Evaluation of the Two Runway Queuing System: Evidence from Soekarno-Hatta International Airport in Indonesia

PRASADJA RICARDIANTO[1], ADRYAN PRAMA PUTRA[1],
SUHARTO ABDUL MAJID[1], PEPPY FACHRIAL[1], JOHAR SAMOSIR[1],
ERMAN NOOR ADI[1], ADITYA WARDANA[2], SALAHUDIN RAFI[2],
IMAM OZALI[3], ENDRI ENDRI[4]

[1]Postgraduate Program, Institute of Transportation and Logistic Trisakti
Jl. Ahmad Yani No.85, Rawasari, Jakarta Timur 13210
INDONESIA

[2]Faculty of Management and Business, Institute of Transportation and Logistic Trisakti
Jl. IPN No.2, Cipinang Besar Selatan, Jakarta Timur 13410
INDONESIA

[3]Vocational Program, Institute of Transportation and Logistic Trisakti
Jl. IPN No.2, Cipinang Besar Selatan, Jakarta Timur 13410
INDONESIA

[4]Faculty of Economics and Business, Universitas Mercu Buana
Jl. Meruya Selatan No. 1, Kembangan, Jakarta Selatan 11650
INDONESIA

Abstract: - This study aims to analyze the queuing system, service performance, and utilization of the two runways at Soekarno-Hatta Airport, Tangerang, Indonesia. The number of aircraft movements at the airport at busy hours exceeds capacity, resulting in long queues. This study uses a quantitative approach and queuing theory with a single server multi-channel queuing system. Discussion of runway service performance at Soekarno-Hatta Airport, by calculating the Queuing System State Probalilities to determine the probability of n units (arrivals) in the system. Five equations have been analyzed in order to Evaluation of the Two Runway Queue System. The findings of this study provide a signal for optimizing airport operator runway utilization by developing runway capacity and adding infrastructure as well as adding taxiways, aprons, and runways. The increase in runway capacity will have an impact on more aircraft services, which also means more effective and efficient runway utilization. To improve the queuing system, it is necessary to improve queuing system services with regular training of directly related officers so that the queuing system can be more effective and efficient. To improve the performance of runway services, it is necessary to increase the capacity of the navigation tools currently owned.

Key-Words: - queue system, service performance, runway capacity, multi-channel single server

Received: April 19, 2021. Revised: January 28, 2022. Accepted: February 21, 2022. Published: April 4, 2022.

1 Introduction

Air transportation has three main components which are closely related to each other. The three components are aircraft as a means of air transportation, airports as infrastructure for departure, arrival, and Air Traffic Services acting as a liaison medium between airports and air traffic controllers. Soekarno-Hatta International Airport experiences an increase in the number of passengers every year and the frequency of flights also increases. In line with the growth of airplane passengers in Indonesia, the development of users of Soekarno-Hatta International Airport as the main airport in Indonesia is also increasing. In a period of 10 years, starting from 2009 to 2019, the number of passengers arriving and departing from Soekarno-Hatta International Airport is described as follows: the highest number was recorded in 2018 with a total of 65,668,776 passengers, an increase of 4, 21% from the previous year 2017 which amounted to 63,015,620 passengers. The highest increase of 19.26% occurred in 2010 when the number of passengers in the previous year was 37,143,719 so it jumped to 44,296,024 passengers.

In the period from 2014 to 2019, the highest number of passenger and aircraft movements occurred in 2018 with a total of 3,181,163 passengers, resulting in an increase in the number of passengers by 3.65%. Meanwhile, the highest number of aircraft movements occurred in 2017 with a total of 447,390 aircraft movements, resulting in an increase of 8.12% from the previous year. In 2011 there was the highest increase of 13.08% from the previous year which amounted to 305,541 aircraft movements, bringing it to 345,508 aircraft movements. Based on data from Airports Council International in 2019, Soekarno-Hatta International Airport, Tangerang, Banten was still ranked in the top 20 largest airports in the world, surpassing Singapore's Changi Airport. Soekarno-Hatta International Airport itself is precisely in the 18th position. In the ASEAN region, there are only two airports that are ranked in the top 20, namely Soekarno-Hatta International Airport in the 18th position and Changi Airport in the 19th position. Many flight services can be done at this airport every day, which can serve more than 1,000 flights per day. Throughout 2019, the total movement of aircraft at Soekarno-Hatta International Airport reached 390,648 take-offs and landing.

The overcapacity of the airport can result in long queues. In 2019, the number of movements of 42 per hour has exceeded the Declared Runway Capacity of only 39 movements per hour. The capability of the capacity of two runways for air side services for aircraft movements at Soekarno-Hatta International Airport based on the Declared Runway Capacity (Table 1).

Tabel 1. Declared Runway Capacity
Soekarno-Hatta International Airport

Time/Slot (UTC)	00.00-13.59	14.00-14.59	15.00-15.59	16.00-16.59	17.00-17.59
Reguler Flight	80	76	39	34	24
Irreguler Flight	1	1	1	2	2
Time/Slot (UTC)	**18.00-18.59**	**19.00-21.59**	**22.00-22.59**	**23.00-23.59**	
Reguler Flight	22	34	68	76	
Irreguler Flight	2	2	2	2	

Based on Table 1 air side services, aircraft movements at Soekarno-Hatta International Airport based on the Declared Runway Capacity of Airnav Indonesia are 80 movements per hour for regular flights and 1 movement for irregular flights at 00.00-13.59/07.00-20-59. The lowest runway capacity is 22 movements per hour for regular flights and 2 movements for irregular flights at 18.00-18.59/ 01.00-01.59.

A large number of aircraft taking off and landing at Soekarno-Hatta International Airport causes long queues for departing and landing aircraft. This causes aircraft to queue up to use the runway. From observations, airports are still often seen queuing airplanes on taxiways that want to take off when the flight frequency is high, especially during feast days.

Based on the background of the problem, several problems have been identified: (1) Soekarno-Hatta International Airport experiences an increase in the number of passengers every year and the frequency of flights also increases, the number of taking off and landing movements at Soekarno-Hatta International Airport is very busy, resulting in aircraft queues on taxiways that want to take-off when flight frequency is high, especially during Lebaran is a bid day for Moslem, (2) long queues can increase the cost of Avtur fuel for Air Transport Business Entities, (3) long queues cause delays so that it can be detrimental passengers and the Air Transportation Business Entity itself, and (4) The number of aircraft movements has exceeded the maximum capacity, resulting in long queues. Based on the identification of the problem, the research problem is limited to what queuing system is used on the Soekarno-Hatta International Airport runway, service performance, and the utilization of two runways on Lebaran Transport in 2019 at Soekarno-Hatta International Airport.

As a comparison for the discussion of two runways, Mascio et al. [1] explain that airports in Italy with high traffic volumes were considered to analyze two layouts and namely new runways and modified operating conditions were considered. Based on the test results at the Hong Kong airport, Lancia and Lulli [2] explained that dynamic runway configuration planning and semi-mixed runway design can utilize runway capacity more efficiently. Air Traffic Control operators will be able to optimize runway capacity by operating dynamic runway configurations on the runway based on air and airport traffic conditions. In research using several models, the results of Stephens and Ayo Agunbiade [3] study show that London Heathrow Airport (LHR) and Munich International Airport (MUC) are efficient in utilizing runways and can be an important reference for airport operators to evaluate and compare various types of runway configurations. During this pandemic, Lai et al. [4] explained that the simulation results show that the overall flight optimization effect is 48 percent and flight delay times are reduced by 50 percent, so it is considered an acceptable scheduling optimization result. Meanwhile, the purpose of the study was to determine and analyze the level of runway utilization at Soekarno-Hatta International Airport. Meanwhile, the purpose of the study was to determine and analyze the level of runway utilization at Soekarno-Hatta International Airport.

2 Literature Review

2.1 Runway

The definition of a runway according to [5] is a rectangular area above the airfield used for landing and taking off of aircraft. The length and width of the runway at each airport are different, according to the needs, conditions of obstacles around the airport. In general, the configuration used is the basic configuration, namely; (1) Single Runway, This configuration is the simplest; (2) Parallel Runway, The capacity of this parallel runway configuration depends on the number of runways and the separation of distances between runways. The number of parallel runways commonly used is two parallel runways, three, and four parallel runways. The distance between runways is divided into three and depends on the centerline dividing the two runways, (a) Close (b) Intermediate, and (c) Far, (3) Intersecting Runway, an airport having two or more runways with different directions that are mutually exclusive. cross each other, this configuration is called an intersecting runway and (4) Open-V Runway, which is several runways placed in different directions, which do not cross each other. Similar to an intersecting runway, the Open-V Runway uses a single runway when strong winds are blowing only to one side.

According to Avery and Balakrishnan [6], weather conditions, traffic demand, air traffic controller workload, and coordination flow with the nearest airport affect the choice of runway configuration. Mesgarpour [7] argues that aircraft takeoff scheduling is formulated to maximize runway departure throughput and minimize total waiting time. Several models for evaluating arrival and departure capacities and ways of calculating runway capacity under various conditions have been designed in several countries previously [8, 9, 10]. The results of the study Tascón and Olariaga [11] at Bogota Airport, Colombia indicate the need for an expansion of airport case studies on the runway system, where the current capacity utilization factor for the number of runways required is set to three until the last simulation period in 2023.

The mixed Mode Parallel Operations approach at Zurich, Switzerland airport expected runway efficiency with a ratio of more than 83.8% [12]. Also in Indonesia, an evaluation of runway capacity has been carried out through the configuration and maximum runway capacity, runway crosswind, and tailwind potential that has been carried out by Andarani et al. [13], Eviane et al. [14], Firdiyan and Muntini [15], Majid et al. [16], and Sardjono et al. [17]. Specifically, the use of several runways through a simulation program at Soekarno-Hatta airport has been previously studied by Ongkowijoyo and Ruseno [18], Sampurno et al. [19], and Saragih et al. [20]. In general, research on parallel runways with mixed-mode or multiple runways will consider the problem of ordering and scheduling aircraft in the uncertainty of arrival and departure delays [21]. The addition of a runway so that it can be operated in parallel, but require twenty years of negotiation, planning and construction [22]. Strategically in the long term, the productivity of runway capacity at airports is also determined by the available infrastructure.

2.2 Queuing Theory

Queues occur when the number of customers to be served exceeds the existing facilities, resulting in the Air Transport Business Entity waiting or queueing to get service. Queuing theory is one of the statistical methods that can be used to overcome these problems. Queuing theory is used to determine the characteristics, models, and performance measures of aircraft queuing systems at airports, namely the time between aircraft arrivals, aircraft service times, and waiting times for aircraft to take off. The use of queuing theory applications is expected to improve the quality of airport services. Theoretically, in transportation, Teodorovic and Nedeljkovic [23] explain that there are many fluctuations in the queuing system in arrival rates and service times, which create queues and reduce the level of service offered to passengers. Based on queuing theory, aircraft tracking data and flight schedules are also used as inputs to characterize the national air traffic network [24]. The queuing-based modeling approach according to Itoh and Mitici [25] suggests that one potential solution is to expand the realization of time-based operations, efficiently shifting from traffic flow control to time-based arrival management.

Ignaccolo [26] states that the results of traditional queuing theory can be used to analyze airport runway systems, analytical approaches and show how to build simulation procedures, and be able to measure the performance of airport runways that are only used for arrivals. According to Thiagaraj and Seshaiah [27] that the results of queuing theory can be used to analyze the runway system, but when the airport is too crowded is realistically required, a simulation approach to be able to measure the performance of airport runways that are only used for arrivals, with different mixtures of traffic and variables. operational. Several researchers have proposed solutions to the runway balancing problem using simulation-based techniques to calculate aircraft delay. The findings Lancia and Lulli [28] with Poisson and Pre-Scheduled Random Arrivals queues have important implications for incoming traffic simulation-based modeling and analysis and can increase the use of available capacity, thereby reducing air traffic delays. Sekine et al. [29] explain that implementing the application of new wake turbulence categories will contribute to reducing air traffic congestion near airports, and to reducing delays in overall arrival traffic while increasing runway throughput. Meanwhile, Jain et al. [30], also explained that with the queuing model simulation, the number of checkpoints at the airport can be increased so that waiting planes can be distributed effectively. Several queuing systems at several international airports in Indonesia studied were stated to be quite good and runway and taxiway capacities were still able to serve air traffic during peak hours [31, 32, 33, 34] add with the queuing theory, Juanda International Airport, Surabaya, is only allowed to make nine flights per day maintain effective service performance. The findings of Stephens [35] on airports in Nigeria with queuing theory shows that the flow of domestic flights will be more than international flights. In the USA, especially at John Fitzgerald Kennedy, New York Airport, research results Lai et al. [36] show that congestion during taxi-outs, waiting for take-off, therefore the optimization method is used to minimize flight delays. At Tokyo International airport, Japan's arrival delay time can be minimized by implementing the proposed arrival traffic strategy along with automation support for air traffic controllers [37, 38].

3 Methodology

The research uses a quantitative method approach and queuing theory with a single server multi-channel queuing system. Queuing conditions often occur for goods that are in the process of going to an area to be served, but then face delays due to the service mechanism being busy. The characteristics of service facilities can be seen from three things, namely the physical layout of the queuing system, queue discipline, and service time. The testing procedure in this research starts with making observations related to the implementation of aircraft movements (taking off and landing) during the 2019 Eid transportation period at Soekarno-Hatta International Airport. Especially, related to what queuing system will be used, then paying attention and observing the phenomena that occur through participatory observation of the movement of the aircraft. Discussion of runway service performance at Soekarno-Hatta Airport, by calculating the Queuing System State Probalilities to determine the probability of n units (arrivals) in the system (P_0). Queuing Formulas calculation is continued to find out the average number of aircraft in the queue, the average waiting time in the queue, the average number of aircraft in the system and the average time in the system.

The calculation of the queuing system uses mathematical formulas with the help of Qm software for windows. Calculation with Multiple Channel Single Server Queue system and calculation of runway utilization encompasses several stages and formula as follows;

(1) The probability that n units (arrivals) in the system,

$$P_0 = 1 \Big/ \left\{ \left[\sum_{n=0}^{s-1} \frac{(\frac{\lambda}{\mu})^n}{n!} \right] + \frac{(\frac{\lambda}{\mu})^s}{S!} \left(\frac{1}{1-\frac{\lambda}{S\mu}} \right) \right\}$$

This service performance calculation formula is to get the probability number of n units of arrival in the system (P_0) through the Queuing System State Probalilities calculation method.

(2) The average number of units in the queue,

$$Lq = \frac{(\lambda/\mu)^2(\frac{\lambda}{S\mu})}{S!\ (1-\frac{\lambda}{S\mu})^2}$$

This Lq formula is to calculate the average number of aircraft queuing during takeoff on the air side of the aircraft movement.

(3) The average waiting time in the queue,

$$W_q = \frac{Lq}{\lambda}$$

This Wq formula is to calculate the average waiting time in the queue when the plane is waiting to take off.

(4) The average waiting time in the system,

$$W_s = Wq + \frac{1}{\mu}$$

This Ws formula is to calculate the average waiting time for aircraft services on the runway until they are finished being served.
(5) The average number of units in the system.

$$L_s = Lq + \frac{\lambda}{\mu}$$

This Ls formula is to calculate the average number of aircraft queuing and being served for air side services for aircraft movements.

4 Results and Discussion

4.1 Queue System and Runway Usage Concept

The queuing system on the runway at Soekarno-Hatta Airport is a queuing system with multi-channel single server is a type of service with more than one service provider. Both runways operate using Mixed Mode Parallel Operations with the following conditions; (1) Each runway is used for departures and arrivals, (2) For aircraft departing for traffic departing from another runway, it is independent as long as both follow the existing Standard Instrument Departure (SID), and (3) For aircraft carrying out an Instrument Landing System (ILS) Approach to an aircraft that is conducting ILS Approach on another runway is the independent parallel approach.

Soekarno-Hatta International Airport has two parallel runways separated by two taxiways of 2,402 m long, namely North Runway (07L/25R) and South Runway (07R/25L) (Figure 1).

Fig. 1: Two runways, namely RWY 07L/25R (North Runway) and RWY 07R/25L (South Runway)

Technically, several concepts of balancing the use of the Soekarno-Hatta Airport runway have been applied, namely; (1) The number of aircraft queues that will depart and land is attempted to be the same on each runway, (2) If there is a queue at the holding point of runway 07L, the departure of aircraft on Apron D and E is diverted to runway 07R., (3) In the event of a queue at the holding point of runway 25R, the departure of aircraft on Apron F, G and H is diverted to runway 25L and (4) This concept is implemented based on coordination between the Supervisor Tower and Approach Control at the airport.

At the time of this study the length of the two Soekarno-Hatta Airport runways had the configuration; The length of runway I (07R/25L) is 3660 meters and the length of runway II (07L/25R) is 3600 meters; and the distance between the center lines of runway I and II is 2402 meters (Table 2).

Table 2. Take Off Run Available (TORA) and Intersection Length

RUNWAY	Intersection Taxiway	Angle from RUNWAY Centreline	TORA (M)
07/L	N7	30◦	2625
	N8	36◦	3048
07/R	S7	30◦	213
	S8	30◦	3541
25/L	S2	30◦	3516
	S3	30◦	2714
25/R	N2	90◦	3488
	N3	30◦	2655

Each runway is used for departures and arrivals. The number of aircraft queues that will depart and land is attempted on each runway is the same. The use of the runway must be by the wind direction and wind speed. If there is a change in wind conditions so that the runway used is not suitable, then the Tower Supervisor is obliged to change the runway. The process of changing the runway must be coordinated with the Jakarta Approach Control unit according to traffic conditions.

4.2 Queue System at Soekarno-Hatta Airport Runway

Soekarno-Hatta International Airport is one of the international standard airports in Indonesia, which can be visited by various types of aircraft both from within and outside the country. Soekarno-Hatta International Airport experiences an increase in the number of passengers every year and the frequency of flights also increases. In line with the growth of airplane passengers in Indonesia, the development of users of Soekarno-Hatta International Airport as the main airport in Indonesia is also increasing. Passenger statistical data from 2009 to 2019 shows a tendency to increase the number of activities with a total of 54,496,625 passengers and total aircraft movements reaching 390,648 aircraft movements taking-off and landing in 2019.

4.3 Soekarno-Hatta Airport Runway Service Performance

Some of the Queuing System State Probalilities calculations in measuring Runway Service Performance with the number of runways (S) as much as two units are as follows; (1) Aircraft movement capacity is 54 aircraft/hour per two runways or 27 aircraft/hour per 1 runway, (2) Service performance in the airside service queue system for aircraft movements shows the arrival rate (λ) is 30,810 aircraft/month or 1,027 aircraft/day or 42.82 aircraft/hour, and (3) Service Level (μ): 1/ μ is 2.22 minutes/aircraft or to 27 aircraft/hour.

With the probability of n units (arrival) in the system (P_0) and two runways in the aircraft movement service, it can be interpreted that the probability of 0 units (arrival) in the system from both runways is 0.115.

$$\mathbf{P_0 = 1} \Big/ \left[\frac{(\frac{42,82}{27})^0}{\mathbf{0}!} + \frac{(\frac{42,82}{27})^1}{\mathbf{1}!} + \frac{(\frac{42,82}{27})^2}{\mathbf{2}!} \left(\frac{1}{1 - \frac{42,82}{54}} \right) \right] = 0,115$$

The result of the calculation of P_0 above based on the number of two runways in the airside service of aircraft movement is a probability of 0 units (arrival) in the system from the two runways of 0.115.

After calculating P_0 which is the probability of n units (arrivals) in the system and the average number of aircraft in the queue, where the average number of aircraft in the queue is three aircraft, the next calculation is in the queue will be known average waiting time.

$$\mathbf{Lq} = \frac{(2,515)\left(\frac{42,82}{54}\right)}{2!\left(1 - \frac{42,82}{54}\right)^2} (0,115) = 2,69 \text{ aircraft} \sim 3 \text{ aircraft}$$

The average number of aircraft in the queue is three aircraft queuing for takeoff in the airside service of aircraft movements.

Queue calculation to find out the average waiting time which is denoted by Wq, based on the formula, is 3.76 minutes, which is the average time airplanes wait for take-off.

$$\mathbf{Wq} = \frac{2,69}{42,82} = 0,06 \text{ hour} = 3,76 \text{ minutes}$$

The average waiting time in the queue is 3.76 minutes, which is the average time airplanes wait for take-off.

The next calculation is the average time needed to wait for the runway service to finish being served in the system. With the formula is 27 planes/hour, the results of the Ws calculation show several 5.99 minutes.

$$\mathbf{Ws = 0,06 + \frac{1}{27} = 0,01} \text{ hour} = 5,99 \text{ minutes}$$

The calculation result of this Ws formula is 5.99 minutes, meaning that the average waiting time for the runway service is until the plane is finished being served.

The average number of aircraft in the system, which is denoted by Ls, means that the average number of aircraft queuing and being served for airside services is four aircraft.

$$\mathbf{Ls} \quad \mathbf{= 2,69 + \frac{42,82}{27}} = 4,27 \sim 4 \text{ aircraft}$$

While the results of Ls are four aircraft. This means that the average number of aircraft queuing and being served for air side services is aircraft movement.

4.4 Runway Service Performance Evaluation

Calculation of queuing system service performance, starting from calculating the Queuing system state probabilities to the calculation of Queuing Formulas, namely calculating the average number of aircraft in the queue, the average time aircraft waiting for landing or take off, the average number of queuing and being served and the average waiting time for runway services to finish being served. The results of the calculation of the Single Server Multi-Channel Queuing System are summarized as Runway Service Performance (Table 3).

Table 3. Summary of Runway Service Performance

Multiple Channel Single Server Queue system	Results
The probability that n units (arrivals) in the system (Po)	0,115
The average number of aircraft in the queue (Lq)	3 aircraft
The average waiting time in the queue (Wq)	3,76 minutes
The average waiting time in the system (Ls)	4 aircraft
The average number of units	5,99 minutes

in the system (Ws)	

Source: Data Processed

Based on the results of calculations with an average of six aircraft per hour, the average aircraft served is seven aircraft per hour, concerning the analysis of the service performance of the queuing system for aircraft movements in the 2019 Lebaran Transportation period and previous relevant research, it can be concluded that the queuing system service at Soekarno-Hatta International Airport can still be not optimal and can be improved again to be more effective and efficient.

4.5 Runway Utilization Evaluation

Runway utilization is calculated based on aircraft movement data during Lebaran transportation in 2019. The weight is calculated on each runway even though at the end of the calculation it will be combined into one runway value.

Table 4. Runway Utilization Percentage (UP) Soekarno-Hatta International Airport

Runway	Movement	%
25L	12.986	79,9%
07R	3.267	20,1%
Total	16.253	100%

Source: [1]

Table 4 explains that the runway utilization rate at Soekarno-Hatta International Airport is 79.9% for Runway 25L and 20.1% for Runway 07R. Based on the calculation results, more aircraft movements are on Runway 25L compared to Runway 07R. Runway utilization also depends on the configuration of the taxiway and parking stand, and the distance between the parking stand and the taxiway. The more taxiways and parking stands, the shorter the separation time, which means the runway capacity to serve aircraft is increasing.

4.6 Discussion

Theoretically and practically, Messaoud [39] has researched aircraft landing operations on several runways. The results of this study support several other researchers such as Bauerle et al. [40], and Bennell et al. [41] with queuing theory simulations comparing two or three runways. The calculation of queuing theory on airport runways with the Multiple Channel Single Server Queue system is also in line with research by Farida et al [31], Kim et al. [42], and Zaki et al. [43]. In conclusion, one of them is the addition of the right terminal building to reduce queuing time and improve more effective services.

Research related to the queuing method in research at Soekarno-Hatta Airport is also in line with several other studies such as that conducted by Rachmansyah and Nahdalina [44], who found that aircraft movement optimization, which was carried out by balancing movements, both on international and domestic routes will reduce the number of existing aircraft movements. This research with two runways also supports the proposed addition of a runway at Soekarno-Hatta Airport, that the addition of a new runway and hourly slot time exceeds the total capacity with queuing theory is one method to overcome current traffic growth [45, 46, 47]. This study is also in line with other findings by Shone et al. [48], with strategic and tactical methods in queuing theory to manage congestion at airports, including the use of slot control, ground holding programs, runway configuration changes, and aircraft sequencing policies.

At Adi Sutjipto airport, Yogyakarta, the average waiting time under normal conditions is 4.57 minutes/aircraft, while during peak hours it reaches 16 minutes/airplane [49, 50]. the average time in the system under normal conditions is 8.57 minutes/aircraft, while during peak hours it is 20 minutes/airplane. Meanwhile, at Ahmad Yani international airport, Semarang, the queue principle applied is first come first served, with the number of capacities for incoming aircraft and unlimited calling sources [51]. Calculations with the queuing theory in the study Samosir et al. [52] are also in line with the findings at I Gusti Ngurah Rai International Airport, Bali as one of the busiest airports in Indonesia which have the potential as a tourist destination for international tourists.

5 Conclusion

To improve the queuing system, it is necessary to improve queuing system services and conduct regular training of officers who are directly related to the queuing system so that the queuing system can be more effective and efficient. To improve the performance of runway services, it is necessary to improve the navigation tools currently owned. The navigation tool plays a role in regulating the movement of the aircraft. With more sophisticated navigation tools, the separation distance between aircraft can be enforced following the separation standards, or at least it can be smaller than currently enforced. The magnitude of the separation distance greatly affects the runway capacity. If the rejuvenation of the navigation equipment can be carried out, it is hoped that the runway capacity can increase, so that the runway can serve more requests for existing aircraft movements.

To optimize the utilization of the runway, it is necessary to design runway capacity development and infrastructures such as the addition of taxiways and aircraft parking runways, as well as runways so that the runway capacity to serve aircraft increases, which also means more effective and effective runway utilization. efficient. Runway utilization is not optimal and can still be improved to be more effective and efficient. More aircraft movement is on Runway 25L compared to Runway 07R. If there is no significant improvement to the runway utilization, there will be a potential for long queues and long delays. The increase in runway utilization can be carried out by designing runway capacity development and adding related infrastructure such as adding taxiways and aircraft parking runways, as well as runways as well as technology development by involving all aviation stakeholders.

References:

[1] Mascio, P.D., Rappoli, G., and Moretti, L, Analytical Method for Calculating Sustainable Airport Capacity, *Sustainability*,Vol. 12, No. 9239, 2020. https://doi.org/10.3390/su12219239

[2] Lancia, C., and Lulli, G, Predictive modeling of inbound demand at major European airports with Poisson and Pre-Scheduled Random Arrivals, *European Jour- nal of Operational Research*, Vol. 280, No. 1, 2020. pp.179–190. DOI:10.1016/j.ejor.2019.06.056

[3] Stephens, M. S., and Ayo Agunbiade, O.T, Airside Capacity Utilization in a Nigerian Airport: A Case Study of Murtala Muhammed International Airport, *American International Journal Multidisciplinary Scientific Research*, Vol. 5, No. 3, 2019 pp. 1-8., 2019. DOI: 10.46281/aijmsr.v5i3.356

[4] Lai, J., Che, L., and Kashef, R, Bottleneck A J. nalysis in JFK Using Discrete Event Simulation: An Airport Queuing Model, in *2021 IEEE International Smart Cities Conference (ISC2)*, 2021, pp. 1-7). DOI:10.1109/ISC253183.2021.9562823

[5] Neufville, R. D., Odoni, A. R., Belobaba, P. P., and Reynolds, T. G, *Airport systems: Planning, design, and management*, 2013. McGraw-Hill Education. 1

[6] Avery, J., and Balakrishnan, H, Predicting airport runway configuration: A discrete-choice modeling approach, *Proceedings of the [Eleventh] USA/Europe Air Traffic Management Research and Development Seminar, ATM2015*, 2015 http://hdl.handle.net/1721.1/106551.

[7] Mesgarpour, M, Airport Runway Optimization. *Ph.D. Thesis, University of Southampton, Southampton, UK*, 2012.

[8] Jacquillat, A., Odoni, A. R., and Webster, M. D, Dynamic control of runway configurations and of arrival and departure service rates at JFK airport under stochastic queue conditions, *Transportation Science*, Vol. 51, No. 1, 2017, pp.155-176.

[9] Kovačič, B., Želodec, D., and Doler, D, Prototype of the Runway Monitoring Process at Smaller Airports: Edvard Rusjan Airport Maribor, *Processes*, Vol. 8, No. 12, 2020, pp. 1689.

[10] Qin, Y., Ng, K. K., Hu, H., Chan, F. T., and Xiao, S, Post-disaster adaptation management in the airport: A coordination of runway and hangar resources for relief cargo transports, *Advanced Engineering Informatics*, Vol. 50, 2021, pp. 101403.

[11] Tascón, D. C., and Olariaga, O. D, Air traffic forecast and its impact on runway capacity. A System Dynamics approach, *Journal of Air Transport Management*, Vol. 90, 2021, pp. 101946.

[12] Pham, D. T., Chan, L. L., Alam, S., and Koelle, R, Real-time Departure Slotting in Mixed-Mode Operations using Deep Reinforcement Learning: A Case study of Zurich Airport, *Proceedings of Fourteenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2021)*, 2021, pp. 1–11.

[13] Andarani, P., Istirokhatun, T., Suhariani, G., and Budiawan, W, Model simulations of noise pollution due to departures and approaches of passenger aircraft around Achmad Yani airport Semarang—Indonesia, *2nd International Conference of Industrial, Mechanical, Electrical, and Chemical Engineering (ICIMECE)*, 2016, pp. 147-151.

[14] Eviane, D., Natsir, T. A., Iswanto, N., Urufi, Z., and Adji, M, Air pollution dispersion modeling of runway and apron at Sam Ratulangi international airport, *Angkasa: Jurnal Ilmiah Bidang Teknologi*, Vol. 13, No. 2, 2021, pp. 103-112.

[15] Firdiyan, N., and Muntini, M. S, The Effect of

Rainfall on The Detection of Standing Water on Runway, *Journal of Physics: Conference Series*, Vol. 1951, No. 1, 2021, pp. 012034.

[16] Majid, S. A., Larasati, E. R., Rizaldy, W., Setiawan, E. B., Pahala, Y., Agusinta, L., Ricardianto, P., and Hernawan, M. A, The Capacity of Runway of Ngurah Rai International Airport Bali Based on The Doratask Method, *Journal of Contemporary Issues in Business and Government*, Vol. 27, No. 1, 2021, pp. 2022-2039.

[17] Sardjono, W., Kusnoputranto, H., Soesilo, T. E. B., Utama, D. N., and Sudirwan, J, Study of runway crosswind and tailwind potential for airport sustainability: A study of Soekarno Hatta airport, Cengkareng, Indonesia, *IOP Conference Series: Earth and Environmental Science*, Vol. 729, No. 1, 2021, pp. 012012.

[18] Ongkowijoyo, H. V., and Ruseno, N, Optimizing the utilization of third runway in Soekarno Hatta International Airport using time space analysis, *Angkasa: Jurnal Ilmiah Bidang Teknologi*, Vol. 13. No. 1, 2021, pp. 59-71.

[19] Sampurno, R. A., Rinodistira, K., and Rizaldy, W, Optimization of Runway Capacity at CKG Airport, *Global Research on Sustainable Transport (GROST 2017)*, 2017, pp. 727-736.

[20] Saragih, H., Wibowo, I. S., Utomo, W. D. T., and Roestam, R, Design Simulation Program of Runway Capacity Using Genetic Algorithm at Soekarno-Hatta, *International Journal of Electrical and Computer Engineering*, Vol. 1, No. 2, 2011, pp. 202.

[21] Ng, K. K. H., Lee, C. K. M., Chan, F. T., and Qin, Y, Robust aircraft sequencing and scheduling problem with arrival/departure delay using the min-max regret approach, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 106, 2017, pp. 115-136.

[22] Bubalo, B., and Daduna, J. R, Airport capacity and demand calculations by simulation—the case of Berlin-Brandenburg International Airport, *NETNOMICS: Economic Research and Electronic Networking*, Vol. 12, No. 3, 2011, pp. 161-181.

[23] Teodorovic, D., and Nedeljkovic, R, Queueing in Transportation Systems, In *Routledge Handbook of Transportation*, 1st Edition, 2015, pp. 420-442. Routledge.

[24] Long, D., and Hasan, S, Improved Predictions of Flight Delays Using LMINET2 System-Wide Simulation Model, *Aiaa Aviation Technology, Integration, & Operations Conference*, 2013, pp. 145-151

[25] Itoh, E., and Mitici, M, Queue-based modeling of the aircraft arrival process at a single airport. *Aerospace*, Vol. 6, No. 10, 2019, pp. 103.

[26] Ignaccolo, M, A simulation model for airport capacity and delay analysis. Transportation Planning and Technology, *Transportation Planning and Technology*, Vol. 26, No. 2, 2003, pp. 135-170.

[27] Thiagaraj, H. B., and Seshaiah, C. V, A queueing model for airport capacity and delay analysis, *Applied Mathematical Sciences*, Vol. 8, No. 72, 2014, pp. 3561-3575.

[28] Lancia, C., and Lulli, G, Predictive modeling of inbound demand at major European airports with Poisson and Pre-Scheduled Random Arrivals, *European Journal of Operational Research*, Vol. 280, No. 1, 2020, pp. 179-190.

[29] Sekine, K., Kato, F., Kageyama, K., and Itoh, E, Data-Driven Simulation for Evaluating the Impact of Lower Arrival Aircraft Separation on Available Airspace and Runway Capacity at Tokyo International Airport, *Aerospace*, Vol. 8, No. 6, 2021, pp. 165.

[30] Jain, R., Bedekar, H., Jayakrishna, K., Vimal, K. E. K., and Kumar, M. V, Analysis and Optimization of Queueing Systems in Airports—Discrete Event Simulation, *Advances in Applied Mechanical Engineering*, 2020, pp. 1189-1194.

[31] Farida, Y., Akbar, F., Hafiyusholeh, M., & Hartono, M, Analysis of Landing Airplane Queue Systems at Juanda International Airport Surabaya. *CAUCHY*, Vol. 7, No. 1, 2021, pp. 49-63.

[32] Oka, I. G., and Mas, G. A. A, Analysis of Soekarno Hatta Airport Runway Capacity Calculation, *Jurnal Ilmiah Aviasi Langit Biru*, Vol. 3, No. 8, 2010.

[33] Prastiwi, D. A., and Kartikasari, P, Analysis non-Poisson systems cases of queuing passenger aircraft at Ahmad Yani Airport, *Natural Science: Journal of Science and Technology*, Vol. 10, No. 1, 2021, pp. 1-5.

[34] Puspitasari, M, *Analysis of Runway Capacity at Ngurah Rai Airport Denpasar*. [Doctoral dissertation], Universitas Atma Jaya Yogyakarta, UAJY), 2011.

[35] Stephens, M. S, Airside Capacity Utilization in a Nigerian Airport: A Case Study of Murtala Muhammed International Airport,

American International Journal of Multidisciplinary Scientific Research, Vol. 5, No. 3, 2019, pp. 1-8.

[36] Lai, J., Che, L., and Kashef, R, Bottleneck Analysis in JFK Using Discrete Event Simulation: An Airport Queuing Model, *IEEE International Smart Cities Conference (ISC2)*, 2021, pp. 1-7).

[37] Itoh, E., and Mitici, M, Analyzing tactical control strategies for aircraft arrivals at an airport using a queuing model, *Journal of Air Transport Management*, Vol. 89, 2020, pp. 101938.

[38] Itoh, E., and Mitici, M, Evaluating the impact of new aircraft separation minima on available airspace capacity and arrival time delay, *The Aeronautical Journal*, Vol. 124, No. 1274, 2020, pp. 447-471.

[39] Messaoud, M. B, A thorough review of aircraft landing operation from practical and theoretical standpoints at an airport which may include a single or multiple runways, *Applied Soft Computing*, Vol. 98, 2021, pp. 106853.

[40] Bäuerle, N., Engelhardt-Funke, O., and Kolonko, M, Routing of airplanes to two runways: Monotonicity of optimal controls, *Probability in the Engineering and Informational Sciences*, Vol. 18, No. 4, 2004, pp. 533-560.

[41] Bennell, J. A., Mesgarpour, M., Potts, C. N, Airport runway scheduling. *4OR*, Vol. 9, No. 2, 2011, pp. 115-138.

[42] Kim, C. S., Mushko, V. V., and Dudin, A. N, Computation of the steady-state distribution for multi-server retrial queues with the phase-type service process, *Annals of Operations Research*, Vol. 201, No. 1, 2012, pp. 307-323.

[43] Zaki, N. H. M., Saliman, A. N., Abdullah, N. A., Hussain, N. S. A. A., and Amit, N, Comparison of queueing performance using queueing theory model and fuzzy queueing model at check-in counter in the airport, *Math. Stat*, Vol. 1, 2019, pp. 17-23.

[44] Rachmansyah, M. I., and Nahdalina, N, Effect of Balancing Aircraft Movements on Airport Performance Improvement (Case Study: Soekarno-Hatta International Airport), *Warta Ardhia*, Vol. 43, No. 1, 2017, pp. 13-26.

[45] Kuntohadi, H., Nusraningrum, D., Sidjabat, S., Samosir, J., and Rafi, S, Analysis of Runway Utilization at Soekarno-Hatta Internasional Airport, *Journal of Advanced Research in Dynamical and Control Systems*, Vol. 12, No. 7, 2020, pp. 788–793.

[46] Wicaksana, A. A., Effendi, F. M., and Warsito, T, Slot Time Capacity in Peak Hour At Soekarno-Hatta International Airport, *Conference on Global Research on Sustainable Transport (GROST 2017)*, Vol. 147, 2017, pp. 650-660.

[47] Ricardianto, P., Wibowo, H., Agusinta, L., Abdurachman, E., Suryobuwono, A., Fachrial, P., Setiawan, A., Rafi, S., Maemunah, S and Endri, E, Determinants of airport train operational performance, *International Journal of Data and Network Science*, Vol.6, No.1, 2021, pp.91-98. doi: 10.5267/j.ijdns.2021.9.019

[48] Shone, R., Glazebrook, K. D., and Zografos, K, Stochastic modeling of aircraft queues: A review, *OR60: The OR Society Annual Conference*, 2018, pp. 61-83.

[49] Saleh, H., and Lukito, I, Predicting Plane Traffic While Takeoff and Landing Using Queue Model As The Measurement of ATC Service Level at Adisutjipto International Airport Yogyakarta, *Journal of Industrial Engineering and Halal Industries*, Vol. 1, No. 1, 2020, pp. 1-18.

[50] Pahala, Y., Widodo, S., Kadarwati., Azhari, M., Muliyati., Lestari, N.I., Madjid, S.A., Sidjabat, S., Limakrisna, N., and Endri, E, The effects of service operation engineering and green marketing on consumer buying interest, *Uncertain Supply Chain Management*, Vol. 9, No. 3, 2021, pp. 603–608. https://doi: 10.5267/j.uscm.2021.5.011

[51] Ratnakusuma, A., Hoyyi, A., and Sugito, S, Analysis of the Aircraft Queue System at Ahmad Yani International Airport, Semarang, *Jurnal Gaussian*, Vol. 4, No. 4, 2015, pp. 725-733.

[52] Samosir, J., Kuntohadi, H., Kurniawan, J., Sihombing, S., and Utomo, B. S, Queuing Analisis of Aircraft Movement at The Apron Area (The Parking Stand) in I Gusti Ngurah Rai International (Bali), *PalArch's Journal of Archaeology of Egypt/Egyptology*, Vol. 17, No. 6, 2020, pp. 12547-12554.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Conceptualization: Prasadja Ricardianto, Adryan Prama Putra. **Data curation**: Imam Ozali, Erman Noor Adi. **Formal analysis**: Adryan Prama Putra, Endri Endri. **Funding acquisition:** Imam Ozali, Salahudin Rafi. **Investigation**: Endri Endri, Erman Noor Adi. **Methodology**: Prasadja Ricardianto, Endri Endri, Aditya Wardana. **Project administration**: Imam Ozali, Peppy Fachrial. **Resources**: Suharto Abdul Majid, Salahudin Rafi. **Software:** Endri Endri, Aditya Wardana. **Supervision**: Endri Endri, Salahudin Rafi. **Validation**: Prasadja Ricardianto, Johar Samosir, Suharto Abdul Majid. **Visualization**: Johar Samosir, Salahudin Rafi. **Writing – original draf**t: Prasadja Ricardianto, Adryan Prama Putra. **Writing – review & editing**: Endri Endri, Peppy Fachrial