AIRLINE CREW PAIRING OPTIMIZATION FOR DOMESTIC FLIGHTS TO A TOURISM DESTINATION PROVINCE IN INDONESIA

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Abstrak

Sejalan dengan penanganan pandemi Corona Virus Disease 2019 (COVID-19), jika pada tahun 2022 sektor penerbangan memasuki periode pemulihan yang diindikasikan dengan pembukaan kembali rute-rute penerbangan yang sempat ditutup dan penambahan frekuensi di rute yang sudah dibuka, sementara tidak diimbangi dengan evaluasi jumlah sumber daya manusia, maka kemungkinannya adalah kru akan bekerja dengan jadwal yang padat. Oleh karena itu, perencanaan mengenai kru perlu dioptimasi agar selain dapat melayani semua jadwal penerbangan, juga memastikan bahwa kru tersebut tidak bekerja melebihi waktu yang telah ditentukan oleh lembaga regulator penerbangan sipil. Model dalam studi ini bertujuan untuk meminimumkan jumlah crew pairing agar mampu memenuhi semua penerbangan. Model berikutnya bermaksud untuk meminimumkan jumlah waktu kru menunggu di bandar udara sebelum melakukan penerbangan selanjutnya. Penyusunan model, konfirmasi data, verifikasi model, dan uji coba model dilakukan pada bulan Juli-Oktober 2022. Teknik pengumpulan data yaitu dokumentasi dan studi pustaka. Jenis data yang dianalisis adalah data sekunder, yang dikelompokkan menjadi data yang berhubungan dengan penerbangan dan data yang berkaitan dengan peraturan pemerintah, serikat kerja, dan maskapai. Penentuan crew pairing dianalisis dengan Metode Integer Programming yang dilakukan dengan bantuan software LINGO 19.0. Berdasarkan hasil penelitian, dapat disimpulkan bahwa minimum jumlah crew pairing untuk melayani 11 penerbangan yang berasal dari pangkalan kru adalah 7 crew pairing. Total minimum waktu tunggu kru di bandar udara sebelum melayani penerbangan selanjutnya adalah 620 menit, dengan waktu tunggu terlama di antara rute-rute penerbangan yaitu 70 menit dan terdapat 3 crew pairing yang tidak memiliki waktu tunggu pada salah satu rute penerbangan yang harus dilayani. Studi ini juga menunjukkan bahwa terdapat kru yang bekerja dengan jadwal yang sangat padat dan kru yang hanya melayani dua rute penerbangan dalam sehari. Perlu dilakukan penelitain tentang crew rostering dengan asumsi jadwal berulang setiap hari atau sama di minggu berikutnya, untuk mengalisis apakah kru akan bertugas secara bergantian pada jadwal yang padat tersebut.

Kata kunci: *crew pairing, maskapai, integer programming, optimasi, penerbangan.*

Abstract

In line with the management of the Corona Virus Disease 2019 (COVID-19) pandemic, in 2022, the aviation sector enters a recovery period, as indicated by the reopening of previously closed flight routes and the addition of frequencies on re-opened routes. However, if it is not balanced out with an evaluation of the number of human resources, then most likely the crew will be working on a tight schedule. Therefore, it is necessary to optimize crew planning to allow the crews handle all the flight schedules as well as to make sure they do not work exceeding the time set by the civil aviation regulatory agency. The model in this study aimed to minimize the number of crew pairings to allow them accommodate all flights. The next model intended to minimize the crew waiting time at the airport before their next flight. Model development, data confirmation, model verification, and model trials were carried out in July-October 2022. Documentation and literature study were used to collect the data. The analyzed data were secondary data, grouped into data related to aviation and data related to government, unions, and airlines regulations. The determination of crew pairing was analyzed using the Integer Programming Method with LINGO 19.0 software. The results of this study indicated that to serve 11 flights departing from the crew base, at least 7 crew pairs are required. The minimum total sit time for the crew at the airport before serving the next flight is 620 minutes, where 70 minutes is the longest sit time between flight routes and there are 3 crew pairs without any sit time for one of the flight routes they serve. This study also shows that there are crews working with an extremely tight schedules and crews that only serve two flight routes a day. It is necessary to carry out a study on crew rostering with the assumption that the schedule repeats every day or is the same for the following weeks, to analyze whether the crew will work alternately on such a busy schedule.

Keywords: *airlines, crew pairing, flight, integer programming, optimization.*

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Received 15 November 2022,, Available Online 15 Desember 2022

https://doi.org/10.56521/manajemen-dirgantara.v15i2.763

Introduction

Since the World Health Organization (WHO) declared Corona Virus Disease 2019, commonly abbreviated as COVID-19, as a pandemic on March 11, 2020 (WHO, 2020), not only widespread health risk, economic problems also have become global for all countries. Almost all sectors are affected by this condition, among the most impacted ones is the aviation sector (Suau-Sanchez *et al.*, 2020). Airlines have high risks of survival and finance-related long-term effects financing (Sun *et al.*, 2021).

Several countries have implemented various policies since the pandemic began, including lockdown regulations and flight bans in certain countries. This led to a drastic decrease in the number of passengers, making most airlines stopped their operations. Based on the study by Iacus *et al.* (2020), most companies in the aviation sector have also begun to improve their efficiency in human resources department, which eventually forces the remaining employees to work with a hectic schedule changeover system.

The above-mentioned impacts of COVID-19 are experienced by all countries in the world, including Indonesia. The pandemic caused a low investor sentiment towards global markets and slowed down the world economy (Nasution *et al.*, 2020). This situation affects Indonesia's economic growth. Kartiko (2020) stated that one of the government's responses to badly-impacted sectors is providing tax incentives for tourism field. As a mode of transportation that plays a major role and is closely related to the tourism industry, especially in an archipelago like Indonesia, it is necessary to pay attention to measures to reduce the impact of the pandemic on the airline business. In managing the impacts of the pandemic in air transportation sector for airlines, one of the elements that needs to be a policy consideration is operational cost management. Total crew costs (including salaries, benefits, and expenses) are the largest expense for an airline; second after fuel purchase (Bazargan, 2010).

In line with the management of the pandemic, in 2022, the aviation sector enters a recovery period, as indicated by the reopening of previously closed flight routes and the addition of frequencies on re-opened routes. However, if it is not balanced out with an evaluation of the number of human resources, then, as stated by Iacus *et al.* (2020), the remaining crew will work on a tight schedule. Therefore, it is necessary to optimize crew planning to allow the crews handle all flight schedules as well as to make sure they do not work exceeding the time set by The Federal Aviation Administration (FAA).

This study analyzes the optimization of crew pairing on a full-service airline for domestic flight routes, from the crew base at Soekarno-Hatta International Airport, Tangerang (Banten Province) to Bali as one of the tourist destination provinces in Indonesia. Flights from Banten to Bali take an average of 2 hours. Based on the FAA's regulation, the maximum total flying time per day is 8 hours, meaning the crew can only handle 4 flights max, provided there are no issues during the flight leading to additional time for one or several flying times. The analysis is focused on one date that has a flight frequency of more than 4 times plus routes connected to Bali on the same date. The model in this study aims to minimize the number of crew pairings to allow them accommodate all flights. The next model intends to minimize the crew waiting time at the airport before their next flight.

Literature Review

Optimization

Optimization is defined as an effort or means to obtain the best results (Language Development and Fostering Agency, 2016). Operation research can help solve problems involving interactions among objects by finding the best decisions for the entire system (Siang, 2014) because it employs optimization principles.

The success of an operation research technique is ultimately measured by the spread of its use as a decision-making tool (Taha, 1996). Since its introduction in the late 1940s, linear programming has proven to be one of the most effective operation research tools.

Crew Pairing

Flight crew scheduling involves the processes of identifying flight sequences and assigning both cockpit and cabin crew, in respective order (Bazargan, 2010); such as creating flight routes, which is usually carried out after fleet assignment. The first phase in crew scheduling is building crew pairings. Crew pairing is a sequence of flights within the same fleet, which starts and ends at the same crew base.

Several things related to crew pairing are as follows (Bazargan, 2010):
1. The sequence of crew pairing must satisfy many constraints such as unions, government, and contract regulations;
2. Crew pairing sequence may typically span from one to five days, depending on the airline;
3. The objective of crew pairing is to find a set of pairings that covers all flights and minimizes the total crew cost;
4. The final crew pairing includes dates and times for each day;
5. The typical assumption in crew pairing is that flight schedules are repeated daily (especially for weekdays); and
6. The assignment of each specific crew member (cockpit or cabin) is not discussed in determining crew pairing because it is on the next stage, i.e. crew rostering.

The following definition is used in addressing crew pairing problems (Bazargan, 2010):
1. Duty: a working day of a crew, may consist of several flight segments. The length of duty is determined by The Federal Aviation Administration (FAA) and the regulations of each airline, one of which is a limitation for pilots, i.e. they have a maximum flight time of 8 hours in 24 hours and must rest for 8 hours in the same time span.
2. Sit connection: connection during duty, including crew waiting time at the airport before serving the next flight. Airlines usually impose a minimum and maximum sit connection time, i.e. between 10 minutes to 3 hours.
3. Rest: the connection between the two duties; overnight or layover.

Research Methods

Research Design

This descriptive quantitative research aimed to explain or describe airline crew pairing optimization based on the results of the formulated model analysis. Model development, data confirmation, model verification, and model trials were all carried out in July-October 2022. The data collection techniques were documentation and literature study. Secondary data were analyzed, grouped into data related to aviation and data related to government, unions, and airlines regulations.
1. Flight data, sourced from companies' daily reports, airlines' official websites, and FlightAware website, in the form of: flight schedule with departures from Soekarno-Hatta International Airport Tangerang, including flight number, arrival airport, departure and arrival time at the airport, and flight duration.
2. Data on regulations; sourced from government, unions, and airlines regulations. The data are related to duty, sit connection, and rest. This includes information regarding:
   a. flying time: the length of service time by the crew in the air on each flight (leg);
   b. briefing time: the length of crew preparation time at the airport before the first flight of the crew pairing;

c. debriefing time: the length of time the crew stays at the airport after the last flight of the crew pairing;
d. ground time: the time it takes the aircraft to land plus the time it takes the crew to leave the aircraft;
e. sit time: the length of time the crew waits at the airport for the next flight; and
f. service time: the total duration of the crew carrying out their flight service-duties; consisting of flying time, briefing and debriefing time, ground time, and sit time.

The limitation and the assumptions employed are as follows:
1. The analyzed flight schedules are from one of the full-service airlines in Indonesia and the flight number is only a number (does not include airline code);
2. The airline's schedules are for domestic flights;
3. The airport where the initial and final crew bases take place is the same, i.e. Soekarno-Hatta International Airport (CGK) in Tangerang City (Banten);
4. The airports that serve as flight destinations are I Gusti Ngurah Rai International Airport in Bali (DPS) in Badung Regency (Bali) and other airports that have route connections on October 10, 2022 (Table 1), i.e. Juanda International Airport (SUB) in Sidoarjo Regency (East Java) and Komodo Airport (LBJ) in West Manggarai Regency (East Nusa Tenggara);
5. The same period, i.e. in one day, meaning each crew pairing begins and ends at the crew base on the same day;
6. All crews are considered able to serve all types of aircraft;
7. All airports are located in the same time zone; and
8. Flight delays on departure and arrival are not taken into account.

Table 1. Flight Data

Flight Number	**Route**	**Travel Time (UTC+7)**	**Duration (Minutes)**
402	CGK-DPS	07:15-09:10	115
400	CGK-DPS	08:00-10:00	120
404	CGK-DPS	09:25-11:20	115
408	CGK-DPS	11:30-13:35	125
414	CGK-DPS	13:00-15:00	120
410	CGK-DPS	14:25-16:20	115
420	CGK-DPS	16:30-18:30	120
306	CGK-SUB	07:05-08:45	100
316	CGK-SUB	08:35-10:15	100
322	CGK-SUB	11:10-12:50	100
312	CGK-SUB	13:30-15:10	100
407	DPS-CGK	11:00-13:05	125
409	DPS-CGK	12:30-14:25	115
411	DPS-CGK	14:55-17:00	125
403	DPS-CGK	15:20-17:25	125
417	DPS-CGK	17:40-19:45	125
4012	DPS-CGK	19:15-21:15	120
7036	DPS-LBJ	10:45-12:00	75
349	DPS-SUB	15:50-17:05	75
7037	LBJ-DPS	13:00-14:15	75
311	SUB-CGK	09:30-11:05	95
321	SUB-CGK	11:00-12:35	95

Sources: daily reports, airline websites, and FlightAware, 2022

Table 1. Flight Data (continued)

Flight Number	Route	Travel Time (UTC+7)	Duration (Minutes)
327	SUB-CGK	13:35-15:10	95
317	SUB-CGK	16:30-18:00	90
325	SUB-CGK	18:40-20:10	90

Sources: daily reports, airline websites, and FlightAware, 2022

The routes in Table 1 include flights in cities located in the Western Region (WIB) and the Central Region of Indonesia (WITA), but all flight times had been adjusted to the UTC+7 standard. In addition, because one of the assumptions used was one day period, flights ending at airports other than the crew base (having rest or overnight) were not included in the analysis. This study formulated a crew pairing model (Vargas *et al*., 2009) with a one-day cycle that repeats in one week, analyzed using the Integer Programming Method.

Suppose $N = \{1,2,3,\ldots,26\}$ is the set of nodes where node 1 represents the crew base, $N_L = \{2,3,\ldots,26\}$ indicates the set of nodes representing flight legs, while A is the set of arcs representing possible leg pairs; *i, j, m* are the indices to denote leg and *k* is the index to denote crew pairing. Parameter c_{max} indicates maximum number of crew pairings = 11, t^s_{max} indicates maximum service time = 14 hours, t^f_{max} is maximum total flying time = 8 hours, t^f_i is flying time on leg i, t^g_i is ground time on destination airport on leg i = 25 minutes, and t^g_1 is briefing time = 25 minutes. Other parameters, t^d_i indicates the departure time on leg *I*, t^a_i indicates the arrival time on leg i, t^{db} indicates debriefing time = 20 minutes, T_{ij} is the sit time between leg *i* and leg *j*, and *M* is a positive constant that relatively of big value. Based on these definitions, the following is the integer programming model in this study.

Decision Variable

$$x^k_{ij} = \begin{cases} 1, \text{if leg pairs } (i,j) \text{are in crew pairing } k \\ 0, \text{others} \end{cases}$$

$$Z_1 = \sum_{k=1}^{11}\sum_{j=1}^{26} x^k_{1j}. \tag{1}$$

$$\sum_{k=1}^{11}\sum_{j=1}^{26} x^k_{ij} = 1, \qquad \forall i = 2,3,\ldots,26. \tag{2}$$

$$\sum_{j=1}^{26} x^k_{ij} - \sum_{j=1}^{26} x^k_{ji} = 0, \qquad \forall i = 1,2,\ldots,26, \qquad \forall k = 1,2,\ldots,11. \tag{3}$$

$$\sum_{j=1}^{26} x^k_{1j} \le 1, \qquad \forall k = 1,2,\ldots,11. \tag{4}$$

$$\sum_{\{j\in N|(1,j)\in A\}} x^k_{1j} - \sum_{\{j \in N|(j,1) \in A\}} x^k_{j1} = 0, \qquad 1 \le k \le c_{max}. \tag{5}$$

$$t_i^a + t^{db} - t_{max}^s - \sum_{(1,m)\in A} \left(t_m^d - t_1^g\right) \cdot x_{1m}^k + M \cdot x_{i1}^k < M,$$

$$\forall i = 2,3, \dots ,26, \qquad \forall k = 1,2, \dots ,11$$

$$t_i^a + t^{db} - t_{max}^s - \sum_{(1,m)\in A} \left(t_m^d - t_1^g\right) \cdot x_{1m}^k + M \cdot x_{ij}^k < M,$$

$$(i,j) \in A, \quad \forall i = 2,3, \dots ,26, \quad \forall k = 1,2, \dots ,11. \tag{6}$$

$$t_i^a + t_i^g - t_j^d + M \cdot x_{ij}^k \leq M, \qquad (i,j) \in A, \qquad 1 \leq k \leq c_{max}. \tag{7}$$

$$\sum_{(i,j)\in A} t_i^f \cdot x_{ij}^k \leq t_{max}^{fp}\,, \qquad \forall k = 1,2, \dots ,11. \tag{8}$$

$$x_{i,j}^k \in \{0,1\}, \quad (i,j) \in A, \quad \forall k = 1,2, \dots ,11. \tag{9}$$

The objective function of the first stage (1) aimed to minimize the number of crew pairings to serve all flights. Constraint (2) states that each leg can only be served by one crew pairing. Constraint (3) requires crew pairing to continue, meaning after serving a leg on a crew pairing, the crew will serve the next leg without repeating the same leg. Constraints (4)-(5) confirm that each flight that starts from the base is once at most in each crew pairing, and crew pairing starts from a base and ends at the same base. Constraints (6), (7), (8) create conditions related to maximum time; which respectively states the difference between the arrival time on leg i and the start time of the briefing for each crew pairing, which cannot exceed the maximum service time; arrival time plus ground time on leg i is shorter than the departure time on leg j; and the total flying time for each crew pairing is shorter than the maximum total flying time. All decision variables are of zero or one value (9).

After obtaining the minimum number of crew pairings, the next step (stage 2) was to analyze the sit time. The aim of the model was changed, i.e. to minimize the amount of time for the crews to wait at the airport before serving the next flight (10).

$$Z_2 = \sum_{k=1}^{11} \sum_{(i,j)\in A} T_{i,j} \cdot x_{ij}^k. \tag{10}$$

$$\sum_{k=1}^{11} \sum_{j=1}^{26} x_{1j}^k = Z_1. \tag{11}$$

Constraint 11 ensures that the minimum crew pairing used is the total number from the previous stage. Therefore, constraints (2)-(9) are also constraints in stage 2.

Results and Discussion

In solving the problem of determining crew pairing, this study used LINGO 19.0 software. Stage 1 carried out the computational process for 6 seconds by providing a minimum number of crew pairing solutions, i.e. 7, as provided in detail in Table 2.

Table 2. The Results of Stage 1 Crew Pairing Analysis

Crew Pairing 1	**Leg**	**5**	**15**			
	Flight Number	**408**	**411**			
	Route	CGK-DPS	DPS-CGK			
	Travel Time	11:30-13:35	14:55-17:00			
Crew Pairing 2	**Leg**	**4**	**14**	**8**	**18**	
	Flight Number	**404**	**409**	**420**	**4012**	
	Route	CGK-DPS	DPS-CGK	CGK-DPS	DPS-CGK	
	Travel Time	09:25-11:20	12:30-14:25	16:30-18:30	19:15-21:15	
Crew Pairing 3	**Leg**	**9**	**22**	**7**	**17**	
	Flight Number	**306**	**311**	**410**	**417**	
	Route	CGK-SUB	SUB-CGK	CGK-DPS	DPS-CGK	
	Travel Time	07:05-08:45	09:30-11:05	14:25-16:20	17:40-19:45	
Crew Pairing 4	**Leg**	**10**	**23**	**6**	**20**	**26**
	Flight Number	**316**	**321**	**414**	**349**	**325**
	Route	CGK-SUB	SUB-CGK	CGK-DPS	DPS-SUB	SUB-CGK
	Travel Time	08:35-10:15	11:00-12:35	13:00-15:00	15:50-17:05	18:40-20:10
Crew Pairing 5	**Leg**	**11**	**24**			
	Flight Number	**322**	**327**			
	Route	CGK-SUB	SUB-CGK			
	Travel Time	11:10-12:50	13:35-15:10			
Crew Pairing 6	**Leg**	**2**	**13**	**12**	**25**	
	Flight Number	**402**	**407**	**312**	**317**	
	Route	CGK-DPS	DPS-CGK	CGK-SUB	SUB-CGK	
	Travel Time	07:15-09:10	11:00-13:05	13:30-15:10	16:30-18:00	
Crew Pairing 7	**Leg**	**3**	**19**	**21**	**16**	
	Flight Number	**400**	**7036**	**7037**	**403**	
	Route	CGK-DPS	DPS-LBJ	LBJ-DPS	DPS-CGK	
	Travel Time	08:00-10:00	10:45-12:00	13:00-14:15	15:20-17:25	

Source: output of LINGO 19.0, 2022

For example, Crew Pairing 4 flies in leg order: 1-10-23-6-20-26-1. Crew Pairing 4 begins its duties by serving Banten-East Java flight at 08:35 WIB and lands at 10:15 WIB. Arriving in East Java, the crews return to Banten at 11.00 WIB and arrive at 12.35 WIB. After that, the crews continue their duties serving Banten-Bali flight departing at 13:00 WIB and arriving at 15:00 WIB. They serve the next flight from Bali to East Java at 15:50 WIB and arrive in East Java at 17:05 WIB. The last flight served by the crews returns to the base (Banten) at 18:40-20:10 WIB.

The next process was to perform computations for the crew pairing model stage 2. This procedure took 20 seconds and generated a minimum number of sit time solutions, namely 620 minutes. The output (Table 3) shows the same number of crew pairings as Table 2, but the composition of the crew pairings was different.

Table 3. The Results of Stage 2 Crew Pairing Analysis

Crew Pairing 1	**Leg**	**11**	**24**	**8**	**18**	
	Flight Number	**322**	**327**	**420**	**4012**	
	Route	CGK-SUB	SUB-CGK	CGK-DPS	DPS-CGK	
	Travel Time	11:10-12:50	13:35-15:10	16:30-18:30	19:15-21:15	
Crew Pairing 2	**Leg**	**3**	**13**	**12**	**25**	
	Flight Number	**400**	**407**	**312**	**317**	
	Route	CGK-DPS	DPS-CGK	CGK-SUB	SUB-CGK	
	Travel Time	08:00-10:00	11:00-13:05	13:30-15:10	16:30-18:00	
Crew Pairing 3	**Leg**	**2**	**19**	**21**	**16**	
	Flight Number	**402**	**7036**	**7037**	**403**	
	Route	CGK-DPS	DPS-LBJ	LBJ-DPS	DPS-CGK	
	Travel Time	07:15-09:10	10:45-12:00	13:00-14:15	15:20-17:25	
Crew Pairing 4	**Leg**	**7**	**17**			
	Flight Number	**410**	**417**			
	Route	CGK-DPS	DPS-CGK			
	Travel Time	14:25-16:20	17:40-19:45			
Crew Pairing 5	**Leg**	**9**	**22**	**5**	**15**	
	Flight Number	**306**	**311**	**408**	**411**	
	Route	CGK-SUB	SUB-CGK	CGK-DPS	DPS-CGK	
	Travel Time	07:05-08:45	09:30-11:05	11:30-13:35	14:55-17:00	
Crew Pairing 6	**Leg**	**10**	**23**	**6**	**20**	**26**
	Flight Number	**316**	**321**	**414**	**349**	**325**
	Route	CGK-SUB	SUB-CGK	CGK-DPS	DPS-SUB	SUB-CGK
	Travel Time	08:35-10:15	11:00-12:35	13:00-15:00	15:50-17:05	18:40-20:10
Crew Pairing 7	**Leg**	**4**	**14**			
	Flight Number	**404**	**409**			
	Route	CGK-DPS	DPS-CGK			
	Travel Time	09:25-11:20	12:30-14:25			

Source: output of LINGO 19.0, 2022

The crew pairing generated from the computational process also provides an overview of the service time by the crew for each crew pairing (Figure 1). The numbers in colors indicate the time, where green represents briefing time, blue represents flying time, orange represents ground time, yellow represents sit time, and red indicates debriefing time. Other legends are dotted arrows that indicate activities at the same airport and solid arrows that indicate flights from the origin airport to the destination airport. The arrow colors have the same meaning as those for crew service activities.

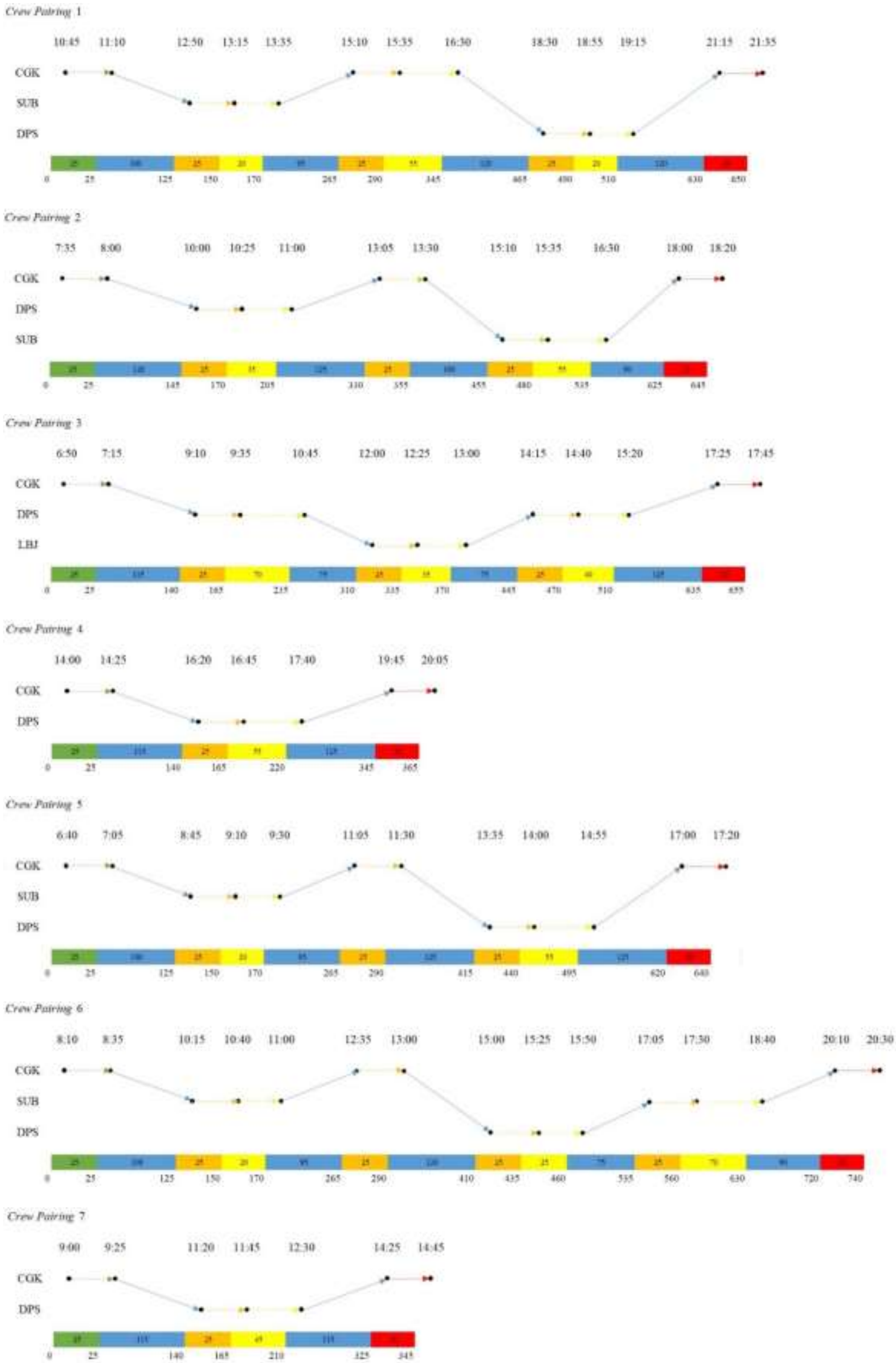

Figure 1. Time Windows for Each Crew Pairing

Crew Pairing 6 for example, the crews begin their duties by attending briefing at the crew base for 25 minutes. The crews serve leg 10 for 100 minutes while the aircraft is in the air. After landing, they need time to leave the plane (ground time), which is 25 minutes. They then wait for 20 minutes before continuing their service on leg 23 for 95 minutes plus 25 minutes to leave the aircraft. The crews do not need to wait to serve leg 6. They serve leg 6 for 120 minutes plus 25 minutes ground time. After waiting for 25 minutes, they continue on leg 20 for 75 minutes and 25 minutes to leave the aircraft. After waiting for 1 hour and 10 minutes, they serve the last leg, i.e. leg 26, for 90 minutes to return to base. The crews end their duties at the crew base for the day by participating in a 20-minute debriefing. Thus, the total crew service time in Crew Pairing 6 is 740 minutes. This means the crew pairing serving maximum number of legs on that day does not exceed the maximum service time, which is 14 hours (840 minutes). In addition, the total flying time for crew pairing is exactly 480 minutes (8 hours), which is the maximum total flying time for one day. The average total service time for all crew pairings is 577.15 (rounded) or around 9 hours 37 minutes 9 seconds; with the longest total service time for the crews on Crew Pairing 6 (as previously explained) and the shortest total service time is for the crews on Crew Pairing 7 (345 minutes or 5 hours 45 minutes).

Based on the comparison on the time windows for each crew pairing, the longest sit time is for Crew Pairing 3 and 6 (70 minutes). The longest time is when the crews wait for flight to East Nusa Tenggara (for Crew Pairing 3) from Bali and flight to Banten (for Crew Pairing 6) from East Java. Figure 1 also indicate that there are crew pairings with no sit time between one leg and the next leg, namely Crew Pairing 2, 5, and 6. Crew Pairing 5 and 6 in particular have similar pattern, where after the aircraft from East Java lands in Banten and the crews' ground time is over, the aircraft immediately take off for Bali. Based on these results, the two flights possibly use the same fleet, and in the 25 minutes ground time, the crews do not get off the aircraft, but remain on board to prepare for the next flight. On the other hand, on Crew Pairing 2, there is no sit time for the crews after landing in Banten from Bali where the next destination is to East Java.

The calculation of each total service time in this study proves Iacus *et al.* (2020) statement that crews, especially they on Crew Pairing 6, work with an extremely busy schedule, because they carry out their activities in maximum flying time. In addition, the discussion of sit time also implies a busy schedule because the crews immediately prepare for the next flight after landing, even though there is a minimum sit time of 10 minutes (Bazargan, 2010). However, if these two flights use the same fleet, then no rules are violated because there is still a 25-minute gap usually used by the crews to disembark and change aircraft.

Meanwhile, compared to other pairings, in Crew Pairing 4 and 7, each crew only serves two flight routes, i.e. CGK-DPS and DPS-CGK, indicating a remaining service time from 8 hours-max. However, if the analysis is extended to flight schedules for one week, there is a possibility that the crews in these pairings serve other flight routes (beyond the data showed in Table 1) before the service time starts on the date in this study (for Crew Pairing 4) and after the service time is over (for Crew Pairing 7).

Crew pairings in this study can only be applied if the flight schedule repeats every day. However, if the flights are different every day of the week but repeated for the following week, then the basic model can be adjusted by removing the assumption that crew pairing starts and ends at the crew base on the same day, meaning the condition in which the crews have to spend the night at the airport other than the crew base can be included in the analysis. However, the record time used is multiplied by 24 hours for 7 days and on the 7th day, the last flight must return to the crew base.

Conclusion

Based on the study results, the minimum number of crew pairings to serve 11 flights on 10 October 2022, from Soekarno-Hatta International Airport to Bali I Gusti Ngurah Rai Airport (7 flights) and Juanda International Airport (4 flights) are 7 crew pairings. The minimum total sit time for crews at the airport before serving the next flight is 620 minutes, with the longest sit time between flight routes is 70 minutes (1 hour 10 minutes), and there are 3 crew pairings with no sit time on one of the flight routes they serve. The results of the analysis cannot be applied to flight plans in the following days if the airline's schedule is not the same every day or the schedule on this date is not repeated.

This study also shows that there are crews working with an extremely tight schedules and crews that only serve two flight routes a day. It is necessary to study the crew rostering with the assumption that the schedule repeats every day or is the same in the following week, to analyze whether the crews will work alternately on such a busy schedule.

Acknowledgement

This research was funded by the Directorate Academic of Strengthening for Vocational Higher Education, the Ministry of Education, Culture, Research, and Technology.

References

Badan Pengembangan dan Pembinaan Bahasa. 2016. KBBI Daring. https://kbbi.kemdikbud.go.id. 25 November 2021 (10.00).

Bazargan M. 2010. *Airports Operations and Scheduling*. Ed ke-2. Ashgate. Burlington.

FlightAware. 2022. Search for Flights by Origin and Destination Airport. https://flightaware.com. 10 Oktober 2022 (08.00).

Iacus, S.M., Natale, F., Santamaria, C., Spyratos, S., Vespe, M. 2020. Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. *Safety Science*, pp. 1-13, May 6.

Nasution, D.A.D., Erlina, dan Muda, I. 2020. Dampak pandemi COVID-19 terhadap perekonomian Indonesia. *Jurnal Benefita*, pp. 212-224, Juli 4.

Kartiko, N.D. Insentif pajak dalam merespons dampak pandemi COVID-19 pada sektor pariwisata. 2020. *Jurnal Pajak dan Keuangan Negara*, pp. 124-137, September 30.

Siang, J.J. *Riset Operasi dalam Pendekatan Algoritmis*. 2014. Ed ke-2. Penerbit Andi. Yogyakarta.

Suau-Sanchez, P., Voltes-Dorta, A., Cuguero-Escofet, N. 2020. An early assessment of the impact of COVID-19 on air transport: just another crisis or the end of aviation as we know it? *Journal of Transport Geography*, pp. 1-8, June 4.

Sun, X., Wandelt, S., Zheng, C., Zhang, A. 2021. COVID-19 pandemic and air transportation: successfully navigating the paper hurricane. *Journal of Air Transport Management*, pp. 1-13, April 14.

Taha, H.A. *Riset Operasi*. 1996. Jilid ke-1. Daniel Wirajaya, penerjemah. Binarupa Aksara. Jakarta.

Vargas, M.A., Walteros, J.L., Medaglia, A.L. 2009. Hybrid approach to airline crew pairing optimization for small carriers. *Proc IIE Annual Conference Institute of Industrial and Systems Engineers (IISE) Norcross*, pp. 1327-1332, December 26-27.

World Health Organization. 2020. WHO Director-General’s Opening Remarks at the Media Briefing on COVID-19 - 11 Maret 2020. *https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020*. 25 November 2021 (09.00).