Autonomy, Authority and Human Interaction Challenges in Air Transportation Systems

Hamsa Balakrishnan
Massachusetts Institute of Technology

CPS PI Meeting
October 3, 2012
Problem: Airport surface congestion
Solution: Pushback Rate Control

- Aircraft pushback from gates, start their engines, and then taxi until they takeoff.

- Control pushbacks in order to maintain runway utilization while avoiding excessive levels of congestion.

- Key challenges:
  1. How do we design the control strategy?
  2. How do we implement control strategy?
  3. How do we interface with human controllers?
1. Designing control strategy

- Dynamic control problem that recommends pushback rate to maintain departure throughput, given taxiway & runway queues
  - **Data-driven modeling** of runway processes and system dynamics
  - **Optimal pushback rate** to balance runway throughput and congestion

![Graph showing optimal pushback rate](image)

Optimal pushback rate: 27, 22L | 22L,22R

Simaiakis and Balakrishnan, American Control Conf., 2012.
2. Implementing control strategy

- On-off control does not work in practice
  - Air traffic controllers are humans, not automata
  - Rather than release an aircraft every time that a flight takes off, controllers prefer a rate at which to let aircraft pushback from their gates
  - **Pushback Rate Control**
  - Rate is updated periodically
3. Interfacing with human controllers

- Suggest pushback rate (color-coded cards or a tablet display)

  - Pushbacks in current time interval can be released (grayed out)
  - Unused rate is carried over to the next time interval, up to 2/min
  - Pushbacks in future time intervals can be reserved (angled)
  - Pushbacks can be reserved for the following 15-min time period
Incorporating humans into control

- Survey of BOS controllers
  - 21 respondents: 15 (BOS Gate 2010), 13 (2011), and 12 (both)
  - General support: “the ability to touch planes,” “reserve spots,” “…count the planes and account for aircraft with long delays,” “allows me to push & tells me to hold,” and “easy to use & understand”
  - Responses were positive about combining BOS Gate & another position

Simaiakis et al., Intl. Conf. on Research in Air Transportation, 2012.
BOS field-test results

- Aug-Sep`10 & Jul-Aug`11
- 4PM-8PM departure push
- Average gate-hold: 4.7 min
- 23-25 tons (6,600-7,300 gal) reduction in fuel burn
- 52-58 kg decrease in fuel burn / gate-held flight
- 71-79 tons CO\textsubscript{2} reduction
- Fair distribution of benefits
- 1 min gate-hold => 1 min of taxi-out time savings
- Positive stakeholder feedback
  - Traffic managers noted improved surface “flows”

<table>
<thead>
<tr>
<th>Configuration</th>
<th># gate holds</th>
<th>Taxi-out time savings (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>63</td>
</tr>
<tr>
<td>27, 32</td>
<td>33L</td>
<td>34</td>
</tr>
<tr>
<td>27, 32</td>
<td>33L</td>
<td>8</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>45</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>19</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>11</td>
</tr>
<tr>
<td>27, 32</td>
<td>33L</td>
<td>11</td>
</tr>
<tr>
<td>27, 32</td>
<td>33L</td>
<td>56</td>
</tr>
</tbody>
</table>

2010 | 247 | 1003 min = 16.7 hours

<table>
<thead>
<tr>
<th>Configuration</th>
<th># gate holds</th>
<th>Taxi-out time savings (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>14</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>42</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>50</td>
</tr>
<tr>
<td>4L,4R</td>
<td>4L,4R,9</td>
<td>11</td>
</tr>
<tr>
<td>4L,4R</td>
<td>4L,4R,9</td>
<td>7</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>6</td>
</tr>
<tr>
<td>27, 22L</td>
<td>22R</td>
<td>12</td>
</tr>
</tbody>
</table>

2011 | 142 | 760 min = 12.7 hours
Key challenges

- Designing control strategies
  - Data-driven modeling

- Implementation/field-testing

- Interfacing with humans

- Evaluation/performance tracking/metrics

- Important to consider tradeoffs/interactions

- Situational awareness is important, but does not equal decision-support!

- Need graceful degradation in case of automation failure
  - “Business-as-usual” may not be feasible fall-back option