Estimating Avoidable Delay in the NAS

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Outline

- Motivation
- The Bertsimas-Stock model for TFMP.
- Benefits assessment of CIWS echo tops product.
- Conclusions and contributions.
Motivation

• Given schedule, optimize airspace (sector, airport) usage through effective holding/routing strategies (Bertsimas et. al., 1995) in response to time-varying capacity.

• Could be viewed as a
  – Decision support tool.
  – Performance evaluation/ benchmarking tool.
  – Benefits assessment tool.
  – Network design system.
  – Pricing support mechanism.
Model Description (Data)

- Schedule (OAG) and filed flight plan.
- Time each aircraft spends in a sector (detailed 3-d trajectory model).
- Airport departure and arrival rates.
- Sector capacity (or a penalty function?).
- Flight connectivity and turnaround time.
- Cost of delay/cancellation.
Model Description (Objective)

- Minimize
  - Total delay of all aircraft.
  - Weighted sum of ground and airborne delay.
  - Total gate-to-gate time.
  - Total passenger delay.
  - Sector overage.
  - Total system cost.
Model Description (Constraints)

- Sector capacity (hard/soft).
- Airport capacity (hard/soft).
- Flight connectivity.
- Min. and max. time of each aircraft in a sector.
- Max total delay per aircraft (cancellation).
Case Study: Aug 24, 2002

Data Sources

- Individual flights data: FAA - ASPM.
- Trajectory information: MIT - Lincoln Lab ETMS Radar Tracks.
- Preferred routes: FAA - CDR.
- Weather coverage: MIT - Lincoln Lab CCFP CIWS.
Case Study: Aug 24, 2002

Figure 1. Severe weather over N-E United States
Assumptions (Airports)

Figure 2. Subset of origin-destination pairs considered.
Assumptions (Flights)

• 2422 flights considered between major airports.
• Time: 1800-2400 Z.
• Flight plans chosen from Coded Departure Routes (CDR).
• Long-range flights considered separately and given priority.
Assumptions (Trajectory)

Parameters were estimated from trajectory data on a good-weather day. Parameters were assumed to be dependent on aircraft type and trip distance.
Assumptions (Capacity)

$K < 100$ % weather coverage

Linear capacity tradeoff function
## Results (shortest route only)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Actual</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne time (Minutes)</td>
<td>194,000 (197,000 filed)</td>
<td>176,400</td>
</tr>
<tr>
<td>Delay/flight</td>
<td>0.62 min (-7.07 min on Aug 7)</td>
<td>4.4 min (3.6 min without connectivity)</td>
</tr>
</tbody>
</table>

Interesting: The model assigned NO airborne delay.
Additional Routes

Figure 3. Added routes shown in black.
# Results (multiple routes)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Model (single route)</th>
<th>Model (multiple routes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne time (Minutes)</td>
<td>176,400</td>
<td>177,900</td>
</tr>
<tr>
<td>Delay/flight</td>
<td>4.4 min (3.6 min without connectivity)</td>
<td>2.7 min (2.1 min without connectivity)</td>
</tr>
</tbody>
</table>

“Delay” for multiple routes is with respect to the flight time on the shortest path for that flight. Again, there was NO airborne holding.
Benefits Assessment of Echo-Tops

Aircraft appear to be using “blocked” sectors!
CIWS Echo-Tops Product

Jan 28, 2004
## Results (Echo-Tops Single Route)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Model (single route)</th>
<th>Model echo tops (single route)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne time</strong></td>
<td>176,400</td>
<td>176,400</td>
</tr>
<tr>
<td>(Minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Delay/flight</strong></td>
<td>4.4 min</td>
<td>1.8 min</td>
</tr>
<tr>
<td>(3.6 min without connectivity)</td>
<td></td>
<td>(1.1 min without connectivity)</td>
</tr>
</tbody>
</table>

High and super high sectors were virtually unaffected.
Conclusions (1)

- It is now possible to answer several questions regarding the performance of the NAS on August 24\textsuperscript{th}.
  - **Decision support**: What routes/delays should be assigned to flights to optimize operations (depending on metric)?
  - **Benchmarking**: How far were the operations from optimal (depending on metric)?
  - **Schedule Evaluation**: Is the given schedule feasible with full capacity?
Conclusions (2)

• Some more questions.
  – **Benefits assessment**: What are the benefits of providing echo-tops information to identify situations where aircraft can safely fly over storms? How much would you be willing to invest in it?
  – **Network design**: How would building an additional runway impact the traffic flows in the NAS?
  – **Pricing mechanisms**: What is the contribution of each aircraft to the total system cost? [Dual prices of LP give marginal utility of each additional unit of resource capacity and marginal cost of each aircraft to the system.]
Contributions of Study

• First application of the Bertsimas-Stock model to a large-scale real-world scenario.
• Cancellations explicitly modeled.
• Problem studied in three dimensions.
• Uses other than decision support were motivated.