Simulating Flight Routing Network Responses to Airport Capacity Constraints in the US

Antony D. Evans
Andreas Schäfer

AIAA ATIO / ANERS Conference
Hilton Head, 21-23 September 2009
Aviation Integrated Modelling (AIM) Project

Goal: Develop policy assessment tool for aviation, environment & economic interactions at local & global levels, now and into the future.
Motivation

Unconstrained forecast of US domestic air transport system growth
Network of 22 primary airports

- Delay forecast unrealistic: Airlines and passengers would respond to delay
  - Potential impact on scheduling, aircraft operated, and routing network
  - Potential impact on air traffic growth, and emissions
Objectives & Methodology

- **Objective**: Develop a model of airline responses to airport capacity constraints
  - Routing network changes
    - Avoiding congested hubs
    - Shift to secondary airports
  - Changes in flight frequency
  - Changes in aircraft size
- **Methodology**: Select each airline’s routing network, flight frequencies, and aircraft to maximize individual profit
  - Simulate game between airlines to capture effects of competition endogenously
  - Model effects of airport capacity constraints on airline costs and demand endogenously
Methodology

- Airline profit function:

\[
\max \left( \sum_{i,j} \sum_{p \in \text{Itin}_{i,j}} \text{Fare}_{i,j} \cdot \text{Pax}_{i,j,p,a} - \sum_{m,n,k} \text{Cost}_{\text{flt}_{m,n,k,a}} \cdot \text{Fltfreq}_{m,n,k,a} - \sum_{i,j} \sum_{p \in \text{Itin}_{i,j}} \text{Cost}_{\text{pax}_{i,j,a}} \cdot \text{Pax}_{i,j,p,a} \right)
\]

- Decision variables:
  - Segment flight frequency \((\text{Fltfreq}_{m,n,k})\)
  - Passenger itinerary demand \((\text{Pax}_{i,j})\)

- Constraints:
  - Demand constraint:
    \[
    \sum_{p \in \text{Itin}_{i,j}} \text{Pax}_{i,j,p,a} \leq \frac{\text{Fltfreq}_{i,j,a}}{\sum_{a \in A} \text{Fltfreq}_{i,j,a}} \times D_{i,j}
    \]
  - Seat constraint:
  - Airport balance constraint:
    \[
    \sum_{n,k} \text{Fltfreq}_{m,n,k} = \sum_{n,k} \text{Fltfreq}_{n,m,k}
    \]
  - Only non-stop and single connection itineraries modeled

Delay a function (among others) of flight frequency \((\text{Fltfreq})\) – modeled by a Delay Calculator

Operating cost \((\text{Cost}_{\text{flt}} \& \text{Cost}_{\text{pax}})\) a function (among others) of delay – modeled by an Operating Cost Calculator

Available passenger demand \((D)\) a function (among others) of delay (travel time) and fare \((\text{Fare})\) – modelled by a Demand Model
Sample Problem

• Model 5 airlines in 14 cities / 22 airports / 11 hubs in the US
  - Served 75% of scheduled flights in the domestic US in 2005

• Validate model by comparing results with 2005 input data to observed data for 2005

• Simulate to 2030 under alternative airport capacity scenarios
  - Proposed airport capacity expansion
  - No airport capacity expansion
  - No airport capacity expansion at ORD, proposed elsewhere
Model Validation

<table>
<thead>
<tr>
<th>Segment Flight Frequency</th>
<th>Fares</th>
<th>OD Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>% diff. System</td>
<td>R²</td>
<td>Mean % diff.</td>
</tr>
<tr>
<td>12% low</td>
<td>0.777</td>
<td>11% high</td>
</tr>
</tbody>
</table>

Percentage connecting passengers: 5.8% (observed) 13.4% (modeled)

Observed Network, 2005

Airline Game Theoretical Equilibrium Network
Simulating to 2030: System

- Population, income, oil price based on MIT CCSP (2007) IGSM scenario

**Avg. System Arrival Delay**

**System Pax Demand**

**System Operations**

**System CO₂**

Case 1: Baseline
Case 2: No Capacity Expansion
Case 3: No ORD Capacity Expansion
Simulating to 2030: ORD

- Population, income, oil price based on MIT CCSP (2007) IGSM scenario
Simulating to 2030: Hubs

- Population, income, oil price based on MIT CCSP (2007) IGSM scenario
Conclusions

• A model was developed that simulates airline flight network routing responses to airport capacity constraints

• The model was validated by applying it to a network of 22 airports and 14 cities in the United States in 2005
  □ Passenger demand, average fares, and segment flight frequencies predicted within a 10-12% range compared to observed values

• The model was applied to simulate operations in the US through 2030 under alternative airport capacity scenarios
  □ Airport capacity constraints may have a significant impact on flight delay
  □ The impact on system-wide passenger demand, air traffic growth, and CO₂ emissions is relatively small
  □ The impact on congested hub airport traffic growth and local airport emissions is more significant because of redistribution of connecting passengers to less congested hubs

• The model may be applied to simulate airline network routing responses to other constraints