Partnership for AiR Transportation Noise and Emission Reduction
An FAA/NASA/TC-sponsored Center of Excellence

Reducing Surface Emissions Through Airport Traffic Optimization

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Motivation

- In 2007, aircraft in the U.S. spent over **63 million minutes** taxiing in to their gates, and over **150 million minutes** taxiing out for departure [FAA ASPM data].

<table>
<thead>
<tr>
<th>Year</th>
<th>&lt; 20 min</th>
<th>20-39 min</th>
<th>40-59 min</th>
<th>60-89 min</th>
<th>90-119 min</th>
<th>120-179 min</th>
<th>≥ 180 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>6.9 mil</td>
<td>1.7 mil</td>
<td>197,167</td>
<td>49,116</td>
<td>12,540</td>
<td>5,884</td>
<td>1,198</td>
</tr>
<tr>
<td>2007</td>
<td>6.8 mil</td>
<td>1.8 mil</td>
<td>235,197</td>
<td>60,587</td>
<td>15,071</td>
<td>7,171</td>
<td>1,565</td>
</tr>
</tbody>
</table>

- Taxiing aircraft burn fuel, and contribute to **surface emissions** of CO$_2$, hydrocarbons, NOx, SOx and particulate matter.
- In Europe, aircraft are estimated to spend 10-30% of their time taxiing [Airbus].
- A short/medium range A320 expends as much as 5-10% of its fuel on the ground [Airbus].
Departure throughput saturation at airports

PHL, VFR, configuration 26, 27R, 35 — 27L, 35

Saturation area

Number of departing aircraft on the ground
Surface congestion results in an increase in taxi times

Departure throughput as a function of number of departures on the surface

<table>
<thead>
<tr>
<th>Airport</th>
<th>$N^*$</th>
<th>Total departures</th>
<th>Pushbacks after saturation</th>
<th>Frequency of saturation</th>
<th>E[taxi time] when saturated</th>
</tr>
</thead>
<tbody>
<tr>
<td>JFK</td>
<td>28</td>
<td>180,171</td>
<td>50,712</td>
<td>17.9%</td>
<td>52.7</td>
</tr>
<tr>
<td>EWR</td>
<td>25</td>
<td>171,280</td>
<td>30070</td>
<td>12.5%</td>
<td>48.8</td>
</tr>
<tr>
<td>PHL</td>
<td>20</td>
<td>204,002</td>
<td>54,756</td>
<td>16.3%</td>
<td>36.0</td>
</tr>
<tr>
<td>BOS</td>
<td>18</td>
<td>155,060</td>
<td>14,410</td>
<td>6.8%</td>
<td>29.5</td>
</tr>
</tbody>
</table>
Evaluation of fuel burn and emissions performance of various airports

- Percentage of (domestic) departures from the top 20 airports vs percentage of the taxi-out fuel burn from these flights
Candidate strategy for evaluation

• Prior studies have highlighted one important ATC strategy: limiting number of aircraft pushing back into the Active Movement Area when surface is already congested
  – Refinement of current approach of controlling pushbacks to within Acceptable Level of Traffic in the movement areas
  – Formalized as N-control strategy

• Demonstrate fuel and environmental benefits of basic N-control strategies

• Evaluate operational and implementation issues associated with N-control
First Phase: Basic N-control

- Conceptually simple: Limit the buildup of queues on the airport surface by controlling the pushback times of aircraft
- Begin with $N_{ctrl} >> N^*$, and decrease gradually
Implementing basic N-control strategies

• Begin with $N_{ctrl} >> N^*$, and decrease gradually
  – Carefully monitor for potential system issues, such as, gate use constraints, downstream flow restrictions, taxi times of different airlines, fairness concerns, etc.
  – At high values of $N_{ctrl}$, we would expect minimal impact on operations (gate use conflicts, etc.)
  – Expect to taxi time/fuel burn/emissions benefits even at higher values of $N_{ctrl}$
  – As constraints emerge, work with stakeholders to determine if modified procedures can resolve issues and allow further reduction of $N_{ctrl}$
Benefits of N-control strategy

- Simplicity of concept
- Minimal additional automation/infrastructure/procedural modification requirements
- Can use this as a way to diagnose system dynamics (system identification)
- Identify initial indicators of problems (for example, gate use conflicts)
- Refinement of airport simulation models to reflect taxiway layouts, paths and procedures
Criteria for identifying candidate airports

- Significant congestion – Taxi times and taxi delays
- Non-attainment areas
- Availability of surface surveillance/operational data (ASDE-X)
- Cooperation from: Tower, Airport, Carriers
- Avoid single carrier dominance
Queuing network model of departure processes

- Developed airport model that predicts taxi times and departure queue wait times, given pushback schedules
  - Also proposed method for estimating unimpeded taxi times

- Model can be used to evaluate baseline emissions as well as the benefits of queue management strategies

[Simaiakis and Balakrishnan, 2009]
Expected impact of basic N-control strategies

- Need periods of congestion at the airport in order to be beneficial
  - Starting at large values of $N_{\text{ctrl}}$ keeps protocol relatively low-risk
  - At larger values of $N_{\text{ctrl}}$, fewer flights experience gate-hold

*values over the course of a year; ~40000 flights departed in VFR under this configuration at BOS in 2007
Expected impact of basic N-control strategies

- Higher $N_{ctrl}$ gets impacts fewer flights, but they benefit from a greater decrease in taxi-out times.

![Graph showing impact of N-control strategies](image)
Expected impact of basic N-control strategies

- Total impact increases as $N_{ctrl}$ decreases due to more flights getting taxi time decreases.
Expected impact of basic N-control strategies

- Airport throughput is not impacted
- Minimal impact on departure delay (wheels-off time under N-control minus wheels-off time in uncontrolled case)
Potential benefits of N-control strategies: Fuel burn and emissions reduction

### 22L, 27 | 22L, 22R; VMC [Annual reduction in fuel burn and emissions]

<table>
<thead>
<tr>
<th>$N_{ctrl}$</th>
<th>10</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burn (gallons)</td>
<td>421,308</td>
<td>178,066</td>
<td>146,445</td>
<td>117,811</td>
<td>93,148</td>
<td>71,880</td>
<td>53,933</td>
<td>39,817</td>
<td>29,317</td>
</tr>
<tr>
<td>HC (kg)</td>
<td>2,766</td>
<td>1,193</td>
<td>988</td>
<td>801</td>
<td>637</td>
<td>496</td>
<td>376</td>
<td>280</td>
<td>208</td>
</tr>
<tr>
<td>CO (kg)</td>
<td>29,412</td>
<td>12,563</td>
<td>10,385</td>
<td>8,397</td>
<td>6,667</td>
<td>5,172</td>
<td>3,907</td>
<td>2,897</td>
<td>2,143</td>
</tr>
<tr>
<td>NOx (kg)</td>
<td>5,347</td>
<td>2,258</td>
<td>1,856</td>
<td>1,492</td>
<td>1,179</td>
<td>908</td>
<td>682</td>
<td>503</td>
<td>371</td>
</tr>
</tbody>
</table>

### 4L, 4R | 4L, 4R, 9; VMC [Annual reduction in fuel burn and emissions]

<table>
<thead>
<tr>
<th>$N_{ctrl}$</th>
<th>10</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burn (gallons)</td>
<td>183,276</td>
<td>57,725</td>
<td>45,468</td>
<td>35,583</td>
<td>27,633</td>
<td>21,526</td>
<td>16,388</td>
<td>12,333</td>
<td>8,986</td>
</tr>
<tr>
<td>HC (kg)</td>
<td>1,234</td>
<td>388</td>
<td>310</td>
<td>244</td>
<td>189</td>
<td>149</td>
<td>114</td>
<td>87</td>
<td>64</td>
</tr>
<tr>
<td>CO (kg)</td>
<td>12,870</td>
<td>4,150</td>
<td>3,291</td>
<td>2,595</td>
<td>2,020</td>
<td>1,581</td>
<td>1,214</td>
<td>919</td>
<td>680</td>
</tr>
<tr>
<td>NOx (kg)</td>
<td>2,319</td>
<td>730</td>
<td>575</td>
<td>450</td>
<td>349</td>
<td>272</td>
<td>207</td>
<td>155</td>
<td>113</td>
</tr>
</tbody>
</table>

### 27, 32 | 33L; VMC [Annual reduction in fuel burn and emissions]

<table>
<thead>
<tr>
<th>$N_{ctrl}$</th>
<th>10</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burn (gallons)</td>
<td>206,954</td>
<td>65,557</td>
<td>52,927</td>
<td>43,575</td>
<td>34,949</td>
<td>27,780</td>
<td>21,899</td>
<td>17,150</td>
<td>13,164</td>
</tr>
<tr>
<td>HC (kg)</td>
<td>1,374</td>
<td>443</td>
<td>359</td>
<td>301</td>
<td>245</td>
<td>196</td>
<td>156</td>
<td>123</td>
<td>95</td>
</tr>
<tr>
<td>CO (kg)</td>
<td>14,416</td>
<td>4,663</td>
<td>3,786</td>
<td>3,142</td>
<td>2,540</td>
<td>2,027</td>
<td>1,618</td>
<td>1,270</td>
<td>981</td>
</tr>
<tr>
<td>NOx (kg)</td>
<td>2,615</td>
<td>830</td>
<td>670</td>
<td>551</td>
<td>441</td>
<td>351</td>
<td>276</td>
<td>216</td>
<td>166</td>
</tr>
</tbody>
</table>
Implementation challenges: Gate conflicts
Implementation challenges:
Expected number of gate conflicts/year

- Gate conflict defined as event when an (arriving) aircraft is assigned the gate in which a departure is being held
- Number of gate conflicts increase as $N_{\text{ctrl}}$ decreases

BOS segment (VMC ; 22L, 27 I 22L, 22R)

Range of $N_{\text{ctrl}}$

Simulation predictions
Implementation issues to be addressed

• Airport geometry, taxi procedures, dynamics must be understood
• Many issues need to be assessed with input from local stakeholders (tower, airport operator, carriers)
  – Controller procedures, “Call ready” protocols
  – Ramp management; Gate ownership, availability, scheduling
  – Sequence basis and fairness
  – Taxi time variability
  – Taxi paths, holding areas, penalty box locations
  – BTS on-time performance statistics
    • Modify policy to base statistics on “call ready to push”? 
    • Gaming concerns
    • Increased predictability and decrease in long taxi delays: benefit with respect to Passenger Bill of Rights
Summary

• N-control is a conceptually simple strategy to limit the build up of surface queues

• Propose to demonstrate fuel burn and emissions reduction through N-control field test
  – Risk-mitigation strategy: Begin at high value of $N_{\text{ctrl}}$ and decrease gradually
  – Potential fuel and emissions savings even at high $N_{\text{ctrl}}$
  – Gate conflicts and other operational issues will be carefully monitored

• Evaluation of operational and implementation issues
  – Need to be identified and addressed in cooperation with stakeholders