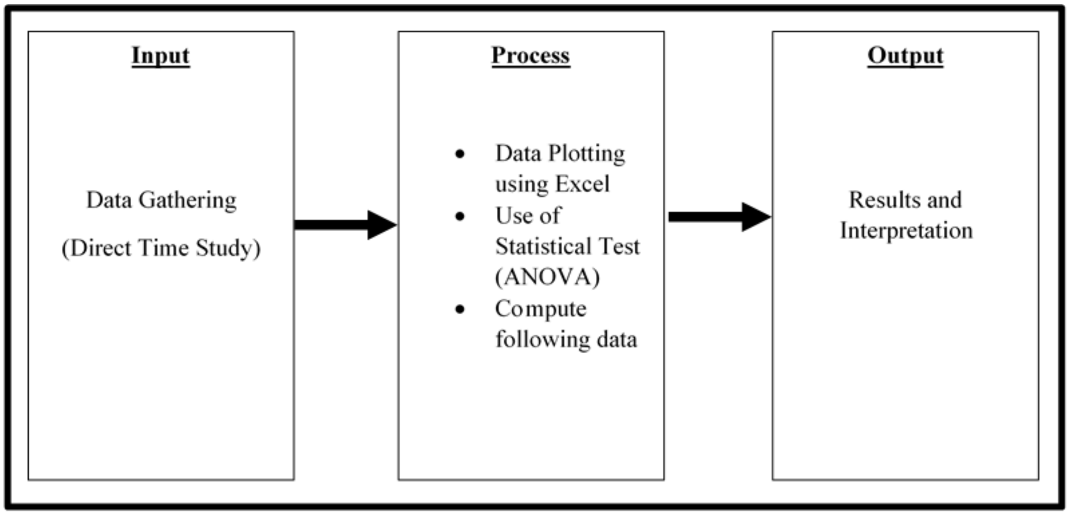

Figure 1. Conceptual Framework

4. Data Collection

There were 4 different queuing (Vaccination Form Filling, Health Screening, vaccination, and Monitoring) on the whole system on the vaccination centers. On gathering the data, direct time study was implemented. Using a watch and timer, the data was collected from each queuing procedure. For a duration of 1 hour, all the information is manually recorded (arrival time, service time, waiting time and departure time). The data collected were the actual raw data from observation of each procedure. For the arrival time, the timer would start counting when the person entered the queue. For the service time, the timer would start counting when the person started the service. For the departure time, the data would be recorded from the moment the person finishes the service. In terms of waiting time, the data is measured throughout the duration of waiting in the queue.

5. Results and Discussion

5.1 Presentation of Results

In determining significance between the waiting time, departure time, and service time of each procedure, ANOVA one-way with unequal variances was used to determine their values. Games-Howell Pairwise Comparison was utilized to infer their differences.

Games-Howell Pairwise Comparisons

Grouping Information Using the Games-Howell Method and 95% Confidence

Factor	N	Mean	Grouping
Step 1	17	0.46887	A
Step 2	13	0.3124	A B C
Step 4	11	0.19539	B
Step 3	8	0.12865	C

Means that do not share a letter are significantly different.

Figure 2. Pairwise Comparison of the Service Time of each Procedures

In figure 2, Games-Howell Pairwise Comparison was used to infer differences between the different service times of each procedure. Based on the data, Step 1 has no significant difference to Step 2, but has significant difference to Step 3 and 4. Step 2 has no significant difference to Step 1, 4 and 3. Step 4 has no significant difference to Step 2 but has significant difference to Step 1 and Step 3. Step 3 has no significant difference to Step 2 but has significant difference to Step 1 and Step 4

Games-Howell Pairwise Comparisons

Grouping Information Using the Games-Howell Method and 95% Confidence

Factor	N	Mean	Grouping
Step 1	17	0.47067	A
Step 2	13	0.2808	A B C
Step 4	11	0.20442	B
Step 3	8	0.13229	C

Means that do not share a letter are significantly different.

Figure 3. Pairwise Comparison of the Department Time of each Procedures

In figure 3, Games-Howell Pairwise Comparison was used to infer differences between the different departure times of each procedure. Based on the data, Step 1 has no significant difference to Step 2, but has significant difference to Step 3 and 4. Step 2 has no significant difference to Step 1,4, and 3. Step 4 has no significant difference to Step 2 but has significant difference to Step 1 and Step 3. Step 3 has no significant difference to Step 2 but has significant difference to Step 1 and Step 4.

Games-Howell Pairwise Comparisons

Grouping Information Using the Games-Howell Method and 95% Confidence

Factor	N	Mean	Grouping
Step 2	13	13.38	A
Step 4	11	12.000	A
Step 1	17	5.176	B
Step 3	8	3.625	B

Means that do not share a letter are significantly different.

Figure 4. Pairwise Comparison of the Waiting Time of each Procedures

In figure 4, Games-Howell Pairwise Comparison was used to infer differences between the different waiting of each procedure. Based on the data, Step 1 has no significant difference to Step 3, but has significant difference to Step 2 and Step 4. Step 2 has no significant difference to Step 4 but has significant difference to Step 1 and Step 3. Step 3 has no significant difference to Step 1 but has significant difference to Step 2 and Step 4. Step 4 has no significant difference to Step 2 but has significant difference to Step 1 and Step 3.

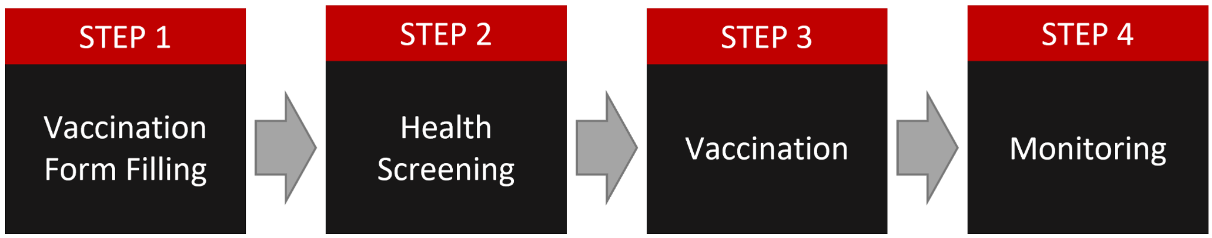

Figure 5. Vaccination Process Representation of M/1/1 Queuing System

The vaccination process involves four steps, these are: (Step 1) Filling-up of Vaccination Forms, (Step 2) Health Screening, (Step 3) the actual Vaccination, and (Step 4) Monitoring.

Table 1. Service Time of Vaccination Form Filling

Step 1 : Vaccination Form Filling				(Departure Time - Service Time)
Person	Service Time	Departure Time	Waiting Time (mins)	Service Rate (mins)
1	10:35	10:36	4	1
2	10:39	10:41	4	2
3	10:43	10:44	5	1
4	10:46	10:47	5	1
5	10:50	10:52	4	2
6	10:52	10:54	6	2
7	11:01	11:02	3	1
8	11:06	11:07	6	1
9	11:11	11:15	4	4
10	11:18	11:24	7	4
11	11:26	11:29	5	3
12	11:32	11:34	5	2
13	11:40	11:43	6	3
14	11:44	11:47	4	3
15	11:50	11:54	8	4
16	11:59	12:03	7	4
17	12:06	12:10	5	4
AVERAGE				**2.470588235**

Table 1 shows that the number of persons is equivalent to 17 people to fill-up the vaccination forms. This occurs from the service time to departure time which will be used to get the service rate. The service rate is equivalent to the difference between the service time and departure time, and the average of the service rate is equivalent to **2.47** in minutes.

- The arrival rate per unit of time (λ) = 0.28 persons/ hour
- The service rate per unit of time (μ)= 24.29 persons/hour

Table 2. Service Time of Health Screening

Step 2 : Health Screening				(Departure Time - Service Time)
Person	Service Time	Departure Time	Waiting Time	Service Rate
1	12:01	12:10	5	9
2	12:11	12:16	9	5
3	12:18	12:25	8	7
4	12:26	12:32	3	6
5	12:34	12:40	7	6
6	12:43	12:51	7	8
7	12:52	1:04	11	12
8	1:06	1:19	13	13
9	1:22	1:35	15	13
10	1:37	1:49	17	12
11	1:52	2:05	21	13
12	2:06	2:17	26	11
13	2:20	2:34	32	14
AVERAGE				**9.923076923**

Table 2 shows that the number of persons is equivalent to 13 people to fill-up the vaccination forms. This occurs from the service time to departure time which will be used to get the service rate. The service rate is equivalent to the difference between the service time and departure time, and the average of the service rate is equivalent to **9.92** in minutes.

- The arrival rate per unit of time (λ) = 0.22 persons/ hour
- The service rate per unit of time (μ)= 6.05 persons/hour

Table 3. Service Time of Vaccination

Step 3 : Vaccination				(Departure Time - Service Time)
Person	Service Time	Departure Time	Waiting Time	Service Rate
1	2:31	2:35	2	4
2	2:42	2:46	3	4
3	2:54	2:59	5	5
4	3:02	3:08	5	6
5	3:11	3:16	7	5
6	3:20	3:26	3	6
7	3:27	3:33	2	6
8	3:35	3:41	2	6
AVERAGE				**5.25**

Table 3 shows that the number of persons is equivalent to 8 people to fill-up the vaccination forms.The service rate is equivalent to the difference between the service time and departure time, and the average of the service rate is equivalent to **5.25 minutes**.

- The arrival rate per unit of time (λ) = 0.13 persons/ hour
- The service rate per unit of time (μ)= 11.43 persons/hour

Table 4. Service Time of Monitoring

Step 4 : Monitoring				(Departure Time - Service Time)
Person	Service Time	Departure Time	Waiting Time	Service Rate
1	3:31	3:40	10	9
2	3:40	4:01	9	21
3	4:02	4:20	9	18
4	4:20	4:32	10	12
5	4:32	4:45	10	13
6	4:46	4:55	13	9
7	4:56	5:07	14	11
8	5:08	5:20	10	12
9	5:21	5:31	15	10
10	5:32	5:46	15	14
11	5:47	6:01	17	14
AVERAGE				**13**

Table 4 shows that the number of persons is equivalent to 11 people to fill-up the vaccination forms. The service rate is equivalent to the difference between the service time and departure time, and the average of the service rate is equivalent to **13 minutes**.

- The arrival rate per unit of time (λ) = 0.18 persons/ hour
- The service rate per unit of time (μ)= 4.62 persons/hour

5.2 Discussion of Results

Table 5. Step 1 Overall Result

Step 1: Vaccination Form Filling

Count of People who took the step	17
Service rate	24.29 persons per hour
Arrival rate	0.28 persons per hour
Average Time in the System	2.50 minutes
Average Waiting Time	16.80 minutes
Average Service Time	2.47 minutes
Probability of No Person	0.99%
Probability of Busy Server	0.01%

According to Table 5, the first step in the system is vaccination form filling. There were 17 people who took the first step. The waiting time per person was also recorded and was shown in the data. The service rate (in minutes) was from the difference between the departure time and service time, resulting in 2.47 minutes and converted to 24.29 per hour. The arrival rate was the count of the people in the first step per hour, resulting in 0.28 persons per hour. The average time in the system resulted in 2.50 minutes, the average waiting time resulted in 16.80 minutes, and the average service time resulted in 2.47 minutes. The researchers also calculated the Probability of no person in the first step and Probability of a busy server, resulting 0.99% and 0.01% respectively.

Table 6. Step 2 Overall Result

Step 2: Health Screening	
Count of People who took the step	13
Service rate	6.04 persons per hour
Arrival rate	0.22 persons per hour
Average Time in the System	10.29 minutes
Average Waiting Time	12.53 minutes
Average Service Time	9.92 minutes
Probability of No Person	0.96%
Probability of Busy Server	0.04%

The second step (health screening) gathered 13 people resulting in 6.04 per hour in the service rate, 0.22 persons per hour in the arrival rate, 10.29 minutes for the average time in the system, 12.53 minutes for the average waiting time, and 9.92 minutes for the average service time. The calculated Probability of no person in the second step and Probability of a busy server, resulting 0.96% and 0.04% respectively. Table 6 shows the details.

Table 7. Step 3 Overall Result

Step 3: Vaccination	
Count of People who took the step	8
Service rate	11. 43 persons per hour

Arrival rate	0.13 persons per hour
Average Time in the System	5.31 minutes
Average Waiting Time	7.91 minutes
Average Service Time	5.25 minutes
Probability of No Person	0.99%
Probability of Busy Server	0.01%

The third step (actual vaccination) gathered 8 people resulting in 6.04 per hour in the service rate, 11.43 persons per hour in the arrival rate, 5.31 minutes for the average time in the system, 7.91 minutes for the average waiting time, and 5.25 minutes for the average service time. The calculated Probability of no person in the third step and Probability of a busy server, resulting 0.99% and 0.01% , respectively. Refer to Table 7.

Table 8. Step 4 Overall Result

Step 4: Monitoring	
Count of People who took the step	11
Service rate	4.62 persons per hour
Arrival rate	0.18 persons per hour
Average Time in the System	13.54 minutes
Average Waiting Time	10.56 minutes
Average Service Time	13 minutes
Probability of No Person	0.96%
Probability of Busy Server	0.04%

Finally, the last step (monitoring) gathered 11 people resulting in 4.62 per hour in the service rate, 0.18 persons per hour in the arrival rate, 13.54 minutes for the average time in the system, 10.56 minutes for the average waiting time, and 13 minutes for the average service time as shown in Table 8. The calculated Probability of no person in the third step and Probability of a busy server, resulting 0.96% and 0.04% respectively. Table 8 presents the details/

Table 9. Overall Comparison of the 4 Steps

Overall Comparison of the 4 Steps				
Representation	Step 1	Step 2	Step 3	Step 4
Average Time in the System	2.50 minutes	10.29 minutes	5.31 minutes	13.54 minutes
Average Waiting Time	16.80 minutes	12.53 minutes	7.91 minutes	10.56 minutes
Average Service Time	2.47 minutes	9.92 minutes	5.25 minutes	13 minutes
Probability of No Person	0.99%	0.96%	0.99%	0.96%

Probability of Busy Server	0.01%	0.04%	0.01%	0.04%

Table 9 denotes that the slowest Average Time in the System is Step 4, Monitoring. For the Average Waiting Time, Step 1 has the longest time. For the Average Service Time, Step 4 is the slowest system. For the Probability of No Person in the system, Step 1 and 3 has the highest percentage and for the Probability of Busy Server, Step 2 and 4 denotes the highest percentage.

6. Conclusion

Based on the results and discussion, different factors are considered in determining which queue line is the slowest: service time, departure time, waiting time, and total time in the system. In terms of service time, step 4 (monitoring) is the slowest with 13 minutes and the fastest is the first step (form filling) with resulting in 2.47 minutes. In terms of waiting time, Step 1 has the longest time recorded with 16.80 minutes and the shortest having 7.91 minutes is in the third step (actual vaccination). In terms of the longest time in the system, Step 4 has the longest time with 13.54 minutes and the shortest is in the first step having 2.50 minutes. For the Probability of No Person in the system, Step 1 and 3 has the highest percentage and for the Probability of Busy Server, Step 2 and 4 denotes the highest percentage. Overall, the people spent the longest time in Steps 1 and 4, vaccination form filling and monitoring. The health screening and actual vaccination process have a shorter average time spent in terms of all the factors. This therefore concludes that the queuing system in these 2 processes were operated faster than in vaccination form filling and monitoring where people have spent more time in the process.

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Biographies

Christlyn Mae C. Valeriano, born on June 1, 2000 in Manila City. Youngest daughter of Lino Valeriano and Angela Valeriano. In her Junior High School, she graduated at Sta. Lucia High School with Honors, a Leadership Awardee as the Student Council President and School's Quezon City Student Representative, and Handog sa Bayan-Center for Excellence (CENTREX) scholar. While in her Senior High School, she took the academic Strand of STEM and graduated at Our Lady of Fatima University with academic awards. She is now studying in college at Mapúa

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Charles Kristian Ilo, is a second year Mapua University student, A member of PIIE and PROMAP currently enrolled and pursuing the course of Industrial Engineering. Born on January 1, 2001, at Bocaue, Bulacan now living at Balagtas, Bulacan, Charles went to Children's Mindware School at Elementary and St. Paul College of Bocaue completed his Primary and Secondary Education, respectively. He received awards with honors awarded to him in Elementary and Nestle Scholarship through High School. In senior High School, he took the academic Strand of STEM. Currently, Charles studies at Mapúa University pursuing the course of Industrial engineering. Industrial Engineering is a great fit choice as the flexibility and wideness of this course is applicable to various fields in the real world.

Jan Aldrin V. Dahilig, is an undergraduate that is currently taking up Bachelor of Science in Industrial Engineering in Mapua University. Aside from his studies, he is also a member of the Philippine Institute of Industrial Engineers organization.

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Rene D. Estember is a Professor in the School of Industrial Engineering and Engineering Management at the Mapua University in Manila City, Philippines. He earned his B.S. in Management and Industrial Engineering from Mapua Institute of Technology, Master's in Business Administration from Ateneo de Manila University, Master of Science in Industrial Engineering from the University of the Philippines, and finishing his Doctorate in Business Administration from the Pamantasan ng Lungsod ng Maynila (PLM), all located in the Philippines. He is presently undertaking consultancy work on quality management systems documentation and also involved as a regular resource speaker of a training company conducting technical trainings. His research interests include human factor and ergonomics, manufacturing, risk management and optimization