CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Assessing Schedule Delay Propagation in the National Airspace System

Prepared for Presentation at

Transportation Research Forum (TRF) Annual Forum

25 March 2006

Jacqueline Kee, William Baden,

James DeArmon, Lorrie Smith

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Objectives

- **The objective of this research is to investigate the influence of *schedule* delay across 35 major U.S. airports, specifically focusing on where delays are taken and how these delays propagate**
- **This research will allow us to evaluate impacts to delay propagation due to changes in the airline industry**
- **This research will not determine the causes of the delay**
- **The goal is to develop an analyst's toolset which can be used to analyze and visualize delay propagation, via analyst-friendly scripts**

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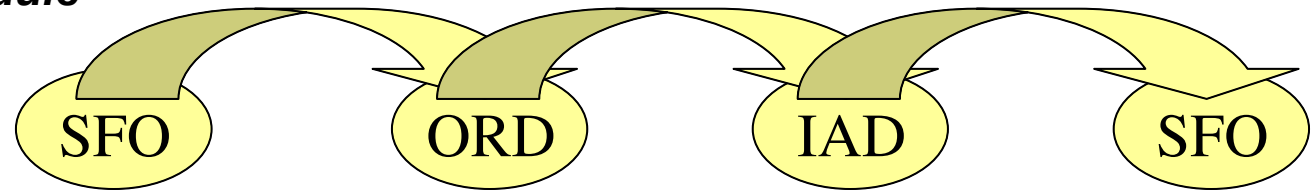
Context
Definition of Delay Propagation

Since aircraft visit multiple airports in a day, delay incurred on one flight segment may persist to downstream flight segments when compared to *schedule*



Flight arrives 1 hour late relative to schedule; flight departs with no additional delay (i.e., 1 hour late)

Flying time is normal, but flight arrives 1 hour late relative to schedule; flight departs with no additional delay (i.e., 1 hour late)

Flying time is normal, but flight arrives 1 hour late relative to schedule

How much of the gate arrival delay at a downstream airport can be attributed back to delays that occurred at upstream flight segments over the course of a day ?

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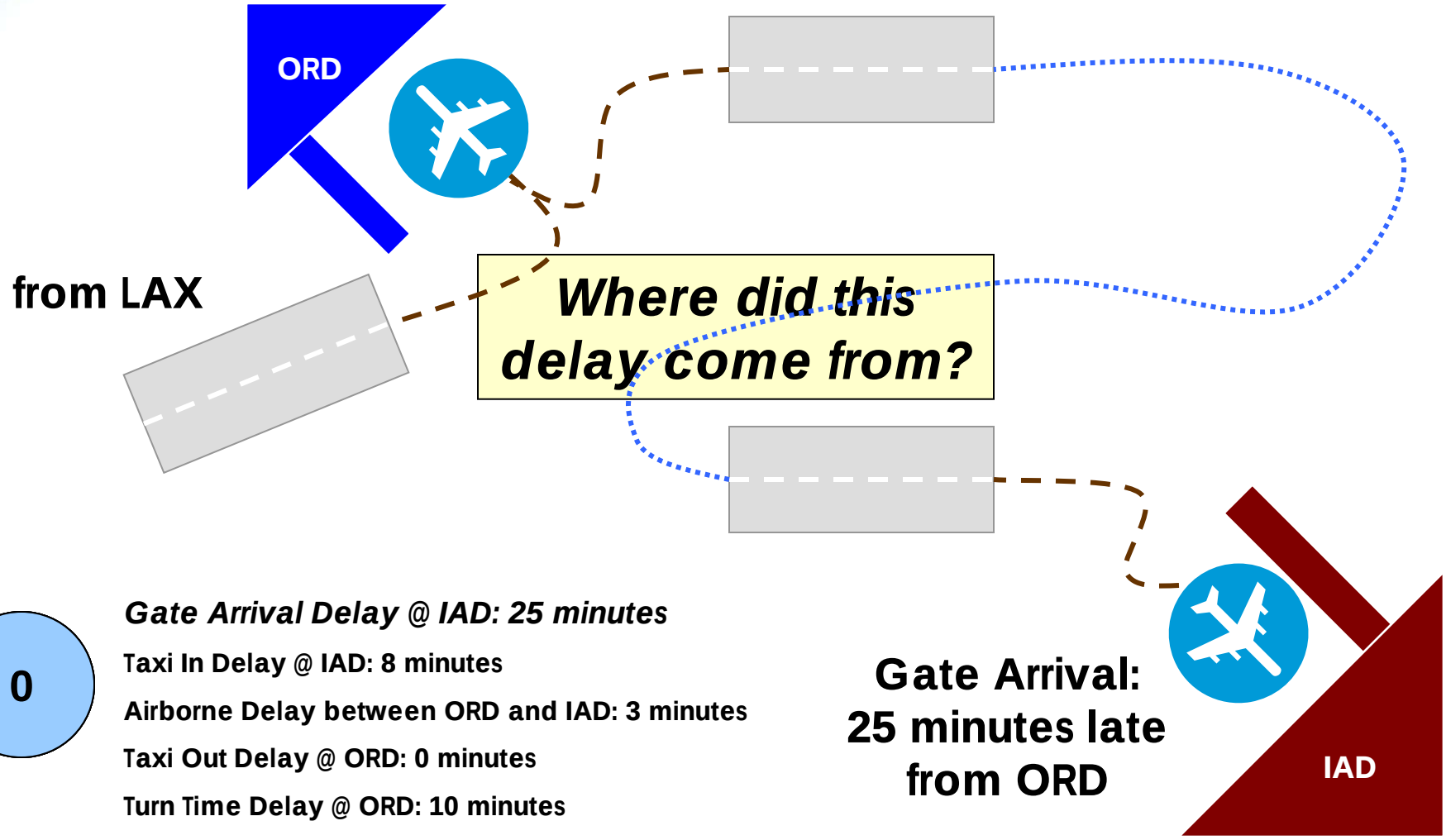
Context
Definition of Algorithm



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Gate Arrival Delay @ IAD: 25 minutes

Taxi In Delay @ IAD: 8 minutes

Airborne Delay between ORD and IAD: 3 minutes

Taxi Out Delay @ ORD: 0 minutes

Turn Time Delay @ ORD: 10 minutes

Taxi In Delay @ ORD: 4 minutes

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Context
Basis for Delay Determination

- **Gate Arrival Delay: relative to schedule**
- **Turn time Delay: relative to schedule**
- **Scheduled times are not released to the public for taxi-in, taxi-out and airborne phases of the flight. Assume scheduled times are the sum of unimpeded times and a slack component.**
  - **Taxi-in and taxi-out delays: relative to unimpeded taxi times (tenth percentile of the taxi time distribution) determined at the airport, carrier, and equipment category level using historical ASQP data *plus* a schedule slack component to account for the difference between schedule block times and unimpeded operational times**
  - **Airborne Delay: relative to unimpeded airborne times (tenth percentile of the airborne time distribution) determined at the segment, carrier, and equipment category level using historical ASQP data *plus* a schedule slack component to account for the difference between schedule block times and unimpeded operational times**

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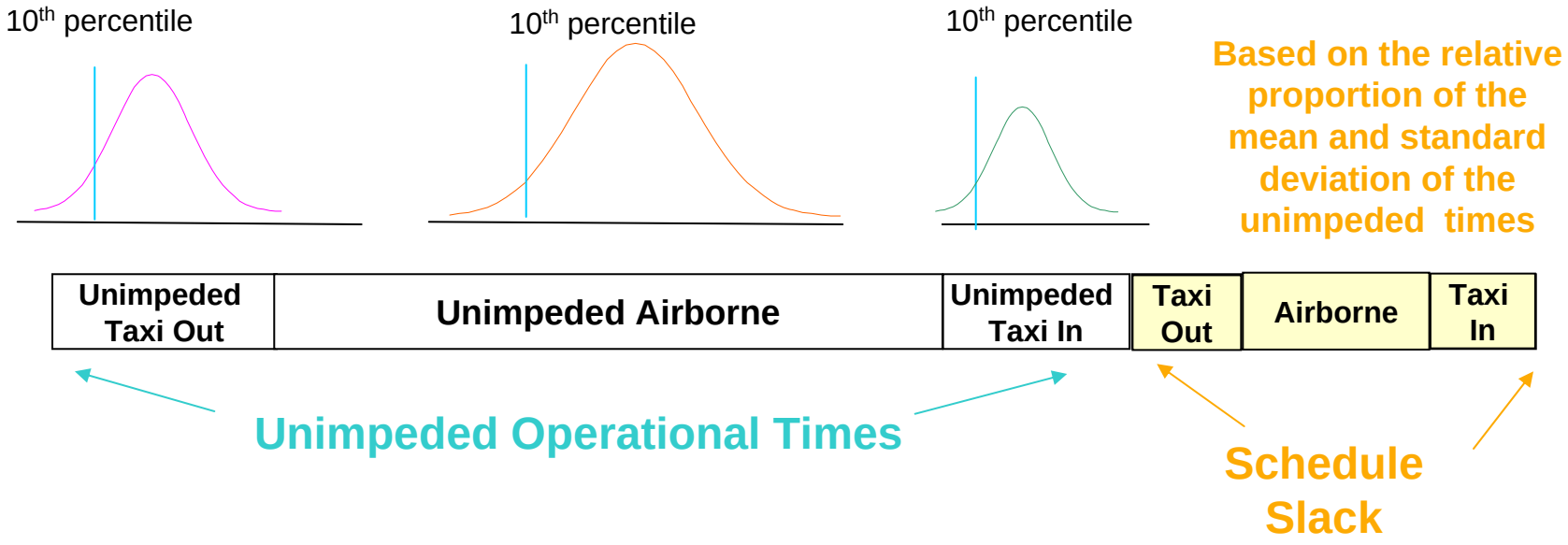
Context
Basis for Delay Determination

The algorithm allocates schedule delay to the different phases of the flight Without published schedule times for the taxi-in, airborne and taxi-out components, propose:



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Validation and Results

- **Validated model assumptions using data from three carriers**
- **Ran algorithm on CY 2004 and CY 2000 data**
- **Propagated delay is arrival delay attributed to a flight segment that is upstream from the current hop**
  - **Analysis by carrier**
  - **Analysis of performance in the NAS across different weather days**
  - **Analysis by airports**

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Delay Propagation by Carrier

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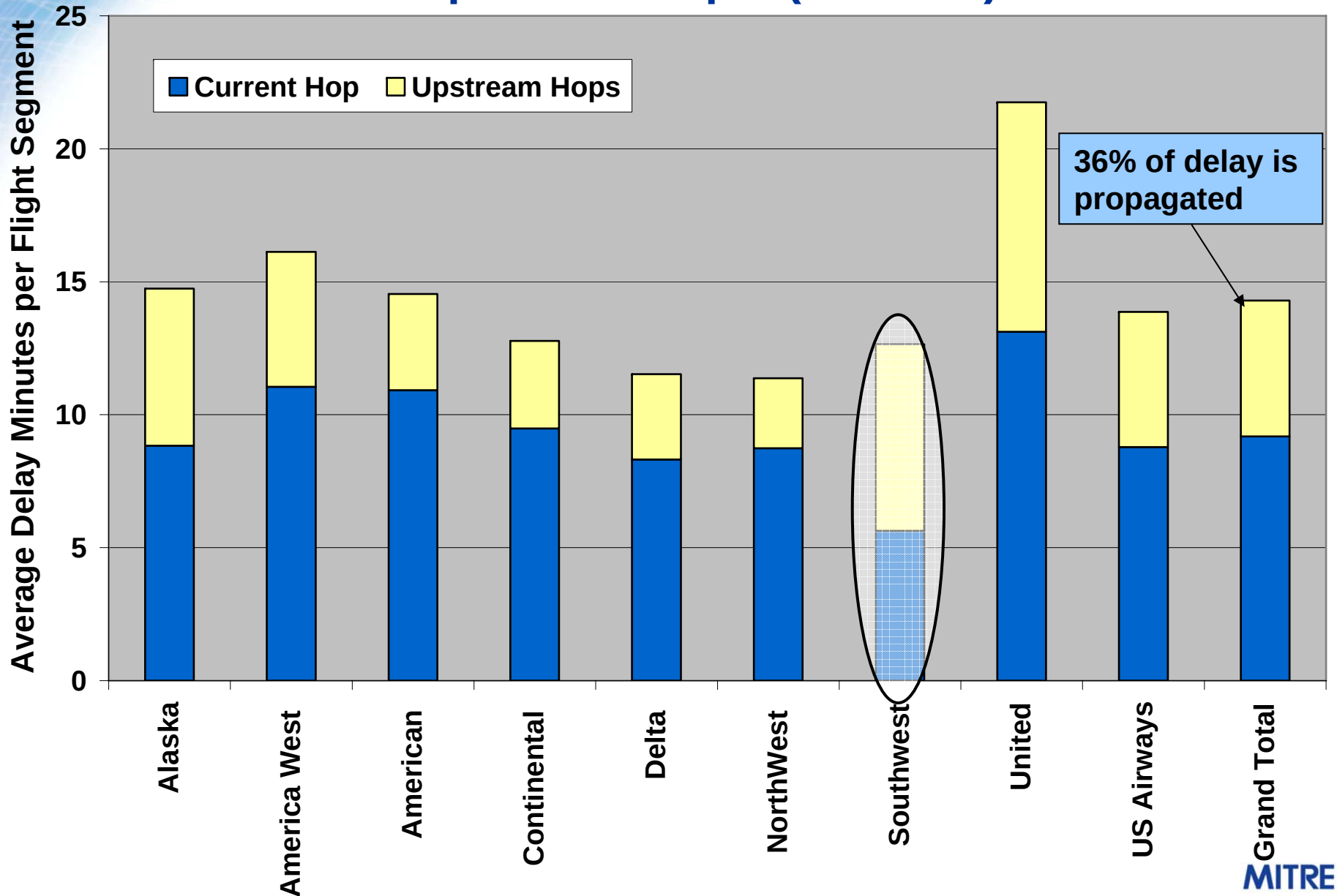
Arrival Delay Attributed to Current Hop versus Upstream Hops (CY 2000)



Source: Analysis based on ASQP Data

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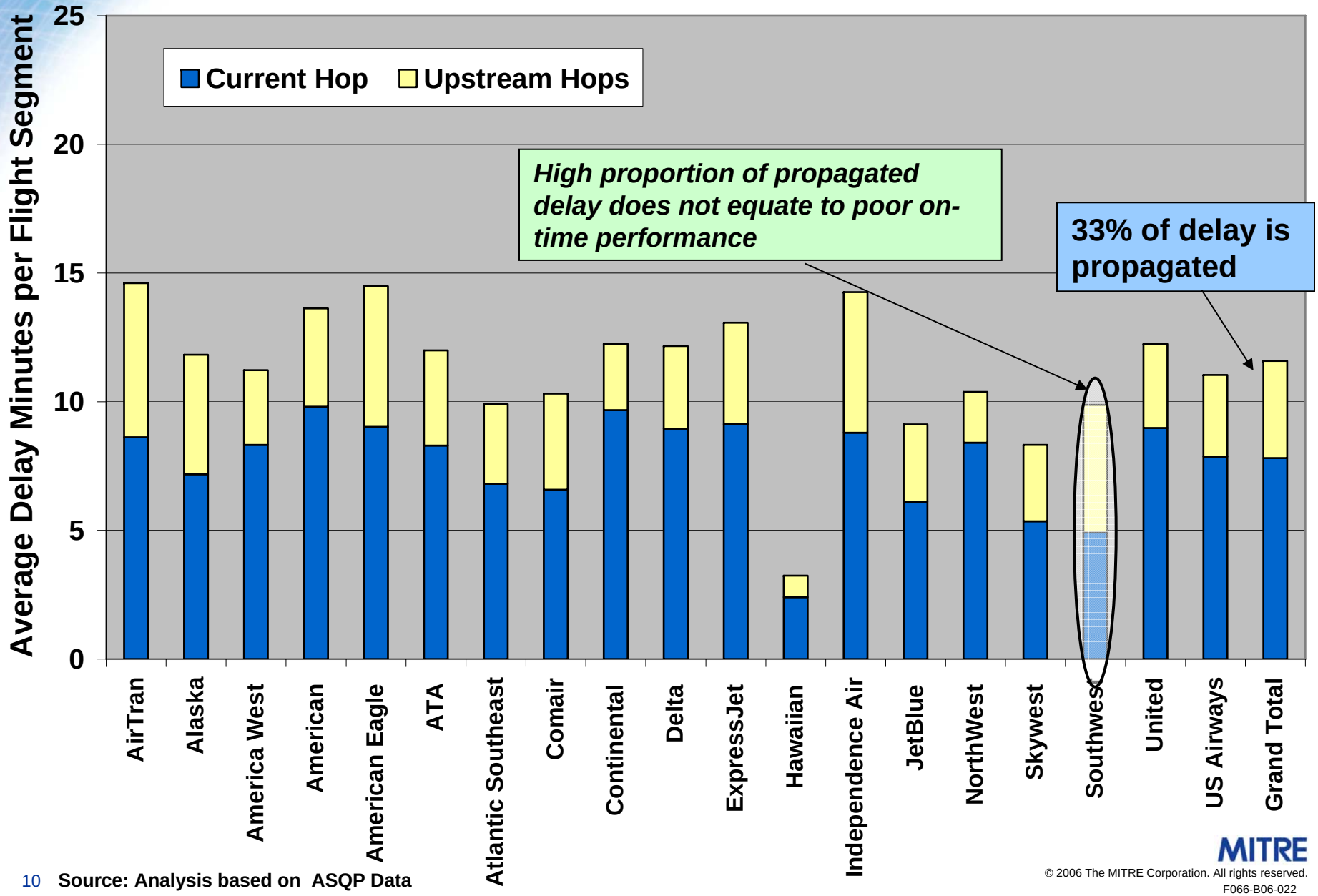
Arrival Delay Attributed to Current Hop versus Upstream Hops (CY 2004)



 Source: Analysis based on ASQP Data

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Delay Propagation on Good and Bad Weather Days in 2004

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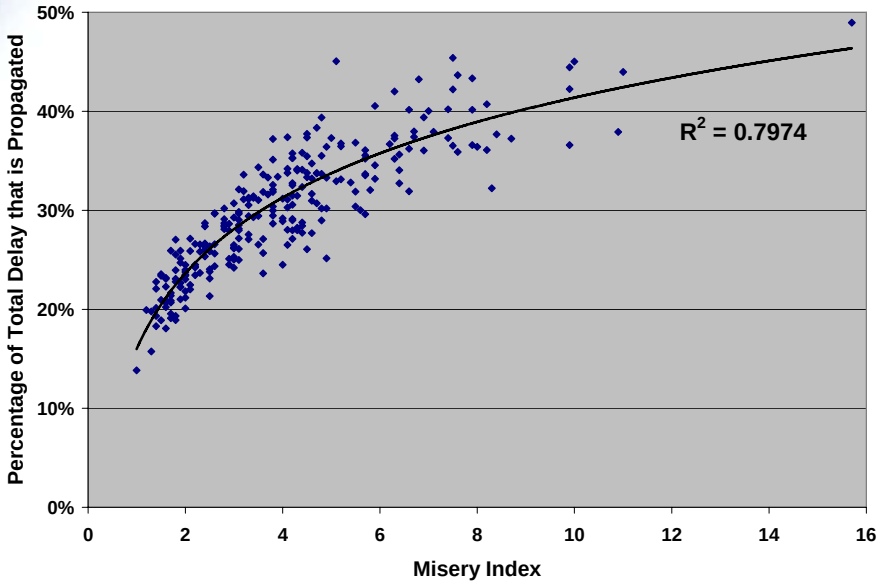
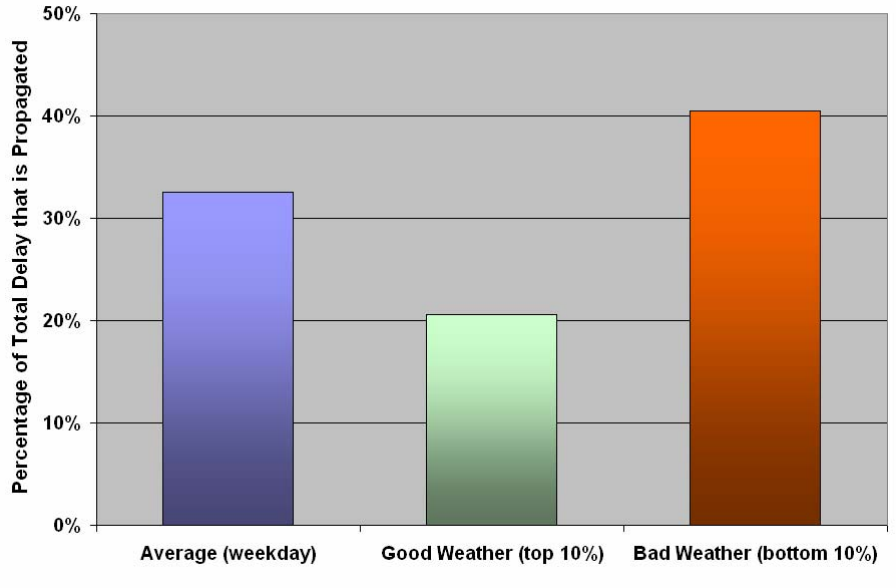
Propagated Delay in the National Airspace System (2004)

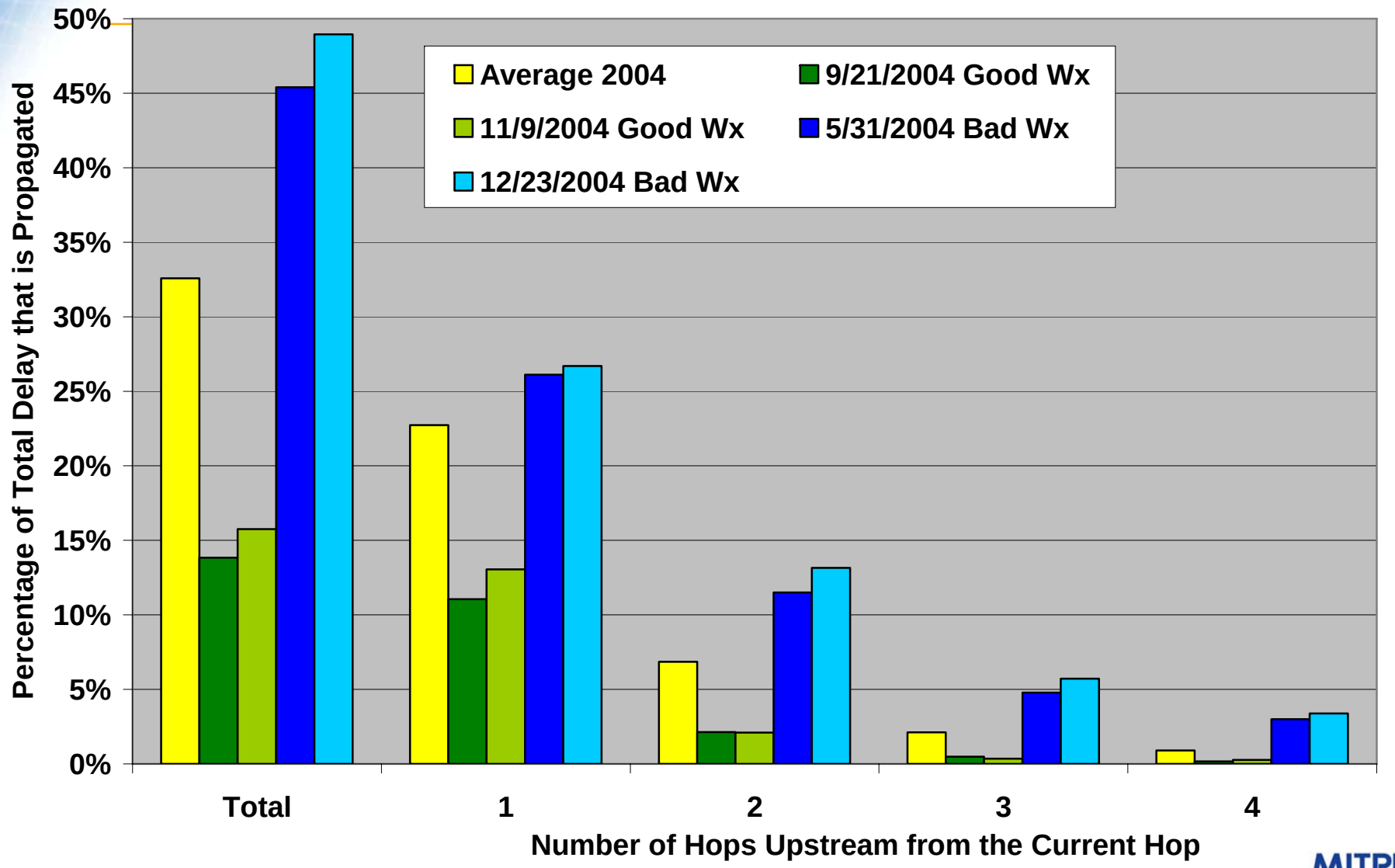




- **There is a strong relationship between the percentage of propagated delay and the Misery Index (metric based on number of cancellations, diversions, and departure delays greater than 30 minutes)**
- **For good weather days (top ten percent performance day), the proportion of delay propagated was 21%**
- **In contrast, for bad weather days (bottom ten percent performance day), the proportion increased to 40%**

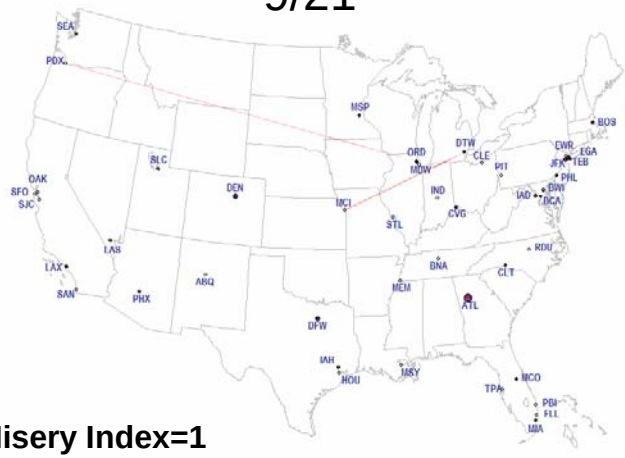
Delay Propagation by Upstream Hop

Annual Average, Good Weather, Bad Weather



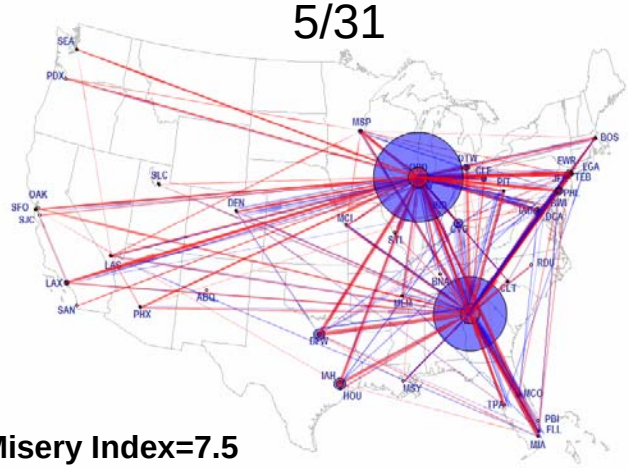
Good Weather versus Bad Weather (Total Delay)

9/21



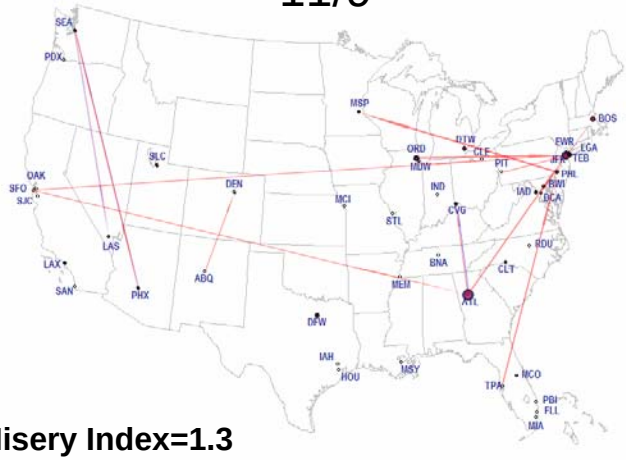
Misery Index=1

5/31



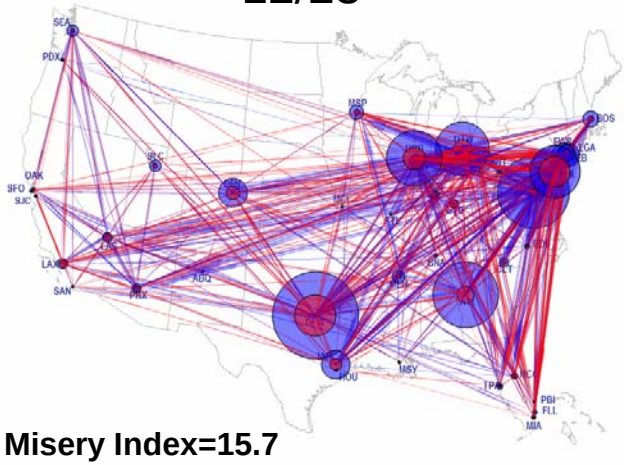
Misery Index=7.5

11/9



Misery Index=1.3

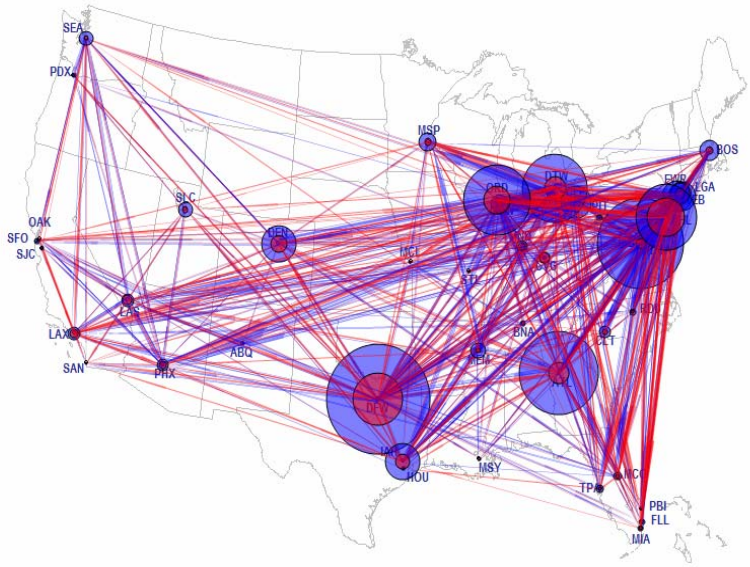
12/23

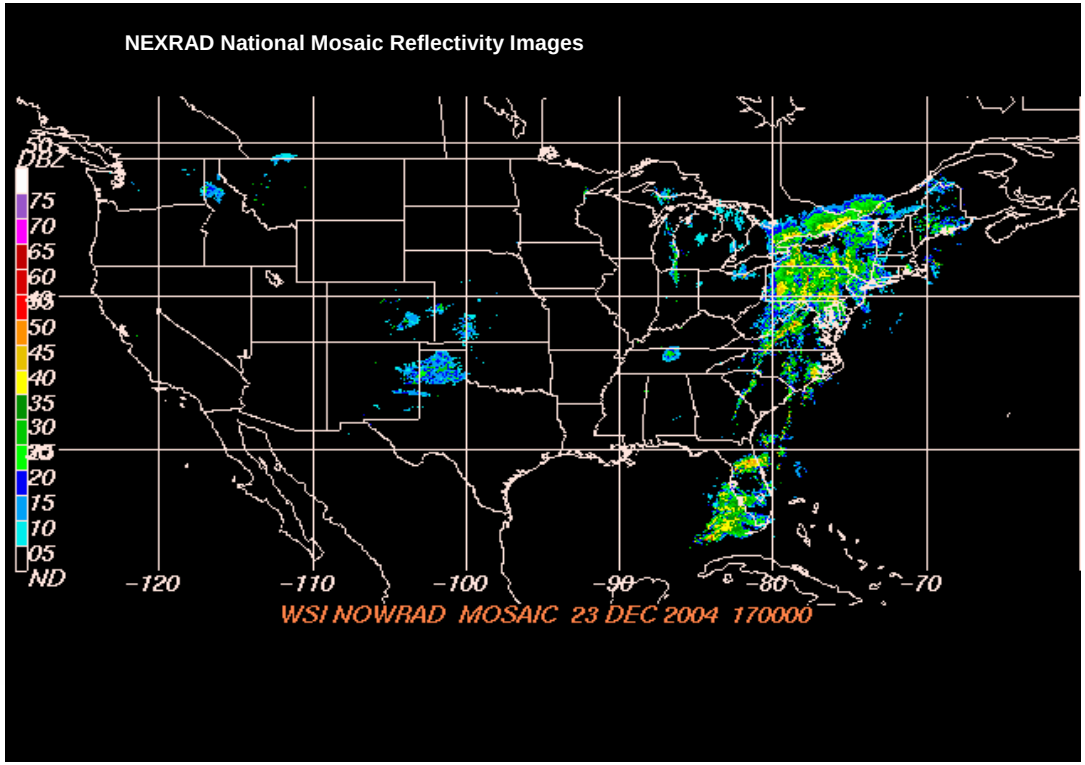


Misery Index=15.7

200 or more minutes of delay per day from “transmitting” airport to receiving airport (“transmitting” airport assumption based on where the delay occurred – taxi out, airborne, taxi in, or turn)

Analysis of December 23, 2004





	OPSNET Total Delays	Delays Caused by Weather
PHL	288	102
ATL	257	253
ORD	238	234
EWR	161	142
LGA	127	108
JFK	123	120
IAD	108	73

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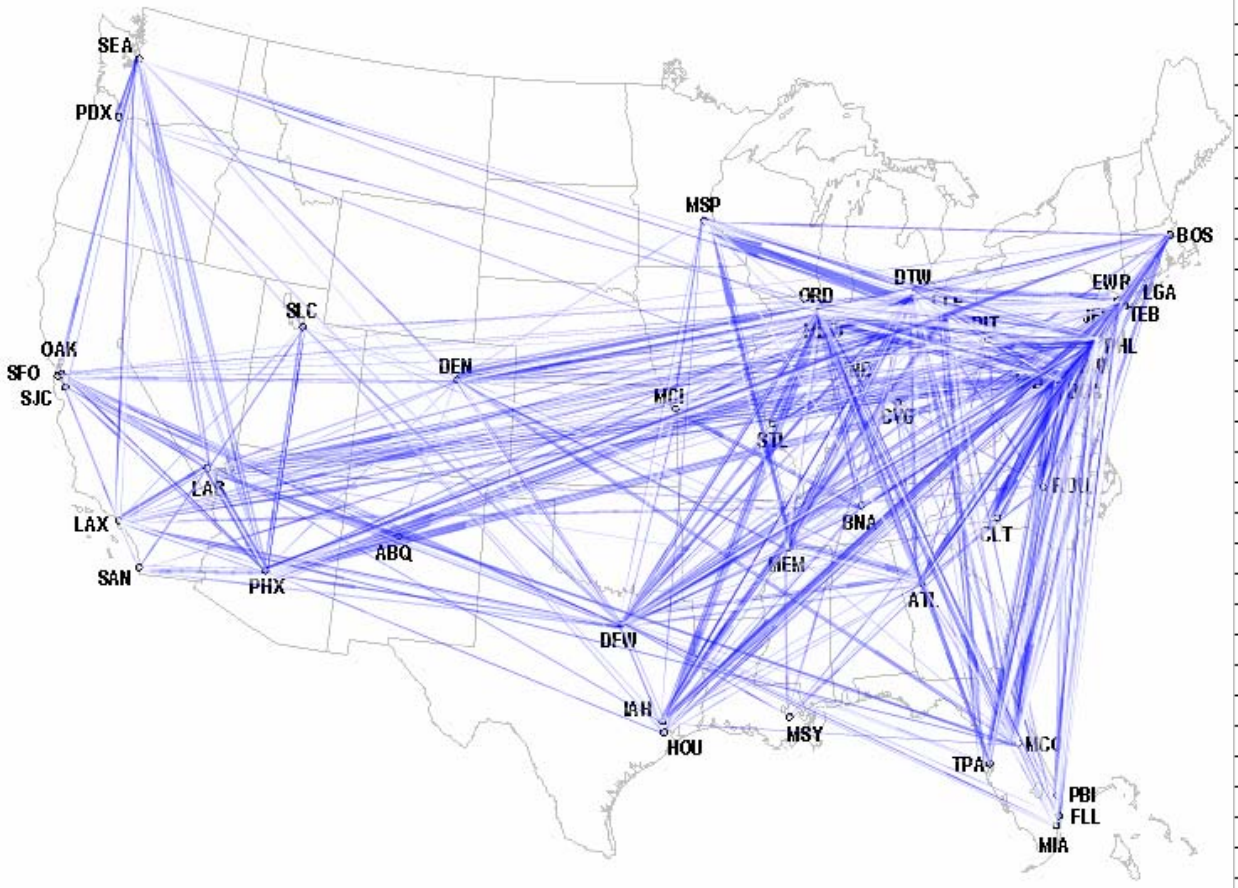
Propagated Delay on December 23, 2004



	ASPM Arrival Delay (minutes)	Percent of Received Delay that is Propagated	
	Dec 23	Dec 23	2004 Average
CLE	128	41%	37%
PHL	78	33%	24%
DTW	77	51%	28%
IAD	76	66%	37%
EWR	75	27%	23%
CVG	74	13%	38%
MEM	70	59%	28%
LGA	62	34%	21%
BWI	59	55%	39%
DCA	56	43%	31%
FLL	56	44%	34%
BOS	54	50%	31%
PIT	53	59%	41%
MCO	52	55%	35%
ATL	52	49%	26%
TPA	51	53%	38%
DFW	51	37%	30%
JFK	50	47%	29%
MDW	49	61%	37%
STL	44	54%	40%
MSP	43	47%	26%
IAH	41	45%	29%
DEN	40	45%	30%
ORD	39	42%	23%
CLT	38	49%	33%
MIA	38	37%	27%
LAS	38	52%	35%
SEA	34	43%	37%
SAN	32	51%	37%
PHX	31	52%	34%
LAX	27	45%	31%
PDX	27	61%	41%
SLC	26	42%	34%
SFO	18	52%	25%

200 or more minutes of delay per day from transmitting airport to receiving airport

Delay Propagation at Airports

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For one minute of arrival delay, how much delay is propagated to the NAS ?

Based on 2004 data

Arrival Airport	Propagated Delay (seconds)
MDW	28
LAS	27
ORD	25
BWI	25
ATL	23
FLL	22
PHL	22
SFO	21
SAN	20
MCO	20
IAD	19
LGA	19
PHX	19
STL	19
MEM	18
TPA	17
DFW	17

Arrival Airport	Propagated Delay (seconds)
EWR	17
DCA	17
DEN	16
PDX	16
CLT	16
PIT	15
CVG	15
SLC	15
BOS	15
SEA	15
LAX	15
CLE	14
DTW	14
IAH	13
JFK	13
MIA	11
MSP	11
HNL	8

- Measures the propensity of an airport to propagate the delay it experiences
- Defined as total propagated delay attributed to flight segments that arrived at the subject airport divided by total arrival delay at the airport*

*Conservative estimate as arrival delay from all segments, not delay from segments that propagate delay, is considered

Propagated Delay (seconds) based on 1 minute of arrival delay at subject airport
Comparing 2004 to 2000

	2000	2004 comp*	2004
ATL	16	21	23
BOS	21	12	15
BWI	25	25	25
CLE	21	16	14
CLT	21	13	16
CVG	18	13	15
DCA	17	15	17
DEN	23	16	16
DFW	15	17	17
DTW	16	13	14
EWR	15	11	17
FLL	22	22	22
HNL	10	4	8
IAD	18	14	19
IAH	15	14	13
JFK	10	8	13
LAS	24	27	27

	2000	2004 comp*	2004
LAX	26	15	15
LGA	23	15	19
MCO	19	20	20
MDW	34	34	28
MEM	17	16	18
MIA	12	10	11
MSP	13	10	11
ORD	24	24	25
PDX	18	16	16
PHL	22	20	22
PHX	25	19	19
PIT	18	12	15
SAN	24	20	20
SEA	18	15	15
SFO	32	16	21
SLC	19	16	15
STL	35	18	19
TPA	18	18	17

***2004 comp dataset for this analysis includes only carriers that reported in 2000**

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Possible Application: Ranking of OEP Airports Using Total Minutes of Average Arrival Delay that is Propagated (2004)

Arrival Airport	ASPM Average Arrival Delay Minutes	ASPM Scheduled Arrivals	Pct Propagated Delay*	Total Propagated Delay Minutes
ORD	19.2	484,859	42%	3,911,613
ATL	15.3	473,249	38%	2,750,148
PHL	16.4	224,381	37%	1,345,203
DFW	11.4	394,112	29%	1,294,103
LAS	13.3	196,144	45%	1,183,197
EWR	18.5	209,575	28%	1,098,554
IAD	15.1	215,986	32%	1,050,112
LGA	15.5	196,310	32%	967,149
PHX	11.6	239,521	32%	876,248
LAX	10.5	307,061	25%	794,003
MDW	12.2	135,948	47%	773,976
SFO	13.3	166,132	35%	762,805
DEN	9.7	273,449	27%	725,543
CVG	11.0	251,102	25%	702,810
BWI	12.1	131,476	41%	660,631
IAH	11.2	246,368	22%	612,099
BOS	13.0	184,869	25%	603,554
MEM	11.5	169,818	30%	590,694

Arrival Airport	ASPM Average Arrival Delay Minutes	ASPM Scheduled Arrivals	Pct Propagated Delay*	Total Propagated Delay Mintues
MCO	11.9	150,352	33%	585,333
FLL	14.4	106,749	37%	563,640
DTW	9.8	250,939	23%	555,750
CLT	9.7	210,977	26%	528,629
JFK	14.9	148,127	22%	488,959
MSP	10.3	253,293	18%	456,738
SEA	10.3	175,080	25%	445,662
SLC	10.2	160,765	25%	418,443
PIT	10.7	150,689	26%	412,613
MIA	14.6	144,138	19%	400,046
STL	9.8	130,684	31%	395,323
DCA	10.0	134,342	28%	370,277
SAN	11.1	95,914	34%	357,245
CLE	11.9	121,774	24%	344,230
TPA	11.3	100,312	29%	329,102
PDX	9.7	107,597	26%	274,516
HNL	10.7	91,206	13%	126,655

*** Based on analysis of ASQP dataset which includes only domestic flights**

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Supplemental Information

Impacts

- **The biggest impact would be the ability to ‘dissect’ delays and to respond rapidly to FAA requests for information. The analysis of delay propagation can provide valuable information to the FAA, especially when corrective or preventive action is required to improve on-time performance in the NAS.**

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Validation of Model Used to Allocate the Schedule Slack

- **Experimented with different allocation schemes**
  - **Use the relative proportion of the mean unimpeded times**
  - **Use the relative proportion of the standard deviation of the unimpeded times**
- **Validated allocation of schedule slack using sample data from three carriers**
- **Using both allocation schemes with equal weights provided the best overall match for all three airlines**
  - **Carrier 1 (mean absolute percentage difference around 10%)**
  - **Carrier 2 (mean absolute percentage difference around 13%)**
  - **Carrier 3, this method tied with another as providing the best match (mean absolute percentage difference around 13%)**

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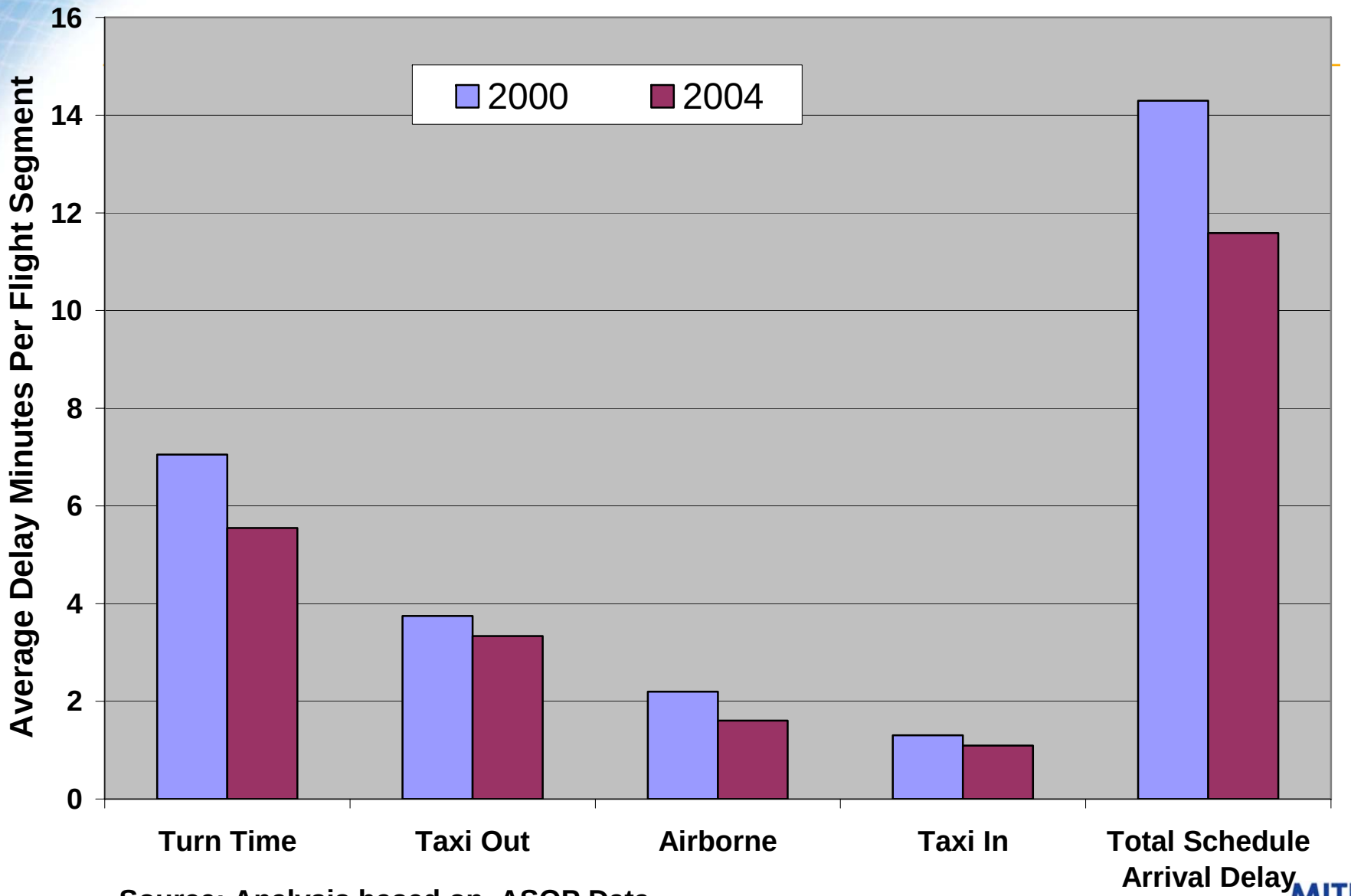
Where is the Arrival Delay Taken ?



Source: Analysis based on ASQP Data

Visualization of Delay Propagation

- **Represent the total delay that is being transmitted to a receiving airport by drawing links between the transmitted airport to the receiving airport**
  - **The links do not reflect the actual flight paths of the transmitted delay but are just notional connections between the transmitting airport and receiving airport**
  - **Airports shown are the top 45 airports**
  - **If the delay is transmitted in a single upstream hop, the link is coded red**
  - **If the delay is transmitted over multiple upstream hops, the link is coded blue**
  - **Circles around the airport indicate that the airport is transmitting delay back to itself**
  - **The width of the link/diameter of the circle indicates the relative amount of delay that is being transmitted**
- **Highlighted links and airports meet a criteria of total delay minutes above a user-defined threshold of 200 minutes per day**
- **Looked at several good and bad weather days in 2004 (picked from the top ten best/worst days defined using Misery Index)**

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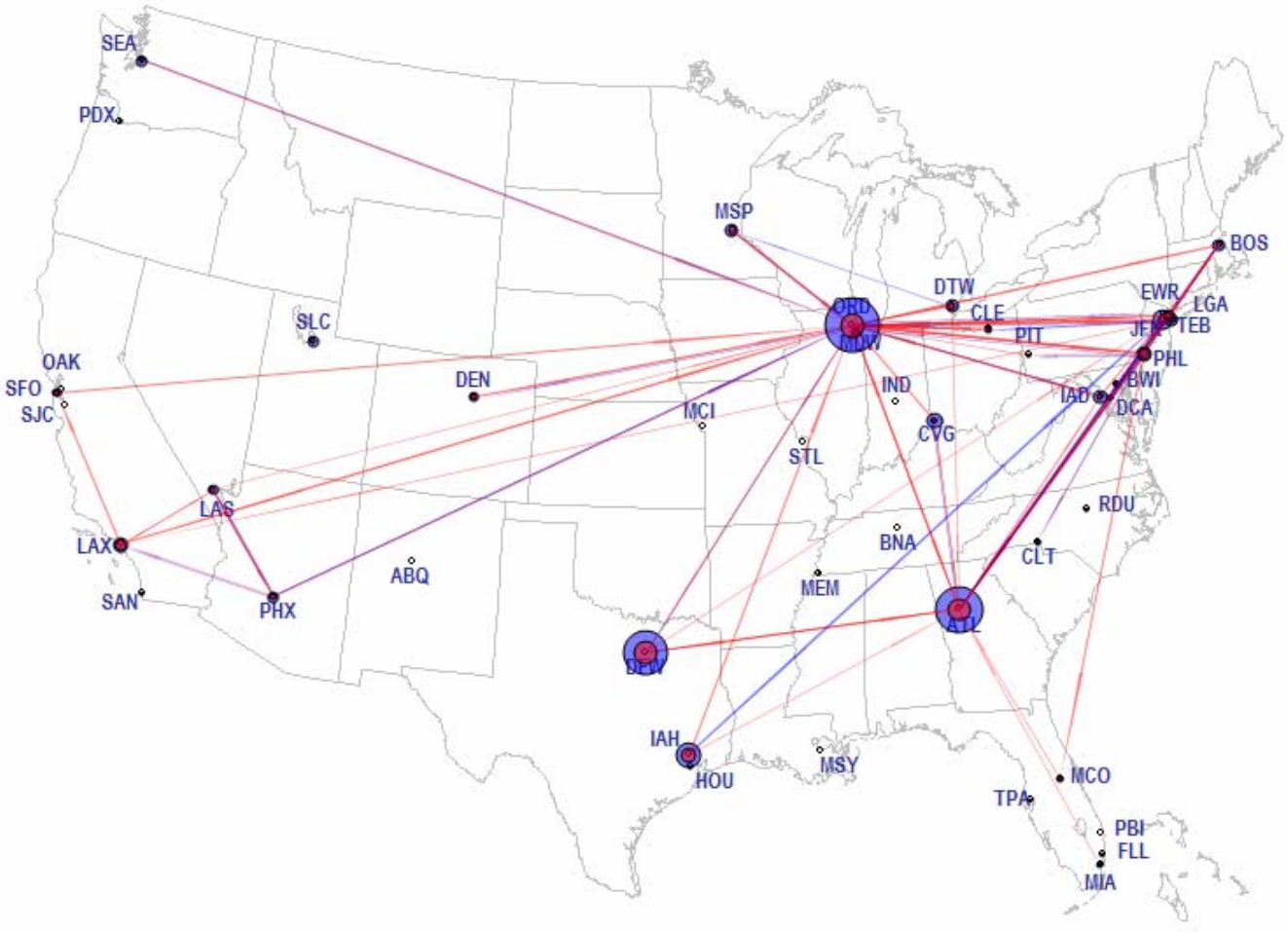
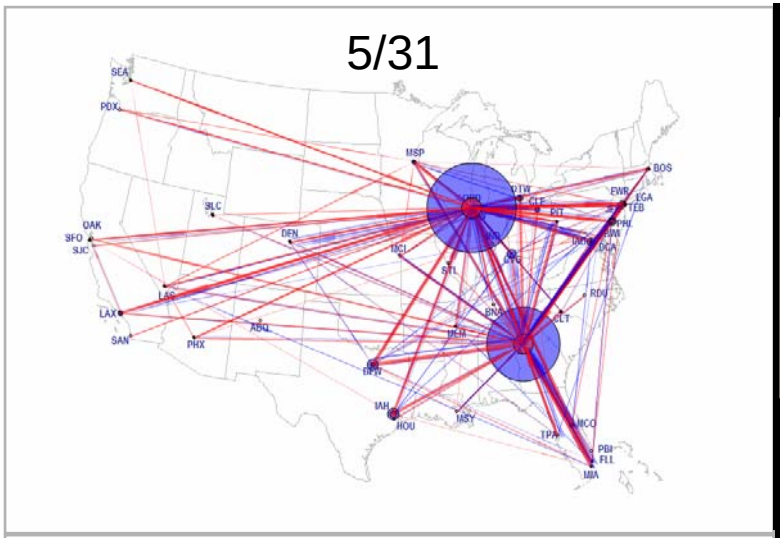
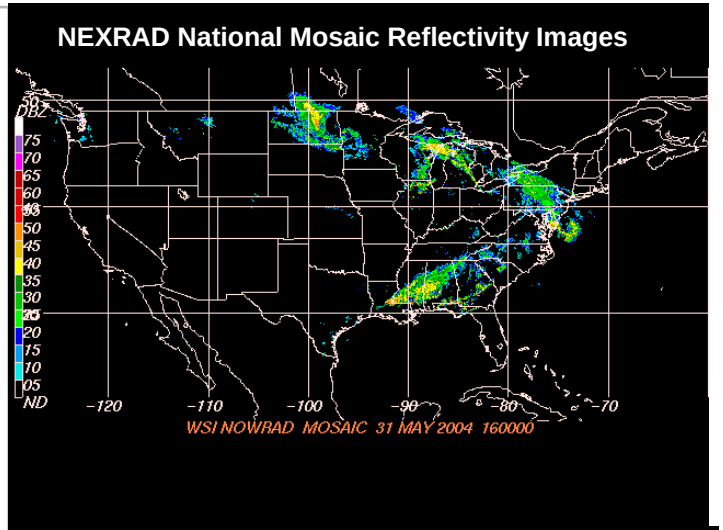
Average of Days in 2004 (Total Delay)

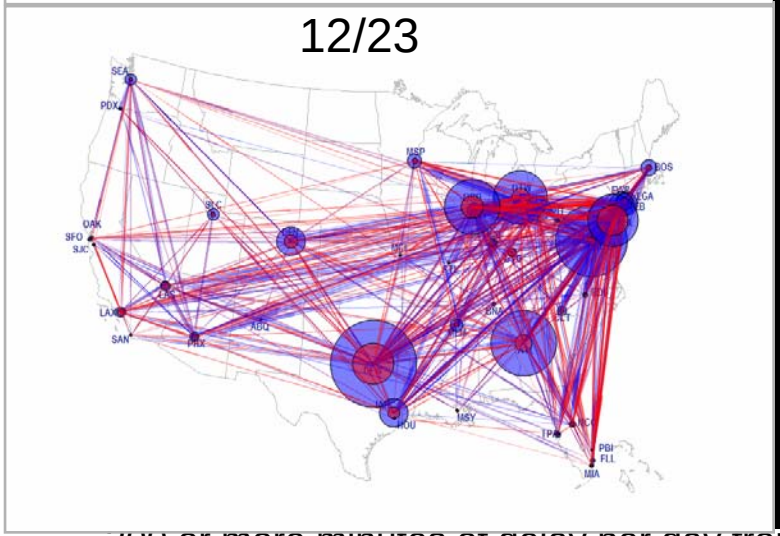


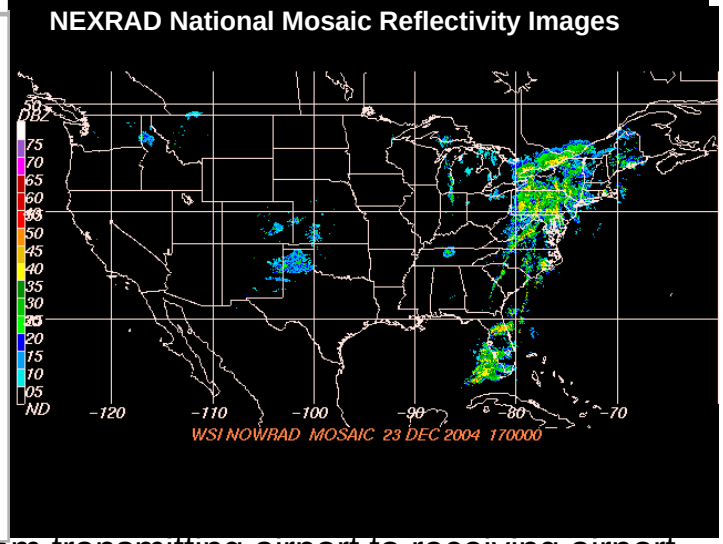
200 or more minutes of delay per day from “transmitting” airport to receiving airport

Analysis of Bad Weather Days









200 or more minutes of delay per day from transmitting airport to receiving airport

Possible Application: Ranking of OEP Airports using Average Arrival Delay and the 1-Minute Arrival Delay Propagation Metric (2004)

	ASPM Arrival Delay	Pct Propagated Delay *	Arrival Delay Ranking	Propagated Delay Ranking
ORD	19.2	42%	1	3
EWR	18.5	28%	2	18
PHL	16.4	37%	3	7
LGA	15.5	32%	4	12
ATL	15.3	38%	5	5
IAD	15.1	32%	6	11
JFK	14.9	22%	7	32
MIA	14.6	19%	8	33
FLL	14.4	37%	9	6
LAS	13.3	45%	10	2
SFO	13.3	35%	11	8
BOS	13.0	25%	12	26
MDW	12.2	47%	13	1
BWI	12.1	41%	14	4
MCO	11.9	33%	15	10
CLE	11.9	24%	16	29
PHX	11.6	32%	17	13

	ASPM Arrival Delay	Pct Propagated Delay *	Arrival Delay Ranking	Propagated Delay Ranking
DFW	11.4	29%	19	17
TPA	11.3	29%	20	16
IAH	11.2	22%	21	31
SAN	11.1	34%	22	9
CVG	11.0	25%	23	24
PIT	10.7	26%	24	23
HNL	10.7	13%	25	35
LAX	10.5	25%	26	28
MSP	10.3	18%	27	34
SEA	10.3	25%	28	27
SLC	10.2	25%	29	25
DCA	10.0	28%	30	19
DTW	9.8	23%	31	30
STL	9.8	31%	32	14
DEN	9.7	27%	33	20
PDX	9.7	26%	34	21
CLT	9.7	26%	35	22

***2004 dataset for this analysis includes all reporting carriers**

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