

Weather Forecast Accuracy: Study of Impact on Airport Capacity And Estimation of Avoidable Costs

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Avoidable Delays and Costs

Delays (and more broadly, costs) can be notionally divided into *avoidable* and *unavoidable*

Avoidable delays/costs can be attributed to:

- airspace design and traffic flow management inefficiencies;
- over-scheduling by airlines at key-market airports;
- conservatism and risk aversion in operational responses;
- accuracy of terminal and en-route weather forecast products;
- also, variability in the accuracy of weather forecast

Initial focus on Terminal Wx Forecast Accuracy and Arrival Delays

"Wx" = Weather

Accuracy of Terminal Wx Forecast Products

Effect of Over- and Under-forecast

An over-forecast may lead to excessive cancellations, GDPs and reroutes that, in hindsight, wouldn't have been necessary.

An under-forecast may cause last-minute TFM actions as the players scramble to mitigate unforeseen Wx impact:

- Unplanned delays and reroutes
- Ripple effects through the NAS
- Planners err widely on the side of caution, apply yesterday's strategies to today's traffic / weather situation, i.e. add to system inefficiencies

Estimating Avoidable Delays and Costs Attributable to Weather Forecast Inaccuracy

Research Methodology (focus on Terminal Wx)

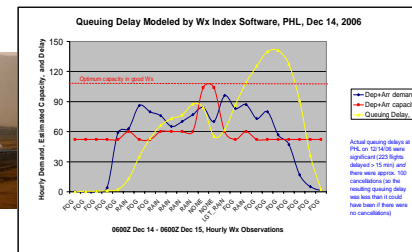
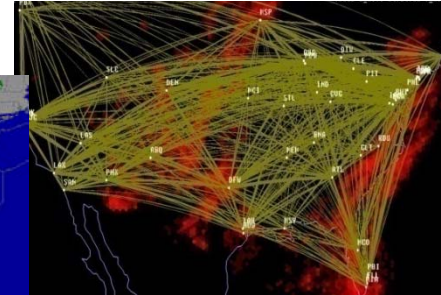
- Quantify impact of *actual* (historically recorded) inclement Wx
- Quantify impact of *forecast* Wx
- Build nomenclature of cases of airport Wx impact under- and over-forecast. For each case:
 - Consider Wx impact on *delays* and *cancellations*;
 - Develop a method for computing the avoidable portion of delays and cancellations attributable to [lack of] *Wx forecast accuracy*
- Process an entire year's data for OEP34 airports
- Estimate benefit pool of improving Wx forecast accuracy

Weather Impacted Traffic Index (WITI)

A Metric and a Model of Wx Impact on Airports

WITI is a weighted sum of three components:

- **En-route Component** reflecting impact of convective weather on routes to/from major airports
- **Terminal Component**
 - **Linear part:** capacity degradation due to surface weather impact, proportional to number of ops
 - **Non-linear (Queuing Delay) part** reflecting excess traffic demand vs. capacity



Used by the FAA on a regular basis:

- Measure system performance in an objective manner
- Compare different seasons' Wx/traffic impact with outcomes (e.g. delays)

Method: Use Airport Arrival Rates

Compute Arrival Rate Deficit

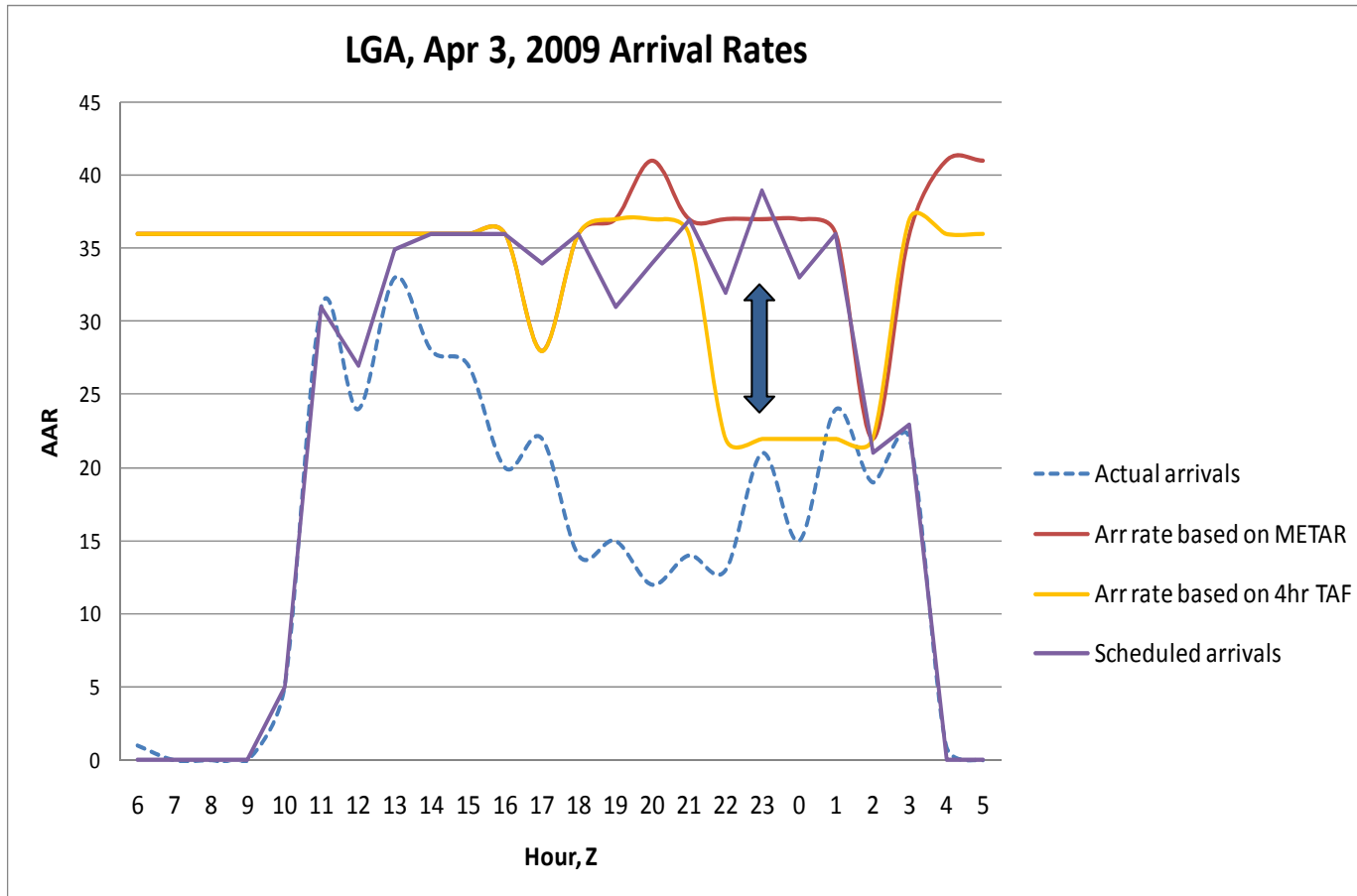
Four different hourly arrival rates are compared:

- *Scheduled* arrival rates from ASPM database
- *Actual* arrival rates, also from ASPM
- WITI model-generated arrival rates based on *METARs* (i.e., actual weather data)
- WITI model-generated rates based on *TAFs* (i.e., forecast weather data)
 - Computed using a parametric model of airport capacity under different Wx conditions
 - Use FAA's airport capacity benchmarks and historical data on actual airport throughput

Any arrival rate deficit ("*possible* minus *actual*") may be an indication of avoidable delays / cancellations

Using Airport Arrival Rates: Example 1

Over-forecast (Wx impact overestimated)

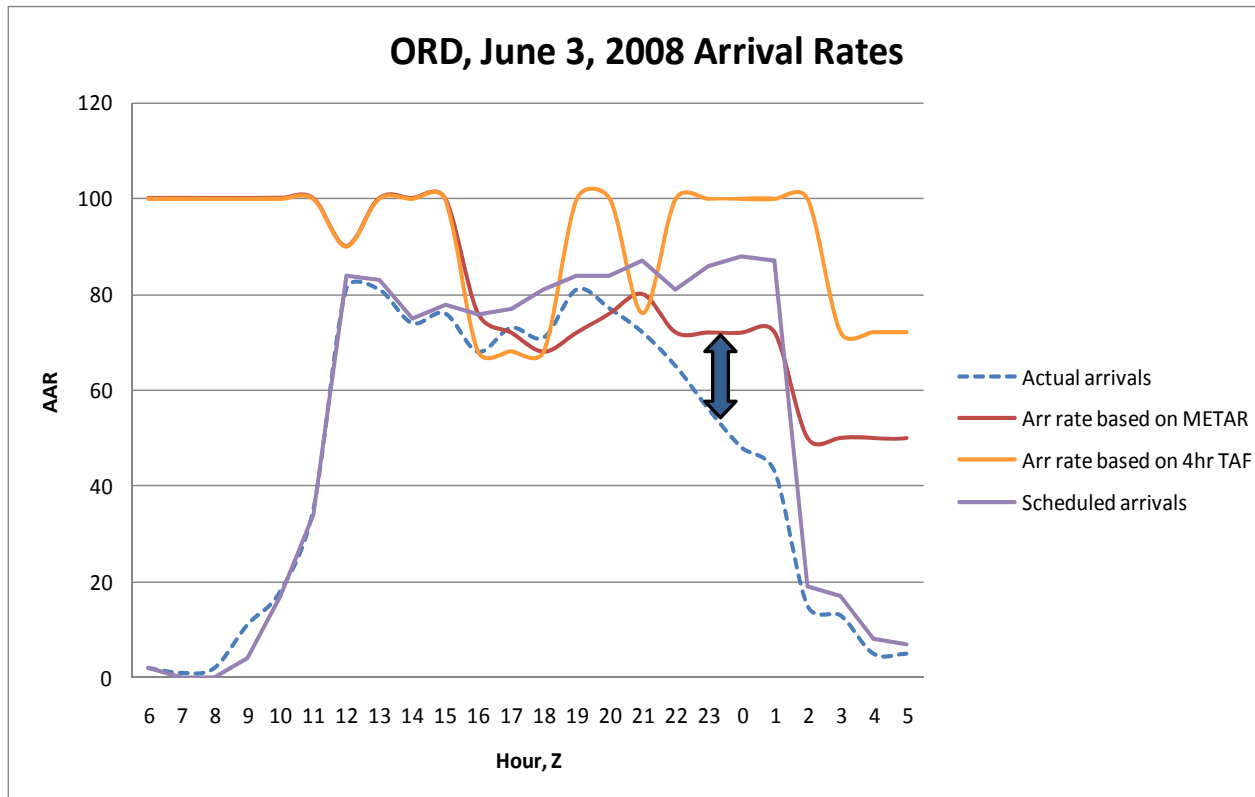


Forecast called for rain, low ceilings and strong winds from the southwest which would have forced LGA into a single-runway operation with low arrival rate.

Actual winds were much weaker. Ceilings lifted earlier than forecast.

Using Airport Arrival Rates: Example 2

Under-forecast (Wx impact underestimated)



ORD had very low ceilings through most of the day.

TAF for midday and early afternoon (1600-1800Z) was accurate.

Later in the day the forecast called for improved conditions (1900-2000Z). Arrival rates began to increase but the weather did *not* improve as hoped (an under-forecast).

This may have been the reason behind the high number of flight cancellations

It could be argued that a portion of this under-forecast has contributed to avoidable cancellations/costs.

Nomenclature of "Arrival Rate Deficit" Cases

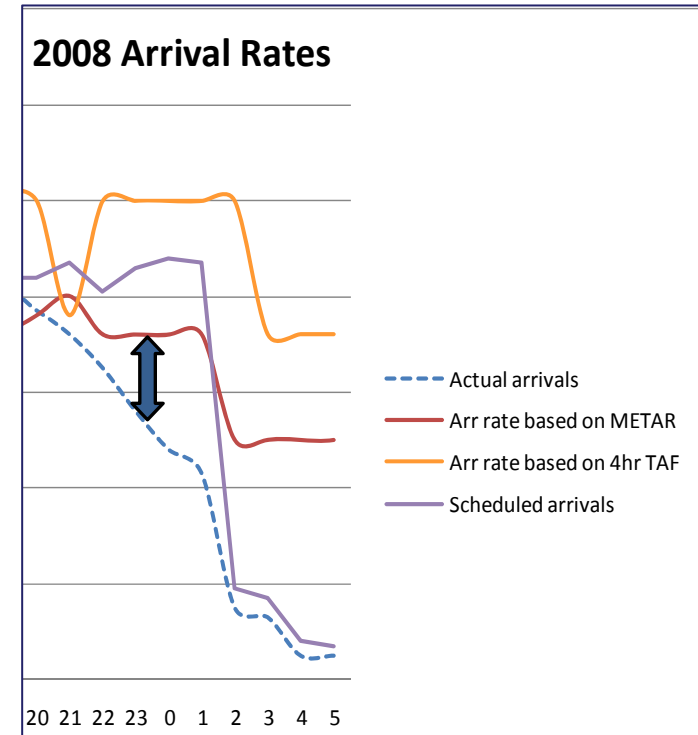
Relationships Between 4 Arrival Rates

24 possible permutations

- Only half, 12, (actual rates < scheduled) need to be examined
- Of these, 3 cases where METAR-based rates < all other rates can be dropped (avoidable portion of delay/cost due to $Wx = 0$).
- Of remaining 9 cases, 6 correspond to over-forecast and 3 deal with under-forecast

Resulting list: 9 meaningful combinations of arrival rate relationships

Next, develop a method to translate arrival rate "deficit" (actual < scheduled) into avoidable-delay and -cancellation estimates.

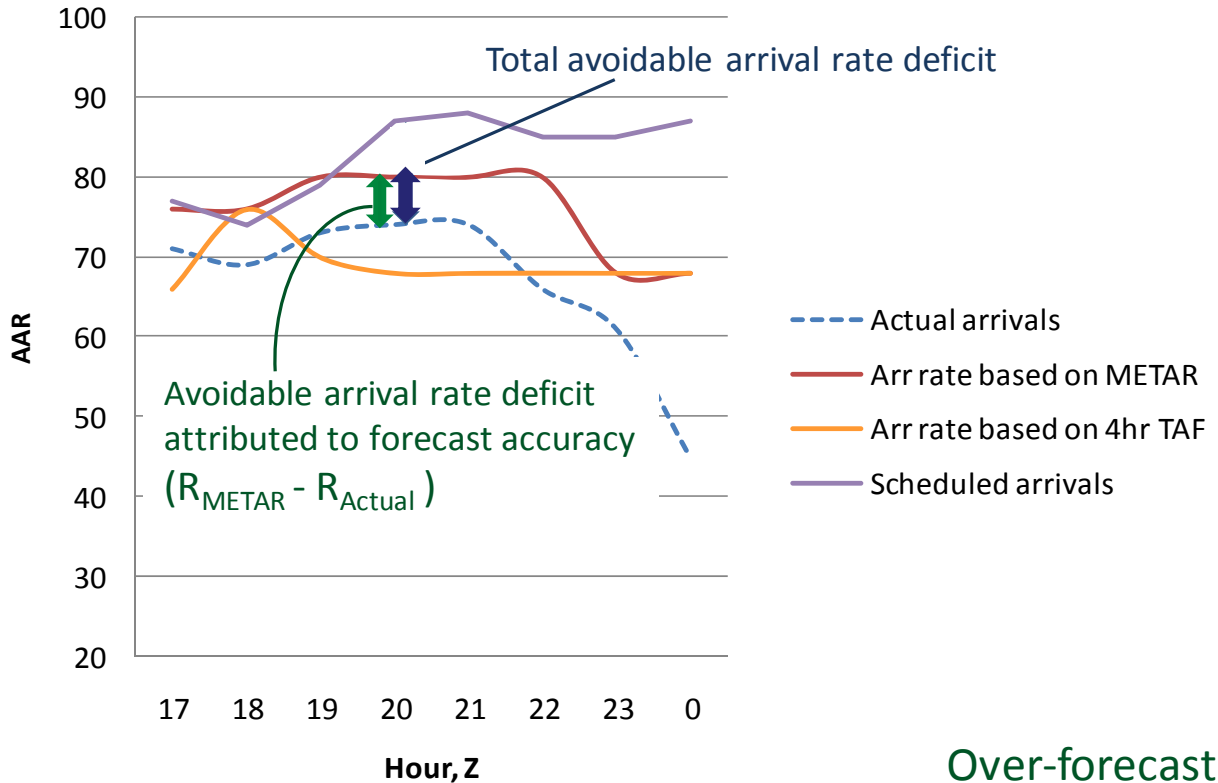


Consider all possible relationships between four different arrival rates (*Actual/Scheduled/METAR-based/TAF-based*)

Examples of Arrival Rate "Deficit" Calculation

Example 1: Over-forecast, A

ORD, Mar 18, 2008 Arrival Rates



Total avoidable arrival rate deficit is:

$$D_{Total} = R_{METAR} - R_{Actual}$$

The portion of total deficit attributable to forecast accuracy ("FA"), is in this case the same:

$$D_{FA} = R_{METAR} - R_{Actual}$$

Here, we assume that actual arrival rates could not go higher than justified by actual weather (METAR).

Examples of Arrival Rate “Deficit” Calculation

Example 2: Over-forecast, B

Scheduled arrival rates < METAR- and TAF-model based rates.
 In principle, airport capacity should not have depended on Wx.
 But if actual rates are < scheduled, we *do* have a deficit. This may be an over-reaction to the inclement-Wx forecast.

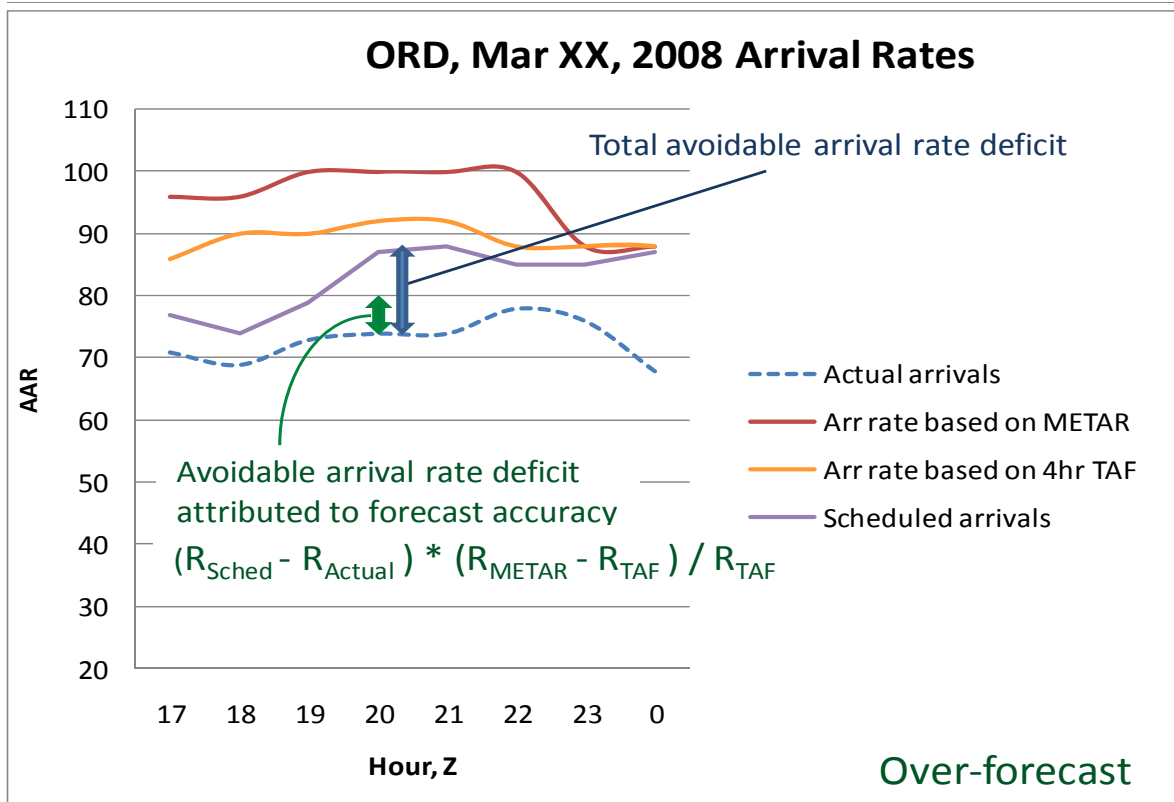
Total avoidable arrival rate deficit is

$$D_{\text{Total}} = R_{\text{Scheduled}} - R_{\text{actual}}$$

while the portion of that total deficit attributable to forecast accuracy (“FA”) is:

$$D_{\text{FA}} = (R_{\text{Scheduled}} - R_{\text{Actual}}) / (R_{\text{METAR}} - R_{\text{TAF}}) / R_{\text{TAF}}$$

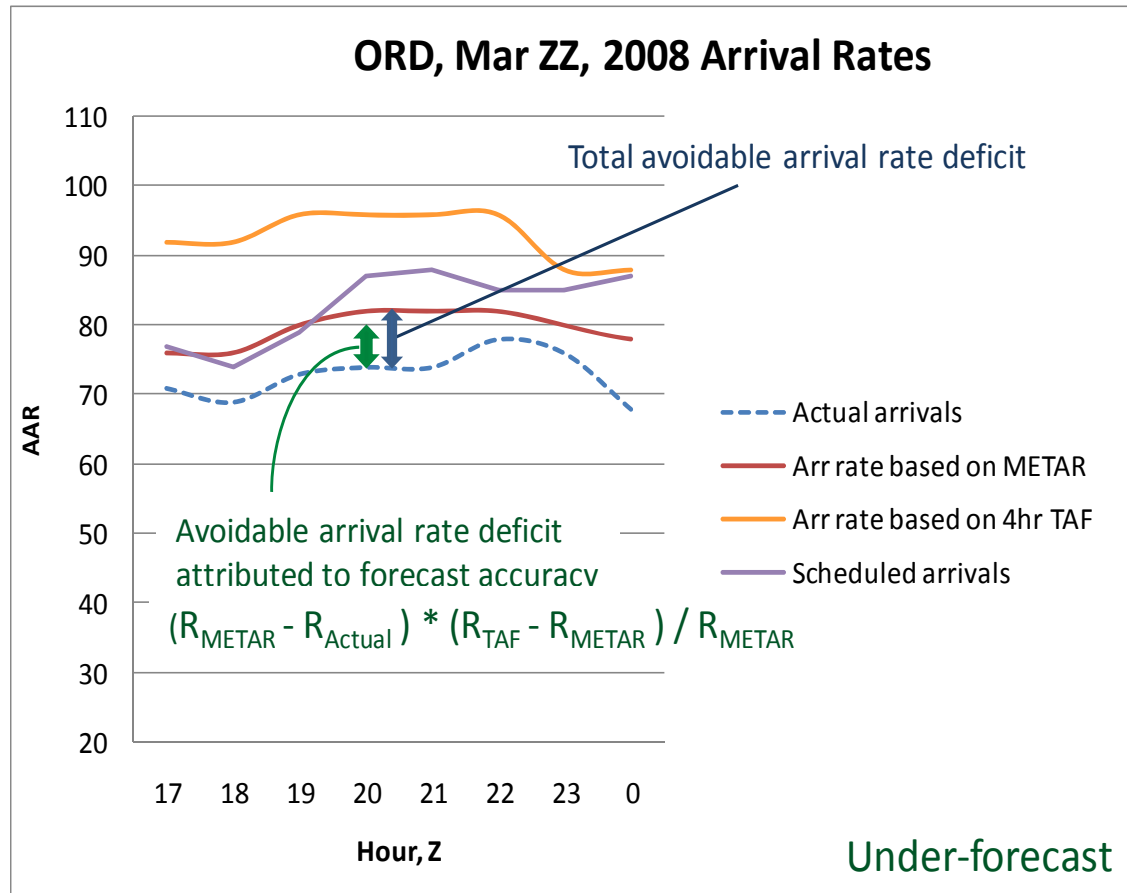
Here, we attribute only a portion of the total arrival rate deficit to forecast accuracy. We assume that avoidable costs are proportional to relative forecast error



Examples of Arrival Rate "Deficit" Calculation

Example 3: Under-forecast

Actual weather was much worse than predicted and the operators' subsequent attitude may have been to reject the forecast.



Total avoidable arrival rate deficit is now

$$D_{\text{Total}} = R_{\text{METAR}} - R_{\text{Actual}}$$

(rather than $R_{\text{Scheduled}} - R_{\text{Actual}}$ because actual arrival rates could not go higher than justified by actual Wx (METAR)).

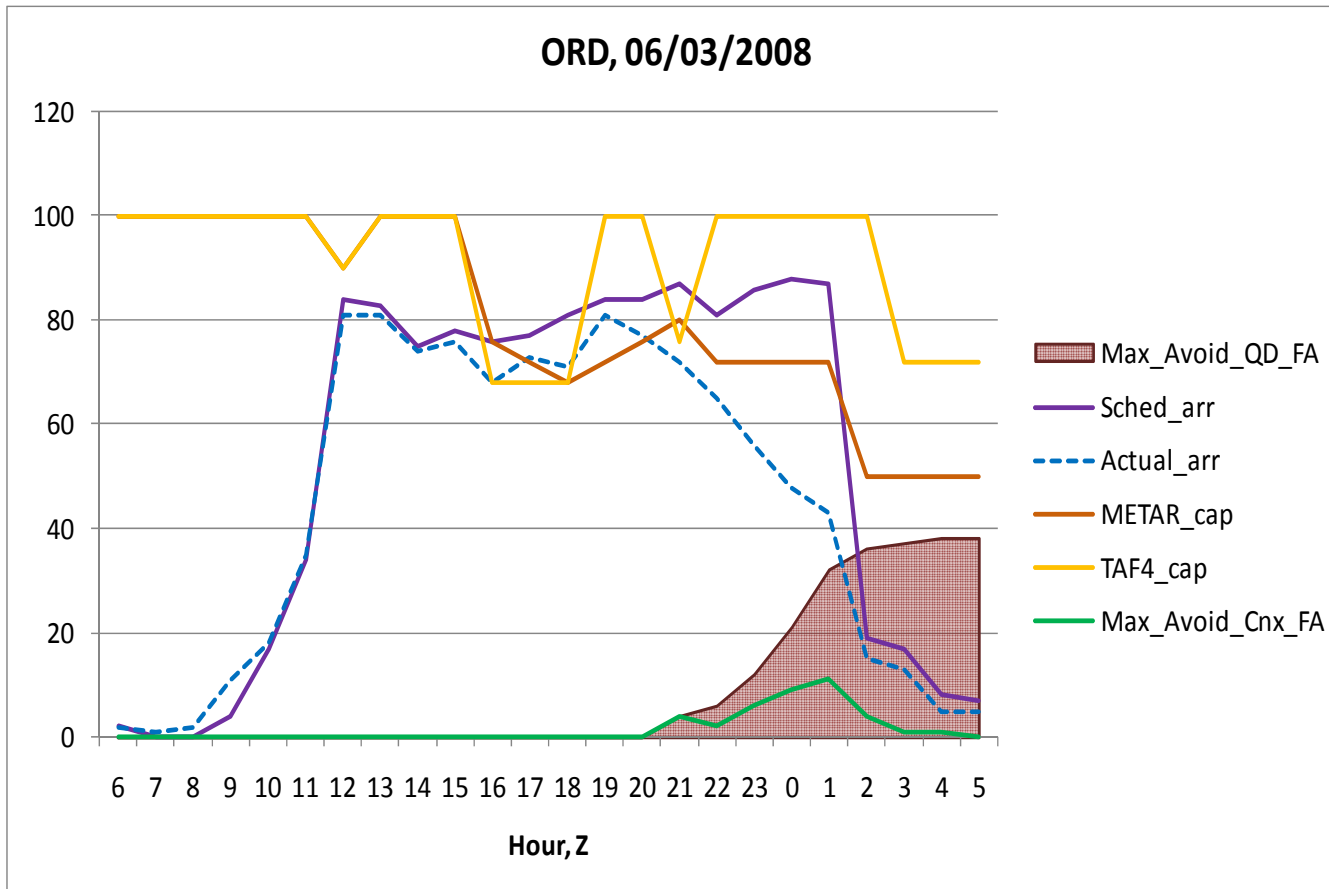
The portion of that total deficit attributable to forecast accuracy ("FA") is:

$$D_{\text{FA}} = (R_{\text{METAR}} - R_{\text{Actual}}) / (R_{\text{TAF}} - R_{\text{METAR}}) / R_{\text{METAR}}$$

i.e., avoidable costs are proportional to relative forecast error

Computing Avoidable Delays and Cancellations

A Simple Queuing Model



From formulas on previous slides, estimate avoidable arrival rate deficit for each of 9 cases

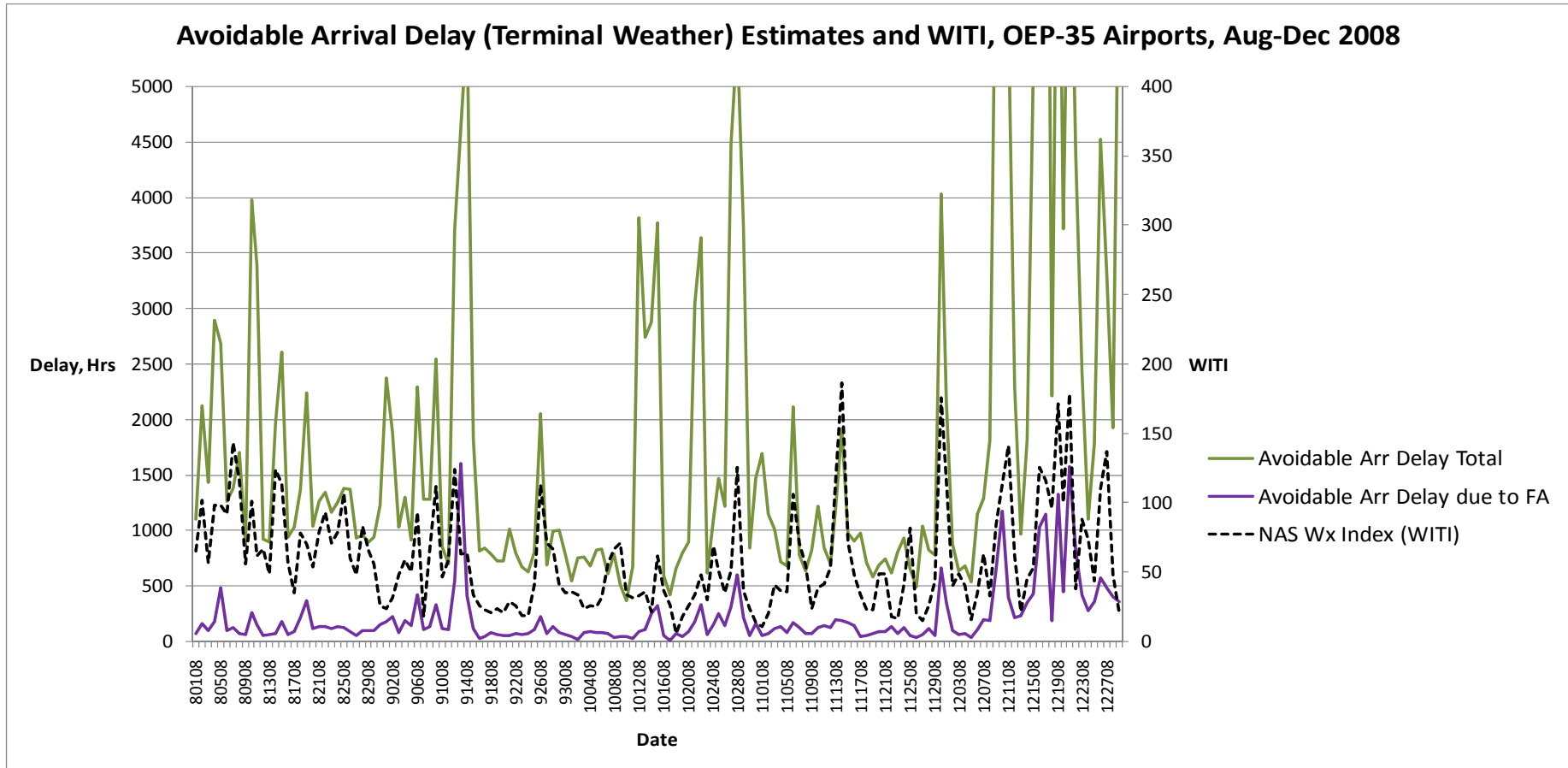
Compute cumulative queuing delays:

Every hour, a deficit of 1 translates into 1-hr arrival delay

Delays ≥ 3 hrs are converted to cancellations

Computing Avoidable Delays and Cancellations

Avoidable Delay due to FA vs. Total Avoidable Delay



Estimating Potential Benefit Pool

Assuming \$53/min average delay cost and \$10,000 per cancellation cost:

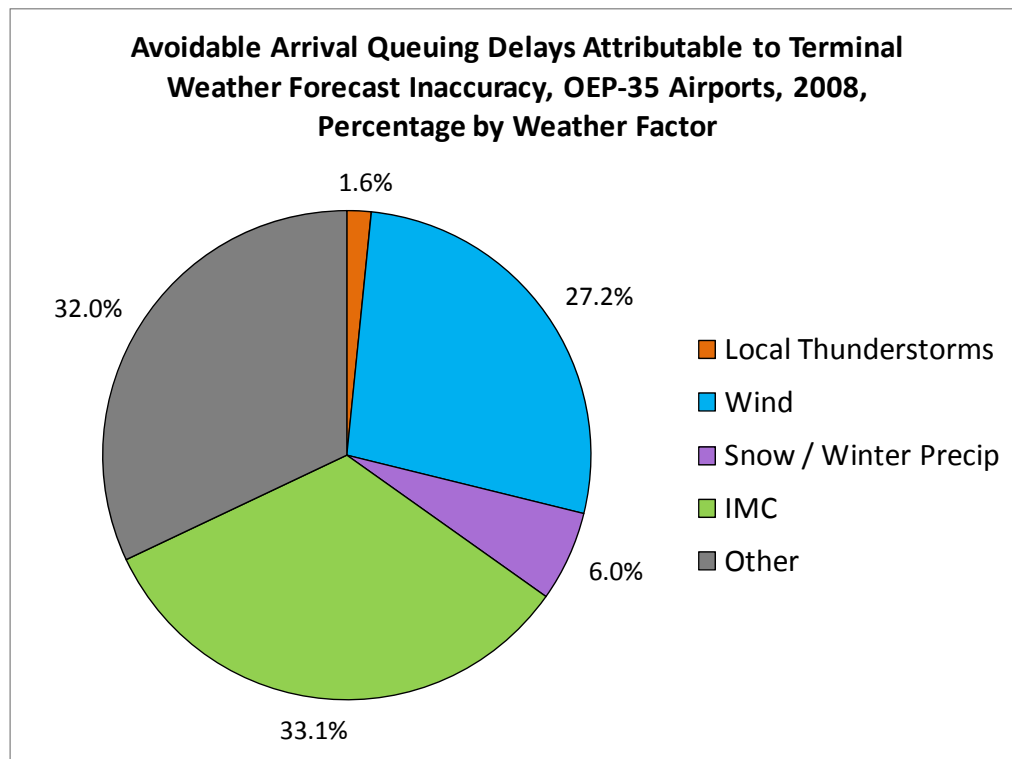
Max Avoid.QD-FA		Max Avoid Cnx-FA	
Hours	81,429	Cancellations	7,308
Cost	\$258,944,220	Cost	\$73,080,000
Percent total	12.2%	Percent total	6.9%

Total benefit pool for avoidable costs attributable to *terminal* Wx forecast inaccuracy: approx. \$330M per year

This is a *lower* bound on benefit estimate:

- Only direct operating costs of passenger carriers calculated
- Adding departure delays would increase estimate
- So would using ASPM-75 airports instead of OEP-35
- Value of passenger time can be added also

Biggest Contributing Factors to Avoidable Delay due to Terminal Wx Forecast Inaccuracy



En-route convective Wx not reflected, only airport surface Wx reports (METARs)

Inaccurate forecast of IMC (low ceilings/visibility, heavy rain) is the largest contributor, followed by wind (speed or gusts > 15 Kt) and winter precip.

“Other” category includes minor weather impacts e.g. wind < 15 Kt (causing airports to use less-than-optimal runway configurations), light rain or drizzle, etc.

Reality Check

Our hypothetical total for avoidable arrival delays due to terminal Wx in 2008 was 40,000,000 minutes

Actual total number of arrival delay minutes for the NAS in 2008 was 102,000,000 minutes

That is, our estimate for avoidable portion of delays due to terminal Wx only is 40%

- of that, approx. 12.2% is due to terminal Wx forecast accuracy

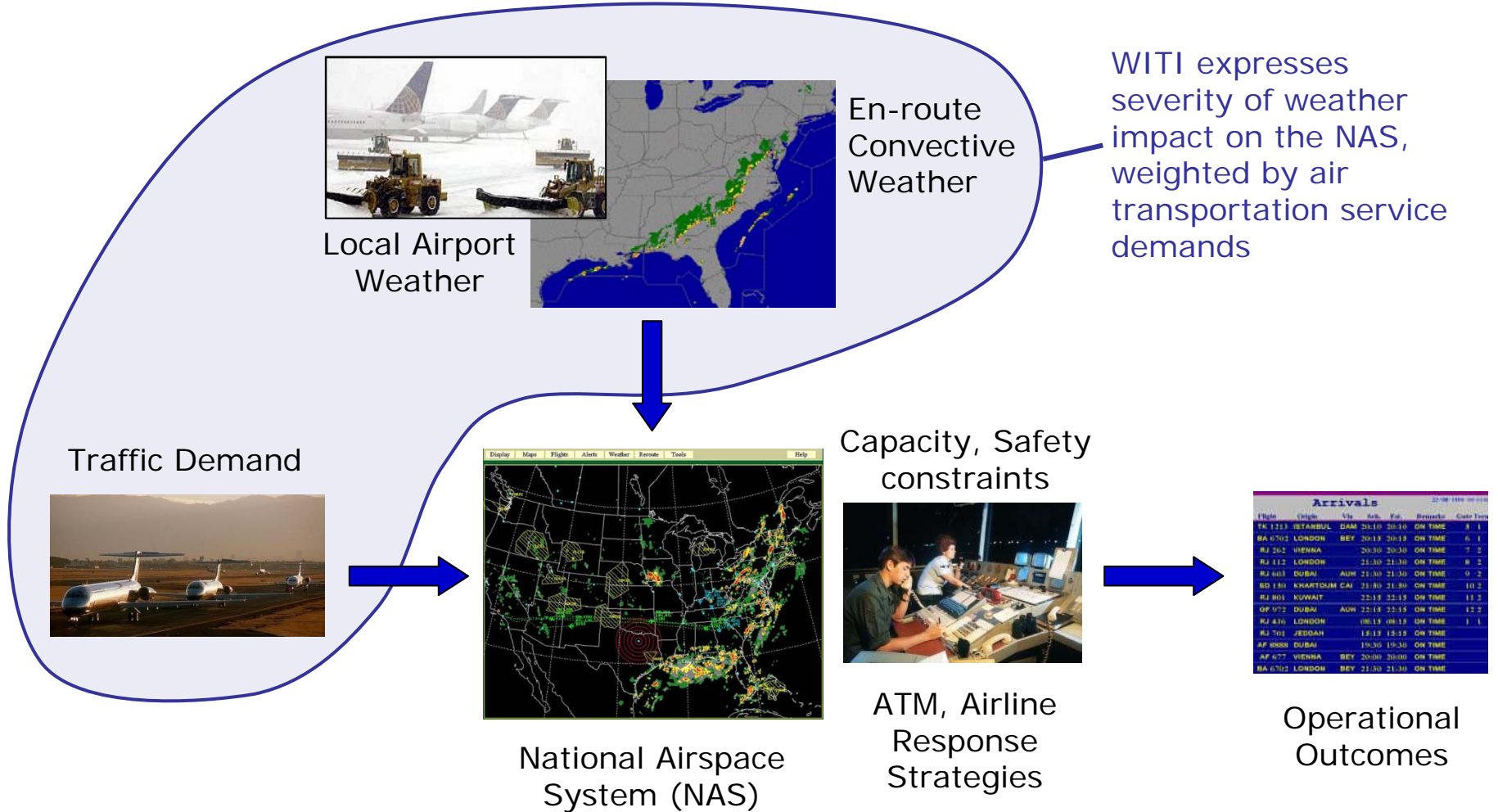
This is not an unreasonable estimate

- Compare to tentative estimates for convective Wx (60% avoidable)
- Dealing with terminal Wx: less flexibility = less avoidable delay

Back-up Slides

WITI: Measuring Weather / Traffic Demand Impact

"The Hand the NAS Is Dealt Every Day"



Analysis for selected airports/days

LGA, Friday, Apr 3, 2009

METAR Based WITI Data

TAF Based WITI Data

Hr, Z	IFR	Dominant Wx	Wind	Ceilings	SIGWX	RWYs	IFR	Dominant Wx	Wind	Ceilings	SIGWX	RWYs		
6	METAR	VSB_0.5	RAIN	050/11G00	3200	'BR'	04_13	4hr_TAF	CLG_0700	RAIN	090/08G-01	700	'BR'	04_13
7	METAR	CLG_0100	RAIN	060/12G00	100	'BR'	04_13	4hr_TAF	CLG_0700	RAIN	090/08G-01	700	'BR'	04_13
8	METAR	CLG_2800	LW_050/09	050/09G00	2800	'none'	04_13	4hr_TAF	CLG_0700	RAIN	090/08G-01	700	'BR'	04_13
9	METAR	VSB_3.0	RAIN	050/11G00	3200	'-RABR'	04_13	4hr_TAF	CLG_0100	RAIN	060/08G-01	100	'BR'	04_13
10	METAR	CLG_1100	RAIN	050/14G00	1100	'-RABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/14G-01	200	'-RABR'	04_13
11	METAR	CLG_1100	LW_060/13	060/13G00	1100	'none'	04_13	4hr_TAF	CLG_0200	RAIN	060/14G-01	200	'-RABR'	04_13
12	METAR	CLG_0700	RAIN	060/15G00	700	'-RABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/14G-01	200	'-RABR'	04_13
13	METAR	CLG_0500	RAIN	040/11G00	500	'-RABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/14G-01	200	'-RABR'	04_13
14	METAR	CLG_0300	RAIN	050/13G00	300	'-RABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/14G-01	200	'-RABR'	04_13
15	METAR	CLG_0300	RAIN	050/11G00	300	'-RABR'	04_13	4hr_TAF	CLG_1500	RAIN	050/15G21	1500	'-RABR'	04_13
16	METAR	CLG_0300	RAIN	050/13G00	300	'-RABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/15G21	200	'-RABR'	04_13
17	METAR	CLG_0100	TSTORM	030/15G00	100	'TSRABR'	04_13	4hr_TAF	CLG_0200	RAIN	060/15G21	200	'-RABR'	04_13
18	METAR	CLG_0300	RAIN	180/16G22	300	'BR'	13_22	4hr_TAF	CLG_0200	RAIN	060/15G21	200	'-RABR'	04_13
19	METAR	CLG_0300	RAIN	180/14G00	300	'BR'	13_22	4hr_TAF	CLG_0500	RAIN	140/13G-01	500	'-SHRABR'	13_22
20	METAR	NONE	NONE	000/-01G00	72200	'none'	13_22	4hr_TAF	CLG_0500	RAIN	140/13G-01	500	'-SHRABR'	13_22
21	METAR	CLG_0300	RAIN	170/08G00	300	'BR'	13_22	4hr_TAF	CLG_0300	RAIN	060/12G-01	300	'-RABR'	04_13
22	METAR	CLG_0300	RAIN	170/12G00	300	'BR'	13_22	4hr_TAF	CLG_0500	RAIN	200/18G25	500	'BR'	22
23	METAR	CLG_0300	RAIN	180/07G00	300	'BR'	13_22	4hr_TAF	CLG_0500	RAIN	200/18G25	500	'BR'	22
0	METAR	VSB_3.0	LW_210/10	210/10G00	7000	'-RABR'	13_22	4hr_TAF	CLG_0500	RAIN	200/18G25	500	'BR'	22
1	METAR	NONE	W_240/19G23	240/19G23	9500	'none'	31_22	4hr_TAF	CLG_0500	RAIN	200/18G25	500	'BR'	22
2	METAR	NONE	HW_270/24G34	270/24G34	4500	'none'	31	4hr_TAF	CLG_0500	RAIN	200/18G25	500	'BR'	22
3	METAR	NONE	W_260/18G23	260/18G23	4300	'none'	31_22	4hr_TAF	CLG_1200	RAIN	180/13G-01	1200	'BR'	13_22
4	METAR	NONE	NONE	000/-01G00	72200	'none'	13_22	4hr_TAF	NONE	W_260/18G25	260/18G25	4000	'none'	31_22
5	METAR	NONE	NONE	000/-01G00	72200	'none'	13_22	4hr_TAF	NONE	W_260/18G25	260/18G25	4000	'none'	31_22