Normalization of Airport and Terminal Area Operational Performance: A Case Study of Los Angeles International Airport

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Outline

- Background and Motivation
- Methods
- Results
- Application
- Conclusions

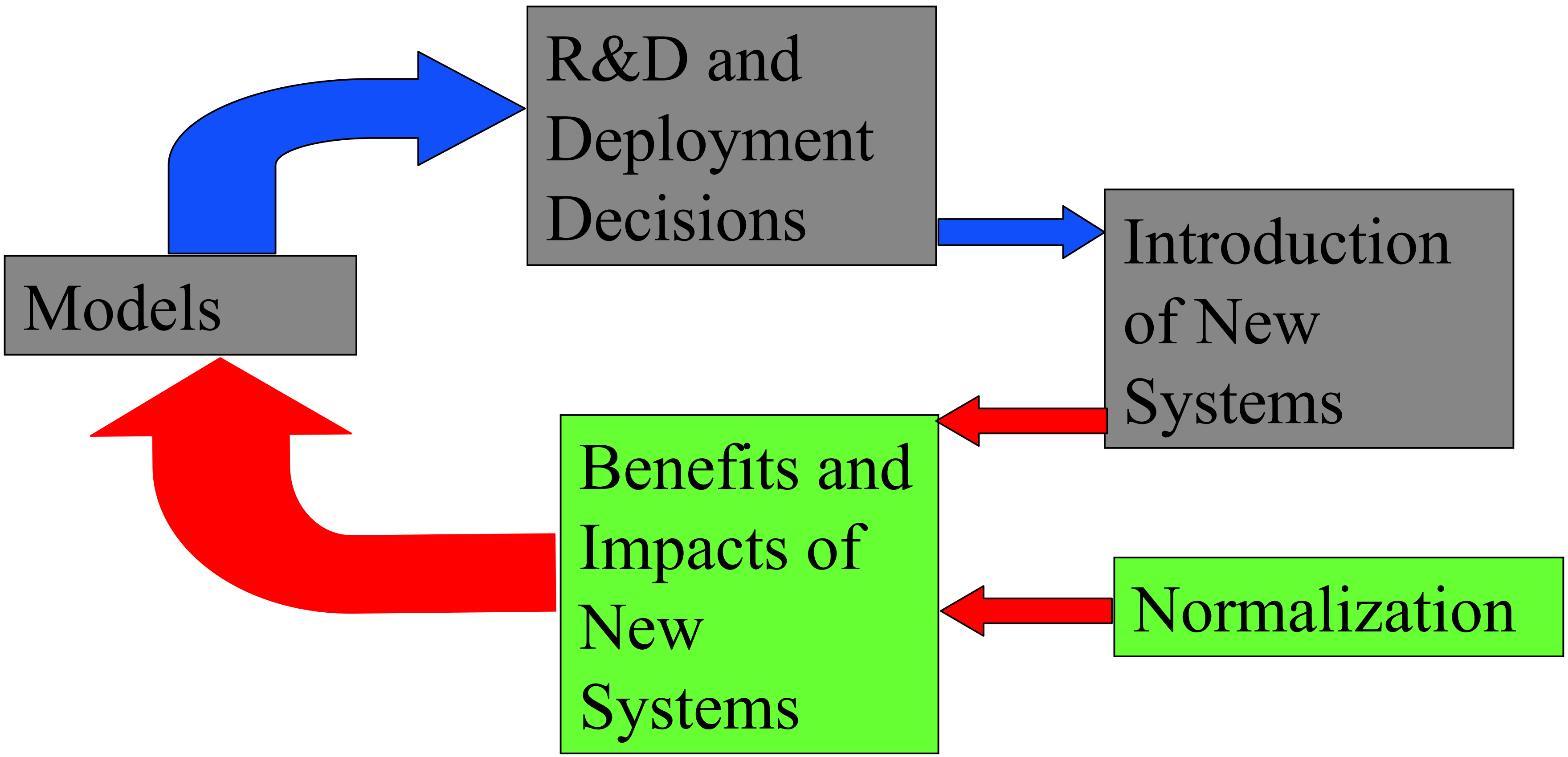
Normalization

- **Analyze trends in aviation infrastructure performance**
- **Determine effects of deployments of new technology or infrastructure**
- **Quantify effects within and outside FAA control**

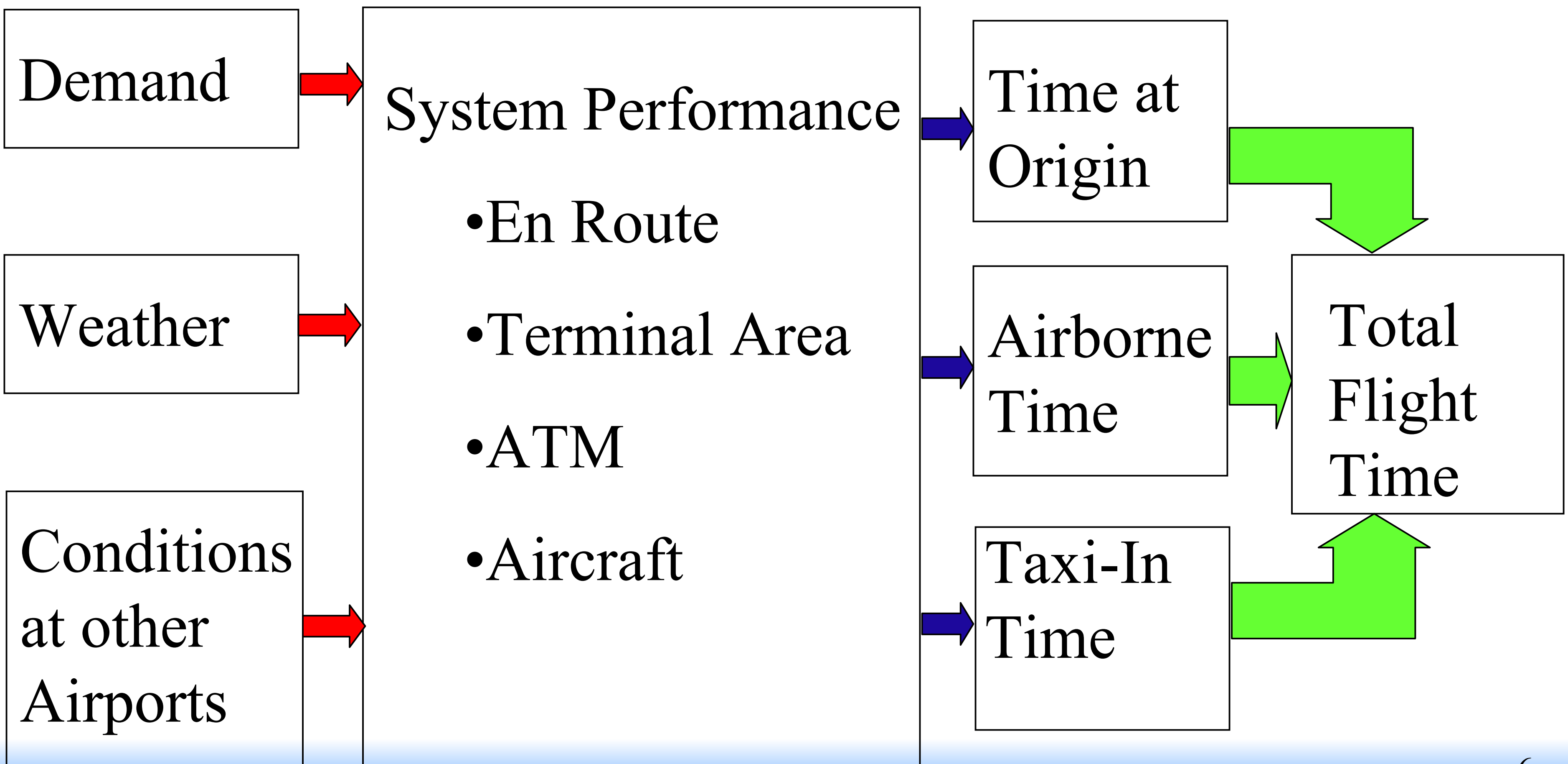
NEXTOR Normalization Work

- Sponsored by FAA Free Flight Office
- Focus on Delays and Time-in-System Metrics
- Analysis at Daily Level

Normalization and the Modeling Cycle



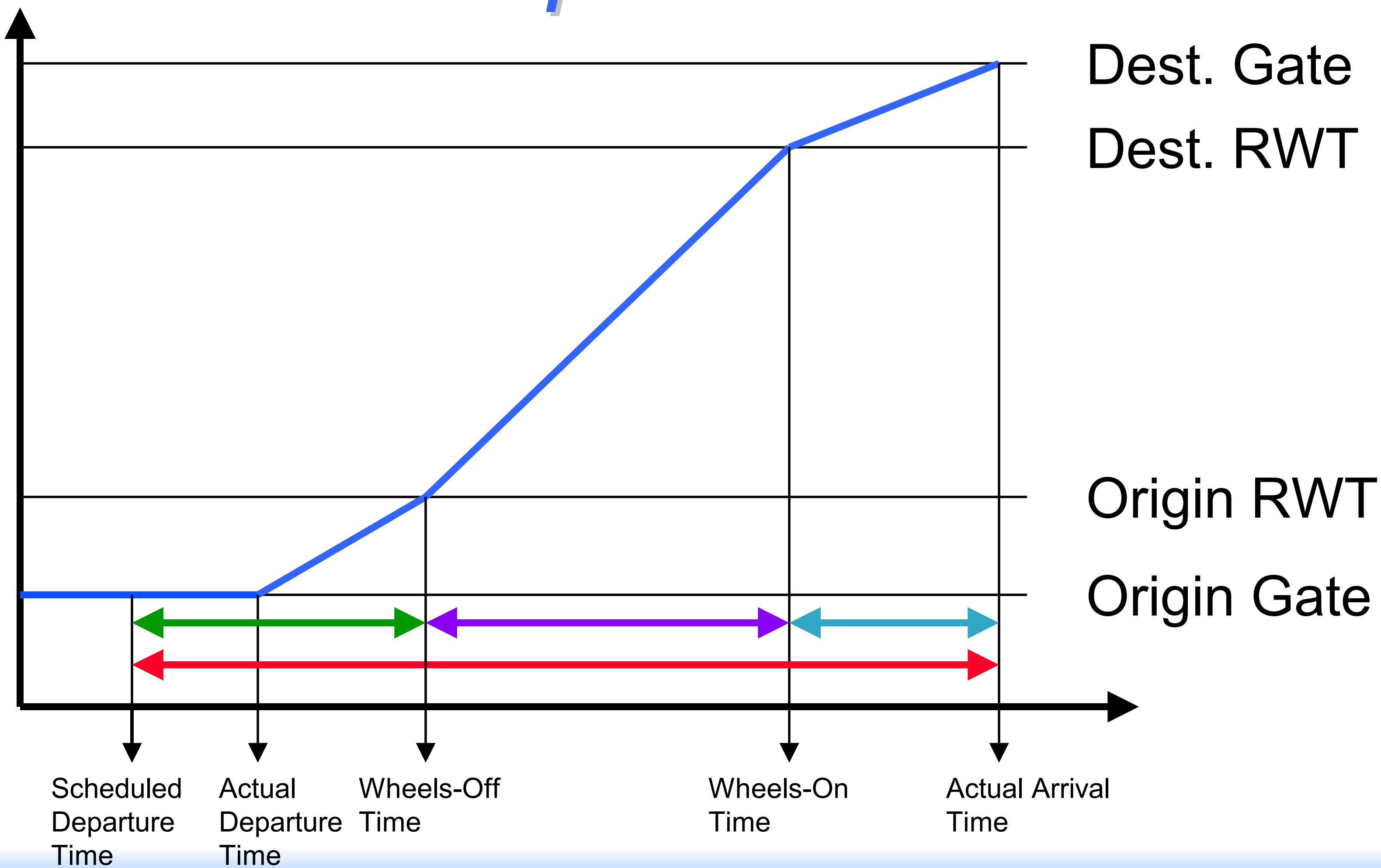
Conceptual Framework



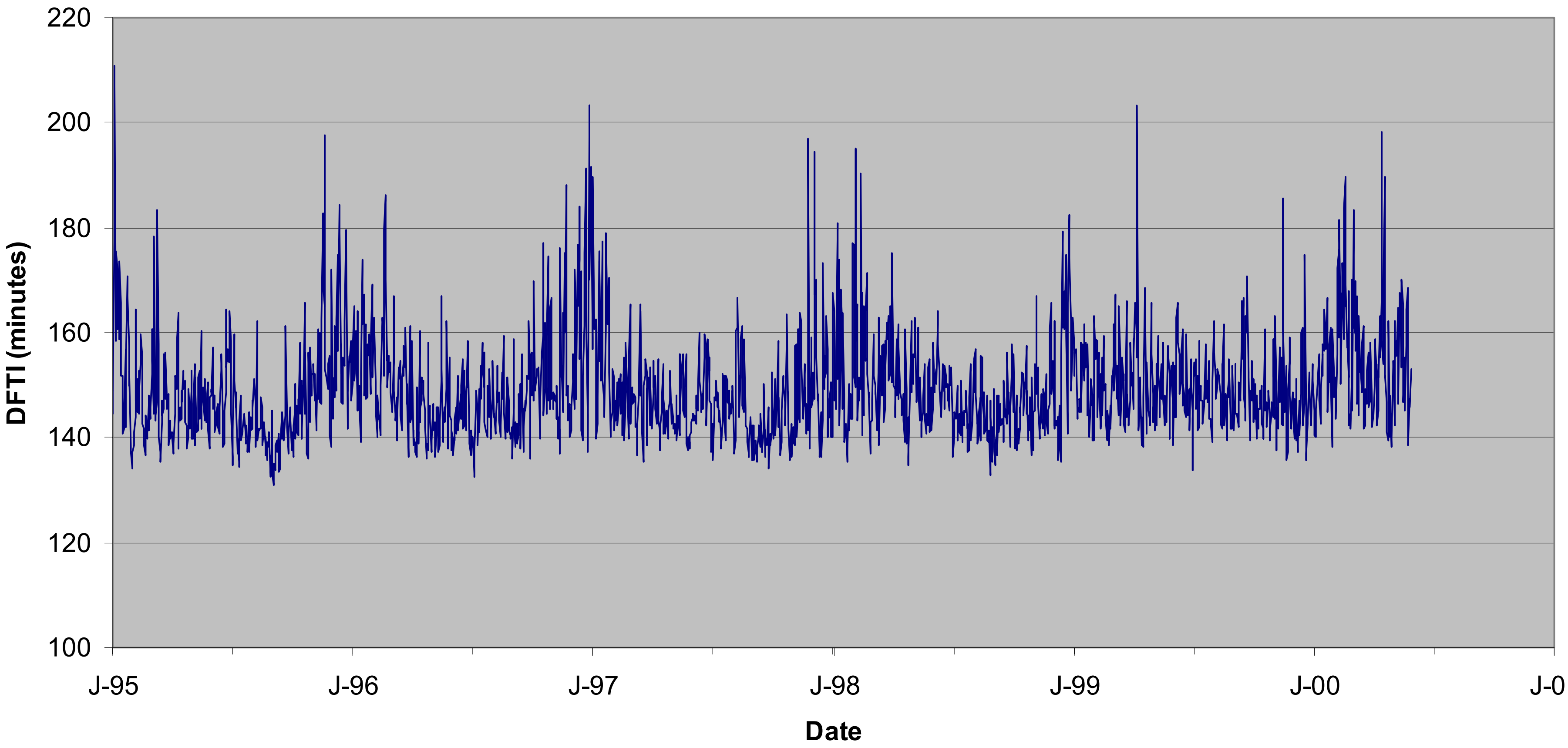
Daily Flight Time Index (DFTI)

- Daily weighted average of flight times to a given airport from a set of origins
- Analogous to a Consumer Price Index
- Origins in “market basket” have at least one completed flight in each day of sample
- Weights reflect origin share of flights to study airport over study period

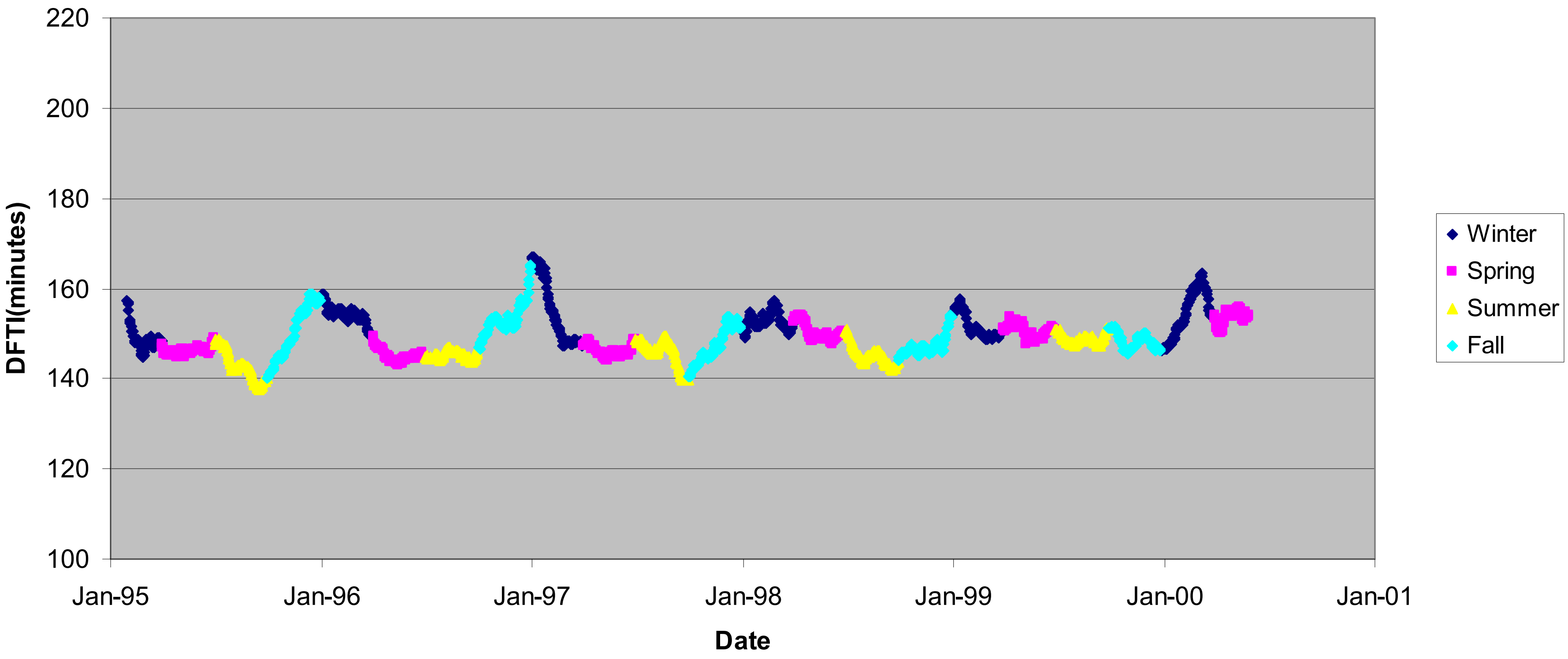
Flight Time and Its Components



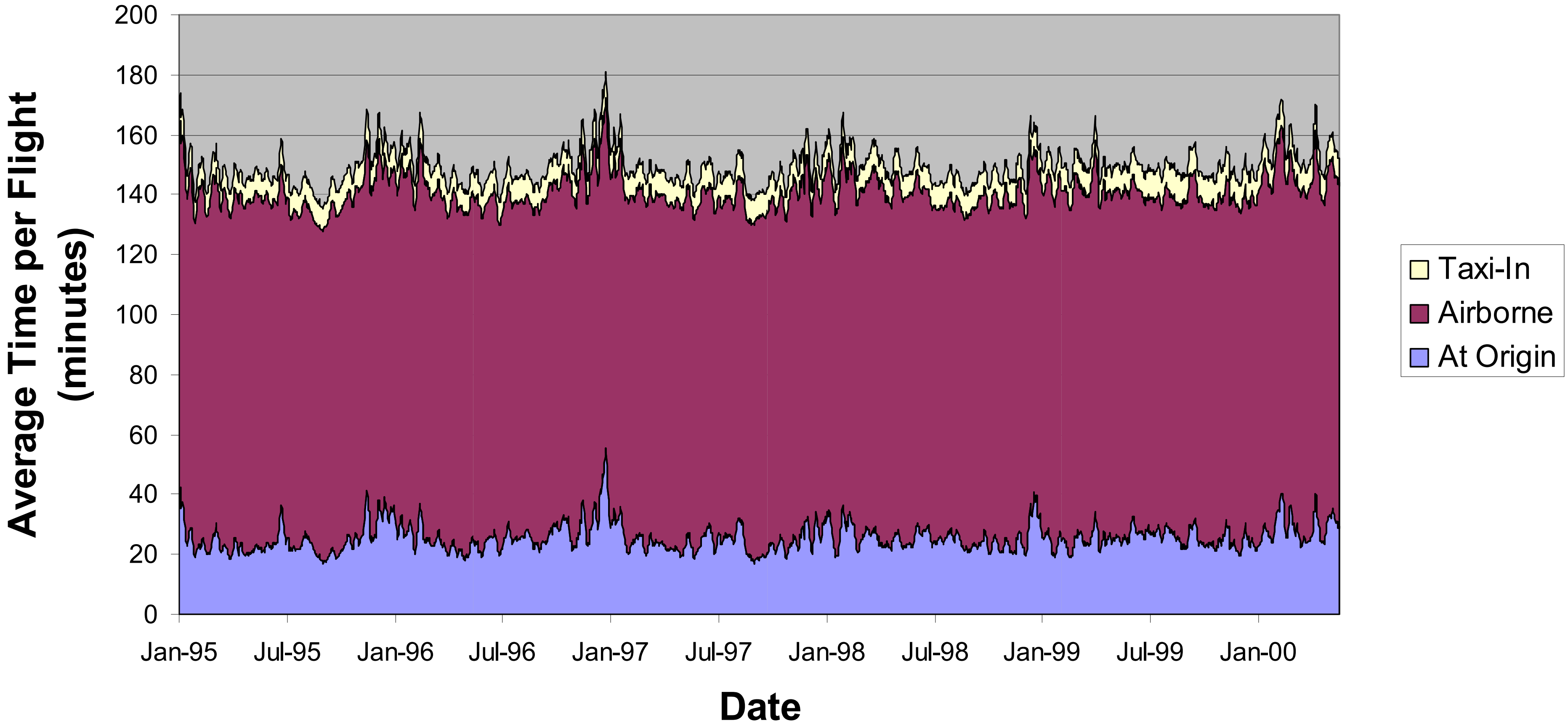
DFTI Time Series for LAX



30-Day Moving Average



7-Day Moving Average with Components

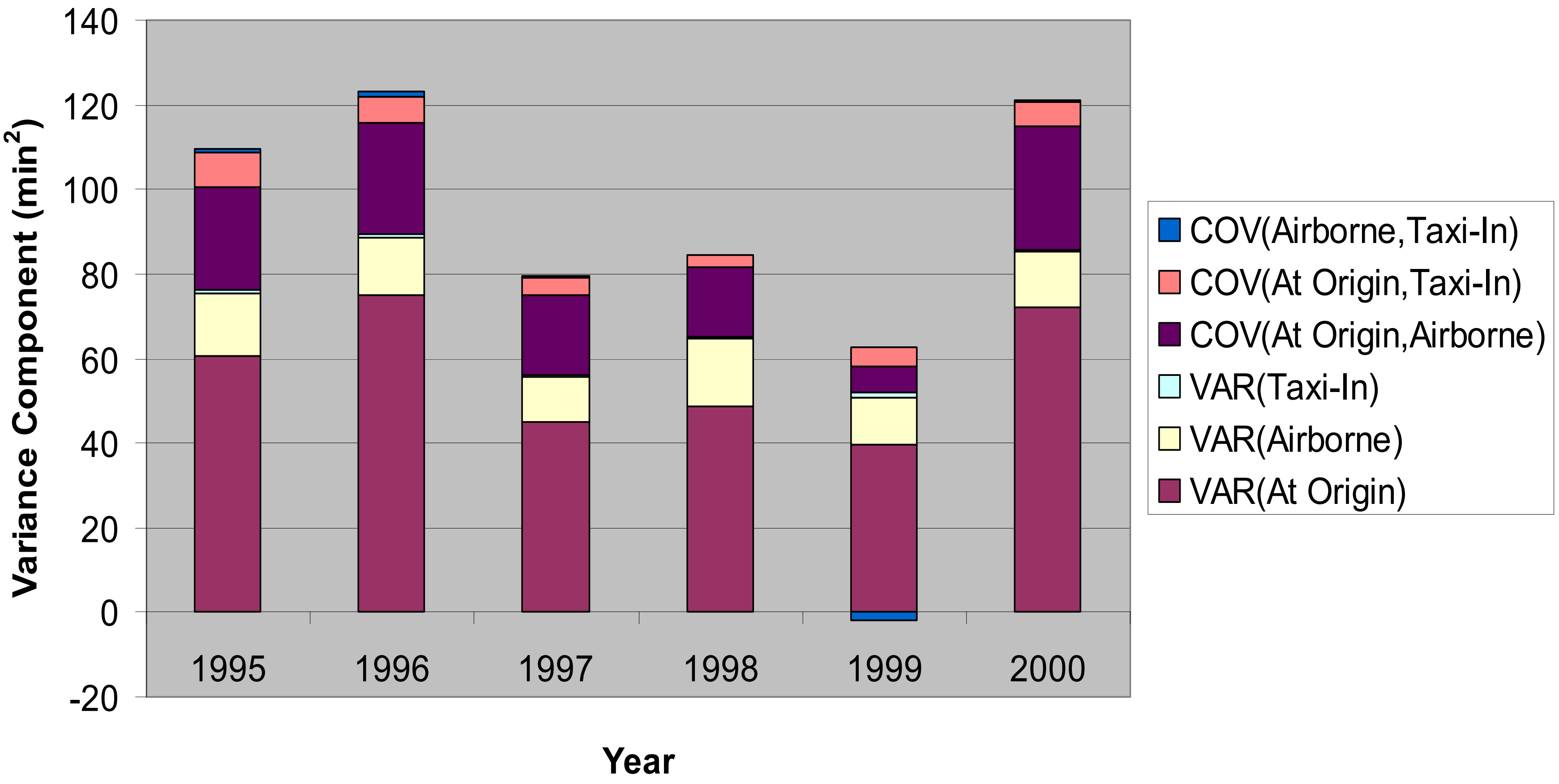


Variance Decomposition

$$DFTI = ORIGIN + AIRBORNE + TAXI-IN$$

$$VAR(DFTI) = VAR(ORIGIN) + VAR(AIRBORNE) + VAR(TAXI-IN) + 2\cdot[COV(ORIGIN, AIRBORNE) + COV(AIRBORNE, TAXI-IN) + COV(ORIGIN, TAXI-IN)]$$

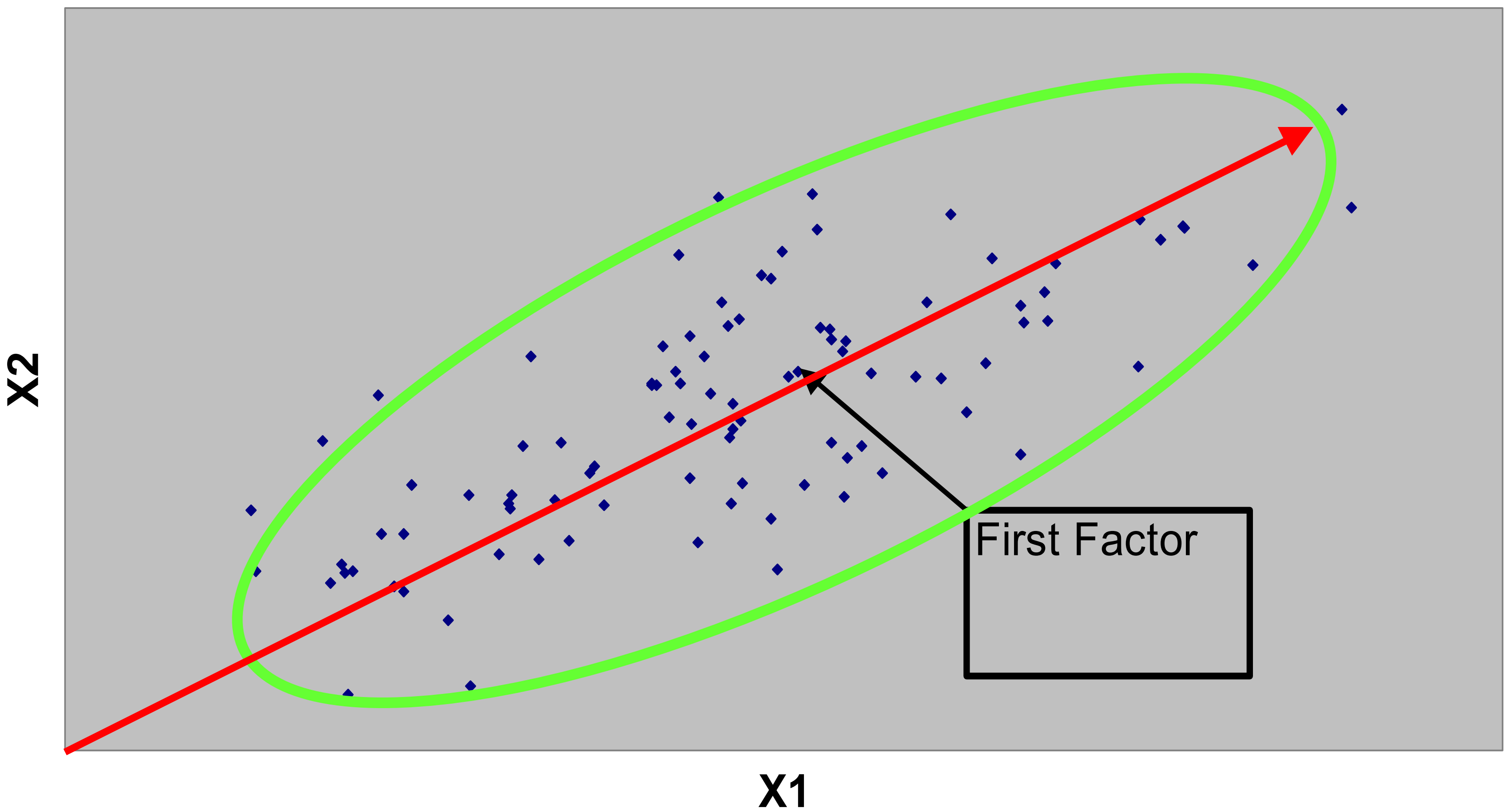
Variance Decomposition



Weather Normalization

- **Based on CODAS hourly weather observations for LAX**
- **Factor analysis of weather data**
  - Create small number of factors that capture variation in large number of variables
  - Factors are linear combinations of original variables
  - Factors correspond to principal axes of N-dimensional data elipse

Factor Analysis with Two Variables



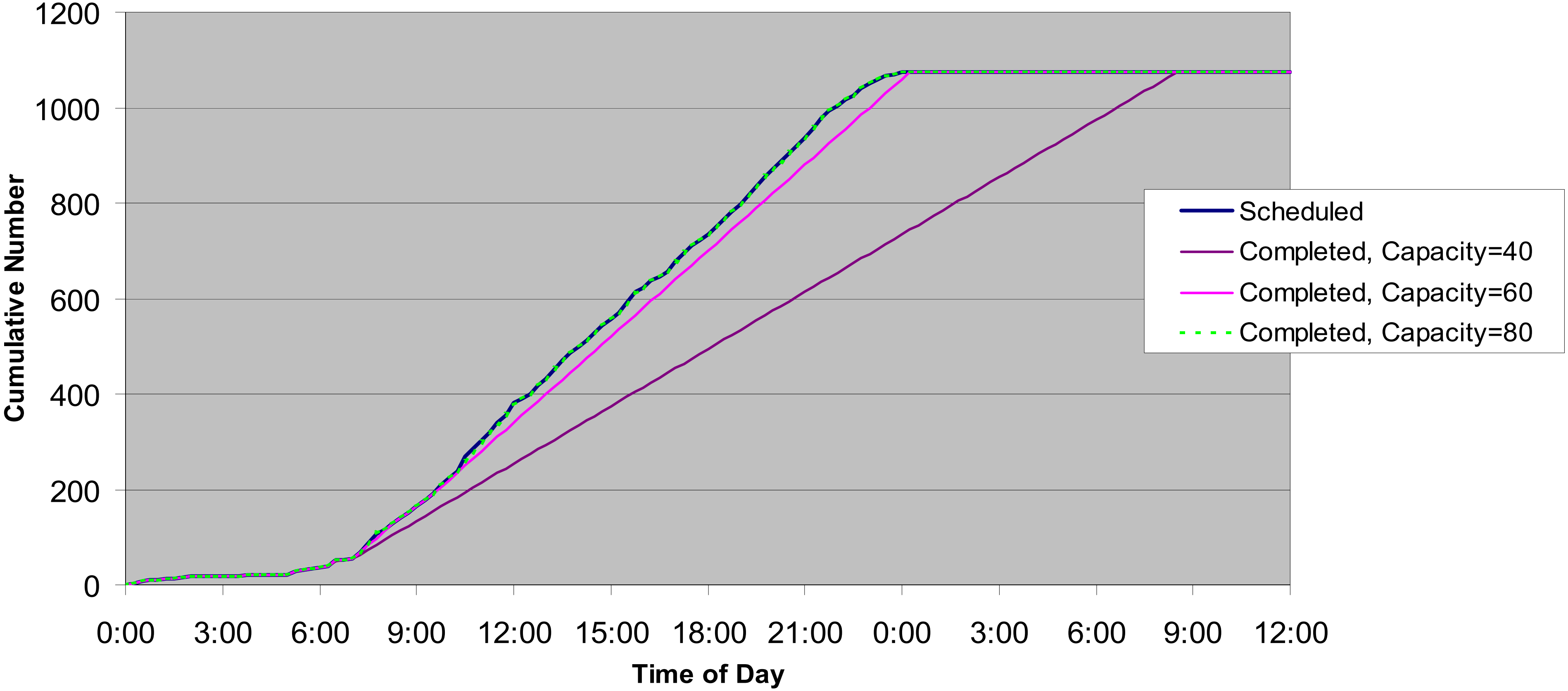
9-Factor Representation of LAX Daily Weather

Factor	Interpretation
1	Warm temperatures throughout day.
2	VFR operations and absence of low cloud ceiling in the morning.
3	VFR operations and absence of low cloud ceiling in the afternoon.
4	High visibility throughout day.
5	Medium cloud ceiling throughout day.
6	High winds throughout day.
7	High ceiling cloud ceiling throughout day; evening precipitation.
8	Precipitation in late morning and afternoon.
9	Precipitation in early morning.

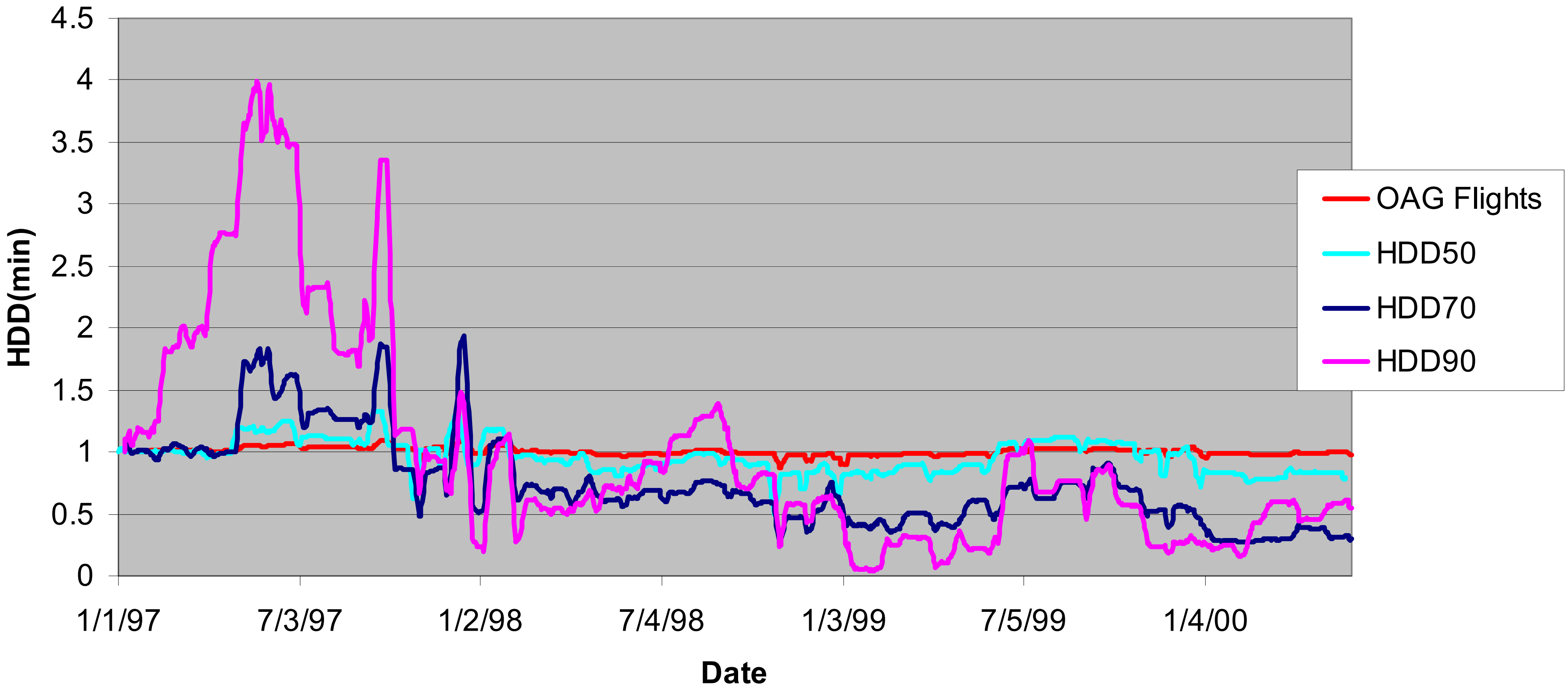
Demand Normalization

- Deterministic Queuing Analysis
- Arrival Curve from Official Airline Guide
- Departure Curves and Average Delays Calculated Assuming Range of Hypothetical Capacities
- Factor Analysis Applied to Obtain Reduced Set of Demand Factors

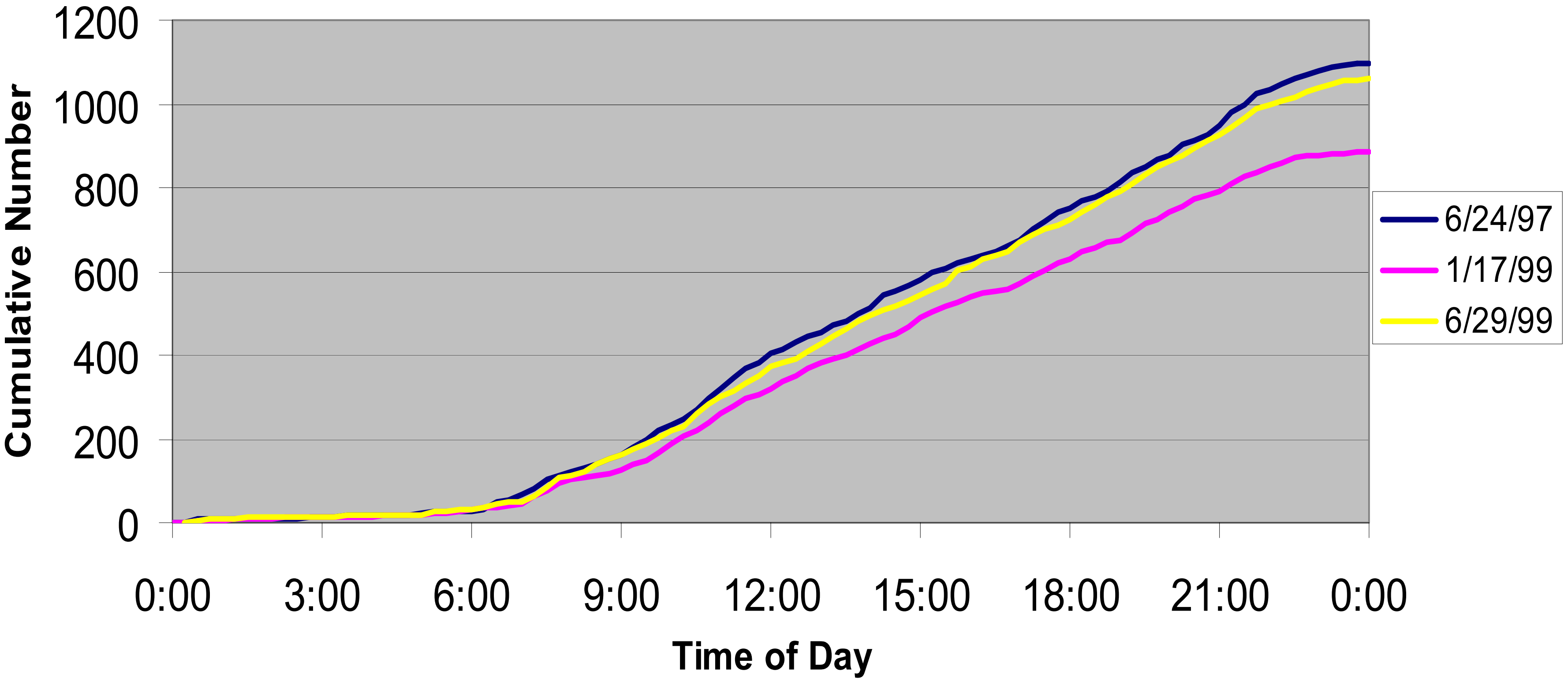
Queuing Diagrams



Trends in Values of HDD Parameters and Scheduled Arrivals since 1997



DAY	HDD50	HDD60	HDD70	HDD80	HDD90	HDD100	HDD110	HDD120
6/24/97	124.55	44.62	6.86	2.64	1.07	0.40	0.16	0.09
1/17/99	52.88	6.96	0.87	0.06	0.00	0.00	0.00	0.00
6/29/99	111.90	28.71	3.11	0.85	0.29	0.11	0.04	0.00



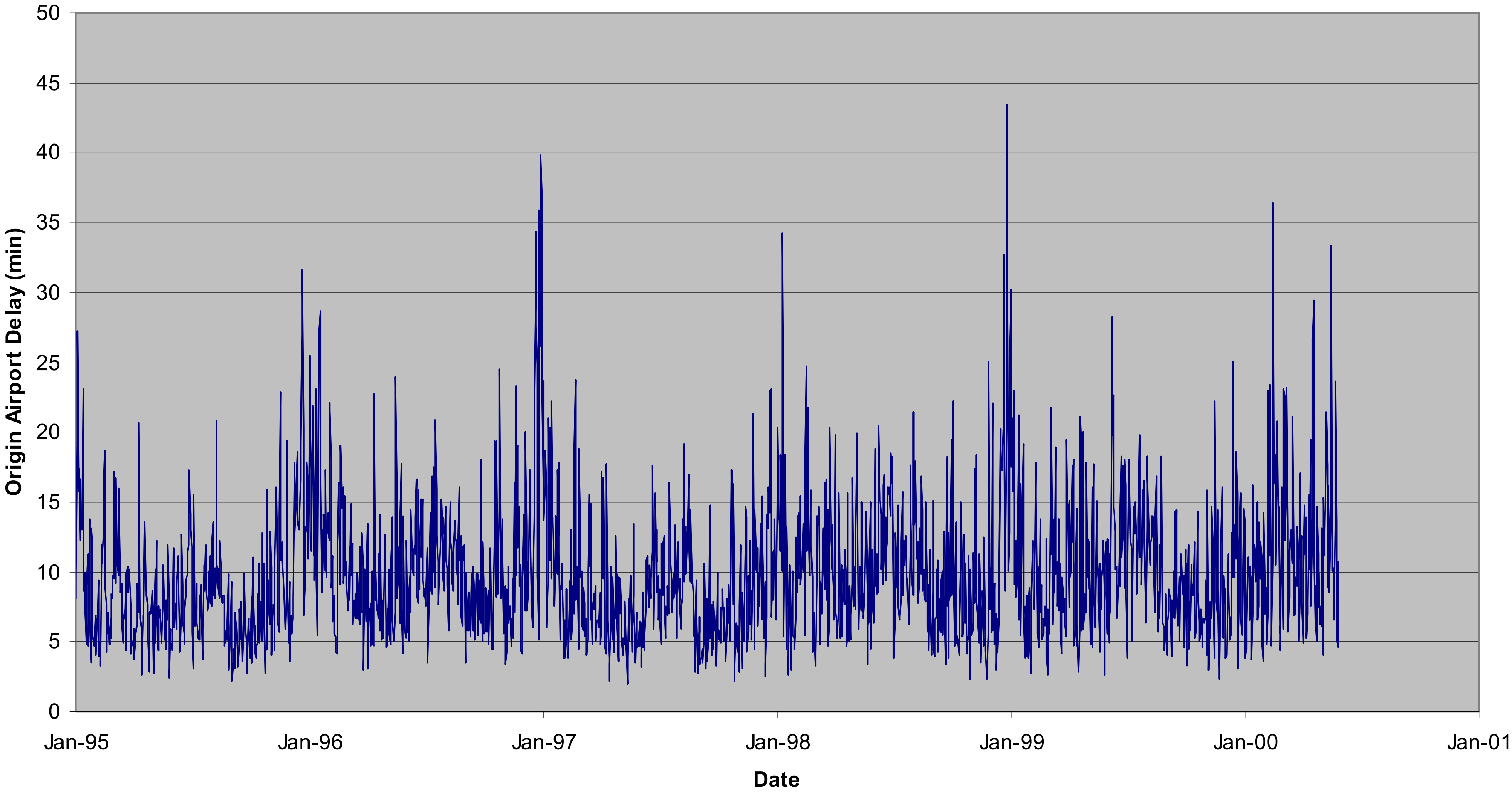
Factor Analysis of HDD Variables

	Initial Factors		Rotated Factors	
	FACTOR1	FACTOR2	FACTOR1	FACTOR2
HDD10	0.86	-0.46	0.95	0.22
HDD20	0.89	-0.42	0.95	0.27
HDD30	0.88	-0.46	0.96	0.24
HDD40	0.87	-0.46	0.96	0.23
HDD50	0.91	-0.37	0.93	0.32
HDD60	0.92	-0.20	0.83	0.45
HDD70	0.92	0.10	0.62	0.68
HDD80	0.89	0.34	0.45	0.84
HDD90	0.86	0.46	0.34	0.91
HDD100	0.82	0.53	0.27	0.94
HDD110	0.78	0.57	0.21	0.94
HDD120	0.70	0.59	0.14	0.91

Normalization for Conditions at other Airports

- Consider airports included in DFTI average
- For each compute daily average departure delay for flights not bound to LAX region
- Average airport departure delays using DFTI weights

Origin Airport Delay Time Series



Performance Models

$$Y_t = f(WX_t, DMD_t, ODEL_t) + \varepsilon_t$$

Where:

Y_t is DFTI or DFTI component for day t;

WX_t is vector of weather factors for day t;

DMD_t is vector of demand factors for day t;

$ODEL_t$ is average origin departure delay for day t;

ε_t is stochastic error term.

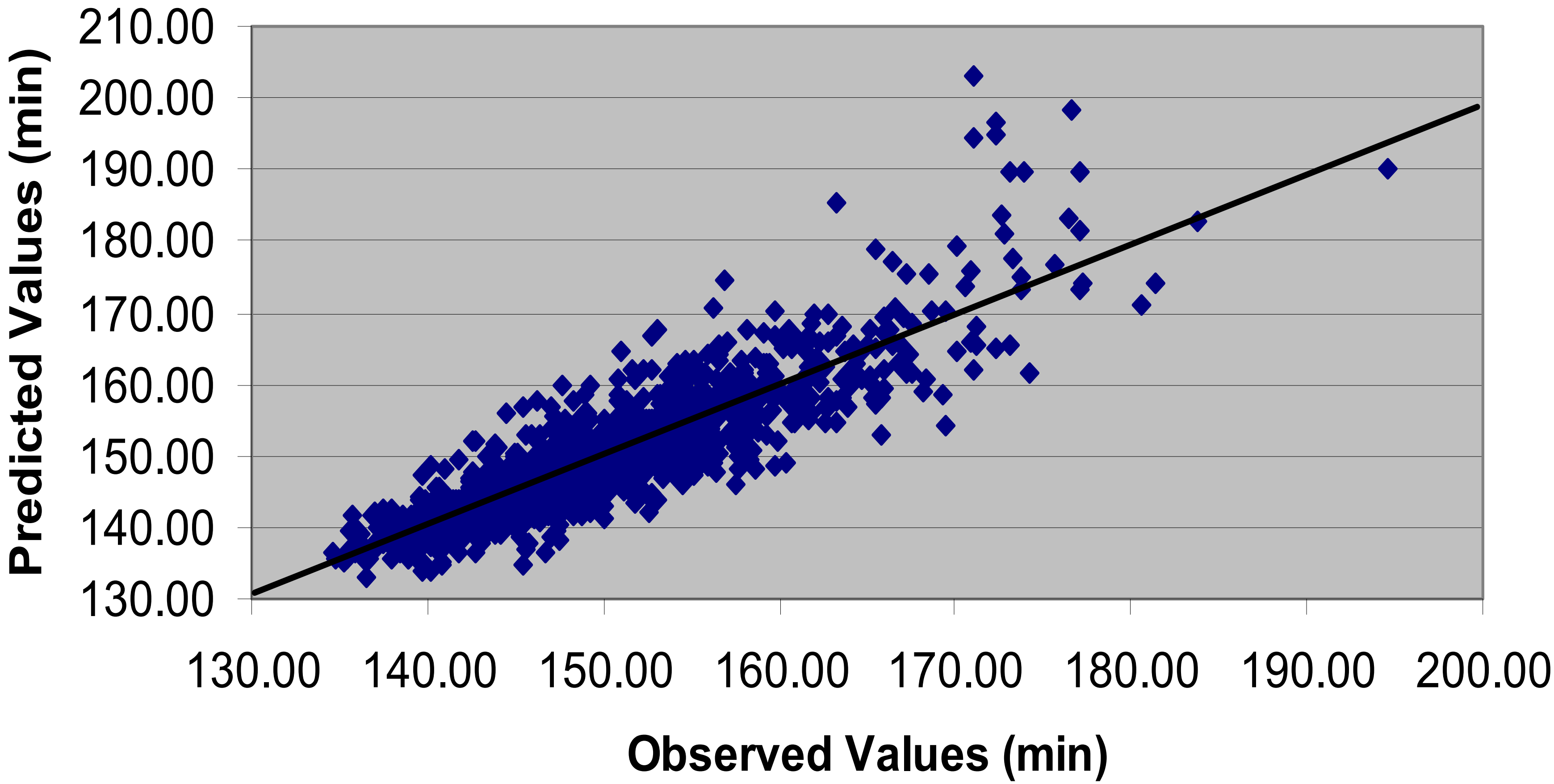
Functional Forms Considered

- **Parametric**
  - Linear (with 3, 6, 9, and 12 weather factors)
  - Quadratic response surface
  - Non-linear
- **Non-parametric**
  - 9 clusters based on 3 weather factors
  - 12 clusters based on 9 weather factors

Linear Model Estimation Results

Variable	Description	Estimate	T - statistic	P - value
INTERCEPT	Intercept	138.055	567.065	0.0001
OAC	Origin airport congestion	1.128	44.351	0.0001
WX_1	Warm daily temperatures	-1.357	-12.101	0.0001
WX_2	VFR ops, no low cloud ceiling in the morning	-0.988	-7.116	0.0001
WX_3	VFR ops, no low cloud ceiling in the afternoon	-1.123	-7.583	0.0001
WX_4	High visibility throughout day	-0.449	-3.575	0.0004
WX_5	Medium cloud ceiling throughout day	1.440	10.555	0.0001
WX_6	High winds throughout the day	0.512	4.531	0.0001
WX_7	High cloud ceiling throughout day	0.911	4.172	0.0001
WX_8	Precipitation in late morning and afternoon	1.871	8.324	0.0001
WX_9	Precipitation in early morning	-0.379	-2.614	0.0091
DMD_1	Peak demand	0.075	0.725	0.4685
DMD_2	Base demand	0.440	4.574	0.0001
ADJUSTED R^2			0.743	

Predicted vs Actual Values



Outliers

- **Used TMU logs to investigate days for which predictions have large errors**
- **Reasons for higher than predicted DFTI**
  - East flow
  - Radar outages
  - Air Force One
  - Over-stringent ground delay program

Models for DFTI Components

	Time-at-origin		Airborne time		Taxi-in time	
Variable	Estimate	P - value	Estimate	P - value	Estimate	P - value
INTERCEPT	14.588	0.0001	115.594	0.0001	7.874	0.0001
ODEL	1.099	0.0001	-0.012	0.4621	0.041	0.0001
WX_1	-0.065	0.4011	-1.474	0.0001	0.182	0.0001
WX_2	-0.722	0.0001	-0.233	0.0100	-0.033	0.2290
WX_3	-0.669	0.0001	-0.348	0.0003	-0.105	0.0003
WX_4	-0.201	0.0198	-0.186	0.0232	-0.062	0.0125
WX_5	0.599	0.0001	0.846	0.0001	-0.005	0.8567
WX_6	0.154	0.0480	0.428	0.0001	-0.069	0.0021
WX_7	0.372	0.0132	0.503	0.0004	0.036	0.3995
WX_8	0.897	0.0001	0.796	0.0001	0.179	0.0001
WX_9	-0.060	0.5485	-0.316	0.0008	-0.003	0.9158
DMD_1	0.034	0.6366	0.234	0.0005	-0.193	0.0001
DMD_2	0.260	0.0001	0.060	0.3367	0.120	0.0001
ADJUSTED R^2	0.804		0.427		0.213	

Response Surface Model

- High demand increases the importance of visibility
- Effects of precipitation and winds re-enforcing
- Diminishing marginal impact of winds

First Order		Second Order FACTOR: ODEL	WX_1	WX_2	WX_3	WX_4	WX_5	WX_6	WX_7	WX_8	WX_9	DMD_1	DMD_2
ODEL	**1.161**	-0.006	-0.001	0.021	0.013	0.020	**0.104**	0.017	-0.032	**0.243**	-0.003	**-0.078**	0.003
WX_1	**-1.639**		-0.186	**0.442**	0.309	**0.439**	0.016	-0.278	0.287	-0.241	0.103	-0.285	0.210
WX_2	**-1.250**			-0.199	0.078	0.244	-0.055	-0.106	**-0.570**	-0.103	**-0.488**	0.044	**-0.468**
WX_3	**-1.005**				0.140	-0.056	0.255	-0.264	-0.296	-0.172	-0.128	0.278	**-0.340**
WX_4	-0.061					0.031	-0.036	**0.402**	0.187	-0.517	0.049	-0.176	-0.085
WX_5	**2.464**						**-0.432**	-0.125	0.016	**0.717**	0.212	**0.321**	0.221
WX_6	**0.594**							**-0.160**	-0.040	**1.050**	0.140	-0.060	-0.066
WX_7	**0.886**								0.057	-0.161	**0.524**	-0.455	**0.591**
WX_8	**1.011**									**-0.346**	-0.027	-0.062	-0.052
WX_9	**-0.987**										**-0.131**	0.221	-0.185
DMD_1	**-0.762**											**0.293**	-0.077
DMD_2	**0.782**												-0.022
ADJUSTED R^2		0.820											

Impacts of a Decision Support Tool at LAX

- **FFP1 Background**
- **The Tool**
- **Deployment Experience**
- **Impacts**

Free Flight Phase I

- **Deploy terminal area/en route decision support tools (CTAS, SMA, and URET) at selected sites**
- **Normalization useful for assessing operational impacts and benefits**

Final Approach Spacing Tool

- Decision support tool for TRACON
- P(assive)FAST advises on runway assignment and landing sequence
- Active FAST provides speed and turn advisories
- Advisories incorporated into ARTS display
- Prior PFAST implementation at DFW

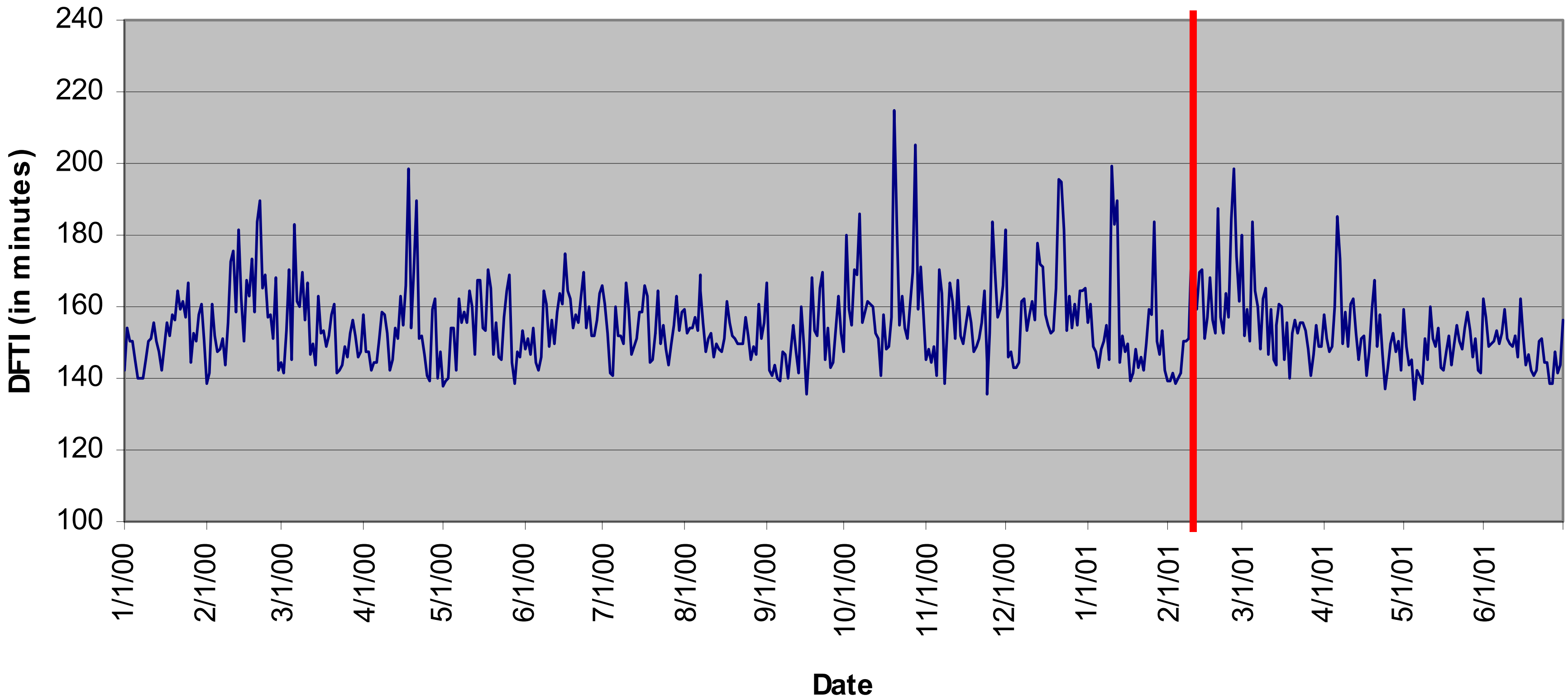
FAST at LAX

- "Passive Passive FAST" (P^2FAST) or "T-TMA"
- No advisories
- Separate displays depict traffic up to 300 nm out using combination of HOST and ARTS data
- A situation-awareness tool instead of a decision automation tool

Why TTMA for LAX?

- **Significant “internal” operations**
  - Departures from within SOCAL TRACON and ZLA Center
  - No acceptable “work-arounds”
- **Initial deployment until DS software can be adapted**

DFTI Before and After Implementation



TTMA Normalization Results

Variable	Parameter Estimates			
	DFTI	At Origin	Airborne	Taxi-in
intercept	***139.29***	***15.23***	***115.9***	***8.11***
TTMA	***-1.99***	***-1.71***	-0.19	-0.07
OAC	***1.39***	***1.29***	**0.03**	***0.06***
Peak Demand	-0.35	-0.1	***-0.24***	-0.01
Base Demand	***0.97***	***0.74***	0.04	***0.19***
Weather Factor1	***-3.37***	***-0.89***	***-2.63***	***0.14***
Weather Factor2	***-2.66***	***-1.8***	***-0.75***	***-0.12***
Weather Factor3	***-1.88***	***-1.36***	***-0.48***	**-0.04**
Weather Factor4	0.19	-0.24	***0.49***	***-0.07***
Weather Factor5	***1.48***	***0.73***	***0.79***	-0.03
Weather Factor6	***0.46***	0.12	***0.31***	0.02
Weather Factor7	***0.64***	0.27	***0.29***	***0.81***
Adjusted R-Square	0.79	0.83	0.55	0.39

Significant at 5% level

Significant at 10% level

Collaborating Evidence

- Evidence of increased throughput rates when system is under stress
- Controllers love it
  - **Anticipate overloads and slow planes down to avoid holding**
  - **Better runway balancing**

Conclusions

- **70-80% DFTI variation "explained" statistically (in case of LAX)**
  - Up-line delay is largest driver
  - Variety of weather impacts
  - Modest gain from more complicated models
- **Normalization shows benefit from TTMA Implementation**