MODELLING AND OPTIMIZATION OF AIRCRAFT TURNAROUND TIME AT AN AIRPORT

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Gate-to-gate punctuality has long been the operational goal of the air transport industry. In this paper, an analytical model is proposed to simulate the efficiency of aircraft turnaround operations at airports. Scenarios for different aircraft punctuality performance have been modelled and tested. The concept of scheduling buffer time into the ground time of aircraft turnaround operations is introduced in the model at the expense of reducing aircraft productivity to minimize system costs from operational uncertainties. Stochastic functions are employed to simulate the inbound punctuality of arrival aircraft in order to take into account the punctuality uncertainties from the operation of flight schedules. Flight data from a European carrier is used to validate the model. Analyses show that the proper use of schedule buffer time in aircraft turnaround time can minimize system costs by balancing trade-offs between schedule punctuality and aircraft utilization.

Keywords: Schedule punctuality, Aircraft turnaround operations, Stochastic models

1. INTRODUCTION

As air transport demand keeps growing, flight delays in the global air transport system increase. According to delay statistics reported by Eurocontrol, 19.5\% (i.e. 7.5 million flights) of intra-Europe flights were delayed by more than 15 min in 1997 [1]. A study carried out by
London Gatwick Airport showed that 30% of flights during the survey period were delayed due to Air Traffic Control (ATC) related causes, in which 10% of flights were delayed by more than 20 min [2]. Among the causes investigated, ground handling and aircraft turnaround related delays were the second largest group of reasons causing flight delays. Airline operational problems accounted for 25% of total delayed flights, in which 15% of delayed flights were delayed by more than 20 min.

When airspace and airport capacity become restricted due to increasing transport demands, flight delays might escalate in the air transport system. Consequently, both passengers and airlines may suffer excessive delay costs. However, it is difficult for the airline industry to improve the airspace and airport capacity. The most effective way for airlines to cope with the problem of reducing and managing delays is to improve schedule reliability and ground service capability by scheduling buffer time in flight schedules. A project by Austrian Airlines showed that the true cost of departure delays could be very high in terms of direct costs, customer disloyalty and network quality costs [3]. An empirical study has also showed that more schedule time has been included in flight schedules in the past decades because of increasing punctuality uncertainties due to restricted airport and airspace capacity [4]. Even though schedule punctuality performance has been a focus for airlines for many years, potential advantages gained from improving the reliability of flight schedules are still not yet clear for the airline industry.

A review of the literature has shown that the aircraft turnaround problem (ATP) has been studied typically using Critical Path Method (CPM) to simulate the turnaround process of an aircraft [5]. The CPM was used to model the aircraft turnaround process and to identify elements along the critical flows of aircraft turnaround activities. More recently, the stochastic gate occupancy time of aircraft has been discussed by Hassounah and Steuart [6]. It was shown from empirical data that the departure lateness of an aircraft had a significant relationship with buffer lateness of an arrival aircraft. Buffer lateness was defined as the delay time which cannot be absorbed by planned schedule buffer time. It was observed that the arrival lateness did not necessarily result in departure delays, unless arrival delay was longer than the scheduled buffer time in turnaround schedules.

The scheduling of aircraft turnarounds is a consequence of both the operational policies and the scheduling strategies of an airline. For instance, Southwest Airlines in the USA showed a low average aircraft
turn time of 17 min and United Airlines an average turn time of 50 min [7]. However, connecting passengers of Southwest Airlines accounted for only 12% of total boarding passengers, compared with United Airline’s 41%. In Europe, the policy of using longer turnaround times at the base airport has been adopted by European non-hubbing carriers. Though there is a longer turnaround time at major airports, which do not have a large hubbing content such as in a US hub, European airlines have a similar utilization of airport gates due to a shorter time between gate occupancy [8].

The significance of turnaround punctuality is not only to reduce delays when turning around an aircraft, but more importantly to maintain the linkage and stability of aircraft rotations [9]. The advantages of maintaining a high turnaround punctuality and reliability are to improve schedule punctuality, to utilize aircraft fleet, to minimize operational disturbance at terminals, and to maximize the utilization of airline resources. This issue becomes even more significant when the emphasis is put on maintaining the gate-to-gate punctuality in the air transport system.

Trade-off conditions occur when airlines try to optimize aircraft rotation schedules. When more ground time is scheduled into aircraft turnaround time, departure delays will be absorbed, but airlines will lose aircraft utilization by employing potential flight hours as a punctuality buffer. The aim of this paper is to investigate the methodology of scheduling turnaround time of an aircraft in order to minimize delay costs from both passengers and air carriers. The development of the proposed model is given in Section 2 with simulation results and case studies of the proposed aircraft turnaround model shown in Section 3. Conclusions and suggestions are presented in Section 4.

2. MODEL DEVELOPMENT

The ‘turnaround’ of an aircraft is defined as the ground operation process to service an aircraft from the ‘on-chock’ time at an airport gate to the ‘off-chock’ time. It is assumed in this paper that the departure time (denoted by $s$) of a turnaround aircraft is influenced mainly by the arrival time of inbound aircraft (denoted by $t$), the turnaround service efficiency (denoted by $m_2$), and the schedule buffer time (denoted by $T$) included in the scheduled turnaround time. The arrival time of the inbound aircraft ($t$) is formulated by probability density functions (PDFs), which describe the schedule punctuality
uncertainties of inbound aircraft. Delays due to occasional ground service disruptions and passenger lateness are not considered individually in this model.

The symbols and variables used in the modelling of aircraft turnaround are summarized as follows:

- \( \alpha \): weight factor, which varies between 0 and 1
- \( C_{AC} \): aircraft delay cost
- \( C_{AL} \): schedule time opportunity cost of a turnaround aircraft
- \( c_{AC}(s) \): marginal delay cost function of an aircraft
- \( c_{AL}(T - T_A) \): marginal schedule time cost function of an airline
- \( c_{p}(s) \): marginal delay cost function of on-board passengers
- \( C_D \): expected departure delay cost of a turnaround aircraft
- \( C_p \): passenger delay cost
- \( C_T \): system cost
- \( C_d \): departure delay cost
- \( f(t) \): arrival time PDF of a turnaround aircraft
- \( g(s) \): departure time PDF of a turnaround aircraft
- \( m_1 \): delay absorption capability of schedule buffer time
- \( m_2 \): turnaround service performance
- \( STA \): scheduled time of arrival of a turnaround aircraft
- \( STD \): scheduled time of departure of a turnaround aircraft
- \( T_{ST} \): scheduled turnaround time of a turnaround aircraft
- \( T \): schedule buffer time
- \( T_G \): mean ground service time of a turnaround aircraft

2.1. Delay of a Turnaround Aircraft

The scheduled turnaround time (denoted by \( T_{ST} \)) of an aircraft is usually composed of two parts: the schedule buffer time (if any) (denoted by \( T \)) and the mean ground service time (denoted by \( T_G \)). It can be expressed by Eq. (1). The scheduled time of departure (\( STD \)) of a turnaround aircraft is therefore the time after the scheduled time of arrival (\( STA \)) and the scheduled turnaround time (\( T_{ST} \)). The relationship between \( STA \) and \( STD \) is represented by Eq. (2):

\[
T_{ST} = T + T_G \quad \text{(1)}
\]

\[
STD = STA + T_{ST} \quad \text{(2)}
\]

The schedule buffer time is used to absorb arrival delays, unexpected departure delays due to ground handling disruptions and to accommo-
date inevitable time gaps in flight schedules. The mean ground service time represents the standard service time for ground handling agents to complete operational procedures to turn around an aircraft for a following flight. Due to the complexity of aircraft turnaround procedures, delays to turnaround aircraft may be caused by many factors such as ground handling equipment serviceability, passenger delays and aircraft arrival delays. Therefore, the departure punctuality of a turnaround aircraft is consequently influenced by the reliability of ground services as well as unexpected up-stream flight delays, which propagate along aircraft rotations.

The development mechanism of aircraft departure delay is illustrated in Fig. 1. If the aircraft arrival delay \( t \) is shorter than the schedule buffer time \( T \), arrival delay will be partially or fully absorbed by the schedule buffer time. The delay absorption capability of schedule buffer time is denoted by \( m_t \), that is, the slope of the former portion of the delay time development curve as demonstrated in Fig. 1. When the arrival delay is longer than the buffer time \( T \), the corresponding departure delay may develop in three scenarios. First, as indicated by curve \( f_2 \) in Fig. 1, departure delays may develop in a linear proportion to arrival delays, no matter how long the arrival delay. Second, following curve \( f_3 \), ground handling agents may be able to ensure a punctual departure and consequently departure delays do not escalate with the increase of arrival delays. Third, curve \( f_1 \) represents a typical curve, when ground operation is further disturbed by late arrivals through late transfer passengers, late passenger check-in, late baggage handling, and disruptions in ground operational plans.

The slope of the curve (denoted by \( m_2 \)) after the turnaround buffer time \( T \) is defined as ground service performance – that is, the ground handling agent’s capability to respond to schedule perturbations. When the value of \( m_2 \) is less than or equal to unity, departure delays develop at a lower rate such as curve \( f_2 \) and \( f_3 \) in Fig. 1. If \( m_2 \) is greater than one, it means that turnaround operations are disturbed by operational disorders, therefore ground operations will need more time to complete. Consequently, turnaround aircraft suffer delays due to arrival lateness as well as turnaround operational disturbance.

One of the responsibilities of airline dispatchers at airport terminals is to deliver punctual flights. If at time \( t \) (shown in Fig. 1) the airline terminal dispatcher takes actions to reduce departure delay of a turnaround aircraft, the curve \( f_1 \) might change to \( f_3 \). As a consequence, a shorter departure delay and the decrease of potential knock-on delays
in aircraft rotations may be achieved. Nevertheless, operating costs of an airline may increase in this way [10].

2.2. Modelling Aircraft Turnarounds

The aircraft turnaround model presented here describes the development of turnaround delays during ground service operations. The departure time of a turnaround aircraft is modelled by the schedule buffer time \( T \) and the ground service performance of ground service agents \( (m_t) \), and illustrated in Fig. 2. It is assumed in this model that if there is no schedule buffer time (thus \( T = T_A \)), departure delay develops as curve A illustrated in Fig. 2. If the schedule buffer time is as long as the maximum limit \( (T_{max}, \text{ where 100\% of flights arrive within the schedule buffer time}) \), departure delay develops according to curve C. In between these extreme cases, ground services with a scheduled ground time \( (T_G) \) and a buffer \( (T) \) exhibit a turnaround performance curve as curve B. For any given buffer time \( T \), there will be a corresponding performance curve, which represents the ground service performance under the given schedule buffer time.

It is assumed that the value of \( m_t \) is a function of schedule buffer time \( (T) \) and ground service performance \( (m_2) \), which represents the operational efficiency of a ground handling agent in dealing with delays. Logically, a longer buffer time results in a smoother curve slope – that is, a better arrival delay absorption ability for turnaround buffer time. Therefore, the relationship between the delay absorption capability \( (m_t) \), the schedule buffer time \( (T) \) and the ground service
performance \((m_2)\) is modelled by a piecewise linear function represented by Eq. (3) and illustrated by Fig. 2:

\[
m_1 = f(T, m_2) = \left(\frac{m_2}{T_{\text{max}} - T_A}\right)^*\left(T_{\text{max}} - T\right) \quad T_A \leq T \leq T_{\text{max}}
\]

where \(T_A\) is the STA of a turnaround aircraft; \(T_{\text{max}}\) is the maximum buffer time to absorb 100% of inbound delays.

Hence, the departure time \(s\) of a turnaround aircraft is formulated as a function of the arrival time of inbound aircraft \(t\), the schedule buffer time \(T\) and ground service performance \((m_1\) and \(m_2\)). The departure time of a turnaround aircraft \(s\) is represented by Eqs (4) and (5). Using these equations, we are able to model departure delays of turnaround aircraft with respect to schedule buffer time \(T\) and ground service performance \(m_2\):

\[
s = m_1^*(t - T_A) \quad T_A \leq t \leq T_{\text{max}}
\]

\[
s = m_1^*(T - T_A) + m_2^*(t - T) \quad T < t \leq T_{\text{max}}
\]

where \(m_1 = \left(\frac{m_2}{T_{\text{max}} - T_A}\right)^*(T_{\text{max}} - T)\) \(T_A \leq T \leq T_{\text{max}}\)

2.3. Delay Costs

When an aircraft is delayed, both the airline and passengers suffer delay costs. The airline loses aircraft productivity due to excessive delay time and incurs higher operational costs. Passengers suffer delays and lose the value of delay time. There are other costs associated with compensation and loss of goodwill of passengers, but these are not considered here. In this paper, departure delay costs \(C_d\)
include aircraft delay cost \( C_{Ac} \) and passenger delay cost \( C_p \), which is expressed by Eqs (6), (7) and (8):

\[
C_d(s) = C_{Ac}(s) + C_p(s)  \tag{6}
\]

\[
C_{Ac}(S) = \int c_{Ac}^m(s) ds  \tag{7}
\]

where \( c_{Ac}^m(s) \) is the marginal delay cost function of an aircraft:

\[
C_p(s) = \int c_p^m(s) ds  \tag{8}
\]

where \( c_p^m(s) \) is the marginal delay cost function of on-board passengers.

\( C_{Ac}(s) \) is the delay cost function of an aircraft, which includes aircraft operating expenses, flight crew costs, and extra gate occupancy charges. The aircraft delay cost is formulated by a marginal delay cost function \( c_{Ac}^m(s) \). \( C_p(s) \) is the delay cost function of passengers who are on-board the delayed aircraft. The passenger delay cost is represented by a marginal delay cost function \( c_p^m(s) \) in Eq. (8). Although the cost functions outlined earlier can take a variety of forms [11], it is assumed in this model that the marginal delay costs of on-board passengers and aircraft are constant. It means that cost functions such as \( C_{Ac}(s) \) and \( C_p(s) \) become linear after integrating the marginal cost functions in Eqs (7) and (8).

To increase aircraft productivity, airlines try to shorten the ground service time as much as they can to keep aircraft in the air to earn revenues. However, a trade-off condition occurs when a shorter schedule buffer time risks a higher probability of delayed turnaround departures, while on the other hand a longer schedule buffer time reduces aircraft productivity. Therefore, the opportunity cost of airline schedule time is formulated by Eq. (9) to represent the cost for an airline to include schedule buffer time in aircraft turnaround schedules. As can be seen in Eq. (9), the airline schedule time cost is the integration of the marginal schedule time cost function, which is denoted by \( c_{Al}^m(T - T_A) \):

\[
C_{Al}(T) = \int c_{Al}^m(T - T_A) dT  \tag{9}
\]

where \( c_{Al}^m(T - T_A) \) is the marginal schedule time cost function of an airline.

The marginal schedule time cost function \( c_{Al}^m(T - T_A) \) is assumed in this model to be a linear function. Hence the opportunity schedule time cost function \( C_{Al}(T) \) becomes a quadratic one. It is understood from current evidence in the airline industry that the schedule time oppor-
tunity cost increases when saved schedule time is sufficiently long for an aircraft to carry out another flight and earn additional revenues. Therefore, the total schedule time cost function is formulated by a quadratic function to represent current conditions.

2.4. System Costs

The inbound arrival time of a turnaround aircraft \( t \) is modelled by stochastic PDFs to simulate uncertainties of aircraft arrival time. The turnaround operation of an aircraft is expressed by Eqs (4) and (5). Hence, the departure time distribution of a turnaround aircraft (denoted by \( g(s) \)) becomes a continuous function derived from the aircraft arrival time distribution \( f(t) \), schedule buffer time \( T \) and ground service performance \( m_2 \). It is expressed in Eq. (10) and illustrated in Fig. 3:

\[
g(s) = F[f(t), T, m_2] | J_s |
\]  

(10)

where \( J_s = dt/\partial s \) Jacobian of variable transformations between \( s \) and \( t \).

Therefore, the expected departure delay cost \( C_D \) of a turnaround aircraft can be formulated by Eq. (11):

\[
C_D = E[C_u(s)] = \int C_u(s)g(s)ds
\]  

(11)

In this model, the trade-off condition between the airline schedule time cost \( C_{AL} \) and the expected delay cost \( C_D \) is modelled by a weight factor \( \alpha \), which varies between 0 and 1 as shown in Eq. (12). Hence, the system cost \( C_T \) incurred in the operation of a turnaround aircraft is formulated analytically in Eq. (12). Eq. (12) becomes Eq. (13) when \( C_D \) and \( C_{AL} \) are substituted by Eqs (11) and (9):

\[
C_T = \alpha C_D + (1 - \alpha) C_{AL}
\]  

(12)
\[ C_T = \alpha \int C_c(s) g(s) ds + (-\alpha) \int c_r(s) (T - T_A) dT \]  
(13)

Therefore, the objective function of the aircraft turnaround model can be summarized as follows:

Minimize \( C_T \):

\[ C_T = \alpha C_D + (1 - \alpha) C_M \]  
(14)

where:

\[ 0 \leq \alpha \leq 1 \]  
(15)

\[ C_D = E[C_c(s)] = \int C_c(s) g(s) ds \]  
(16)

\[ C_c(s) = C_{AC}(s) + C_p(s) \]  
(17)

\[ C_M(T) = \int c_r(T - T_A) dT \]  
(18)

\[ g(s) = F[f(t), T, m_s] \]  
(19)

\[ s = m_1(t - T_A) \quad T_A \leq t \leq T \]  
(20)

\[ s = m_1(T - T_A) + m_2(t - T) \quad T < t \leq T_{\text{max}} \]  
(21)

where:  
\[ m_1 = (m_2T_{\text{max}} - T_A)/(T_{\text{max}} - T) \quad T_A \leq T \leq T_{\text{max}} \]

3. RESULTS

3.1. Optimization of Schedule Buffer Time

With respect to the STA of an inbound aircraft, there are mainly three categories of arrival patterns, namely early arrivals, quasi-normal arrivals and late arrivals. A graphical illustration of three aircraft arrival patterns is given in Fig. 4. The Beta function was arbitrarily selected in this paper to simulate arrival patterns of inbound aircraft \( f(t) \) in Eq. (19)) because of its analytical tractability. Due to the analytical difficulty of solving the objective Eq. (14), MATLAB mathematical software was used to carry out integration and numerical calculations.

A Beta(3,10) distribution was selected to simulate an early arrival pattern having a STA of 10 min with respect to the arrival time domain of 1 h (shown in Fig. 4). 90% of flights arrive within 24 min in Beta(3,10) arrivals as shown in Fig. 5. In other words, in this case 90% of flights arrive within a 14 min delay time and 30% of flights arrive punctually. A Beta(10,10) was used to represent a quasi-normal case of arrivals with a STA of 30 minutes and 55% of punctual arrivals as shown in Figure 4. 90% of flights arrive within a delay of 10 min in the Beta (10,10) case. A Beta(10,3) was used to represent a late arrival pattern with a STA of 40 min, and had only 20% flight punctuality.
The values of the parameters used in the numerical studies in this paper were derived from published financial data by International Civil Aviation Organisation (ICAO) and given in Table I [12, 13]. British Airways (BA) and bmi/British Midland (BD) were chosen to be case study airlines to represent long-haul and short-haul dominated airlines respectively. However, the parameter values given in Table I should not be taken to represent the real values of specific airlines due to the unavailability of detailed financial information. However, the simplification in the use of parameter values in the turnaround model does not impair the performance of the model, as proper parameters can be easily derived once detailed information is available for analyses. The

<table>
<thead>
<tr>
<th>Parameter values used in case studies</th>
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<tr>
<td>$C_{AC}$</td>
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<tr>
<td>Aircraft operating costs ($/hr$)</td>
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<tr>
<td>--------------------------------------</td>
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<tr>
<td>British Airways¹ (BA)</td>
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<tr>
<td>British Midland² (BD)</td>
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Notes: ¹Average aircraft size for BA European flights is selected to be 200 seats with an average load factor of 0.7. The average hourly wage rate of British passengers is estimated to be $42 per hour (Wu and Caves, 2000) [13].

²Average aircraft size for BD is selected to be 150 seats with an average load factor of 0.65 (Wu and Caves, 2000) [13].
calculation of passenger delay cost was based on the average hourly wage of British passengers according to an air passenger survey by the UK Civil Aviation Authority [14].

From numerical analyses using Beta(3,10) arrivals in the BA case, the expected delay cost, which is denoted by 'BA-Cu' in Fig. 6,

![Diagram](image)

**FIGURE 5** Cumulative arrival punctuality performance for Beta functions.

![Diagram](image)

**FIGURE 6** Cost curves of Beta(3,10) arrivals in BA and BD examples.
decreases as schedule buffer time increases. On the other hand, the schedule time opportunity cost, denoted by ‘BA-Cal’, increases sharply as the use of buffer time increases. Therefore, it can be observed from Fig. 6 that the minimum system cost, denoted by ‘BA-CT’, occurs when the optimum schedule buffer time is set to be 10 min. Compared with the BA example, flights with a Beta(3,10) distribution for bmi/British Midland (BD) exhibit a similar system cost curve. It can be seen from Fig. 6 that the optimum schedule buffer time for BD flights is also 10 min. Hence, if the mean ground service time of, for example, a Boeing B767 is 45 min, the scheduled turnaround time becomes 55 min, which includes 10 min schedule buffer time.

The cost curves shown in Fig. 6, however, are rather flat concave curves but growing sharply as the schedule buffer time increases. This is attributable to the conservative assumption of linear delay cost functions of passengers and quadratic schedule time cost functions of airlines. One can observed from Fig. 6 that the schedule time cost increases more significantly than the improvement of expected delay cost with the use of schedule buffer time. The implication of this observation validates the previous assumption that an airline is expected to save operational costs by optimising aircraft turnaround time. Also observed from Fig. 6 is that the expected delay cost from airlines and passengers (BA-Cu and BD-Cu in this case) is not as high as the one from airline’s schedule time opportunity cost (BA-Cal and BD-Cal). This result is due to rather small delay cost figures coming from low expected delay time of Beta(3,10) arrivals. As observed from Figs 4 and 5, the Beta(3,10) function is a right-tailed probabilistic function, which is used to represent an early arrival pattern with some occasional late arrivals.

Although Beta functions are analytically suitable for stochastic modelling in the aircraft turnaround model, it is not yet clear whether Beta functions are able to model the inbound arrival patterns of aircraft. As a consequence, real flight punctuality data from a European carrier were collected for three different routes to validate the use of Beta functions in modelling schedule punctuality performance. Fitted PDFs from flight data are shown in Fig. 7. PDFs were tested statistically using both the K-S test and $\chi^2$ goodness-of-fit test. Three different types of arrival patterns represent three different routes respectively. Domestic flights show a quasi-normal distribution of Beta(18,20). Short-haul international flights, on the other hand, exhibit a right-tailed arrival time distribution of Beta(4,14), which is similar to the Beta(3,10) previously chosen in this paper. Long-haul flights,
which exhibit a Beta(2,13) arrival pattern, are more punctual than short haul, because of a longer block time in the air.

Buttressed by empirical data analysis, a Beta(3,10) function is believed to be suitable to simulate a certain type of flight which is commonly observed from some international European short-haul flights. 30% of flights arrive punctually in this case when we set the STA to 10 min. The mean delay time in this case is 0.16 h (9.6 min) and 90% of flights arrive within a delay time of 15 min as shown in Fig. 4. In other words, the use of such a function like Beta(3,10) represents those flights with relatively good arrival punctuality, but a higher probability to have long arrival lateness. Hence, the expected delay cost curve shown in Fig. 6 shows a lower value compared with the cost curve of schedule buffer time because of the good punctuality of the Beta(3,10) case.

3.2. Influence of Aircraft Arrival Punctuality

It has been found from previous results that the punctuality performance of inbound aircraft influences the optimum of system costs. Hence, different punctuality scenarios of arriving aircraft were studied in order to investigate the influence of inbound aircraft punctuality on the use of schedule buffer time. When Beta(10,3) is used to model the PDF of inbound aircraft, the total expected delay cost is found to be
more significant than the Beta (3,10) case as shown in Fig. 8. Although there are only 20% of flights arriving punctually, 100% of flights arrive within 20 min and there are no long-delayed flights in this case. The mean delay time in the Beta(10,3) case is 0.23 h (13.8 min), and 80% of flights concentrate within a 20 min delay. As a consequence, the expected delay cost is higher than the one in Beta(3,10) case as shown in Fig. 8. The use of buffer time in the Beta(10,3) case is limited to 20 min because it is sufficient to accommodate 100% of arrivals. Therefore, it is observed from Fig. 8 that the optimum schedule buffer time for Beta(10,3) arrivals is 20 min, due to a relatively low schedule time cost when compared with a high expected delay cost from aircraft operations and passengers.

It is of interest here to compare results from a centrally distributed arrival pattern with the ones from skewed arrival PDFs. In addition, it might be argued that a normal or a quasi-normal distribution is more suitable to simulate the punctuality performance of a flight. Hence, the Beta(10,10) function is used to analyse the sensitivity of arrival punctuality of inbound aircraft on the departure punctuality of outbound aircraft. Results from BA and BD examples are shown in Fig. 9.

With equal weights to the punctuality performance and the schedule time cost in the objective function (where \( \alpha = 0.5 \)), the optimal schedule buffer time is about 10 min for both examples. The expected delay time is 0.09 h (6 min) due to 55% of flights arriving punctually and
almost 95% of flights arrive within a 10 min delay. In other words, Beta(10,10) represents a type of good punctuality performance in which aircraft arrive within a short period of delay with a relatively low possibility of having long arrival delays. This assumption is supported by results from empirical flight data analyses given in Fig. 7, which shows certain flights exhibit a similar arrival pattern.

Therefore, it is concluded that the use of schedule buffer time should depend on the individual punctuality performance of routes, as well as on the standard turnaround time requirement for aircraft. The improvement of arrival punctuality of inbound aircraft significantly influences the departure punctuality of turnaround aircraft.

### 3.3. Airline Scheduling Strategies

The trade-off between punctuality and turnaround time is generally well recognized in the airline industry. A weight factor ($\alpha$) is therefore introduced into the turnaround model (Eq. (14)) to represent this situation and set to 0.5 to balance the trade-off condition. When a higher value of $\alpha$ is chosen, the emphasis is put on expected delay costs, that is, the punctuality performance. A lower value of $\alpha$ puts the emphasis on an airline’s schedule time cost. The weight factor $\alpha$ also reflects the scheduling strategy of an airline.

For the Beta(3,10) cases for both BA and BD, the influence of different weights on punctuality and schedule time is shown in Fig. 10. It is observed that when $\alpha$ is set to have an effect on schedule punctuality performance, the required schedule buffer time becomes
FIGURE 10  Influence of airline scheduling strategy on the use of schedule buffer time.

higher than the equal-weight trade-off with a $\alpha$ value of 0.5. In contrast, when more concentration is required for a shorter ground time, the $\alpha$ value is chosen to be lower than 0.5 and, therefore, the required schedule buffer time is reduced as shown in Fig. 10.

Three different arrival patterns are investigated to find the influence of airline scheduling strategies on the use of schedule buffer time in

FIGURE 11  Requirements of schedule buffer time for different scheduling strategies of airlines.
aircraft turnarounds. Results are summarized in Fig. 11. It can be seen from the graph that more schedule buffer time is needed for the Beta(10,3) arrival case, due to relatively high delay costs. It is also observed in Fig. 11 that when the scheduling emphasis is put on the overall punctuality of turnarounds, a longer schedule buffer time is needed to achieve the system optimum.

Therefore, it can be concluded that the optimal schedule time for a turnaround aircraft depends on the arrival pattern of inbound aircraft as well as the scheduling strategy of an airline. When the expected delay cost is relatively lower than the operating cost of an airline, the airline might choose to minimize the turnaround time to reduce operating costs and to increase fleet productivity, exemplified for example by the Beta (10,10) and Beta (3,10) cases. However, when the schedule buffer time is available due to a low probability of having long-delayed flights, the airline could utilize the schedule buffer time to reach the system optimum without compromising punctuality performance, as per the Beta(10,3) case.

4. CONCLUSION

The robustness of the aircraft turnaround model proposed here has been demonstrated in this paper. Results show that the proper use of schedule buffer time is able to manage the punctuality performance of turnaround aircraft by minimizing system costs. The influence of the arrival punctuality of inbound aircraft is found to be significant on the departure punctuality of turnaround aircraft. It is found that the arrival time distribution of a turnaround aircraft influences the use of schedule buffer time. It is recommended, therefore, that the scheduling of turnaround aircraft should consider the individual punctuality performance of each route, and different schedule buffer time should be applied on different routes with different punctuality behaviour. The model proposed in this paper makes it possible for airlines to realise effects of aircraft turnaround efficiency on flight punctuality performance. Furthermore, the turnaround model facilitates the realisation of emphasis on the trade-off between flight punctuality performance and ground time for turnaround aircraft.

On the other hand, airports also benefit from the improvement of facility utilisation due to a superior management of aircraft operations on the ground. The advantage of the turnaround model comes from the
mathematical modelling of stochastic effects on aircraft ground operations. Due to the complexity of aircraft ground operations, the punctuality of flight schedules becomes so volatile that even minor improvements to the system can significantly ‘stabilize’ the whole system and improve the utilisation of current airport resources.

The success of a turnaround operation also depends on ground serviceability and most importantly depends on an airline’s determination to achieve its operational goals. Austrian Airlines and Lufthansa have both shown their determination to tackle the schedule punctuality problem due to increasing schedule delays in the European sky [3, 15]. The importance of schedule punctuality is not only for a single flight but, more significantly, for the overall operational profitability of an airline [16]. The improvement of schedule punctuality can help airlines reduce operating costs, and meanwhile improve airport facility utilisation. The improvement of gate-to-gate punctuality does not only aim to save airlines and passengers delay costs. More significantly, the improvement of aircraft turnaround efficiency will dramatically change the strategies of fleet rotation and utilization, when aircraft rotation reliability is optimized on a network scale.

References


