

# Do More U.S. Airports Need Slot Controls?: A Welfare Based Approach to Determine Slot Levels

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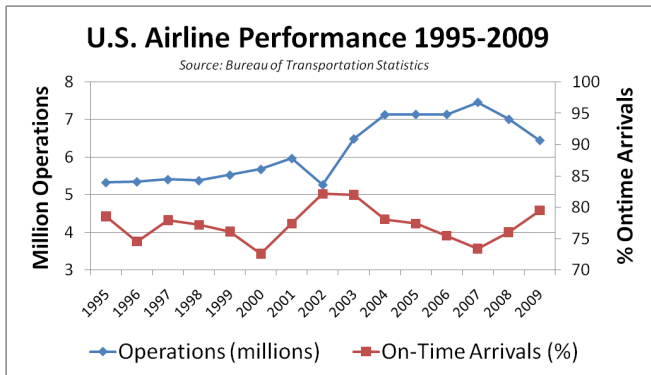
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They do not reflect any official opinions or policies of the FAA or the U.S. Department of Transportation.

- 1 Introduction
  - Motivation
  - Research Agenda
- 2 Slot Controls: Design Issues and Tradeoffs
- 3 Estimation Models
  - Schedule Delay
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- 4 Results and Conclusions
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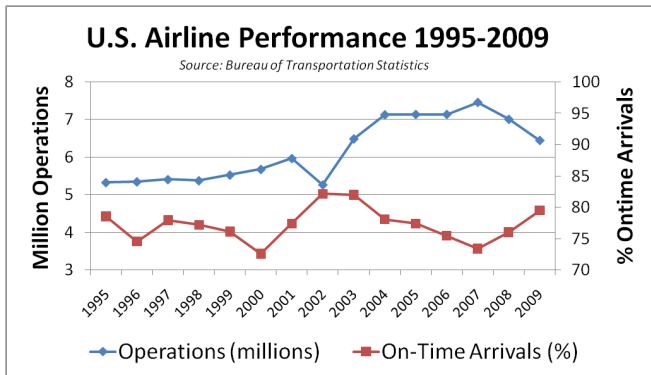
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- As capacity utilization increases, suffers non-linear delays.
- Significant costs to airlines, passengers, and society.

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## Increase Supply

- Infrastructure enhancements:
- New runways, airports, capacity-enhancing technology and systems.
- Expensive, politically controversial, technically challenging.

## Manage Demand

- Reduce peak capacity utilizations:
- Slot controls, congestion pricing.
- Influence behavior of passengers and/or airline companies.
- Likely to reduce service.
- Social and political hurdles.

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# Contrasting Approaches to Congestion Management

## Europe

- Virtually all major European airports are slot controlled (based on EEC and IATA rules).
- “Grandfather rights” and “use-it-or-lose-it” rules.
- Slot limits set near bad weather conditions (IMC), i.e. lower level of operations.

## U.S.

- Largely first-come-first-served system.
- Access limited only by availability of terminal facilities.
- Historical exceptions:
  - High density rule (HDR), 1968.
  - Chicago OHare (ORD), Washington Reagan National (DCA) and NY airports: LaGuardia (LGA), Kennedy (JFK) and Newark Liberty (EWR).
  - HDR similar to IATA, but included buy-sell provision.
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# Airport Congestion Management in the U.S.

## Inherent problem

- Multiple, competing airlines seek to use common airport capacity.
- Incremental addition of a flight may cause much more delay to other flights, than experienced by itself.
- ...without controls, an airport will naturally evolve to a highly congested state.

## Solution attempts

- A flurry of activity in last 8 years.
- Some bold proposals advanced, including a slot auction, but in the end strong entrenched forces have blocked change.
- ...need for research that examines impact on all stakeholders, most importantly the passenger.

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# Fundamental Research Questions

- 1 What are the key tradeoffs involved in setting a limit on the number of operations at an airport?
- 2 Should more US airports have slot controls?
- 3 How should the level of operations be set at slot controlled airports?
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# Two Related NEXTOR Research Projects

## Congestion Management for US Airports

- Project funded by the FAA and US Department of Transportation; motivated by expiration of High Density Rule at LGA.
- Specifically considered various congestion management options for LGA (and other US airports).
- Project conducted two multi-day “strategic simulations” that brought together decision makers from airports, airlines and the Federal Government.

## Total Delay Impact Study

- Quantified the total cost impact of all US air transportation delays at \$28.9 b.
- Employed recent NEXTOR research that modeled passenger delays taking into account flight cancellations and missed connections.
- Quantified impact of demand lost to other modes.
- Expanded science base quantifying delays and their economic impact.

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# Cost-Benefit Analysis of Slot Controls for Passengers

## Primary Effects

- Movement of flights from peak to off-peak hours in schedule.
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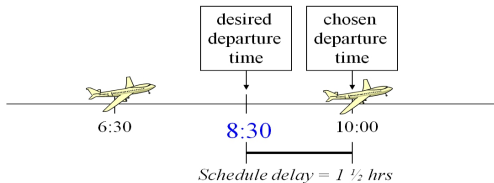
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- Implementation issues, eg, small community access, incentives, international flights, local vs Federal control.

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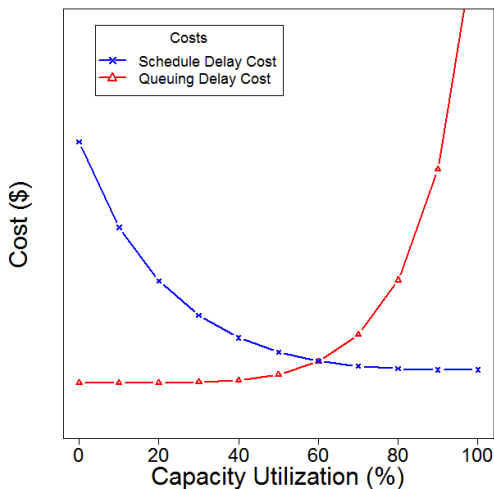
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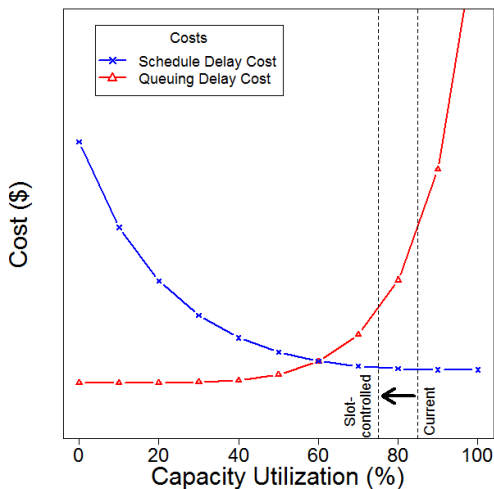
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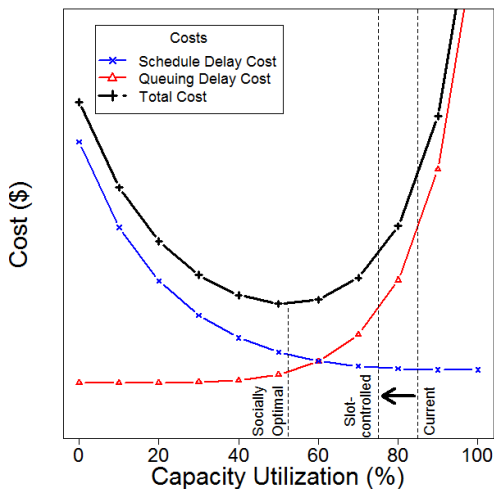
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# Approaches to Estimate Schedule Delay

## *FlightMove* Model

- Assumes airlines will not drop any flights upon imposing slot-controls.
- Suitable for relatively higher slot-levels.
- We use it for airports with sufficient capacity to handle current demand despite slot-controls.

## *FlightTrim* Model

- Assumes airlines will drop flights in excess of slot-control limits.
- Suitable for stringent slot-levels.
- We use it for airports where current demand can not be served at one or more time-periods upon introducing slot-controls.

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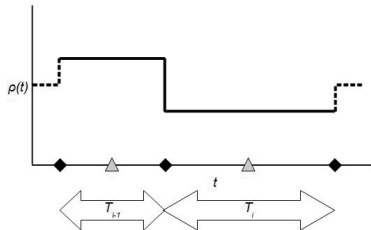
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# Flight Trim Model



- Simple cost function derived for schedule delay cost from first principles.
- Marginal cost computed by iteratively dropping an “average” flight.
- Excess flights dropped until remaining flights are below the slot-level capacity.
- Marginal cost summed up over each iteration and destination.
- Cost of deleting one average flight (assuming 4-hour period):

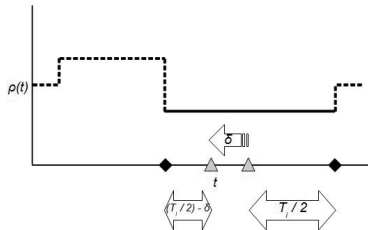
$$MSDC^{FT} = \sum_d 4\Lambda\rho_d \left( \frac{1}{N_d - 1} - \frac{1}{N_d} \right)$$

$\Lambda$  = passenger valuation of time

$\rho_d$  = demand density function for destination  $d$

$N_d$  = number of remaining flights for destination  $d$

# FlightMove Model



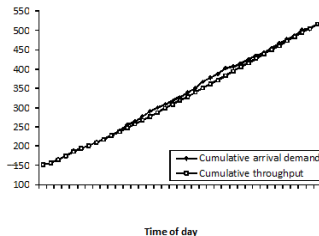
- Uses simulation to randomly perturb current schedule.
- At a time-point with excess flights, a portion of flights for selected destinations are moved to a nearby time-point.
- Iterates until all time-points have flights below the desired slot-level.
- Finds minimum cost of perturbation from actual schedule to simulated predicted schedule, using Transportation Model.
- Cost function derived for schedule delay on moving a flight across time-periods:

$$MSDC^{FM} = \sum_d \Lambda \rho_d \delta_d^2 f_d$$

$\delta_d$  = number of time-periods perturbed

$f_d$  = number of flights of  $d$  perturbed

# Deterministic Queuing Delay Model



- Models the operational demand and supply relationship.
- Predicts the observed flight delays at the national level well.
- Based on the time profile of scheduled flight demand and airport capacity over the course of a day
- Capable of capturing temporal characteristics of scheduled demand, such as peakedness.
- Employing Little's Law, total deterministic queuing delay is calculated as the area between the cumulative scheduled arrivals and cumulative throughput curves.
- Procedure repeated for each day in 2007 and each of the OEP35 airports.

# Approach to Estimate Delay Against Schedule

Econometric specification:

$$D_{it} = \beta_0 + \beta_1 Q_{it} + \beta_2 Q_{it}^2 + \beta_3 Q_{it}^3 + \beta_4 IFR_{it} + \beta_5 IFR_{it}^2 + \beta_6 Wd_{it} + \beta_7 Temp_{it} \\ + \beta_8 AAR_{it} + \beta_9 Connect_{it} + \sum_k \omega_k q_k(t) + \sum_j \lambda_j m_j(i) + \epsilon_{it}$$

$D_{it}$	=	Average positive arrival delay against schedule per flight, in minutes, at airport $i$ during day $t$ ,
$Q_{it}$	=	Average deterministic arrival queuing delay per flight, in minutes, at airport $i$ during day $t$ ,
$Q_{it}^2$	=	The square of average deterministic arrival queuing delay per flight,
$Q_{it}^3$	=	The cube of average deterministic arrival queuing delay per flight,
$IFR_{it}$	=	The portion of time during day $t$ in which airport $i$ operated under Instrument Flight Rules (IFR) conditions,
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## Estimation Procedure:

- Panel created for all OEP35 airports for (almost) each day in 2007.
- Deterministic queuing delay model ran for all airports for each day.
- Prais-Winsten regression allowing first-order auto-correlations conducted.

## Estimation Results Summary:

- All coefficients' signs as expected.
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- Higher  $IFR$  causes more delay, effect non-linear due to negative  $IFR^2$  coeff.
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- $Q$  coeff almost one, higher-powers have smaller coeff's.
- Higher *IFR* causes more delay, effect non-linear due to negative  $IFR^2$  coeff.
- Stronger *Wd* and lower *Temp* cause higher delays.
- Larger *AAR* has smaller delays.
- Higher *Connect* leads to larger delays.

## Prediction:

- Daily predictions using estimated coeff's averaged into monthly delays.
- Monthly average predictions also fit monthly average delays well.
- Finally, predictions made for **slot-controlled schedules**.

# Data

## Data Sources:

- FAA's Aviation System Performance Metrics (ASPM) for aggregate schedule and capacity data.
- US DOT's Bureau of Transportation Statistics (BTS) for on-time performance and load factors.
- Official Airline Guide (OAG) for detailed schedules.

## Period:

- August, 2007 is target period of study.
- 2007 had worst on-time performance in history.
- August represents an "average" month, has no weather and holiday extremities.
- Tuesday, Wednesday, Thursday data used to capture busy period.

## Scope:

- Arrival operations at each airport.

- 1 Introduction
  - Motivation
  - Research Agenda
- 2 Slot Controls: Design Issues and Tradeoffs
- 3 Estimation Models
  - Schedule Delay
  - Delay Against Schedule
  - Data
- 4 Results and Conclusions
  - Results
  - Wrap-up

# Combined Results

SL	Net Benefit(SL) = MQDC_SL – MSDC_SL			Incremental Benefit(SL)		Benefit Ratio(SL) = $\frac{MQDC\_SL}{MSDC\_SL}$			Rec SL
	80%	90%	100%	80%	90%	80%	90%	100%	
Airport	(i)	(ii)	(iii)	(iv)=(i)-(ii)	(v)=(ii)-(iii)	(vi)	(vii)	(viii)	(ix)
ATL	-\$127,268	\$130,015	\$99,556	-\$257,283	\$30,459	0.63	3.42	4.78	90%
CLE	\$50,774	\$49,059	\$40,904	\$1,715	\$8,155	5.74	8.07	9.55	80%
CLT	\$98,902	\$99,351	\$86,283	-\$449	\$13,068	5.57	8.98	12.00	90%
DCA	\$28,851	\$34,950	\$29,623	-\$6,099	\$5,327	3.48	7.41	10.34	90%
DTW	\$58,467	\$54,708	\$46,440	\$3,758	\$8,268	3.07	4.31	6.20	80%
EWR	\$351,971	\$389,256	\$30,565	-\$37,285	\$358,691	3.90	9.91	1.82	90%
IAD	\$30,065	\$24,060	\$17,657	\$6,004	\$6,403	5.47	6.83	8.50	80%
JFK	\$418,418	\$387,939	\$34,517	\$30,478	\$353,423	3.94	8.40	2.07	80%
LAX	-\$9,791	\$9,189	\$3,081	-\$18,980	\$6,108	0.64	3.73	4.89	90%
LGA	\$152,468	\$170,489	\$31,547	-\$18,021	\$138,943	3.47	7.25	4.54	90%
MSP	\$31,558	\$23,743	\$12,143	\$7,815	\$11,600	2.83	3.85	4.04	80%
ORD	\$64,012	\$122,215	\$47,737	-\$58,202	\$74,477	1.63	7.44	6.66	90%
PHL	-\$101,722	\$77,302	\$83,597	-\$179,024	-\$6,295	0.62	2.64	5.38	100%
PHX	\$46,851	\$51,243	\$44,986	-\$4,392	\$6,257	5.19	9.09	11.54	90%
SAN	-\$18,270	\$29,065	\$33,305	-\$47,335	-\$4,240	0.67	4.83	13.93	100%
SEA	\$2,977	\$10,704	\$7,814	-\$7,727	\$2,890	1.21	6.83	11.90	90%

16 airports in the U.S. could benefit by slot-limits set even at 100% capacity.

12 of them while serving current demand.

# Combined Results

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4 airports will see **drop in service** when slot-limits are at 80% and 90% capacity.

SL	EWR	JFK	LGA	ORD
80%	11%	9%	15%	7%
90%	4%	4%	7%	2%

# Combined Results

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	80%	90%	100%	80%	90%	80%	90%	100%	
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Slot-limits at 90% and 100% capacity are justified at all of these 16 airports.

4 airports **do not justify** slot-limits at 80%: ATL, LAX, PHL, SAN.

# Combined Results

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	80%	90%	100%	80%	90%	80%	90%	100%	
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(iv) and (v) give Incremental Benefit for each airport going stepwise from 100% to 90% (v), and from 90% to 80% (iv).

2 airports **have better incremental returns** with slot-levels set at 100%: PHL, SAN.

9 airports **have negative incremental returns** with slot-levels set at 80%.

Remaining 5 airports have best incremental returns with slot-levels set at 80%.

# Combined Results

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(vi), (vii), (viii) give “Returns on Investment” for each airport at the three slot levels.

Note diminishing returns.

# Combined Results

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Currently slot-controlled airports: DCA, EWR, JFK, LGA are in the list.

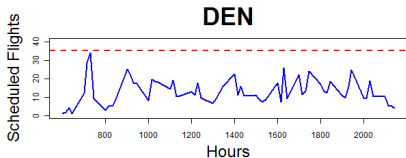
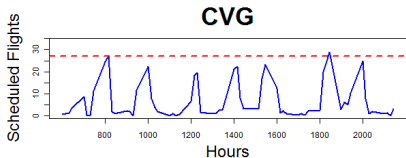
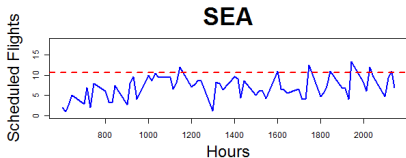
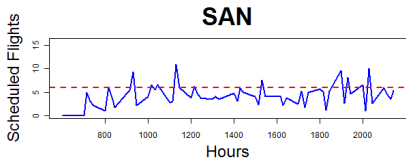
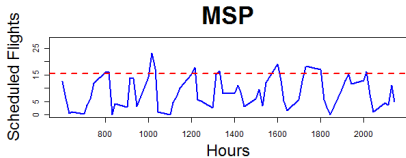
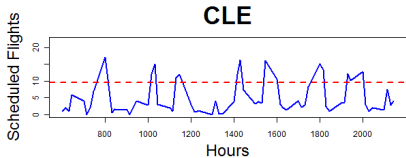
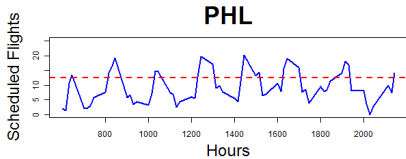
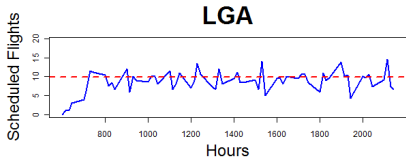
Indicates current slot-control levels are **set too high**.

# Combined Results

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List includes airports not considered to be highly congested: CLE, MSP, SAN, SEA.

These have few demand peaks beyond peak capacity, and **leveling those peaks could be valuable** at these airports.



# Wrap-Up

## Summary of Contributions:

- Broad view of issues involved in imposing slot-controls at U.S. airports.
- Experience and feedback from Federal Government proposed rulemakings incorporated in outlining guidelines and concern areas.
- Non-linear relationship specified between queuing delay costs and schedule delay costs as functions of peak capacity utilization.
- Models developed to quantify costs and benefits of implementing slot-controls at major U.S. airports.
- Results indicate justification of more pervasive use of slot-controls.

## Limitations:

- Impact on competition and fares not modeled.
- Administration and other costs involved in implementing slot-control not included.

# Do More U.S. Airports Need Slot Controls?: A Welfare Based Approach to Determine Slot Levels

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Opinions expressed are solely those of the authors.

They do not reflect any official opinions or policies of the FAA or the U.S. Department of Transportation.