Frequency Competition and Congestion

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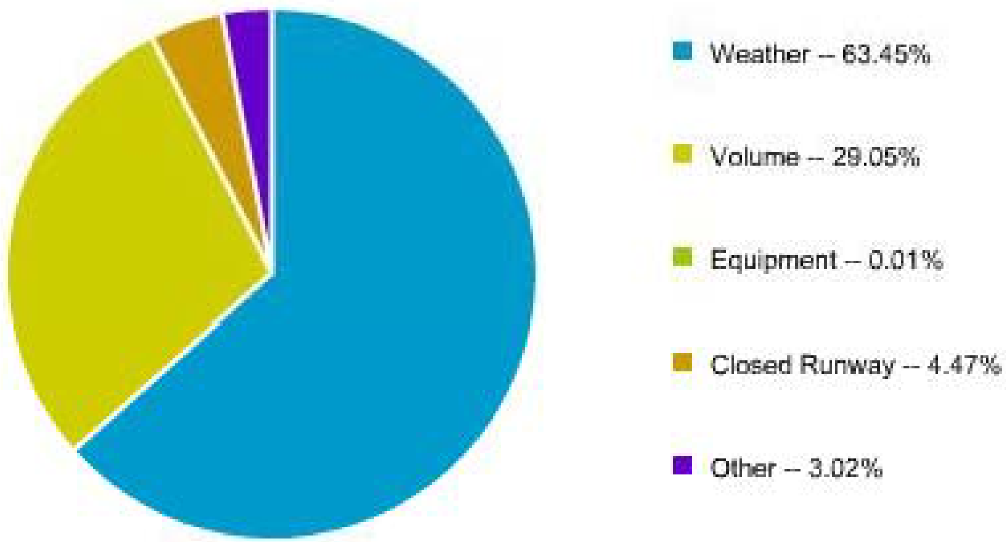
Delays and Demand-Capacity Imbalance

- Estimated cost of domestic flight delays to US economy in 2007≈ $41 B*
  - $19 B in additional aircraft operating costs
  - $12 B in passenger delay costs
  - $10 B in indirect costs to other industries
- 92.5% of National Aviation System (NAS) delays attributed to demand exceeding the realized airport capacity

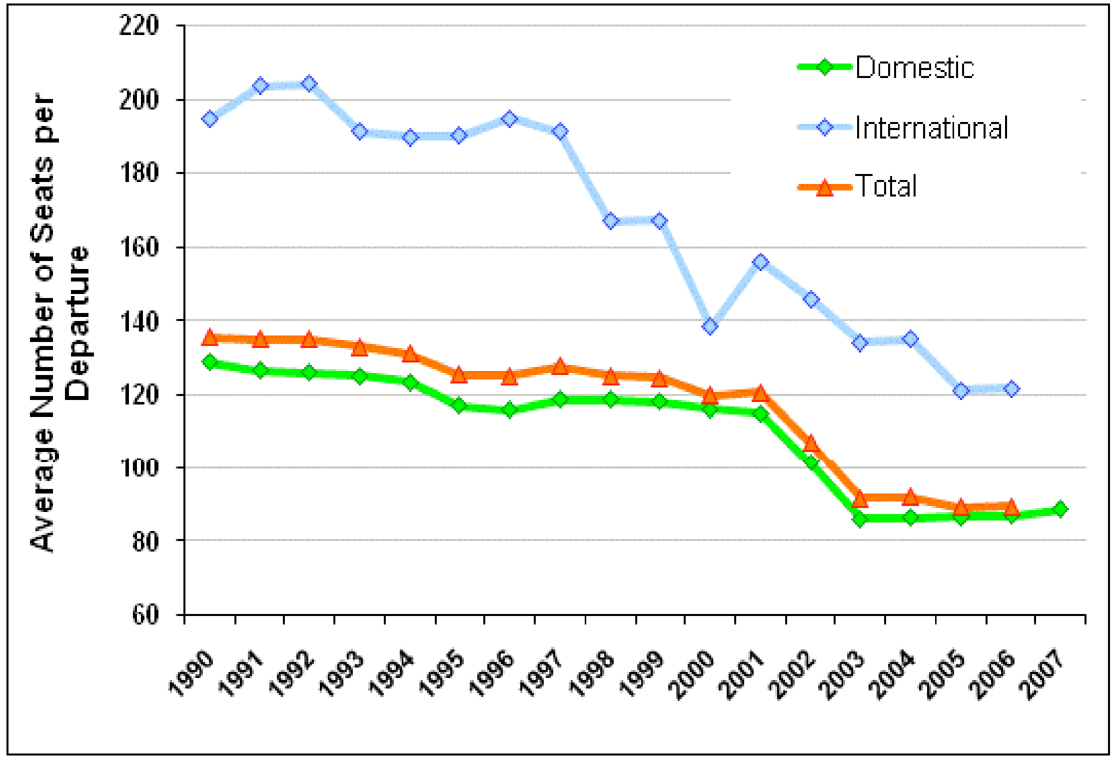
Causes of National Aviation System Delays:



*US Congress Joint Economic Committee Report (Schumer and Maloney, 2008)

Aircraft Sizes and Load Factors

1. Airlines prefer to fly many small planes rather than few big planes
   => Fewer seats per aircraft
2. Low load factors on routes between congested airports
   => Fewer passengers per seat



<u>As a result:</u>

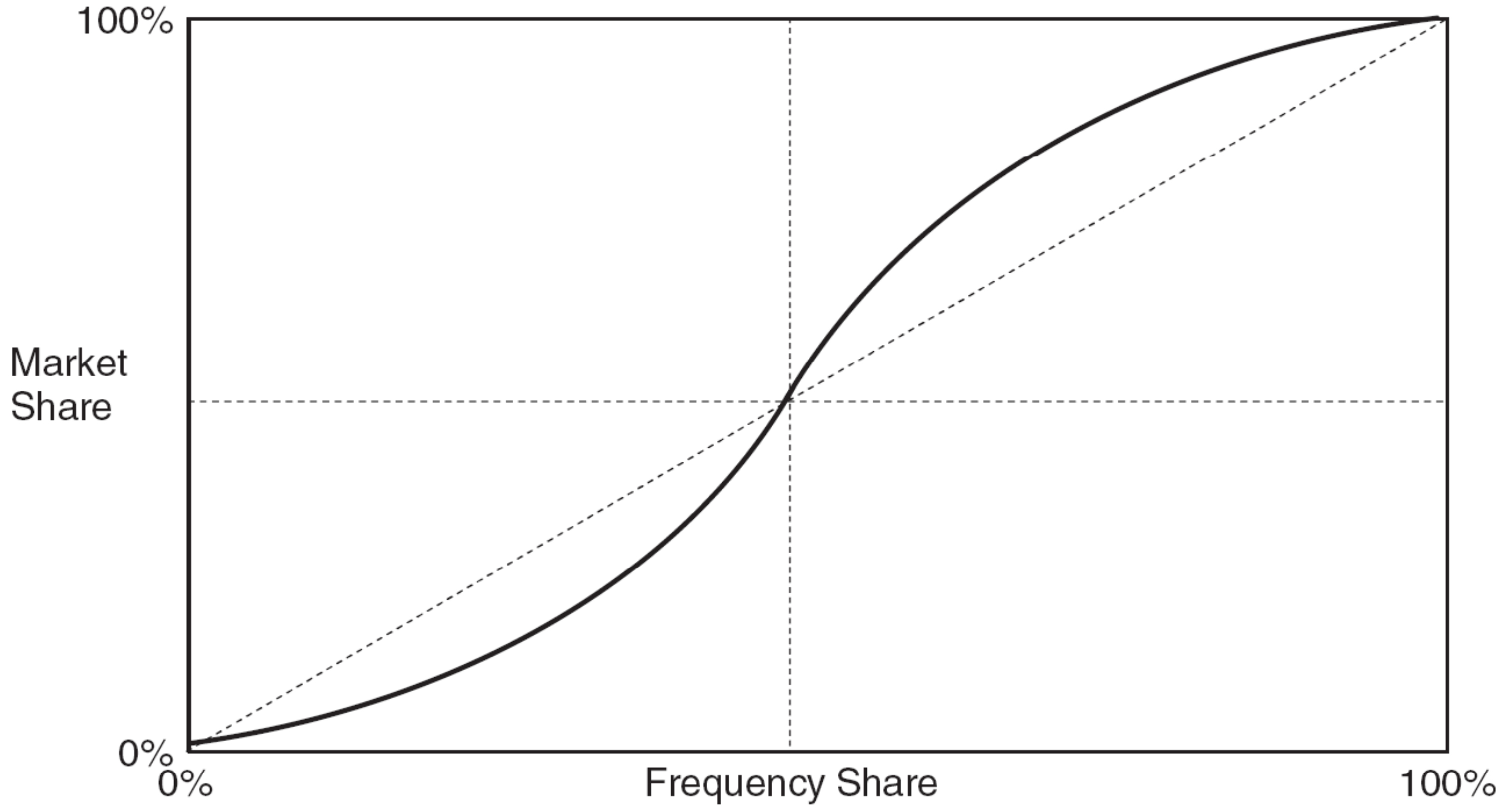
– Very few passengers per aircraft out of congested airports
– Out of LGA: 67 pax/flight on average

Some extreme examples:
(<u>Source:</u> T100 Segment Data)

Origin	Destination	Load Factor
BOS	LGA	53.3%
LGA	BOS	52.5%
DCA	LGA	50.4%
LGA	DCA	50.8%

Frequency Competition

- S-curve relationship between market share and frequency share
- Higher frequency shares associated with disproportionately higher market shares



Model of Frequency Competition

- Objective: Predict the airline frequency decisions under competition
- Focus: Nonstop segments out of LGA airport
- Solution concepts
  - Nash equilibrium
  - Myopic best response algorithm: While there exists an airline whose current frequencies are not optimal in relation to competitors' frequencies, re-optimize for that airline
  - Dynamic programming-based optimization methodology

Optimization Sub-Model

$$Maximize: \sum_{s \in S} (P_{a,s} * Q_{a,s} - C_{a,s} * f_{a,s})$$

Maximize total profit =
fare revenue – operating cost

Subject to:

$$Q_{a,s} \leq \frac{f_{a,s}{}^{\propto}}{\sum_{a' \in A} f_{a',s}{}^{\propto}} * M_s \ \forall s \in S$$

S-curve relationship between market share and frequency share

$$Q_{a,s} \leq Seats_{a,s} * f_{a,s} \ \forall s \in S$$

Seating capacity constraint

$$\sum_{s \in S} f_{a,s} \leq MAX\_SLOTS_a$$

Maximum number of available slots

$$\sum_{s \in S} f_{a,s} \geq MIN\_SLOTS_a$$

Minimum number of slots that must be utilized (Use-It-Or-Lose-It)

$$f_{a,s} \in \mathbb{Z}^+ \ \forall s \in S$$

Solution using Dynamic Programming

- Nonlinear constraints together with integrality constraints
- But the structure is suitable for dynamic programming since:
  - Slot restrictions are the only coupling constraints across different segments
  - Objective function is additive across segments
- No. of stages = No. of segments
- No. of states per stage = Maximum no. of slots

$$\text{Profit}(s,n) = \text{Segment s profit due to exactly n flights per day}$$

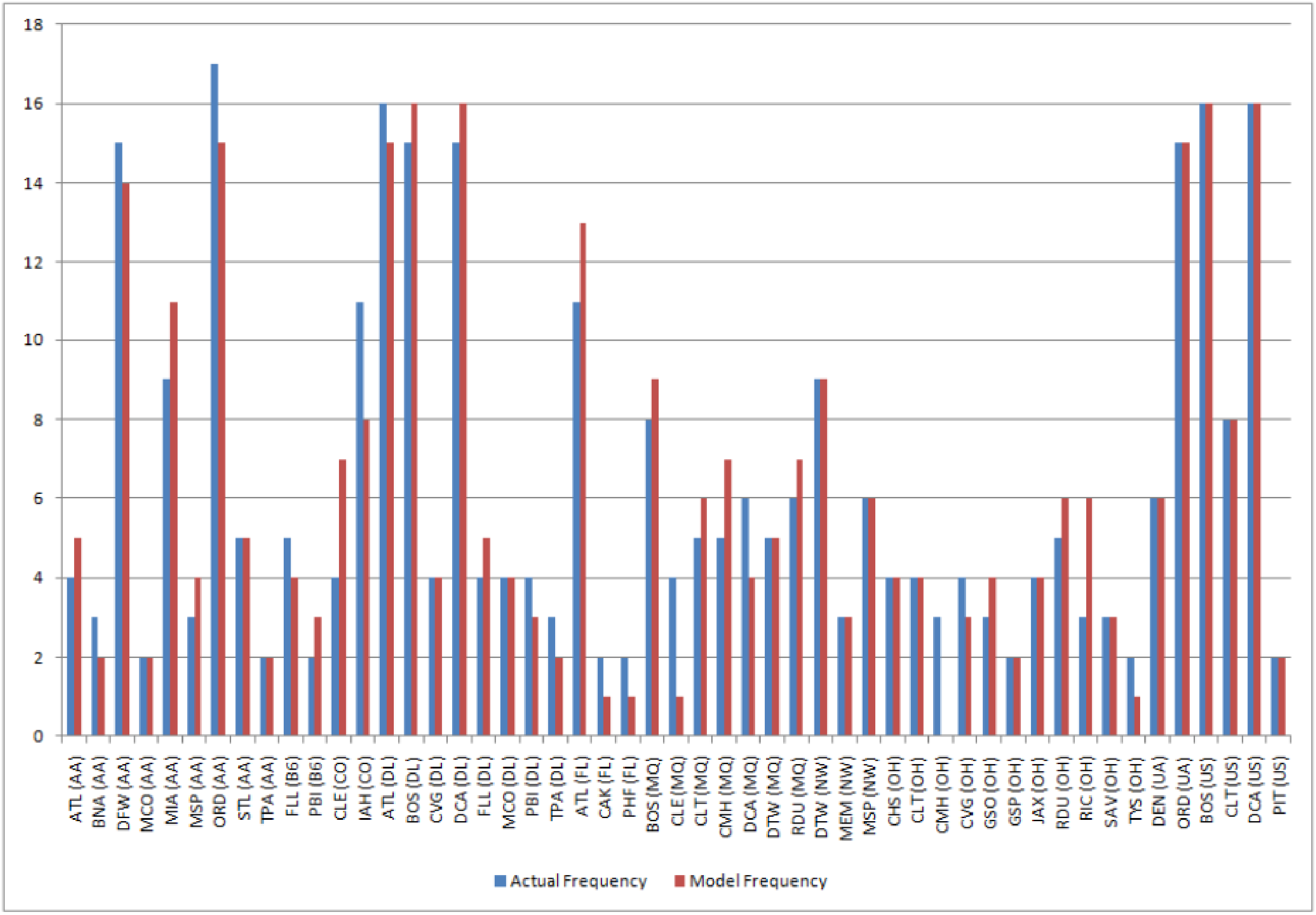
$$R(0,0) = 0, \quad R(0,n) = -\infty \; for \; n \geq 1$$

$$R(s,n) = \max_{0 \leq n' \leq n} \left(R(s-1, n') + Profit(s, n-n') \right)$$

$$Optimal\,total\,profit = \max_{MIN\_SLOTS_a \leq n \leq MAX\_SLOTS_a} R(|S|, n)$$

Empirical Validation:
Nonstop Segments Out of LGA

- Model predicted actual frequencies within 7% error



Slot Reduction Schemes Tested

1) Proportionate slot reduction
   - Number of slots available to each carrier reduced by same proportion
2) Reward based slot reduction
   - Slot reduction for each carrier proportional to inverse of passengers/slot
   - Idea is to reward those who are using their slots efficiently

<u>Assumptions:</u>

1) The aircraft sizes remain unchanged
2) The average load factor on any segment can never exceed 85%
3) Leg based deterministic demand and constant average fares
4) Revenue calculated assuming full itinerary fare (no fare proration)

Overall Impacts

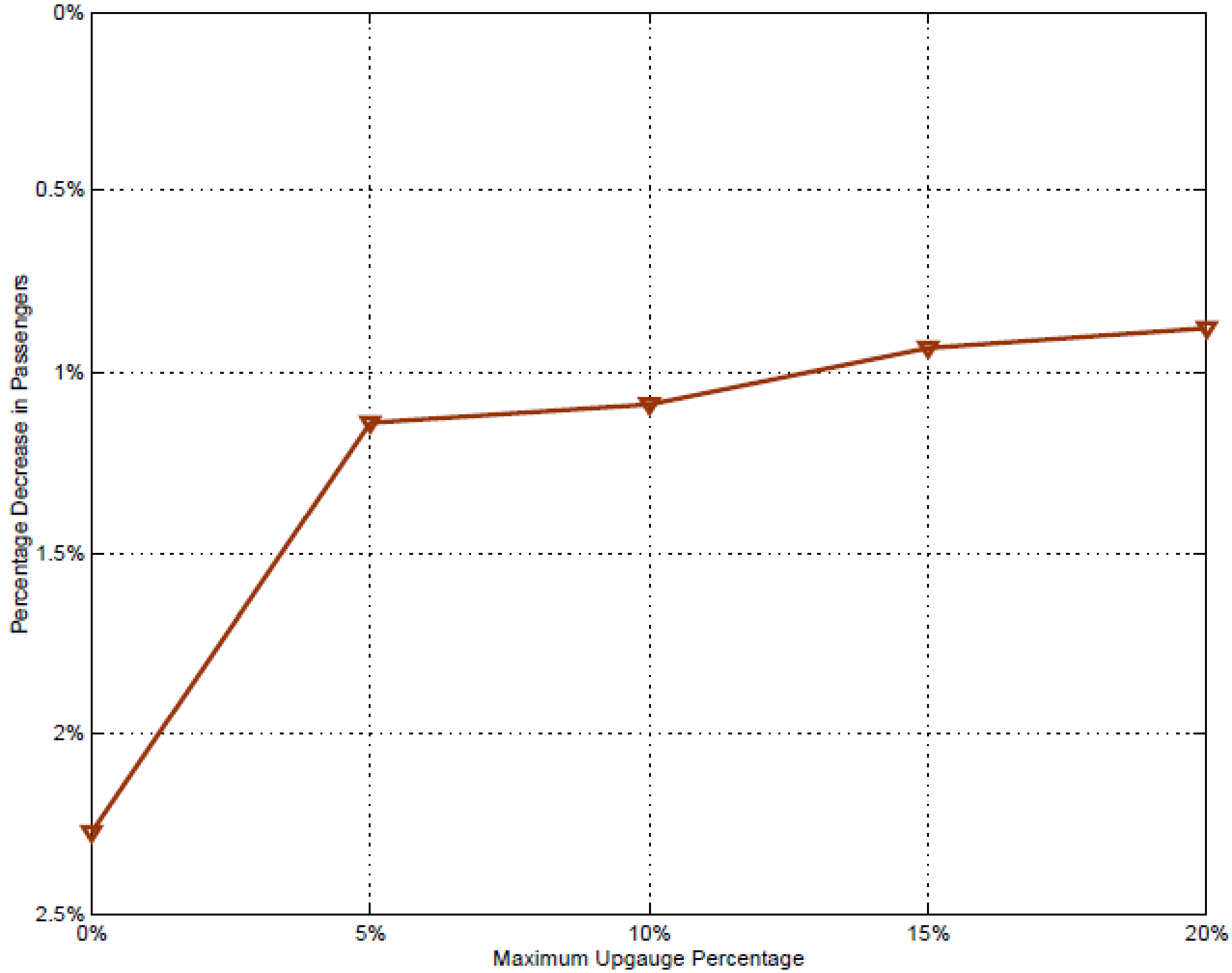
		No Reduction	12.3% Reduction	
Stakeholder	Metrics		Proportionate	Reward-based
Airline	Total Operating Profits (Excluding Flight Delay Costs)	$1,237,623	$1,475,217 (19.20%)	$1,446,520 (16.88%)
	NAS Delay per Flight	12.74 min	7.52 min (-40.97%)	7.52 min (-40.97%)
Passengers	Total Passengers Carried	22,184	21,680 (-2.27%)	21,728 (-2.05%)
	Average Passenger Delay (due to NAS Delays)	25.10 min	14.81 min (-40.97%)	14.81 min (-40.97%)
	Average Schedule Displacement	25.35 min	27.58 min (8.8%)	27.55 min (8.7%)

Impact on Individual Airlines

	No Reduction	12.3% Reduction	
Carrier		Proportionate	Reward-based
Network Legacy Carrier 1	$366,952	$416,322 (13.45%)	$406,107 (10.67%)
Low Cost Carrier 1	$48,061	$59,507 (23.82%)	$59,507 (23.82%)
Network Legacy Carrier 2	$65,996	$74,466 (12.83%)	$70,581 (6.95%)
Network Legacy Carrier 3	$196,215	$252,231 (28.55%)	$252,900 (28.89%)
Low Cost Carrier 2	$39,694	$46,632 (17.48%)	$48,331 (21.76%)
Regional Carrier 1	$19,831	$31,318 (57.92%)	$29,831 (50.43%)
Network Legacy Carrier 4	$112,578	$143,084 (27.10%)	$130,316 (15.76%)
Regional Carrier 2	- $1,579	$39,126 (n.a.)	$40,582 (n.a.)
Network Legacy Carrier 5	$208,020	$224,697 (8.02%)	$218,922 (5.24%)
Network Legacy Carrier 6	$181,855	$187,834 (3.29%)	$189,443 (4.17%)

With Limited Aircraft Upgauging

Percent Decrease in Passengers Vs. Maximum Upgauge Percentage (for 12.3% proportionate reduction)



With Different Assumptions about the Maximum Average Segment Load Factors

Maximum Average Segment Load Factor	Increase in Total Profits		Change in Total Passengers Carried	
	Proportionate	Reward-based	Proportionate	Reward-based
75%	15.83%	14.33%	-2.44%	-2.23%
80%	17.39%	17.55%	-2.52%	-1.94%
85%	19.20%	16.88%	-2.27%	-2.05%
90%	22.79%	16.44%	-0.41%	-1.49%
95%	18.90%	17.59%	-1.82%	-0.94%

With Distance-Based Fare Proration

	No Reduction	12.3% Reduction	
Metrics		Proportionate	Reward-based
Total Operating Profit (Excluding Flight Delay Costs)	$907,248	$1,067,706 (17.69%)	$1,121,707 (23.64%)
Total Passengers Carried	22,145	21,116 (-4.65%)	21,751 (-1.78%)

With Multiple Nested Fare Classes and Demand Uncertainty

	No Reduction	12.3% Reduction	
Metrics		Proportionate	Reward-based
Total Operating Profit (Excluding Flight Delay Costs)	$1,246,129	$1,511,805 (21.32%)	$1,468,370 (17.83%)
Total Passengers Carried	22,347	21,940 (-1.82%)	22,066 (-1.26%)

Summary

- Illustrated the impacts of frequency competition on airlines and passengers
- Modeled frequency competition out of LGA
- Tested two different demand management strategies
- Showed that slot reduction schemes can lead to:
  - approximately 15% to 20% increase in total airline profits
  - approximately 1% to 2% decrease in passengers carried
- Found the results to be not very sensitive to the assumptions