Impact of Stochastic Delays, Turnaround Time and Connection Time on Missed Connections at Low Cost Airports

Hasnain Ali, Yash Guleria, Sameer Alam and Vu N. Duong
Air Traffic Management Research Institute, Singapore

&

Michael Schultz
Dresden University of Technology (Ex-DLR), Germany

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Motivation: LCC’s Contribution to Traffic Growth

Annual aircraft departures and arrivals at Changi Airport, Singapore

- **2004**: 20% y-o-y increase
  - Tiger Air and Jet Star introduced in 2003/04

- **2011**: 15% y-o-y increase
  - Scoot Airlines introduced 2011

Year on year change (%)

Number of aircrafts

Year

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Motivation: Emergence of Low Cost Terminals

Characteristics of Budget/LCC terminals

‘No frill’ terminals: designed for
- reduced passenger transit time and
- quicker turnaround times (TAT) for aircraft.

Point-to-point networks with limited passenger connection visibility [Neufelli, 2008] Complete travel itineraries not known to the airport management or airlines which serve these passengers.
Q. How operational uncertainties at airports affect transfer passengers’ in the form of missed connections?

Factors affecting passenger connections at an airport:

**Arrival Delays:** Passenger-centric metrics are needed to see the full impacts of operational change as simple flight-centric metrics are insufficient. [Cook, 2015].

**Turnaround Time (TAT):** the period for which an aircraft occupies an apron or a gate position. It is crucial for airline schedule adherence and economic productivity [Schultz et. al., 2012]. LCC business model demands tighter TATs which may impact passenger connections.

**Minimum Connection Time (MCT):** refers to the required connection time to travel from one gate to another by combination of walking and using the available airport transportation facilities, such as people movers and moving walkways [Pternea & Haghani, 2019].
Optimal Assignment

4 hrs.

Turnaround time

1 month arrival ADS-B data

Delay Distribution

Arrival Delays

Flight schedule

Aircraft type and capacity

Number of Transfer passenger

Minimum connection time

Simulation of transfer passenger flows b/w flight pairs

Allocation of gates to flights

Minimize transit time for transfer passengers

Tabu search Heuristic

Missed connections

Legend

Data

Operation

Infrastructure

Critical variables

Computations

Output variable

Box

Box

Box
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Start

Input distance matrix

Input flight schedule

Generate passenger flow matrix

Apply Tabu search heuristic to minimize passenger transit time

Input arrival delays

Optimum gate assignments

Re-evaluate if passengers can reach departure gates in time.

Yes

Can flight connection be made?

No

Missed passenger connections+=Affected flight-pair passengers

Is every connection evaluated?

Yes

Stop

No
Generate Input Data

- Inter-gate distance matrix

- Flight schedule and occupancy

Layout of Terminal 4 at Changi airport

- Average occupancy based on Passenger load factor
  - 81.3% (ICAO 2017)

- Seating capacity based on aircraft type
  - FlightStats.com / Seatguru.com

- Arrival and Departure flight sequence
  - Changi Airport Website
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Start

- Input distance matrix
- Input flight schedule
- Generate passenger flow matrix
  - Apply Tabu search heuristic to minimize passenger transit time
  - Input arrival delays
  - Optimum gate assignments
    - Re-evaluate if passengers can reach departure gates in time.
      - Can flight connection be made?
        - Yes
          - Can flight connection be made?
            - Yes
              - Input arrival delays
              - Optimum gate assignments
            - No
              - Missed passenger connections+=Affected flight-pair passengers
        - No
          - Is every connection evaluated?
            - Yes
              - Stop
            - No
              - Re-evaluate if passengers can reach departure gates in time.
Transfer rate: 40 Percent

Model passenger flows in random bursts/groups

Poisson Distribution - probability of arrival passengers transferring to different available departure aircraft (connecting flights) in a given time period, given the expected number ($\lambda$) of transfers.

$$f(k, \lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$
Modelling Passenger flows

**Multinomial Distribution** - probability of arrival passengers transferring to different available departure aircraft (connecting flights) in a given time period, uniformly.

\[
P(X_1 = x_1, ..., X_n = x_n) = \frac{N!}{\prod_{i=1}^{n} x_i!} \prod_{i=1}^{n} \theta_i^{x_i} \quad \sum_{i=1}^{n} x_i = N \quad \sum_{i=1}^{n} \theta_i = 1
\]

**Model uniform passenger flows**

\[
\theta_i = \frac{1}{n_i} \quad \text{where } n_i \text{ refers to total number of available connecting flights for flight } i.
\]

**Model passenger flows based on aircraft size**

\[
\theta_i = \frac{C_i}{\sum_{i=1}^{n} C_i} \quad \text{where } C_i \text{ refers to seating capacity of flight } i
\]
Generate passenger flow matrix

Apply Tabu search heuristic to minimize passenger transit time

Input arrival delays

Optimum gate assignments

Re-evaluate if passengers can reach departure gates in time.

Can flight connection be made?

Yes

No

Missed passenger connections+=Affected flight-pair passengers

Is every connection evaluated?

Yes

No

Start

Input distance matrix

Input flight schedule

Stop

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Gate Assignment Formulation

Objective: \[ \min \ F = \sum \sum \sum \sum p_{i,e} \frac{d_{j,k}}{v_{avg}} x_{i,j} x_{e,k} \]

Where,
- \( d_{j,k} \) represents distance between gate \( j \) and \( k \)
- \( p_{i,e} \) represents flow of passengers from aircraft \( i \) to \( e \)
- \( v_{avg} \) represents average walking speed inside airport terminal

Constraints:

\[
(t_{i}^{out} - t_{i}^{in})(t_{e}^{out} - t_{e}^{in}) \leq M(2 - x_{i,j} - x_{e,k}) \quad \forall (i, e) \in f, i \neq e, \forall j \in g
\]

\[
\sum_{j \in g} x_{i,j} = 1 \quad \forall i \in f
\]

Where,
- \( t_{i}^{out} \) represents scheduled departure time of aircraft \( i \)
- \( t_{i}^{in} \) represents scheduled arrival time of aircraft \( i \)
- \( M \) is a very large number

\[ x_{i,j} \in 0, 1 \quad \forall i \in f, \forall j \in g \]
Start

Input distance matrix

Input flight schedule

Generate passenger flow matrix

Apply Tabu search heuristic to minimize passenger transit time

Input arrival delays

Optimum gate assignments

Re-evaluate if passengers can reach departure gates in time.

Yes

Can flight connection be made?

No

Missed passenger connections += Affected flight-pair passengers

Is every connection evaluated?

No

Yes

Stop
Arrival Delays

Arrival Delay* = Actual block-in time - Scheduled block-in time

*Source: ADS-B data with 13403 arrivals information to and from Singapore Changi airport, for the month of June-2016.
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Start → Input distance matrix → Input flight schedule → Generate passenger flow matrix → Apply Tabu search heuristic to minimize passenger transit time → Input arrival delays → Optimum gate assignments → Re-evaluate if passengers can reach departure gates in time.

- Yes: Can flight connection be made?
  - Yes: Stop
  - No: Missed passenger connections += Affected flight-pair passengers → Is every connection evaluated?
    - Yes: Stop
    - No: Yes

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Result: Impact of TAT and Arrival Delays on missed connections

Effect of turnaround time

- When the TATs increase, chances of passengers missing their connections gradually decrease.
- With higher TATs, aircraft stay longer on the ground and thus passengers find it easier to make connections.

Effect of arrival delays

- The most critical factor to decide missed connections.
- If the delays are contained within 70% of the current delay spread, the missed connection occurrences would reduce sharply.
Impact of MCT on missed connections

Effect of minimum connection time on missed connections

From the passenger point-of-view that in the present operational scenario, a minimum buffer time of 60 min must be ensured by passengers between connecting flights at Changi Airport terminal 4.
Missed Connection Hotspots

Using the present framework, passenger missed connection probability can be evaluated for gates that would service flights with known delay history.

Missed connection sensitivity of Terminal 4 arrival gates at Changi Airport for the flight scheduled on 8-Feb-2018
Conclusion

- Making TATs more aggressive leads to higher airline productivity, but it may also mean higher passenger missed connections, especially when the connections are tight (low MCT).

- By increasing minimum connection time, passengers (on average) shall wait longer at an airport, but this may come at the benefit of lesser missed connections.

- By restricting arrival delays, the chances of missed connections can be significantly reduced.

- For Changi airport Terminal-4, by maintaining the flight turn around time at ~50 min, minimum connection time at ~60 min and by containing arrival delays within 70% of the current delay spread, transfer passenger missed connections can be prevented for almost all the flights.

- The proposed framework and methodology are generic and can be applied to any budget terminal/airport to gain valuable insights for airport operation managers and LCC airlines for better schedule coordination and passenger-centric operations.
Summary

- Transfer passenger-centric analysis of missed connections

- 3 variables that affect passenger itineraries:
  - turnaround times
  - minimum connection times
  - stochastic arrival delays

- Case study: Singapore Changi Airport budget Terminal (Terminal 4), considering an optimum gate assignment of flights based on a Tabu search heuristic method.

- By increasing turnaround time and minimum connection time and by reducing delays, the chances of missed connections can be significantly reduced.
Selected References


