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Analysis of Landing Airplane Queue Systems at Juanda International Airport Surabaya

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ABSTRACT

Before the covid-19 pandemic hit all over the world, Juanda International Airport was preparing to realize the construction of terminal 3. This construction project impression that Juanda Airport is experiencing an overload, including in the airplane landing queue. This study aims to analyze the queuing system at the Juanda International Airport apron before the pandemic, whether effective, quite effective, or less effective in serving the number of existing flights with two terminals. An analysis of the queuing system was conducted in several scenarios. They are in normal/regular condition, a scenario if there is an increase in flight frequency, and a scenario if there is a reduction in aprons' number because of certain exceptional situations. To analyze the airplane's landing queue at Juanda airport apron, the queuing model (M/M/51): (FCFS/∞/∞) is used. From this model, the results show that in normal conditions, the estimated waiting time for each airplane in the system is 0.18 hours with a queue of 2 up to 3 planes/hour, categorized as effective. In one apron reduction scenario, each airplane's estimated waiting time in the system is 0.7 hours, with a queue of 6 up to 7 planes categorized as less effective. In the scenario of additional flights, only 9 other flights are allowed every day to keep the service performance still quite effective. By obtaining this results analysis, the decision of PT. Angkasa Pura 1 (Persero) to build terminal 3 is suitable to reduce queuing time and improve Juanda International Airport services to be more effective.

Keywords: Queueing System Model; Juanda Internasional Airport; Landing Airplane Queue; Waiting Time; Multi-Channel Single-Phase

INTRODUCTION

Juanda International Airport Surabaya has been named the 3rd busiest airport in Indonesia after the first position is Soekarno – Hatta International Airport Jakarta. The second position is I Gusti Ngurah Rai International Airport Denpasar Bali. Surabaya Juanda International Airport has also been called the 6th largest airport after Padang Minangkabau International Airport. [1]. Due to the high activity of Juanda Airport every year, as seen in 2020, the average movement of its aircraft has increased by 97.2%, or 13,504 aircraft. It has grown in average passengers by 175% or 1,133,855 passengers, causing Juanda International Airport Surabaya to realize Terminal 3. This project aims to increase the number of facilities from existing services. Terminal 3 construction is carried

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out to accommodate passengers' number, which continues to grow every year. If the linkages are connected, the airplane's more passengers will also increase [2].

An increase in airplane passengers' number usually increases each route's flight frequency and opens new destination routes [2]. The increase in flight frequency can cause queuing problems that are getting longer. The impact of long airplane queues will make customers feel less satisfied and the potential for passengers to switch to other modes of transportation so that the airport can decrease the number of passengers for the domestic flight, but for the international flight will give a negative impression to foreign tourists and lead to a reduction in the assessment of airport services ratings in the world [3]. Reducing the number of passengers will also be followed by reducing the number of airplanes used, so finally, it impacts decreasing income for PT. Angkasa Pura 1 (Persero) as an organization that manages the Juanda International Airport.

One of the airports' performances is determined by the airplane's queue that will park at the apron. With the number of aprons available, if the plane's number continues to increase, the waiting time for the plane in the queue will also be longer [4]. A situation like this can endanger the plane that will make a landing at the airport, the amount of fuel used by the plane is always adjusted to the flight route, the distance traveled, and the total capacity of the plane filled, so that the plane is only filled with sufficient fuel [5]. The danger of a very long queue in a landing airplane can cause the plane to run out of fuel to make an emergency landing or land at the nearest airport. The flight schedule will also be delayed [6], [7].

The landing plane's waiting time in the Juanda International Airport apron can be analyzed using the queuing system analysis concept, a statistical method used to solve a queue problem. A. K. Erlang invented this method in 1909 with the research title "Probability Theory of Telephone Conversations" [8]. Queuing occurs when customers who come to be served to exceed the facilities, resulting in customers waiting for service and a queue appearing [9]. In some cases, services can be improved to avoid growing queues [10]. However, the cost of improving services can cause significant losses because it requires enormous costs if it is not right on target. So that in this study, the performance analysis of the Juanda airport apron was carried out using a queuing system model.

In queuing at the airport, the queuing system is modeled by assuming aprons are servants while airplanes are considered customers [11], [12]. The apron is used as a parking space for an airplane, where the plane does dropping and picks up passengers, so the apron is considered a servant [13]. Meanwhile, an airplane is regarded as a customer because it lands to enter the airport and leave it [14], [15]. The queuing process on an airplane occurs when the plane comes to the airport to make a landing, but with the complete apron condition so that the plane carries out a holding process or rotates in the sky before making a final approach and then landing [16].

Holding is when the plane delays carrying out the final approach process and take-around flight near the airport. The plane will land until it arrives at the time the plane lands to land. In contrast, the final approach is when the aircraft has made the final approach to the runway for landing [17], [18]. The final procedure can be carried out when the airport has allowed the plane to land, provided there is an apron available for the plane to park and carry out the process of dropping and raising passengers [19]. If all the apron conditions are still used, the plane that will make the landing will hold it until there is one apron available and land according to the plane's order [20], [21].

Several studies related to the airport's queuing system, including research conducted by Thiagaraj and Seshaiah investigated the queuing system at the Bengaluru International Airport Devanahalli, India [22]. In this study, airport facilities considered servants are in the form of a runway used as several servers, focusing on the aircraft queuing system. Still, this research also models the passenger queuing system at the terminal. Therefore, this study aims to model the queuing system to analyze the impact or effect of delays in-service performance and cost losses. However, this study does not explain whether the apron airport's service performance as a whole is effective, quite effective, or ineffective.

The following research was conducted by Afsah Novita Sari, its investigation regarding the plane queuing system model at Yogyakarta Adi Sutjipto International Airport [23]. In this study, the data were obtained from Apron Movement Control for 21 days for commercial aircraft landing and taking off. The number of aprons is 11 pieces. That research only makes queuing models without analyzing the queuing system's performance.

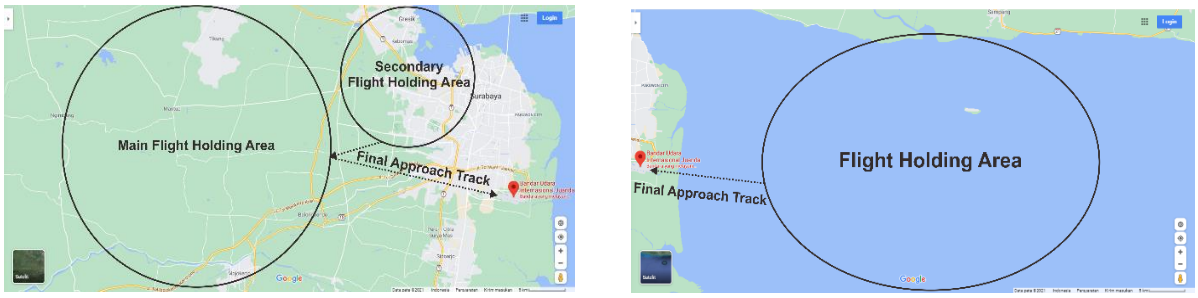
The following research was conducted by Anggit Ratnakusuma et al., related to the queuing system analysis at Semarang Ahmad Yani International Airport [24]. The data was obtained from Apron Movement Control for seven days for commercial airplane landing and taking off. The number of aprons used at the airport is six (6) aprons. The data obtained has a Poisson distribution. This research only makes queuing models without analyzing the queuing system's performance.

Referring to the various studies above, this study will model the queuing system and analyze the existing queuing system's performance of apron at Juanda International Airport. An analysis of the queuing system was conducted in several scenarios; they are normal conditions, a scenario if there is an increase in flight frequency, and a scenario if there is a reduction in the number of aprons because of certain exceptional conditions. It is hoped that this research will provide an objective assessment of apron performance as one of the key performance indicators for the service of Juanda International Airport. Finally, the analysis results can be used as input to evaluate the terminal 3 construction project's feasibility at Juanda International Airport.

METHODS

Data Collection

This research was conducted at Juanda International Airport by observing Apron Movement Control (AMC) from aircraft movement activities. This observation is also carried out based on monitoring from the Flightradar 24 application. It aims to observe aircraft holding in the sky near the airport—International Juanda Surabaya and data correction. The plane holding location is carried out in the sky over the Gresik area if it lands on the runway direction 10, as in Figure 1. The sky above the eastern sea between Java and Madura islands lands on the runway at 28, as in Figure 2. Research time for data collection was conducted for seven consecutive days starting from Monday, December 23, 2019, to Sunday, December 29, 2019.



(a) (b)

Figure 1. Flight Holding Area of **(a)** Runway 10 and **(b)** Runway 28 (Source: Google Maps)

The decision to land on runway direction 10 or direction 28 is determined from the wind's direction that blows in the airport area. Aircraft are required to land and take off against the wind blowing. When the wind blows from the east, the plane will land and take off from the runway direction 10, and this event often occurs during the dry season in Indonesia. When the wind blows from the west, the plane will land and take off from the runway at 28, and this event often occurs during Indonesia's dry season.

Data collection was carried out in the apron, amounting to 51 units, observing the queue system, recording the aircraft that landed, then parked at the apron, then took off. The number of planes in and out of the apron is recorded every time with an interval of 1 minute, where each point is observed for 1 hour from 04.30 WIB to 22.30 WIB. Furthermore, the researcher interviewed several Air Traffic Controller employees of Airnav Indonesia about the airport's queuing system in general. This interview aims to add references or general knowledge about the queuing system at the studied airport because each airport's queuing system is different. This difference depends on the condition of the service facilities owned by each airport.

Queueing System Analysis

This research was conducted to measure the performance of the queue time for aircraft landing under normal conditions. Assuming that security procedures are met, no obstacles can hinder the landing process, such as bad weather, technical airport operations, wind direction changes, and other factors. This aims to limit the research problem so that the discussion can be more focused on time.

In carrying out this research, steps are used to run systematically and precisely according to the desired target. The research steps are presented in the flow chart of Figure 3.

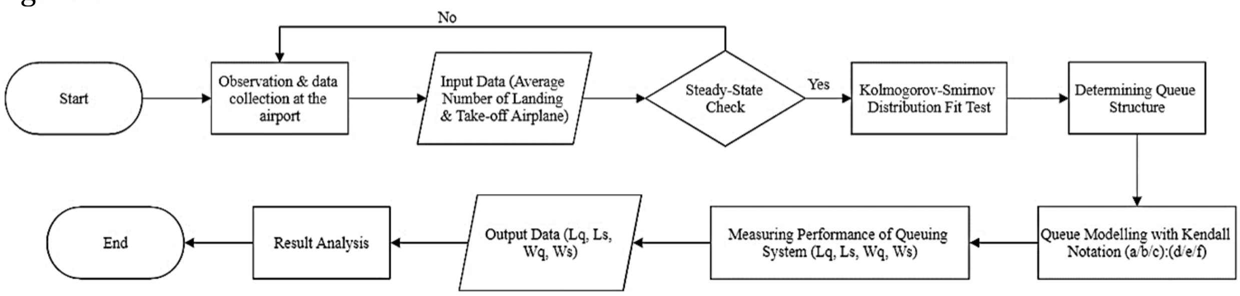


Figure 2. Research Flowchart and Data Processing

From the flowchart in figure 3, some of the equations needed in the calculations to process the data that have been obtained are described as follows:

1. Average Rate Amount of Airplane

Calculate the average number of the plane landing (λ) and the number of the plane taking off (μ), by Equations (1) and (2) [25].

$$\lambda = \frac{\text{Average Landing Airplane}}{\text{Time}} \tag{1}$$

$$\mu = \frac{\text{Average Takeoff Plane}}{\text{Time}} \tag{2}$$

2. Steady-State Check

Performing steady-state checks with Equation (3).

$$\rho = \frac{\lambda}{S\mu} < 1 \tag{3}$$

By the number of servers or aprons (S) in use, the steady-state condition (ρ) is said to be achieved if the conditions of the average number of the plane landing are more significant than the average number of the plane taking off, or it can be written as $\lambda > \mu$ or also $\rho < 1$ [26].

3. Kolmogorov-Smirnov Distribution Fit Test

Perform a distribution fittest. Form a distribution on the landing data or take-off data with the Kolmogorov-Smirnov test using Equation (4) with a significant level (α) of 5%.

$$D = Sup|S(x) - F_o(x)| \tag{4}$$

with,
Sup : The largest value limit used
$S(x)$: Cumulative distribution of sample data
$F_0\ (x)$: The cumulative Distribution of the hypothesized data

Data can be said to be Poisson distributed when $D < D * (\alpha)$. $D * (\alpha)$ is obtained from the Kolmogorov - Smirnov table [27].

4. Determining The Queue Structure

There are four types of queuing structures; the selection of these structures can be determined based on the system's queuing system to be studied. Below is an explanation of the four queuing forms [28], [29].

(a) Single-Channel Single-Phase

This structure is used when there is only one server serving and only one incoming and outgoing path, as shown in figure 4 [30].

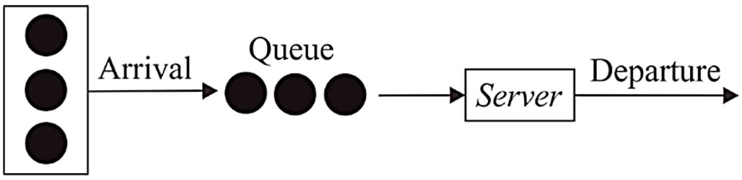


Figure 3. Single-Channel Single-Phase Structure

(b) Single-Channel Multi-Phase

This structure is used when multiple servers serve consecutively and only have one incoming and outgoing path, as shown in figure 5 [30].

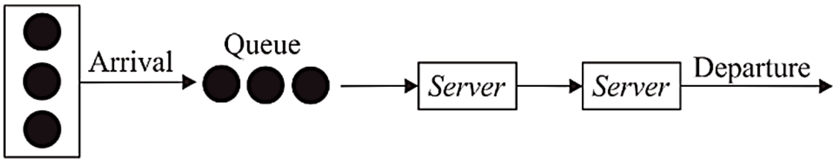


Figure 4. Single-Channel Multi-Phase Structure

(c) Multi-Channel Single-Phase

This structure is used when two or more servers serve simultaneously and only have two or more incoming and outgoing paths, as shown in figure 6 [31].

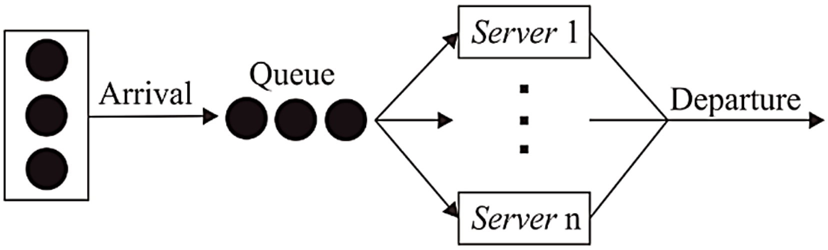


Figure 5. Multi-Channel Single-Phase Structure

This queue structure is suitable for this study. The airplane landing queue in the apron uses a multi-channel single phase, where there are 51 aprons (which represent multi-channel), and there is only one queue phase, namely the runaway.

(d) Multi-Channel Multi-Phase

This structure is used when two or more servers serve simultaneously and sequentially and have two or more incoming and outgoing paths, as shown in figure 7 [31].

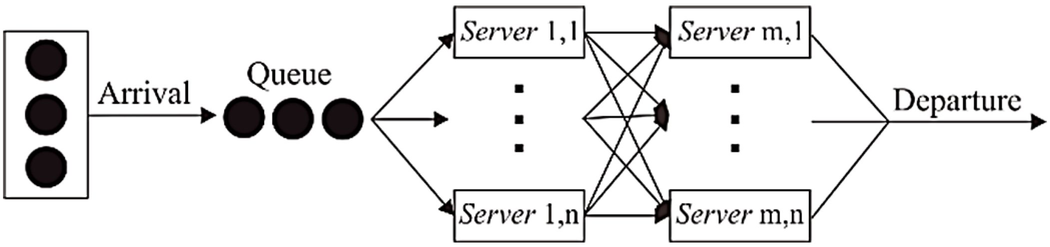


Figure 6. Multi-Channel Multi-Phase Structure

5. The Use of Kendall Notation

Kendal notation is a notation that is now the global standard for queuing system models. A series of symbols and slashes describe the queuing process with notation as follows [32], [33]:

$$(a/b/c) : (d/e/f)$$

The symbols *a, b, c, d, e,* and *f* are the queue model's essential elements with characteristics shown in Table 1.

Table 1. Kendall Distribution Description

Characteristics	Notation	Explanation
Arrival Time Distribution (a) and Service Time Distribution (b)	M	Markovian (or Poisson arrivals or equivalently Exponential interarrival or service time distribution)
	D	Deterministic
	E_k	Erlang k type
	GI	The general distribution of interarrival time
	G	The general distribution of service time
Number of Parallel Server (c)	$1, 2, \dots, \infty$	finite or infinite
Queue Discipline (d)	FCFS	The first one comes served first
	LCFS	The last one comes served first
	SIRO	Random selection of services
	PQ	Priority Queue
	PS	Processor Sharing
	GD	General Discipline
Maximum System Capacity (e)	$1, 2, \dots, \infty$	finite or infinite
Size of the calling source (f)	$1, 2, \dots, \infty$	finite or infinite

This study illustrates the airplane landing queueing system model using (M/M/51): (FCFS/∞/∞) uses Poisson arrival with exponential service time distribution. There are 51 aprons as servers, and the queuing discipline is First Come First Service (FCFS). There are no limited customers on the entire system, and the size of the source from which customers arrive is infinite, too.

6. Modeling and Calculating The Queueing System

Because this study uses a queuing system model (M/M/51): (FCFS/∞/∞), then to measure the performance of the queuing system using the formula for the model (M/M/S):(FCFS/∞/∞). This model helps determine how to analyze the system appropriately. In most queues found, usually, the data used is Poisson distributed; this is because, in the queue, there is a period. Here is the explanation [34].

- $(\boldsymbol{M/M/S})$: $(\boldsymbol{FCFS}/\infty/\infty)$ **Queue Model**

In this model, the first sign (M) shows the arrival rate with a Poisson distribution. The second sign (M) shows the exponential distribution of the service time [35]. Queuing model is a Poisson distributed service with a server capacity limit of (S) [36]. A reasonably simple model but has several assumptions that need to be fulfilled. This model has more than one number of aprons or servers so that the maximum number of individuals can be served simultaneously by as many servers (S) [37]. In this model, the mean plane landing rate (λ) and the mean take-off rate (μ) follow the Poisson Distribution, and the service time $\left(\frac{1}{\mu}\right)$ follow the exponential distribution.

By supposing $r = \lambda / \mu$ and $\rho = r / S$, the queuing system model for (M/M/S): (FCFS/∞/∞) is, using Equation (5) to Equation (9) [38].

$$P_0 = \left\{ \left[\sum_{n=0}^{S-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} \right] + \frac{\left(\frac{\lambda}{\mu}\right)^S}{S!\,(1-\rho)} \right\}^{-1} \tag{5}$$

$$L_q = \left(\frac{\rho \left(\frac{\lambda}{\mu}\right)^S}{S!\,(1-\rho)^2} \right) P_0 \quad (6)$$

$$L_s = L_q + \frac{\lambda}{\mu} \quad (7)$$

$$W_q = \frac{L_q}{\lambda} \quad (8)$$

$$W_s = W_q + \frac{1}{\mu} \quad (9)$$

with,
P_0 : Chance of not queuing
L_q : Estimated airplane in the queue (planes)
L_s : Estimated airplane in the system (planes)
W_q : Estimated waiting time in the queue (hour)
W_s : Estimated waiting time in the system (hour)

RESULTS AND DISCUSSION

An Overview Of The Airplane Queuing System Model At Juanda International Airport Surabaya

In general, the queuing system at Juanda International Airport Surabaya only consists of a single-phase (because the airport only has one runway) with multi-channels (there are 51 active aprons). The illustration of the queuing system will be explained in Figure 7.

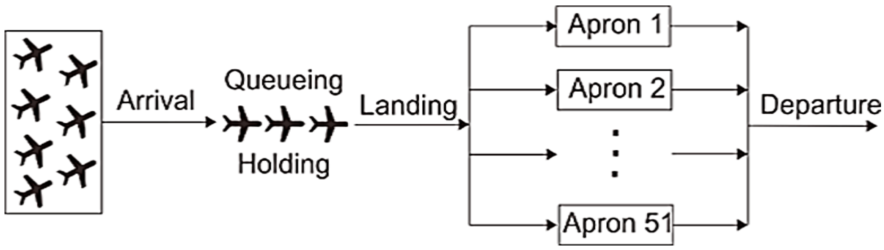


Figure 7. Simulation of Aircraft Queueing System Model at Juanda International Airport Surabaya

A plane can be said to land if the airplane has successfully landed on the runway, then parked on the apron, then dropped the passengers. Meanwhile, an airplane can take off when a passenger has boarded the plane, then exits the apron to the runway, and then the plane manages to fly after the wheels take off from the runway.

Steady-State Condition Check

From the data that has been obtained after making observations for one week, the data will be looked at for the average rate with time intervals of one hour. After obtaining the average rate of the plane landing (λ) and taking off (μ), then the Steady-State value (ρ) is obtained as follows.

The average rate of landing airplanes:
$$\lambda = \frac{220}{17} = 12.94 \text{ airplanes/hour}$$

The average rate of take-off airplanes:

$$\mu = \frac{188.85}{17} = 11.10 \text{ airplanes/hour}$$

With steady-state size:

$$\rho = \frac{\lambda}{S\mu} = \frac{12.94}{51 \times 11.10} = 0.02$$

Because $\rho = 0.02 < 1$, it can be said that the Steady-state conditions are met for the queuing system at Juanda Airport.

Distribution Suitability Test With Data

After the queuing system at Juanda International Airport can be proven that the steady-state conditions are met, the next step is to test the data distribution's suitability. The data used will be checked whether the data is included in the Poisson Distribution or general Distribution.

Test the distribution of the amount landing airplane:

$D = Sup|S(x) - F_o(x)| = 0.304$

$D * (\alpha) = 0.803$

Because $D < D * (\alpha)$ is fulfilled, the data for the number of planes that land is a Poisson distribution.

Test the distribution of the amount take-off airplane:

$D = Sup|S(x) - F_0(x)| = 0.604$

$D * (\alpha) = 1.598$

Because $D < D * (\alpha)$ is fulfilled, the data for the number of planes that take off is an Exponential distribution.

Model of The Regular Queuing System For Juanda International Airport Surabaya

Following the minister of transportation of the Republic of Indonesia number PM 89 years 2015, concerning flight delays as described in Chapter II Section 3 and chapter V Section 9 Subsection 1. We can assume the queue time for aircraft at the airport apron is categorized as effective, quite effective, and less effective if it meets the following conditions as shown in table 2 as follows [39], [40]:

Table 2. Performance Category

Category	W_q, W_s (hour)	L_q, L_s (planes)
Effective	$< 0,5$	< 3
Quite Effective	$< 0,5$	> 3
	$0.5 - 1$	≤ 3
Less Effective	$0.5 - 1$	> 3
	> 1	≥ 1

After checking the steady-state conditions and testing the distribution of data on the airplane number that landed and the number of airplanes that take-off using the Kolmogorov-Smirnov compatibility test, It is known that the queuing system model for Juanda International Airport follows (M/M/51) : (FCFS/∞/∞). The queuing discipline in this model includes First Come First Service (FCFS), where first come first will be served by the number of planes that land and the source of calls has no limit. The distribution test found that the data were Poisson distributed with 51 aprons in use. By using the formula that has been presented, the results are obtained as follows.

Table 3. Normal Queue System

No	Performance Measure	Result
1	Average Rate amount of Landing Airplane (λ)	12.94 planes/hour
2	Average Rate amount of Takeoff Airplane (μ)	11.10 planes/hour
3	Chance of Not Queueing (P_0)	31.16 %
4	Estimated Airplane in Queue (L_q)	1.2 planes
5	Estimated Airplane in System (L_s)	2.36 planes
6	Estimated Waiting Time in Queue (W_q)	0.09 hour
7	Estimated Waiting Time in System (W_s)	0.18 hour

The queuing system analysis in table 3, indicates that under normal conditions, the apron queuing system performance in Juanda International Airport Surabaya is categorized as **effective.**

Queuing System Scenario When There is a Reduction In The Number of Aprons

It was assumed that when there is a reduction in the number of aprons used. The duration of time spent serving aircraft landing and taking off was extended, from operating 17 hours a day to 24 hours a day. This is because to serve all flights with a reduced number of aprons, it is not enough to operate for the usual duration. It will take longer to service all scheduled flights.

After running the scenario, the reduction of one apron, of which only 50 aprons were left in operation. The simulation results can be used as evaluation material for the management of Juanda Surabaya International Airport if they want to use other aprons for purposes other than commercial plane operational activities. One example is when essential state guest planes, logistics, military, and emergencies land Emergency at Juanda International Airport.

Table 4. Queuing System Simulation When There is a Reduction in the Number of Aprons

No	Performance Measure	Result
1	Average Rate amount of Landing Airplane (λ)	9.16 planes/hour
2	Average Rate amount of Takeoff Airplane (μ)	7.86 planes/hour
3	Chance of Not Queueing (P_0)	31.16 %
4	Estimated Airplane in Queue (L_q)	5.28 planes
5	Estimated Airplane in System (L_s)	6.44 planes
6	Estimated Waiting Time in Queue (W_q)	0.58 hour
7	Estimated Waiting Time in System (W_s)	0.70 hour

The queuing system analysis that simulates the reduction of one apron in table 4 indicates that in the reduced condition of one apron used at Juanda International Airport Surabaya, the queuing system service performance is categorized as **less effective**.

Queuing System Scenario When There is an Increase in Flight Frequency

The scenario of adding a landing or take-off flight schedule every day is carried out as an evaluation material for the management of Juanda International Airport in serving airlines that want to add new flight route schedules, both domestic and international routes. This scenario is carried out to determine the extent to which the tolerance limit for the maximum addition of Juanda International Airport's performance in Surabaya is still sufficiently effective to turn out to be less effective.

Thus, the average number of planes landing and taking off within 17 hours of airport operational time is the estimate obtained. Therefore, the performance of increasing the number of flights will be measured as follows.

Increasing the number of flights one by one using software POM QM to obtain the maximum limit that Juanda International Airport Surabaya to maintain reasonably effective service performance. The increase in the number of flights that can be done is only 9 flights.

Table 5. Queuing System When There is Increase 9 Flight Frequency

No	Performance Measure	Result
1	Average Rate amount of Landing Airplane (λ)	12.41 planes/hour
2	Average Rate amount of Takeoff Airplane (μ)	10.57 planes/hour
3	Chance of Not Queueing (P_0)	30.91 %
4	Estimated Airplane in Queue (L_q)	4.33 planes
5	Estimated Airplane in System (L_s)	5.50 planes
6	Estimated Waiting Time in Queue (W_q)	0.35 hour
7	Estimated Waiting Time in System (W_s)	0.44 hour

The queuing system analysis in Table 5 indicates that with the addition of 9 flight frequencies at Juanda International Airport Surabaya, the queuing system service performance is still considered **quite effective**.

To measure service performance, we added back the number of flight frequencies one by one. After the addition of more than 9 flights, the queue system service performance becomes overloaded. The queueing system performance indicated this changed from quite effective to less effective. The time for the aircraft to land becomes more delayed than before.

Overload at Juanda International Airport can occur when the additional 10 flight frequencies are added. This overload is obtained from the performance measurement results shown in table 6 as follows.

Table 6. Queueing System When There is Increase 10 Flights Frequency

No	Performance Measure	Result
1	Average Rate amount of Landing Airplane (μ)	12.35 planes/hour
2	Average Rate amount of Takeoff Airplane (μ)	10.51 planes/hour
3	Chance of Not Queueing (P_0)	30.88 %
4	Estimated Airplane in Queue (L_q)	7.97 planes
5	Estimated Airplane in System (L_s)	9.14 planes
6	Estimated Waiting Time in Queue (W_q)	0.65 hour
7	Estimated Waiting Time in System (W_s)	0.74 hour

The queuing system analysis in table 6 indicates that with 10 flight frequencies at Juanda International Airport Surabaya, the queuing system service performance is categorized as **less effective**.

Discussion

This research was conducted through observation at Juanda International Airport Surabaya by the end of 2019 when the COVID-19 pandemic virus had not yet hit

Indonesia. The flight schedule was running normally; unlike today (2021), there was a pandemic COVID-19 virus that made the government make a social restriction policy. This policy caused a decrease drastically in the number of flight frequencies so that the airport was very rarely even had almost no queue.

In the data collection during the week conducted before the pandemic, the busy conditions of domestic and international flights at Juanda International Airport Surabaya usually went on average the number of domestic flight arrivals as many as 200.86 flights/day or 201 flights/day and international flights as many as 19.14 flights/day or 20 flights/day. While the number of domestic flights departures is as many as 169.71 flights/day or 170 flights/day, the number of international flights departures is as many as 19.14 flights/day. The number of domestic and international airlines is 14 airlines.

The performance of the queuing system in three scenarios was presented in the graph as shown as in Figure 9 (the y-axis represents the number of planes) and Figure 10 (the y-axis represents the waiting time in an hour):

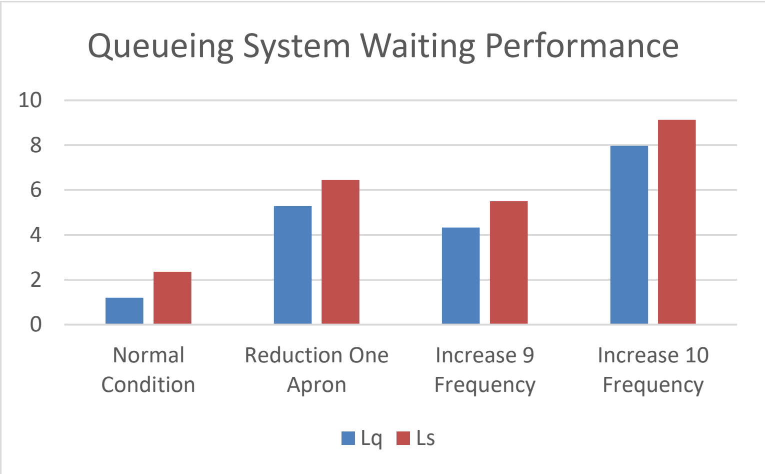


Figure 8. Comparison Graph of Queueing System Waiting Performance

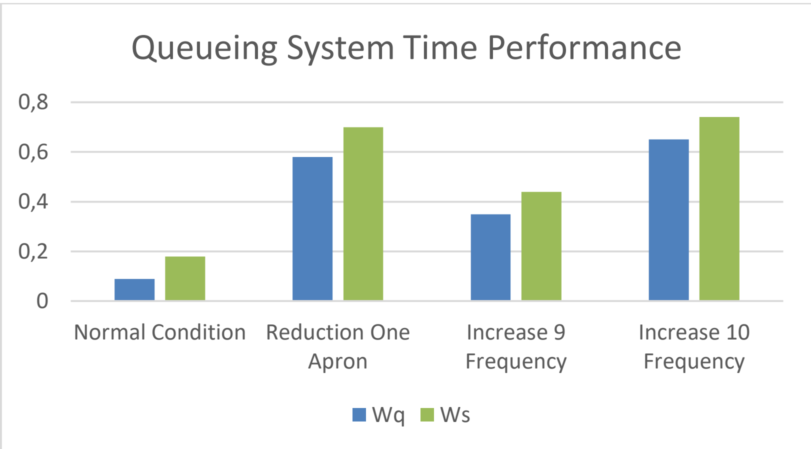


Figure 9. Comparison Graph of Queueing System Time Performance

From figure 9 and figure 10, we can conclude that under normal conditions, the performance of the queue system is effective but is prone to **turning less effective** in the following two scenarios:

- In the emergency or specific conditions, which must reduce an apron, although just only one apron is reduced, it will potentially decrease Juanda International

Airport's service performance to be less effective because it will cause long queues.

- In the scenario if there were an additional 10 flights. In this scenario, if there is an increase in the number of airplane passengers, then the tolerance limit for the number of different flight routes allowed is only 9 flights. This number is not comparable with the many domestic and international airlines, including 14 airlines. It does not satisfy the airline because, of course, not all additional airline flight routes can be allowed. There will be a strict review to determine which airlines are allowed to add their flight routes.

From the analysis above, So the decision of PT. Angkasa Pura 1 (Perero) to build terminal 3 is suitable to improve airport performance quality in serving passengers and airlines. Also, the number of passengers can be accommodated a lot so that the airlines will also have more frequent flights, which will increase income for PT. Angkasa Pura 1 (Persero).

In the future, research can be developed by examining airports that have more than one runway. Because at the airport, other variables can affect the aircraft queuing system, namely the number of runways, so that the servants in the queuing system at the airport are the apron and the runway.

CONCLUSIONS

The queuing system model used at Juanda International airport is (M/M/51): (FCFS/∞/∞). In normal conditions, the queuing system's performance at Juanda International Airport Surabaya can be considered **effective**. But, it was prone to **turning into less effective** in reducing aprons, although only one apron. The tolerance limit for the number of additional flight routes allowed is only 9 flights. This tolerance limits relatively small compared to the potential increase in the number of airplane passengers every year. So the decision of PT. Angkasa Pura 1 (Persero) to build terminal 3 is suitable to improve airport performance quality in serving passengers and airlines. The development of terminal 3 will make the queuing system's service performance will be more effective.

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REFERENCES

[1] E. Herlambang, "Jumlah Bandara di Indonesia, 20 Paling Sibuk!," *Pariwisata Indonesia*, 2020.

[2] Redaktur, "Pemprov Jatim Desak Percepatan Realisasi Proyek T3 Bandara Juanda," *JUANDAAIRPORT.COM*, 2018.

[3] M. Wang, "Application of the Queuing Theory in Characterizing and Optimizing the Passenger Flow at the Airport Security," *J. Appl. Math. Phys.*, vol. 5, no. 9, pp. 1620–1628, 2017.

[4] Y. ZHU, J. WANG, Y. CHEN, and Y. WU, "Calculation of Takeoff and Landing Performance Under Different Environments," *Int. J. Mod. Phys. Conf. Ser.*, vol. 42, p.

1660174, 2016.
[5] Lukiana, “Konsumsi Bahan Bakar Maksimum Maskapai Penerbangan Lion Air Untuk Memenuhi Tingginya Permintaan Penerbangan Domestik,” *War. Ardhia*, vol. 24, no. 1, pp. 52–58, 2012.
[6] C. Setyarini and E. Ahyudanari, “Analysis of the Effect of Displaced Runway Holding Position toward Runway Occupancy Time and Runway Capacity (Case Study: Juanda International Airport),” *War. Ardhia*, vol. 43, no. 2, pp. 105–116, 2017.
[7] V. V. Satanaryana, S. Dawood, Karthikeyan, and N. Khan, “Application of Queuing Theory Models for Optimized Service To Air Line,” *Int. J. Curr. Res.*, vol. 7, no. 9, pp. 20544–20547, 2015.
[8] H. A. Taha, *Operations Research An Introduction*, 10th ed. London: Pearson, 2017.
[9] R. R. Gilliam, “An Application of Queueing Theory to Airport Passenger Security Screening,” *Interfaces (Providence).*, vol. 9, no. 4, pp. 117–123, 1979.
[10] N. Jhala and P. Bhathawala, “Application of Queueing Theory to Airport Related Problems,” *Glob. J. Pure Appl. Math.*, vol. 13, no. 7, pp. 3863–3868, 2017.
[11] I. Simaiakis and H. Balakrishnan, “A queuing model of the airport departure process,” *Transp. Sci.*, vol. 50, no. 1, pp. 94–109, 2016.
[12] Y. Liu, “Research on Airport Security Based on Virtual Queuing Theory,” *Adv. Intell. Syst. Res.*, vol. 147, no. NCCE, pp. 7–11, 2018.
[13] N. A. Ademoh, Anosike, and E. Nneka, “Queuing Modelling of Air Transport Passengers of Nnamdi Azikiwe International Airport Abuja, Nigeria Using Multi-Server Approach,” vol. 21, no. 12, pp. 2326–2338, 2014.
[14] H. Idris, J.-P. Clarke, R. Bhuva, and L. Kang, “Queuing Model for Taxi-Out Time Estimation,” *Air Traffic Control Q.*, vol. 10, no. 1, pp. 1–22, 2001.
[15] D. Fakinos, “ The G/G/ 1 Queueing System with a Particular Queue Discipline,” *J. R. Stat. Soc. Ser. B*, vol. 43, no. 2, pp. 190–196, 1981.
[16] E. Itoh and M. Mitici, “Queue - Based Modeling of The Aircraft Arrival Process At a Single Airport,” *Aerospace*, vol. 6, no. 10, pp. 1–20, 2019.
[17] A. Selvi and R. Matthew, “A Queueing System For Airport Buses,” *Transp. Res. Part B Methodol.*, vol. 7, no. 6, pp. 427–434, 1983.
[18] H. S. Ahn, I. Duenyas, and M. E. Lewis, “Optimal control of a two-stage tandem queueing system with flexible servers,” *Probab. Eng. Informational Sci.*, vol. 16, no. 4, pp. 453–469, 2002.
[19] H. Kutohadi, J. Samosir, D. Nusraningrum, S. Rafi, and S. Sidjabat, “Analysis of runway utilization at Soekarno-Hatta international airport,” *J. Adv. Res. Dyn. Control Syst.*, vol. 12, no. 10S, pp. 3242–3247, 2020.
[20] K. G. Zografos, M. A. Stamatopoulos, and A. R. Odoni, “An Analytical Model for Runway System Capacity Analysis,” *IFAC Proc. Vol.*, vol. 30, no. 8, pp. 29–34, 1997.
[21] D.-U. Kim, M.-S. Jie, and W.-H. Choi, “Airport Simulation Based on Queuing Model Using ARENA,” *Int. J. Adv. Sci. Technol.*, vol. 115, pp. 125–134, 2018.
[22] H. B. Thiagaraj and C. V. Seshaiah, “A queueing model for airport capacity and delay analysis,” *Appl. Math. Sci.*, vol. 8, no. 72, pp. 3561–3575, 2014.
[23] A. N. Sari, “Model Sistem Antrian Pesawat Terbang Di Bandara Internasional Adisutjipto Yogyakarta,” *Gamatika*, vol. 2, no. 1, pp. 16–24, 2011.
[24] A. Ratnakusuma, A. Hoyyi, and Sugito, “Analisis Sistem Antrian Pesawat Terbang Di Bandara Internasional Ahmad Yani Semarang,” *Gaussian*, vol. 4, no. 4, pp. 725–733, 2015.
[25] M. F. Faris, Y. Farida, D. C. R. Novitasari, N. Ulinnuha, and M. Hafiyusholeh, “Implementation of The Open Jackson Queuing Network to Reduce Waiting Time,”

MANTIK, vol. 6, no. 2, pp. 83–92, 2020.
[26] D. Gross, J. F. Shortle, J. M. Thompson, and C. M. Harris, *Fundamentals of Queueing Theory*, 4th ed. New Jersey: Wiley, 2008.
[27] G. N. P. Martha, I. K. G. Sukarsa, and I. P. E. N. Kencana, "Analisis Sistem Antrian Pada Loket Pembayaran PT. PLN (Persero) Area Bali Selatan Rayon Kuta," *E-Jurnal Mat.*, vol. 1, no. 1, pp. 6–11, 2012.
[28] P. T. Adeke, "Modelling of Queuing Process at Airport Check-In System: A Case Study of Manchester and Leeds-Bradford Airports," *Niger. J. Technol.*, vol. 37, no. 1, p. 35, 2018.
[29] L. Yang, S. Yin, K. Han, J. Haddad, and M. Hu, "Fundamental diagrams of airport surface traffic: Models and applications," *Transp. Res. Part B Methodol.*, vol. 106, pp. 29–51, 2017.
[30] H. Brunceel and S. Wittevrongel, "Analysis of a Discrete-Time Single - Server Queue With An Occasional Extra Server," *Perform. Eval.*, vol. 116, no. November, pp. 119–142, 2017.
[31] D. Dyatmika, O. Sudana, and G. A. A. Putri, "Untethering the Queue based on Multi-Channel Access (MCA) Technology at Hospital Radiology Section," *J. Inf. Syst. Eng. Bus. Intell.*, vol. 5, no. 2, pp. 146–155, 2019.
[32] D. G. Kendall, "Stochastic Processes Occurring in the Theory of Queues and their Analysis by the Method of the Imbedded Markov Chain," *Ann. Math. Stat.*, vol. 24, no. 3, pp. 338–354, 1953.
[33] M. A. M. Ferreira, M. Andrade, J. A. Filipe, and M. P. Coelho, "Statistical Queuing Theory with Some Applications," *Int. J Latest Trends Fin. Eco. Sc.*, vol. 1, no. 4, pp. 190–195, 2011.
[34] R. Aniyeri and R. Nadar, "Passengers queue analysis in international airports terminals in Kerala using the multiphase queuing system," *Int. J. Math. Oper. Res.*, vol. 12, no. 1, pp. 1–30, 2018.
[35] J. W. Baek, Y. H. Bae, H. W. Lee, and S. Ahn, "Continuous-type (s, Q)-inventory model with an attached M/M/1 queue and lost sales," *Perform. Eval.*, vol. 125, pp. 68–79, 2018.
[36] A. T. Al-Sultan, "Simulation and Optimization for Modeling the Passengers Check-in System at Airport Terminal," *Rev. Integr. Bus. Econ. Res.*, vol. 7, no. 1, pp. 44–53, 2018.
[37] K. Mitchell and A. Van de Liefvoort, "Approximation models of feed-forward G/G/1/N queueing networks with correlated arrivals," *Perform. Eval.*, vol. 51, no. 2–4, pp. 137–152, 2003.
[38] E. Itoh and M. Mitici, "Analyzing tactical control strategies for aircraft arrivals at an airport using a queuing model," *J. Air Transp. Manag.*, vol. 89, no. June 2019, pp. 1–13, 2020.
[39] Kemenhub, "Penanganan Keterlambatan Penerbangan (Delay Management) Pada Badan Usaha Angkutan Udara Niaga Berjadwal Di Indonesia," no. PM 89, pp. 1–20, 2015.
[40] A. Susetyadi, "Waktu Tunggu Take Off dan Landing Pesawat Udara Pada Runway Bandar Udara Soekarno Hatta," *War. Penelit. Perhub.*, vol. 24, no. 6, pp. 559–566, 2012.