Comparison of Taxi Time Prediction Performance Using Different Taxi Speed Decision Trees

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• Motivation
• Experiment set-up
• Three test runs with different taxi speed values
  – Run 1: Initial decision trees (baseline)
  – Run 2: Various taxi speeds by runway-spot-ramp area
  – Run 3: Constant taxi speed for each runway
• Prediction performance comparison
  – Spot/Off time for departures
  – Off time in unimpeded taxi-out condition
  – Spot/In time for arrivals
• Summary
• Unimpeded taxi time estimates
  – Provide earliest feasible takeoff times for departures and earliest gate-in times for arrivals
  – \((\text{Remaining taxi distance}) / (\text{Nominal taxi speed})\)
• Airport node-link model and taxi routes
• Taxi speed decision trees
Initial Taxi Speed Decision Trees

• Taxi speed decision trees in STBO system
  – Two decision trees for estimating taxi-out times of departures and taxi-in times of arrivals
  – Each branch has two taxi speed values both in AMA and Ramp

• Various taxi speed values for each branch
  – Based on previous studies for taxi time analysis at CLT
  – Four criteria applied
    • Runway
    • Spot
    • Ramp area (subdivided sectors in each concourse)
    • Weight class
  – Used actual surface surveillance data at CLT in May through December, 2015 and taxi route data
    • 10th percentile taxi time values (90th percentile taxi speed)
Motivation

• Research motivation
  – Initial taxi speed decision trees have not been updated.
    • Based on old surface surveillance data
    • More reliable data from STBO systems become available.
  – Taxi time prediction accuracy is not satisfactory.
    • Large variations on the difference between actual and predicted times
    • Longer taxi time prediction even in unimpeded conditions
    • Wrong takeoff sequence prediction (see the next slide)

• Objective
  – To find optimal taxi speeds for better taxi time estimation
Inaccurate Off Time Estimation: Example

Actual sequence for Rwy 36C:
..., AAL1840, JIA5049, JIA5326, ...

Estimated sequence for Rwy 36C:
..., JIA5049, AAL1840, JIA5326, ...

< STBO Client Timeline and Map >
• Experiment procedure
  – Install STBO system software with different taxi speed settings in three test machines
    • Run 1: initial taxi speed decision trees (baseline)
    • Run 2: various taxi speeds by runway-spot-ramp area pairs
    • Run 3: constant taxi speed per runway
  – Run them with live data for a few days
  – Archive output data
    • Actual Spot/Off/In times
    • Undelayed Spot/Off/In times (unimpeded time estimates)

• Test run data
  – 2/13/2017 2PM ~ 2/20/2017 1AM (155 hours in total)
Three Different Taxi Speed Settings

- Run 1: initial taxi speed values (baseline)
  - Use old surface surveillance data (5/1/2015-12/31/2015)
- Run 2: various taxi speed values by runway-spot-ramp area pairs
  - Use recent STBO data (9/18/2016-12/31/2016)
  - 90th percentile taxi speeds in the Ramp and AMA for each runway-spot-ramp area pair
  - AMA taxi speed adjusted to avoid overtaking on taxiways
- Run 3: constant taxi speed values per runway
  - Simplified version of Run 2
  - Use recent STBO data (9/18/2016-12/31/2016)
  - 90th percentile taxi speeds in the Ramp and AMA for each runway
Run 1: Initial Taxi Speeds for Departures

- 89 branches depending on runway-spot-ramp area-weight class pair
- Various taxi speed values even in the same spot-runway pair, leading to takeoff sequence changes in runway queue
- Too low taxi speed generally, leading to longer taxi time prediction
Run 1: Initial Taxi Speeds for Arrivals

- 145 branches depending on runway-spot-ramp area-weight class pair
Run 2: Various Taxi Speeds for Departures

- 72 branches depending on runway-spot-ramp area pair
- Constant AMA taxi speeds per runway assumed to prevent flights toward the same runway from overtaking on taxiways
Run 2: Various Taxi Speeds for Arrivals

- 96 branches depending on runway-spot-ramp area pair
- Different runway-spot pairs can have different AMA taxi speeds, depending on the locations.
Run 3: Constant Taxi Speed per Runway

- Departures: 90th percentile value of taxi-out speeds for all departures going to each runway
- Arrivals: 90th percentile value of taxi-in speeds for all arrivals from each runway

<table>
<thead>
<tr>
<th>Departure Runway</th>
<th>Taxi Speed (in knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMA</td>
</tr>
<tr>
<td>18C</td>
<td>10.2</td>
</tr>
<tr>
<td>18L</td>
<td>16.4</td>
</tr>
<tr>
<td>36C</td>
<td>14.0</td>
</tr>
<tr>
<td>36R</td>
<td>13.4</td>
</tr>
<tr>
<td>Default</td>
<td>13.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arrival Runway</th>
<th>Taxi Speed (in knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMA</td>
</tr>
<tr>
<td>18C</td>
<td>17.2</td>
</tr>
<tr>
<td>18L</td>
<td>13.9</td>
</tr>
<tr>
<td>18R</td>
<td>18.3</td>
</tr>
<tr>
<td>23</td>
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<tr>
<td>36C</td>
<td>24.8</td>
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<tr>
<td>36L</td>
<td>18.9</td>
</tr>
<tr>
<td>36R</td>
<td>25.4</td>
</tr>
<tr>
<td>Default</td>
<td>20.6</td>
</tr>
</tbody>
</table>
Test Dataset Analysis – Departures

- Taxi-out time histograms
  - Very short ramp taxi time from Concourse A to Runway 18C/36C
  - Short AMA taxi time to Runway 18L
  - Long AMA taxi time to Runway 36C

![Ramp Taxi Time Distribution by Runway](image1)

![AMA Taxi Time Distribution by Runway](image2)
Test Dataset Analysis – Arrivals

- Taxi-in time histograms
  - Shorter taxi times both in the Ramp and AMA, compared to departures
  - Longer taxi-in time from West due to longer taxi distance
Spot Time Prediction Errors for Departures

• Box plots for spot time difference at gate by concourse
  – Show ramp taxi-out time prediction accuracy
    • (Actual spot time) – (Undelayed spot time estimate) @ pushback
  – Run 1: longer ramp taxi times predicted
    • Negative values on y-axis for most flights

R1: Baseline

R2: Various speeds

R3: Constant speed

[Diagrams showing box plots for spot time difference at gate by concourse for each regime (R1, R2, R3)].
Off Time Prediction Errors at Spot

- Box plots for takeoff time difference at spot by runway
  - Show AMA taxi-out time prediction accuracy
    - (Actual off time) – (Undelayed off time estimate)\(\text{@spot}\)
  - Positive mean values are expected because runway separations are accumulated in actual off times.

R1: Baseline

R2: Various speeds

R3: Constant speed
Off Time Prediction Errors at Gate (1/2)

- Box plots for takeoff time difference at gate by runway
  - Show total taxi-out time prediction accuracy
    - (Actual off time) – (Undelayed off time estimate)@pushback
    - No significant difference by departure runway

R1: Baseline

R2: Various speeds

R3: Constant speed
Off Time Prediction Errors at Gate (2/2)

- Box plots for takeoff time difference at gate by concourse
  - Show total taxi-out time prediction accuracy
    - (Actual off time) – (Undelayed off time estimate)\textsubscript{@pushback}
  - Large variations observed in Concourse A and Etc.

R1: Baseline

\begin{center}
\includegraphics[width=0.3\textwidth]{R1.png}
\end{center}

R2: Various speeds

\begin{center}
\includegraphics[width=0.3\textwidth]{R2.png}
\end{center}

R3: Constant speed

\begin{center}
\includegraphics[width=0.3\textwidth]{R3.png}
\end{center}
• Departure queue size histogram from test dataset
  – Count the number of departures going to the same runway on the surface when a flight pushes back from its gate
  – Queue size less than 4 aircraft is assumed to be in unimpeded taxi conditions.
• Enable to better compare actual and undelayed OFF times

Queue size < 4: ~17%
Off Time Prediction Errors at Gate

- Box plots for takeoff time difference at gate by runway
  - Departures only in queue size < 4 (from gate to runway)
  - Longer taxi-out times predicted in Run 1 (baseline)

R1: Baseline
R2: Various speeds
R3: Constant speed
Off Time Prediction Errors at Spot

- Box plots for takeoff time difference at spot by runway
  - Departures only in queue size < 4 (from gate to runway)
  - Better prediction accuracy in Run 2 and 3 for Runway 36R

R1: Baseline  
R2: Various speeds  
R3: Constant speed
Spot Time Prediction Errors for Arrivals

- Box plots for spot time difference when landing, grouped by runway
  - Show AMA taxi-in time prediction accuracy
    - (Actual spot time) – (Undelayed spot time estimate)@landing
  - Better prediction performance for arrivals than departures

R1: Baseline  
R2: Various speeds  
R3: Constant speed
In Time Prediction Errors at Spot

- Box plots for gate-in time difference at spot by concourse
  - Show ramp taxi-in time prediction accuracy
    - (Actual gate-in time) – (Undelayed gate-in time estimate)@spot
  - No significant difference between three runs
    - Relatively poor performance for Concourse A

R1: Baseline
R2: Various speeds
R3: Constant speed
In Time Prediction Errors When Landing (1/2)

- Box plots for gate-in time difference when landing, grouped by concourse
  - Show total taxi-in time prediction accuracy
    - (Actual gate-in time) – (Undelayed gate-in time estimate)_{landing}

R1: Baseline


R2: Various speeds


R3: Constant speed


In Time Prediction Errors When Landing (2/2)

- Box plots for gate-in time difference when landing, grouped by runway
  - Show total taxi-in time prediction accuracy
    - (Actual gate-in time) – (Undelayed gate-in time estimate)@landing

R1: Baseline

R2: Various speeds

R3: Constant speed
Better Off Time Estimation in Run 3

Actual sequence for Rwy 36C:
... AAL1840, JIA5049, JIA5326, ...

Estimated sequence for Rwy 36C:
... AAL1840, JIA5049, JIA5326, ...

< STBO Client Timeline and Map >
• Three different taxi speed settings were tested to obtain the better taxi time prediction.

• Test results showed that
  – The best prediction performance was obtained when using constant taxi speed for each runway (Run 3).
  – Arrivals showed the better prediction accuracy, but there was no significant difference between three runs.

• We still have much room to improve the prediction for:
  – Ramp taxi-out time for non-AAL flights
  – AMA taxi-out time with congestion factor in runway queues
  – Ramp taxi-in time for Concourse A
  – AMA taxi-in time from West (Runway 18C/18R/36L)