Data Driven Methods for Airspace Performance Analysis

Lance Sherry

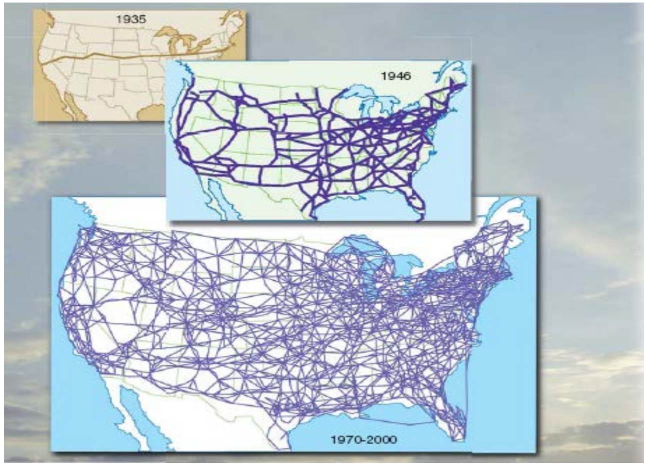
John Shortle

Students

Research and Business Opportunities

Optimized Stochastic, Capacity-limited Networked Operations

Complexity of Interactions in Network of Distributed Agents



Barnstorming Operations

Point-to-Point Scheduled Operations

Networked Scheduled Operation

Optimized Networked Operations

Aircraft
- Basic Aero
- Propulsion

Air Transportation
- Air Transportation - Mail

Air Traffic Control
- Basic Airport Traffic Control

Air Transportation
- National Air Carriers
- Point-to-Point Service
- Inter-modal

Air Traffic Control
- En-route Air Traffic Control
- Terminal Area Traffic Control

Air Transportation
- National/International Network airlines
- Civil Aviation Board

Air Traffic Control
- Radar
- Precision Approach
-

Air Transportation
- Deregulation
- Hub monopolies
- Schedule/Network optimization
- Overscheduling
- Yield Management
- Fuel Management airlines

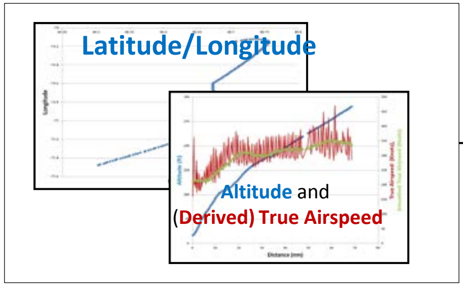
Air Traffic Control
- Radar
- Precision Approach

Air Transportation
- Flexible Airline Business Models
- Low Cost Carriers/Regional Jet Airlines
- Network configurations (Hub, point-to-point)

Air Traffic Control
- Collaborative Decision Making
- Revenue/Cost Synchronization
- Aircraft Self-separation
- Facility Resizing
- Safety/Capacity Tradeoff

1920 1940 1960 1980 2000 **Years**

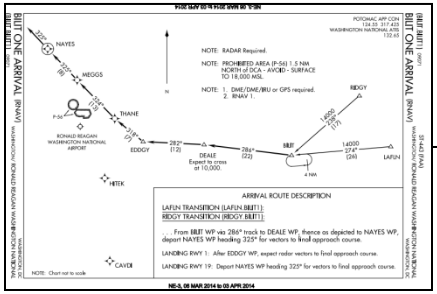
Big Data Analytics in Air Transportation



Surveillance Data

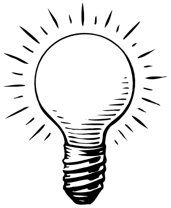
Flight Data

Aircraft Performance

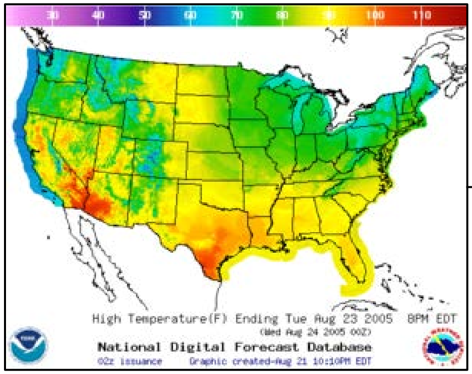


Procedures

Model-based Engineering & Big Data Analysis



Insights & Understanding for Operators, Planners, & Investors



Weather Data

Aircraft Performance Models

$$T_i = D_i + \frac{m_i \times g \times \frac{dh}{dt}}{TAS_i} + m_i \times \frac{dTAS}{dt}$$

Automation Behavior Models

Automation Behavior Models

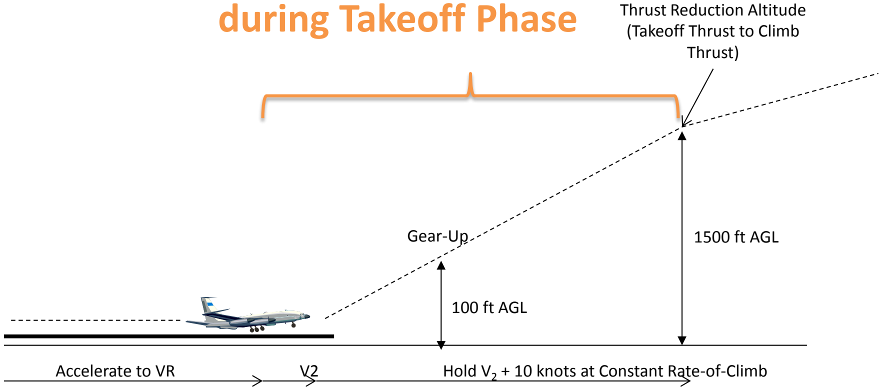
Validation

Emission Inventory

Context

- Airport Management is required to report Emissions Inventory for aircraft Landing and Takeoff Operations (LTO):
  1. Sustainability planning
  2. Climate Change Registries
  3. Environmental Impact Studies

Maximum Emissions generated during Takeoff Phase



$$\overbrace{CnHm + S}^{\textbf{Fuel}} + \overbrace{N + O}^{\textbf{Air}} \rightarrow$$

$$\underbrace{\mathbf{CO + H\ O + N + O}}_{\textbf{Products of Ideal Combustion}} + \underbrace{NOx + CO + SOx + Soot + UHC}_{\textbf{Products of Non-Ideal Combustion}}$$

Context

- Monitoring by sensors inaccurate due to *dispersion* effects/prohibitively expensive
- Inventory Models
  - Mass of pollutants generated
  - ICAO Reference Model

Pollutant mass per flight =

Number of Engines x

Time in Phase of Flight (T) x

Fuel Flow Rate (FFR) x

Emissions Index (EI)

- T, FFR, EI averages from ICAO data-base

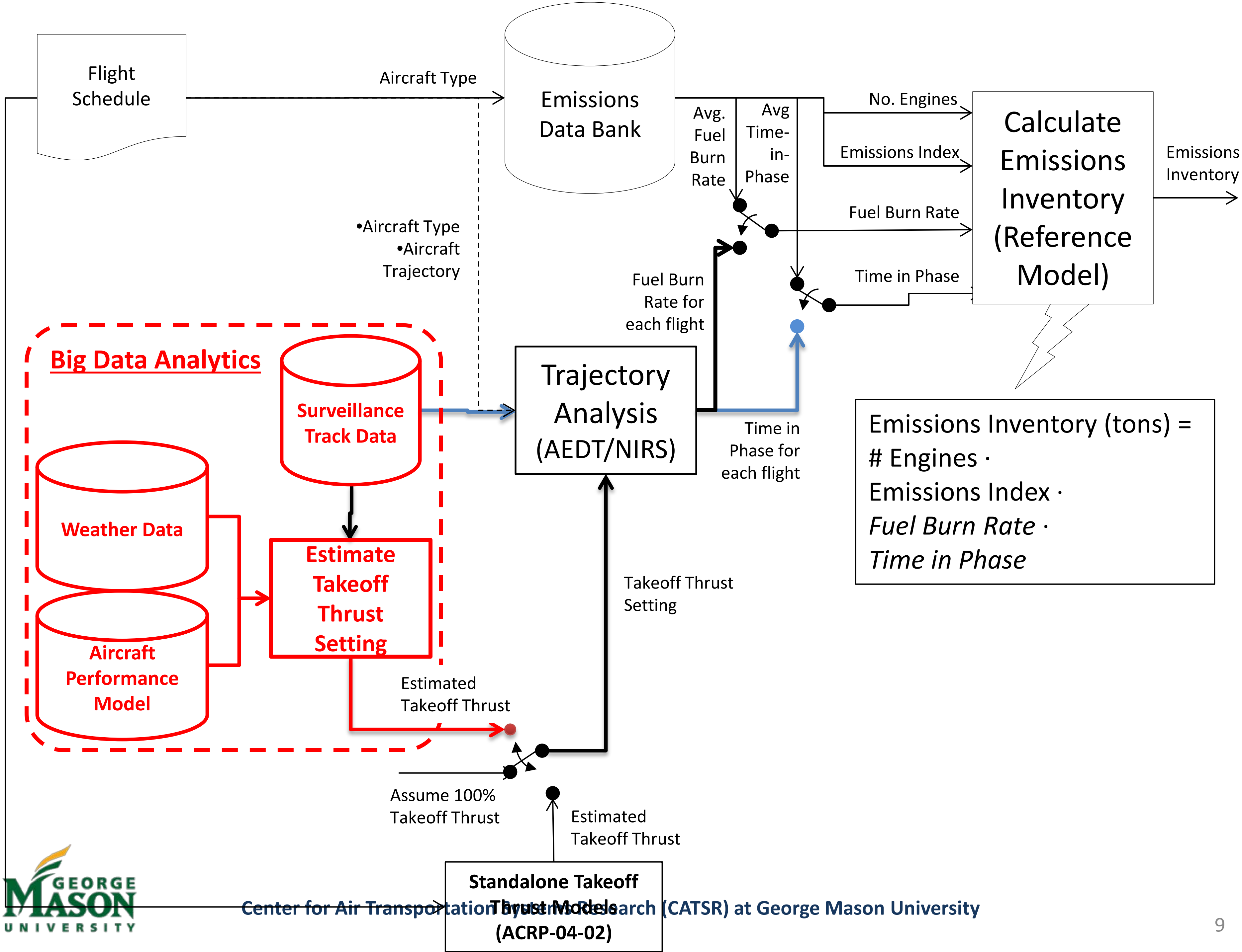
Problem

- “Static” Inventory Models *over-estimate* Emissions Inventory
- Two assumptions:
  1. ***Average Time-in-Phase (assumed 2.9 mins takeoff)***
  2. **Thrust Setting for Takeoff (assumed 100%)**

Pollutant mass per flight =
Number of Engines * ***Time in Phase of Flight*** * **Fuel Flow Rate** * Emissions Index

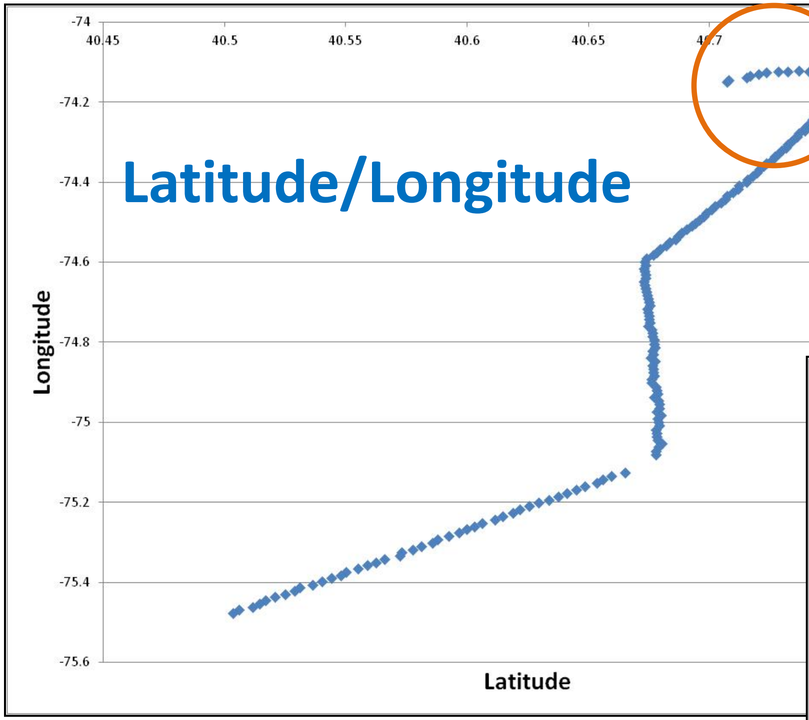
Solution

- Improve accuracy in Emissions Inventory Estimate using
  1. High-fidelity track surveillance data
  2. Procedure data (i.e. navigation data-base)
  3. Aircraft performance model
     - Validated by Flight Data
  4. Weather data



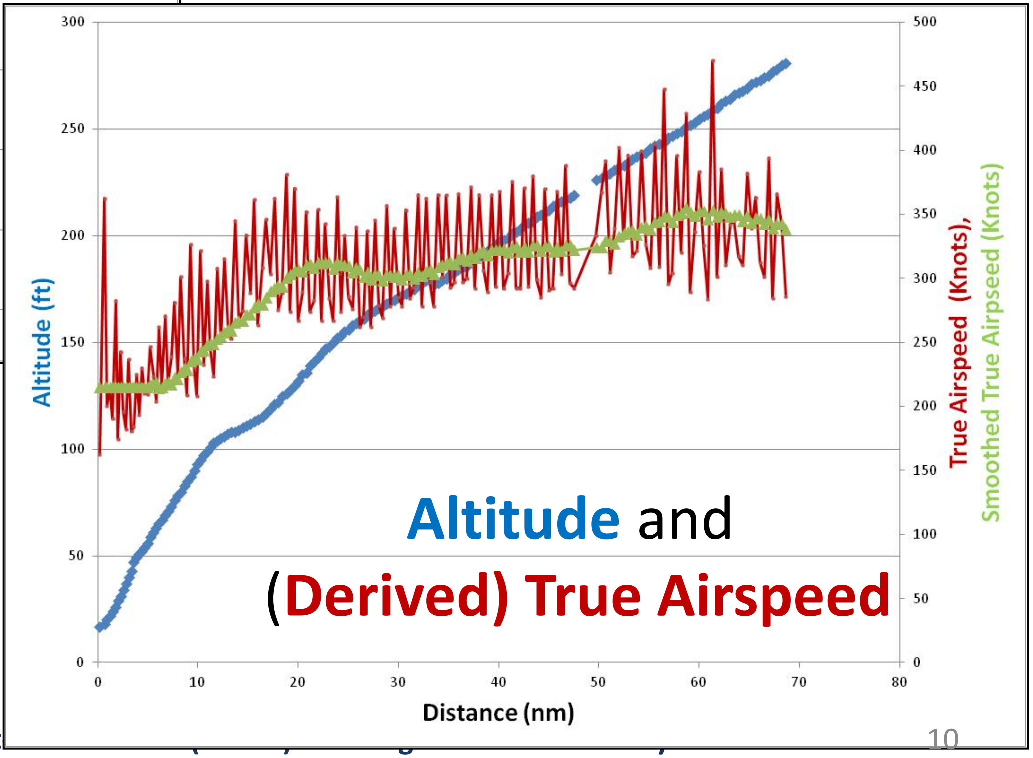
Emissions Inventory (tons) =
Engines ·
Emissions Index ·
Fuel Burn Rate ·
Time in Phase

Surveillance Track Data



Latitude/Longitude

$$V_{TAS}=\begin{bmatrix}(V_G \cdot Sin(\theta)) - & (V_W \cdot Sin(\phi)) \\ (V_G \cdot Cos(\theta)) - & (V_W \cdot Sin(\phi))\end{bmatrix}$$



Altitude and
(Derived) True Airspeed

Alternate filtering techniques developed

Aircraft Performance Equations

Total-Energy model: rate of work done by forces acting on the aircraft = rate of change of potential and kinetic energy

$$(T_i - D_i) \times TAS_i = m_i \times g \times \frac{dh}{dt} + m_i \times TAS_i \times \frac{dTAS}{dt}$$

Rearranging for Thrust

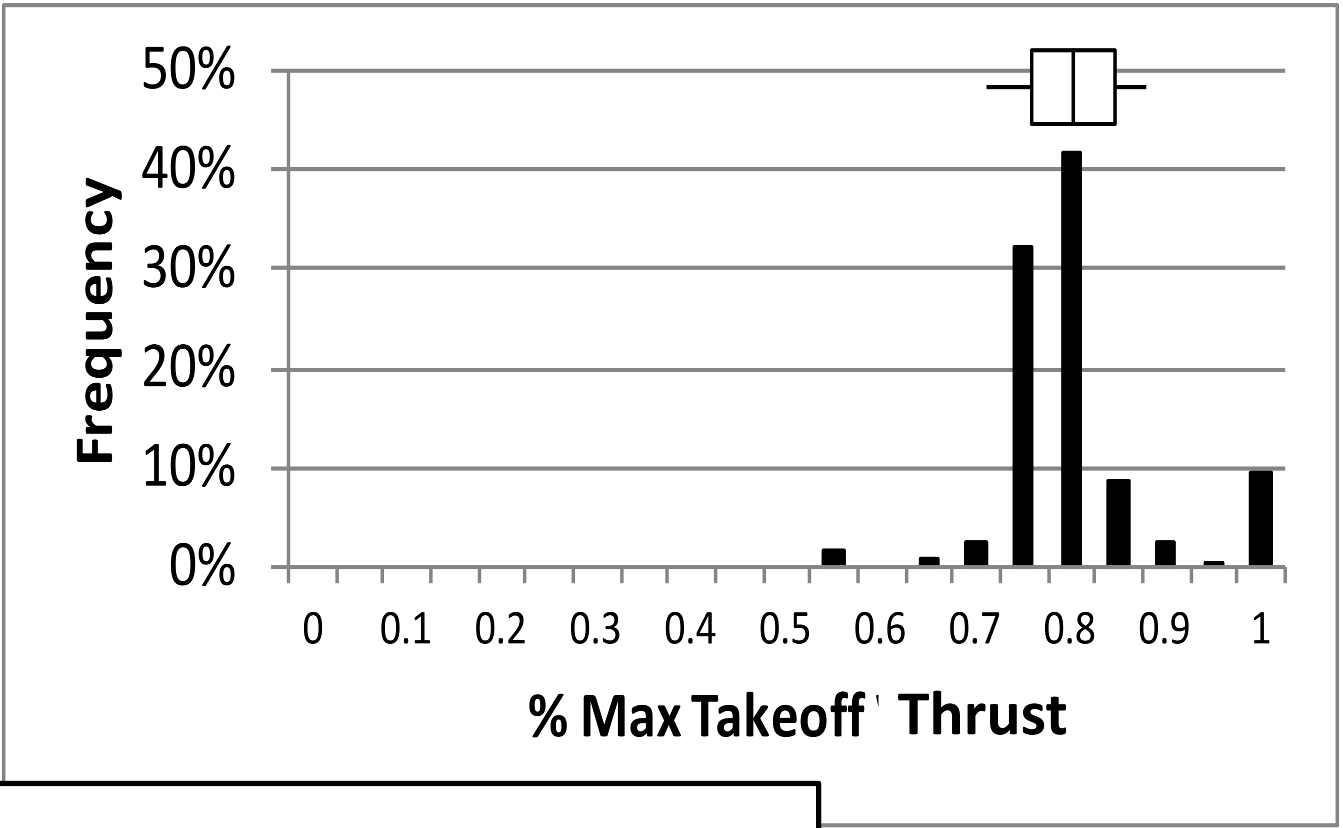
$$T_i = D_i + \frac{m_i \times g \times \frac{dh}{dt}}{TAS_i} + m_i \times \frac{dTAS}{dt}$$

○ Aircraft performance ○ Surveillance track data ○ Weather (i.e. wind)

Results

Thrust Settings for 1200 departures at ORD

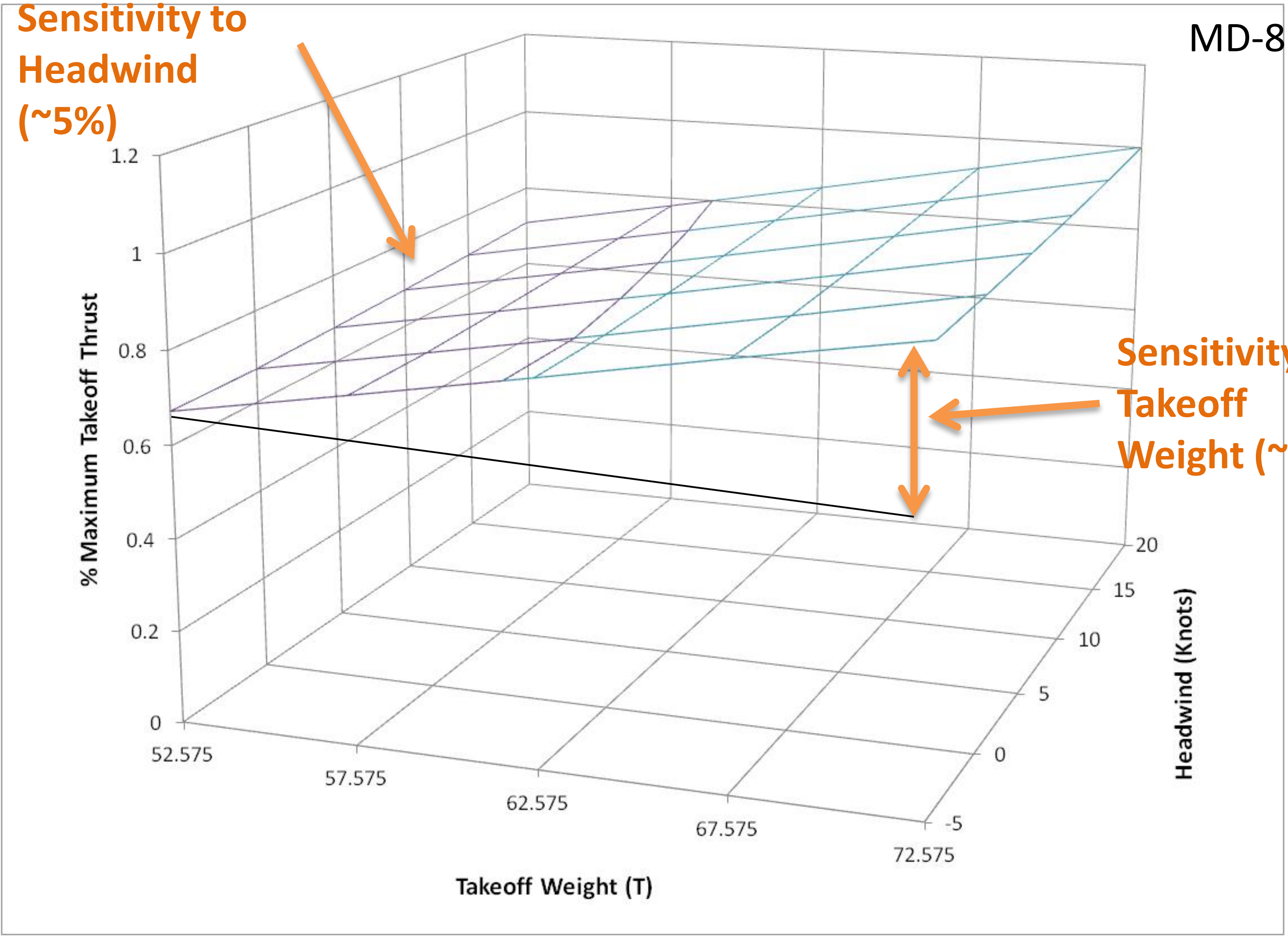
μ = 86% Max Takeoff Thrust, σ = 11%



Validation:

- Airline supplied takeoff thrust settings.
- Range in thrust reduction from 0% to 24 %
- An average thrust reduction of 13%, standard deviation of 8%.

Sensitivity Analysis – TOW and Headwind



MD-83 (Super MD-80)

(Marginal) Sensitivity to Headwind (~5%)

Sensitivity to Takeoff Weight (~30%)

Modernization Cost/Benefits Analysis: Metroplex Flow De-confliction Using RNP Procedures at Midway Airport

Akshay Belle

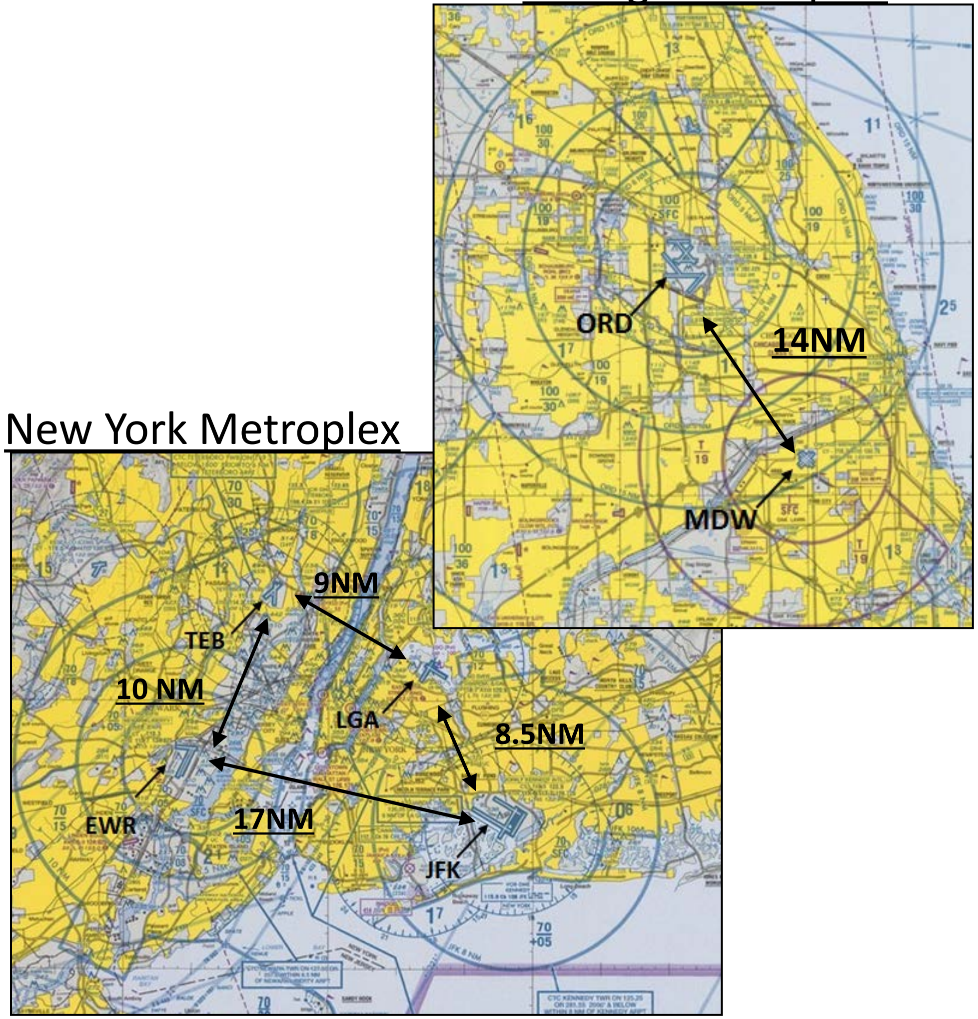
Metroplex Examples

Top 10 Metroplexes in the US

Sl.no	Metroplex	Ops per day (Year 2012)	# Airports within 30NM
1	New york	3257	4
2	Chicago	3055	2
5	Los Angeles	2797	4
3	Atlanta	2542	1
4	District of Columbia	2434	3
6	Dallas	2236	2
7	San Francisco	1903	3
8	Miami	1734	2
9	Denver	1697	1
10	Charlotte	1498	1

Total of 21 Metroplexes in the U.S serving metropolitan area that account for:

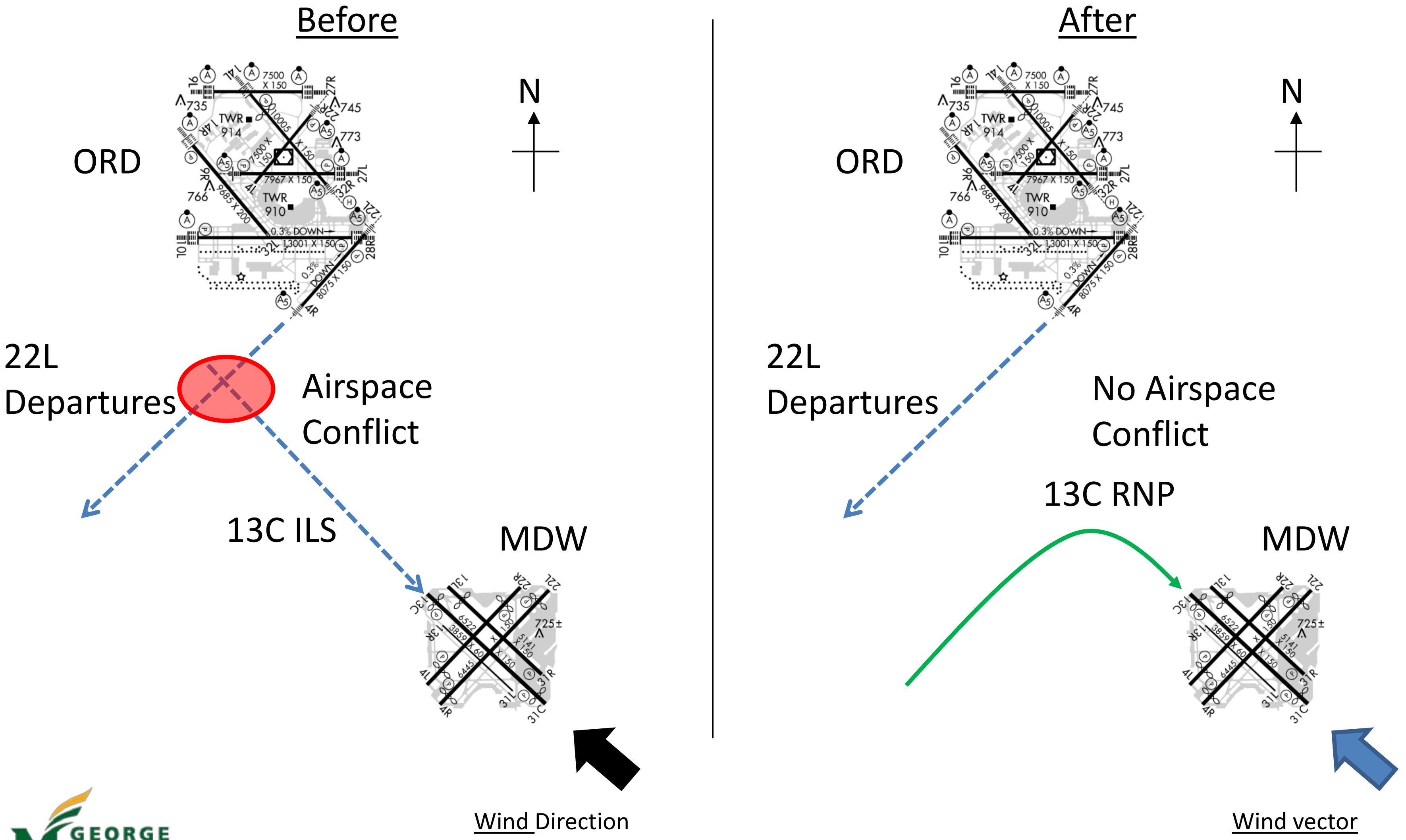
- 35% of the nation’s population (314 M) (United States Census Bureau, 2012)
- 44% of the gross domestic product ($15.68 trillion) (U.S. Department of Commerce, 2012)



Chicago Metroplex

New York Metroplex

Metroplex De-confliction – Terminal Airspace Redesign (Spatial Strategy)



Before

ORD

N

22L Departures

Airspace Conflict

13C ILS

MDW

Wind Direction

After

ORD

N

22L Departures

No Airspace Conflict

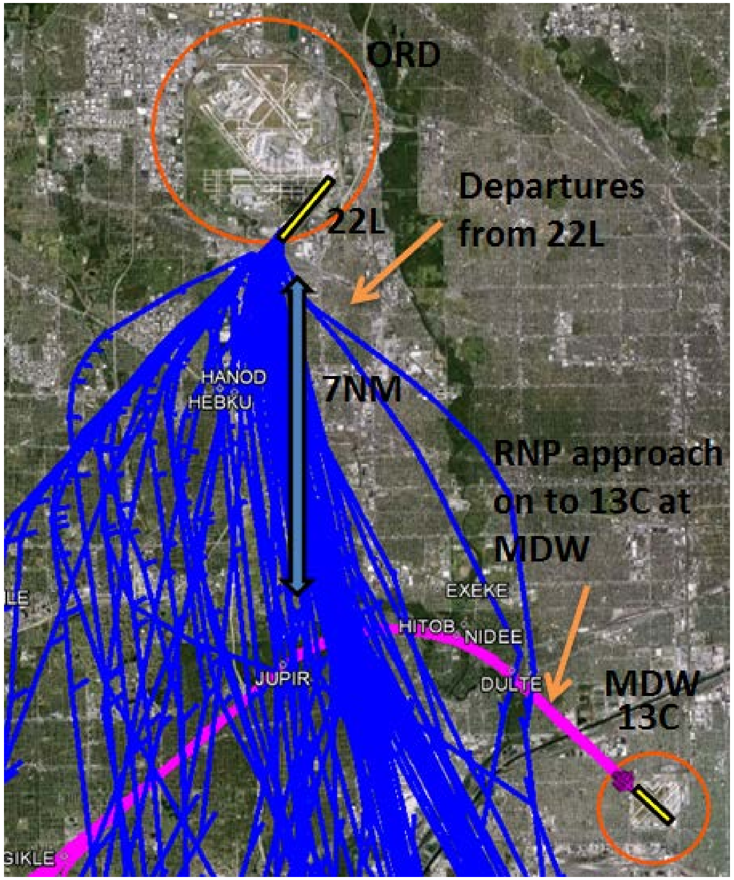
13C RNP

MDW

Wind vector

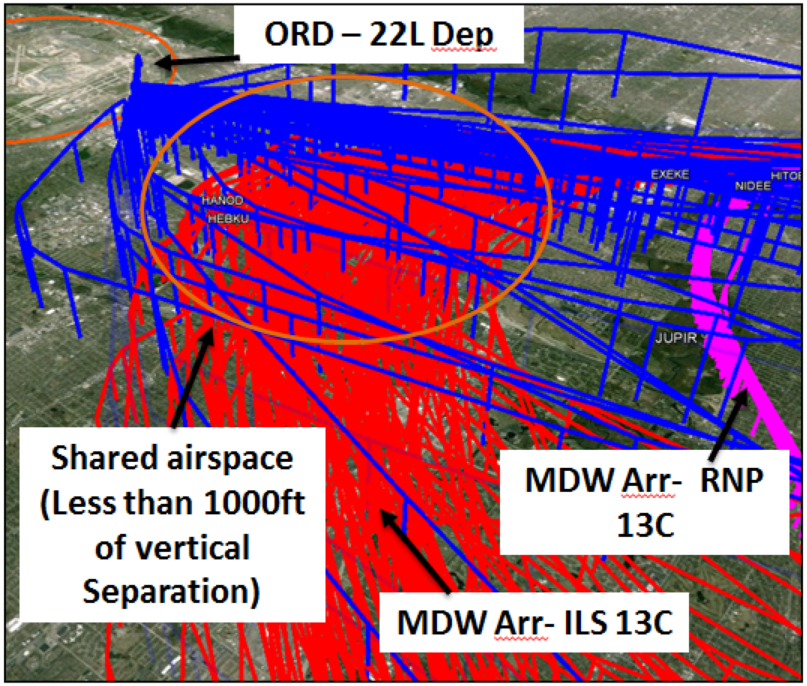
Chicago Metroplex De-confliction

MDW - RNP0.3 w/RF Leg approach on to 13C



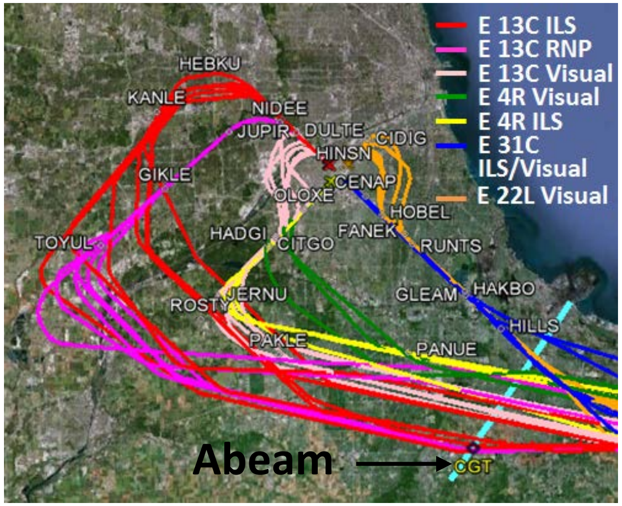
- Chicago Metroplex De-confliction
  - RNP0.3 w/RF Leg approach on to 13C at MDW
  - Safe Vertical Separation

Metroplex De-confliction – Vertical Profile

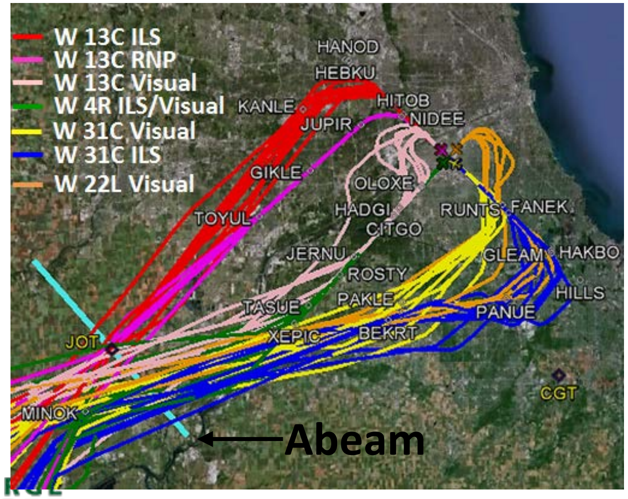


MDW Flows from East and West

Flows From East



Flows From West

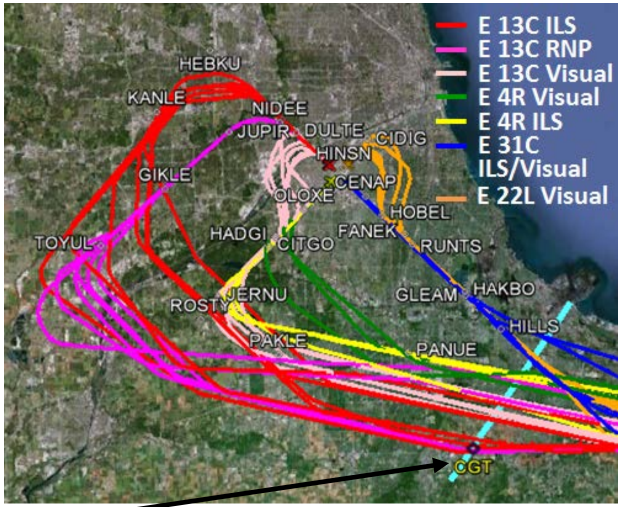


Flows and their respective Track count

Sl.no	Direction	Runway	Approach	Count
1	E	**13C**	**ILS**	**798**
2			**RNP**	**87**
3			**Visual**	**1026**
4		13L	Visual	8
5		**22L**	**Visual**	**840**
6		22R	Visual	70
7		**31C**	**ILS**	**1467**
8			**Visual**	**345**
9		31R	Visual	5
10		4L	Visual	48
11		**4R**	**ILS**	**390**
12			**Visual**	**1181**
13	W	**13C**	**ILS**	**568**
14			**RNP**	**151**
15			**Visual**	**857**
16		13L	Visual	9
17		**22L**	**Visual**	**650**
18		22R	Visual	56
19		**31C**	**ILS**	**387**
20			**Visual**	**987**
21		31R	Visual	2
22		4L	Visual	50
23		**4R**	**ILS**	**729**
24			**Visual**	**564**

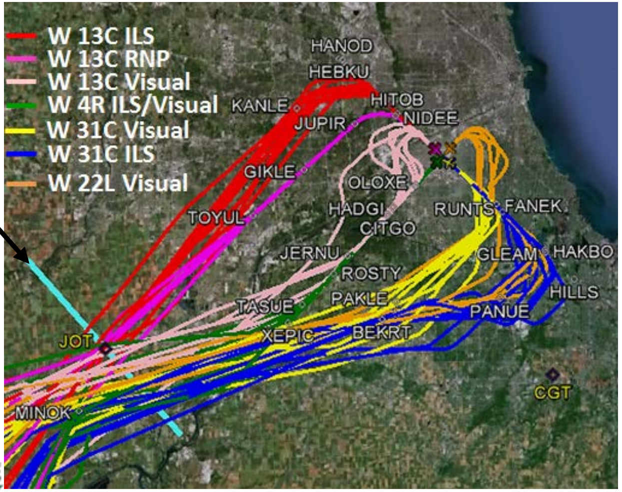
TRACON Flow Track Distance & Time Performance

Flows From East



Abeam - Final waypoint on STAR

Flows From West



Track distance and time, lower the better

Ranking of flow from the East

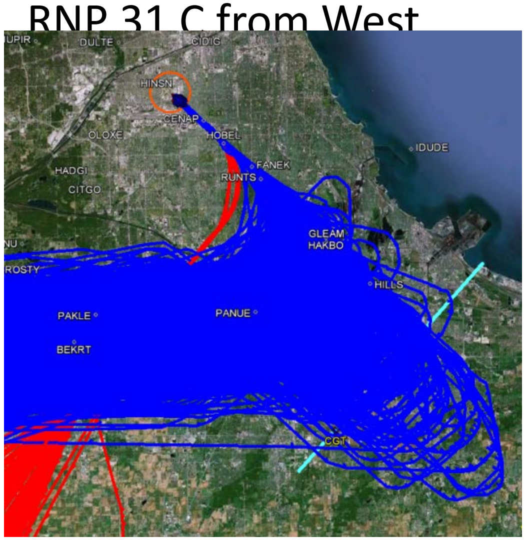
Dir/Runway/Approach			Count	Track Time (min)		Distance (NM)		# of Turns in the Terminal Airspace
				Mean	SD	Mean	SD	
E	31C	ILS	1467	5.90	0.69	16.56	1.44	Straight-In
E	31C	Visual	345	6.12	0.80	16.77	2.48	Straight-In
E	22L	Visual	840	6.71	0.83	20.39	1.25	One turn
E	4R	Visual	1181	8.84	1.77	28.74	4.17	One turn
E	13C	Visual	1026	9.62	1.59	32.58	4.08	Two turns
E	4R	ILS	390	10.92	2.58	33.59	5.52	One turn
E	13C	RNP	87	13.40	1.88	45.31	4.81	Two turns
E	13C	ILS	798	14.37	2.21	48.20	5.37	Two Turns

Ranking of flow from the West

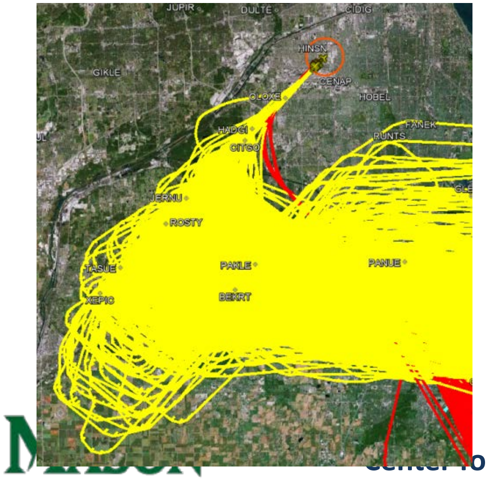
Dir/Runway/Approach			Count	Track Time (min)		Distance (NM)		# of Turns in the Terminal Airspace
				Mean	SD	Mean	SD	
W	4R	ILS	729	8.58	0.89	28.94	0.64	Straight-In
W	4R	Visual	564	9.07	1.27	29.34	2.05	Straight-In
W	13C	RNP	151	9.47	0.67	32.67	0.64	One turn
W	13C	Visual	857	9.65	1.11	33.59	1.98	One turn
W	13C	ILS	568	10.63	1.01	36.22	1.78	One turn
W	31C	Visual	987	11.91	1.94	42.90	4.58	One turn
W	22L	Visual	650	12.39	2.07	46.16	5.20	Two turns
W	31C	ILS	387	13.77	2.39	47.44	5.60	One turn

Benefits RNP Approaches for MDW (all Runways)

RNP 31 C from West



RNP 4R from the East

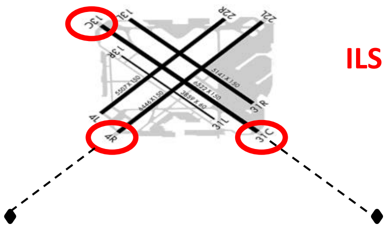


ILS Approach Arrival Flows

Runway	Track Count	Fuel Burn (kg)		Track time (min)		Level Time (min)		% Level
		Mean	SD	Mean	SD	Mean	SD	
31C	1757	189.3	117.994	9.05613	3.67215	1.80877	2.19502	19.97
4R	1972	189.5	91.9926	9.169	1.7488	1.94704	1.8282	21.24
13C	937	332.6	124.49	12.6552	2.5809	4.62652	2.90397	36.56

RNP Approach Arrival Flows

Runway	Track Count	Fuel Burn (kg)		Track time (min)		Level Time (min)		% Level
		Mean	SD	Mean	SD	Mean	SD	
31C	1093	118.4	50.883	6.52555	1.59695	0.442422	0.854984	6.78
4R	1118	148.5	50.801	8.48937	1.14568	1.05441	1.20379	12.42
13C	237	251.9	108.773	10.962	2.39199	2.4628	2.27441	22.47
22L	237	258.7	135.346	10.6915	4.97851	2.52982	3.01863	23.66



ILS available

Chicago Heights (CGT)

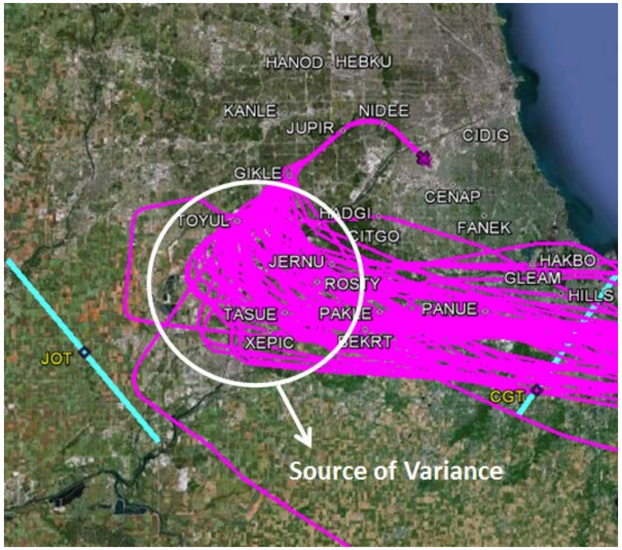
Joliet (JOL)

Source of variance in RNP flows

MDW- Flows to runway 13C from the east

ILS Approach

RNP Approach

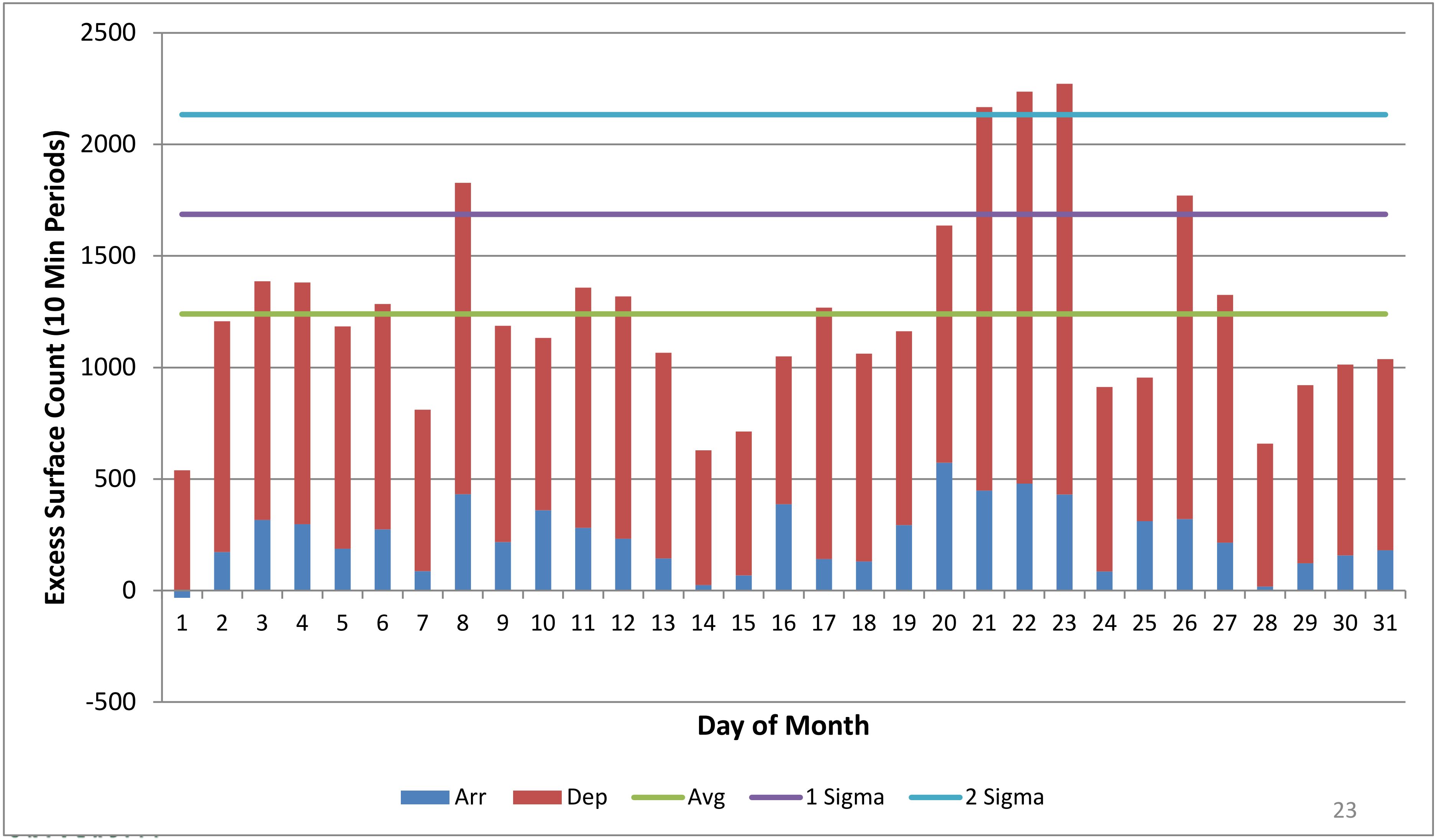


“Vectors" up to the Start of the RNP approach (base leg) introduce as much variation in track distance/time as the ILS approaches.

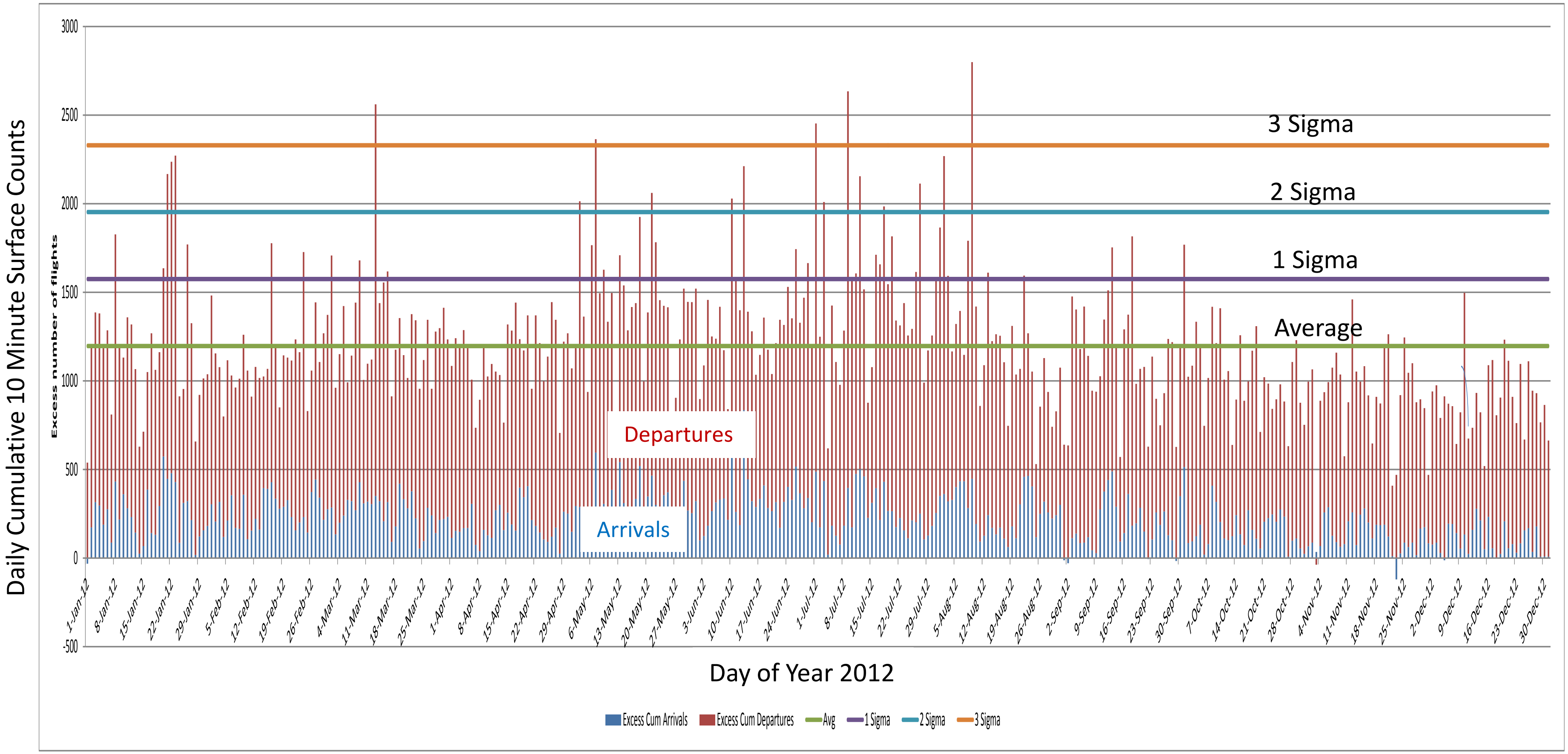
Airport Surface Operations Analysis

Anvardh Nanduri, Kevin Lai

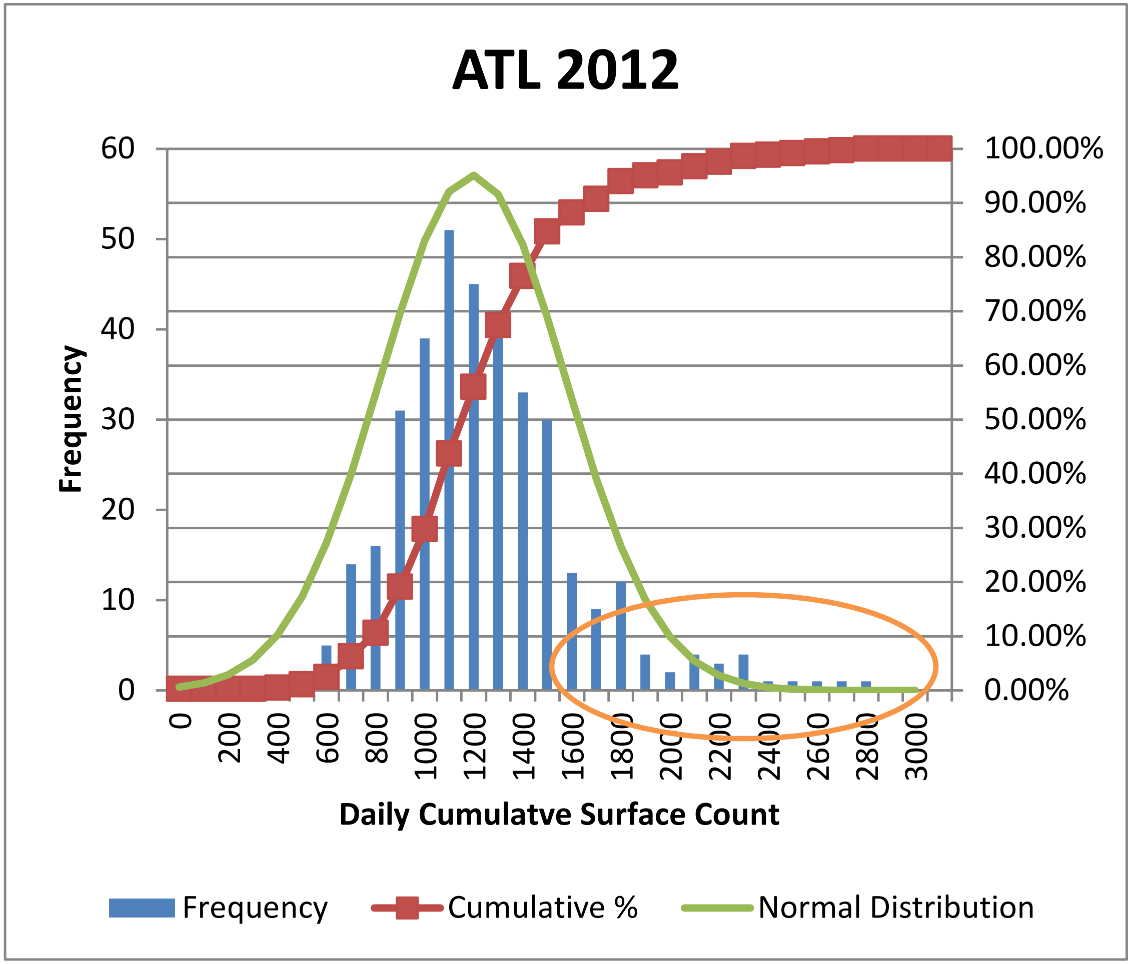
ATL 2012 Jan -


2500
2000
1500
1000
500
0
-500
Excess Surface Count (10 Min Periods)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day of Month
Arr
Dep
Avg
1 Sigma
2 Sigma

Annual Surface Ops

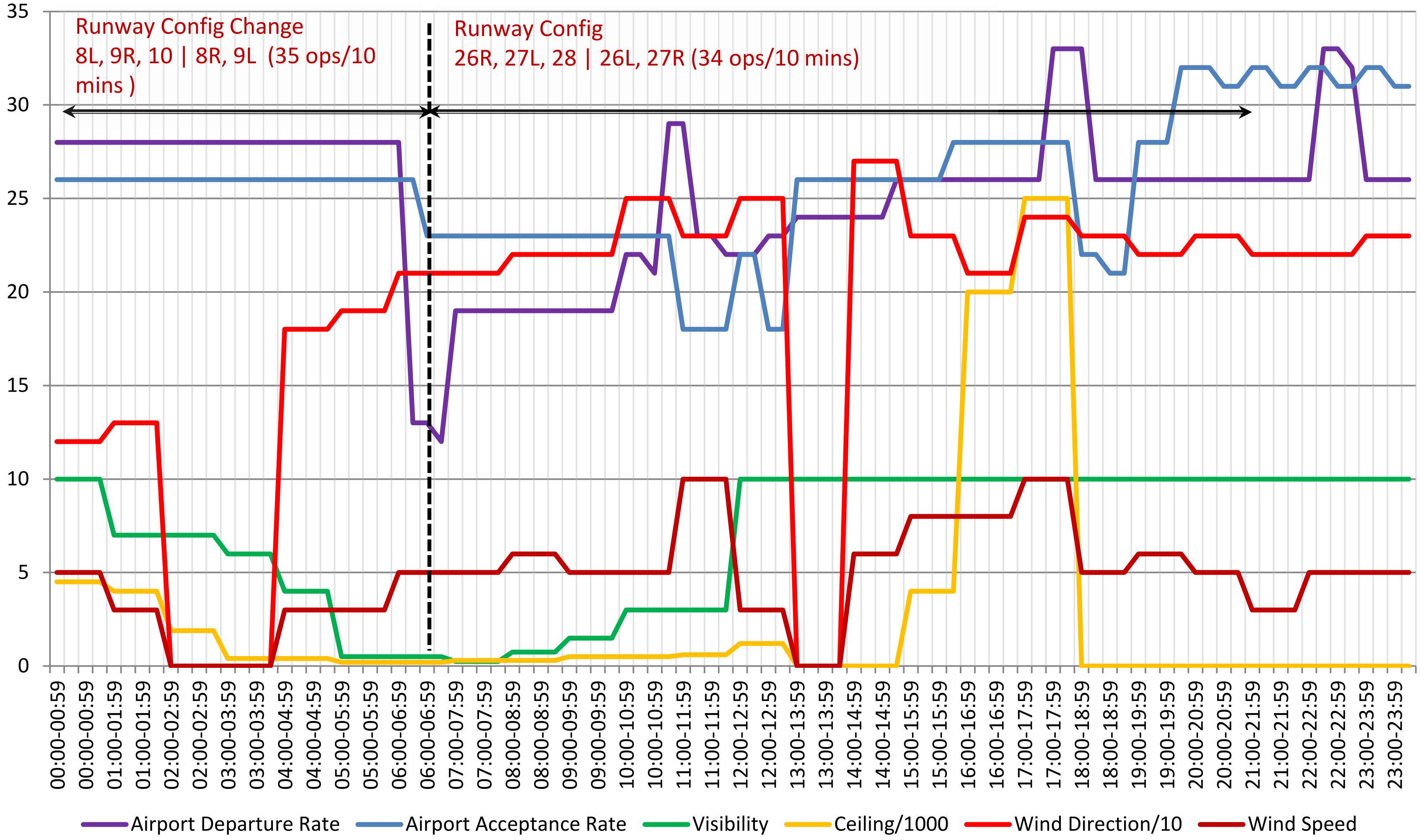


Daily Cumulative Surface Count



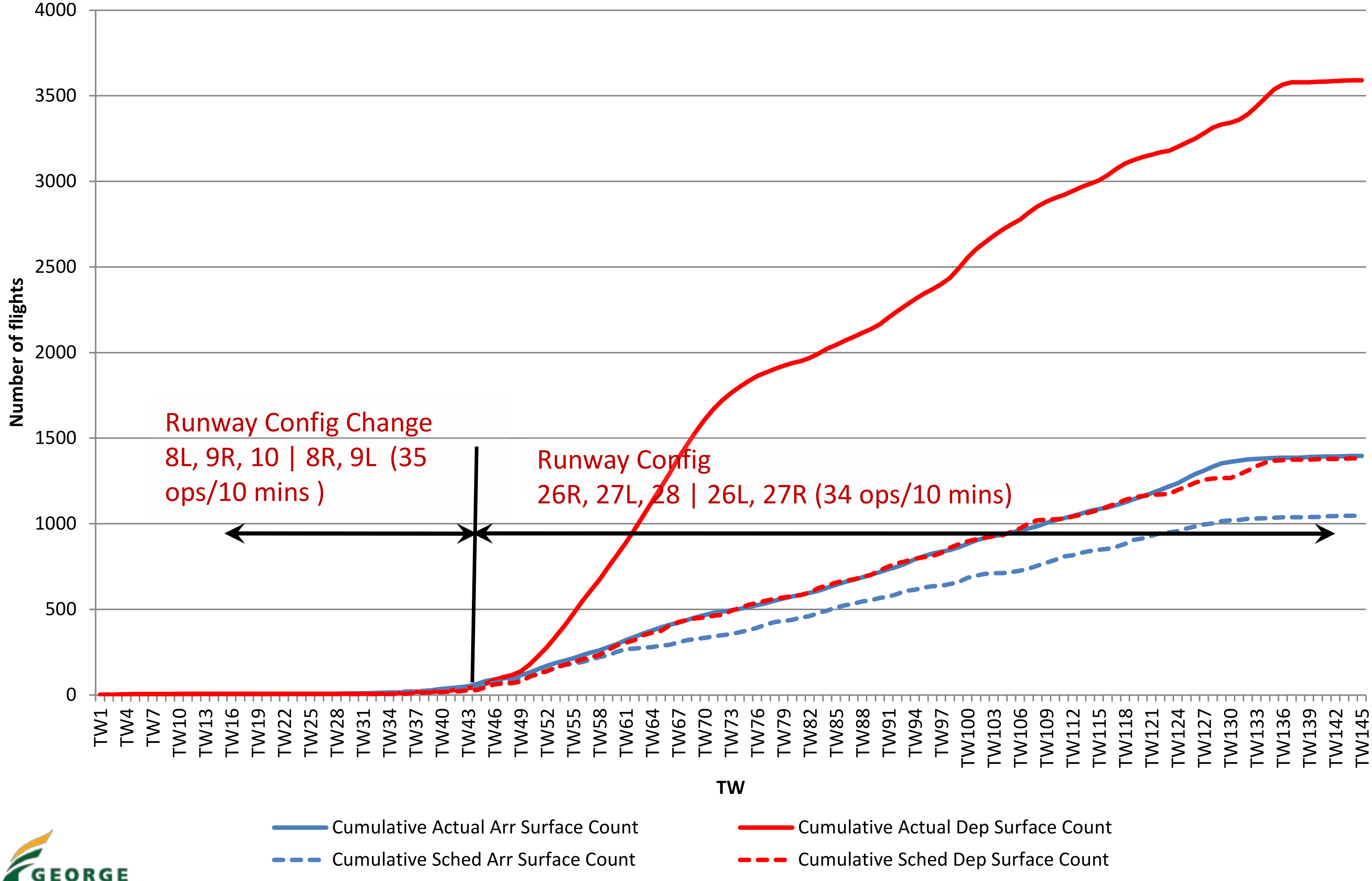
Center for Air Transportation Systems Research (CATSR) at George Mason University

Causal Analysis- Reduced Departure Rate - Mar 13, 2012 (ATL)

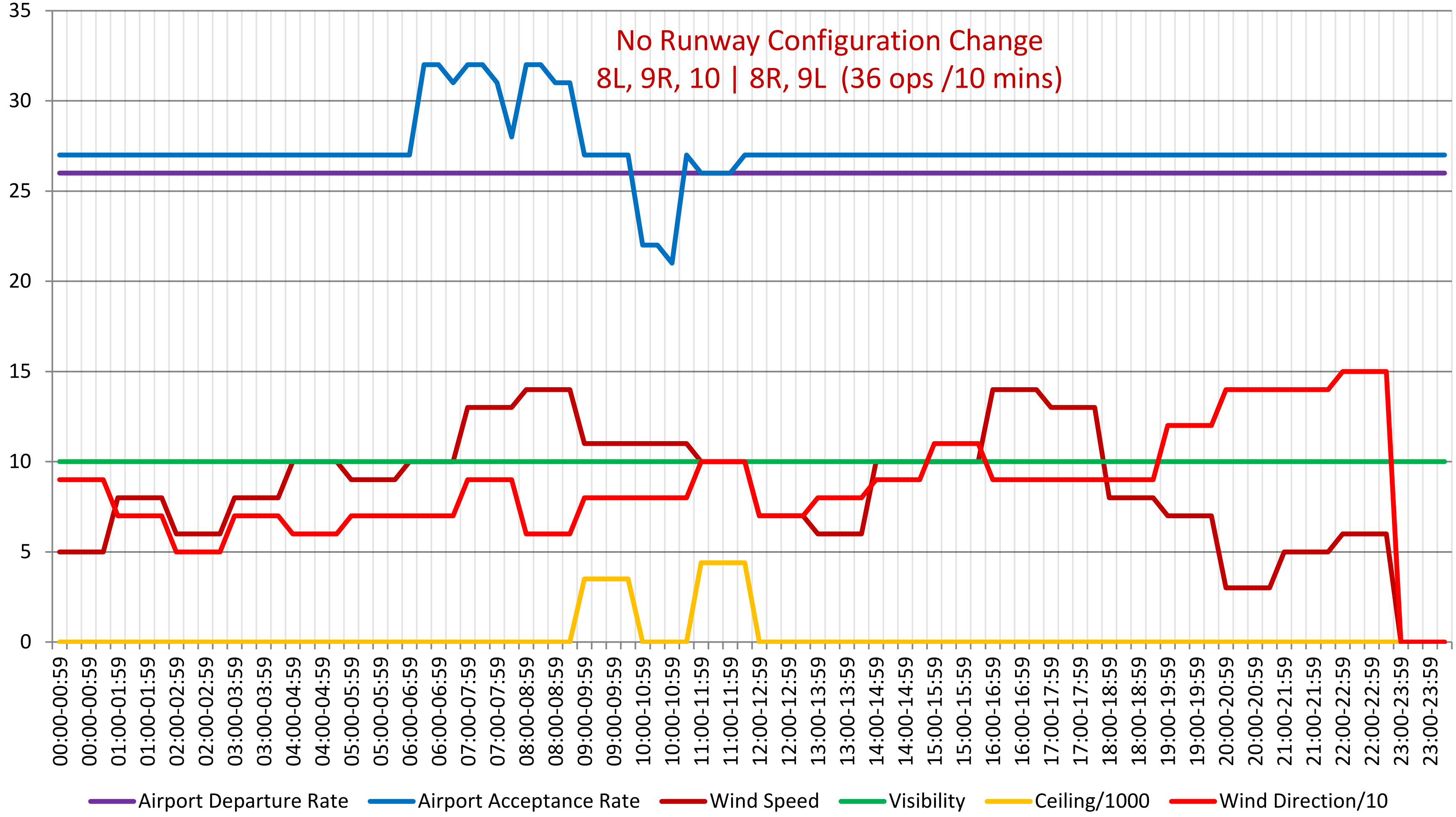


Center for Air Transportation Systems Research (CATSR) at George Mason University

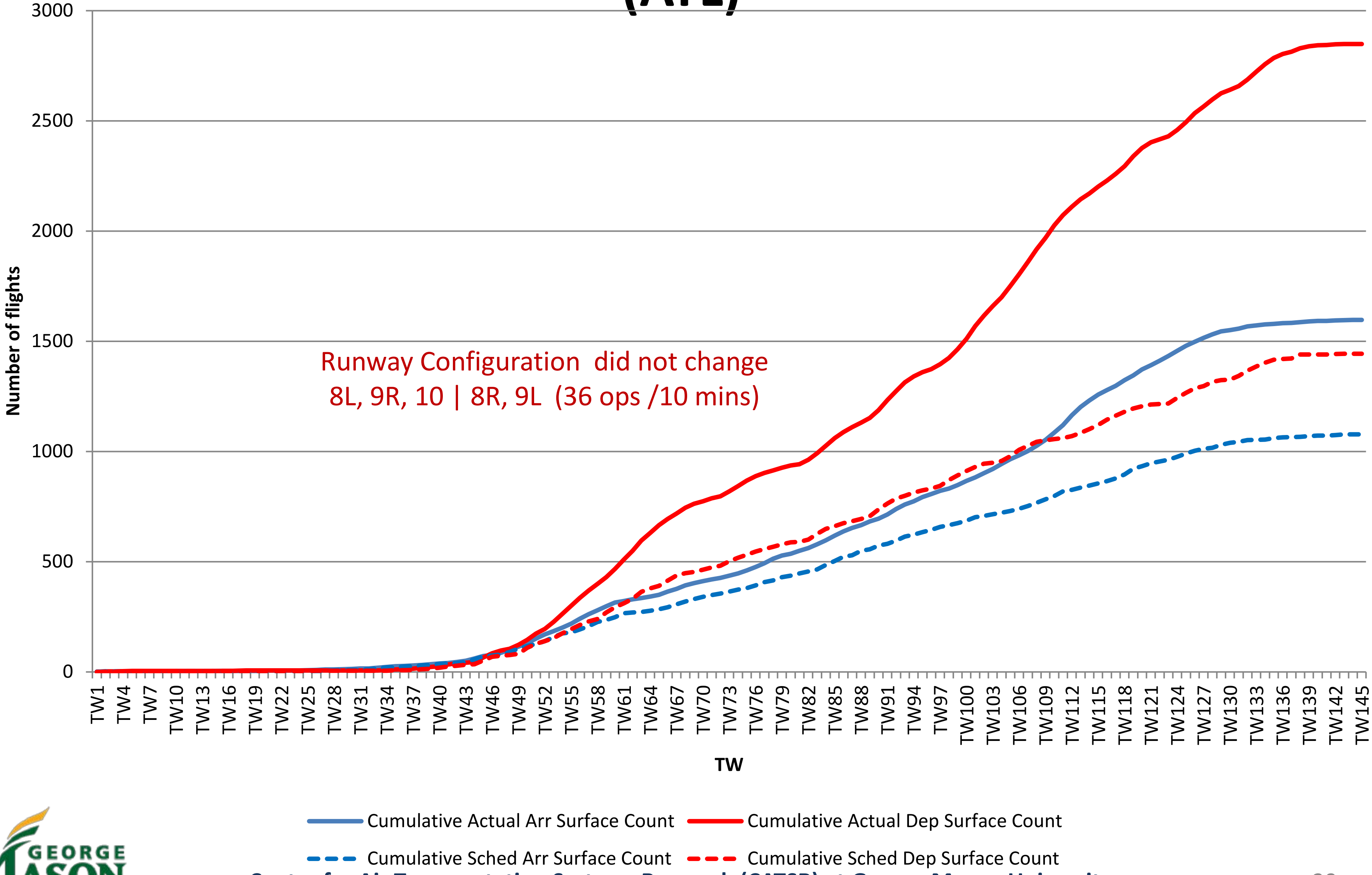
Cumulative Surface Counts - Reduced Departure Rate - Mar 13, 2012 (ATL)



Causal Analysis- “Blue Sky” - May 18, 2012 (ATL)

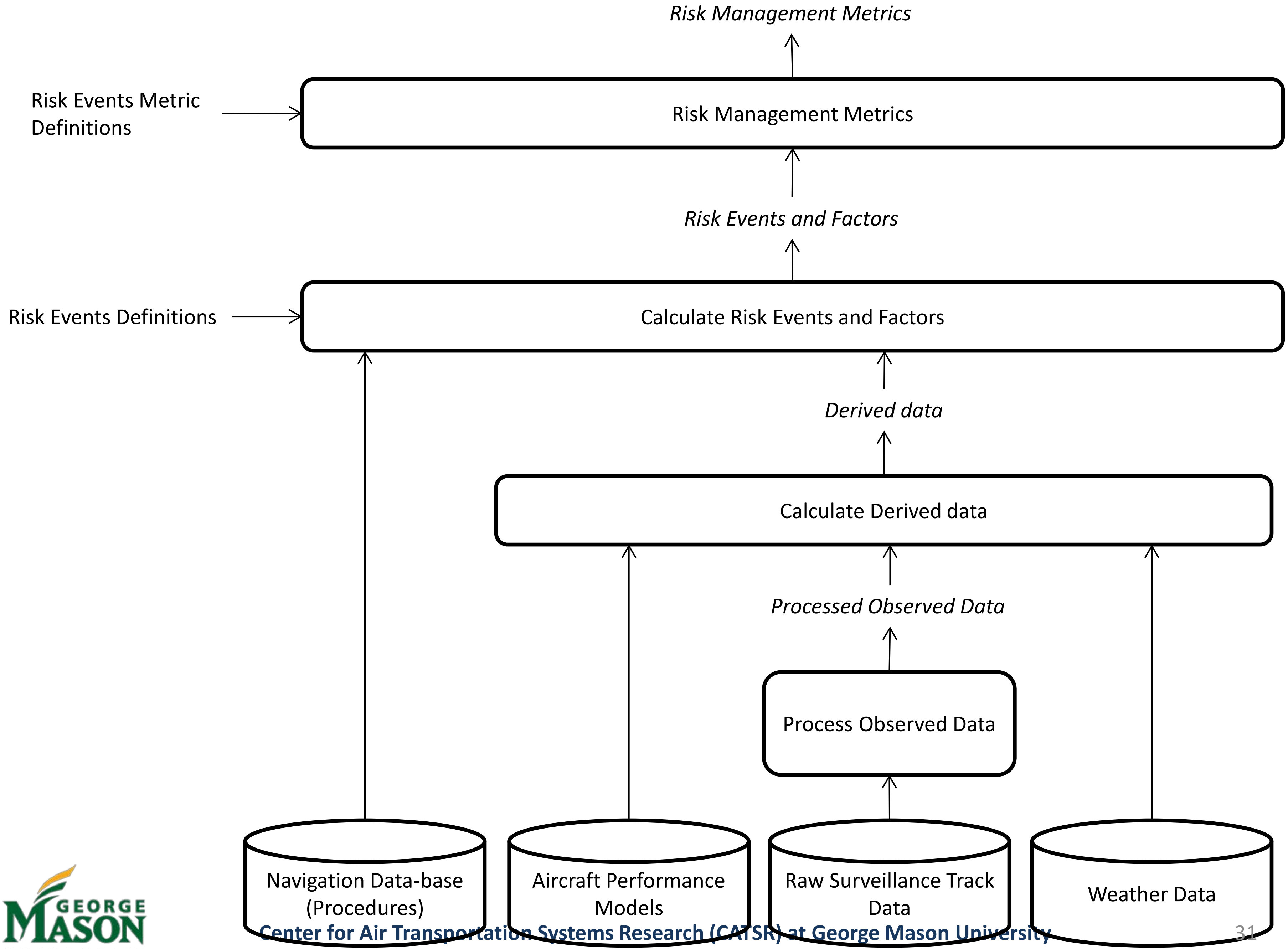


Cumulative Surface Counts – Blue Sky - May 18, 2012 (ATL)



Airspace Risk Management
- Go Around
Stabilized Approaches

Zhenming Wang, Houda Kerkoub



Risk Management Metrics

Risk Events Metric Definitions

Risk Management Metrics

Risk Events and Factors

Risk Events Definitions

Calculate Risk Events and Factors

Derived data

Calculate Derived data

Processed Observed Data

Process Observed Data

Navigation Data-base (Procedures)

Aircraft Performance Models

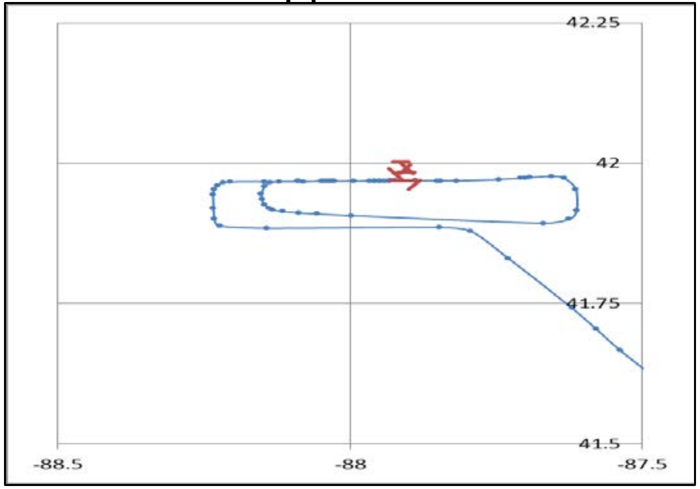
Raw Surveillance Track Data

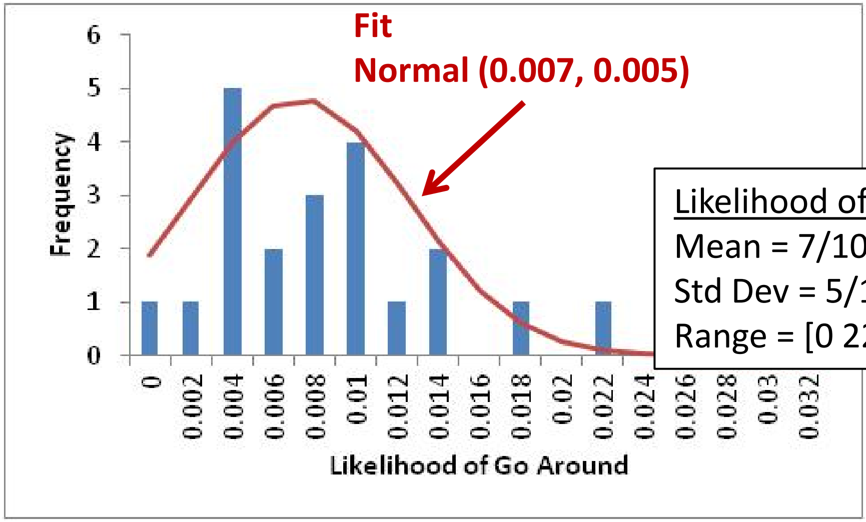
Weather Data

Go Arounds

- Go Arounds are not measured/reported.
- Track data used to count and analyze

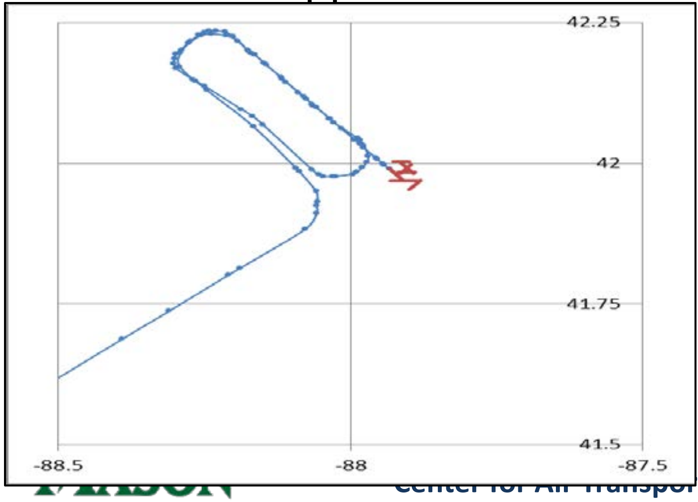
Missed Approach – 20%





Likelihood of a Go Around
Mean = 7/1000
Std Dev = 5/1000
Range = [0 22/1000]

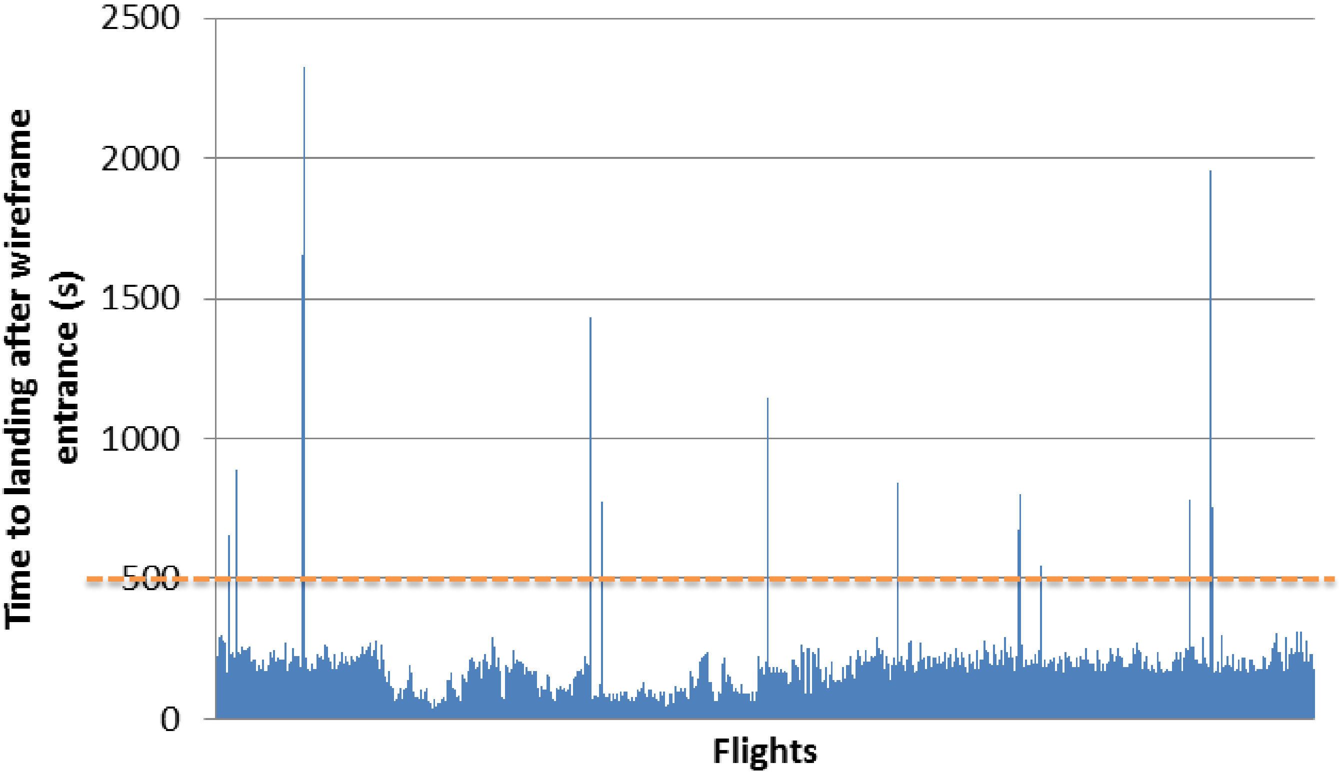
Aborted Approach – 80%



local time	18:00-18:59	18:00-18:59	19:00-19:59
quarter hour	3	4	1
arrival runway configuration	9R, 22L, 28	9R, 22L, 28	9R, 22L, 28
airport acceptance rate	15	15	15
arrival demand	72	72	73
ceiling (ft)	1200	1200	1000
wind direction	180° - S	180° - S	190° - S
wind speed (kts)	14	14	10
visability (miles)	3	3	3
temperature (°F)	32	32	32
on-time arrival %	16.67%	26.32%	16.67%
avg. arrival delay (min)	134	77	122

Go-arounds

- 19 out of 3548
- About 5.4 per 1000 flights



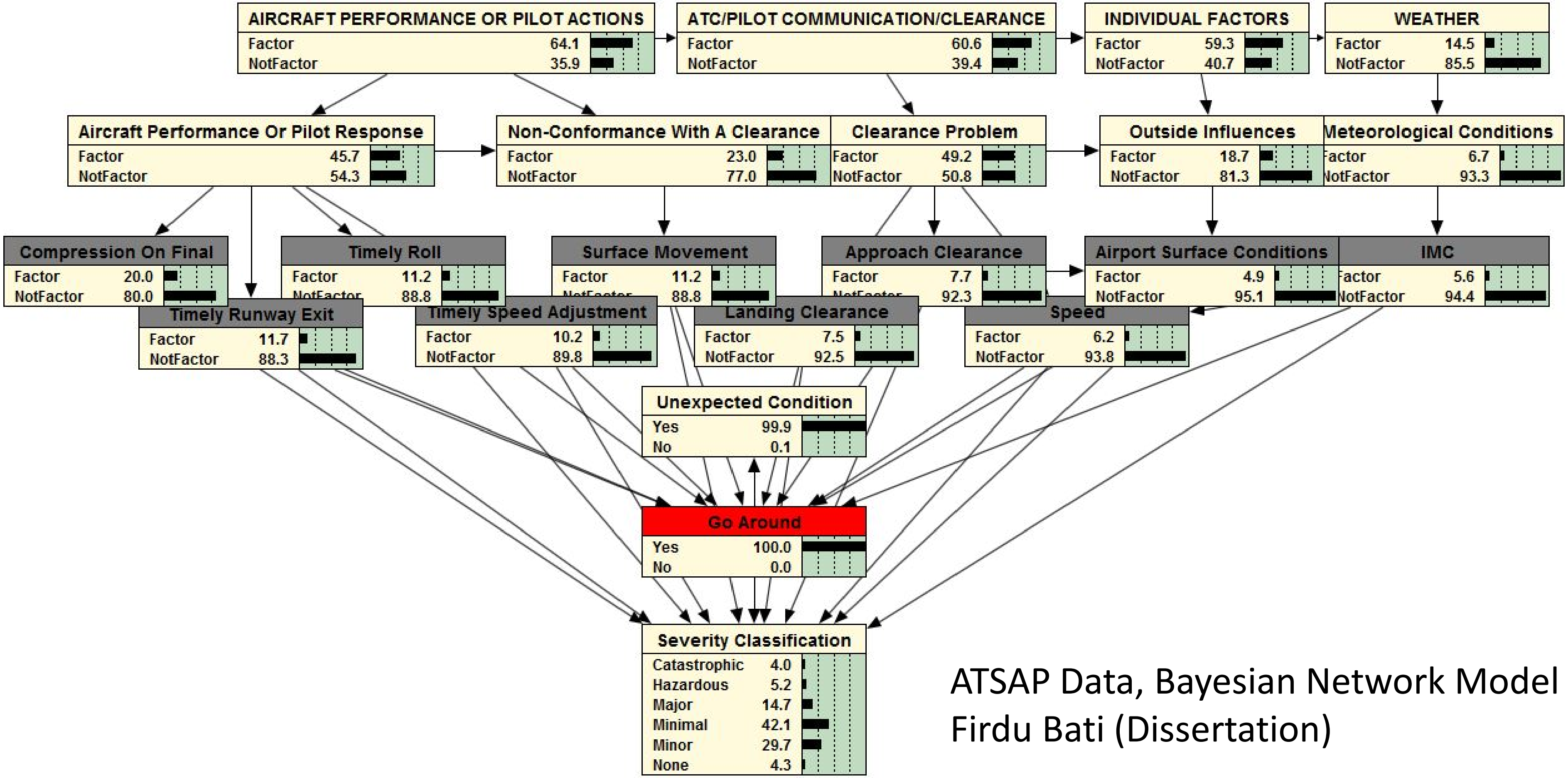
Go Arounds - ASRS Taxonomy

Factor	**% ASRS Reports**
Airplane Issues	54%
Separation Violation	21%
Weather	17%
Flight/TAC Interaction	8%
Runway Issues	5%
No Reason provided	6%

Go Arounds - ASRS Taxonomy

1. Airplane Issue			**53.74%**
	1.1 Unstable Approach		9.52%
		1.1.1.High and Fast	6.12%
		1.1.2 Other Approach Issue	3.40%
	1.2 Alerts		4.08%
	1.3 Onboard failures		**40.14%**

Go Arounds – ATSAP Taxonomy



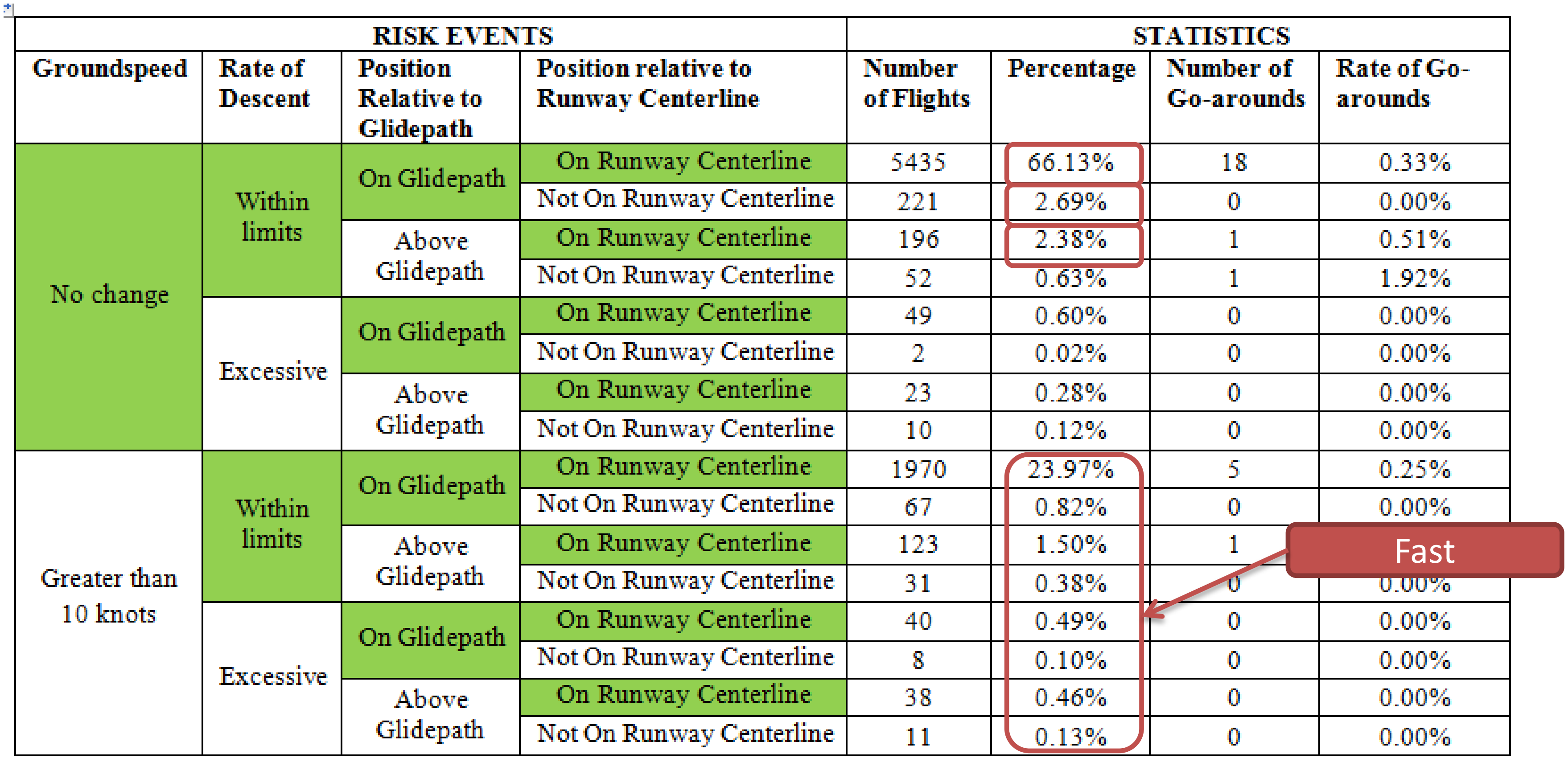
ATSAP Data, Bayesian Network Model
Firdu Bati (Dissertation)

Stabilized Approach

- 1000’ AGL
  - On Runway Center-line
  - On Glidepath
  - At Landing Speed (V_{Ref})
  - At Rate of Descent for Glide-path (< 1000fpm)

Stabilized Approaches

Frequency of risk events from 1000 ft. AGL to runway threshold

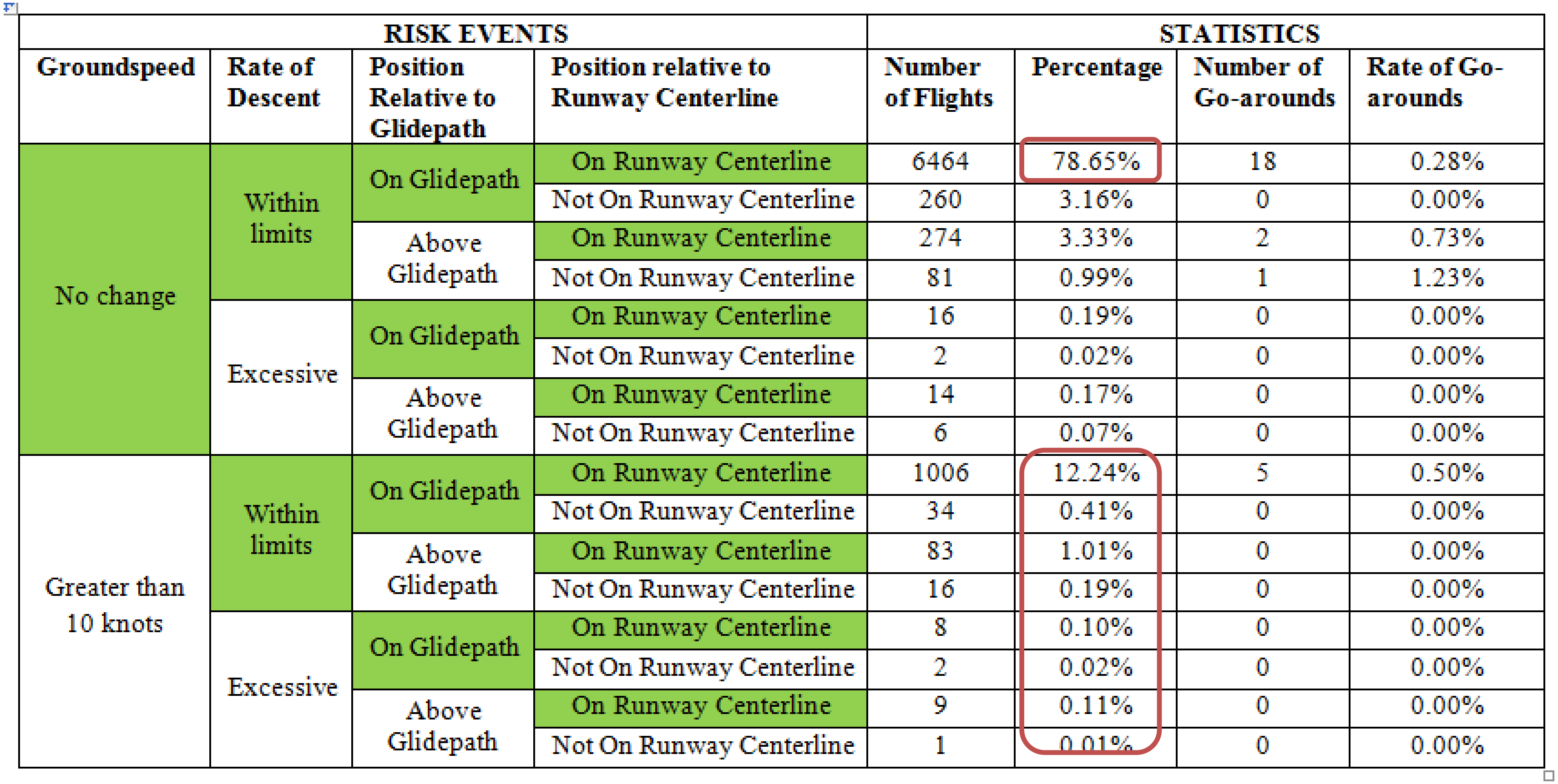


RISK EVENTS				STATISTICS			
Groundspeed	**Rate of Descent**	**Position Relative to Glidepath**	**Position relative to Runway Centerline**	**Number of Flights**	**Percentage**	**Number of Go-arounds**	**Rate of Go-arounds**
No change	Within limits	On Glidepath	On Runway Centerline	5435	66.13%	18	0.33%
			Not On Runway Centerline	221	2.69%	0	0.00%
		Above Glidepath	On Runway Centerline	196	2.38%	1	0.51%
			Not On Runway Centerline	52	0.63%	1	1.92%
	Excessive	On Glidepath	On Runway Centerline	49	0.60%	0	0.00%
			Not On Runway Centerline	2	0.02%	0	0.00%
		Above Glidepath	On Runway Centerline	23	0.28%	0	0.00%
			Not On Runway Centerline	10	0.12%	0	0.00%
Greater than 10 knots	Within limits	On Glidepath	On Runway Centerline	1970	23.97%	5	0.25%
			Not On Runway Centerline	67	0.82%	0	0.00%
		Above Glidepath	On Runway Centerline	123	1.50%	1	[illegible]
			Not On Runway Centerline	31	0.38%	0	0.00%
	Excessive	On Glidepath	On Runway Centerline	40	0.49%	0	0.00%
			Not On Runway Centerline	8	0.10%	0	0.00%
		Above Glidepath	On Runway Centerline	38	0.46%	0	0.00%
			Not On Runway Centerline	11	0.13%	0	0.00%

Fast

Stabilized Approaches

Frequency of risk events from 750 ft. AGL to runway threshold



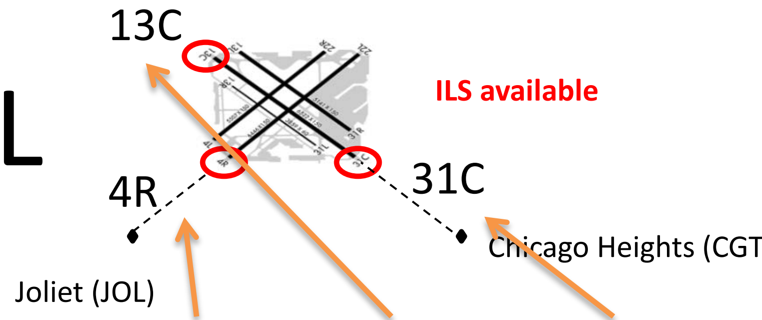
RISK EVENTS				STATISTICS			
Groundspeed	**Rate of Descent**	**Position Relative to Glidepath**	**Position relative to Runway Centerline**	**Number of Flights**	**Percentage**	**Number of Go-arounds**	**Rate of Go-arounds**
No change	Within limits	On Glidepath	On Runway Centerline	6464	78.65%	18	0.28%
			Not On Runway Centerline	260	3.16%	0	0.00%
		Above Glidepath	On Runway Centerline	274	3.33%	2	0.73%
			Not On Runway Centerline	81	0.99%	1	1.23%
	Excessive	On Glidepath	On Runway Centerline	16	0.19%	0	0.00%
			Not On Runway Centerline	2	0.02%	0	0.00%
		Above Glidepath	On Runway Centerline	14	0.17%	0	0.00%
			Not On Runway Centerline	6	0.07%	0	0.00%
Greater than 10 knots	Within limits	On Glidepath	On Runway Centerline	1006	12.24%	5	0.50%
			Not On Runway Centerline	34	0.41%	0	0.00%
		Above Glidepath	On Runway Centerline	83	1.01%	0	0.00%
			Not On Runway Centerline	16	0.19%	0	0.00%
	Excessive	On Glidepath	On Runway Centerline	8	0.10%	0	0.00%
			Not On Runway Centerline	2	0.02%	0	0.00%
		Above Glidepath	On Runway Centerline	9	0.11%	0	0.00%
			Not On Runway Centerline	1	0.01%	0	0.00%

Stabilized Approaches

Frequency of risk events from 500 ft. AGL to runway threshold

RISK EVENTS				STATISTICS			
Groundspeed	**Rate of Descent**	**Position Relative to Glidepath**	**Position relative to Runway Centerline**	**Number of Flights**	**Percentage**	**Number of Go-arounds**	**Rate of Go-arounds**
No change	Within limits	On Glidepath	On Runway Centerline	7167	87.20%	22	0.31%
			Not On Runway Centerline	288	3.50%	0	0.00%
		Above Glidepath	On Runway Centerline	346	4.21%	2	0.58%
			Not On Runway Centerline	96	1.17%	1	1.04%
	Excessive	On Glidepath	On Runway Centerline	4	0.05%	0	0.00%
			Not On Runway Centerline	2	0.02%	0	0.00%
		Above Glidepath	On Runway Centerline	5	0.06%	0	0.00%
			Not On Runway Centerline	3	0.04%	0	0.00%
Greater than 10 knots	Within limits	On Glidepath	On Runway Centerline	322	3.92%	1	0.31%
			Not On Runway Centerline	8	0.10%	0	0.00%
		Above Glidepath	On Runway Centerline	29	0.35%	0	0.00%
			Not On Runway Centerline	5	0.06%	0	0.00%
	Excessive	On Glidepath	On Runway Centerline	1	0.01%	0	0.00%
			Not On Runway Centerline	0	0.00%	0	0.00%
		Above Glidepath	On Runway Centerline	0	0.00%	0	0.00%
			Not On Runway Centerline	0	0.00%	0	0.00%

1000’ AGL

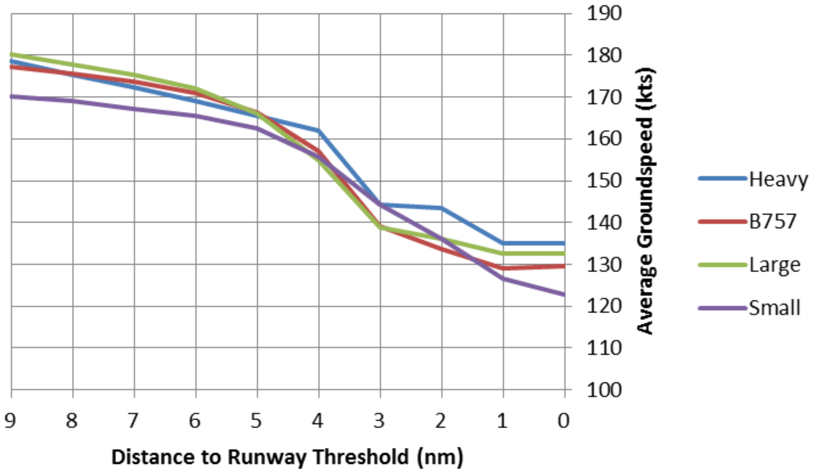


ILS available

Groundspeed Change	Rate of Descent	Position with Glidepath	Position with Runway Centerline	04R		13C		31C	
				#	%	#	%	#	%
No change	Within limits	On Glidepath	On Runway Centerline	721	74.56%	411	29.19%	987	84.22%
			Not On Runway Centerline	35	**3.62%**	492	**34.94%**	52	**4.44%**
		Above Glidepath	On Runway Centerline	3	0.31%	0	0.00%	38	3.24%
			Not On Runway Centerline	2	**0.21%**	96	**6.82%**	0	**0.00%**
	Excessive	On Glidepath	On Runway Centerline	2	0.21%	1	0.07%	1	0.09%
			Not On Runway Centerline	0	**0.00%**	2	**0.14%**	0	**0.00%**
		Above Glidepath	On Runway Centerline	0	0.00%	0	0.00%	1	0.09%
			Not On Runway Centerline	0	0.00%	24	**1.70%**	0	0.00%
Greater than 10 knots	Within limits	On Glidepath	On Runway Centerline	177	**18.30%**	14	**0.99%**	82	**7.00%**
			Not On Runway Centerline	18	**1.86%**	233	**16.55%**	3	**0.26%**
		Above Glidepath	On Runway Centerline	1	**0.10%**	0	**0.00%**	5	**0.43%**
			Not On Runway Centerline	0	**0.00%**	102	**7.24%**	0	**0.00%**
	Excessive	On Glidepath	On Runway Centerline	4	**0.41%**	0	**0.00%**	3	**0.26%**
			Not On Runway Centerline	3	**0.31%**	2	**0.14%**	0	**0.00%**
		Above Glidepath	On Runway Centerline	2	**0.21%**	0	**0.00%**	0	**0.00%**
			Not On Runway Centerline	0	**0.00%**	31	**2.20%**	0	**0.00%**
					20%		26%		8%

Stabilized Approaches - Factors

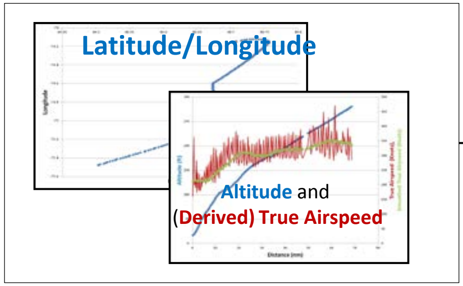
Weight Class	% Flights 750 ft. AGL – Change in Speed	Average Groundspeed at the Runway Threshold
Heavy	20.9%	134.5 knots
B757	15.1%	129 knots
Large	12.0%	132 knots
Small	47.0%	122.5 knots



Every approach/runway is different

Procedure	% dv>10kts from 1000' to THR	% dv>10kts from 750' to THR	% dv>10kts from 500' to THR
ILS	5.97%	1.19%	0.17%
RNP	4.23%	0.00%	0.00%
VFR	50.15%	12.35%	0.59%

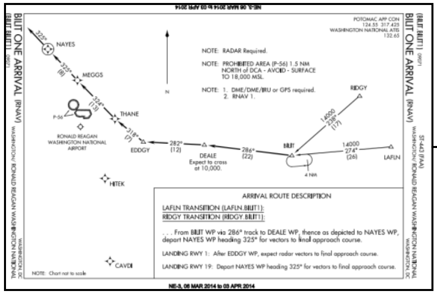
Big Data Analytics in Air Transportation



Surveillance Data

Flight Data

Aircraft Performance



NOTE: RADAR Required.

NOTE: PROHIBITED AREA (P-56) 1.5 NM NORTH of DCA - AVOID - SURFACE TO 18,000 MSL.

NOTE: 1. DME/DME/IRU or GPS required.
2. RNAV 1.

ARRIVAL ROUTE DESCRIPTION

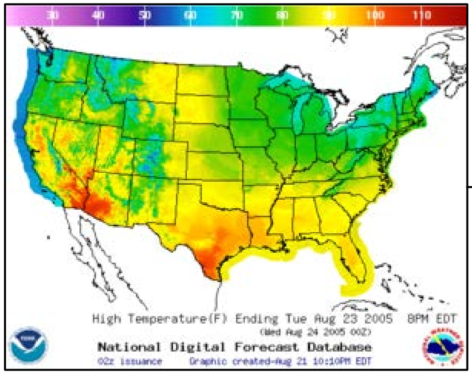
LAFLN TRANSITION (LAFLN.BILIT1):
RIDGY TRANSITION (RIDGY.BILIT1):

. . . From BILIT WP via 286° track to DEALE WP, thence as depicted to NAYES WP, depart NAYES WP heading 325° for vectors to final approach course.

LANDING RWY 1: After EDDGY WP, expect radar vectors to final approach course.

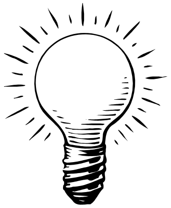
LANDING RWY 19: Depart NAYES WP heading 325° for vectors to final approach course.

Procedures



Weather Data

Model-based Engineering & Big Data Analysis



Insights & Understanding for Operators, Planners, & Investors

Aircraft Performance Models

$$T_i = D_i + \frac{m_i \times g \times \frac{dh}{dt}}{TAS_i} + m_i \times \frac{dTAS}{dt}$$

Automation Behavior Models

Automation Behavior Models

Validation