Operational Performance and Demand Management

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NEXTOR Short Course

10/14/04

Outline

- Recent trends in NAS Operational Performance
- The Costs of Delay
- Operational Impacts of Supply and Demand Side Changes
  - DFW Case Study
  - LGA Case Study
- The Case for Demand Management

Recent Trends in NAS Operational Performance

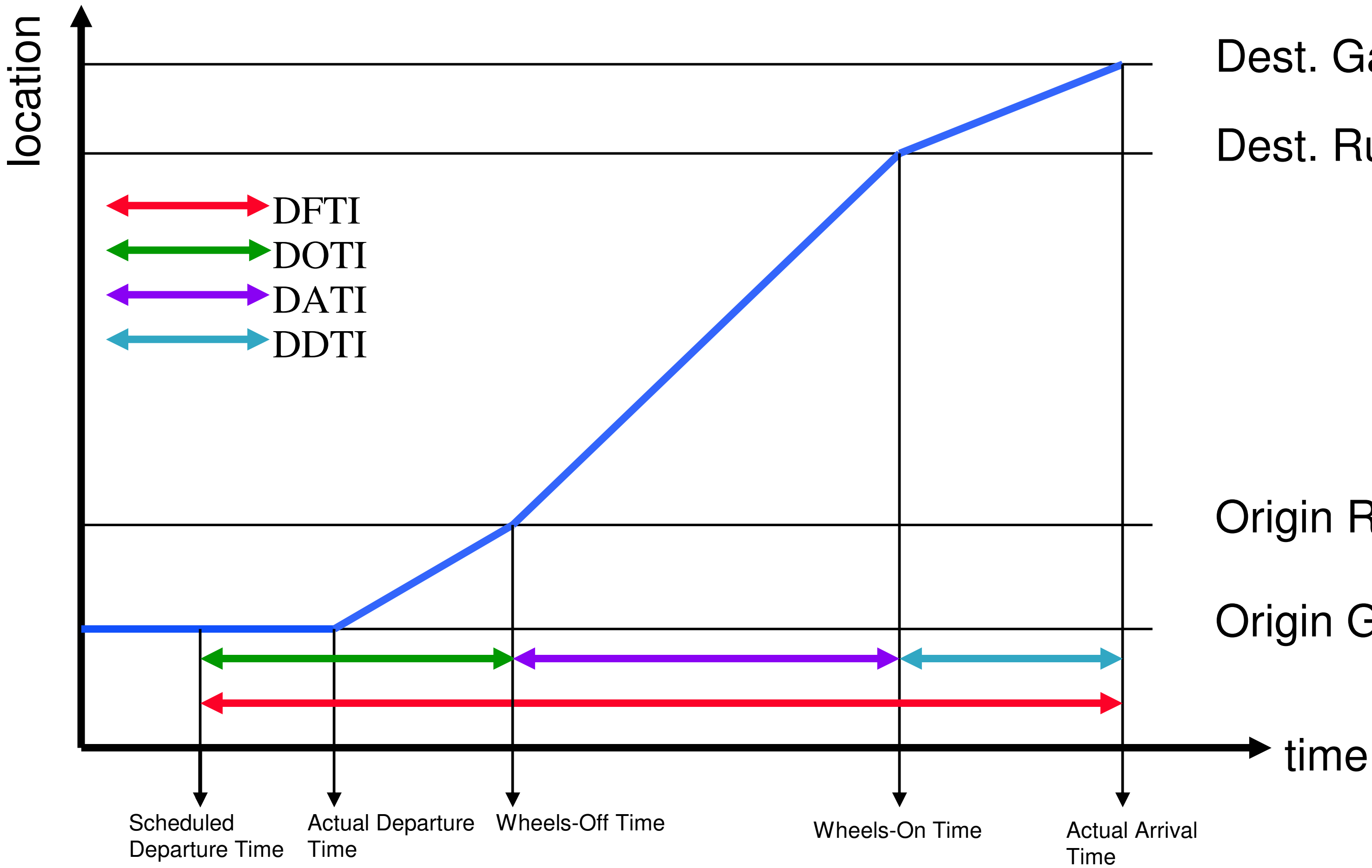
- The Daily Flight Time Index

- Average Arrival Delay

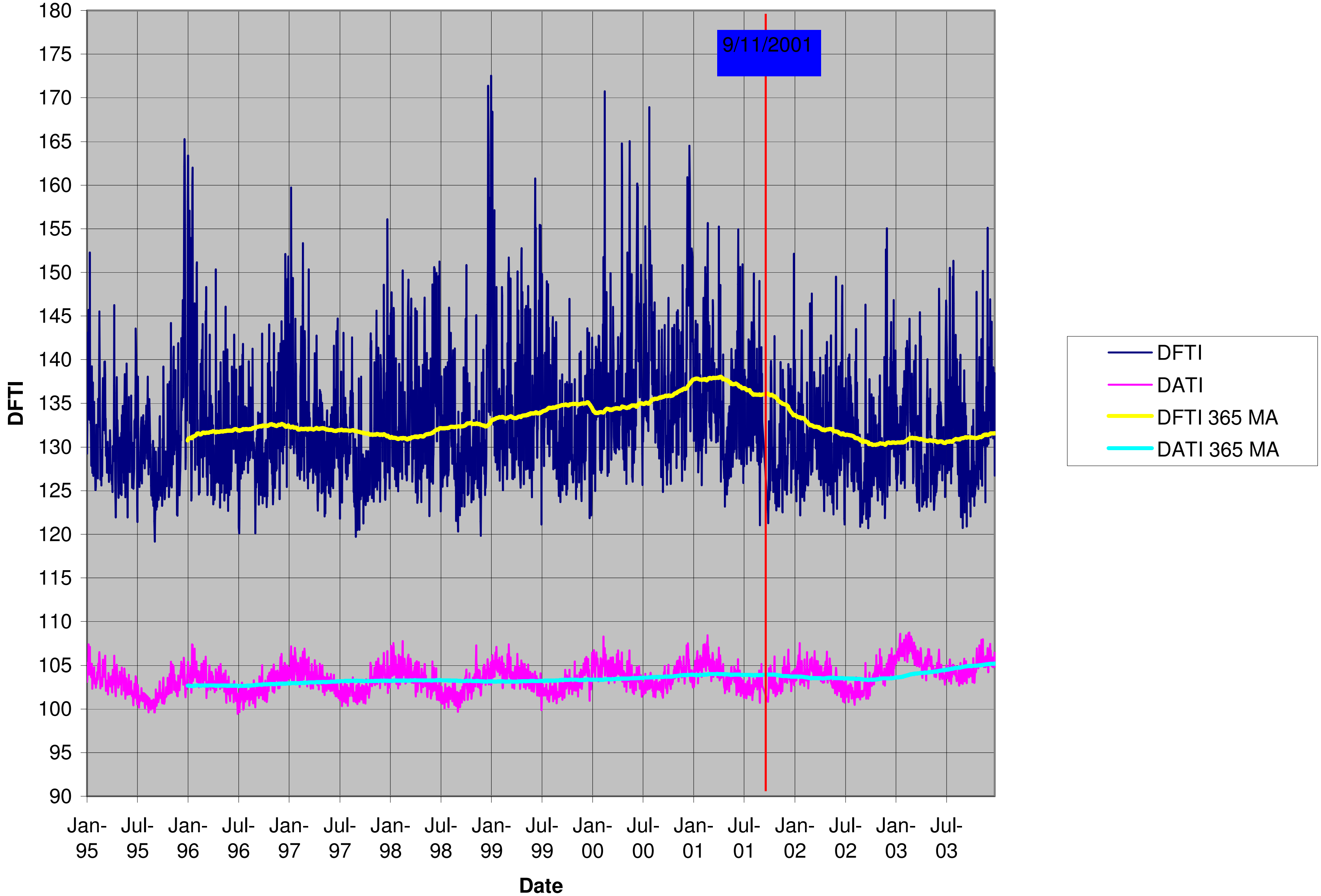
Daily Flight Time Index

- Daily Flight Time Index (DFTI) is a NAS performance metric that reflects the flight time and its components for an "average" commercial passenger flight
- DFTI has been calculated for 1995-2003
- Key trends
  - Increased 7 min from 1995-2000
  - Decreased to 1995 levels by summer 2002
  - Subsequently increased 2 min, mainly due to increased airborne time

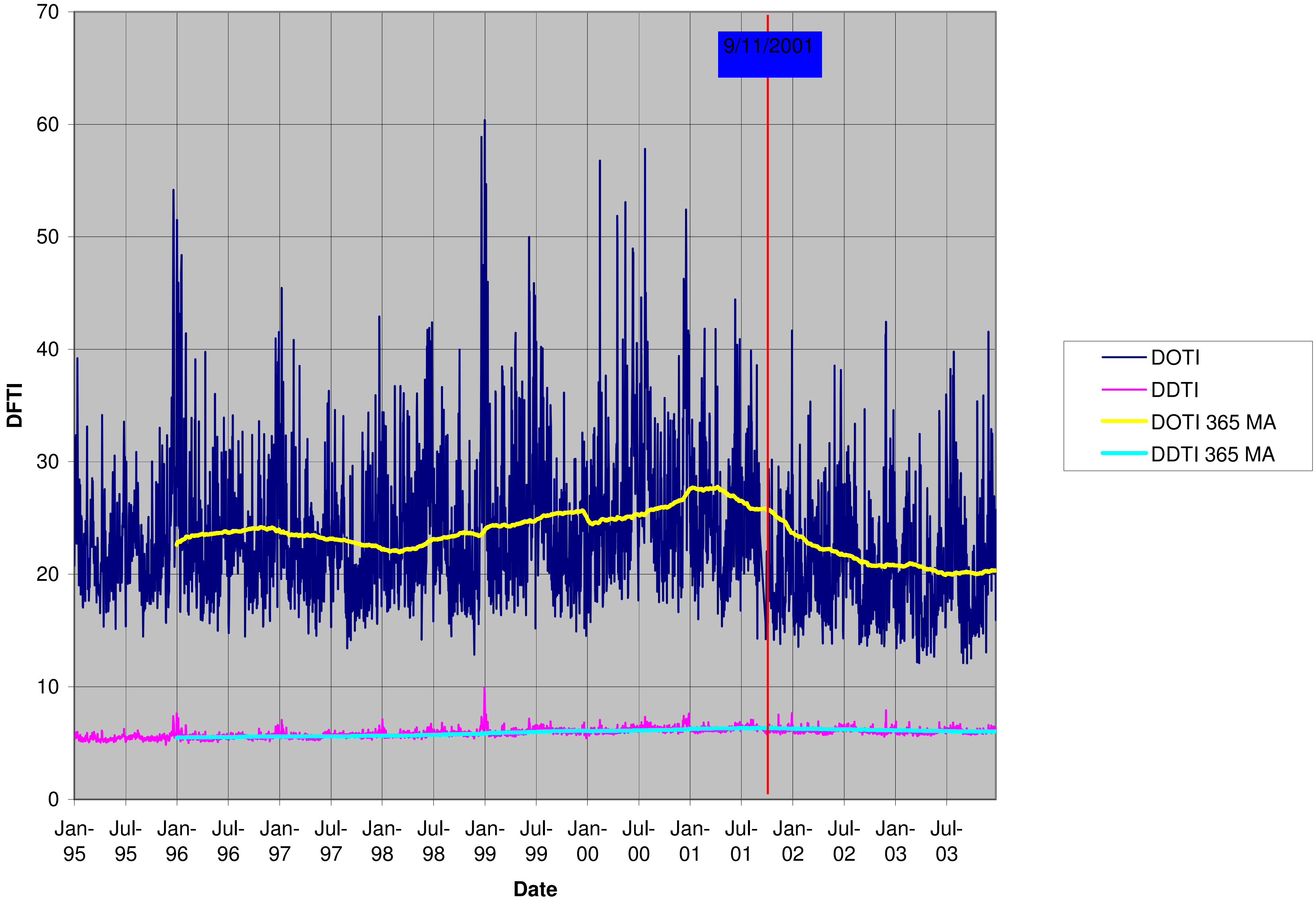
DFTI and its Components



DFTI Trends: 1995-2003



DFTI Trends: 1995-2003



Constructing the DFTI (New Method)

- Based on ASQP data
  - Covers all flights by major pax carriers
  - Provides out-off-on-in times for all domestic flights
- Weighted Average
  - Set of city pairs identified and city-pair weights calculated
  - Average flight time calculated for each city pair
  - City-pair weights applied to determine overall average
- City pairs and their weights adjusted monthly
- Control for effects of re-weighting to maintain comparability

Steps in Constructing the DFTI

- Identify city-pairs
- Calculate city-pair weights
- Calculate unadjusted DFTI
- Calculate adjustment factors and adjusted DFTI

Identify City Pairs and Calculate Weights

- Identify city pairs for which there is
  - at least one completed flight with valid data every day over a two-month period
  - valid data: departure delay > -30 min and arrival delay<480 min
- Calculate weights as $$W_i = \frac{F_i}{\sum_{j \in CP} F_j}$$

W_i- **Weight for city-pair i**

F_i- **Flights for city-pair j during study period**

CP **– Set of city-pairs in the DFTI**

City Pair Daily Average Flight Time

f—Flight index

i—City-pair index

d—Day index

$$DAFT_{id} = \frac{\sum_{f \in S_{id}} FT_f}{N_{id}}$$

S_{id}—Set of flights for city-pair *i* on day *d*

N_{id}—Number of flights in S_{id}

$$DAOT_{id} = \frac{\sum_{f \in S_{id}} OD_f + TO_f}{N_{id}}$$

Daily Average Origin Time

$$DAAT_{id} = \frac{\sum_{f \in S_{id}} AB_f}{N_{id}}$$

Daily Average Airborne Time

$$DADT_{id} = \frac{\sum_{f \in S_{id}} TI_f}{N_{id}}$$

Daily Destination Destination Time

NEXTOR

Daily Flight Time Index

$$DFTI_d = \sum_{i \in cp} W_i DAFT_{id}$$

$$DOTI_d = \sum_{i \in cp} W_i [DAOT_{id}]$$

Origin Time

$$DATI_d = \sum_{i \in cp} W_i [DAAT_{id}]$$

Airborne Time

$$DDTI_d = \sum_{i \in cp} W_i [DADT_{id}]$$

Destination Time

Adjusted DFTI

- Allows DFTI to incorporate large and continually changing mix of city pairs (around 2000)
- Preserves comparability over time
- Based on comparing DFTI's for common month calculated with different weights

Alternative Weights for Month 2

City Pair	Month 1	Month 2	Month 3
1	W_1^{12}	W_1^{12} 0	0
2	W_2^{12}	W_2^{12} W_2^{23}	W_2^{23}
3	W_3^{12}	W_3^{12} W_3^{23}	W_3^{23}
4	0	0 W_4^{23}	W_4^{23}

Adjustment Factors

- Calculate unadjusted DFTI's for months 1-2 and months 2-3: $DFTI_d^{12}$ and $DFTI_d^{23}$
- Compare results for month 2
- Calculate adjustment factors:
  - Want:

$$AVG(\beta_2 + \alpha_2 DFTI^{12}) = AVG(DFTI^{23})$$

$$VAR(\beta_2 + \alpha_2 DFTI^{12}) = VAR(DFTI^{23})$$

  - Solution:

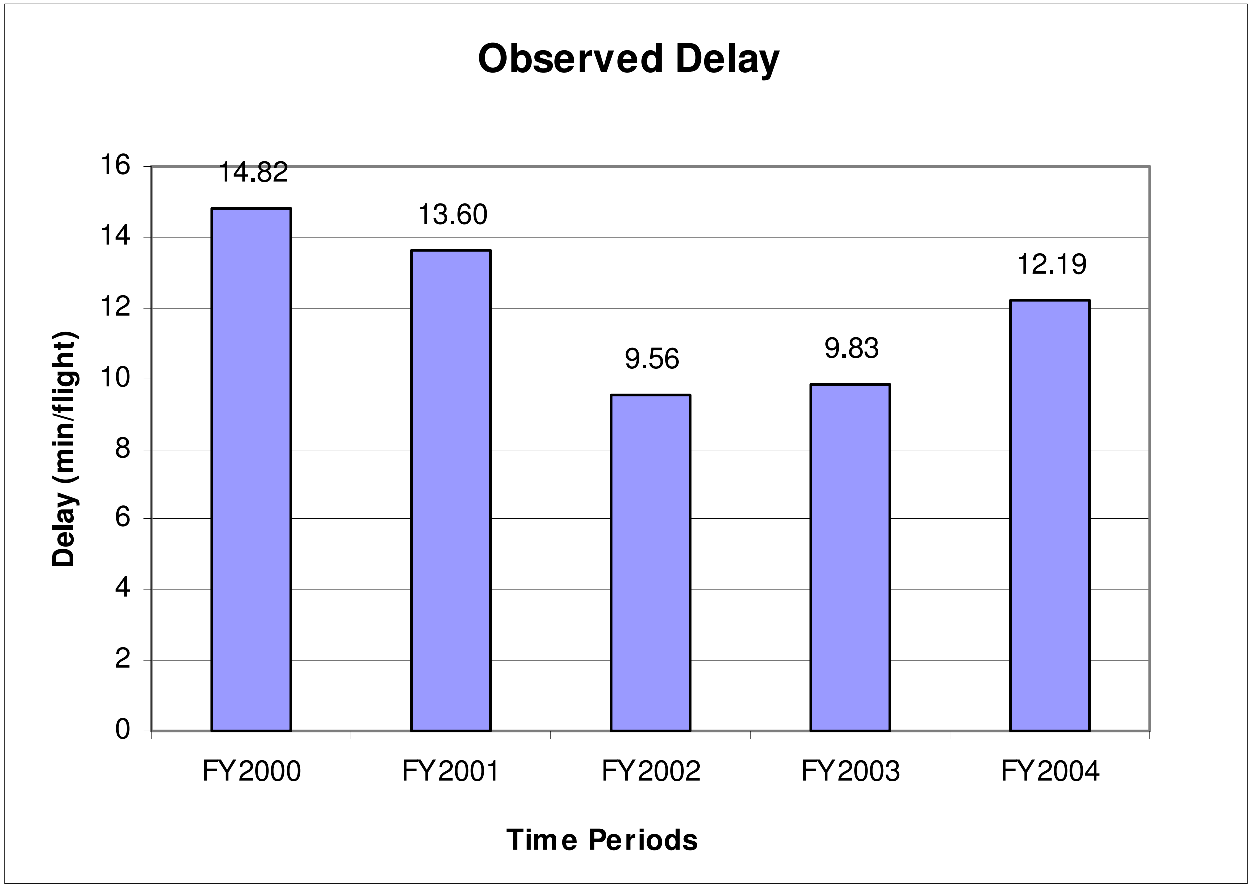
$$\alpha_2 = \sqrt{\frac{VAR(DFTI^{23})}{VAR(DFTI^{12})}}$$

$$\beta_2 = AVG(DFTI^{23}) - \alpha_2 AVG(DFTI^{12})$$

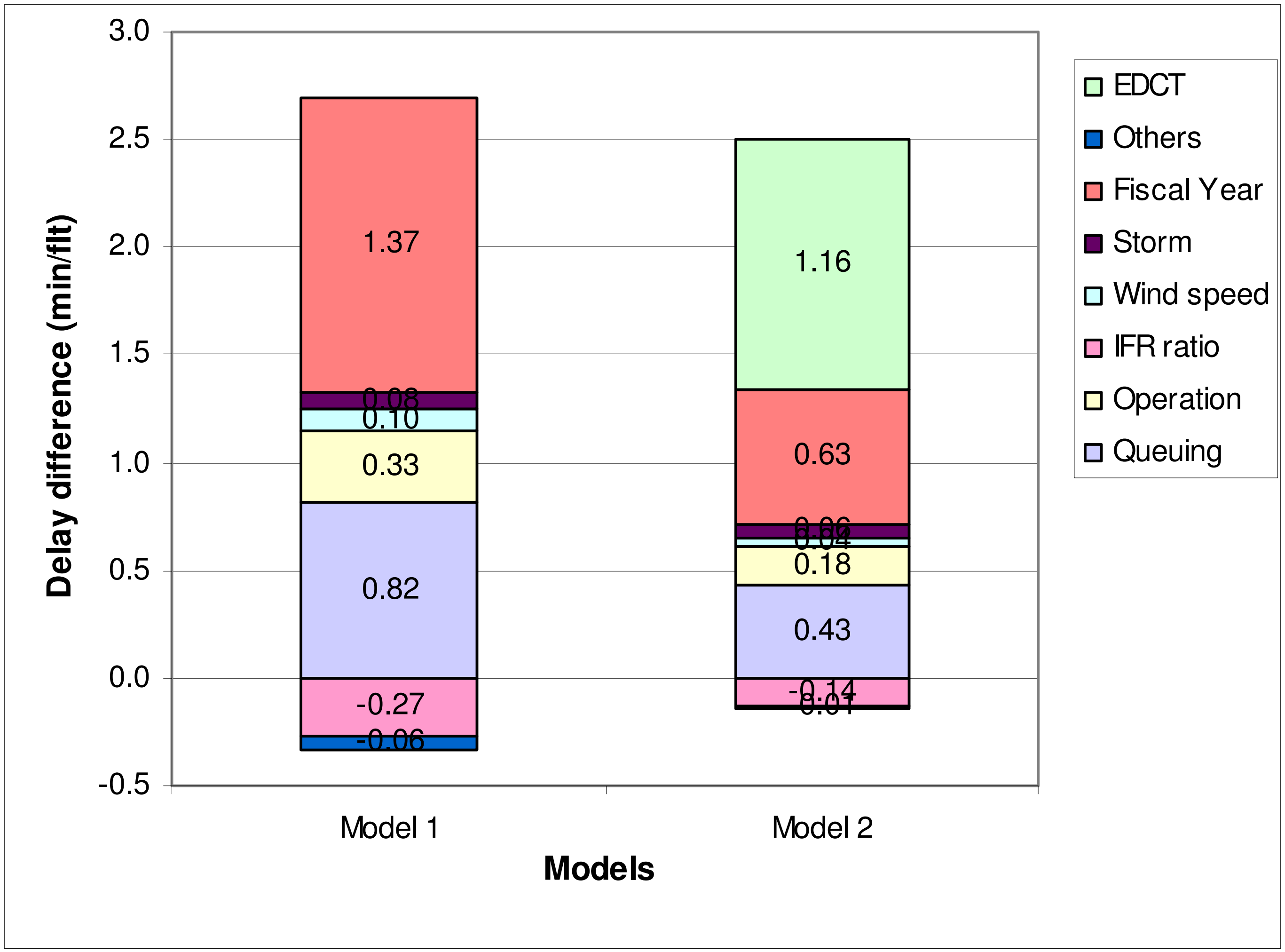
Adjusted DFTI

- Determine baseline month (in our case this is January 2000)
- Calculate adjustment factors recursively forward and backward to beginning and end of time period
- Calculate adjusted DFTI

Trends in Arrival Delay Against Schedule



Decomposition of Delay Difference by Causes (2004 vs. 2003)



The Costs of Delay

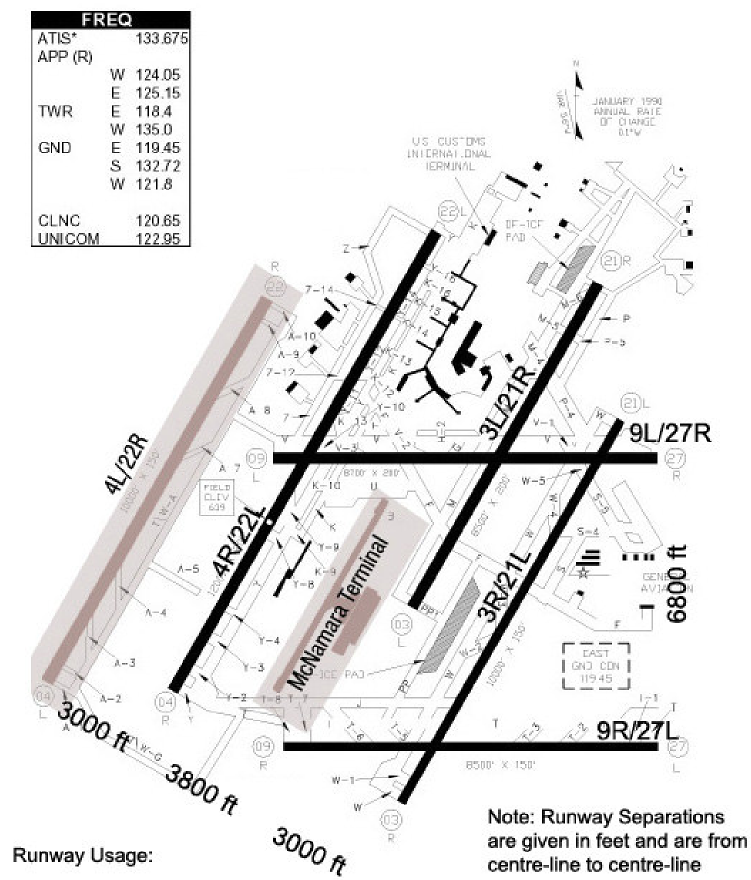
- Not linear or additive—these are accounting conventions, not empirically supported relationships
- Airline cost function study
  - Cost= f(output, factor prices, ops metrics)
  - Metrics included delay, irregularity, and disruption
  - Only disruption had significant effect on costs
- Aggregate cost estimates of similar magnitude to those using standard cost factors: $2-4 billion in 1997
- Does not include costs to passengers

Operational Impact of Demand and Supply Side Changes

- Case study of new runway at DTW
- Case study of Air-21 at LGA

Effect of New Runway at DFW

Fig.1: Airfield Layout Plan of DTW showing the New Runway 4L/22R and McNamara Terminal for NWA



Runway Usage:

4L/22R & 3R/21L are normally used for arrivals
4R/22L & 3L/21R are normally used for departures

Runways 9L/27R & 9R/27L are used only during light cross-winds

FIGURE 4
15-min Arrival and Departure Counts at DTW, VMC Conditions, Jan-June 2002

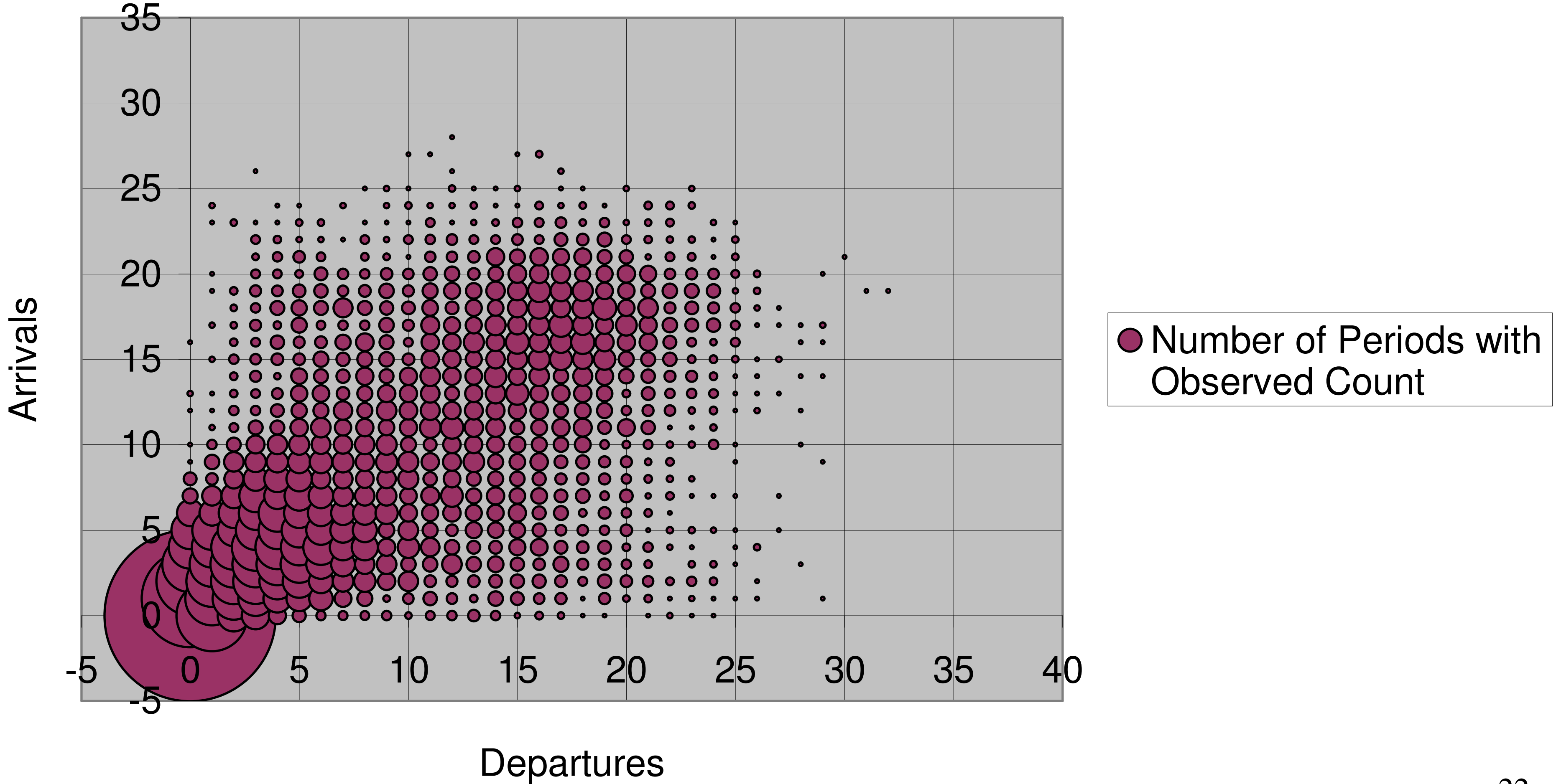


FIGURE 5
Change in Distribution of Arrival and Departure Counts, VMC Conditions, Jan-June 2001-2002

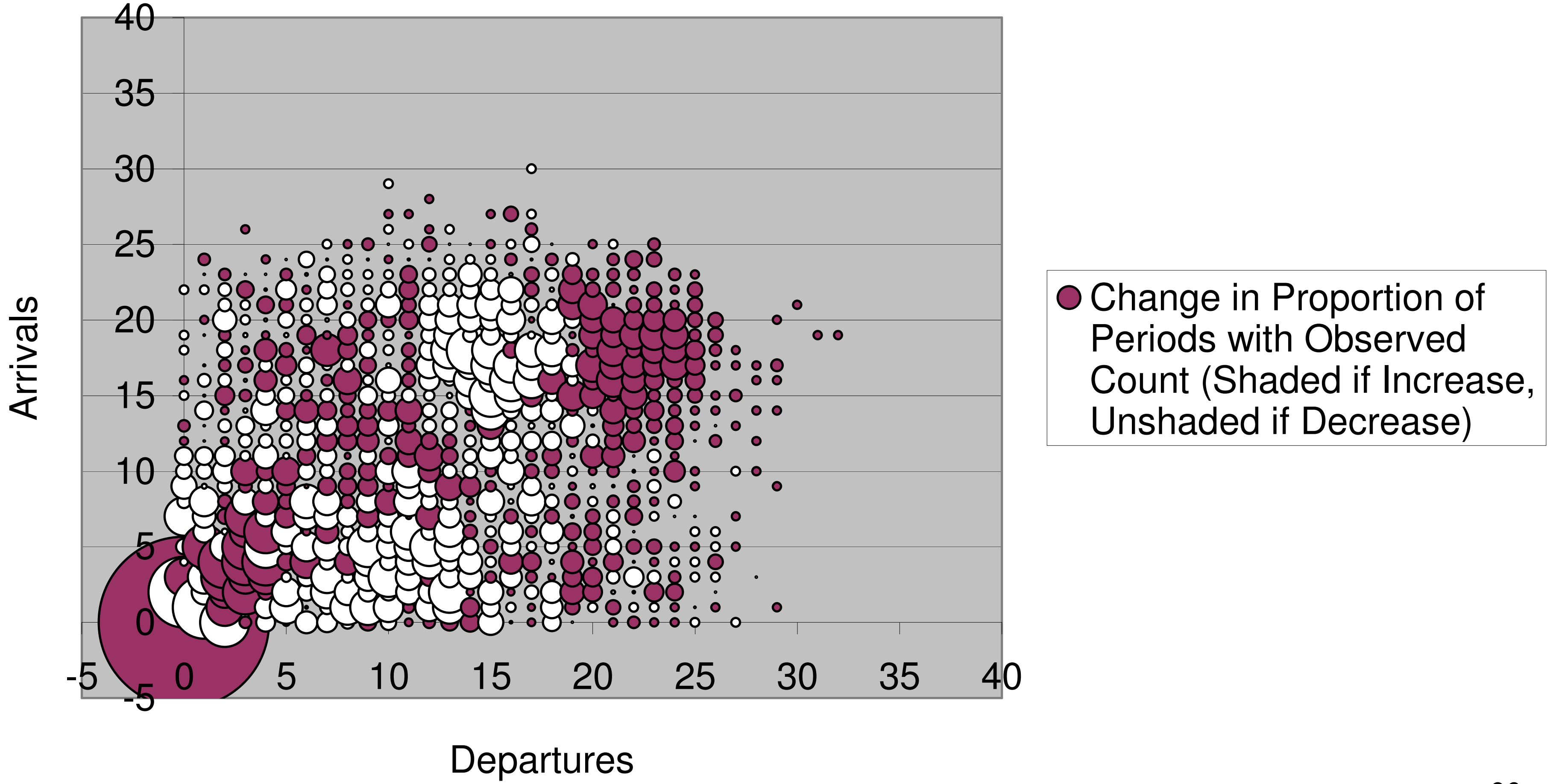


FIGURE 6
Change in Distribution of Arrival and Departure Counts, IMC Conditions, Jan-June 2001-2002

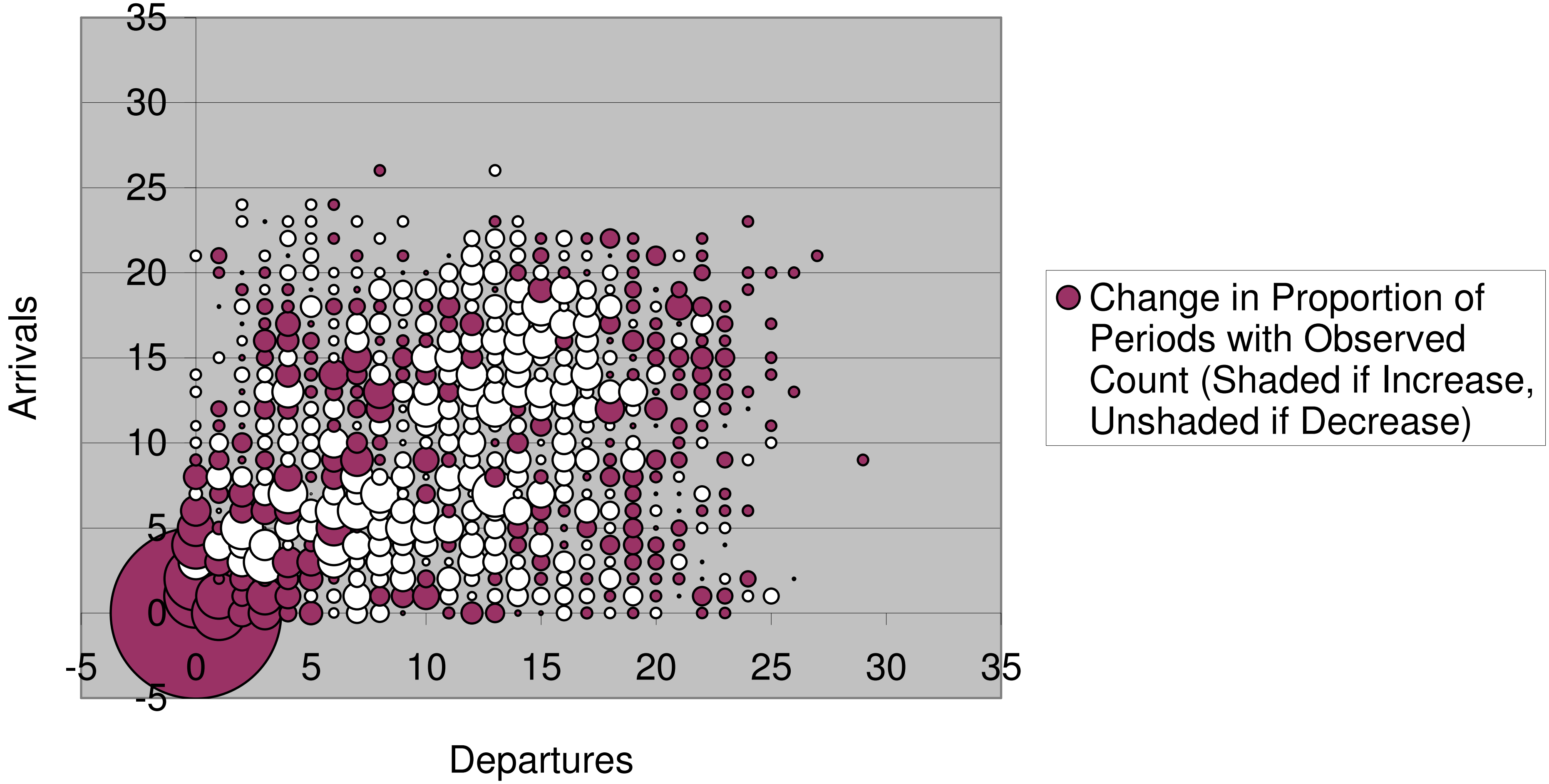


FIGURE 7
Clearance Rates, DTW Arrivals, by Year and Visibility Condition

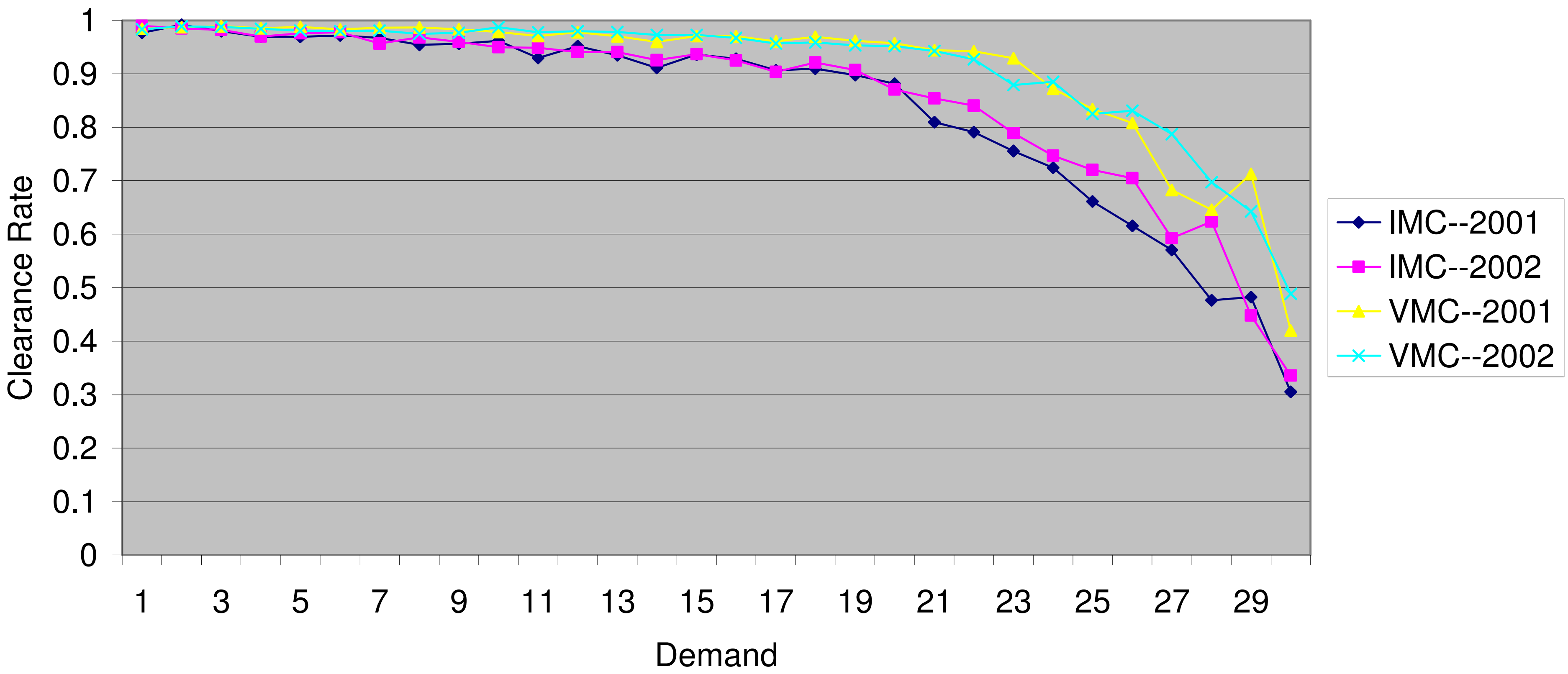
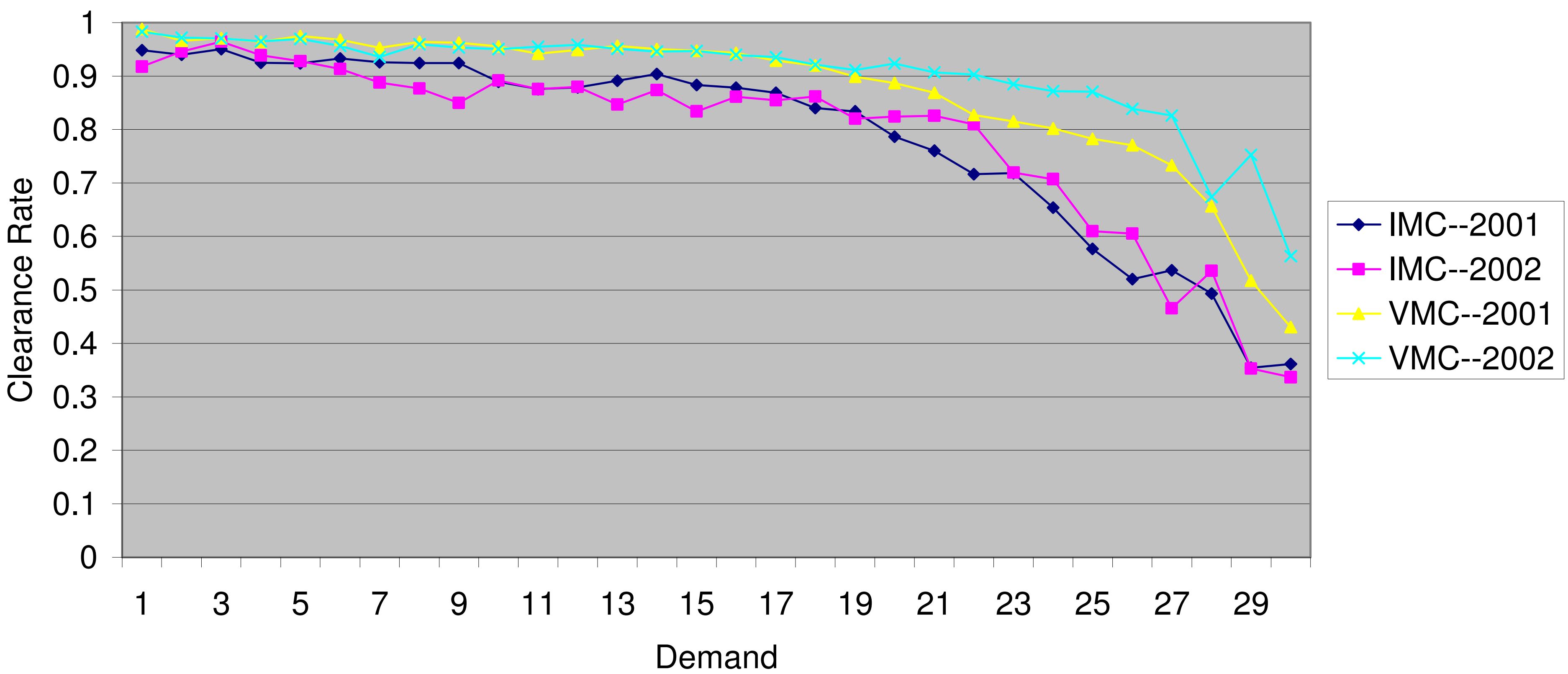


FIGURE 8
Clearance Rates, DTW Departures, by Year and Visibility Condition



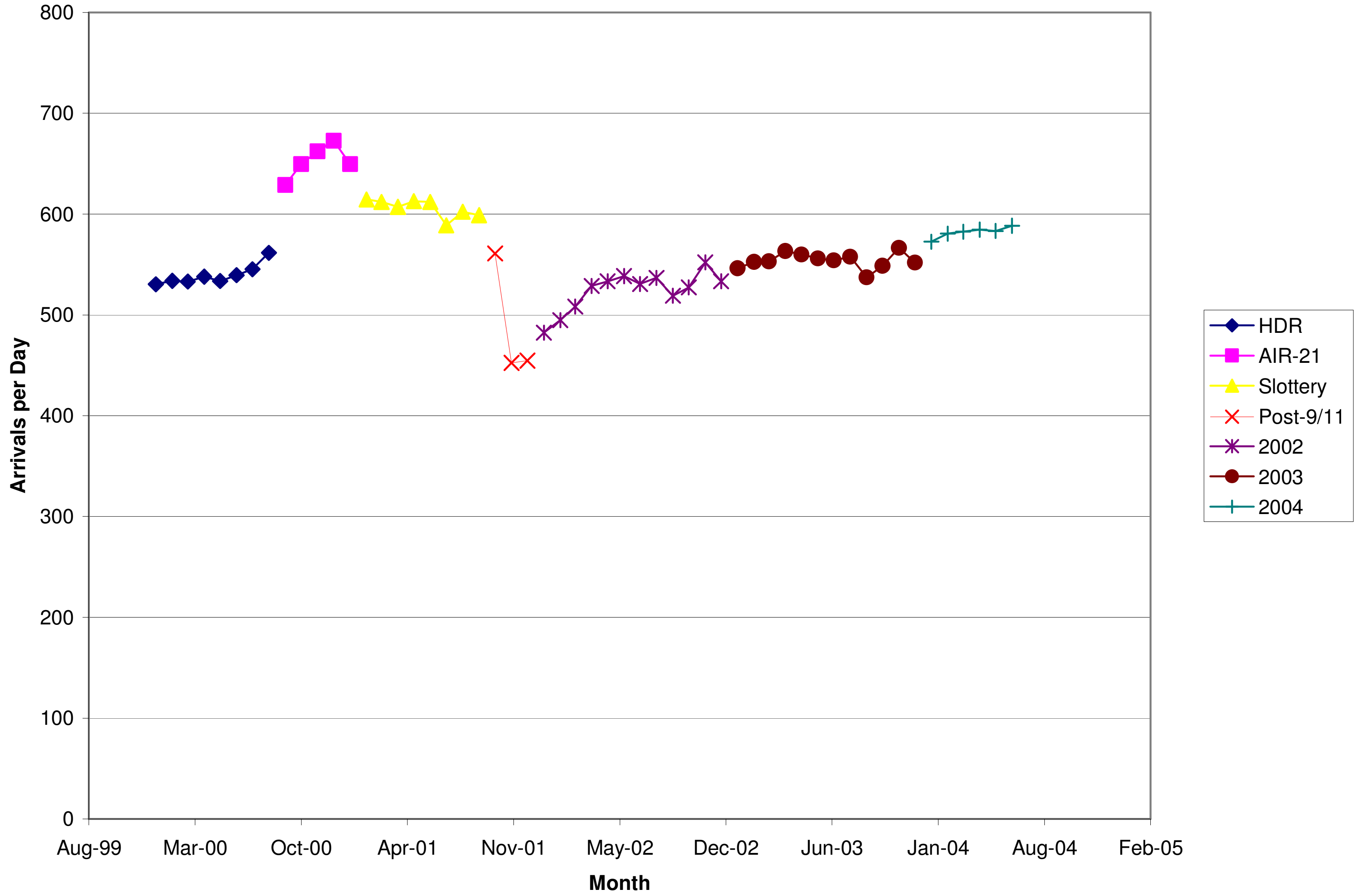
Air-21 at LGA

- Effects of past policies on operational performance at LGA
- Interaction of LGA and the rest of the National Airspace System (NAS)

Epochs

- The HDR period: from January through August of 2000.
- The AIR-21 period: from September, 2000 through January of 2001.
- The Slottery period: from February 2001 through September 10, 2001.
- Post 9/11 period: through the end of 2001.
- Year 2002.
- Year 2003.
- The first half of Year 2004.

Average Weekday Scheduled Arrivals at LGA, by Month



Operational Performance Metrics at LGA

- Average Arrival Delay
- Cancellation Rate
- Saturation Rate
- Arrival Count at saturation
- Arrival Demand at saturation
- Airport Acceptance Rate

Operational Performance of LGA

Periods	Average Delay		Cancellation Rate		Saturation Rate		Arrival Count*		Arrival Demand*		AAR	
	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC	VMC	IMC
HDR	17.80	33.29	0.03	0.07	0.31	0.27	10.02	9.73	10.16	11.80	8.69	8.29
AIR-21	34.84	42.93	0.07	0.14	0.40	0.30	10.66	10.39	20.34	20.26	8.94	9.09
Slottery	15.31	31.33	0.05	0.14	0.35	0.27	10.49	10.31	11.91	16.69	9.00	8.69
Post 9/11	5.90	10.41	0.02	0.02	0.23	0.19	9.92	10.35	8.19	9.68	8.60	8.93
Year2002	9.88	21.55	0.02	0.05	0.28	0.27	10.40	10.15	9.96	14.02	8.93	8.74
Year2003	10.88	19.07	0.03	0.08	0.33	0.29	10.51	10.24	11.05	13.65	8.81	8.58
Year2004	11.95	25.21	0.06	0.08	0.40	0.40	10.24	10.19	11.18	15.16	8.19	8.00

Multivariate Model of LGA and NAS Delay

- Dependent variable
  - Arrival Delay
    - For LGA, arrival delay at the rest of the system
    - For the rest of the system, arrival delay at LGA
- Explanatory variables
  - Deterministic Queuing Delay
  - Adverse Weather
    - En-route (Thunderstorm ratio)
    - Terminal (IFR ratio)
  - Expected Departure Clearance Time (EDCT) Holding (EDCT ratio)
  - Total Flight Operations

Model Specification

- Model 1 (Arrival delay at LGA)

$$D_L(t) = \alpha + \beta_1 \times \boxed{\hat{D}_S(t)} + \beta_2 \times LQ(t) + \beta_3 \times I_L(t)$$
$$+\beta_4 \times I_L(t)^2 + \beta_5 \times E(t) + \beta_6 \times E(t)^2$$
$$+\sum_k \lambda_{kL} W_k(t) + \sum_i \omega_{iL} S_i(t) + \sum_j \theta_{jL} D_j(t) + \nu(t)$$

- Model 2 (Arrival delay at rest of Benchmark Airports)

$$D_S(t) = \alpha \times OP(t) + \gamma_1 \times \boxed{\hat{D}_L(t)} + \gamma_2 \times SQ(t) + \gamma_3 \times I_S(t) + \gamma_4 \times I_S(t)^2$$
$$+\sum_l \lambda_{lS} W_l(t) + \sum_m \omega_{mS} S_m(t) + \sum_n \theta_{nS} D_n(t) + u(t)$$

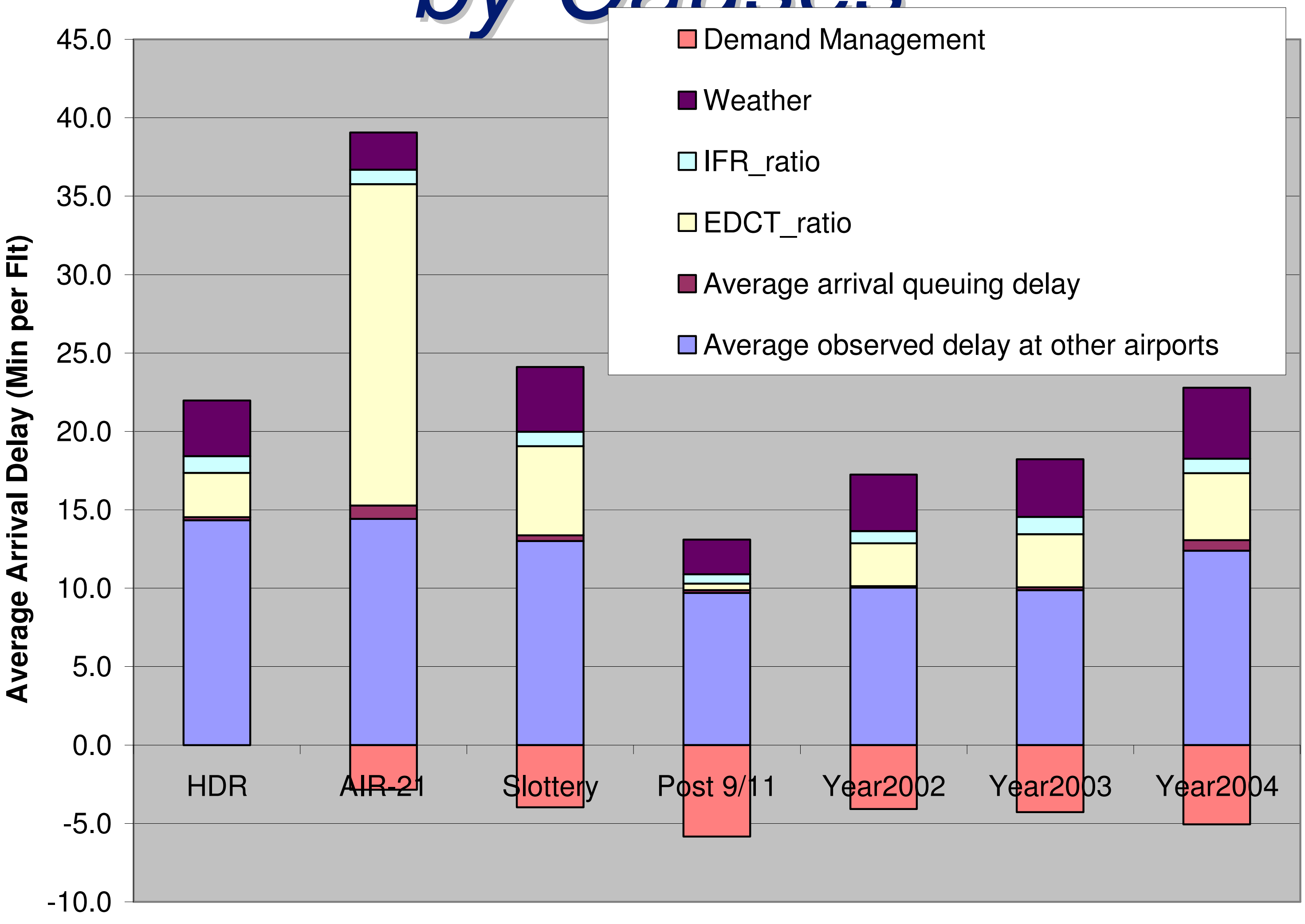
Estimation Results of Delay at LGA (1)

	Description	Estimate	Standard Error	p-Value
Intercept		3.92	1.26	0.00
Ds(t)	Predicted arrival delay for NAS	0.76	0.06	<.0001
LQ(t)	Average queuing delay at LGA	0.02	0.01	0.06
E(t)	EDCT_ratio (count of EDCT holding arriving at LGA / total scheduled arrivals)	30.61	2.69	<.0001
$E(t)^2$	Square of EDCT_ratio	20.67	3.74	<.0001
I(t)	IFR_ratio (Proportion of the day operated under IMC condition)	11.24	2.07	<.0001
$I(t)^2$	Square of IFR_ratio	-9.48	2.22	<.0001
$W_5(t)$	Thunder storm ratio (number of stations reported thunderstorm / total amount of stations) in Region 5	27.94	2.59	<.0001
R-Square		0.76		

Estimation Results of Delay at LGA (2)

	Description	Estimate	Standard Error	p-Value
$D_1(t)$	Dummy variable for the AIR-21period	-2.85	0.98	0.00
$D_2(t)$	Dummy variable for the Slottery period	-3.97	0.92	<.0001
$D_3(t)$	Dummy variable for the post 9/11 period	-5.83	1.90	0.00
$D_4(t)$	Dummy variable for Year 2002	-4.09	0.85	<.0001
$D_5(t)$	Dummy variable for Year 2003	-4.29	0.78	<.0001
$D_6(t)$	Dummy variable for Year 2004	-5.06	0.93	<.0001
$S_1(t)$	Dummy variable for Quarter1	-0.93	0.77	0.22
$S_2(t)$	Dummy variable for Quarter2	-1.56	0.82	0.06
$S_3(t)$	Dummy variable for Quarter3	-0.69	0.80	0.39

Decomposition of LGA Delay by Causes



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Estimation Results of NAS Delay

	Description	Estimate	Standard Error	p-Value
Intercept		1.92	1.17	0.10
OP(t)	Total operations (Arrivals) in the system	0.002	0.00	<.0001
$D_L(t)$	Predicted average arrival delay at LGA	0.05	0.01	<.0001
SQ(t)	Average arrival queuing delay of system	0.89	0.06	<.0001
I(t)	IFR_ratio (Proportion of the day operated under IMC condition)	8.55	2.85	0.00
$I(t)^2$	Square of IFR_ratio	11.55	5.43	0.03
$W_1(t)$	Thunderstorm ratio in Region 1	1.79	0.71	0.01
$W_2(t)$	Thunderstorm ratio in Region 2	4.06	0.91	<.0001
$W_3(t)$	Thunderstorm ratio in Region 3	3.04	0.81	0.00
$W_4(t)$	Thunderstorm ratio in Region 4	4.62	0.59	<.0001
$W_5(t)$	Thunderstorm ratio in Region 5	5.66	1.05	<.0001
$W_6(t)$	Thunderstorm ratio in Region 6	13.89	0.87	<.0001
R-S		0.70		

Estimation Results of NAS Delay

	Description	Estimate	Standard Error	p-Value
$D_2(t)$	Dummy variable for the AIR-21 period	-0.88	0.66	0.18
$D_3(t)$	Dummy variable for the Slottery period	-1.42	0.51	0.01
$D_4(t)$	Dummy variable for the post 9/11 period	-2.99	0.88	0.00
$D_5(t)$	Dummy variable for year 2002	-3.24	0.50	<.0001
$D_6(t)$	Dummy variable for year 2003	-3.34	0.49	<.0001
$D_7(t)$	Dummy variable for year 2004 (half of the year)	-1.72	0.51	0.00
$S_1(t)$	Dummy variable for quarter 1	-0.54	0.52	0.30
$S_2(t)$	Dummy variable for quarter 2	-3.44	0.54	<.0001
$S_3(t)$	Dummy variable for quarter 3	-3.41	0.58	<.0001
R-Square		0.70		

Conclusion

- AIR-21 period witnessed operational improvements at LGA
- The entire delay impact of AIR-21 was in the form of increased EDCT-related delays
- 1 minute delay at LGA generates about 1.7 minutes delay for the rest of the system
- Traffic and delay at LGA are approaching pre-9/11 levels

The Case for Demand Management

- Microanalysis of Queuing Delay at LAX
- Demand-side Aspects of the Delay Problem
- Delay Management Altnernatives
- Final Thought

Example Interarrival Times for L=7nm

Leading		Trailing: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Embraer 120	1.3	1.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
2	Jetstream Super31	1.3	1.3	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
3	Airbus 319	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
4	Airbus 320	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
5	BAe 146	2.4	2.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
6	Boeing 727	2.8	2.8	1.1	1.1	1.6	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
7	Boeing 737	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
8	Douglas DC 9	2.7	2.8	1.1	1.1	1.6	1.1	1.1	1.1	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
9	Douglas MD 80	2.8	2.8	1.1	1.1	1.6	1.1	1.1	1.1	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
10	Douglas MD 90	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.2	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
11	Saab 340	2.3	2.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
12	Airbus 310	3.9	3.9	2.2	2.2	2.9	2.2	2.2	2.3	2.2	2.2	3.0	1.7	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
13	Airbus 340	3.9	4.0	2.2	2.2	2.9	2.2	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
14	Boeing 747 1*	3.9	4.0	2.2	2.2	3.0	2.3	2.3	2.4	2.3	2.2	3.0	1.8	1.8	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
15	Boeing 747 2*	4.2	4.2	2.5	2.5	3.2	2.5	2.5	2.6	2.5	2.4	3.3	2.0	2.0	1.9	1.6	1.9	1.9	2.0	2.0	1.9	1.8	2.5
16	Boeing 767	4.0	4.0	2.3	2.3	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.8	1.8	1.7	1.6	1.7	1.7	1.8	1.8	1.7	1.6	2.3
17	Boeing 777	3.9	4.0	2.2	2.2	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.8	1.8	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
18	Douglas DC 10	3.9	4.0	2.2	2.2	3.0	2.3	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
19	Douglas MD 11	3.9	4.0	2.2	2.2	3.0	2.3	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
20	Ilyushin Il-96	4.0	4.0	2.3	2.3	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.9	1.8	1.7	1.6	1.7	1.7	1.8	1.8	1.7	1.6	2.3
21	Lockheed L1011	4.0	4.1	2.3	2.3	3.1	2.4	2.4	2.5	2.4	2.3	3.1	1.9	1.9	1.8	1.6	1.8	1.8	1.8	1.8	1.7	1.6	2.3
22	Boeing 757	3.3	3.4	1.7	1.7	2.4	1.8	1.8	1.9	1.8	1.7	2.5	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	1.7

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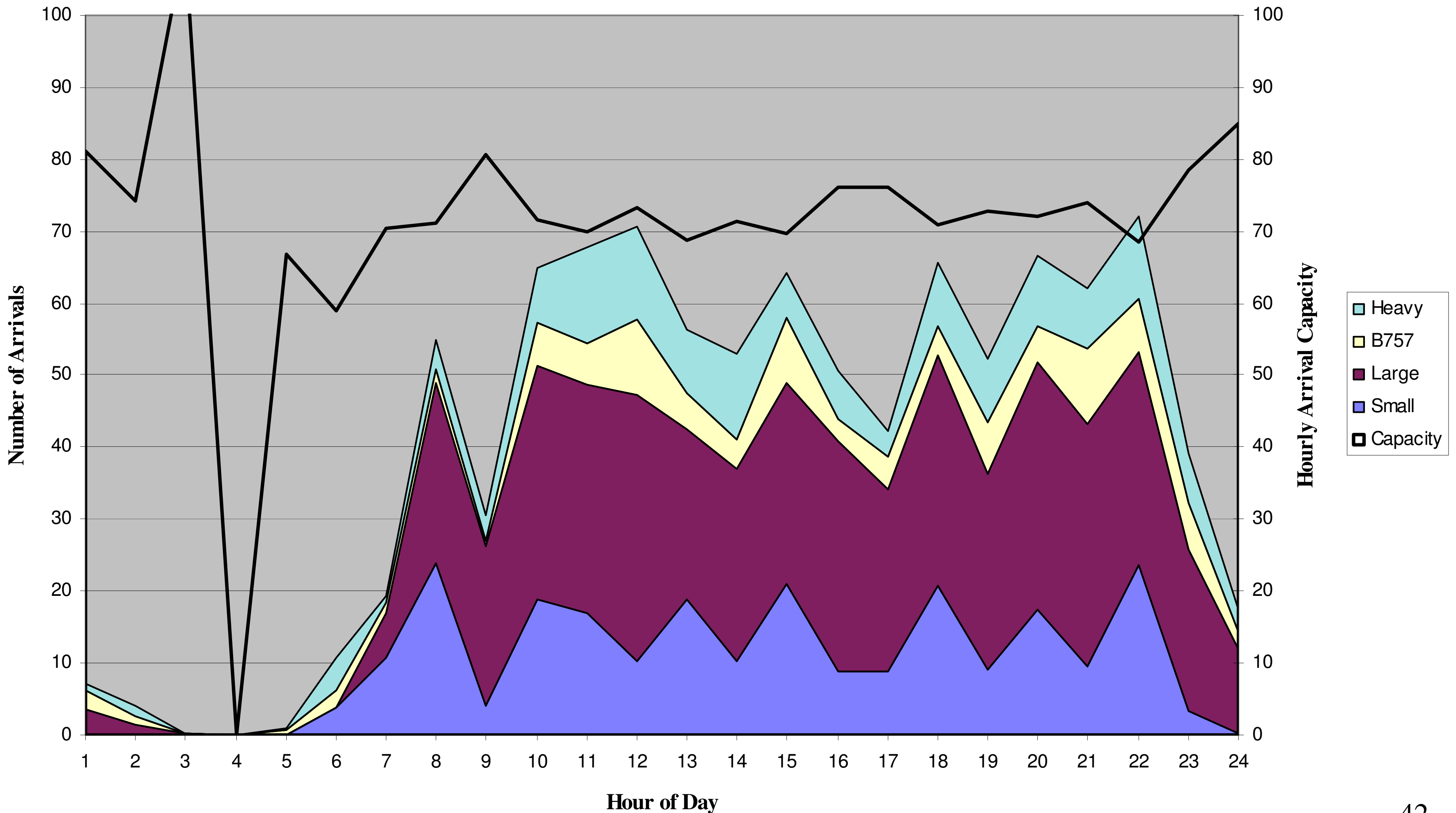
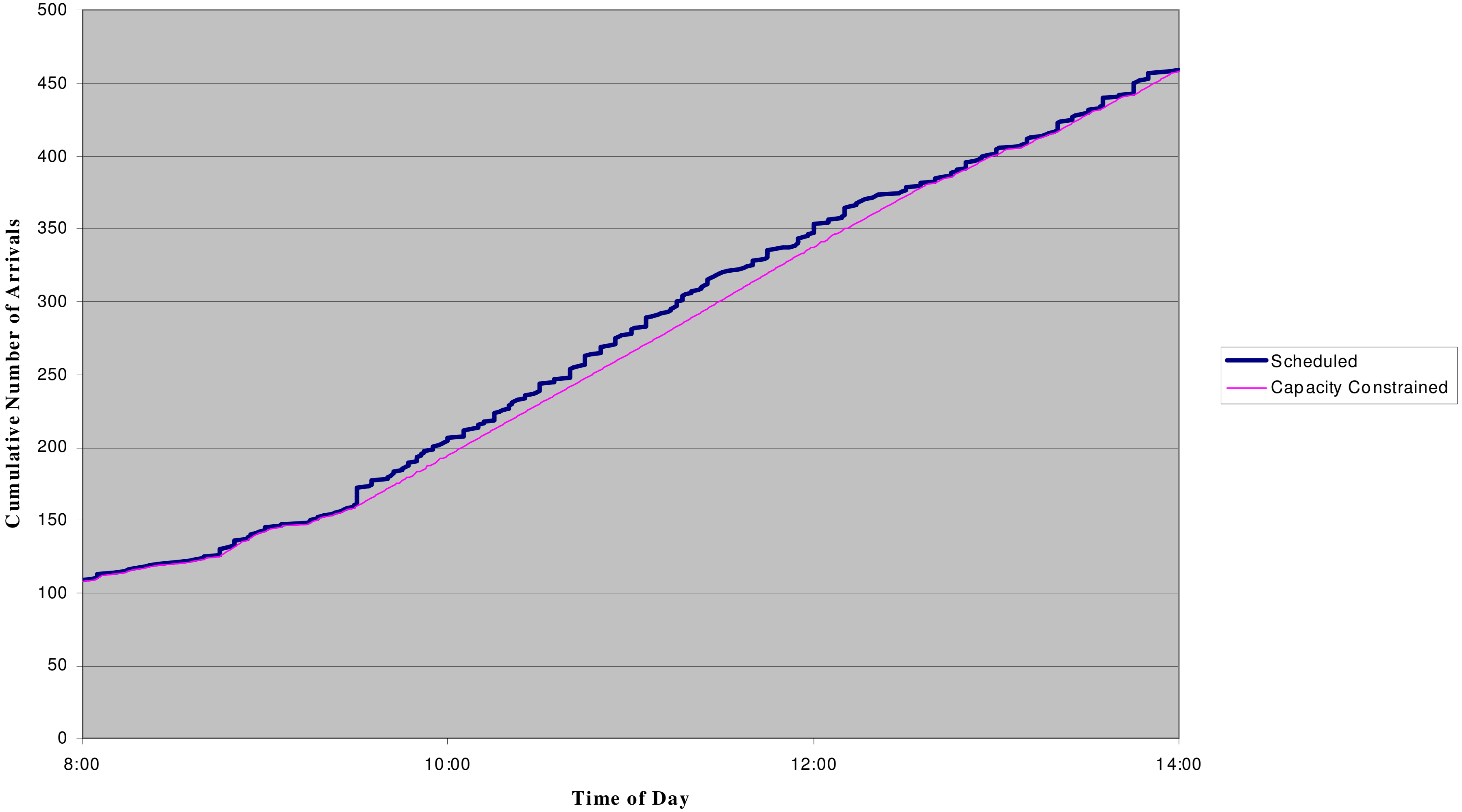
Impact of Fleet Mix on IFR Arrival Capacity



Delay Impacts

- Used deterministic queueing analysis to assess marginal delay impacts of individual flights
- First-cut analysis
  - IFR Nominal Separations
  - Two arrival runways
  - No flight cancellations
  - No traffic flow management

Queuing Diagram for LAX



Queuing Diagram II

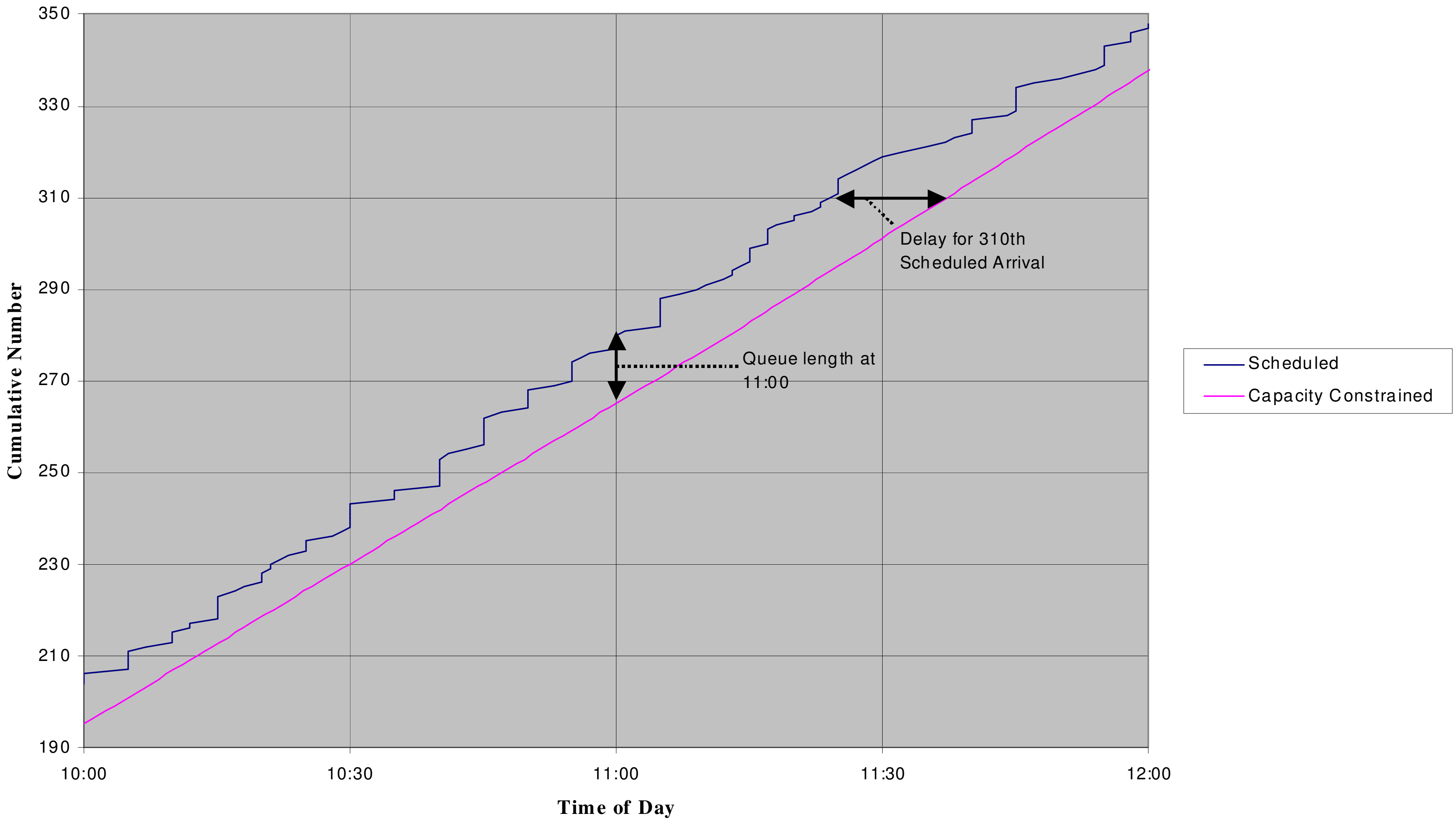
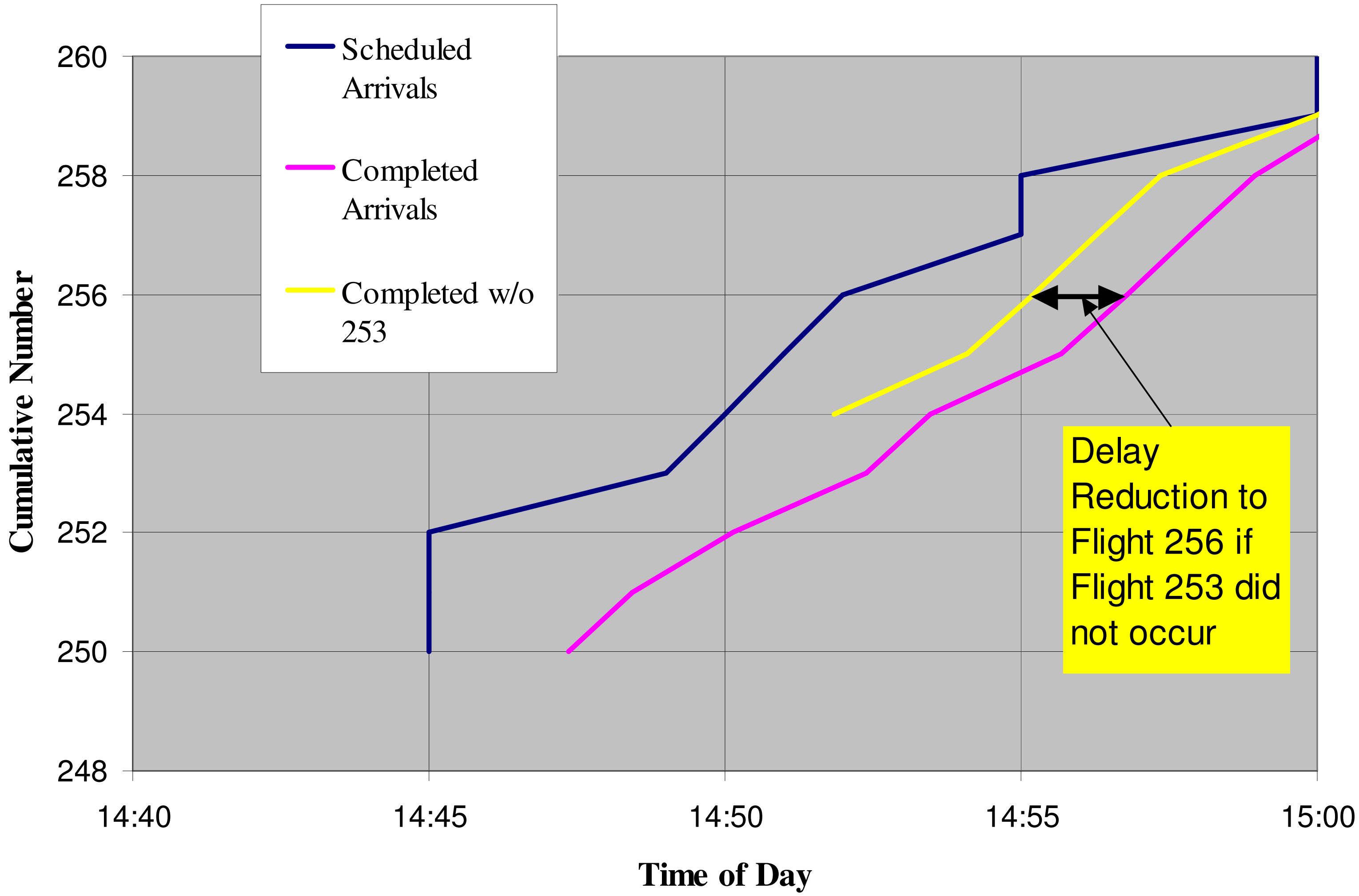
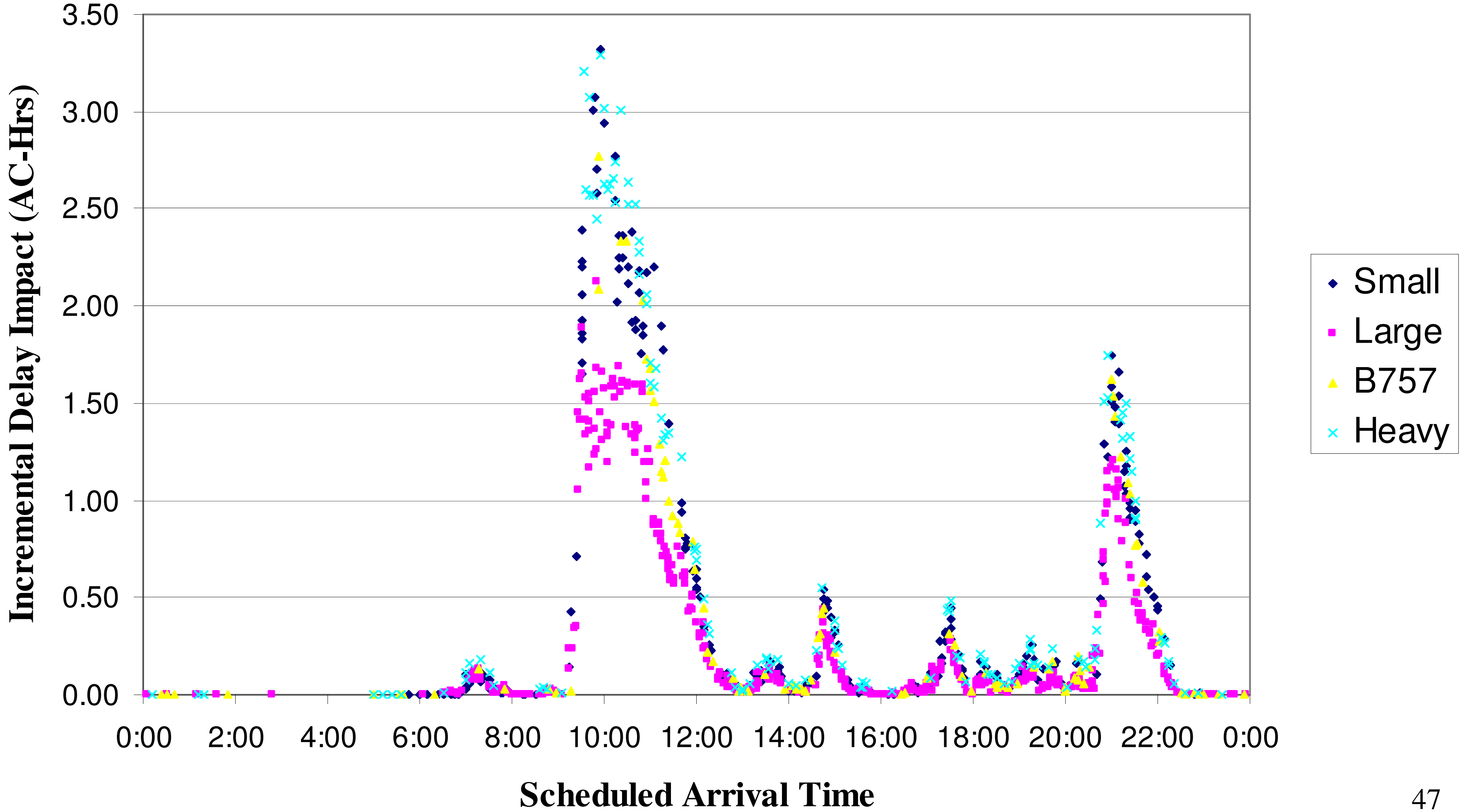


Illustration of Procedure



During Peak Periods, Flights Generate Significant Incremental Delays



Delay Impact Ratio (DIR)

- Weighs delay impact against convenience
- Numerator is congestion delay impact (CDI) of a flight (in seat-hrs)
- Denominator is extra “schedule delay” if flight did not occur, and passengers had to take previous flight from same origin on same airline (SDI)
- Any flight with DIR>1 is of dubious social value

Delay Impact Ratio (DIR)

$$DIR = \frac{congestion\ delay\ caused\ by\ flight(seat - hrs)}{schedule\ delay\ saved\ by\ flight(seat - hrs)}$$

NEXTOR

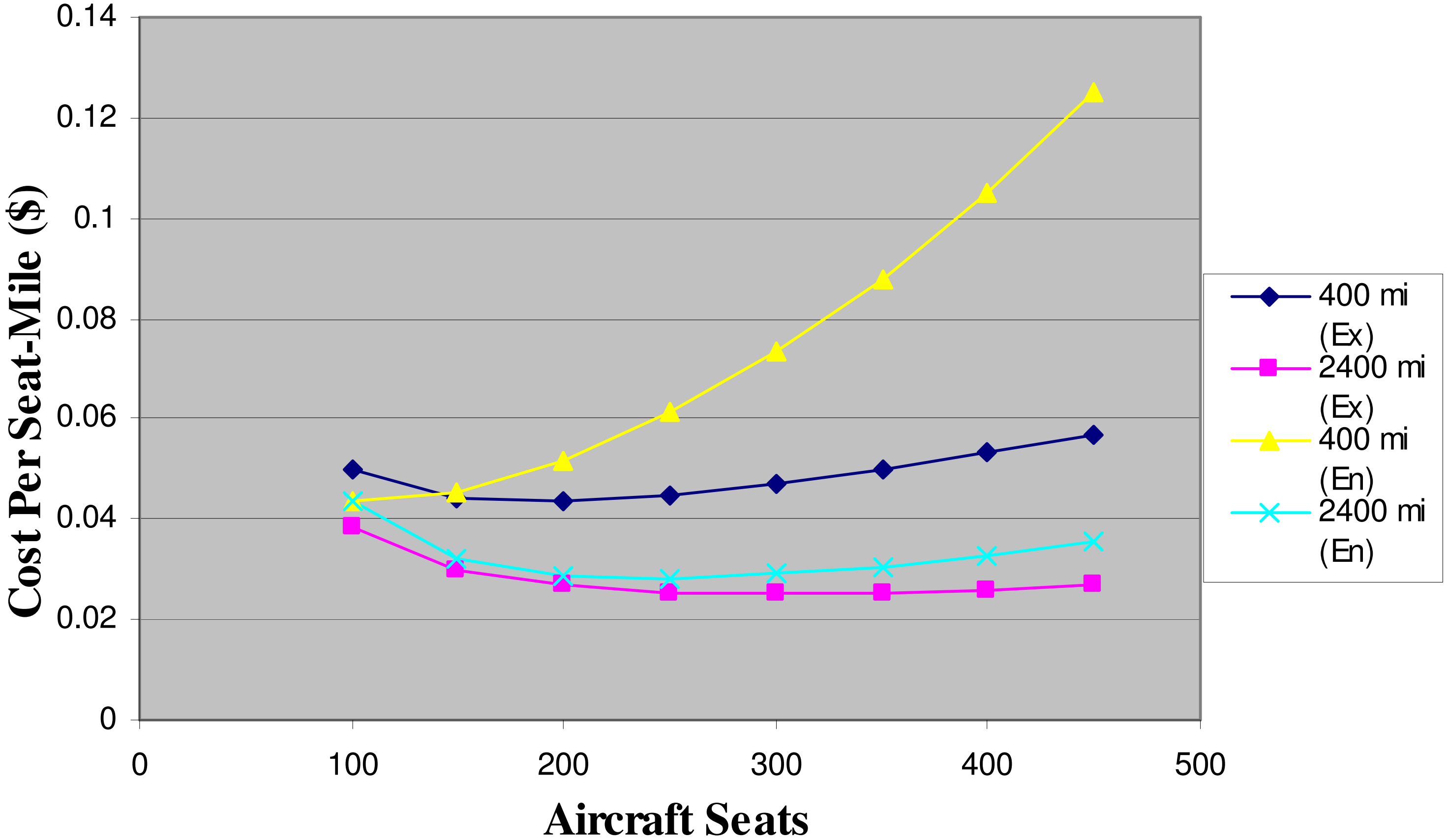
Some Flights Have Very High DIRs

Flight	Type	Seats	Origin	Time of Departure	Previous Flight: Flight Number	Previous Flight: Time of Departure	SDI	CDI	DIR
US3 4759	J31	18	SAN	9:50	4707	9:35	5	247	55.0
US3 4734	J31	18	FAT	9:45	4729	9:25	6	282	47.0
US3 4707	J31	18	SAN	9:35	4793	9:10	8	292	38.9
US3 4793	J31	18	SAN	9:10	4768	8:30	12	398	33.2
UA3 5218	EM2	30	SAN	9:00	5216	8:30	15	425	28.4
UA3 5220	EM2	30	SAN	9:30	5218	9:00	15	261	17.4
OE 7338	J31	18	OXR	9:55	7336	8:50	20	308	15.8
UA3 5222	EM2	30	SAN	10:00	5220	9:30	15	228	15.2
OE 7017	J31	18	SNA	9:45	7015	8:30	23	338	15.0
UA3 5224	EM2	30	SAN	10:30	5222	10:00	15	217	14.5
US3 4789	J31	18	SAN	20:10	4741	19:25	14	191	14.2
UA3 5468	EM2	30	PSP	9:05	5466	8:05	30	409	13.6
UA3 5426	EM2	30	MRY	9:35	5424	8:45	25	293	11.7
A1 3206	SF3	33	PSP	8:40	3228	8:00	22	253	11.5
UA3 5128	EM2	30	SBA	10:00	5126	9:10	25	259	10.4
OO 5657	EM2	30	SAN	9:38	5655	8:38	30	313	10.4
UA 2015	735	108	SFO	8:35	2011	8:25	18	180	10.0
UA3 5470	EM2	30	PSP	10:05	5468	9:05	30	282	9.4

Demand-side Aspects of Delay Problem

- Schedule competition (frequency and flight times)
- Limited cost economies in aircraft size
- User charges geared toward cost recovery instead of capacity allocation

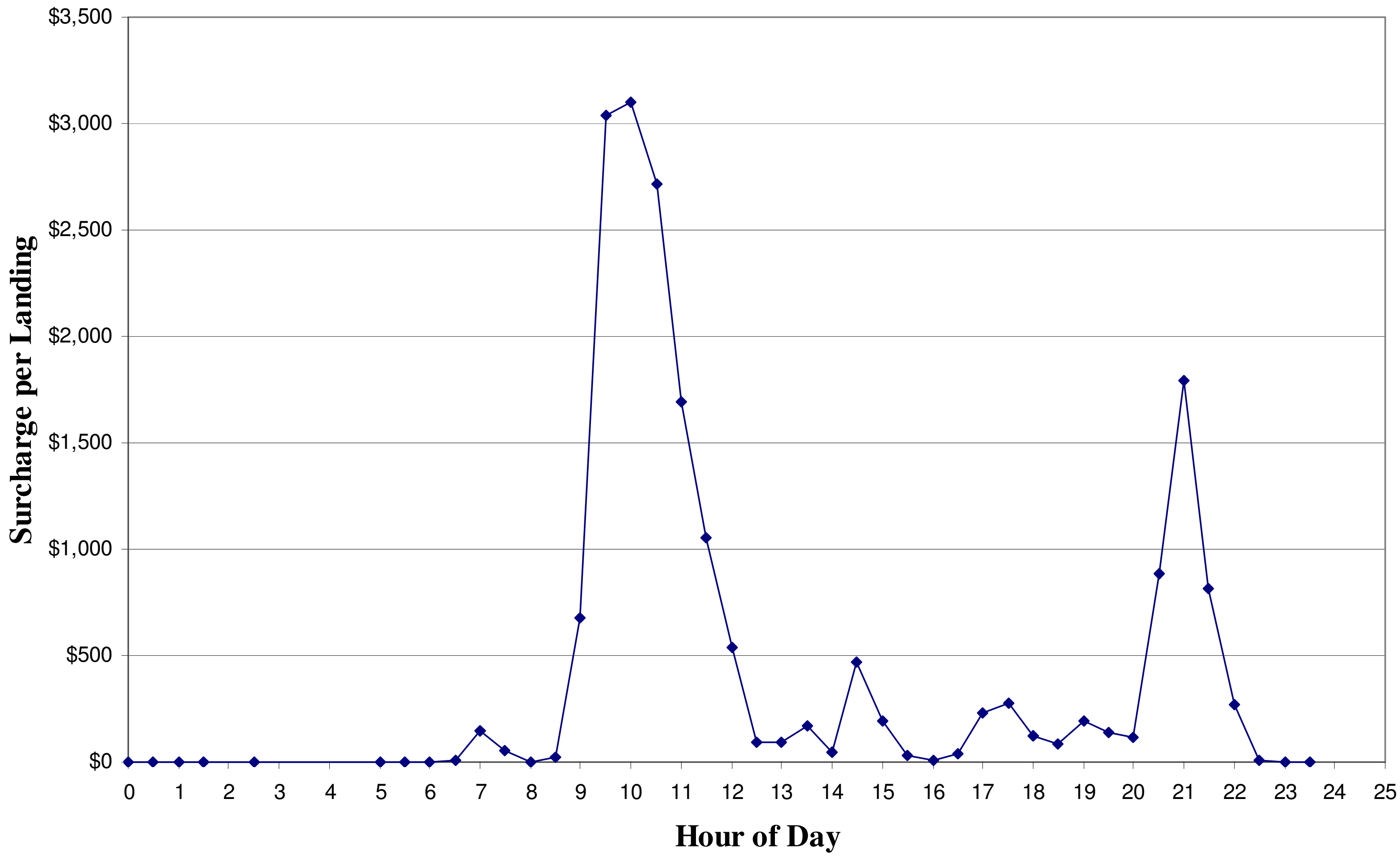
But, Because Pilot Cost Increases with Aircraft Size, Airlines Don't Save from Upsizing



Demand Management Alternatives

- Auctions
  - Currently under consideration for LGA
  - Various forms
  - Challenges
    - What is appropriate number of slots
    - Service to small communities
    - Need to other resources (gate, curbside, baggage handling)
- Pricing
  - Present pricing structure is obsolete
  - Charge “Congestion Surcharges” During Peak Periods
  - Significant Implementation Issues
- Administrative Alternatives

Flights During Peak Generate High Marginal Costs



Administrative Alternatives

- Slightly Modified HDR
- Slot Use Restrictions
- Performance-Based Allocation
- Industry Self-regulation with Government Facilitation

Alternative 1-Slightly Modified HDR

- Grandfathered allocation with blind secondary market and use or lose provision
- Three slot categories: air carrier, small communities, non-scheduled
- ~3% of slots per year re-allocated to new entrants based on lottery

Alternative 2-Slot Use Restrictions

- All slots re-allocated over 5 year period
- Staged re-allocation based on a/c size classes: 150+ seats, 100-149 seats, <100 seats
- Restrictions carry over intro secondary market
- Possibly modify perimeter rule
- Possibly designate time windows for small aircraft slots
- Possibly allow joint operation of larger flights

Alternative 3-Performance Based Allocation

- 5% of slots re-allocated every six months
- Formula-based withdrawal and re-allocation
  - Withdraw more slots from airlines with low pax/slot ratios in previous six months
  - Award more slots to airlines with high pax/slot ratios at LGA or pax/flight ratios elsewhere
  - May also consider
    - Higher weights for small community pax or separate categories for small communities
    - Exemptions for “minimum market presence” slots
    - On-time performance

Alternative 4-Self-regulation

- Turn over regulatory responsibility to airlines
- Form Responsible Scheduling Committee of all interested airlines (not just incumbents)
- Create principles, metrics, and criteria for responsible scheduling
- Create support tools and methods to enable airlines to schedule responsibly
- Scheduling conflict resolution mechanisms
- Graduated sanctioning for bad actors
- Circuit-breaker allows FAA to re-impose slot controls is ops situation degrades unacceptably

A Final Thought

- What is efficient use of LGA?
- Maximize pax throughput and thus time savings generated by the airport?
- Maximize WTP of those using LGA?
- Should we weight everyone’s time equally of everyone’s money equally?