Improvement of Pushback Time Assignment via Stochastic Optimization

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Background (1)

- Aviation growth causes airport congestions.
  - Runways are bottlenecks.
  - Departure and arrival aircraft wait in long queues.
    - A departure aircraft queue is relatively easy to control.
- Pushback time control management (called TSAT operation: Target Start-up Approved Time) is promising.
  - Benefit
    - Reduce taxi-out time (wait at the spot) ➔ save fuel
  - Disadvantage
    - Not investigated and discussed thoroughly yet…

Target pushback time (TSAT) is assigned.
• Possible disadvantage of TSAT operation is…
  – Take-off time delay due to uncertainty

*All aircraft are assumed to be ready for pushback at 06:00.*
• Optimal airport operation should be decided considering both pros and cons
  ➔ This research focuses on the “real” optimal airport operation.
    – How much delay is caused by uncertainty?
• Evaluation:
  – Stochastic airport operation simulation model is developed.
    ➔ Previous research (briefly explained later)
  – TSAT assignment algorithm is developed.
    ➔ Main topic of this presentation
Target Airport

- Tokyo International Airport (Haneda Airport)
  - The busiest airport in Japan with more than 1,000 take-offs and landings per day.
  - 4 intersecting runways.
    - Runway dependencies exist.
  - A trial of TSAT operation started in 2013.
Departure Aircraft Operation Flow

- Pilot contacts clearance delivery
  - Departure clearance
  - Door close
  - Pushback clearance

- Pushback start
- Pushback finish

- Start taxiing
- Ready for take-off if there is no congestion

- Take-off

FCFS basis calculation (take-off & landing separation is stochastically distributed considering wake turbulence category & runway intersection effects)

Taxiing time vs. Taxiing distance

Regression line + normal distribution or Erlang distribution
• Runway sequencing system
  - Take-offs/Landings are sequenced in advance based on the estimated RWY arrival time.
• TSAT assignment system ← Focus of this research
  - TSAT is assigned to each aircraft based on the runway sequence.
Pre-Departure Runway Sequencing System

- Based on ETOT (Estimated Take-Off Time), departure sequence is determined in advance by a virtual queue.
  - The aircraft is ordered by ETOT.
  - Priority to landing aircraft based on ELDT (Estimated Landing Time).
  - Runway sequence is updated every minute.

Virtual runway queue

<table>
<thead>
<tr>
<th>Time</th>
<th>Callsign (ETOT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06:00</td>
<td><strong>XXX1 (06:00)</strong> → <strong>XXX1 (06:03)</strong></td>
</tr>
<tr>
<td>06:02</td>
<td><strong>YYY1 (06:02)</strong></td>
</tr>
<tr>
<td>06:04</td>
<td><strong>XXX2 (06:02)</strong></td>
</tr>
<tr>
<td>06:06</td>
<td><strong>XXX1 (06:03)</strong></td>
</tr>
<tr>
<td>06:08</td>
<td></td>
</tr>
<tr>
<td>06:10</td>
<td></td>
</tr>
<tr>
<td>06:12</td>
<td></td>
</tr>
</tbody>
</table>

**Departure aircraft**

**Landing aircraft**
• TSAT assignment is the same as the buffer assignment to each aircraft.
• The straightforward buffer assignment is “constant buffer” strategy.
  – The assigned constant “buffer” corresponds to the maximum uncertainty considered.

VTT: Variable Taxi Time
Problem Formulation

- The best buffer should be obtained under the current situation.
  - The best strategy should maximize the following objective function.
    \[ r = \Delta t_{\text{save}} - \beta \Delta t_{\text{delay}} \]
  - Directions to solve the problem:
    - Small buffer should be set when delay is hardly expected.
    - Large buffer should be set when delay is expected with high chance.

How do you predict the expected delay?

Several kinds of information are available to estimate the delay.
How to reduce delay? (1)

Time

○ : ETOT (Expected time at the runway)
○ : TTOT (Assigned take-off time)
Line length: Actual buffer

- The best buffer is changed based on $x_1$ (=average buffer of the preceding aircraft).
  - If the average buffer is small, large buffer should be set to absorb the uncertainty of the preceding aircraft.

$x_1 : E(TTOT - ETOT)$
How to reduce delay? (2)

- If the considered aircraft is delayed, the delay will propagate to the following consecutive aircraft.
  - If $x_2$ is large, the total delay will increase.

$x_2$: number of the following consecutive aircraft
Optimal Strategy

• The buffer \((b)\) is set based on the following rule:

\[
b = b_0 + f(x_1) + g(x_2)
\]

\(f(x_1), g(x_2) \in \{-2, -1, 0, 1, 2, 99\} \quad \text{[min]}
\]

\(x_1 \in \{> 1, 2, 3, \ldots, 8, 9, 10 \} \quad \text{[min]} \quad \ldots \text{average buffer of the preceding aircraft}
\]

\(x_2 \in \{0, 1, 2, 3, \ldots, 17, 18, 19 \} \quad \ldots \text{number of the following consecutive aircraft}
\]

• The optimal strategy \((F(x))\) should be found.

\[
F(x) = (f(> 1), f(2), \ldots, f(10 <), g(0), g(1), \ldots, g(18), g(19 <))^T
\]

– The possible combination of solutions is \(6^{30} (=2.2E23)\).

→ Tabu search is used to find the optimal solution.

• The strategy is optimized to maximize \(r\).

\[
r = \Delta t_{save} - \beta \Delta t_{delay}
\]
Tabu Search

- Tabu search is a metaheuristic search method and proceeds with the following steps:
  - Several neighbors around the current solution are searched, and the best neighbor becomes the new current solution.
    - The solution becomes worse if all neighbors are worse than the current solution.
  - The current solution is put into the tabulist, and the solution within the solution list cannot be a neighbor.
    - To avoid the convergence to local minima.
  - The best neighbor is obtained after a sufficient number of steps.

- SAA (Sample Average Approximation) is used to obtain the objective function under stochastic environment.
  - 1000 ~ 50000 simulation runs are conducted.
Simulation Environment

• To consider uncertainty effect,
  – Simulations are conducted multiple times in each scenario.
    • The average taxiing time saving and average take-off delay are considered.

• To obtain a general rule,
  – 5 scenarios based on 5 days are used. (Day1-Day5)
    • “Scenario” includes the initial condition. (the pushback ready time of departure aircraft or the landing time of arrival aircraft, spot position, used runway, taxiing route)
    • Traffic density in each time range is set the same as the actual.
  – Data between 6pm and 9pm are used.
    • This time range includes both “congested time” and “non-congested time”.

• Two patterns (with & without TSAT allocation) are calculated.
  – The difference of average taxiing time $\rightarrow$ Saved taxiing time by TSAT
  – The difference of average take-off time $\rightarrow$ Take-off delay caused by TSAT
Simulation Accuracy

<table>
<thead>
<tr>
<th>Day</th>
<th>Actual total waiting time [minutes]</th>
<th>Average total waiting time in simulations [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day1</td>
<td>257.7</td>
<td>230.4</td>
</tr>
<tr>
<td>Day2</td>
<td>257.3</td>
<td>237.4</td>
</tr>
<tr>
<td>Day3</td>
<td>199.9</td>
<td>214.8</td>
</tr>
<tr>
<td>Day4</td>
<td>479.0</td>
<td>453.0</td>
</tr>
<tr>
<td>Day5</td>
<td>214.6</td>
<td>282.8</td>
</tr>
</tbody>
</table>

Waiting time of each aircraft in a departure queue on Day3
Simulation Results
Constant Buffer Method

![Graph showing simulation results for different buffer methods.]
Simulation Results
Optimal Strategy (1)

• Optimal strategy ($\beta = 20$):  
  
  \[ r = \Delta t_{\text{save}} - \beta \Delta t_{\text{delay}} \]

  \[ F(x) = \{99, 1, 99, 1, 99, 99, -2, -2, -1, -1, \ldots \} \]

  \[ \ldots \text{Average buffer of preceding aircraft} \]

  \[ 1, 1, 1, 0, 0, -1, 2, 2, 99, 1, -1, -2, 99, 99, 99, 99, 1, 99, 1, 99, 1, 99 \} \]

  \[ \ldots \text{Number of following consecutive aircraft} \]
Simulation Results
Optimal Strategy (2)

- Both methods show a similar delay, but the optimal strategy reduces taxiing time more.
Summary and Future Works

• A new TSAT assignment algorithm was evaluated via stochastic optimization.
  – Statistical airport simulation model was developed.
  – TSAT was evaluated in respect to both taxiing time saved and take-off delay.
    • Two informative variables are found to reduce take-off delay.
  – Optimal strategy was found via Tabu search.
    • Optimal strategy shows a better performance than a “constant buffer method”.

• Future works
  – Algorithm update to improve the performance.
    • Optimization technique will be improved.
    • Additional useful information might be available.
  – Proceed discussions with stakeholders about optimal operations.
    • How long a delay is acceptable for airlines?
Thank you for your attention!

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