Competitive Frequency Analysis and Impacts on Congestion

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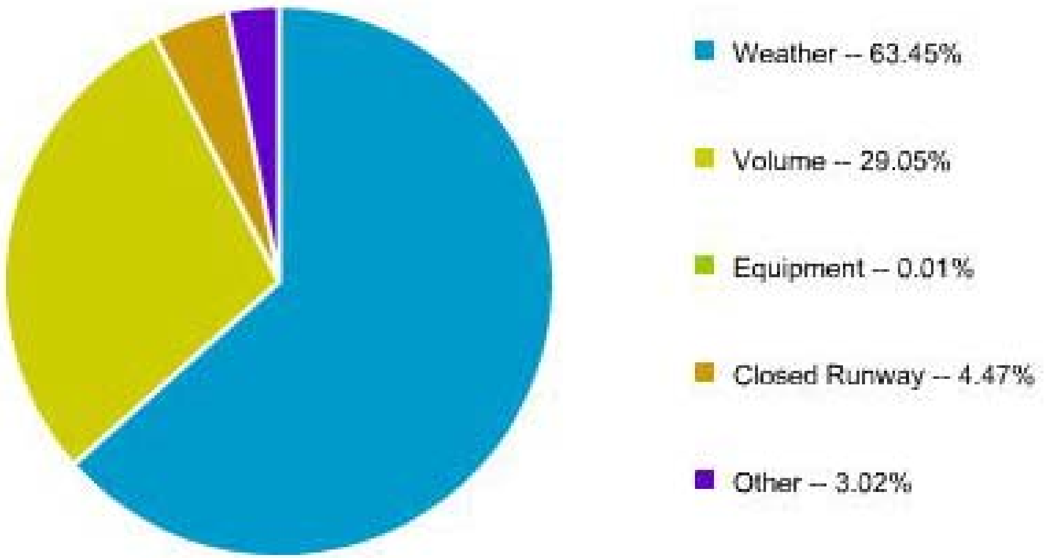
Delays and Over-scheduling

- Total aircraft delay in 2007: 134M minutes [1] (cost = $8.1B[1])
- Total passenger delay in 2007: 17B minutes [2] (cost = $8.5B[2])
- 92.5% of National Aviation System (NAS) delays attributed to scheduling more than the realized capacity

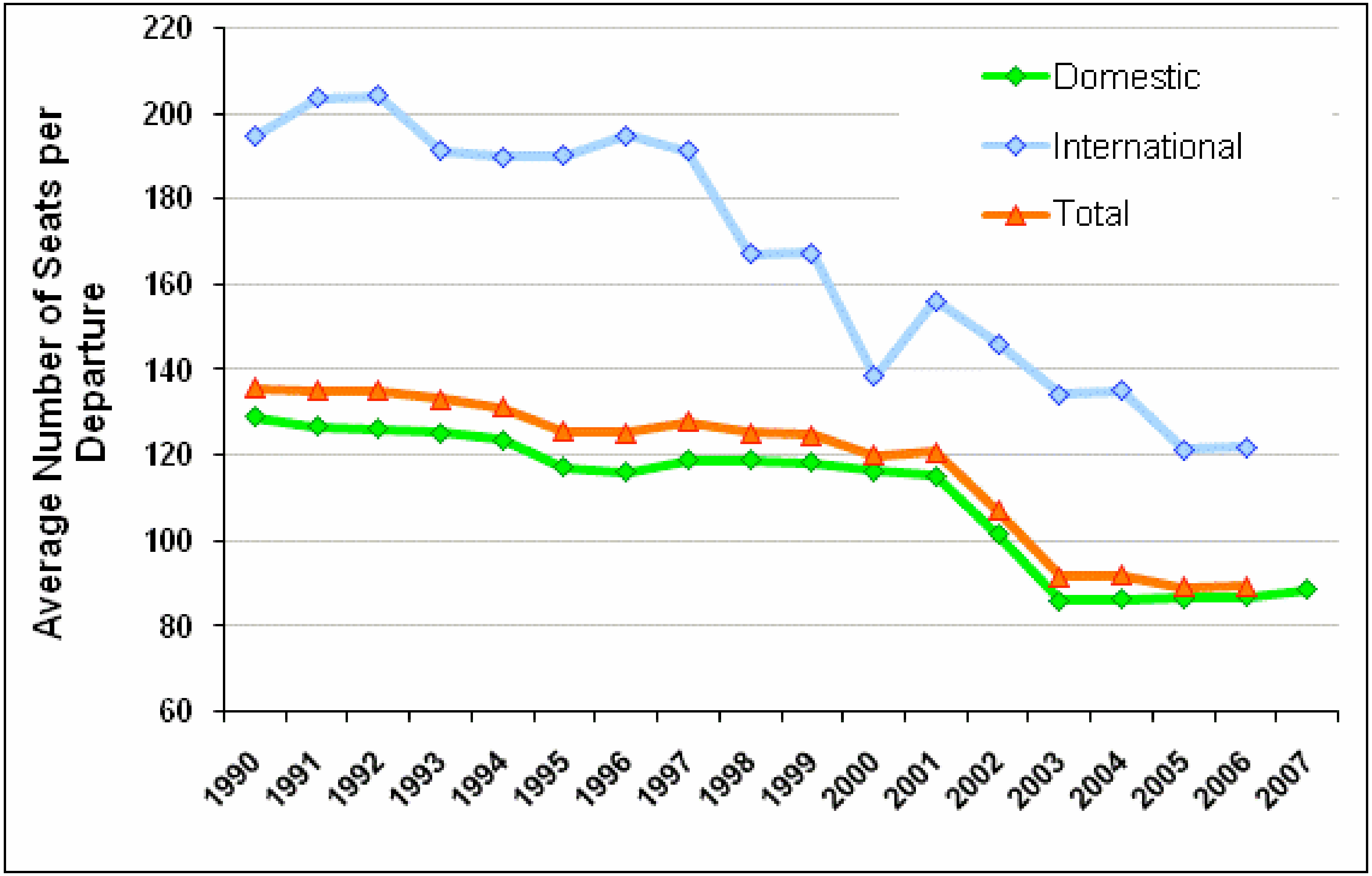


Causes of National Aviation System Delays

[[1]Source: Air Transport Association, 2008; [2]Source: U.S. Airline Passenger Trip Delay Report, 2008; [3]Source: Bureau of Transportation Statistics, 2009]

Decreasing Aircraft Sizes

- Airlines prefer to fly many small planes rather than few big planes



[Source: Bonnefoy and Hansman, 2008]

An Example of Over-scheduling

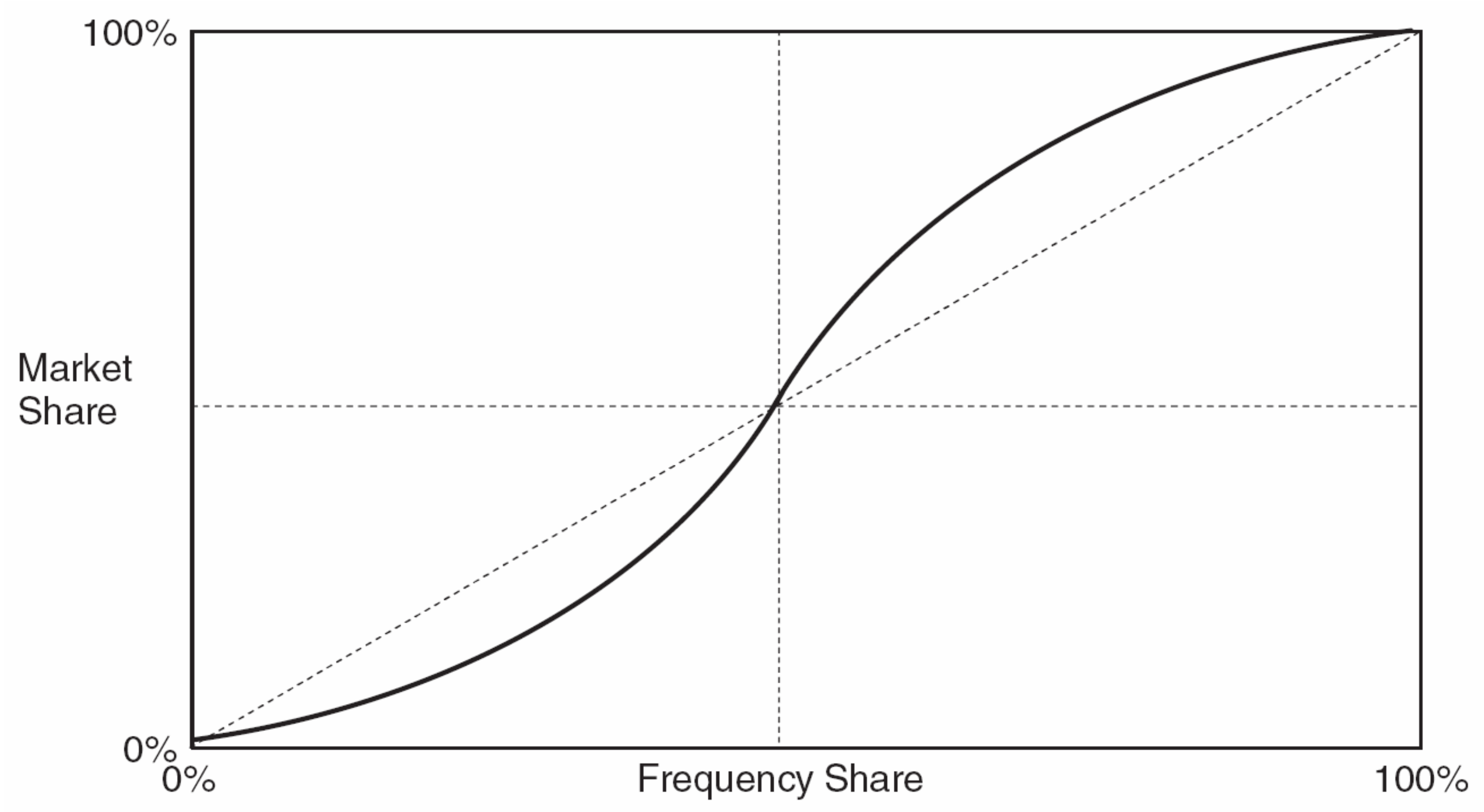
LGA-BOS:

40 direct flights per day

Carrier	Flight No.	Dep. Time	Arr. Time
DL	1906	**6:00**	**7:00**
US	2114	**6:00**	**7:00**
DL	1908	**6:30**	**7:34**
MQ	4803	**7:00**	**8:15**
US	2116	**7:00**	**8:12**
DL	1910	7:30	8:37
US	2118	8:00	9:12
MQ	4802	8:20	9:30
DL	1912	8:30	9:40
US	2120	9:00	10:16
DL	1914	9:30	10:46
US	2122	10:00	11:15
DL	1916	10:30	11:47
MQ	4805	10:50	12:05
US	2124	11:00	12:15
DL	1918	11:30	12:46
US	2126	12:00	13:10
DL	1920	12:30	13:39
US	2128	13:00	14:11
DL	1922	13:30	14:39

Frequency Competition

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



Computation of a Lower Bound on Airport Congestion

- Problem Statement:
  - Design a schedule to minimize airport congestion while satisfying all the demand and maintaining the same level-of-service
  - Carry as many passengers as being carried currently for each market for each time of the day
  - Provide a daily frequency equal to the maximum daily frequency provided currently in that market
- Results:
  - No more than 92% of bad-weather capacity (IFR) is required
  - Substantial reduction in airport congestion can be achieved with existing capacity

Multi-Agent Model

- A system of profit maximizing agents
- Optimal frequency decision (f_a) for an airline *a* depends on actions by other airlines (f_{-a})
- Nash Equilibrium:

  A frequency profile f is a Nash Equilibrium if for every airline *a*,

  f_a is the best response to f_{-a}

- Solution Methodology: "Myopic Best Response"

  While there exists a carrier whose current decision is not optimal in relation to others' decisions, re-optimize for that carrier

- Optimization problem solved using dynamic programming

Results fit reality reasonably well: 7% error in frequency estimates

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

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

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

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

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

Slot Reduction Schemes

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

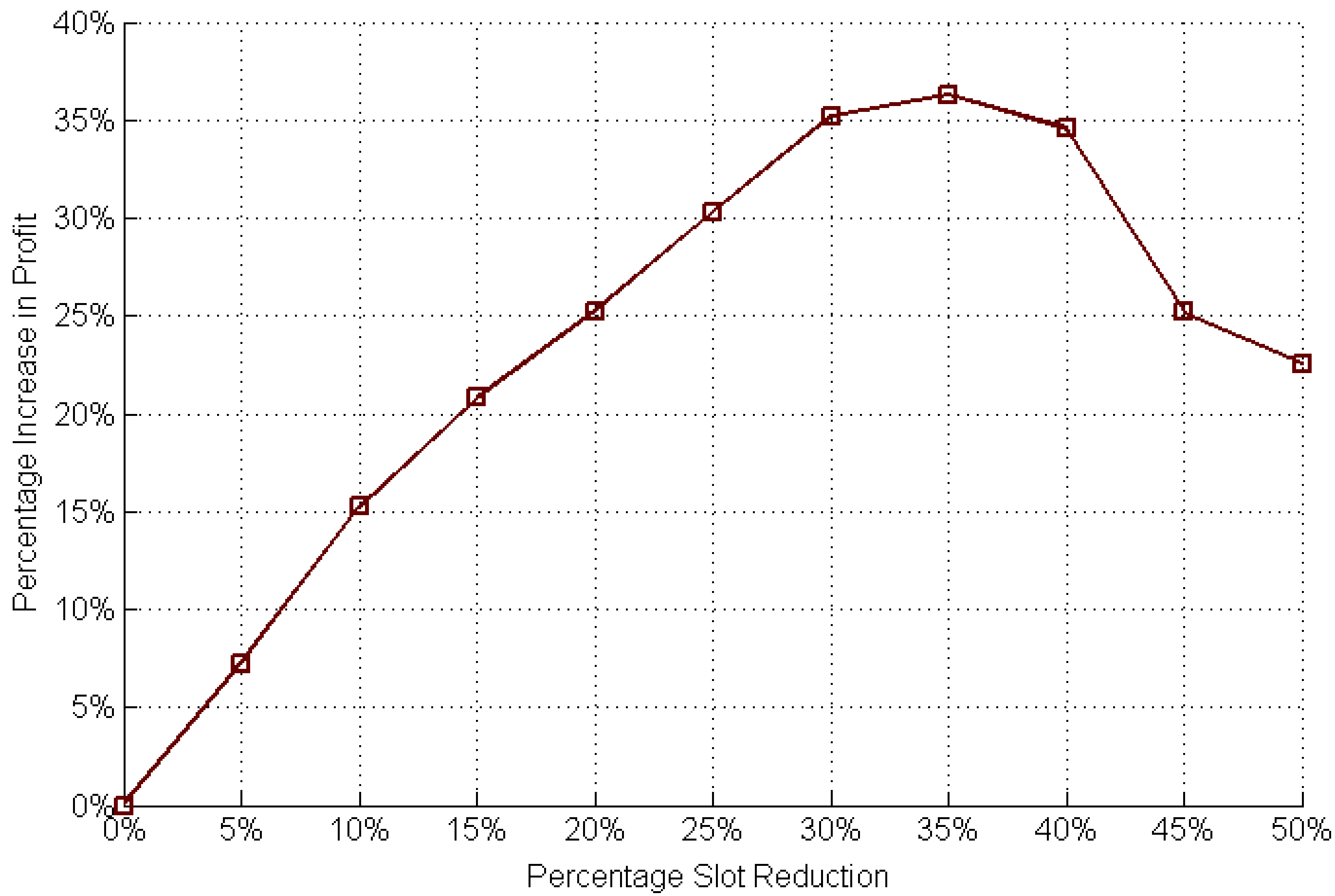
Note: In this experiment we assume that the aircraft sizes remain unchanged

Overall Impact

Scheme	Do Nothing	20% Reduction (Proportionate)	20% Reduction (Reward-based)
Total Operating Profit	$ 1,252,362	$ 1,568,814 (25.27%)	$ 1,565,490 (25.00%)
Passengers Carried	22,260	21,291 (-4.35%)	21,464 (-3.58%)
NAS Delay per Flight	12.74 min	7.52 min (-40.97%)	7.52 min (-40.97%)

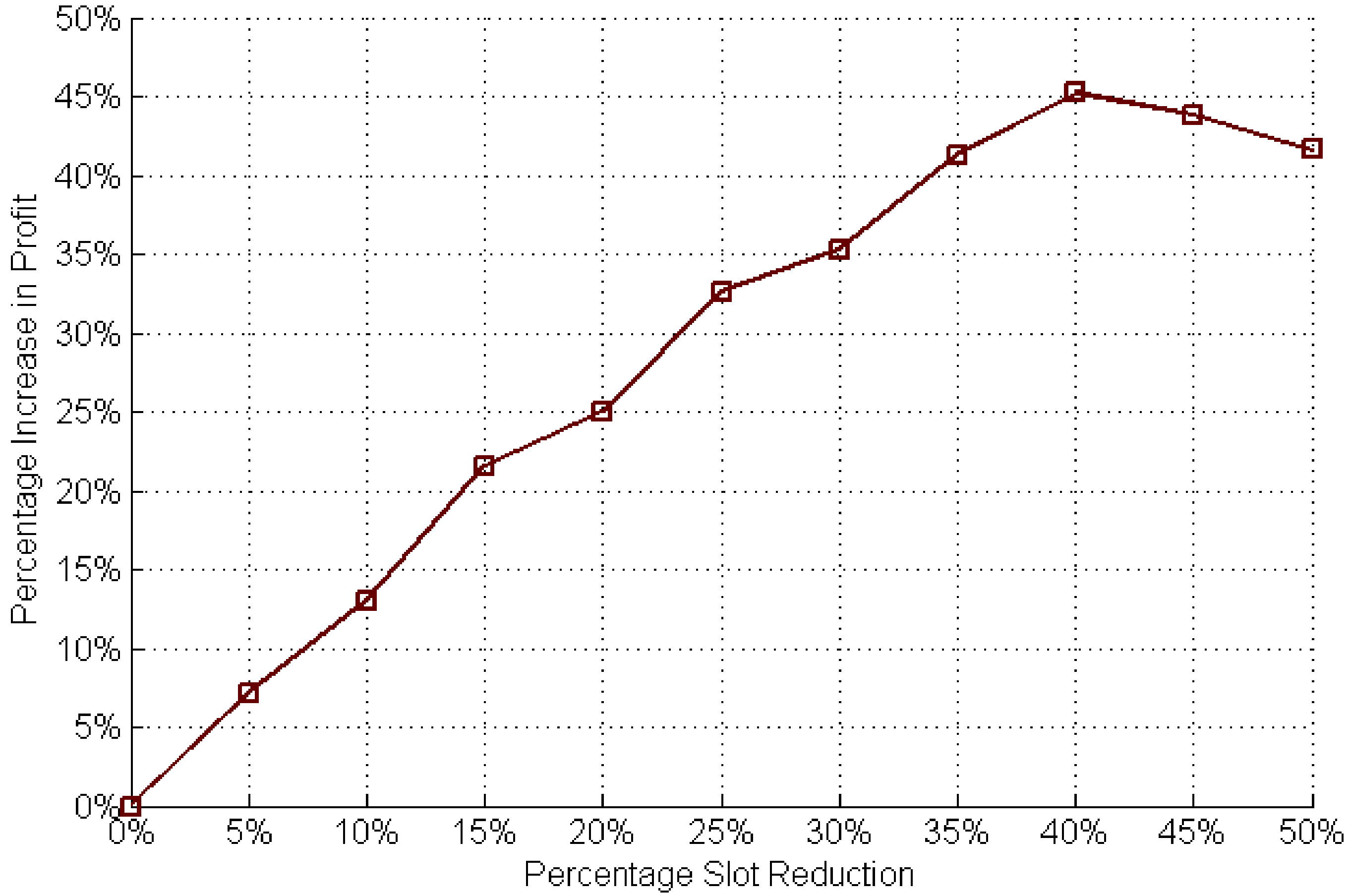
Proportionate Slot Reduction Scheme

Increase in Profit Vs. Slot Reduction Percentage



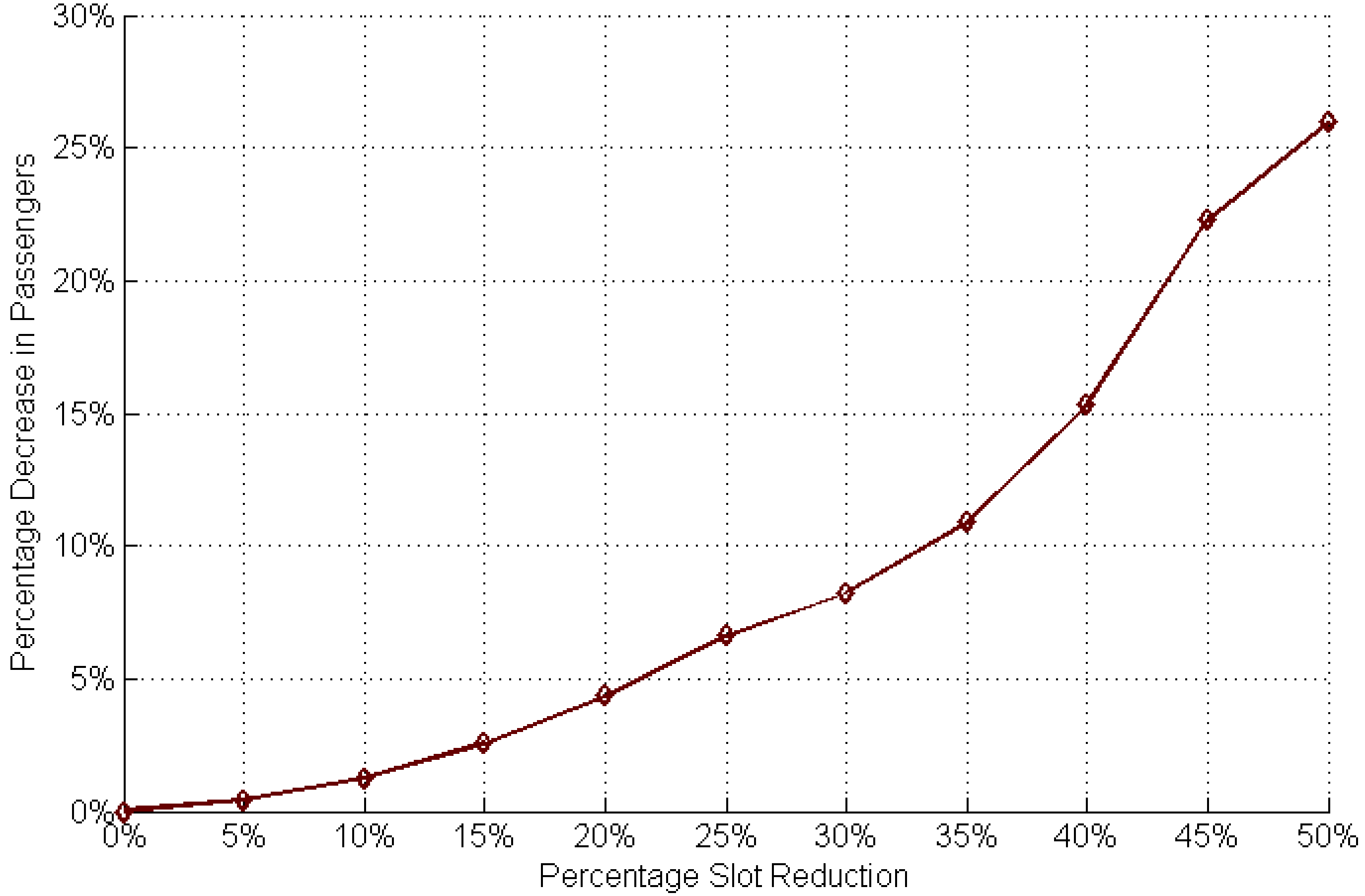
Reward Based Slot Reduction Scheme

Increase in Profit Vs. Slot Reduction Percentage



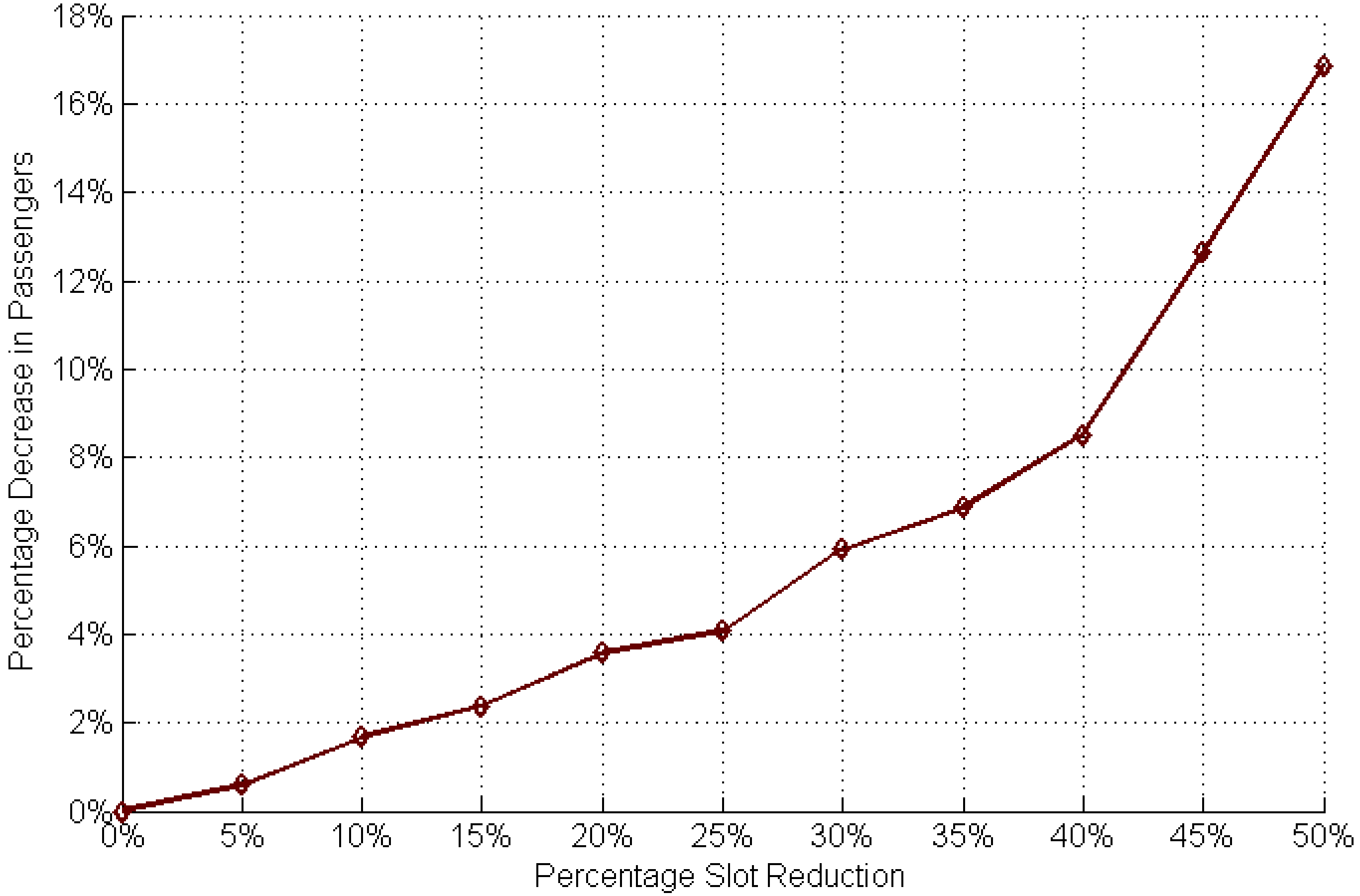
Proportionate Slot Reduction Scheme

Decrease in Number of Passengers Vs. Slot Reduction Percentage



Reward Based Slot Reduction Scheme

Decrease in Number of Passengers Vs. Slot Reduction Percentage

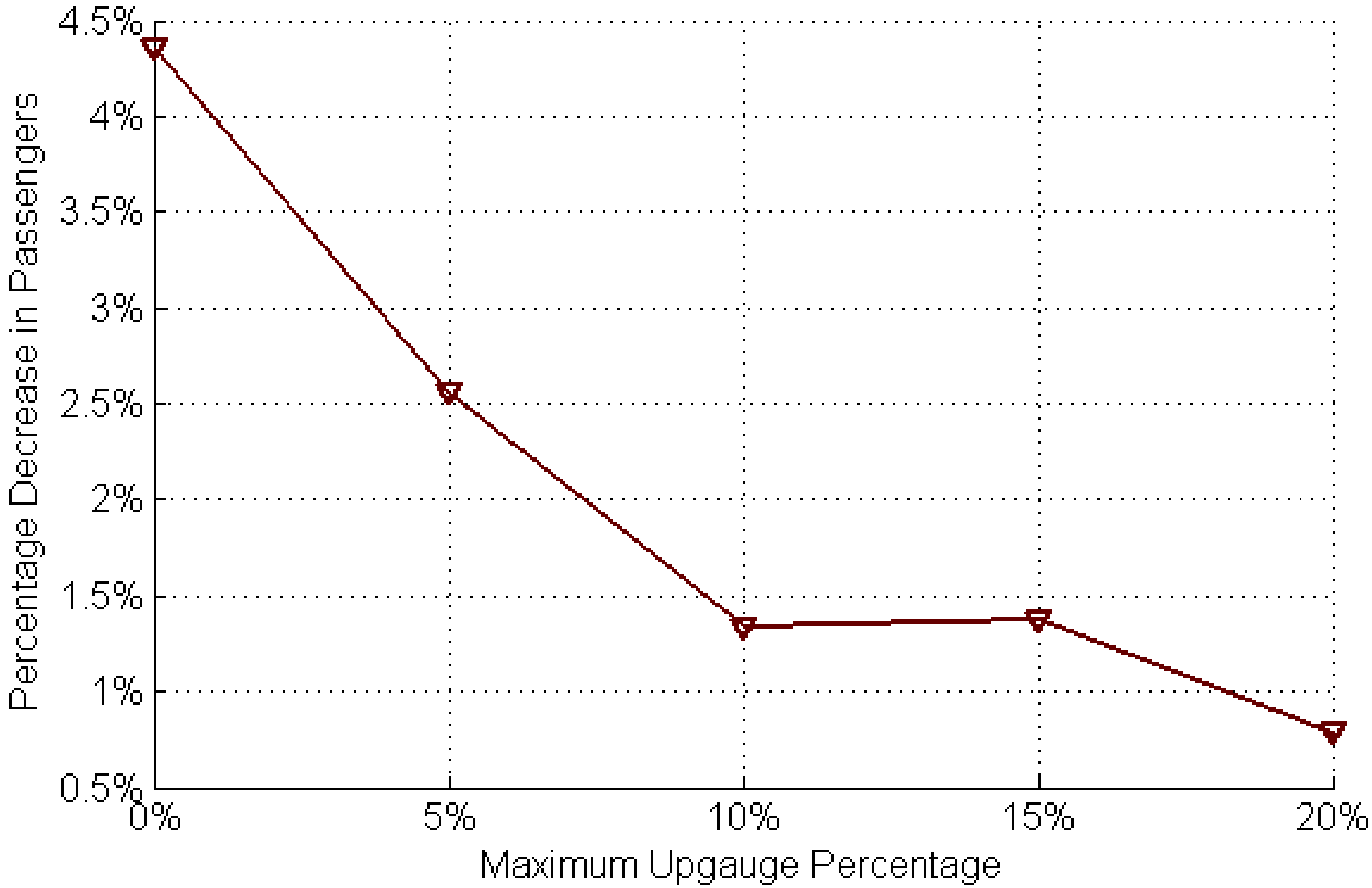


Impact on Individual Airlines

Slots	100%	80%			
Scheme	-	Proportionate		Reward Based	
Carrier	Profit	Profit	Profit Increase	Profit	Profit Increase
AA	365,582	447,897	22.52%	422,943	15.69%
CO	66,450	73,205	10.17%	79,820	20.12%
DL	188,352	285,531	51.59%	274,352	45.66%
FL	36,908	52,891	43.30%	55,406	50.12%
MQ	33,630	43,579	29.58%	35,705	6.17%
NW	107,006	107,920	0.85%	127,265	18.93%
OH	34,638	54,144	56.31%	54,916	58.54%
UA	200,796	233,188	16.13%	241,936	20.49%
US	170,939	225,209	31.75%	227,897	33.32%
Total	1,252,362	1,568,814	25.27%	1,565,490	25.00%

Impact of Aircraft Upgauges

Decrease in Number of Passengers Vs. Upgauge Percentage (20% proportionate reduction)



Conclusions

- Significant part of airport congestion and delays can be attributed to inefficient utilization of airport capacity
- Frequency competition can be depicted as a Nash equilibrium model where frequency decisions of each airline depend on those of its competitors
- Simple slot control schemes have the potential to reduce the congestion and become attractive to all the stakeholders
- Next steps:
  - integrate aircraft size decisions with frequency planning
  - introduce time-of-the-day element in slot allocation

Thank You!

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