

Comparative Analysis of Hangar Intensity Based on Aircraft Base Maintenance Planning and Queuing Theory

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Article Info

Article History:

Submitted: 12 Desember 2024

Revised : 8 Januari 2025

Accepted : 27 Februari 2025

Keywords:

Hangar

Maintenance

Planning

Queuing Theory

Turn Around Time

ABSTRACT

Aircraft maintenance is essential to ensure operational safety and reliability. Hangar facilities play a significant role in various types of maintenance, such as base and line maintenance. However, limited hangar capacity and variations in maintenance duration often lead to aircraft queues, so an optimization analysis using Queuing Theory is required to improve hangar usage efficiency. This study aims to compare the intensity of hangar usage based on Aircraft Base Maintenance Planning (ABMP) data with the results of Queuing Theory calculations to optimize the allocation and effectiveness of aircraft maintenance. This study uses the Queuing Theory method with exponential distribution to analyze the aircraft queuing pattern in Hangar 1 and 3 of PT XYZ for January- June 2024. The data used includes the number of aircraft, types of maintenance (D-Check, C-Check, painting, and landing gear change), and Turn Around Time (TAT). Calculations are carried out to determine the level of service intensity, waiting time, and the number of aircraft in the queue. The analysis showed that the highest service intensity occurred at D-Check (126%), while the lowest was at L/G Change (38%). Overall, the service intensity in Hangars 1 and 3 reached 77%, with C-Check having the most representative queuing pattern of the overall maintenance system. These findings suggest that while hangar utilization is still within optimal limits, improved maintenance schedule management strategies are needed to reduce queues and increase operational efficiency.

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INTRODUCTION

Aircraft are one of the vital forms of air transportation that support global mobility, especially in long-distance travel, which requires high speed and safety. However, like every other complex machine, aircraft have a lifespan and require careful maintenance to perform optimally[1]. Proper maintenance plays an important role in ensuring flight safety and avoids potential risks that could arise from failure to comply with established maintenance standards [2].

Every aircraft has a Maintenance Program with detailed maintenance schedules and methods. The program is designed to manage all aspects of maintenance, from routine inspections to more in-depth repairs[3] [4]. As the main place for aircraft maintenance, the hangar handles various types of repairs and maintenance, from light to heavy. This process is essential to keep the aircraft in top condition and ensure all components function properly[5].

Regularly scheduled aircraft maintenance can accumulate aircraft in the hangar, potentially resulting in queues[6]. A more systematic approach is required to manage these queues more effectively. One method that can be used is an analysis based on queuing theory, which utilizes data from Aircraft Base Maintenance Planning[7].

Queuing theory analyses and optimises waiting lines in various industries, helping reduce waiting times, allocate resources efficiently, and predict system performance. It offers a strong mathematical foundation, cost efficiency, and predictive capabilities, making it valuable for systems with random demand patterns. However, its reliance on simplifying assumptions, limited scalability for complex systems, and lack of real-time adaptability can be disadvantages. Compared to other methods like simulation, heuristics, and AI-based models, queuing theory provides analytical precision but may lack flexibility in dynamic environments. Despite its limitations, it remains a fundamental tool for managing service efficiency.

METHOD

Queuing Theory

Queuing Theory is a branch of mathematics that studies situations where people or goods wait to be served in a system[8]. Queuing theory allows for analyzing the performance of queuing systems using models that represent various queuing situations in real life. Research using a single-phase multi-stage queuing structure where when two or more service facilities are connected to a single queue, this service design involves servers arranged in parallel[9], [10]. While the queuing model used is the queuing model (M / M / S) in a double-line queuing system, the assumption is that customers waiting for service form a queue that will be served by several service facilities available first. This queuing theory uses a formula like the following [11]:

- Intensity level Service facilities (P)

$$P = \frac{\lambda}{s\mu} \quad (1)$$

Where,

- λ : Average arrival rate per unit time
- μ : Average service level per unit time

- Average number of customers expected in the system (L_s)

$$L_s = L_q + \frac{\lambda}{\mu} \quad (2)$$

- Number of customers expected to wait in the queue (L_q)

$$L_q = \frac{P_0 \left(\left(\frac{\lambda}{\mu} \right)^s \right) P}{s! (1 - P)^2} \quad (3)$$

Where,

s : Number of service facilities

- Customer's expected time in the system (W_s)

$$W_s = W_q + \frac{1}{\mu} \quad (4)$$

- Expected time customers wait in queue (W_q)

$$W_q = \frac{L_q}{\lambda} \quad (5)$$

- Probability that there are no customers in the system (P_0)

$$P_0 = \frac{1}{\left\{ \sum_{n=0}^{c-1} \left[\frac{\left(\frac{\lambda}{\mu} \right)^n}{n!} \right] + \frac{\left(\frac{\lambda}{\mu} \right)^s}{s! \left(1 - \frac{\lambda}{s\mu} \right)} \right\}} \quad (6)$$

RESULT AND DISCUSSION

Arrival Distribution

Table 1 Arrival Distribution

HANGAR	LINE	Number of Aircraft
1	1	5
1	2	9
3	1	9
3	2	11
3	3	5
6-MONTH AIRCRAFT AVERAGE		6,5

Table 1 shows the distribution of arrivals at the hangar for January - June 2024 obtained from Aircraft Base Maintenance Planning data, which is spread out with a minimum number of arrivals of 5 aircraft. In comparison, the maximum number of arrivals was 11. Total aircraft arrivals were 39, with an average monthly arrival (λ) of 6.5

Service Distribution

Table 2 Service Distribution

Type of Work	AVERAGE TAT	μ
D CHECK	58,11	0,52
C CHECK	34,51	0,87
PAINTING	21,33	1,41
L/G CHANGE	17,47	1,72
ALL	35,65	0,84

Table 2 shows that at Hangar XYZ in the period January-June 2024, the distribution of aircraft service time varies, ranging from the fastest, taking only 17.47 days to complete an aircraft L/G Change job, to the longest taking 58.11 days to complete an aircraft D-Check job. Moreover, from this data, the value of each aircraft job can be obtained.

Calculation of Average TAT

The data used for the calculation of average TAT is based on Aircraft Base Maintenance Planning data.

a. Average TAT D-check

The average D-Check is obtained from various D-Check maintenance activities in the hangar. This type of D-Check maintenance is carried out in conjunction with other work, but the main focus of D-Check work can be seen in Table 3 below:

Table 3 Average TAT D-Check

Type of Work	A/C Reg	TAT (Turn Around Time)
D-CHECK	PK-001	54,5
D-CHECK	PK-002	44,69
D-CHECK	PK-003	44,69
D-CHECK	PK-004	45,69
D2-CHECK	PK-005	59,31
D CHECK	PK-035	50,69
D02-CHECK+ Add	PK-036	107,19
Average		58,11

b. Average L/G Change

The average L/G Change is obtained from various L/G Change maintenance activities carried out in the hangar. This type of L/G Change maintenance is carried out in conjunction with other work, but the main focus of L/G Change work can be seen in Table 4 below:

Table 4 Average TAT L/G Change

Type of work	A/C Reg	TAT(Turn Around Time)
Eng Change +L/G Change + C03-Check	PK-009	29,26
L/G Change + A-Check	PK-010	1
36+42M + L/G Change	PK-033	17,47
L/G Change	PK-034	17,47
Average		17,47

c. Average TATA C-Check

The average C-Check is obtained from various C-Check maintenance activities carried out in the hangar. This type of C-Check maintenance is carried out in conjunction with other work, but the focus of C-Check work can be seen in Table 5 below:

Table 5 Average TAT C-Check

Type of Work	A/C Reg	TAT(Turn Around Time)
C02 Check + L/G Replace	PK-006	97,5
1C+2C Check	PK-007	70,13
1C+2C Check	PK-008	15,6
C03-Check + L/G Change	PK-011	27,26
C03-Check	PK-013	13,63
C03-Check	PK-014	36,25
13C-Check	PK-015	28,25
15C-Check	PK-017	32,25
5C-Check	PK-018	25,63
C04 Check	PK-019	14,63
6YR + C03 Check	PK-020	29,44
5C-Check	PK-021	9,81
C CHECK	PK-022	46,38
C05 + L/G Ovh + Rib 6 Mod	PK-023	31
6YR + C03 Check	PK-024	28,25
C06 + L/G Change	PK-025	21,44
5C-Check	PK-027	40,88
C06 + L/G Change	PK-028	30,44
C02 Check + Seat Reconfig For Haji	PK-029	17,47
C01-Check + Add	PK-030	14,63
C02-Check + Add	PK-031	13
C02-Check	PK-037	74,31
C02-Check	PK-038	74,31
C-Check	PK-039	33,44
Average		34,51

d. Average TAT Painting

The average painting is obtained from various maintenance activities in the hangar. This type of painting maintenance is carried out in conjunction with other work, but the main focus of painting work can be seen in Table 6 below:

Table 6 Average TAT Painting

Type of Work	A/C Reg	TAT(Turn Around Time)
Painting	PK-015	22,63
Painting	PK-016	14
Painting	PK-026	21,44
Eng#2 Change + Painting	PK-032	27,25
Average		21,33

Queuing Theory Calculation

In this queuing theory calculation using the Exponential Distribution, Where the overall Turn Around Time (TAT) value is 35.65, D-Check 58.11, C-Check 34.51, Painting 21.33, and L / G Change 17.47, this value varies depending on the type of work performed. The average number of aircraft

entering the hangar is $\lambda = 6.5$ Aircraft/month, with the number of lines used for Aircraft maintenance $s = 10$.

a. Overall Queue Theory Calculation

Aircraft arrivals $\lambda = 6.5$ aircraft per month, with work in the hangar taking 35.65 days. So the service level $\mu = \frac{30}{35,65} = 0,84$ aircraft per month and the number of lines $s = 10$

- Hangar Use Intensity Level (P) using the equation (1):

$$P = \frac{6,5}{10 \times 0,84} = 0,77 = 77\%$$

This figure shows that the hangar will be busy servicing aircraft for 77% of the time.

- The probability of no aircraft in the system (P_0) using equation (6):

$$P_0 = \frac{1}{\left(\frac{\left(\frac{6,5}{0,84}\right)^0}{0!} + \frac{\left(\frac{6,5}{0,84}\right)^1}{1!} + \frac{\left(\frac{6,5}{0,84}\right)^2}{2!} + \frac{\left(\frac{6,5}{0,84}\right)^3}{3!} + \frac{\left(\frac{6,5}{0,84}\right)^4}{4!} + \frac{\left(\frac{6,5}{0,84}\right)^5}{5!} + \frac{\left(\frac{6,5}{0,84}\right)^6}{6!} + \frac{\left(\frac{6,5}{0,84}\right)^7}{7!} + \frac{\left(\frac{6,5}{0,84}\right)^8}{8!} + \frac{\left(\frac{6,5}{0,84}\right)^9}{9!} + \frac{\left(\frac{6,5}{0,84}\right)^{10}}{10! \left(1 - \frac{6,5}{10 \cdot 0,84}\right)} \right)} = 0,00057$$

- The number of aircraft expected to wait in the queue (L_q) can be calculated using Equation (2), as follows:

$$L_q = \frac{0,00057 \left(\left(\frac{6,5}{0,84}\right)^{10}\right) 0,77}{10!(1-0,77)^2} = 1,78 \text{ aircraft}$$

This figure shows that there are 1.78 aircraft waiting in the queue.

- The time expected by the aircraft while waiting in the queue (W_q) can be calculated using Equation (3), as follows:

$$W_q = \frac{1,78}{6,5} = 0,27 \text{ months or } 8,21 \text{ days}$$

This figure shows that the average time an aircraft waits to be served in the queue is 0.27 months (8.21 days).

- The expected time of the aircraft in the system (W) can be calculated using Equation (4), as follows:

$$W = 0,27 + \frac{1}{0,84} = 1,46 \text{ months dan } 43,8 \text{ days}$$

This figure shows that the average time an aircraft is expected to be in the system is 1.46 months (43.8 days).

- The expected average number of aircraft in the system (L) can be calculated using Equation (5), as follows:

$$L = 1,78 + \frac{6,5}{0,84} = 9,50 \text{ Aircraft}$$

This figure shows that the average number of aircraft expected to be in the system is 9.50.

Using the same Queuing Theory calculations, the calculations for other types of work are not written down. Results can be seen in **Table 7**

Calculation Analysis

Based on the results in **Table 7**, the results of the calculation of queuing theory using TAT (Turn Around Time) as a whole experience a busy intensity of 77%. If the calculation of queuing theory using TAT (Turn Around Time) D-Check experiences a busy intensity of 126%. For queuing theory calculations using TAT (Turn Around Time) C-Check, the intensity of busyness is 75%. For the calculation of queuing theory

using TAT (Turn Around Time), Painting experienced a busy intensity of 46%. Finally, for the calculation of queuing theory using TAT (Turn Around Time), L / G Change experienced a busy intensity of 38%.

The calculation of the 5 variations that have been carried out can be seen in **Table 7** as follows

Table 7 Queuing Theory Calculation Results

Type of work	D Check	C Check	Painting	L/G Change	Overall
λ (Aircraft)	6,5	6,5	6,5	6,5	6,5
TAT (Days)	58,1	34,51	21,33	17,47	35,64
μ	0,52	0,87	1,41	1,72	0,84
S (line)	10	10	10	10	10
P (%)	126%	75%	46%	38%	77%
P₀	1,99900,E-05	0,00071	0,0099	0,023	0,00057
L_q (Aircraft)	10,35	1,25	0,019	0,0037	1,78
W_q (months)	1,6	0,19	0,003	0,00057	0,27
W (months)	3,53	1,34	0,71	0,58	1,46
L (Aircraft)	22,94	8,73	4,64	3,78	9,5

Therefore, from the calculation of the queuing theory based on Aircraft Base Maintenance Planning for January-June 2024, it can be analyzed that the calculation of the hangar queuing theory experiences an intensity of 77%. Meanwhile, from the calculation of 4 variations of TAT (Turn Around Time), the intensity value close to the hangar is C-Check, which experiences an intensity of 75%. From this calculation, the research results can use TAT C-Check to meet the hangar intensity during the January-June 2024 period because the intensity value is close to the hangar intensity value based on Aircraft Base Maintenance Planning.

CONCLUSION

Based on the results of the calculations and analysis carried out, it can be concluded that the hangar allocation calculations in this study used five TAT variations: Overall TAT, TAT D-Check, TAT C-Check, TAT Painting, and TAT L/G Change. Among these variations, the highest level of service intensity based on the type of work was found in the TAT D-Check variation, with a percentage of 126%. In this condition, the number of aircraft waiting in the queue reached 10.35, with an average waiting time of 47.762 days. Additionally, the number of aircraft waiting in the system was 22.94, with an average waiting time of 105.871 days. Meanwhile, the lowest level of service intensity was observed in the TAT L/G Change variation, with a service intensity of 38%. Under this condition, the number of aircraft waiting in the queue was only 0.0037, with an average waiting time of 0.0171 days. The number of aircraft waiting in the system was 3.78, with an average waiting time of 17.48 days.

The comparison was made based on the overall calculation of aircraft base maintenance planning data, which showed high intensity in hangars 1 and 3. Meanwhile, in queue theory, an intensity of 77% was observed in hangars 1 and 3. From the TAT variations that have been calculated, the intensity value closest to the overall TAT variation is the C-Check TAT variation. Based on the calculations, it can be assumed that the C-Check TAT variation can determine the overall intensity level. The average type of work performed in the hangar is assumed to be C-Check.

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