Airport Demand Management under Airline Frequency Competition

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Aviation Delays: Costs and Causes

- **$31.2** billion cost to US economy in 2007\(^{[1]}\)
  - Just **$5.0** billion total profits of US airlines\(^{[2]}\)

- Causes of delay\(^{[3]}\): 84.5% delays due to demand exceeding realized capacity (airport congestion)

All values normalized to 100 for 2007 (www.bts.gov, 2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Passengers</th>
<th>Number of Flights</th>
<th>Total Arrival Delays to Flights (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2001</td>
<td>93.34</td>
<td>96.47</td>
<td>78.15</td>
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<tr>
<td>2002</td>
<td>92.06</td>
<td>102.32</td>
<td>59.75</td>
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<tr>
<td>2003</td>
<td>97.29</td>
<td>119.65</td>
<td>75.18</td>
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<tr>
<td>2004</td>
<td>105.04</td>
<td>126.09</td>
<td>103.58</td>
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<tr>
<td>2005</td>
<td>109.62</td>
<td>126.98</td>
<td>107.80</td>
</tr>
<tr>
<td>2006</td>
<td>109.81</td>
<td>122.86</td>
<td>120.99</td>
</tr>
<tr>
<td>2007</td>
<td>113.28</td>
<td>124.46</td>
<td>138.58</td>
</tr>
</tbody>
</table>

- Increase in number of flights much greater than that in passengers
  - #passengers: **13.3%**↑
  - #flights: **24.5%**↑
  - #passengers per flight: **9.0%**↓

\(^{[1]}\)NEXTOR TDI Study (2010), \(^{[2]}\)Air Transport Association (2008), \(^{[3]}\)Bureau of Transportation Statistics (2008)
Frequency Competition

- More frequent flights attract more passengers
- Higher frequency shares associated with disproportionately higher market shares
  - Sigmoidal (or S-shaped) relationship\[10]\[11]\[12]\[13]

\[
MS_i = \frac{FS_i^\alpha}{\sum_{j=1}^{n} FS_j^\alpha}
\]

- $MS_i$: Market share of airline $i$
- $FS_i$: Frequency share of airline $i$
- $n$: Number of competing airlines
- $\alpha$: Model parameter

Hence a tendency towards flying more frequent flights with smaller aircraft
Prior Research

a. In the presence of competition,
   – level of congestion directly proportional to the intensity of competition
     (Vaze and Barnhart, 2010)

b. In the absence of competition,
   – existing capacity more than enough to satisfy all passenger demand, with a similar level-of-service
   – over 80% reduction in congestion related delays
     (Vaze and Barnhart, 2011)

• How to mitigate congestion imposed by competition?
  – Quantity-based control (administrative)
  – Price-based control (congestion pricing)
Game Theoretic Model of Decision Making under Competition

maximize: \[ \text{Revenue} - \text{Operating Cost} - \text{Delay Cost} \]

subject to:

- Passengers carried depends on my frequency and competitors’ frequencies.
- Passengers carried cannot exceed available seats.
- My total number of flights cannot exceed the maximum slots available to me.
- My total number of flights cannot be lower than those dictated by use-it-or-lose-it rules.

\[ f_{as} \in \mathbb{Z}^+ \forall s \in S_a \]

- Extremely large number of possible solutions > \(10^{50}\)
- Solved using **successive optimizations heuristic**
  - Each optimization performed using **dynamic programming**
Quantity-based Controls

- Slot controls: very common in practice
  - Five congested US airports
  - Many major airports in Europe and Asia
Experimental Setup

• All flights into LGA airport
• Passenger demands, operating costs, fares, and seating capacities obtained from BTS website

Obtain Nash equilibrium solution for:
1. Existing slot controls (validation)
2. 12.3% slot reduction (policy analysis)
   (~reduce the planned #operations from VMC level to IMC level)
   a. Proportionate allocation: slots distributed in same ratio as current slots
   b. Reward-based allocation: slots distributed in same ratio as current passengers
Empirical Validation

Radius of each circle = #observations corresponding to that point
Impact of Administrative Slot Reduction

Avg. Flight Delays (min.)
-41%

Passengers Carried
-1.3%

Operating Profit ($)
+21% +17%
Profit Impact on Individual Airlines

- Each airline’s profit increases under both strategies

Slot reduction reduces delays to flights and passengers, and also improves profits of all airlines considerably.
Price-based Controls

• Congestion pricing: not common in practice
  – Expected passenger benefits due to delay reduction
  – Expected airline benefits through operating cost reduction (due to fewer flights) and delay reduction

\[
\text{Tolls} = f(\text{Your slots, Total slots})
\]

$\cdots$
Price-based Controls

Summary of results:

• Effectiveness of congestion pricing can change dramatically with the characteristics (intensity) of competition
  – Congestion pricing can increase airline profits!!! (despite toll payments)
  – A major part of the benefits due to more passengers per flight, as slots get expensive
  – Marginal cost pricing more promising than flat pricing

• Airline-industry specific factors need to be modeled
  – Factors not captured by general micro-economic models
  – Can make-or-break the case for congestion pricing
References


QUESTIONS?