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Research Article

The Implementation of Queue Theory and Monte Carlo Simulation on the Number of Covid-19 Patients in Batam

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Abstract: The number of Covid-19 patients is the main thing to be concerned about in the time of pandemic, because Covid-19 can directly affect the sustainability of human life. Thus, adequate health services are needed in treating Covid-19 patients. One of the health services is referral hospital. For example, in Batam City, there were 3 referral hospitals and one of them is a special hospital to hospitalized the Covid-19 patients. In this research, we were using queuing theory and Monte Carlo simulation to predict the queuing system of the patients. Queue conditions have levels density more than 100%, that means the number of patients that can be treated in those hospitals is less than the number of new Covid-19' patients. To know the condition a simulation is carried out using a minimum number of hospitals. It is obtained that at least 5 referral hospitals are required so that the density level becomes 83%. Based on the Monte Carlo simulation, it is suggested that the minimum number of hospitals is about three to four hospitals. When the minimum number is fulfilled, the average number of patients waiting to be treated and currently under treatment reduced to 3-4 people from the original, that is 4-5 people. The average waiting time to get treatment is about 5 minutes, originally 18 minutes and average waiting time to get treatment until it was stated that the condition had improved enough to be 5 hours which was originally 8 hours.

Keywords: Queuing Theory, Queuing System, Monte Carlo Simulation, Covid-19

Introduction

Corona Virus Disease 19 or better known as Covid-19 is a family of viruses that can cause disease in humans or animals. In humans it can cause infection of the respiratory tract, starting with the common cold to serious illnesses such as Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS). Covid-19 is a disease caused by a new type of coronavirus called SARS-CoV-2. Indonesia confirmed its first case of Covid-19 on March 2nd 2020 in Depok, West Java. One of the affected regencies/cities in Indonesia is Batam City, in the province of Kepulauan Riau. The city of Batam is one of the areas in Indonesia that is directly adjacent to neighboring countries, Singapore and Malaysia, so it is no wonder that many people work and travel on business between nations. Those can increase the chance for the Covid-19 virus to enter the Batam City area and make Batam City a red zone. This made the Indonesian government to prepare construction of observation or quarantine facilities to control infectious disease infections, especially Covid-19 in Batam City. The facility utilizes the location of an ex-Vietnamese shelter located on Galang Island, Batam City. The Galang Island's Covid-19 Special Hospital began operating on April 12th 2020 and is expected to be able to anticipate, handle, and accommodate the surge in the number of Covid-19. However, the number of positive cases of Covid-19 continues to soar, making the Special Hospital on Galang Island fully booked. That also happens with other two hospital in Batam City which have been referral hospitals for Covid-19 patients. So there are three hospitals in total to treat the Covid-19 patients. The local government ensures that the community must get the best service. The best service mentioned is the patients are getting services to be treated properly until they recover from Covid-19. The analysis to be used in this research is queuing theory analysis.

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The queuing process itself is a process related to the arrival of people or goods at a constant or varying rate at a service facility, waiting in a queue line if it has not been served, then being served and finally leaving the facility if it has been served [1]. Queuing theory has been widely applied, including in the health sector, such as queue analysis in hospitals and health facilities[2]. In this study, queuing theory will be applied to a larger area. The queuing method used to estimate the rate of the new patients and how many patients will stay on the deceased condition in certain period of time by using the number of new patients and the number of recovered patients data. Actually, we can estimate the probability that the patients will stay in deceased condition using survival analysis, but it required the personal data of the patients related to time-to-recovered and those kind of data' are not easy to collect[3]. The number of new Covid-19 patients is seen as the arrival component, the servers for the queuing system are the hospitals, and the service component is the patient being treated by the hospital. The application of a queuing system can be used to estimate the queuing situations such as the length of service time or the length of waiting time in the queue. Arrival rate is defined when the patient has tested positive for Covid-19. Then, Covid-19 positive patients queue up to be served or get treatment at a referral hospital. Then the patient enters and gets treatment at the hospital. After that, when the patient has been cured, the patient can leave the hospital. The queuing system at Batam City Hospital uses a Multi Channel-Single Phase queuing structure. The discussion on queues is also focused on the problem of the number of referral hospitals (servers) provided. When the number of hospitals is not proportional to the number of new patients, it will cause long queues of patients waiting to be served. Service improvements can be made by increasing the number of service units, in this case, the number of hospitals[4]. In addition, it is also necessary to predict whether in the future there will be a decrease in the number of patients or not. In that case, we are using Monte Carlo simulation because it can be used to check whether the service to the patient is optimal or not[5]. Queue simulation using Monte Carlo has also been applied in many fields such as queues of customers, goods, and patients in a hospital[6]. In this study, monte carlo simulation will be applied to a queue system with a larger area, namely the city of Batam.

When the pandemic situation hits the world, many researches have been conducted related to the Covid-19. Some of them analyze from the health perspective and some of them analyze using the statistical method to estimate the death rate and the prediction of the new and the recovered patients. The method chosen for prediction is using the machine learning algorithm such as Artificial Neural Networks (ANN) so the results can be used to design an effective blood supply chain [7]. Some research also study about the transition of the virus in the epidemiological models, which is a SIR-type model. The transition of the virus assumed in a discrete time transition model and interpreted using stochastic method [8]. There is also an advanced research to diagnose whether a person is infected by Covid-19 or not. The aim of that research is to identify the patients as fast as possible so the information about the clinical condition of the person can be estimated correctly and quickly so the information hopefully reliable enough. The method used is using deep learning techniques [9]. In this paper, we want to calculate the rate of the new patients and the recovered rate using the application of queue theory. Based on those two rates, the number of patients in a certain amount of time and the time to recovered can be predicted. Hopefully this result can give the real pandemic condition in Batam.

Based on this introduction, this research will discuss the application of the queue model on the number of Covid-19 patients, especially in the city of Batam, and simulate the development of the number of Covid-19 patients in the future using Monte Carlo Simulation. Based on the results of this study, recommendations for the minimum number of hospitals needed to treat Covid-19 patients will be obtained as well as an estimate of whether the number of Covid-19 patients will increase or decrease in the coming future.

Data and Methods

Data

The sampling technique used is purposive sampling, which is a sampling technique based on certain criteria [10]. The specified criteria in this study are: Cases of positive and recovered Covid-19 patients were collected from March to October 2020 because the first Covid-19 case in Batam City occurred on March 19th 2020; and Patients who are confirmed positive for Covid-19 are patients with co-morbidities or without co-morbidities. So, the sample collected in this study were all patients who were confirmed positive for Covid-19 and patients who had been cured of Covid-19 in Batam City from 19 March 2020 to 31 October 2020. This study uses two variables with operational definitions of the variables written in **Table 1**.

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Table 1. The Definition of Variables

Variables	Definition
Number of New Cases of Covid-19 (x)	The number of people confirmed positive for Covid-19 based on the RT-PCR Swab Test
Number of Cured Patients (y)	The number of Covid-19 patients who can be served or who are in a stable condition from the symptoms of Covid-19

Queue Models for Multi Channel-Single Phase

The queue structure is drawn on the **Figure 1**.

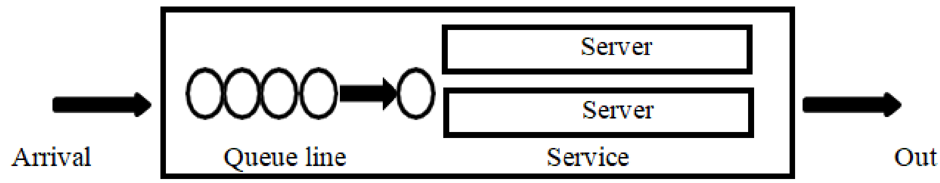

Figure 1. Simple Queue Structure

The structure consists of two servers and single phase. Visitors in a queue that has a number of server c, can be served on the first server or available server. The arrival rate at the system is λ visitors per unit time. All c servers are identical, meaning that the level of service for all servers is μ visitors per unit time. Each visitor in the system is assigned with a number which defines that the visitor is in service and waiting in a queue [11]. When the requirement of steady state $\rho = \frac{\lambda}{\mu} < 1$ is not meet, then the queue condition on the system is bad [12].

The characteristics of a queuing system can be summarized in this standard notation: (a/b/c):(d/e/f) where a: arrival distribution; b: time service distribution; c: the number of servers; d: queue structure; e: the maximum number of visitors allowed in the system; and f: the population. The standard notation for the distribution of arrivals and services (a and b) is: M (Poisson or Exponential), D (the arrival and time service are assumed to be constant, E (Erlang distribution), and G (General Distribution). To determine which distribution would be used, the distribution of arrival and service time should be checked, for example using Kolmogorov-Smirnov test. Then the standard notation for symbol d are consist of: FIFO (First In First Out), LIFO (Last in First Out), SIRO (Service in Random Order), and PS (Priority Service) [11]. For example, if the arrival and time service Generally distributed with the number of server is c, with structure FIFO, and the number of population and visitors allowed in the system are infinite, then the queue model is (G/G/c): (FIFO/∞/∞). From the queue model, the performance of the system can be estimated using some measurement, those are: L_q (the number of the visitor in the queuing line), L_s(the number of visitor in the system), W_q(the average time spent in the queuing line), and W_s(the average time spent in the system).

The (G/G/c): (FIFO/∞/∞) Queue Models

The performance measurement using (G/G/c) model is by computing the $L_{q_{M/M/c}}$, L_s, W_q, and W_s [13].

a) The number of the visitor in the queuing line (L_q) can be estimated using formula on Eq. 1.

$$L_q = L_{q_{M/M/c}} \frac{\mu^2 v(t) + v(t')\lambda^2}{2} \tag{1}$$

where $L_{q\ M/M\ /c}$ is the number of the visitor in the queuing line calculated using M/M/c model, written on Eq. 2.

$$L_{q\ M/M\ /c} = \frac{1}{(c)c!\left(1 - \frac{\lambda}{c\mu}\right)^2} \left(\frac{\lambda}{\mu}\right)^{c+1} P_0 \tag{2}$$

where P_0 is the probability that no visitors in the system. P_0, $v(t)$ and $v(t')$ can be obtained using formula on Eq. 3, 4, and 5.

$$P_0 = \left\{ \sum_{k=0}^{c-1} \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k + \frac{1}{c!} \left(\frac{\lambda}{\mu}\right)^c \left(\frac{c\mu}{c\mu - \lambda}\right) \right\}^{-1} \quad (3)$$

$$v(t) = \left(\frac{1}{\mu^2}\right)^2 \quad (4)$$

$$v(t') = \left(\frac{1}{\lambda^2}\right)^2 \quad (5)$$

b) The number of visitor in the system (L_s) can be estimated using formula on Eq. 6.

$$L_s = L_q + \frac{\lambda}{\mu} \quad (6)$$

c) The average time spent in the queuing line (W_q) can be estimated using formula on Eq. 7.

$$W_q = \frac{L_q}{\lambda} \quad (7)$$

d) The average time spent in the system (W_s) can be estimated using formula on Eq. 8.

$$W_s = W_q + \frac{1}{\mu} \quad (8)$$

Monte Carlo Simulation

Monte Carlo is a simulation method based on artificial samples generated using a set of random numbers. The process is repeated n times. Monte Carlo simulation is carried out to determine the performance of the system at different conditions or times [14]. The steps to carry out a queue simulation using the Monte Carlo are:

a) Create a frequency distribution table for the number of coming visitors and/or the number of the serviced visitor. The table consists of two columns; those are class and class frequency.
b) Determine the empirical cumulative distribution based on the results in a).
c) Determine the random number interval based on the results in b).
d) Generate random numbers.
e) Determine the sample value of the simulation results by paying attention to the suitness between the generated random numbers and the random number intervals.
f) Repeat steps d) dan e).
g) For each iteration on steps f), calculate the λ and/or μ.

Result and Discussion

The Descriptive Statistics

In this study, the number of new cases of Covid-19 is named patient arrivals, while the number of patients recovering from Covid-19 is named patient service. The daily number of new patients is fluctuated. That can be seen in the **Figure 2.**

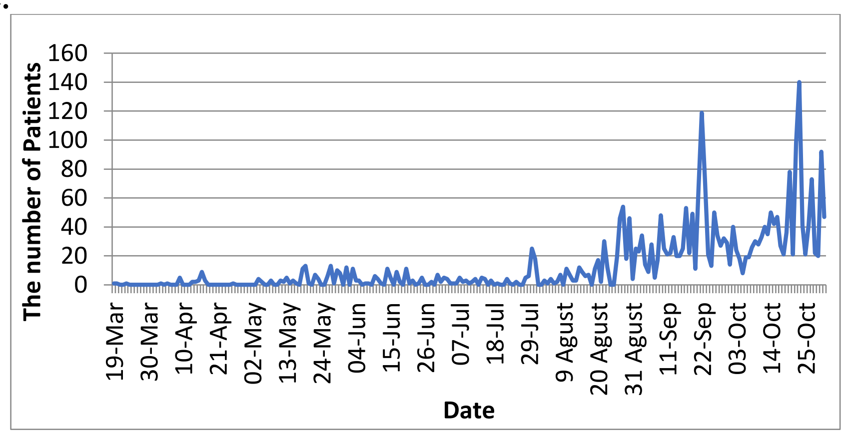

Figure 2. Line chart for the number of new patients of Covid-19

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In the period from March to mid-July 2020, the number of new patients was still below 20 people per day, while from the end of July to the end of October 2020, the number of new patients fluctuated, where the number of new Covid-19 patients peaked in mid-October 2020. From August to September 2020, there was a continuous increase in new cases of Covid-19. This is because the community does not yet have the awareness to implement health protocols, one of which is not wearing masks. At the end of September to early October 2020, new cases of Covid-19 began to decrease because the Government conducted mask raids, where people who did not wear masks would receive a warning and be asked to make a statement so they would not repeat their actions. If the person violates again, they will be given more severe sanctions, for example social and administrative sanctions. But still, the number of patients is increasing again on mid-October 2020.

The daily recovered Covid-19 patient is shown on **Figure 3.**

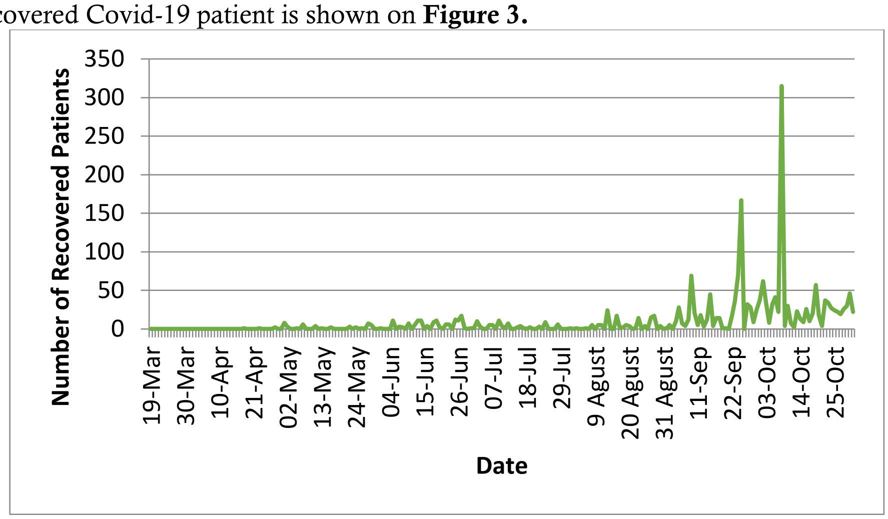

Figure 3. Line chart for the number of recovered patients of Covid-19

From March to early September 2020, the average number of recovered patients was below 50 people, while from early September the number of recovered patients fluctuated. From mid-October to the end of October 2020 there was an extreme decrease in the number of patients recovering from Covid-19. This was because during that period there the number of new cases of Covid-19 is increasing.

The Queue Analysis for the number of Covid-19 Patients

The rate of arrival and service of Covid-19 patients was calculated.

$$\lambda = \frac{total\ sum\ of\ the\ number\ of\ patients}{amount\ of\ observation\ days} = 12.72 \text{ people per day}$$

$$\mu = \frac{total\ sum\ of\ recovered\ patients}{amount\ of\ observation\ days} = 3.08 \text{ people per day}$$

Each days, the average number of new Covid-19 patients was 12.72 people and the average patient that could be served was about 3 people. To simplify the interpretation, we can say that the average number of new Covid-19 patients was 127 people and the average patient that could be served by health workers was about 30 people, per 10 days. With only three hospitals, the steady state is not fulfilled because $\rho = \frac{12.72}{(3.08)(3)} = 1.38 > 1$. If there are additional two hospitals, then the steady state would meet its requirement because $\rho = \frac{12.72}{(3.08)(5)} = 0.83$. Therefore we suggest that at least there are five hospital for Covid-19 patients in Batam.

Next, the distribution of arrival and service should be checked, whether it is poison distributed or not. Using the Kolmogorv-Smirnov test, the absolute difference between the empirical CDF $\left(S(x)\right)$ and theoretical CDF $\left(F(x)\right)$ are obtained and shown on the **Table 2.**

Table 2. The absolute difference of $S(x)$ and $F(x)$ for each number of new patients

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Number of new patients	|S(x)-F(x)|	Number of new patients	|S(x)-F(x)|	Number of new patients	|S(x)-F(x)|
0	0.295151	19	0.206747	40	0.092511
1	0.396435	20	0.208645	41	0.0837
2	0.449056	21	0.195774	42	0.079295
3	0.505299	22	0.187851	46	0.070485
4	0.541684	23	0.186374	47	0.061674
5	0.573033	24	0.18352	48	0.057269
6	**0.57306**	25	0.166688	49	0.052863
7	0.563116	26	0.162669	50	0.044053
8	0.521093	27	0.15404	53	0.039648
9	0.466869	28	0.145312	54	0.035242
10	0.379888	29	0.140943	67	0.030837
11	0.305049	30	0.132148	73	0.022026
12	0.206248	32	0.127752	78	0.017621
13	0.10986	33	0.118942	92	0.013216
14	0.019087	34	0.110132	98	0.008811
17	0.173916	35	0.105727	119	0.004405
18	0.196198	36	0.101322	140	0

The maximum value of $|S(x) - F(x)|$ is 0.57306. Using Kolmogorov-Smirnov table, for $\alpha = 5\%$, it is clear that 0.57306 > 0.0896. That means that the maximum value of difference between Poisson theoretical cumulative probability and empirical cumulative probability is greater than the threshold value given by Kolmogorv-Smirnov table. Therefore, for H_0: data is poison distributed, the number of new patients data is not sample from Poisson distribution.

As for the number of recovered patients, the absolute difference between $S(x)$ and $F(x)$ is shown in **Table 3.**

Table 3. The absolute difference of $S(x)$ and $F(x)$ for each number of recovered patients

Number of Recovered Patients	|S(x)-F(x)|	Number of Recovered Patients	|S(x)-F(x)|	Number of Recovered Patients	|S(x)-F(x)|
0	0.444838	17	0.147249	36	0.048458
1	0.527649	18	0.142128	37	0.044053
2	0.563185	19	0.139519	38	0.039648
3	0.576939	20	0.135945	41	0.035242
4	**0.596079**	21	0.131905	45	0.030837
5	0.585894	22	0.118843	46	0.026432
6	0.519898	23	0.1145	57	0.022026
7	0.431431	24	0.105713	62	0.017621
8	0.312483	25	0.101317	69	0.013216
9	0.198797	26	0.092509	70	0.008811
10	0.090554	27	0.088105	167	0.004405
11	0.014849	28	0.079295	315	0
12	0.050665	30	0.070485		
13	0.102279	32	0.061674		
14	0.126076	34	0.057269		
15	0.144495	35	0.052863		

The maximum value of $|S(x) - F(x)|$ is 0.596079 and it is greater than 0.0896. Therefore the number of recovered patients' data is also not sample from Poisson distribution. Therefore, it can be said that the arrival and service generally distributed so the queue analysis would be conducted using G/G/5 model. The number of servers is 5 because it is the minimum requirement to fulfill the steady state condition. In other word, we want to know how is the condition if the number of hospitals added from 3 to 5. The probability of no visitors in the system is calculated first.

$$P_0 = \left\{ \sum_{k=0}^{5-1} \frac{\left(\frac{12.72}{3.08}\right)^k}{k!} + \frac{\left(\frac{12.72}{3.08}\right)^5}{5!} \left(\frac{(5)(3.08)}{(5)(3.08) - 12.72} \right) \right\}^{-1} = 0.0106$$

It can be said that the probability of no visitors is close to zero. In another word, there are almost new patients of Covid-19 on a daily basis. From that probability, the $L_{q_{M/M/5}}$ can be calculated.

$$L_{q_{M/M/5}} = (0.0106) \left(\frac{1}{(5)(5!)\left(1 - \frac{12.72}{(5)(3.08)}\right)^2} \right) \left(\frac{12.72}{3.08}\right)^{5+1} = 2.85$$

Therefore

$$L_q = (2.85) \left(\frac{(3.08)^2 \left(\frac{1}{3.08^2}\right)^2 + \left(\frac{1}{12.72^2}\right)^2 (12.72)^2}{2} \right) = 0.159$$

$$L_s = 0.159 + \left(\frac{12.72}{3.08}\right) = 4.285$$

So, if there are five hospitals in the city, the number of patients waiting to be served very much likely is close to zero. Therefore almost no patients are waiting if there are enough hospitals. As for L_s values, it can be said that the number of patients waiting and to be served in the hospitals are about four to five patients each days. Next, the waiting time for the patient would be calculated.

$$W_q = \frac{0.11}{12.72} = 0.013$$

$$W_s = 0.013 + \frac{1}{3.08} = 0.337$$

If there are five hospitals in the city, the average amount of time patients needed until he/she get a treatment is 0.013 days = 0.2998 hours = 17.99 minutes and the average amount of time needed until the patients get better is about 0.337 days = 8.086 hours for each patients. That situation is very good if there are enough hospitals which provide the Covid-19 patients. Therefore, it is necessary to meet the minimum requirement of the number of hospitals for Covid-19 patients. That condition applies on year 2020. For the coming future, the simulation must be carried out because of the limited data. In this paper, Monte Carlo simulation is used.

First, the frequency distribution tables for arrivals of patients are created.

Table 4. The frequency distribution for new patients' data

Class	Freq	f(x)	F(x)	Middle value of Class	Interval for Random Numbers
0-6	137	0.6035	0.6035	3	0-0.604
7-13	25	0.1101	0.7137	10	0.605-0.714
14-20	13	0.0573	0.7709	17	0.715-0.771
21-27	17	0.0749	0.8458	24	0.772-0.846
28-34	10	0.0441	0.8899	31	0.847-0.890
35-41	6	0.0264	0.9163	38	0.891-0.916
42-48	6	0.0264	0.9427	45	0.917-0.943
49-62	5	0.0220	0.9648	55.5	0.944-0.965
63-69	1	0.0044	0.9692	66	0.966-0.969
70-76	2	0.0088	0.9780	73	0.970-0.978
77-90	1	0.0044	0.9824	83.5	0.979-0.982

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Class	Freq	f(x)	F(x)	Middle value of Class	Interval for Random Numbers
91-97	1	0.0044	0.9868	94	0.983-0.987
98-118	1	0.0044	0.9912	108	0.988-0.991
119-139	1	0.0044	0.9956	129	0.992-0.996
140-146	1	0.0044	1	143	0.997-1

Then the random numbers is generated for new patients' data. The number of generated random number is 365 because the simulation is for the next year.

Table 5. Generated random numbers for new patients' and recovered patients' data

No.	Random Numbers for new patients' data	The number of new patients simulated
1	0.476124	3
2	0.517073	3
3	0.605499	10
4	0.940214	45
5	0.95399	55.5
6	0.8943	38
7	0.392722	3
8	0.807981	24
9	0.056478	3
10	0.829969	24
…	…	…
365	0.934858	45

Based on the simulated data, the arrival and service rate is calculated.

$$\lambda_{sim} = \frac{3+3+\cdots+45}{365} = 14.02 \text{ person per day}$$

The process is also carried on for the recovered patients' data. Also, the process is repeated, for example 20 times, so there are 20 λ_{sim} and μ_{sim}. Then, the average of λ_{sim} and μ_{sim} were calculated. In this study, the obtained $\overline{\lambda_{sim}}$ and $\overline{\mu_{sim}}$ are 14.37 and 4.79 people per days respectively. For the steady state requirement, it is not meet because $\frac{14.37}{4.79} > 1$. Therefore the number of service (hospitals) is not enough if there is only one hospital in the coming year. To meet the requirement of the steady state condition, it should be at least three hospitals operated in the next year, so that $\frac{14.37}{(4.79)(3)} > 1$. Using the same queue model, but now with the number of server is 3, that is G/G/3 model [13], the results is:

Table 6. The simulated queue model performance

λ	μ	c	ρ	P_0	L_q	L_s	W_q	W_S
14.37	4.79	3	0.99	0.114	0.045	3.048	4.994	5.089

It can be seen that the ρ value is close to 1, meaning that the availability of three hospitals is very minimal, so at least three to four hospitals should be provided to handle Covid-19 patients. This condition is good because in the previous year, the minimum number of hospitals needed was five hospitals. In other words, there was an improvement in the condition of the number of Covid-19 patients in Batam.

Discussion

In this paper, we are using the estimation of L_s and W_s to know how many treated patients in Batam and how long the treated patients will be recovered. The probability that there are no patients in Batam is 0.114. To know the probability that the patients still in the deceased condition, we can also use the survival analysis. But, for those purpose we have to collect the time-to-recovered data for each patients which is impossible to do at that time of pandemic. But it is possible to do so by collecting some representative sample. The aim of this research is to know the pandemic situation in Batam which can be identified by looking at the number of new patients, the number of deceased, and number of recovered patients. For those purpose, we were using queuing analysis instead of survival analysis because we can estimate the number of patients and how long they were treated. Also, the method we were choosing is impacted by the data we had. Therefore, the best method to analyze the data we had is using the application of queue theory. It is possible to perfect this research by collecting the data for each patients so that the probability of survive and death rate can be estimated using survival analysis.

At that time, there were only three hospitals that can treat Covid-19 patients, Rumah Sakit Khusus Infeksi (RSKI) Covid-19 pulau Galang, RSUD Embung Fatimah, and RS Bp Batam. We suggest opening additional hospital or just health care to treat the Covid-19 patients because it is impossible to build a hospital in the short amount of time. Therefore what we mean with the hospital is some health center which provide the neediness to treat the Covid-19'patients. Actually, the RSKI pulau Galang is additional health center specialized to treat the Covid-19 patients. Therefore we can say that, at first there were only two hospitals that able to treat the Covid-19 patients. When the number of new patients is at its peaks on 2020, those three hospitals already reach their maximum capacity. Therefore the government decides to add one more hospital to treat Covid-19 patients, that is RS. Bhayangkara Polda Kepri. Nowadays, the number of hospitals is reduced to three, excluding the RSKI pulau Galang because the number of new Covid-19' patients is already decreasing.

Conclusion

The minimum number of hospitals for Covid-19 patients is five hospitals so that the patients do not have to wait longer to get treatment for their disease. If the requirement for minimum number of hospital is meet, then almost no patients waiting to be treated. If patients must wait, the waiting time is not exceed 18 minutes and when the average time for patients to be treated until get better is about eight hours. As for the coming future, the Covid-19 condition in Batam is getting better because the minimum number of hospitals is decreasing. In other words, the number of Covid-19 patients is decreasing. In order to suppress the number of Covid-19 patients, it is necessary that the health facilities are available and in enough number. Also, people must not neglect the health protocol such as wearing mask and physical distancing.

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