Estimating Sources of Temporal Deviations from Flight Plans

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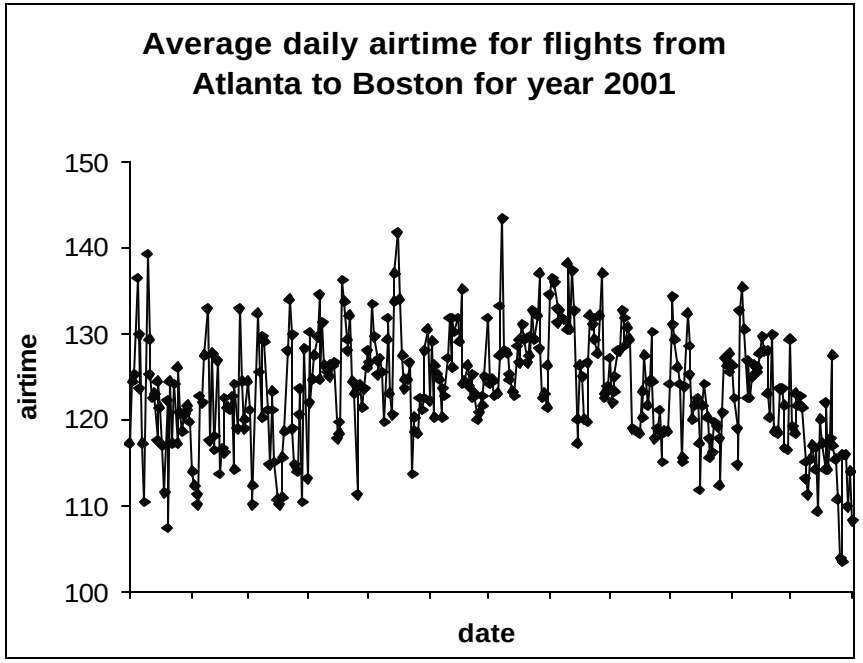
Agenda

- FAA interests: system predictability, assessing interventions
- Problem introduction
- Proposed methodology
- Evaluation of alternative estimation methods
- System implementation in SAS for annual and next-day reporting
- Ongoing research
  - Operational validation
  - Statistical analysis of results

Motivation and FAA sponsorship

- **Client:** Free Flight Program of the Federal Aviation Administration
- **Need:** improve system predictability and decrease unexpected flight delays
- **More specifically:** trace flight delays to their sources, and quantify them
- **Intended use:** next-day and annual reporting, special studies
- **Potential use:** evaluating impact of FAA initiatives

Problem introduction



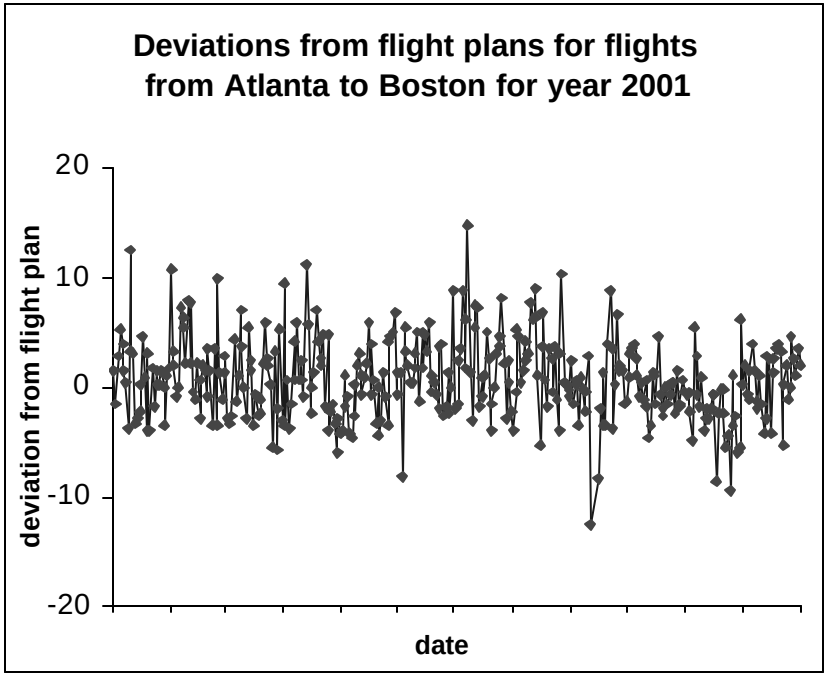
- Average airtime fluctuates (due to winds aloft, weather and congestion in airports, etc.)
- Flight plans anticipate "normal problems"

↓ Shift attention to

Deviation = Actual Airtime – Flight Planned Time

2 types of Deviations: "ETE" and "G2G"

Problem introduction: Deviations

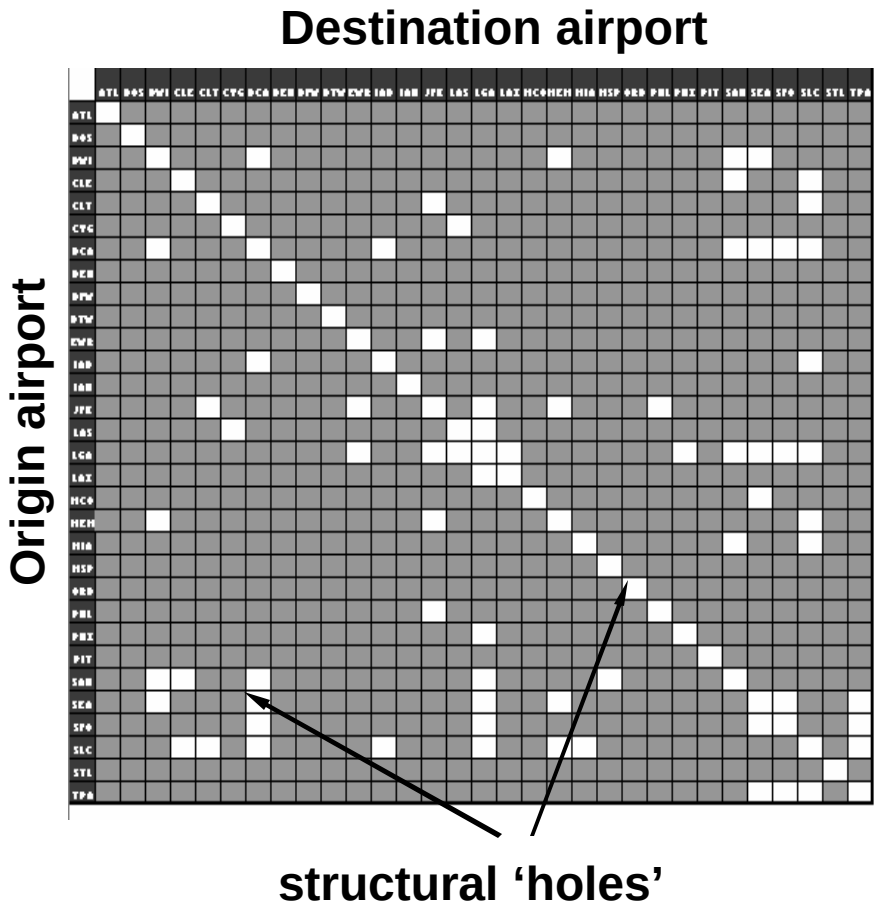


- Deviations from flight plans measure unanticipated problems, or “surprises”
- Common factors for different flights are considered as systemic sources of deviations

- Decompose deviations into four sources:

System + Origin airspace + Destination airspace + En route airspace

FAA data as a two-way table



- 31 major US airports
- Each table represents one day of operations
- Each cell contains an average deviation from flight plan
- One observation per cell, averaging over multiple flights
- Data available for January ’01-March ’03
- Presence of structural ‘holes’

Fragment of the table

Destination airport

Origin airport

	ATL	BOS	BWI	CLE	CLT	CVG	DCA	DEN	DFW	DTW	EWR	IAD	IAH
ATL	.	6.33	3.93	-0.80	6.33	2.36	6.80	-3.47	0.93	2.50	-1.74	0.22	-4.00
BOS	4.50	.	3.30	0.20	5.43	-2.71	4.67	2.43	2.00	-1.25	-7.71	7.88	-2.17
BWI	4.71	0.45	.	7.55	0.13	8.40	.	-0.17	1.00	15.17	-5.29	4.20	-1.2
CLE	1.27	7.80	7.40	.	0.83	-1.08	2.75	0.00	4.80	0.08	-12.8	8.50	1.
CLT	3.31	-2.00	1.43	5.00	.	4.25	7.33	1.67	3.00	8.00	0.36	18.80	-3.
CVG	5.40	2.67	-1.25	-2.45	-4.88	.	7.40	7.40	0.00	5.78	-11.1	11.38	-4
DCA	6.53	-0.84	.	2.00	-0.73	3.75	.	-4.00	1.54	8.29	-16.5		
DEN	4.25	7.86	7.00	-6.25	3.25	1.50	.	.	2.80	3.50	3.31		
DFW	5.03	-7.92	9.17	-2.33	1.85	4.22	5.18	-0.37	.	3.92			
DTW	5.06	4.75	-2.50	2.71	-0.33	1.57	-1.14	0.13	4.67				
EWR	-2.46	-9.48	4.83	-1.57	0.40	-1.80	-3						
IAD	3.06	-0.09	.	-0.33	-5.00	1							
IAH	5.00	-10.0	-1										

Row + Column Analysis

origin \ destination	1	2	…	m
1	y_{11}	y_{12}	…	y_{1m}
2	y_{21}	y_{22}	…	y_{2m}
…		…		
n	y_{n1}	y_{n2}	…	y_{nm}

linear additive model

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

	en route effects (residuals) 1	2	…	m	origin effects
1	ε_{11}	ε_{12}	…	ε_{1m}	α_1
2	ε_{21}	ε_{22}	…	ε_{2m}	α_2
…		…			…
n	ε_{n1}	ε_{n2}	…	ε_{nm}	α_n
destination effects	β_1	β_2	…	β_m	μ

system effect

μ = system effect (e.g., September 11th)

α_i = origin effect (e.g., restricted departure gates)

β_j = destination effect (e.g., fog)

ε_{ij} = en route effect (e.g., convective weather, MIT, circular holding)

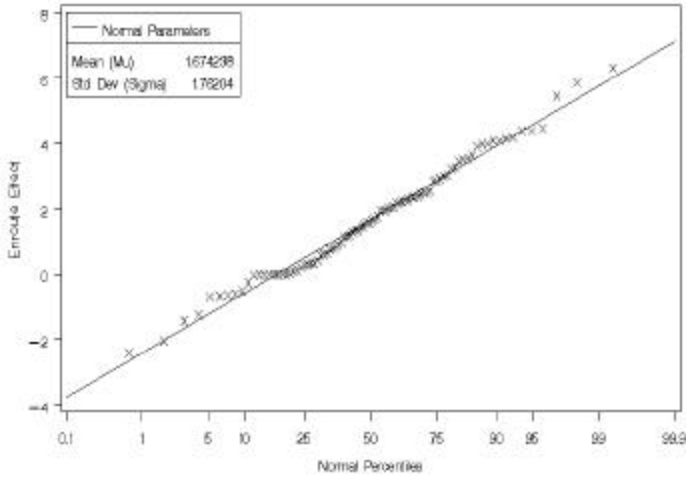
Which estimation method to use?

- **Methods:**
  - Ordinary Least Squares
  - Least Absolute Deviations (LAD)
  - Median Polish

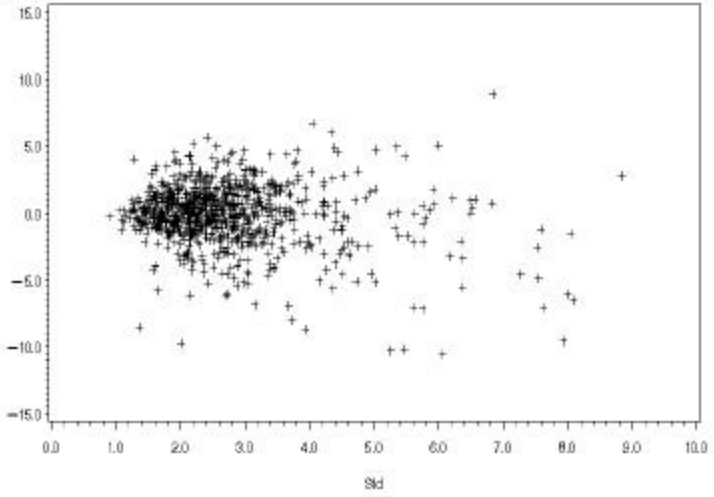
- **Full factorial design:**
  - Factors (at 3 levels each):
    - table size
    - percentage of holes
    - percentage of outliers
  - Responses (comparison criteria):
    - accuracy of estimates (RMSE and MAE for effects)
    - outlier detection capability (sensitivity and specificity)

Modeling FAA data

Normal probability plot for BWI:IAD effect



Scatterplot of μ against σ for en route effects



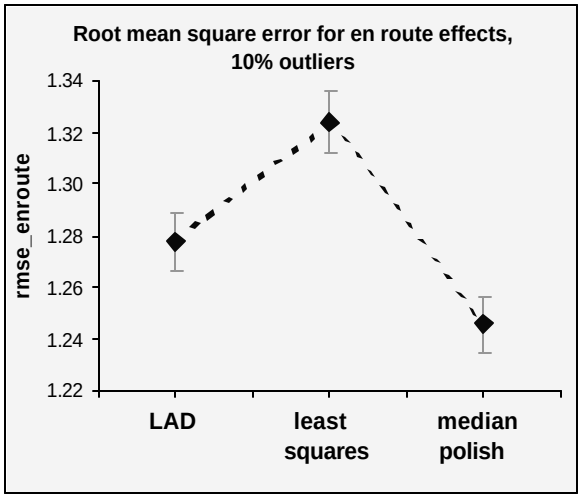
- Can use estimates from LAD
- Generate origin, destination and en route effects independently

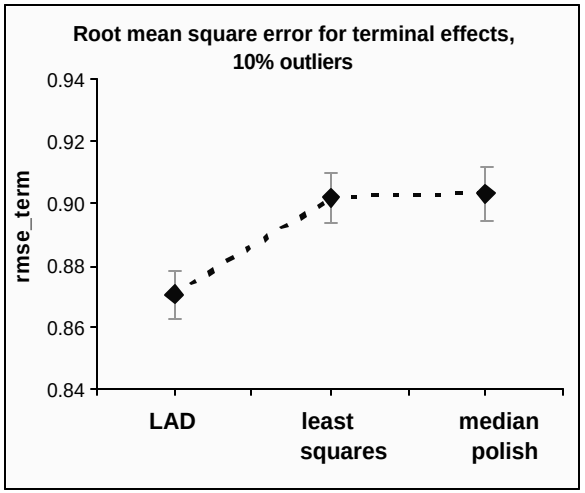
➔ Most effects can be modeled by $N(\mu, \sigma^2)$ after removing outliers

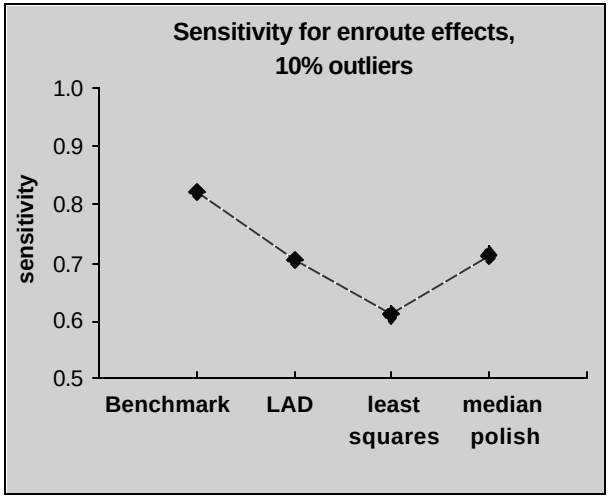
➔ μ and σ of effects can be modeled independently

- μ is modeled by Normal
- σ is modeled by Lognormal

Major findings







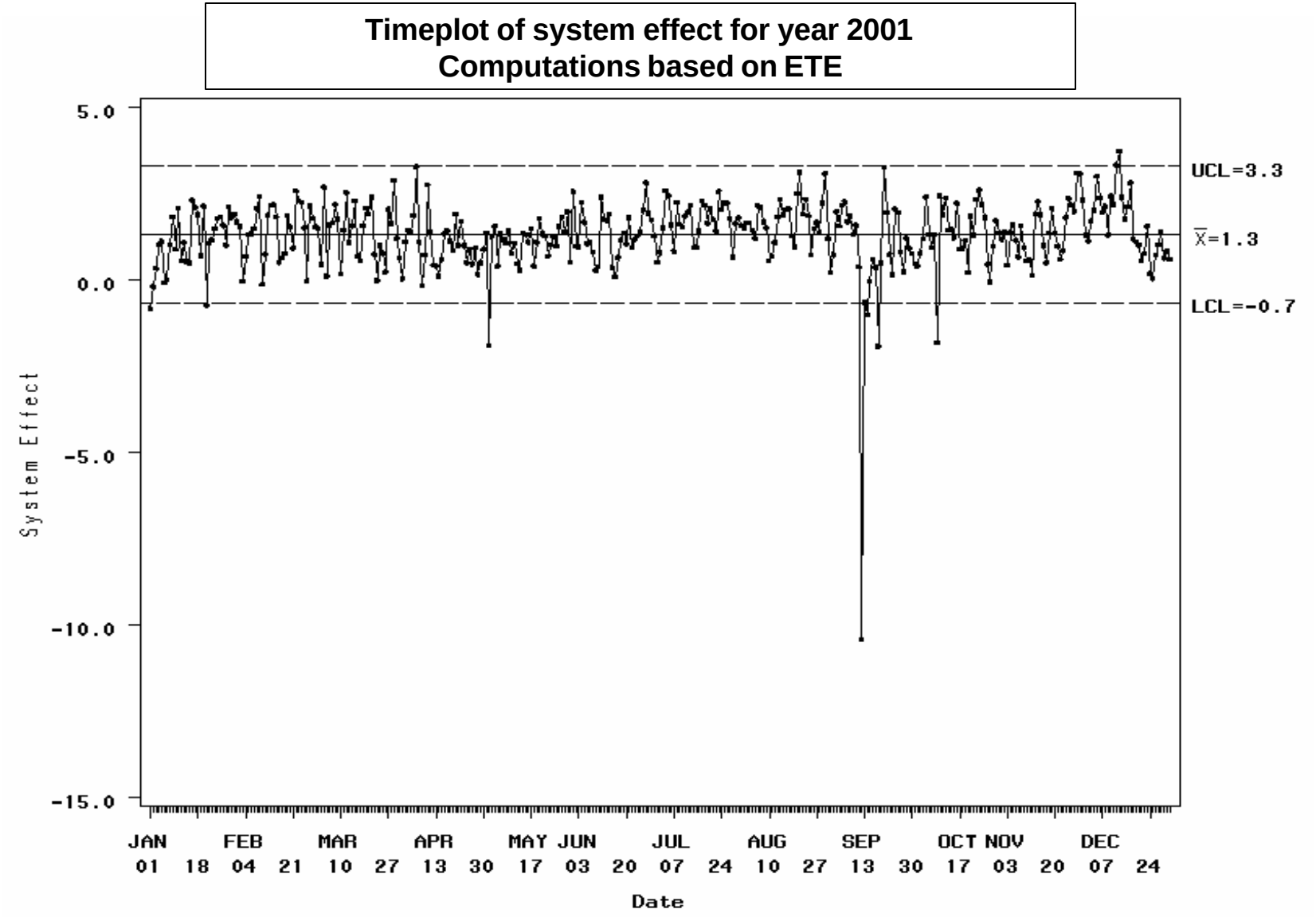
- All error measures are on the order of only one minute for all three methods !
- Since FAA data have up to 10% outliers, we choose resistant methods (better in accuracy and outlier detection capability)
- LAD is slightly better in estimating terminal effects than median polish
- Choose LAD for estimation

System implementation for the FAA

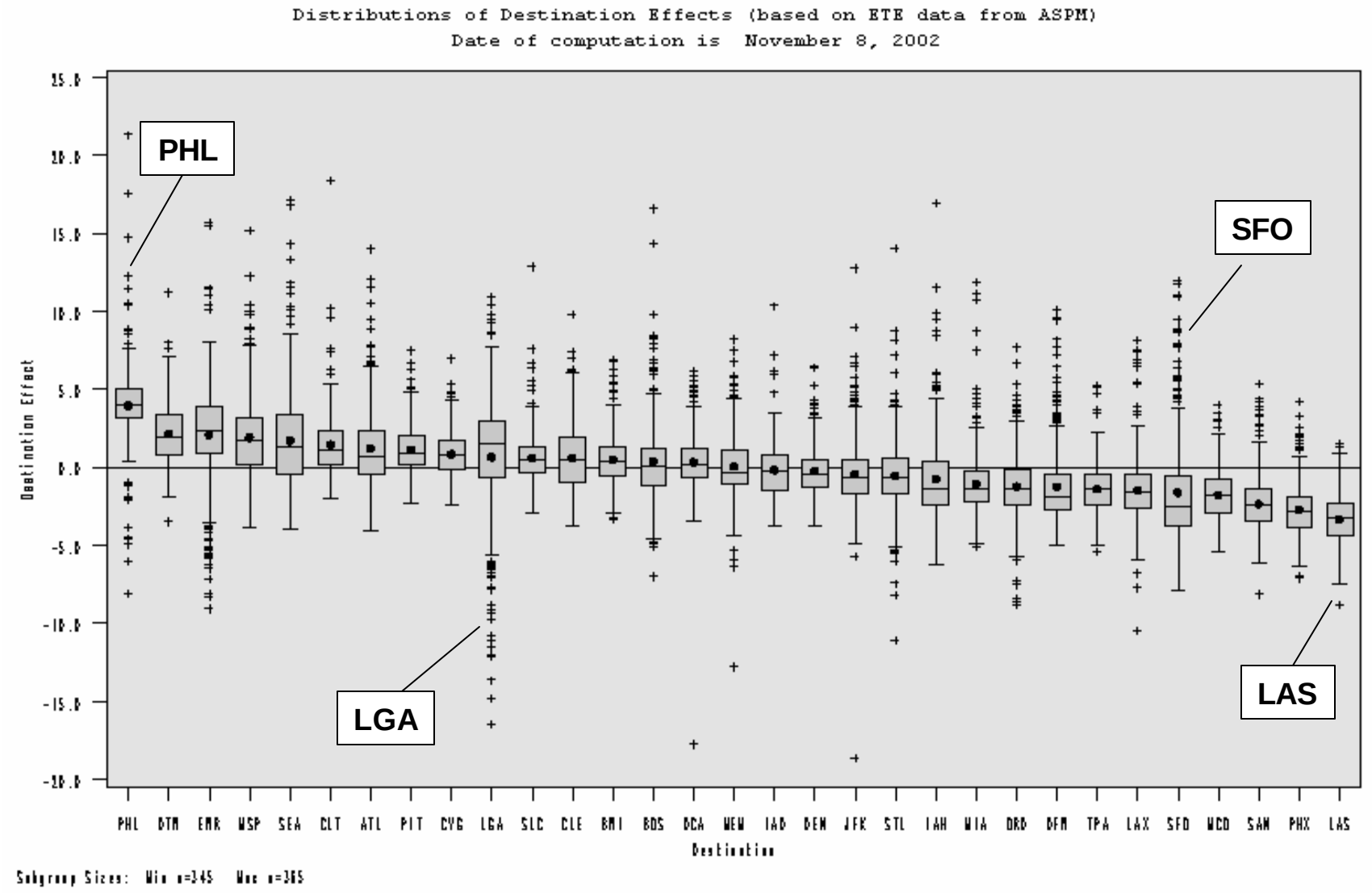
A turnkey system implemented in SAS that produces:

- Next-day estimates of effects
- Map-based displays
- Statistical graphics
- Datasets for use in one-off statistical studies

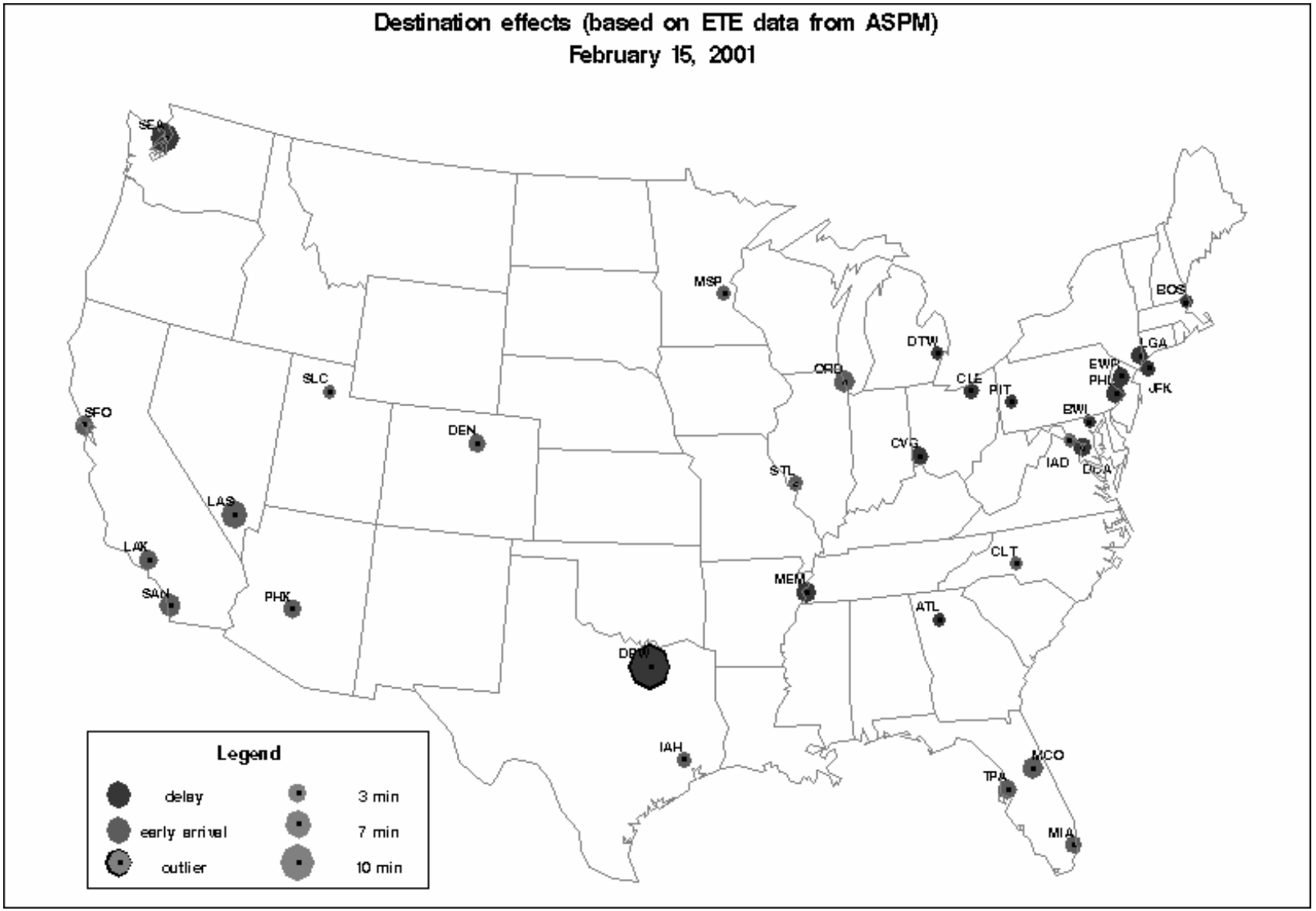
Timeplot of system effects, 2001



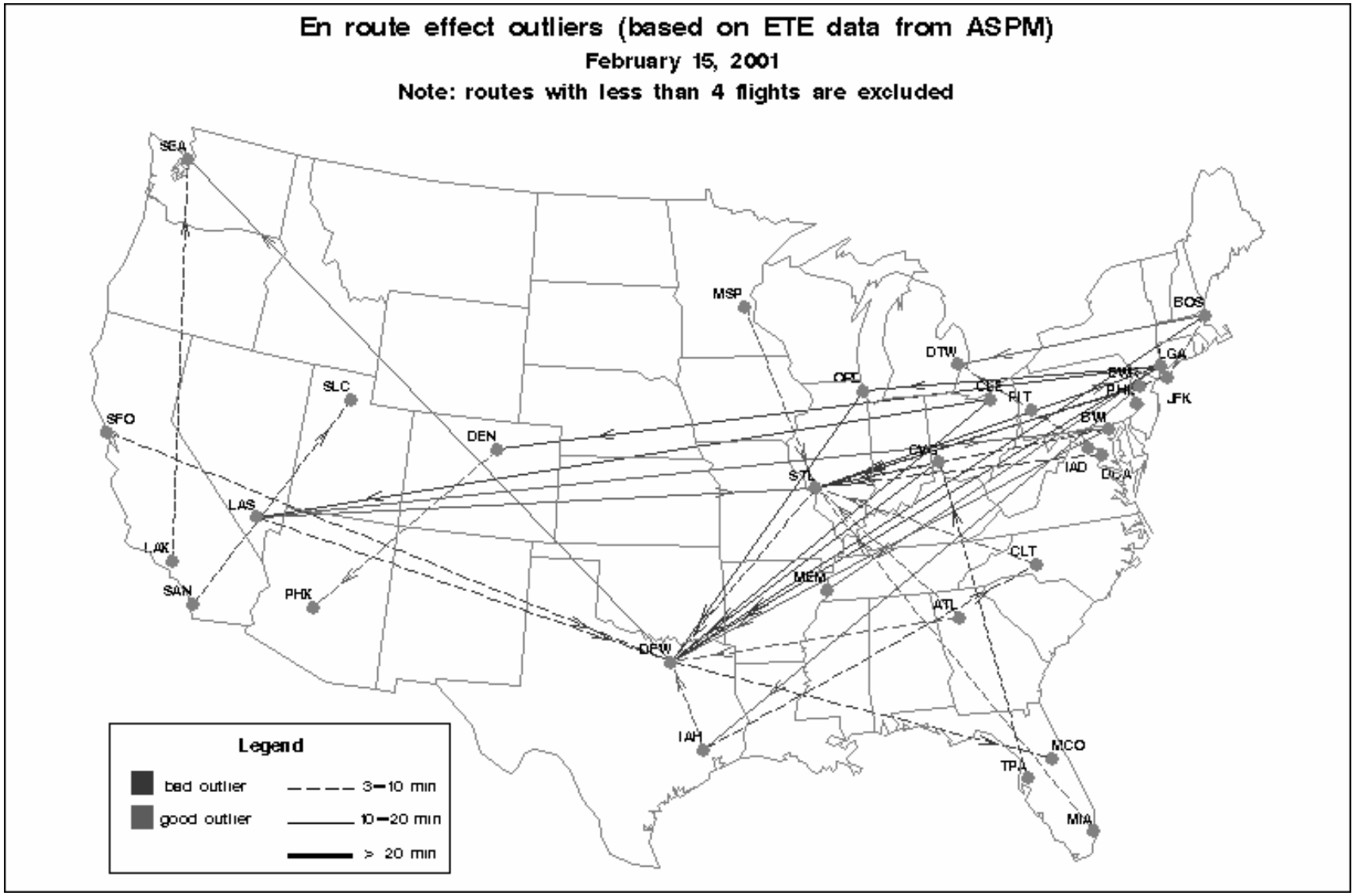
Boxplots of destination effects, 2001



Map of destination effects



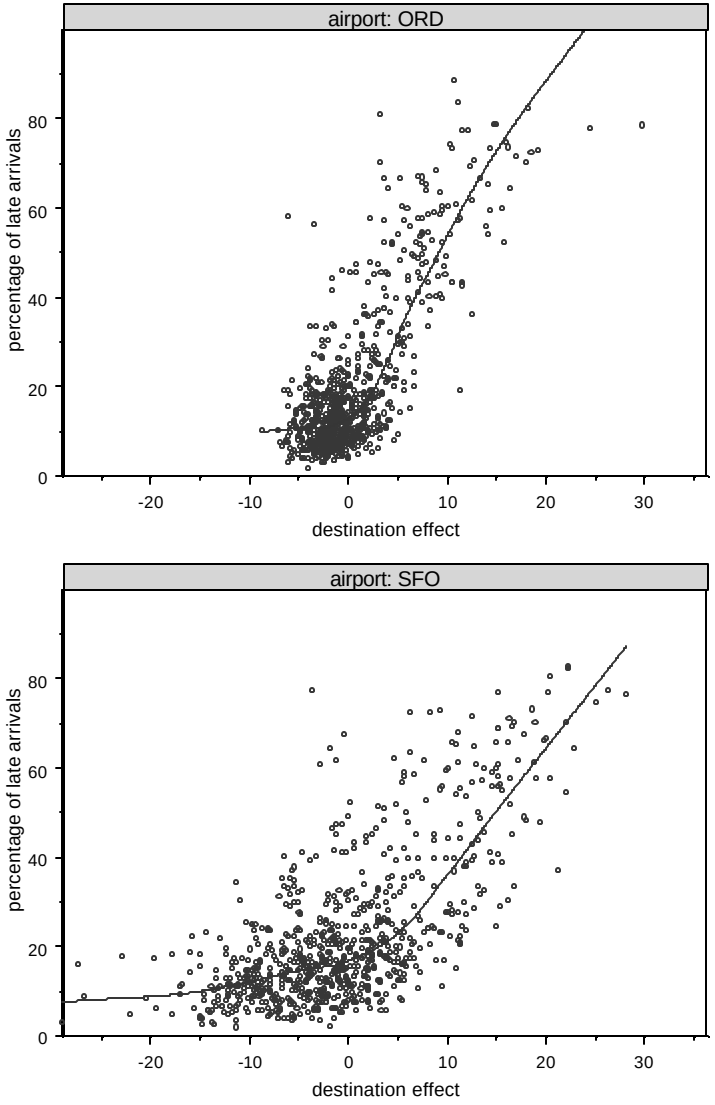
Map of en route effect outliers



Ongoing research #1: Operational validation

- Validate the results against other databases:
  - Aviation System Performance Metrics (ASPM)
  - Operations Network (OPSNET)
  - Post Operations Evaluation Tool (POET)
  - Strategic Plans of Operation (SPO)
  - National Oceanic and Atmospheric Administration (NOAA)
- Conduct at two levels:
  - Macroscopic validation (compare statistics for a certain time period)
  - Microscopic validation (detailed validation for selected days)

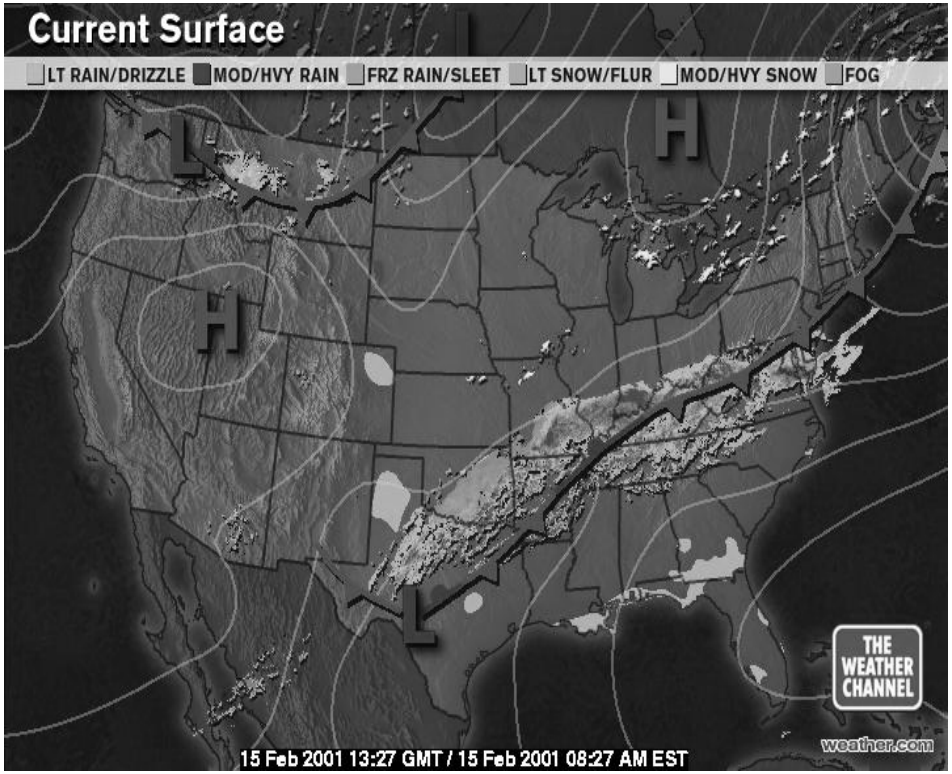
Macroscopic validation: ASPM

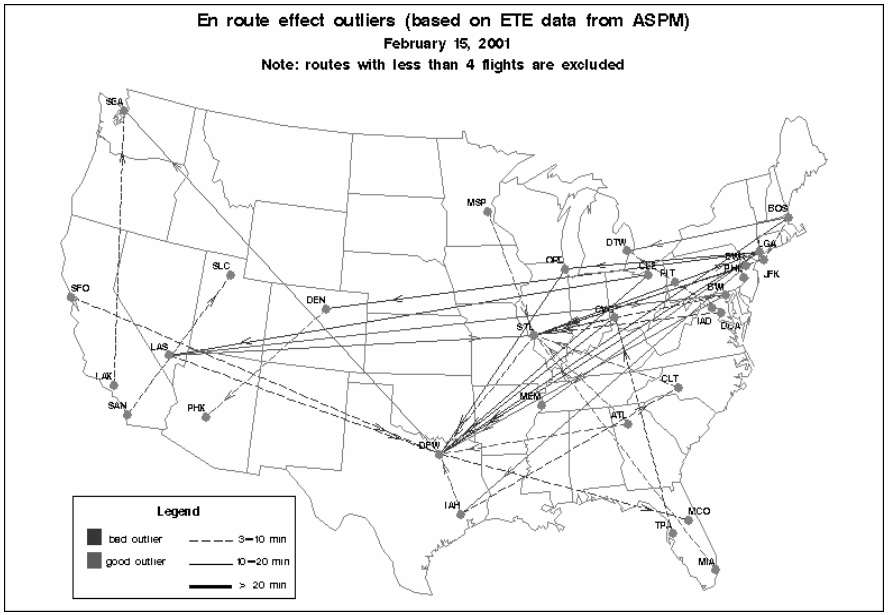


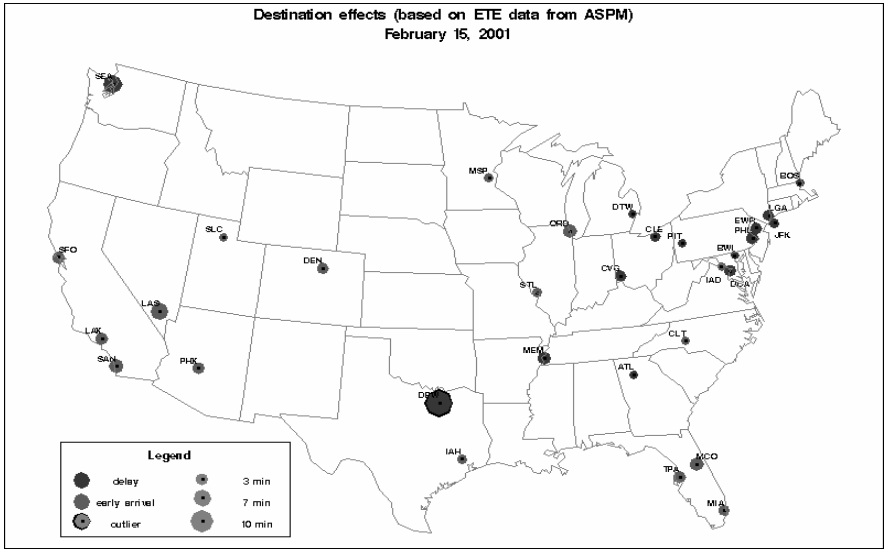
- Strong correlation between destination effects (calculated from G2G data) and ASPM percentage of late arrivals (Jan'2001-March'2003)

Microscopic validation: Weather

February 15, 2001



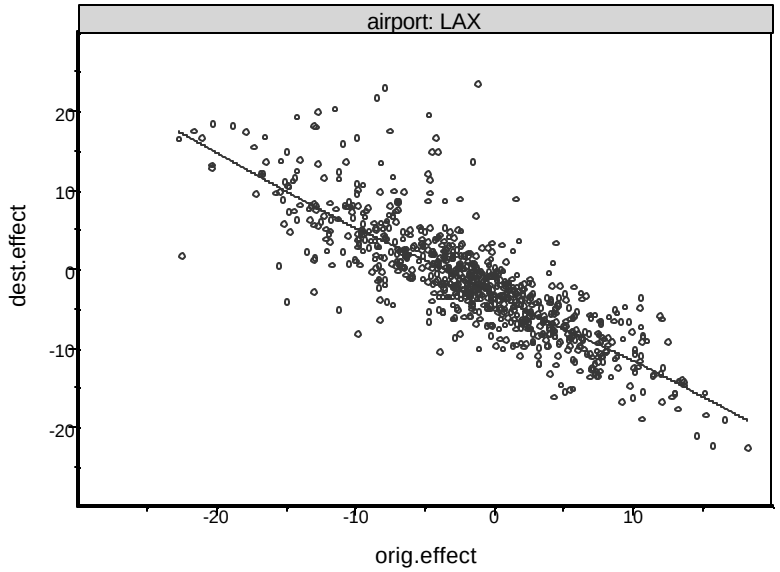




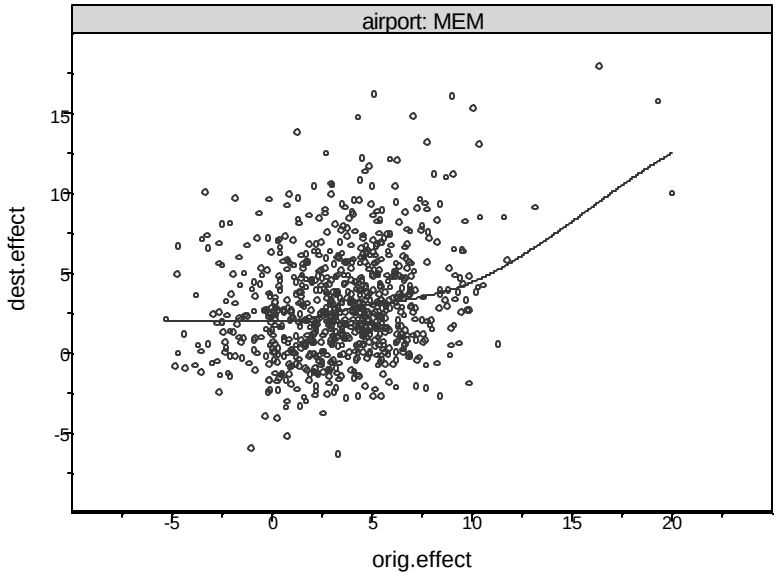
Ongoing research #2: Statistical analysis of effects

Objective: Use the estimated effects to study the NAS

- Origin versus destination effects for LAX (G2G): negative correlation

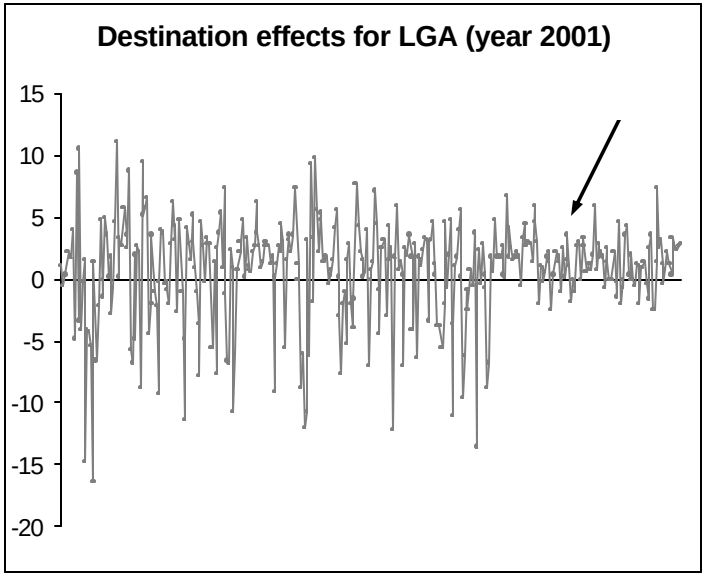


- Origin versus destination effects for MEM (G2G): no correlation

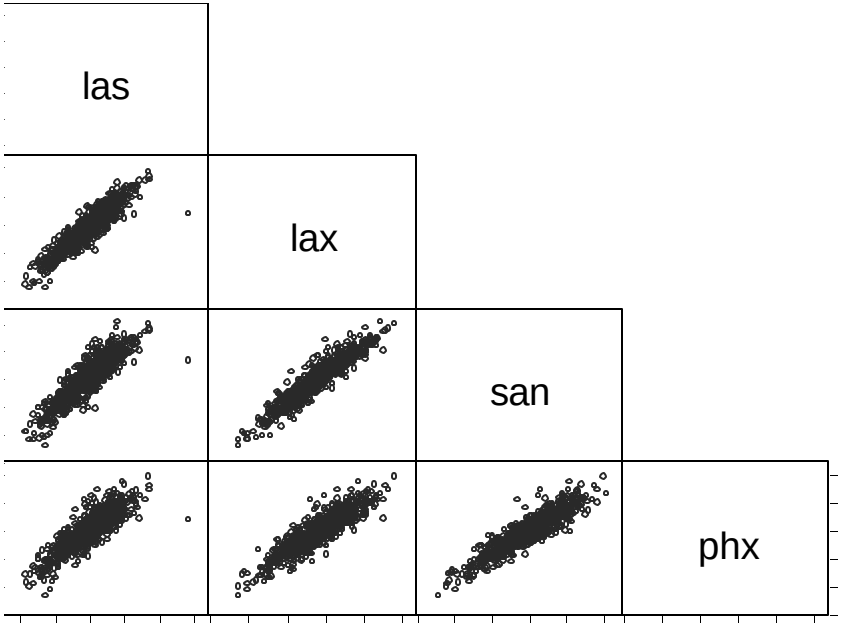


Statistical analysis of effects

- Heteroscedasticity (ETE)



- Positively correlated origin effects (G2G)



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