US Airline Network: A Framework of Analysis and Some Preliminary Results

Dipasis Bhadra and Brendan Hogan

Paper to be presented at the Airline Evolution and Change: Deregulation and Beyond Session of the 46th Annual Forum of the Transportation Research Forum

Aviation Institute, Marvin Center
George Washington University

March 7, 3:30-5:00
The Airline Industry is Undergoing Structural Change

“What ails the airlines…was evident before 9/11, and goes well beyond the current downturn in the economy, to something more fundamental.”

Donald Carty, Chairman and CEO American Airlines
September 6, 2002

But what will the “restructured” future look like?
Declining Share of Network Carriers are Being Filled up By LCCs and Regional Carriers; More RJs Substitute for Large Jets and Turbo Props

Airline Market Share by Available Seat Miles

<table>
<thead>
<tr>
<th>Year</th>
<th>Network</th>
<th>Low Fare</th>
<th>All Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/2000</td>
<td>65%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>4/2001</td>
<td>64%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>4/2002</td>
<td>60%</td>
<td>21%</td>
<td>23%</td>
</tr>
<tr>
<td>4/2003</td>
<td>67%</td>
<td>22%</td>
<td>21%</td>
</tr>
<tr>
<td>4/2004</td>
<td>53%</td>
<td>21%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Types of Aircraft: Changes in Number of Scheduled Flights by Types of Aircraft: from April 2000 to April 2004

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>April, 2000</th>
<th>April, 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turboprop</td>
<td>100,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Large Jets</td>
<td>400,000</td>
<td>550,000</td>
</tr>
<tr>
<td>Piston</td>
<td>50,000</td>
<td>75,000</td>
</tr>
<tr>
<td>Regional Jets</td>
<td>20,000</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Source: Mark Dayton, 2004
While Large Hub Airports (i.e., OEP 35) Lose Relative Importance, Smaller Airports Gain

Source: Derived from T100 Segment, Bhadra/Texter 2004.
Although the Underlying Market Structures Have Not Changed Fundamentally
Upper End of the O&D Markets (Both in Terms of Numbers and Passengers) Appear To Be Fairly Stable Over Time
Airline Network Used To Be Primarily Hub-and-Spoke

January 03, 2003 (Domestic)
Some of the Leading LCCs are also Hub-and-spoke Network Carriers
However, with Increasing Importance of Southwest, Network Has become Far More Distributed

January 03, 2003
Visual Example of a Centralized Market

Market Share by Itinerary: 2003 Q2 PHL to LAX

Legend: Percentage Share of Market Pax
- 50% ≤ Market Share
- 20% ≤ Market Share < 50%
- 10% ≤ Market Share < 20%
- 5% ≤ Market Share < 10%
- 1% ≤ Market Share < 5%
Visual Example of a Distributed Market

Market Share by Itinerary: 2003 Q2 PHL to OAK

Legend: Percentage Share of Market Pax
- 50% ≤ Market Share
- 20% ≤ Market Share < 50%
- 10% ≤ Market Share < 20%
- 5% ≤ Market Share < 10%
- 1% ≤ Market Share < 5%
Quantitative Difference between Example Distributed and Centralized Markets

64% LAX pax take the most common routing (PHL-LAX)

Top 4 OAK itineraries carry the same fraction of pax as the top 1 LAX itinerary.

20% OAK pax take the most common routing (PHL-DEN-OAK)

Cumulative Fraction of Passengers

Distinct Itineraries
Number of stops observed to vary by market type

Passenger Distribution by Number of Stops, DB1B Market Data 2003 Q2

- OEP<->OEP
- OEP<->nonOEP
- nonOEP<->nonOEP
Analytical Model to Determine Itinerary Number of Stops by Market

\[ P_i (y_i = j | x_i, \beta) = \alpha_{ij} + \beta_1 \text{(passengers Inline)} + \beta_2 \text{(Average Distance)} + \beta_3 \text{(Passengers O\&D Market)} + \beta_4 \text{(Weighted Average Fare)} + \beta_5 \text{(Presence of Network Carriers)} + \beta_6 \text{(Presence of LCC Carriers)} + \varepsilon_i \quad (E.1) \]
Network Information from Itinerary Data

Types of Itinerary in the NAS: Aggregated by Origin and Destination (O&D)
2nd Quarter, 2003: N=359,837

- Direct trip: 27,880 (8%)
- One Stop: 2,485 (0.69%)
- Two Stop: 157,703 (44%)
- Three Stop: 162,018 (45%)
- Four Stop: 543 (0.15%)
- Five Stop: 9,208 (3%)

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### Estimated Results from Multi-nominal Logit

<table>
<thead>
<tr>
<th>Parameters*</th>
<th>One Stop Vs. Direct Route</th>
<th>Two Stop Vs. Direct Route</th>
<th>Three Stop Vs. Direct Route</th>
<th>Four Stop Vs. Direct Route</th>
<th>Five Stop Vs. Direct Route</th>
<th>Direct Route Vs. All Non-Direct Routes**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.3093</td>
<td>1.7519</td>
<td>0.8474</td>
<td>-1.3892</td>
<td>-2.2153</td>
<td>-1.5764</td>
</tr>
<tr>
<td>Passengers Inline</td>
<td>-0.0129</td>
<td>-0.4963</td>
<td>-1.8749</td>
<td>-2.9525</td>
<td>-2.6818</td>
<td>0.0154</td>
</tr>
<tr>
<td>Passengers O&amp;D Market</td>
<td>0.00177</td>
<td>0.00187</td>
<td>0.00192</td>
<td>0.00196</td>
<td>0.00199</td>
<td>-0.00182</td>
</tr>
<tr>
<td>Weighted Average Fare</td>
<td>0.00616</td>
<td>0.00496</td>
<td>0.00460</td>
<td>0.00538</td>
<td>0.00502</td>
<td>-0.00586</td>
</tr>
<tr>
<td>Average Distance</td>
<td>0.000282</td>
<td>0.00128</td>
<td>0.00161</td>
<td>0.00176</td>
<td>0.00181</td>
<td>-0.00062</td>
</tr>
<tr>
<td>Presence of Network Carriers</td>
<td>0.4609</td>
<td>0.4126</td>
<td>0.6635</td>
<td>1.0609</td>
<td>-0.00869</td>
<td>-0.4640</td>
</tr>
<tr>
<td>Presence of LCC Carriers</td>
<td>-0.7429</td>
<td>-1.4307</td>
<td>-1.4664</td>
<td>-1.5098</td>
<td>-2.7836</td>
<td>0.9311</td>
</tr>
</tbody>
</table>

* : All parameters are statistically significant at greater than 99% level of significance ; ** : There are two ways of deriving this. First, we can rerun logit program using different base and derive the parameters; and/or use all non-direct routes (i.e., itinerary stops ≥ 1) as a choice against the alternative of direct route as a binary model. We run the latter to extract the model parameters for direct route.
Predictive Performance of Logit Model

**Performance for Actual Direct Trips**
- 33% of Direct Trips predicted correctly

**Performance for Actual One Stop Trips**
- 73% of One-Stops predicted correctly

**Performance for Actual Two Stop Trips**
- 92% of Two-Stops predicted correctly

**Performance for Actual Three Stop Trips**
- 0% of Three-Stops predicted correctly
Overall Allocation of Number of Stops

Distribution of Itinerary Number of Stops

- **Predicted Itineraries**
- **Actual Itineraries**

<table>
<thead>
<tr>
<th>Itinerary Number of Stops</th>
<th>Percentage of Itineraries with that Number of Stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>0.9%</td>
</tr>
<tr>
<td>One-Stop</td>
<td>38.0%</td>
</tr>
<tr>
<td>Two-Stop</td>
<td>45.0%</td>
</tr>
<tr>
<td>Three-Stop</td>
<td>0.1%</td>
</tr>
<tr>
<td>Four-Stop</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

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Recap…and Next Steps

• We have developed a model for the number of stops between an OD pair
  – Carriers have been aggregated together to do this
• It remains to determine where they will stop
• The economics of hubs and the cost advantages between carriers must be built into the model
Passenger Routings Give Insight into Airline Cost Advantages

Passenger Distribution: 2003 Q2 PHL to OAK

<table>
<thead>
<tr>
<th>Route</th>
<th>Average Daily Passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHL-ORD:OAK</td>
<td>$288 (UA)</td>
</tr>
<tr>
<td>PHL-DEN:OAK</td>
<td>$360 (UA)</td>
</tr>
<tr>
<td>PHL:PHX:OAK</td>
<td>$309 (AA)</td>
</tr>
<tr>
<td>PHL:LAX:OAK</td>
<td>$229 (HP)</td>
</tr>
<tr>
<td>PHL:SLC:OAK</td>
<td>$226 (UA)</td>
</tr>
<tr>
<td>PHL:JAD:OAK</td>
<td>$271 (DL)</td>
</tr>
<tr>
<td>PHL:ATL:OAK</td>
<td>$300 (UA)</td>
</tr>
<tr>
<td>PHL:OAK</td>
<td>$278 (DL)</td>
</tr>
<tr>
<td>PHL:IAH:OAK</td>
<td>$433 (UA)</td>
</tr>
<tr>
<td>PHL:JAH:OAK</td>
<td>$329 (CO)</td>
</tr>
</tbody>
</table>
Southwest’s cost advantage over others
Carrier Average Fares by Distance Group

Average Per Mile Fares by Stage Length, 2003Q2

Fare per mile ($/mile)

Distance Group (x500 miles)

- American Airlines AA
- Alaska Airlines AS
- Jet Blue B6
- Continental Airlines CO
- Delta Airlines DL
- Atlantic Southeast EV
- Airtran Airways FL
- Hawaiian Airlines HA
- America West HP
- American Eagle MQ
- Spirit NK
- Northwest NW
- Comair OH
- Continental Express RU
- ATA TZ
- United Airlines UA
- US Airways US
- Southwest Airlines WN
**Will low-cost carriers and hence their network structure inherit the earth?**

Answer lies in understanding cost advantage

**Zone I:**
Hub-and-spoke carriers have natural economies of scale over distributed carriers

**Zone II:**
Distributed carriers have economies of scale over hub-and-spoke carriers

**Zone III:**
Distributed carriers may or may not have economies of scale over hub-and-spoke carriers, depending on the MC curve

Solve for ASM* depending on the costs and intersections

nw: network carriers; dc: distributed carriers
Please leave us your contacts for details and a revised paper

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• Visit us at: www.mitrecaasd.org

Thank you
Back Up Slides
Relative cost advantage of low-cost carriers have been maintained over time

Cost Structure of Network and Low-Cost Carriers
Airline Network: Our Definition for this Analysis

- **Spoke Network**: Travel is between non-major hubs and airports;
  - example: TEB-HGA; \textit{network} = 0;

- **Hub Network**: Travel is between major hubs;
  - example: travel between ATL-BOS; \textit{network} = 1;

- **Outbound**: Origin is a major hub but destination is not a major hub, i.e., variation of HS;
  - example: ATL-TEB; \textit{network} = 2;

- **Inbound**: Origin is not a major hub but destination is a major hub, i.e., variation of HS;
  - example: TEB-ATL; \textit{network} = 3;

- Major Hubs (35), according to the last OEP Definition:

  ATL; BOS; BWI; CLT; CVG;
  DCA; DEN; DFW; DTW;
  EWR; HNL; IAD; IAH; JFK;
  LAS; LAX; LGA; MCO;
  MEM; MIA; MSP; ORD;
  PHL; PHX; PIT; SAN; SEA;
  SFO; SLC; STL; TPA;
  MDW; FLL; PDX; and CLE;
Analytical Model to Determine Itinerary Number of Stops by Market

\[ P_i (y_i = j | x_i, \beta) = \alpha_{ij} + \beta_1 \text{ (passengers Inline)} + \beta_2 \text{ (Average Distance)} + \beta_3 \text{ (Passengers O&D Market)} + \beta_4 \text{ (Weighted Average Fare)} + \beta_5 \text{ (Presence of Network Carriers)} + \beta_6 \text{ (Presence of LCC Carriers)} + \epsilon_i \]  

(E.1)
Airline Network Used To Be Primarily Hub-and-Spoke

<table>
<thead>
<tr>
<th>Hub category</th>
<th>Number of airports</th>
<th>Percent of total U.S. passengers enplaned</th>
<th>Average number of passengers enplaned</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>31</td>
<td>69</td>
<td>14,746,705</td>
<td>Lambert-St. Louis International Airport, St. Louis, MO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 2000 population (metro area) = 2.6 million</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Annual enplanements = 13,264,751</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Number of carriers serving = 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Average daily flights = 560</td>
</tr>
<tr>
<td>Medium</td>
<td>36</td>
<td>20</td>
<td>3,628,823</td>
<td>Kansas City International Airport, Kansas City, MO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 2000 population (metro area) = 1.8 million</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Annual enplanements = 5,614,347</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Number of carriers serving = 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Average daily flights = 235</td>
</tr>
<tr>
<td>Small</td>
<td>69</td>
<td>8</td>
<td>729,712</td>
<td>Springfield-Branson Regional Airport, Springfield, MO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 2000 population (metro area) = 326,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Annual enplanements = 320,029</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Number of carriers serving = 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Average daily flights = 28</td>
</tr>
<tr>
<td>Non</td>
<td>400</td>
<td>3</td>
<td>54,857</td>
<td>Joplin Regional Airport, Joplin, MO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 2000 population (metro area) = 157,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Annual enplanements = 30,837</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Number of carriers serving = 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Average daily flights = 5</td>
</tr>
</tbody>
</table>

Source: GAO (analysis), FAA (data), Sabre (data), and U.S. Census Bureau (data).
Competition Cluster

Short-Haul Competition Cluster: USAir vs. Southwest

Medium Haul Competition Cluster: Delta, Northwest, vs. Frontier, America West

Medium to Long-Haul Competition Cluster: American, United, Continental vs. America West, JetBlue
70% take the most common routing (direct)

20% take the most common routing (direct)
How Well Does the Model Perform?

Predictive Power of the Logit Model

Deviation of Predictions from Actual Data by Hops

Perfect Performance Point

Direct trip
One Stop
Two Stop
Three Stop
Four Stop
Five Stop

0.00% 20.00% 40.00% 60.00% 80.00% 100.00%
Accuracy %

Prediction is "five off" (minus)
Prediction is "four off" (minus)
Prediction is "three off" (minus)
Prediction is "two off" (minus)
Prediction is "one off" (minus)
Prediction Matches Data Exactly
Prediction is "one off" (plus)
Prediction is "two off" (plus)
Prediction is "three off" (plus)
Prediction is "four off" (plus)
Prediction is five off" (plus)
Predictive Performance of Model Across Itinerary Types

- Direct Trip
- One Stop
- Two Stops
- Three Stops
- Four Stops

Actual Number of Stops vs Predicted Number of Stops

Percentage of Trips Assigned to that Category

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Direct Trip  One Stop  Two Stops  Three Stops  Four Stops

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We observe that major US airports are located where the population centers are....

Density Distribution in Metropolitan Statistical Areas (MSAs) and Location of Hubs

Population density
people/sq. mi.
year 2000
0 to 150
150 to 300
300 to 450
450 to 600
600 to 750
750 to 900
900 to 1050
1050 to 1200
1200 to 1350
1350 to 1500
above 1500
and….higher the per capita income, the greater the likelihood of major airports

Income Distribution in MSAs and Location of Hubs
Aviation activities result from economics and demographics: Metropolitan areas as engine of growth

Uneven density results from uneven economic and demographic activities

Source: http://www.manifold.net/press/us_pops_scrn.jpg
Airports and airlines serve peoples’ needs

GAO Report #02-432: Air Service Trends at Small Communities since October 2000