Benefit and Cost Assessment of Integrating Arrival, Departure, and Surface Operations with ATD-2

NRA Final Briefing

ATAC Corporation, MCR Federal, Massachusetts Institute Of Technology

03/30/2018

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Outline

- Quick recap of NRA objectives
- Benefits analysis methodology
- Simulation platform
- Simulation scenario selection
- High-fidelity simulations results
- Benefits nationalization results
- Benefits monetization and annualization results
- Cost analysis results
- Final benefits and costs analysis
- Conclusions and future work ideas

Recap of NRA Objectives

- Develop a catalog of operational shortfalls, ATD-2 benefit mechanisms, performance metrics
- Select sites for assessing benefits through modeling and fast-time sims
- Develop simulation environment and conduct simulation experiments
- Analyze benefits results and extrapolate to nationwide benefits
- Analyze costs for implementing ATD-2 on a nationwide scale

Methodology

- Identify ***operational shortfalls*** that ATD-2 can address and associated ATD-2 ***benefit mechanisms*** and ***benefit metrics***
- Develop a ***combined airspace-surface simulation platform*** that can simulate key operational shortfalls and benefit mechanisms
- Conduct ***high-fidelity surface-airspace simulations*** for simulating current-day and future ATD-2 operations at ***three airport sites*** and ***carefully selected simulation days***
- Extrapolate results to FAA Core 30 airports using ***medium-fidelity queuing simulation models*** and FAA ***TFDM benefits analysis results***
- Extrapolate to annualized benefits by conducting medium-fidelity simulations at a larger set of days and by using carefully generated ***"similar number of days in a year" based multipliers***
- Follow ***FAA-recommended processes*** for cost analysis
- Compute ***advantages to the FAA's TFDM program:*** enhancement in benefits, reduction in costs, overall a ***beneficial impact on the TFDM B/C ratio***

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COMBINED SURFACE-AIRSPACE SIMULATION PLATFORM

Combined Airspace-Surface Simulation Platform Architecture

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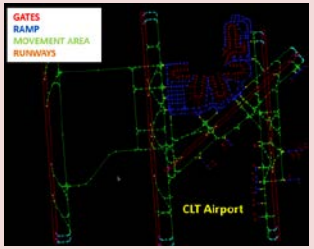
SOSS



Added models
- Push readiness
- EOBT uncertainty
- Taxi rerouting

- Surface traffic state
- Taxi routes

Simulated Surface Trajectory

- ETOTs
- Airspace routes

AOSS: ATD-2 Tactical Surface Scheduler

Gate delays for APREQ/EDCT flights

Surface delays for MIT flights

ATOTs

AOSS: Center TFM

- Existing processes for fitting departures into overhead enroute traffic stream slots
- Focus airport flights merging with overhead traffic at TBFM meter arcs

APREQ takeoff time window constraints

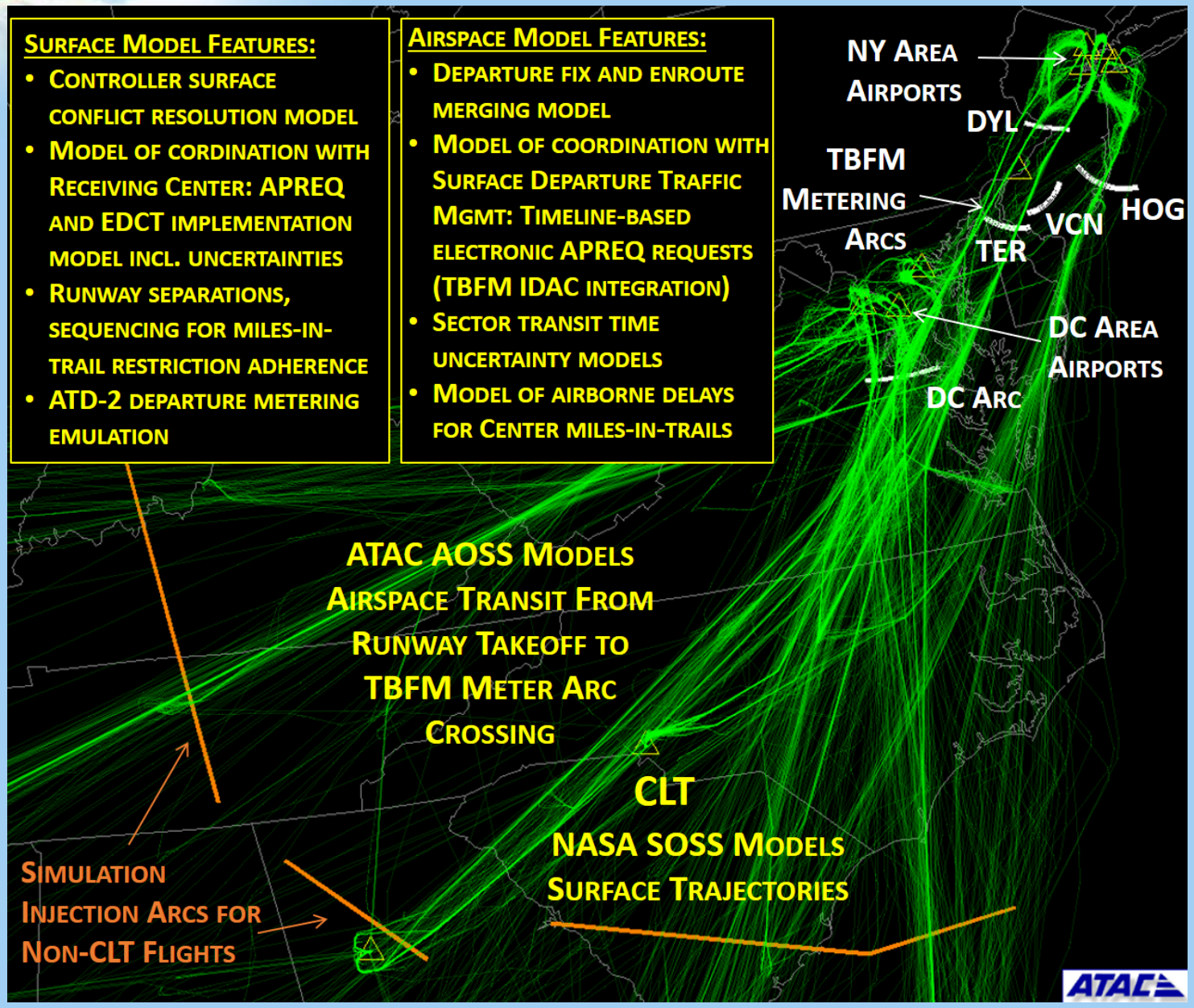
AOSS*: Airspace Sim

Sector-based Airspace Model
- Takeoff → Departure Fix Xing → Sector 1 → Sector 2 → … → TBFM Metering Arc
- Enroute and Departure fix merge models
- Queuing at nodes estimates in air delays

Simulated Airspace Trajectory

*AOSS: Airspace Operations Simulator & Scheduler

CLT Combined Surface-Airspace Model



Modeling of ATD-2 Benefit Mechanisms

ATD-2 FUNCTIONS

CAUSAL LINKS

POTENTIAL BENEFITS

Flight-specific trajectory predictions with outputs shared between ATC and airlines. Predictions factor in new and improved intent/constraint data:

- **EOBT**
- Runway assi
- **TMIs**

Improved awareness of flight status and intent

More accurate demand predictions

Better airline and ATC resource management (e.g. gate availability)

lay, fuel, issions

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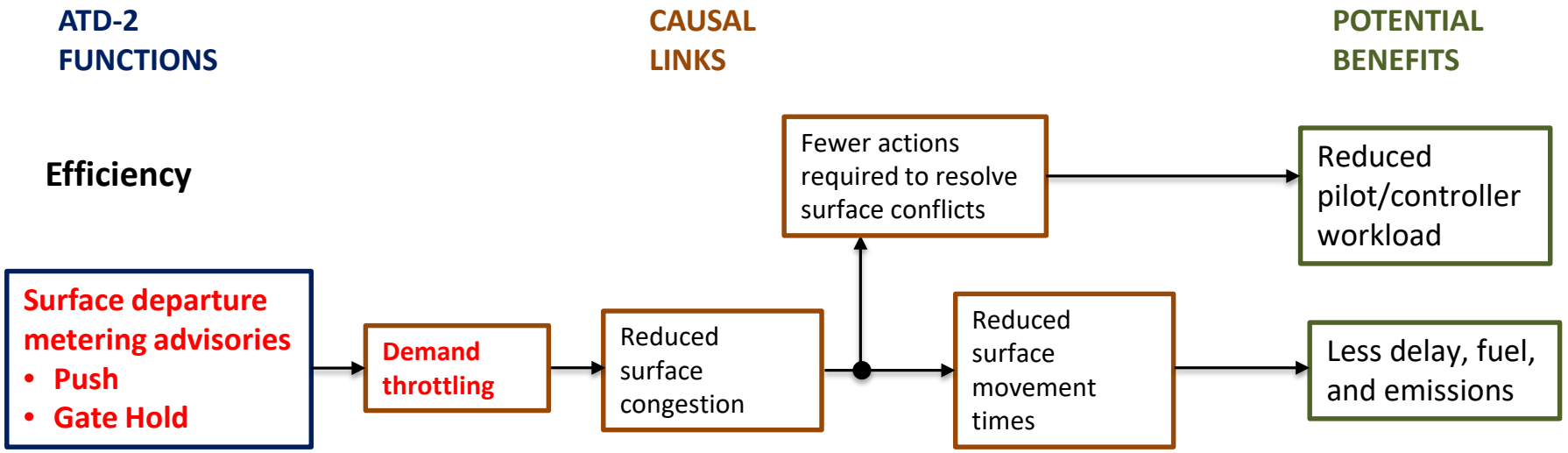
ed ontroller workload

- **Push Ready Times and EOBTs different from SOBT**
- **EOBT provided to the ATD-2 Surface Tactical Scheduler**
- **Model of full current-day and ATD-2 APREQ procedures**
  - **Current-day: Pilot calls @ Push Ready Time, ATCT estimates taxi-out time, ATCT requests runway release time, Center finds slot in overhead traffic stream, Sends back release time, Pilot estimates taxi-out and pushes back in order to make the APREQ window**
  - **ATD-2: Scheduler uses accurate taxi-out time estimates to request runway release times for APREQ flights, Scheduler allocates correct amount of gate delay to make APREQ window; For non-APREQ flights also get correct gate delay allocation because of more accurate taxi-out time estimates**

Dashed line
Indicate lor
term benef
mechanisms

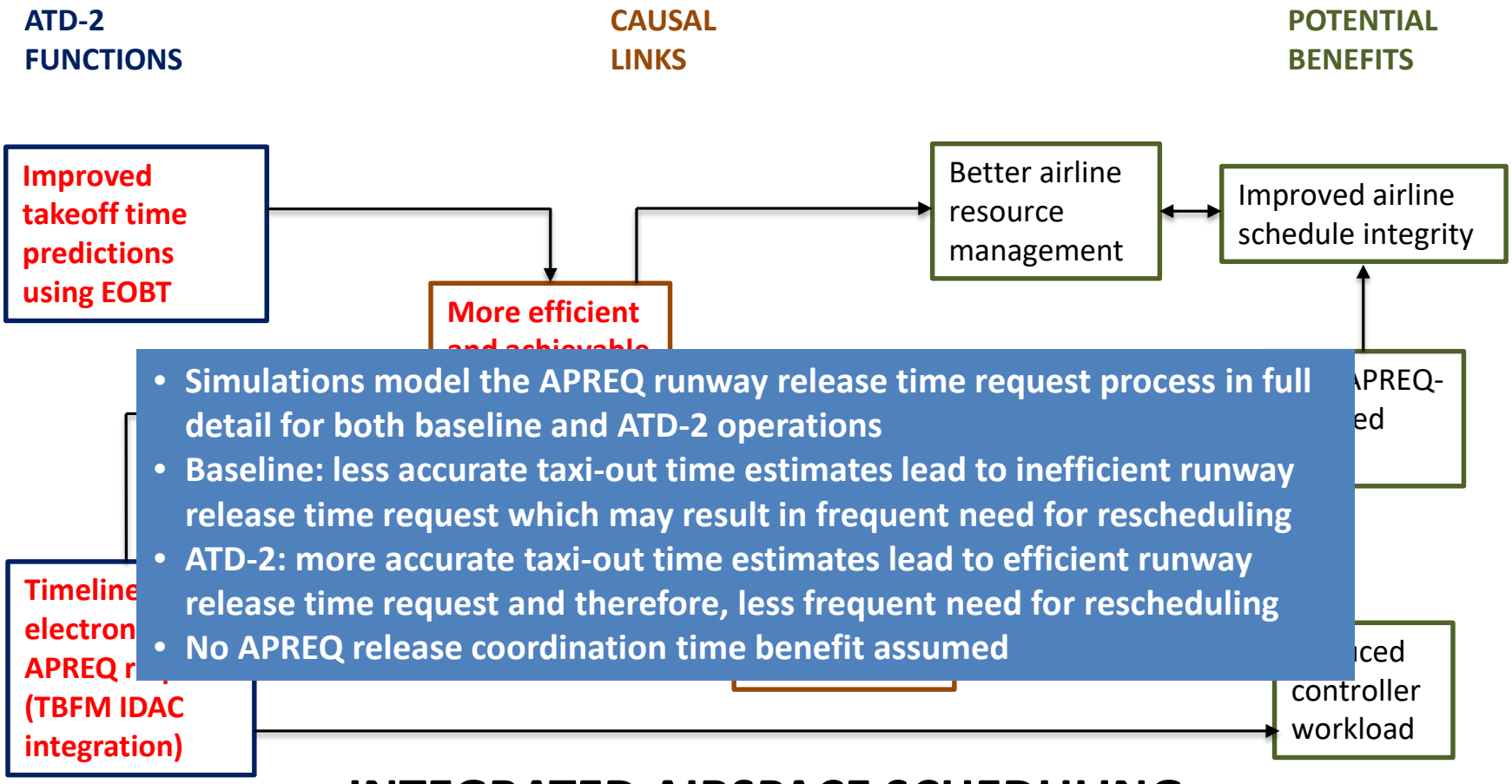
DATA EXCHANGE

Modeling of ATD-2 Benefit Mechanisms



- ATD-2 simulations include full ATD-2 Surface Tactical Scheduler model
  - Follows the NASA scheduler steps
  - Model the dynamics of the scheduler with the departures transitioning from “UNCERTAIN” to “AT GATE PLANNED” to “AT GATE READY” and “TAXIING” phases
  - Additional models for departure-fix MIT and MINIT restrictions application at runway departure

Modeling of ATD-2 Benefit Mechanisms



INTEGRATED AIRSPACE SCHEDULING

TMI COMPLIANCE

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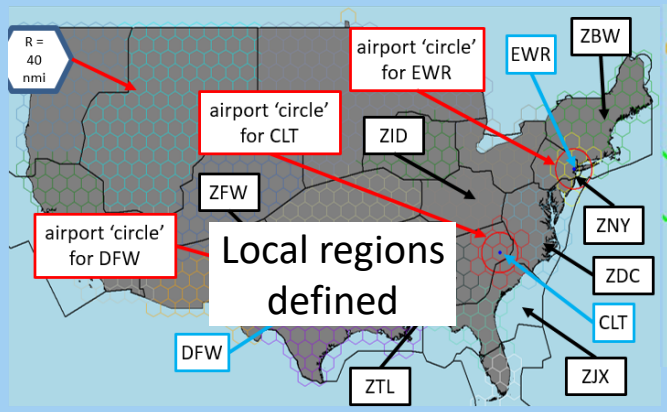
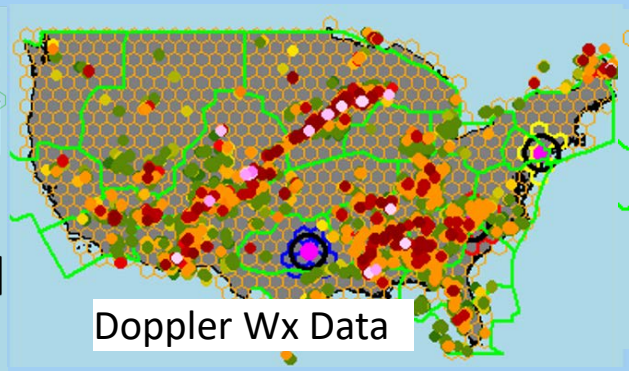
SIMULATION DAYS/SCENARIOS SELECTION

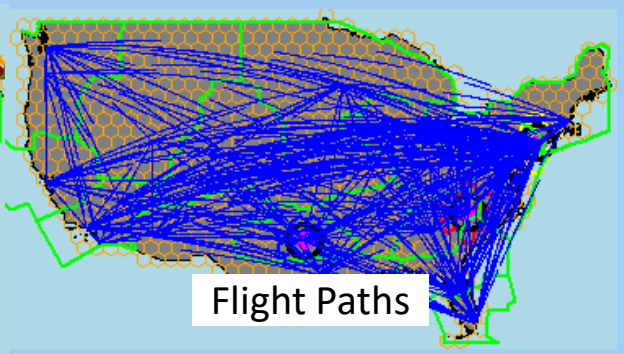
Simulation Days Selection

Considers Weather and Traffic Demand Impacts

- Goal
  - Select a set of simulation dates for benefits estimation ATD-2
  - Support extrapolation across the CONUS on an annual basis
- Local and national weather/traffic demand conditions considered for days selection
  - Weather impact traffic index (WITI) computation for NAS-wide and regional weather impact
  - Traffic Management Initiative (TMI) impact on departure airport also captured using APREQ and MIT impact indices







Simulation Dates for KCLT

Condition	TMI/ APREQ Indices	Weather		Demand	Recom. Date	# Days	% Occur.	Total Daily Precip (in)
		CONUS	Apt					
1	2	2	2	2	6/15/2016	16	14.3%	2.74
2	1	2	2	2	5/17/2016	15	13.4%	0.87
3	2	2	1	2	6/1/2016	13	11.6%	0.1
4	1	2	1	2	8/15/2016	8	7.1%	0.27
5	1	1	1	2	5/6/2016	6	5.4%	0.28
6	0	1	1	2	8/13/2016	4	3.6%	0
7	2	1	1	2	5/31/2016	4	3.6%	0.59
8	1	1	2	2	4/12/2016	4	3.6%	0.39
9	1	1	0	0	7/23/2016	3	2.7%	0
10	0	0	0	2	6/4/2016	3	2.7%	0
11	1	0	0	2	6/5/2016	3	2.7%	0.08
12	2	2	0	2	6/21/2016	3	2.7%	0
13	0	2	2	2	6/17/2016	3	2.7%	0
14	1	0	0	0	7/4/2016	2	1.8%	0
15	2	0	0	0	5/1/2016	2	1.8%	1.2

Σ % Occur. = 80%

Encompasses 80% of operational conditions for FY2015

Tercile grouping rules

Condition	Good (0)	Fair (1)	Poor (2)
APREQ/MIT indices	Both < 50%	One > 50%	Both > 50%
CONUS WITI	≤ 33⅓ %	> 33⅓ % and ≤ 66 ⅔%	> 66 ⅔%
Local WITI	≤ 33⅓ %	> 33⅓ % and ≤ 66 ⅔%	> 66 ⅔%
Departure index	≤ 33⅓ %	> 33⅓ % and ≤ 66 ⅔%	> 66 ⅔%

Experiment Matrix

Airport	Simulation Day	Annualization Day Rank	Runway Config	Simulation Timeframe (UTC)	Baseline Sim #	ATD-2 Sim #
CLT	6/15/2016	1	South	1000-1600	1	2
CLT	6/2/2016	4	South	1200-1500	3	4
CLT	5/17/2016	2	South	0900-1700	5	6
CLT	6/1/2016	3	North	1000-1500	7	8
CLT	5/6/2016	5	North	1600-2100	9	10
CLT	5/31/2016	7	North	1600-2100	11	12
DFW	6/4/2016	6	East	1700-2300	13	14
DFW	5/12/2016	1	East	1000-1700	15	16
DFW	6/3/2016	2	West	1500-2100	17	18
DFW	7/5/2016	3	West	1500-2100	19	20
DFW	7/17/2016	4	West	1000-1600	21	22
DFW	7/28/2016	5	West	1000-1600	23	24
EWR	7/3/2016	5	South	0900-1600	25	26
EWR	7/21/2016	1	South	0800-1800	27	28
EWR	5/6/2016	3	North	1400-2000	29	30
EWR	7/29/2016	2	North	0900-1800	31	32

Three sensitivity studies: (1) Push at SOBT, (2) Phase II benefits, (3) Phase III benefits

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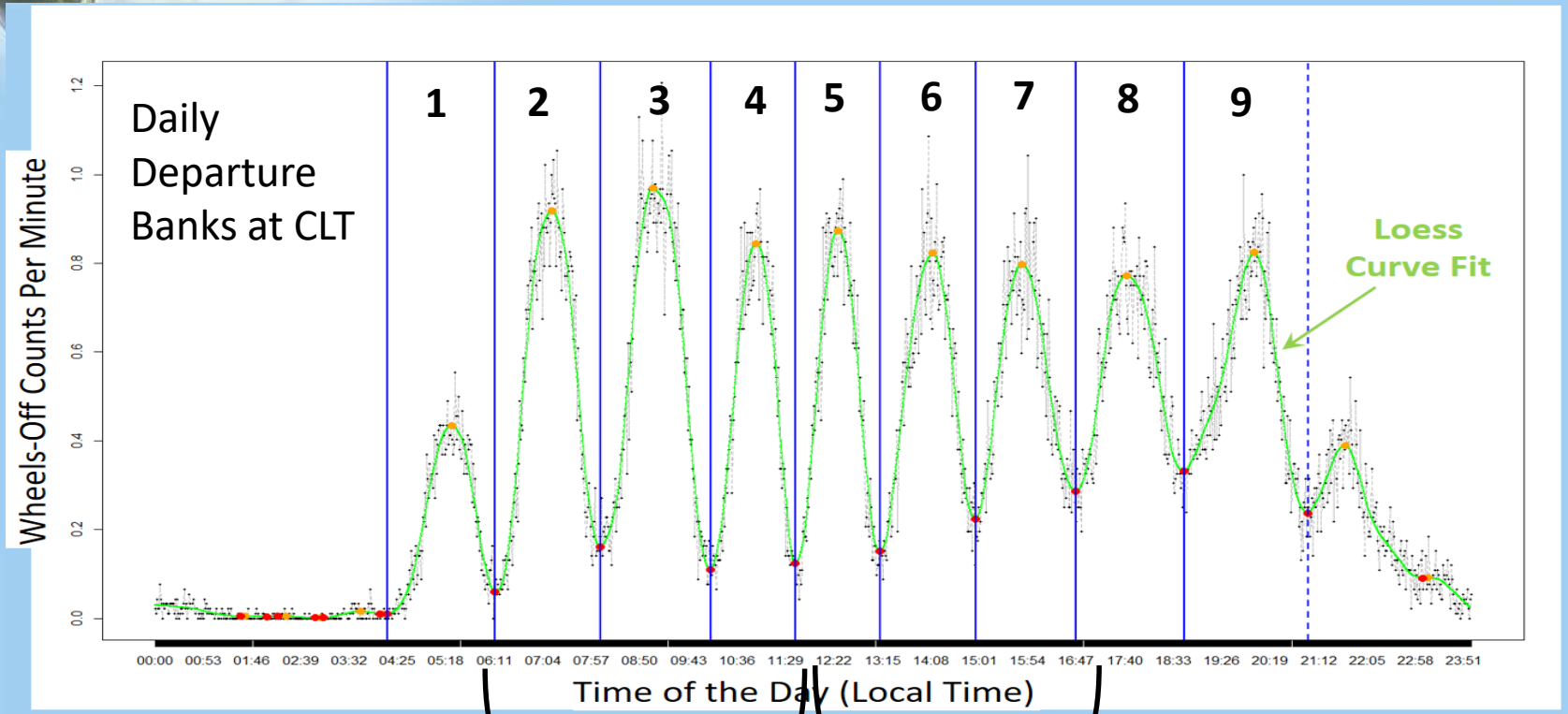
RESULTS FROM HIGH-FIDELITY SIMULATIONS

Simulation Scenarios



Sim #1

06/15/2016, 1000-1600 UTC
South Flow
APREQs for LGA, EWR, DCA, ORD, DTW flights
No GDP

Sim #2

05/06/2016, 1600-2100 UTC
North Flow
APREQs for LGA, EWR, JFK, ORD flights
GDP for SFO flights

Efficiency: Taxi-Out Time Savings

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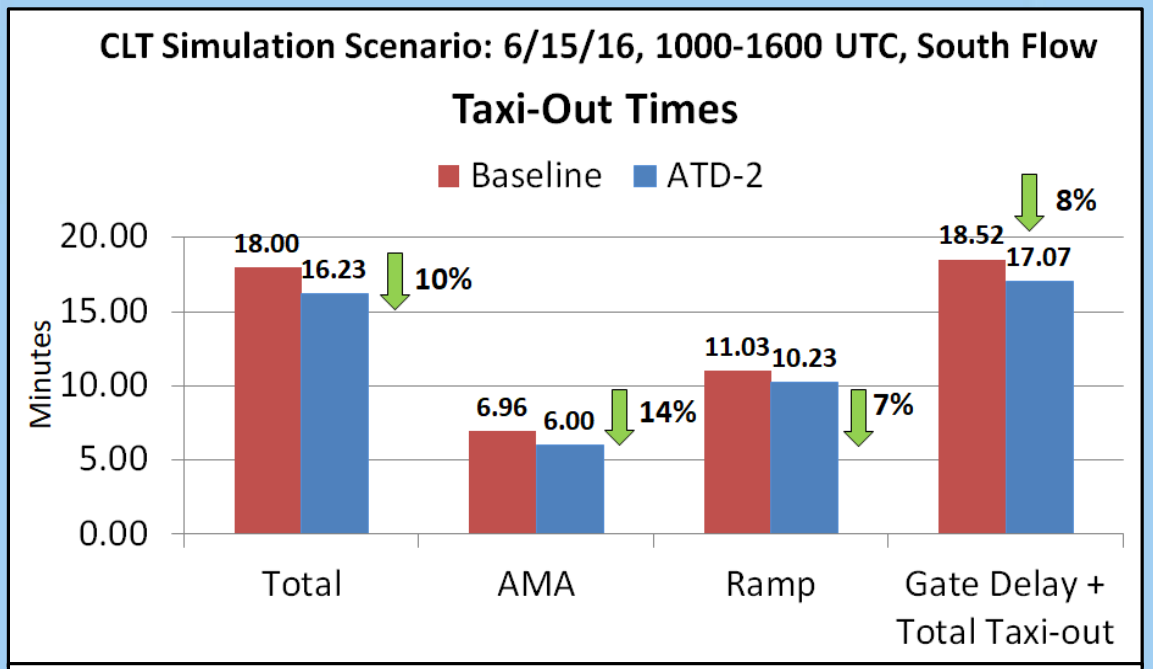
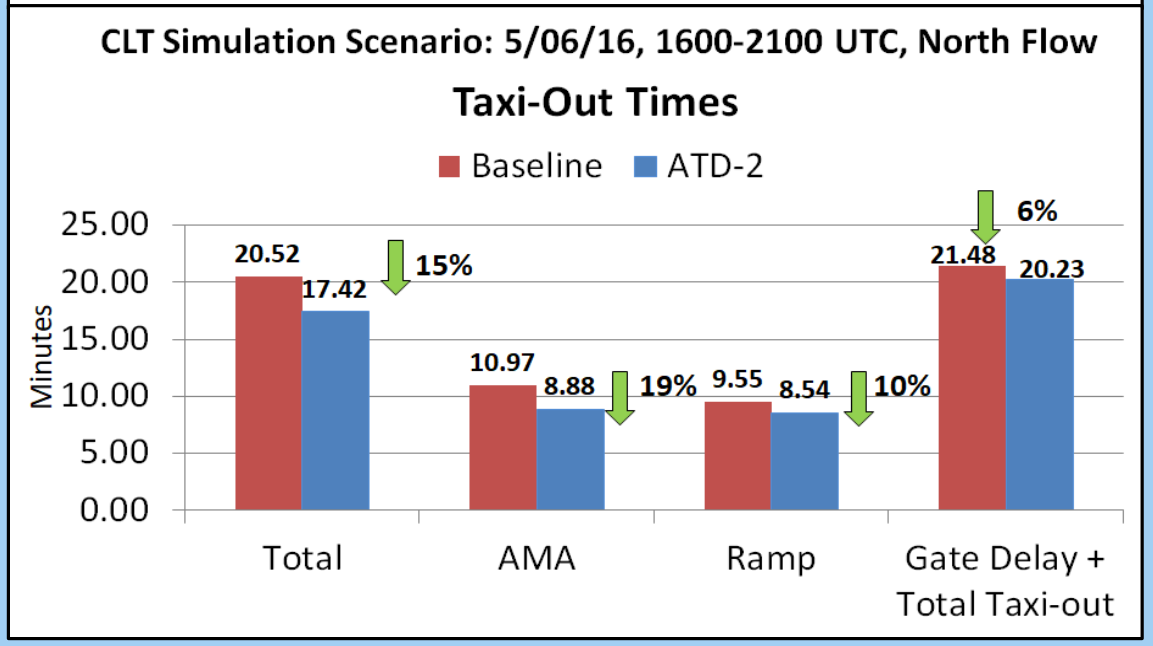
Sim #1: 06/15/2016
South Flow
1000-1600 UTC

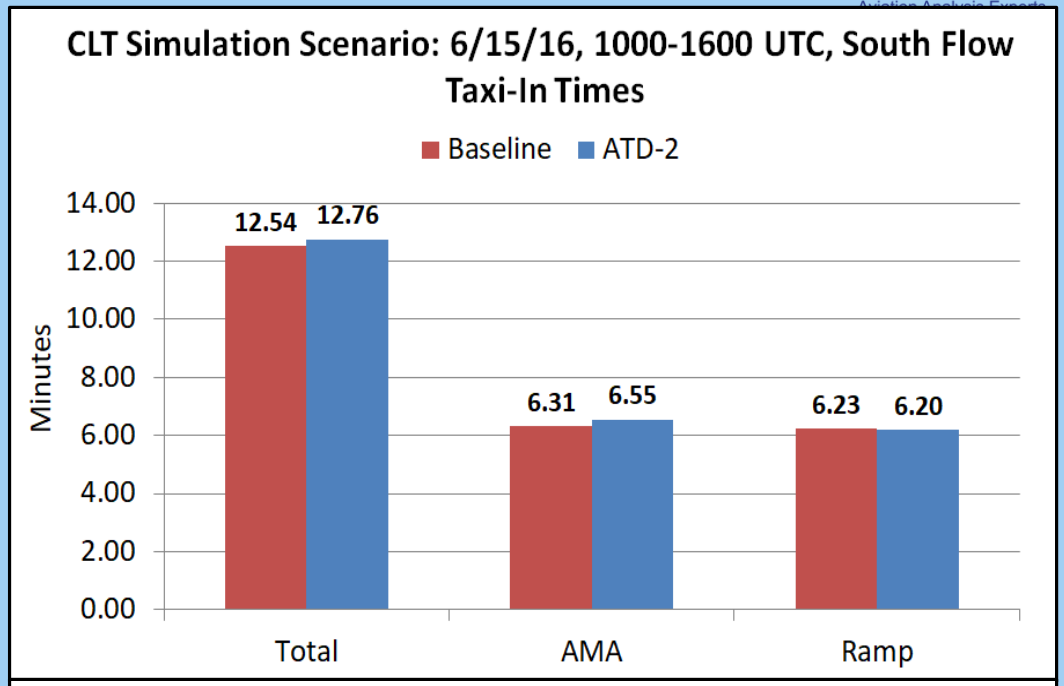


Sim #2: 05/06/2016
North Flow
1600-2100 UTC

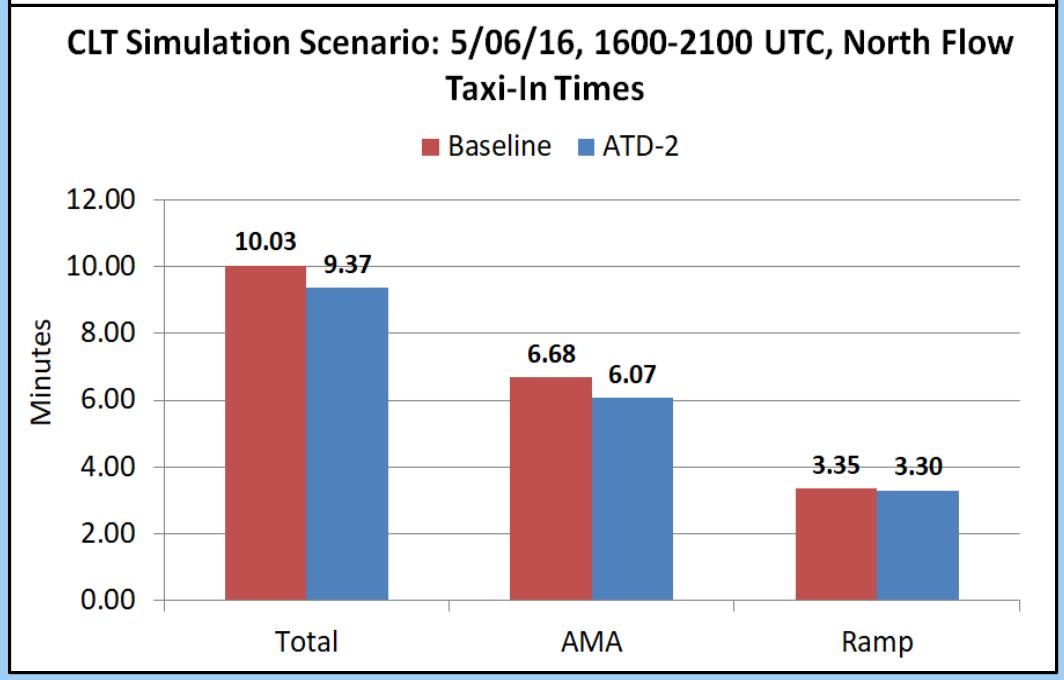


Impact on Taxi-In Times

Sim #1: 06/15/2016
South Flow
1000-1600 UTC

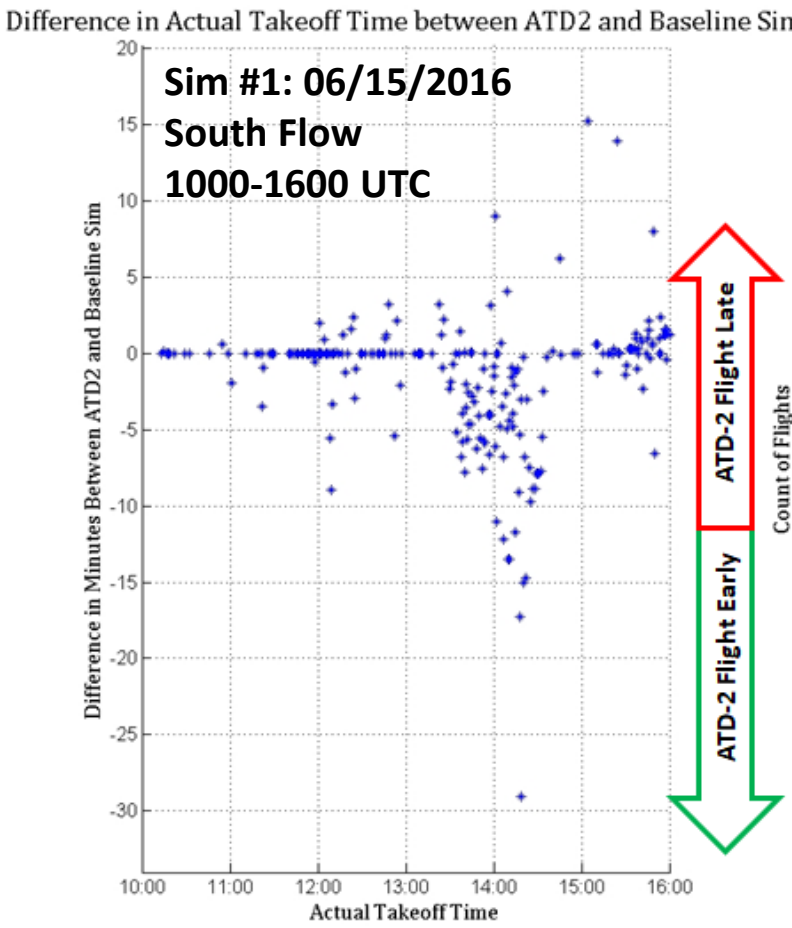


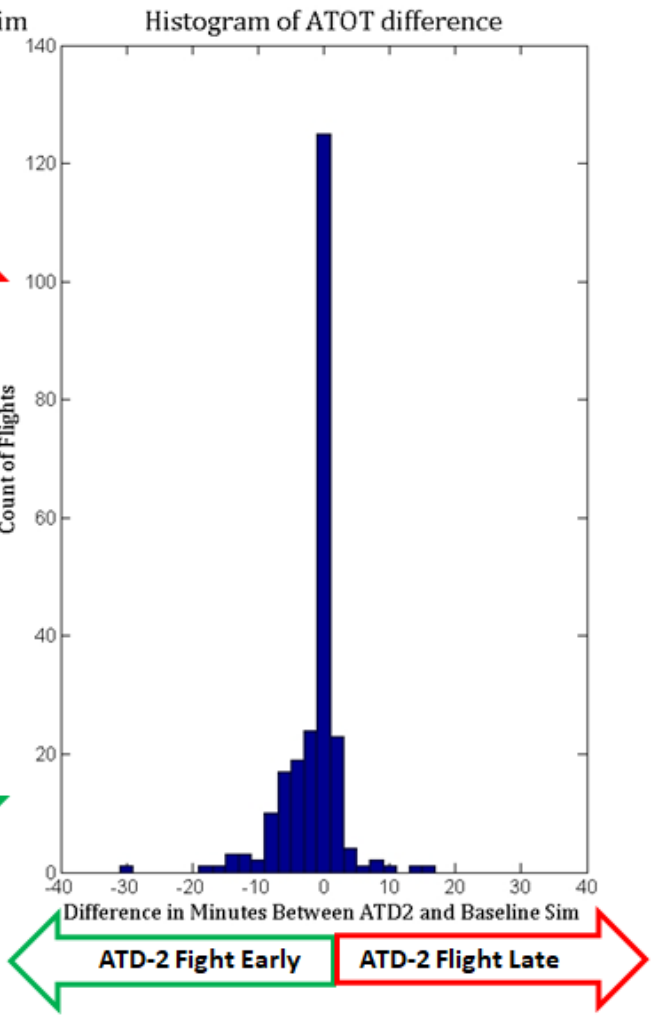
Sim #2: 05/06/2016
North Flow
1600-2100 UTC



Impact on OFF-Time Performance

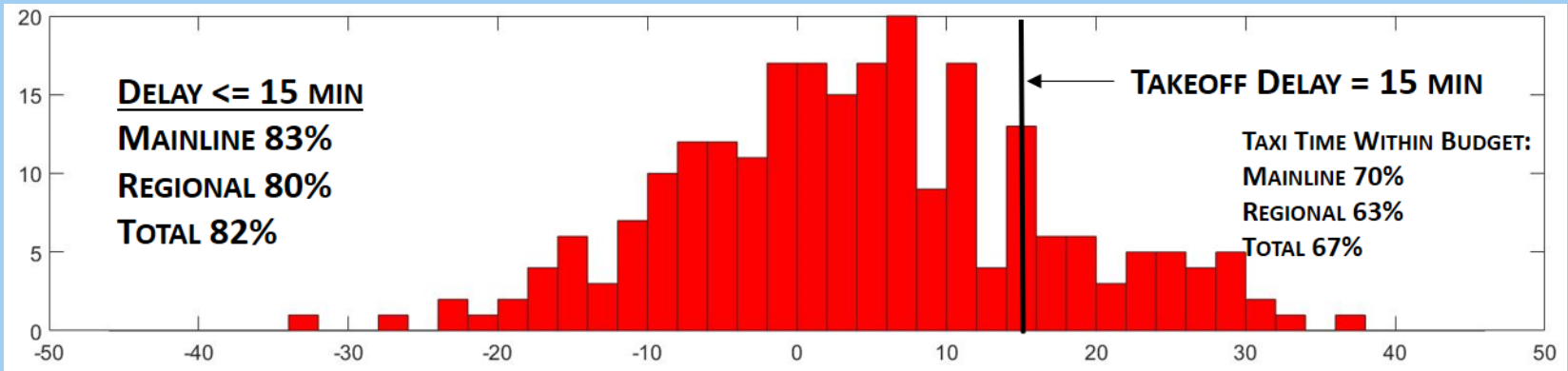
Simulated Takeoff Time Difference
ATD-2 Sim Flight – Baseline Sim Flight



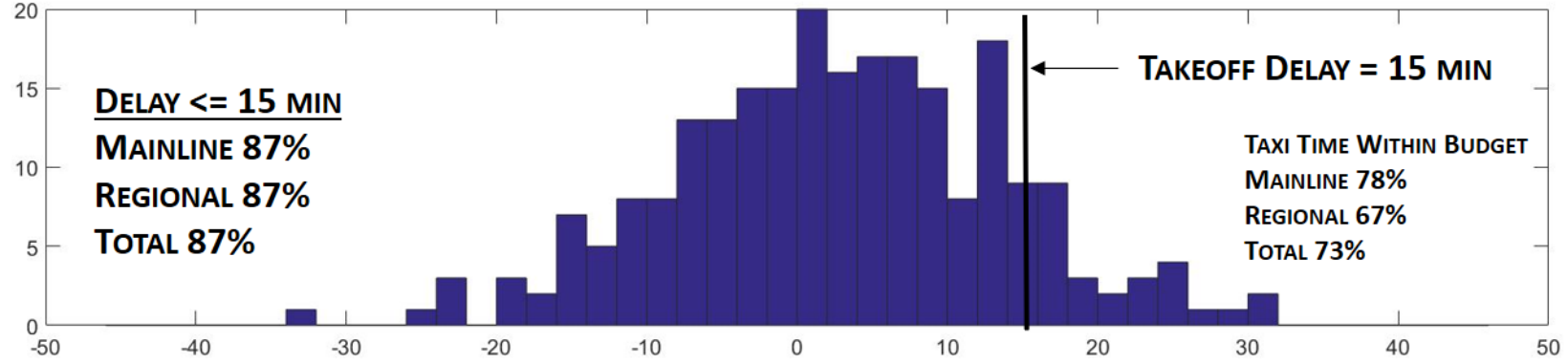


Impact on OFF-Time Peformance

Simulated Takeoff Time as compared to SOBT + AAL Taxi Budget
Simulated Taxi Out Time as compared to AAL Budget



TOTAL TAXI OUT TIME + GATE HOLD TIME – AAL TAXI TIME BUDGET (BASELINE SIM)



TOTAL TAXI OUT TIME + GATE HOLD TIME – AAL TAXI TIME BUDGET (ATD-2 SIM)

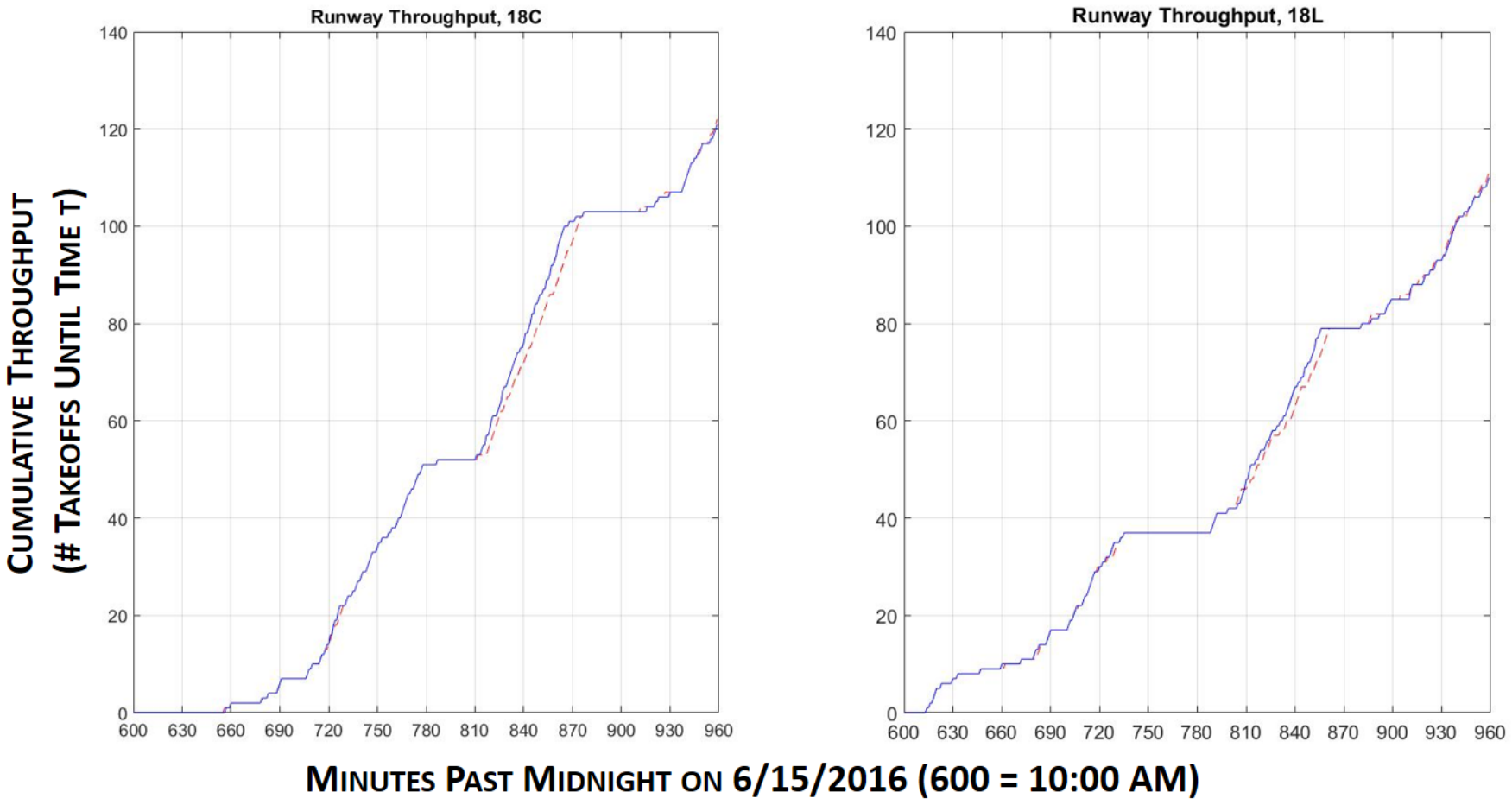
Impact on Airport Throughput

Cumulative Runway Takeoff Counts

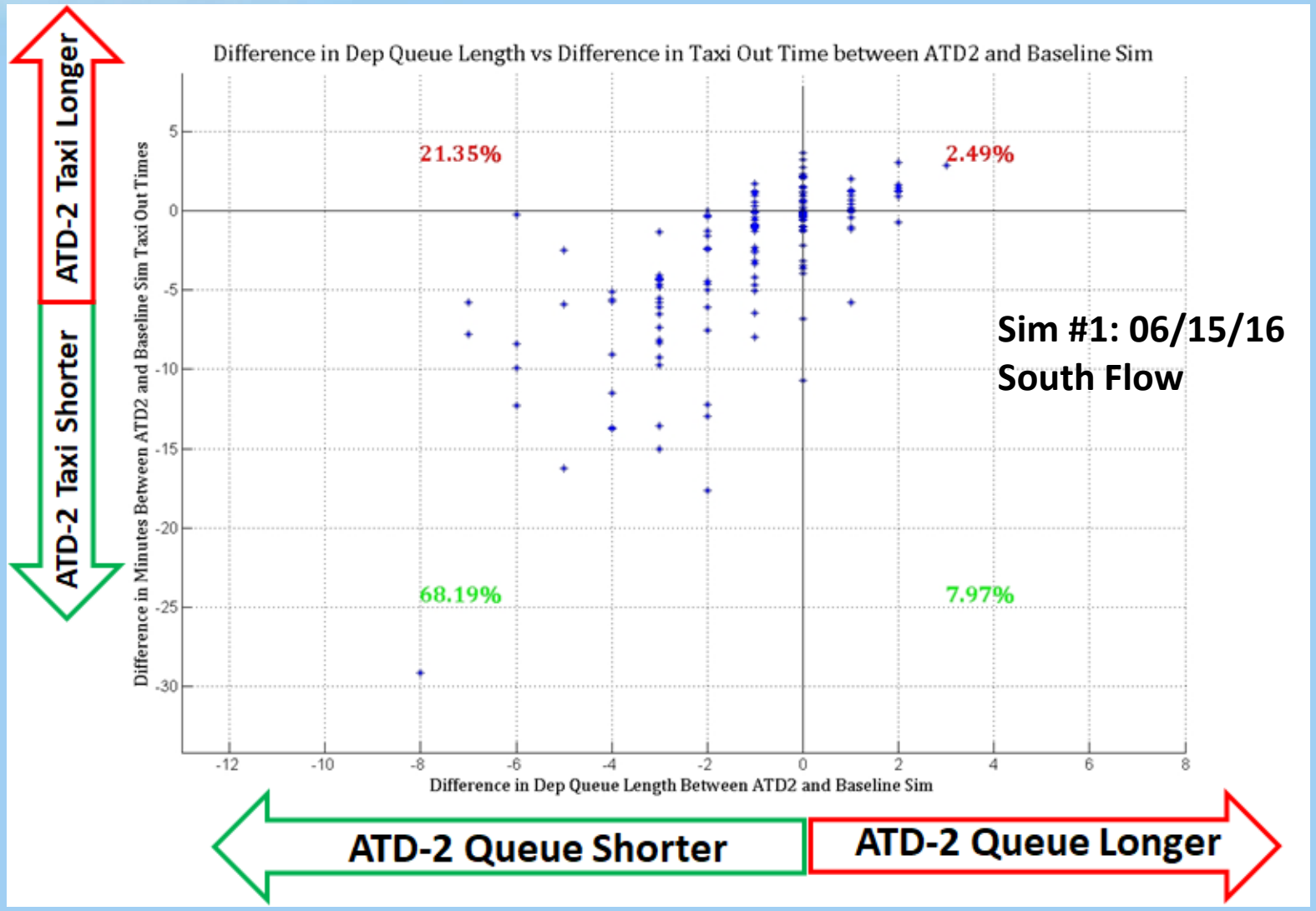
Red – Baseline (current-day) operations

Blue – ATD-2 operations

Sim #1: 06/15/16
South Flow

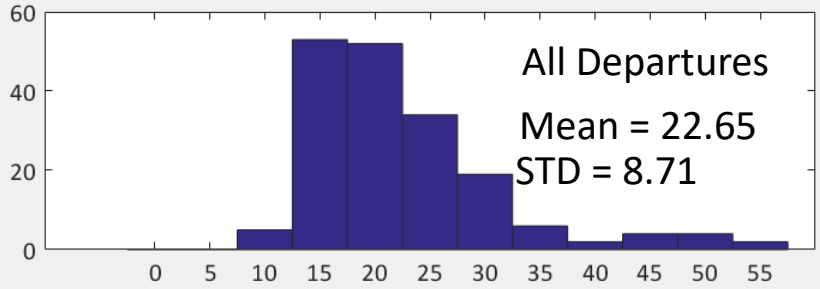


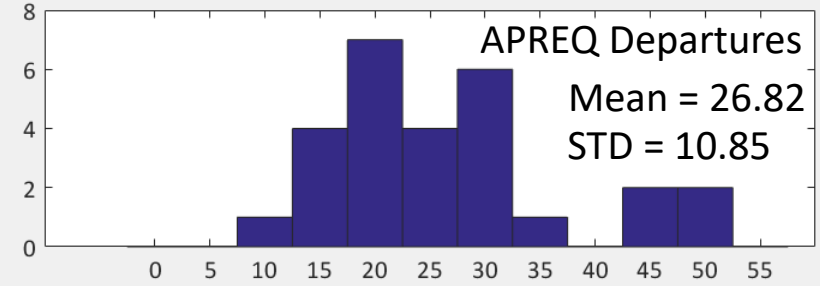
Benefit Mechanism: Demand Throttling

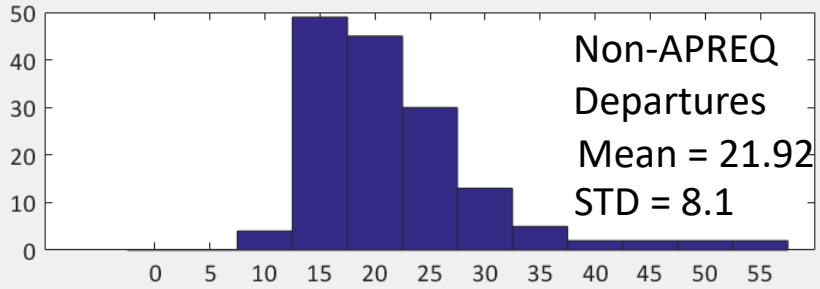


Benefit Mechanism: APREQ Coordination

BASELINE

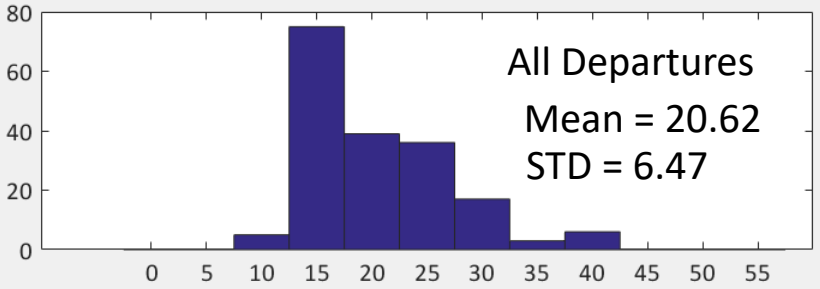


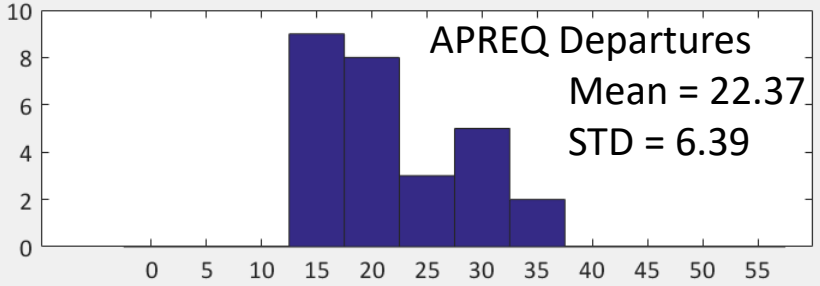


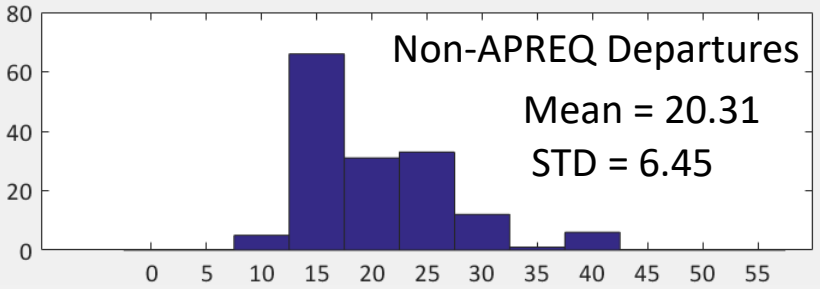


Taxi Out Times (min)

ATD-2



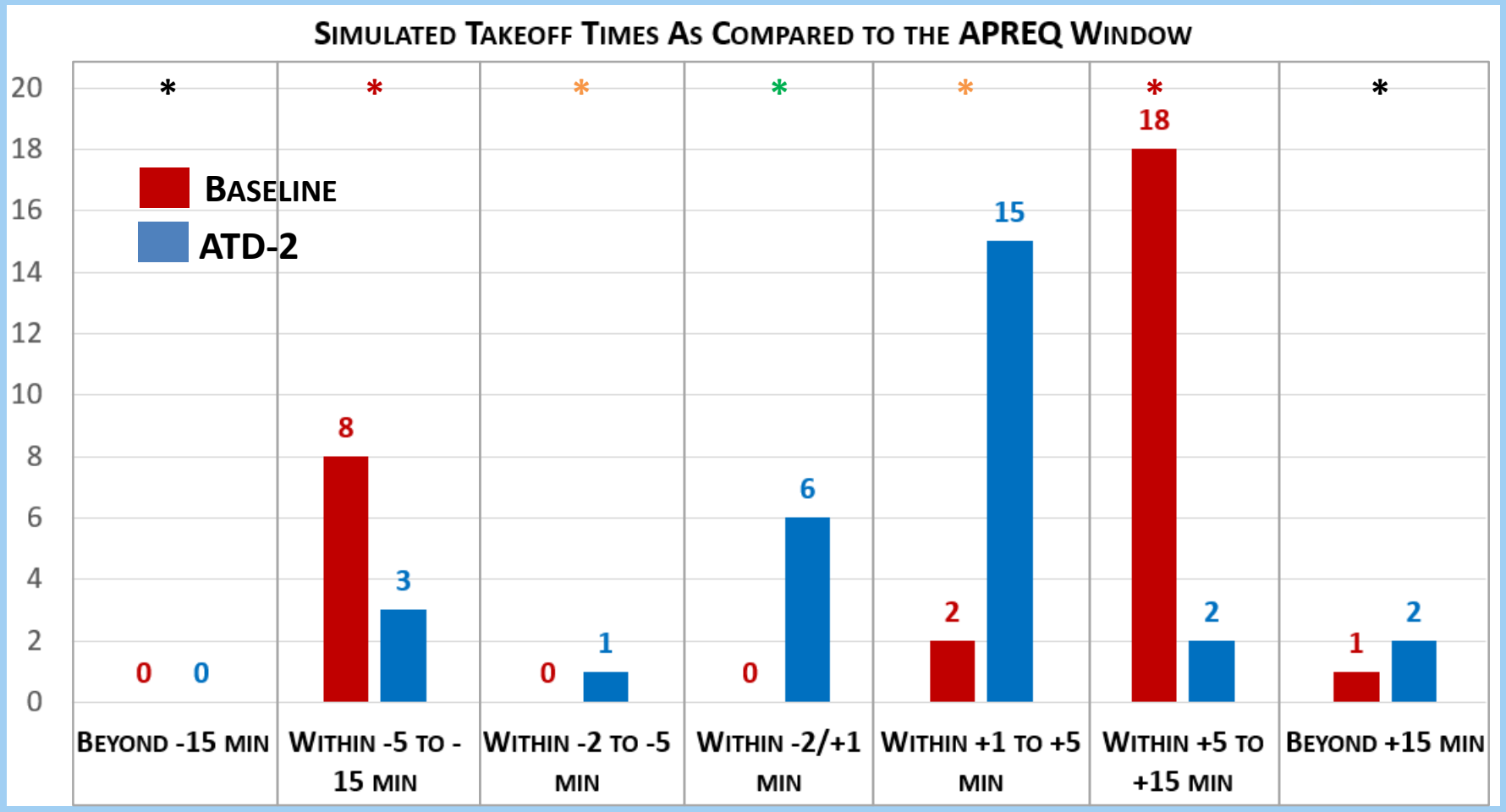




Taxi Out Times (min)

Sim #2: 05/06/2016, North Flow, 1600-2100 UTC

Benefit Mechanism: TMI Compliance



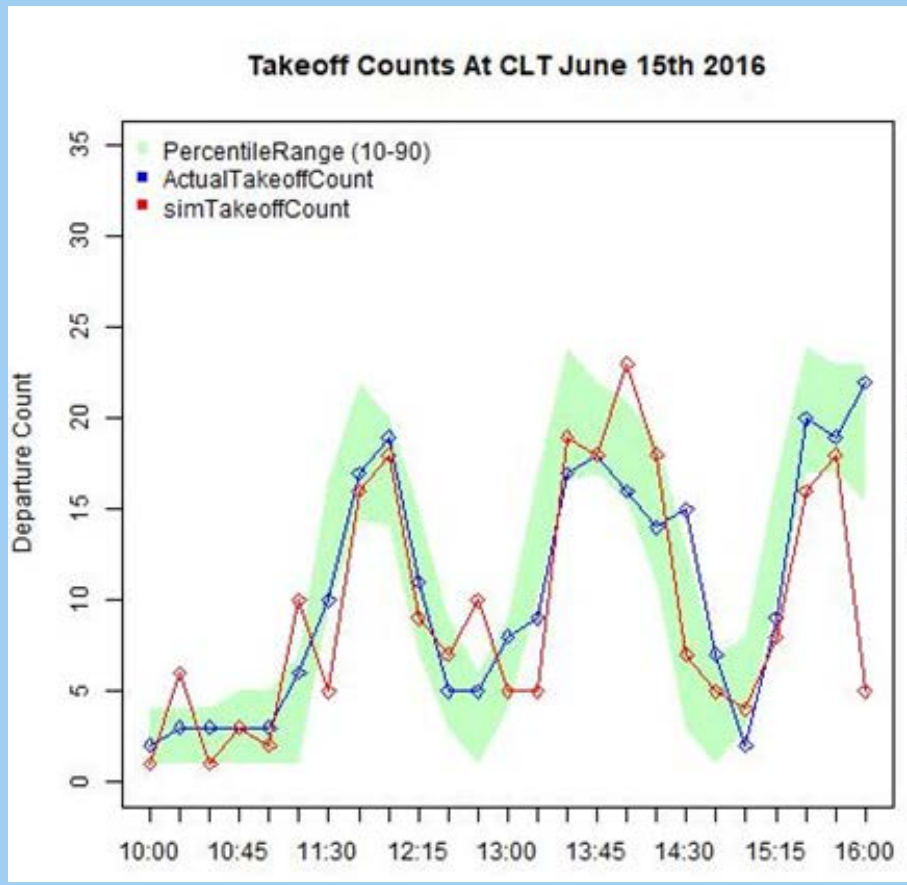
Sim #1: 06/15/16, South Flow

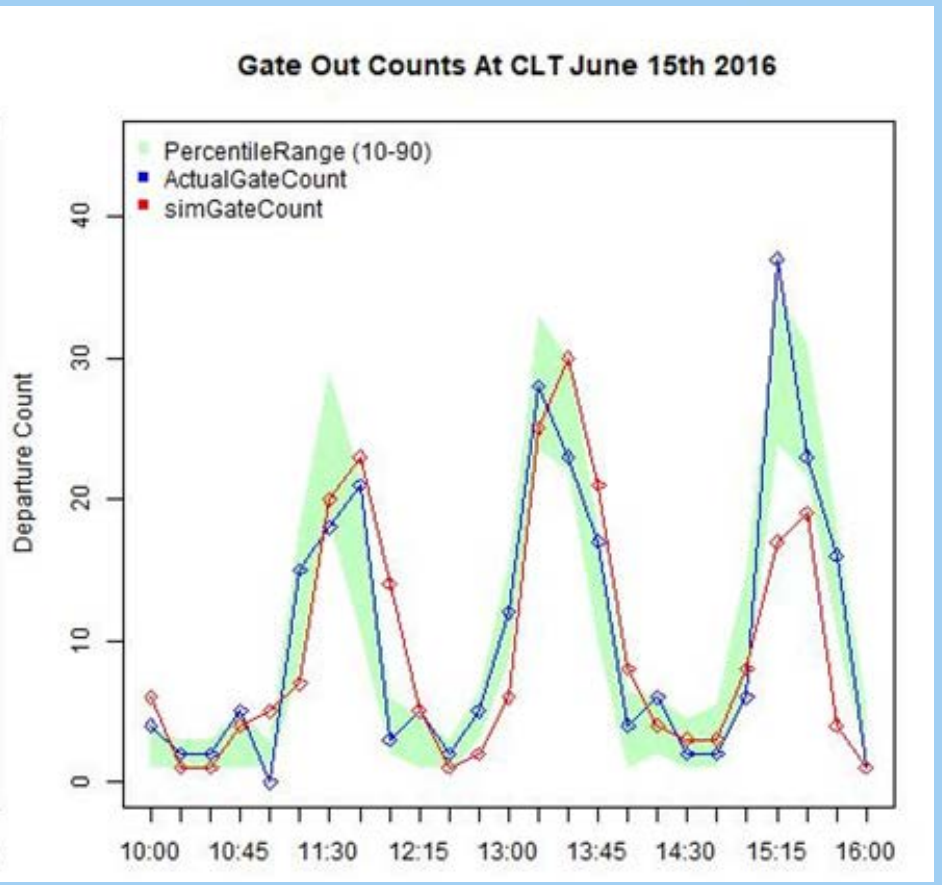
Model Validation

- Two-pronged approach
  - Try to match the model start times, taxi routes, gate/runway allocations and transit times with actual operations
  - Model all the current-day procedures as well as ATD-2 benefit mechanisms accurately

Validation: Runway and Gate Counts

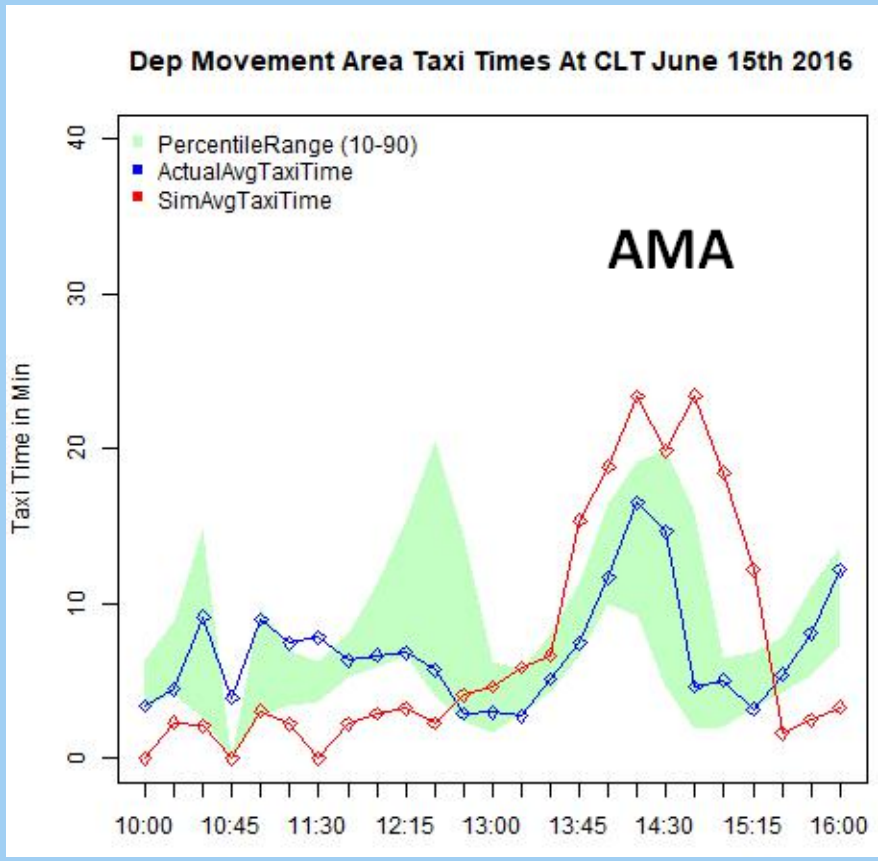
Sim #1: 06/15/2016, CLT South Flow, 1000-1600 UTC

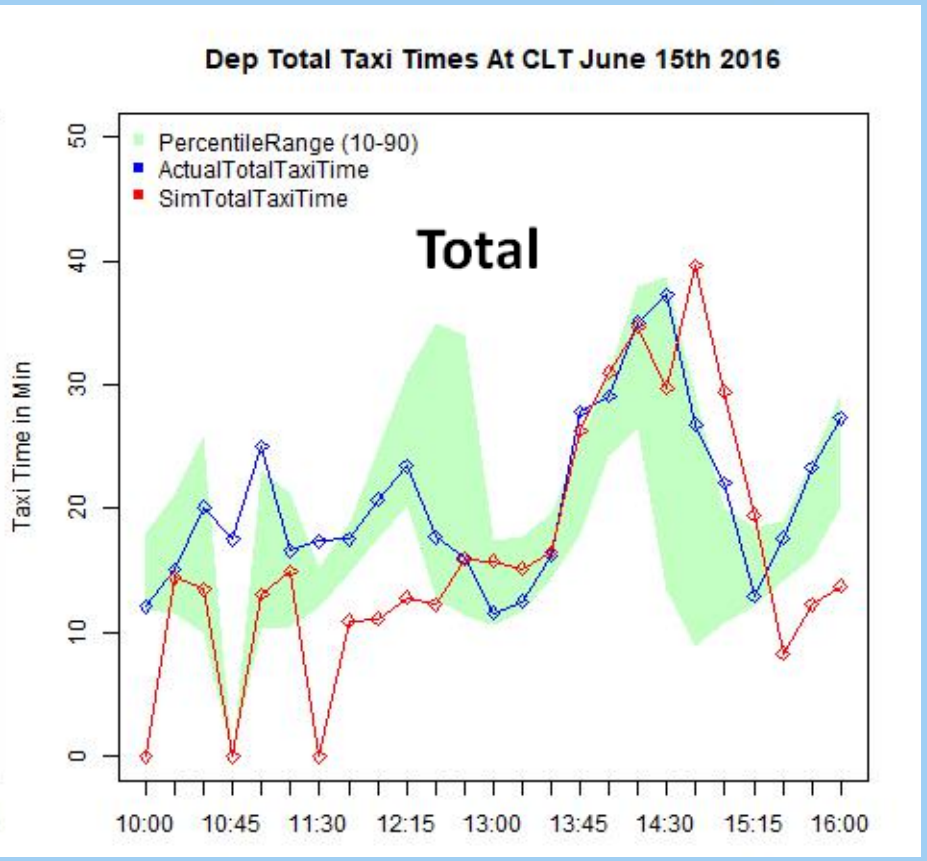




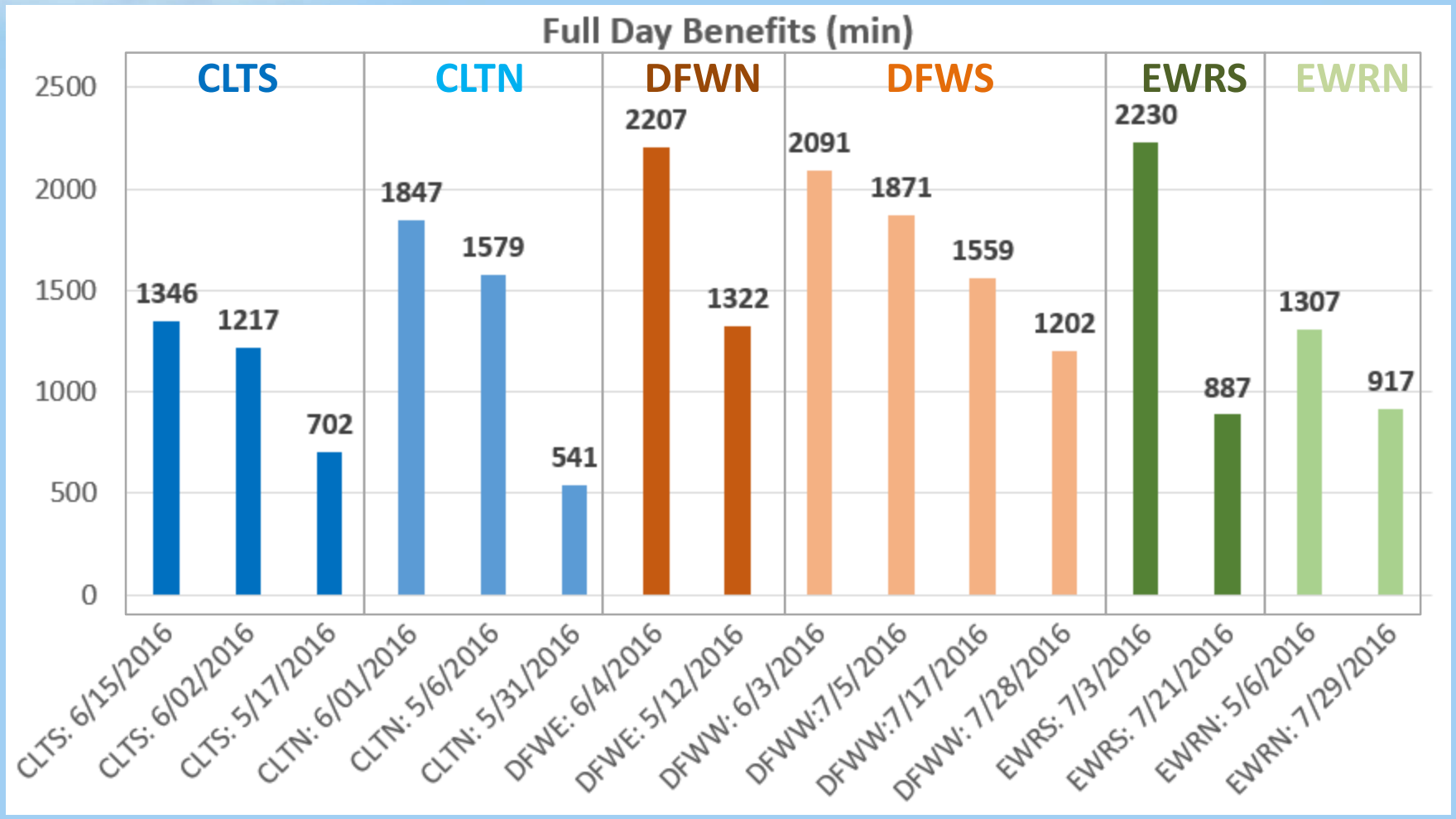
Validation: Taxi-Out Time

Sim #1: 06/15/2016, CLT South Flow, 1000-1600 UTC



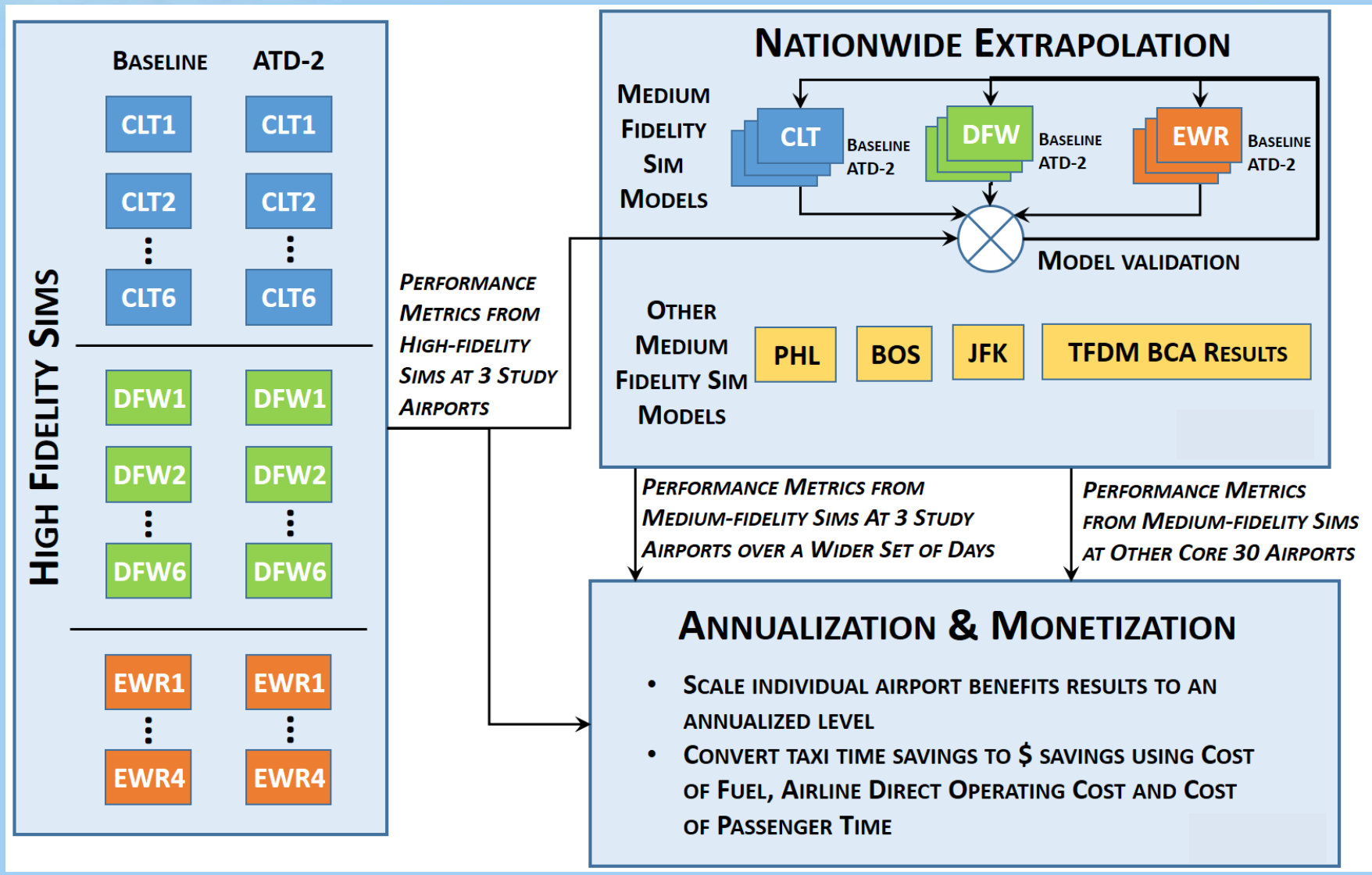


Summary of Taxi-Out Time Saving Benefits



	CLT	DFW	EWR
AVERAGE PER DEPARTURE TAXI-OUT TIME SAVING (MIN) =	1.72	1.89	2.34

Benefits Analysis & Extrapolation



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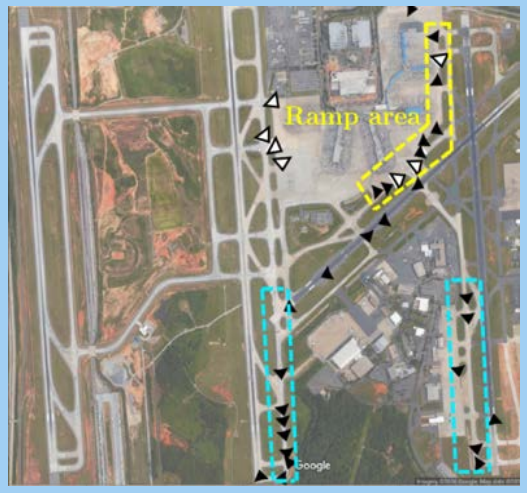
BENEFITS NATIONALIZATION

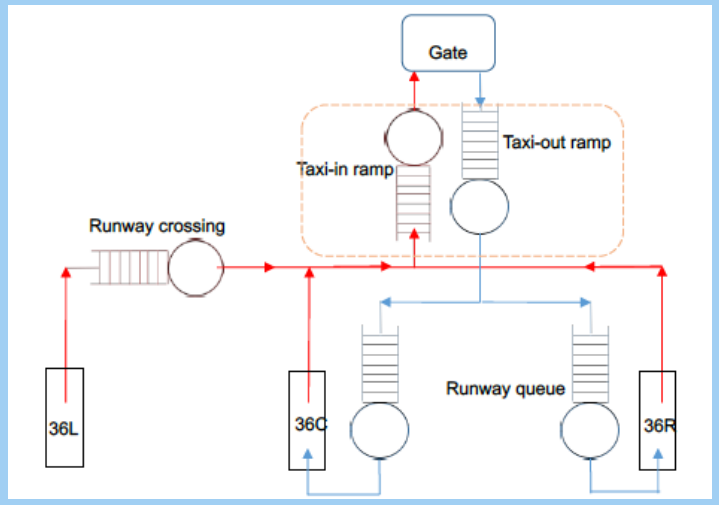
Benefits Nationalization

- Use mesoscopic (medium-fidelity) models of surface operations, adapted to CLT, EWR and DFW
- Compare benefits from mesoscopic models to those predicted by SOSS simulations to determine scaling factors
- Compare to N-Control or TFDM benefits estimates for LGA, PHL, BOS and other airports
- Use network delay propagation models to estimate knock-on effects

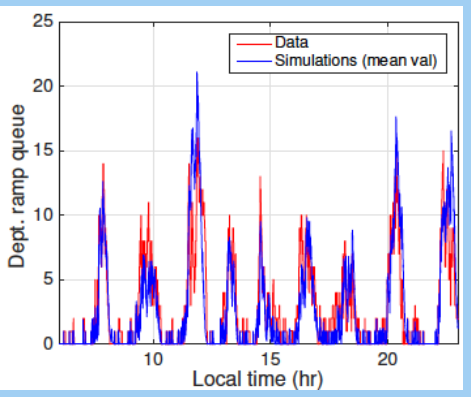
Mesoscopic Models of CLT

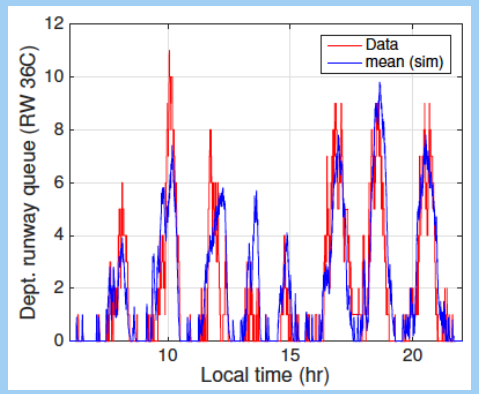
- Baseline (no metering)

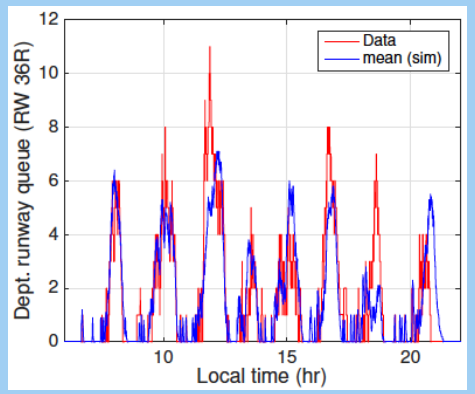


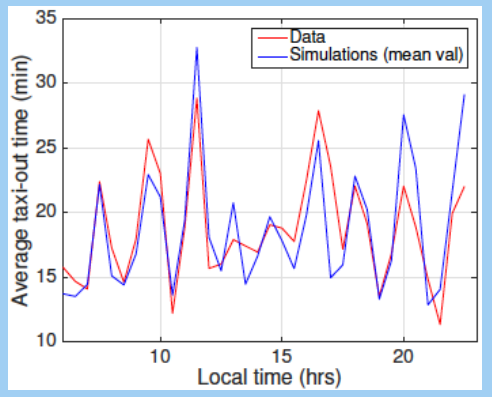


Departures	Actual	Error
(14,122 flights)	Avg. (min)	
Taxi-out time	20.2	0.7
Gate to spot	9.7	-0.3
Spot to runway	10.5	1.0
Arrivals (16,383 flts)	10.2	0.5



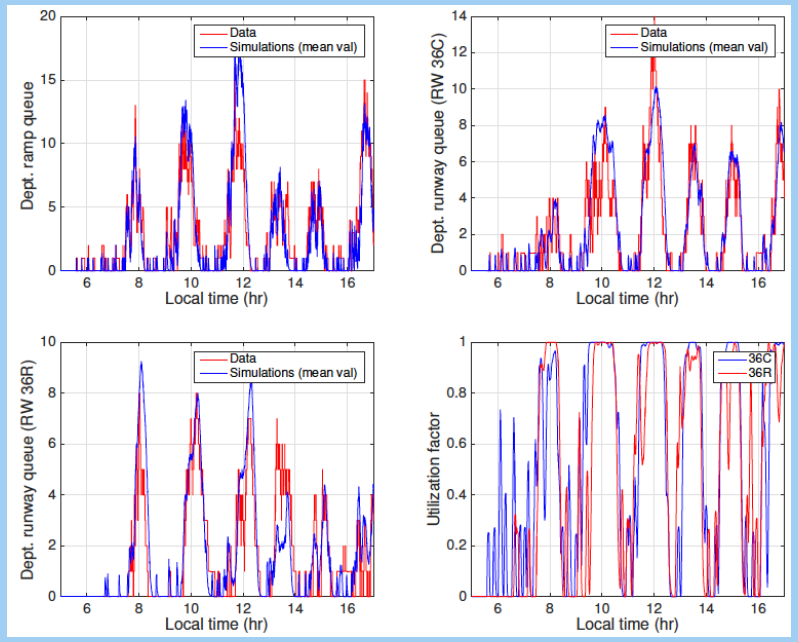


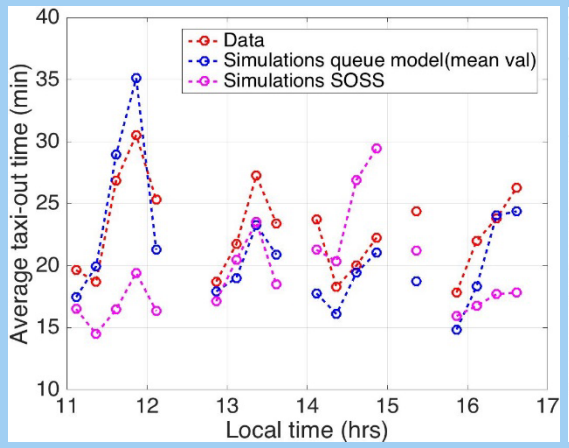


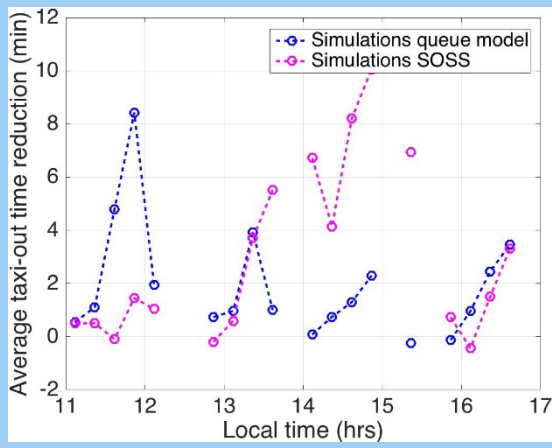


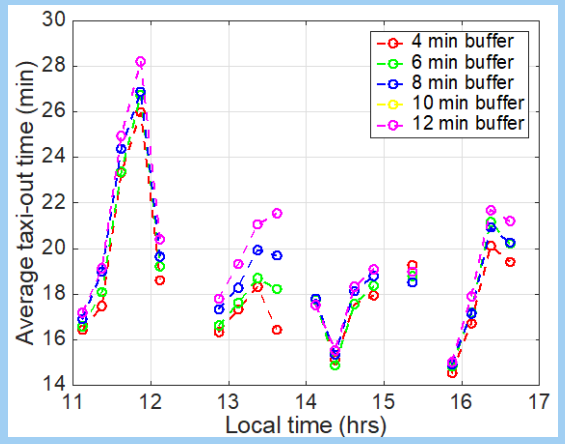
CLT Metering Scenario: 05/06/2016

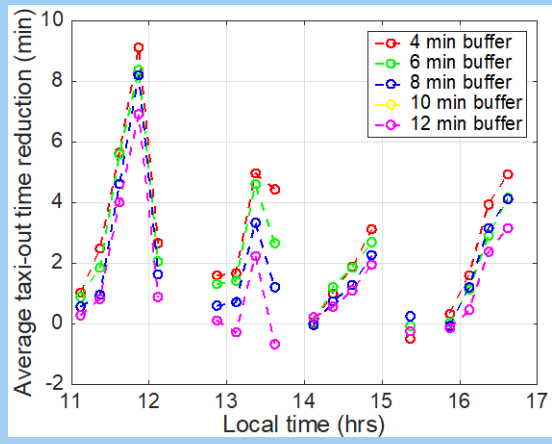
- Estimate taxi-out time reduction from ATD-2







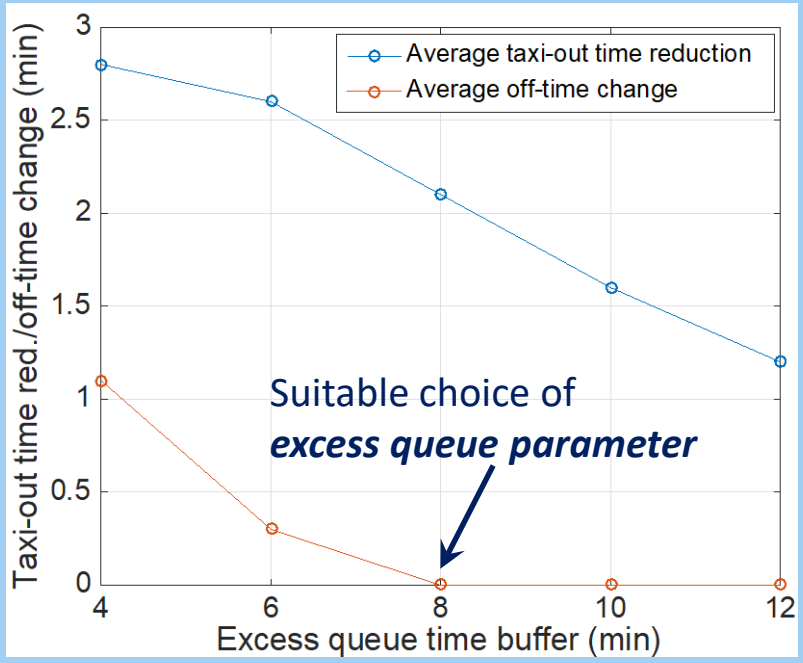




Impact of Excess Queue Parameter

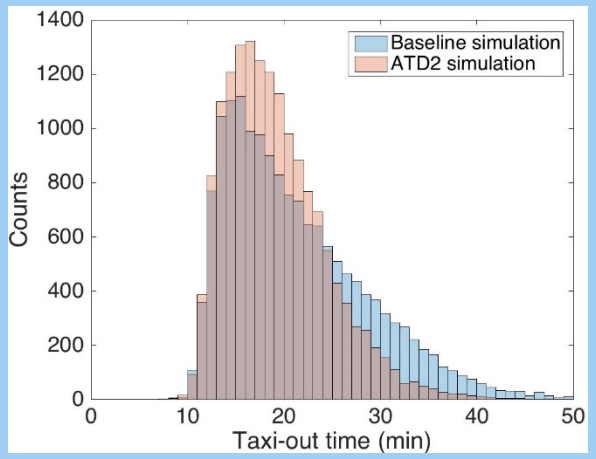
- North Flow (35 days; 15,718 departures)

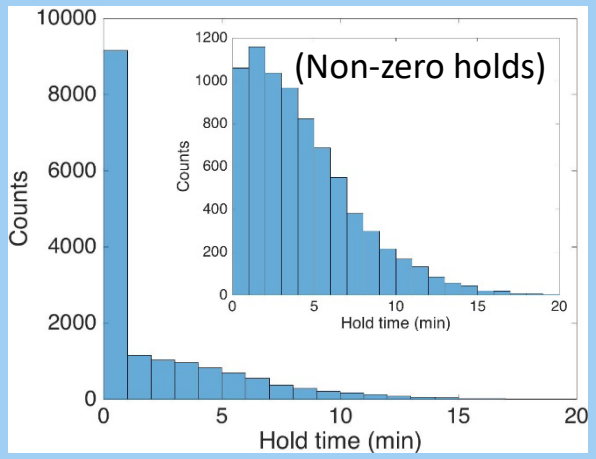
	Excess queue parameter (min)				
	4	**6**	**8**	**10**	**12**
Mean hold time over all flights	4.0	2.9	2.1	1.5	1.1
Fraction of flights held	0.7	0.6	0.5	0.4	0.3
Mean hold time of flights held	5.4	4.7	4.3	4.1	3.7
Fraction of flights held >2 min	0.6	0.4	0.3	0.3	0.2
Mean hold time of flights held > 2min	6.6	6.1	5.7	5.5	5.2
Taxi-out reduction (baseline-metering)	2.8	2.6	2.1	1.6	1.2
Mean off-time change (taxitime_meter+hold_time-taxitime_base)	1.1	0.3	0.0	-0.1	-0.1
Taxi-in reduction (baseline-metering)	0.0	-0.1	-0.1	0.1	0.0

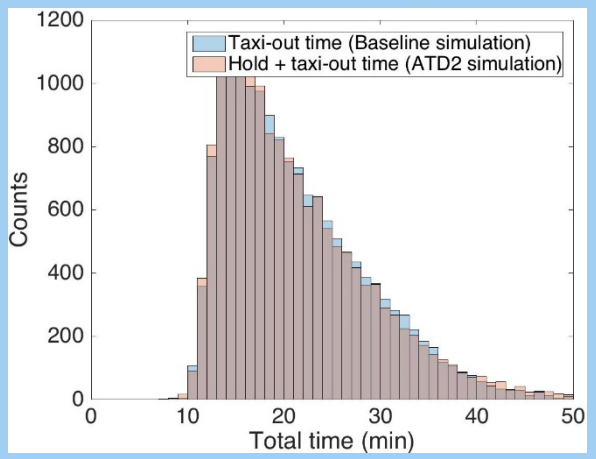


CLT Metering Impacts

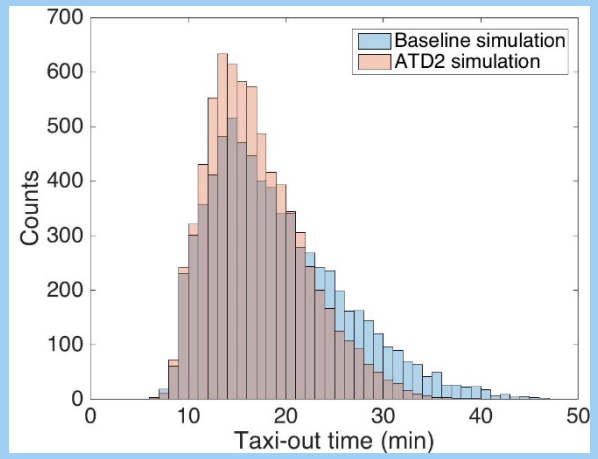
- North Flow (35 days; 15,718 departures; 16,383 arrivals; excess queue: 8 min)

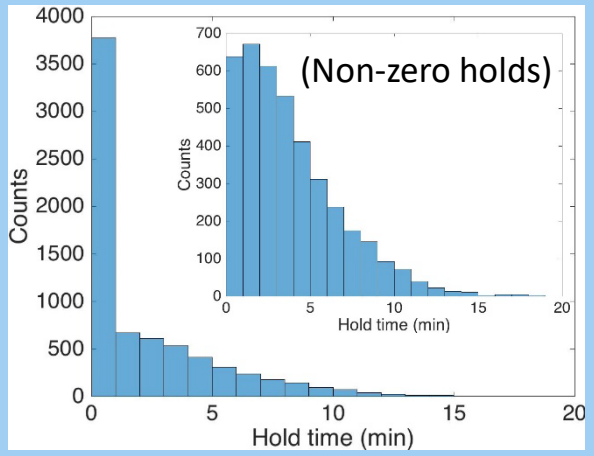


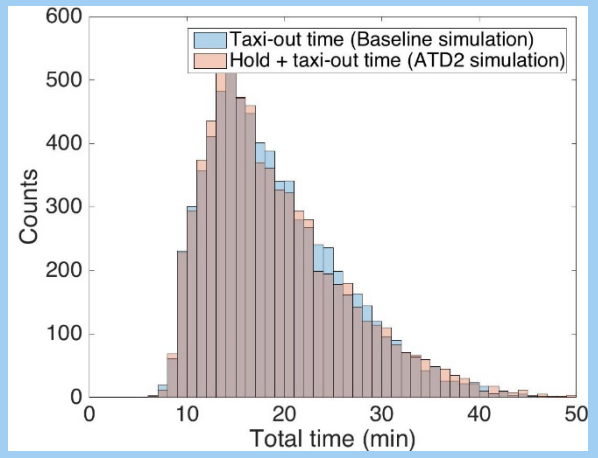




- South Flow (20 days; 7,069 departures; 7,499 arrivals; excess queue: 5 min)







SOSS vs. Queuing Model Simulations: CLT

- ATD-2 benefits in terms of taxi-out time reduction

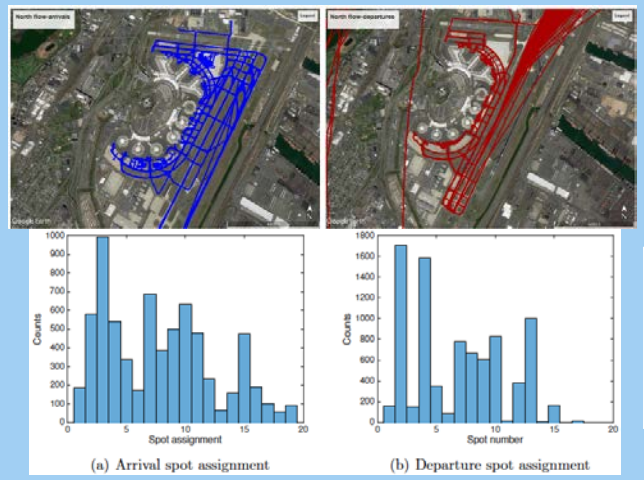
Taxi-out time (in minutes)

	Date	SOSS			Queuing model			Actual
		Baseline	ATD-2	Reduction	Baseline	ATD-2	Reduction	Baseline
North Flow	05/06/2016	20.5 (228)	17.4 (228)	3.1, 15.1% (228)	21.9 (284)	19.5 (284)	2.4, 10.7% (284)	22.7 (284)
	05/31/2016	18.5 (222)	17.8 (222)	0.7, 3.8% (222)	21.2 (269)	18.1 (269)	3.1, 14.4% (269)	23.1 (269)
	06/01/2016	22.7 (181)	20.6 (181)	2.1, 9% (181)	21.1 (249)	18.4 (249)	2.7, 12.8% (249)	21.1 (249)
South Flow	05/17/2016	20.1 (283)	19.0 (283)	1.1, 5.7% (283)	20.3 (265)	17.8 (265)	2.5, 12.2% (265)	23.5 (265)
	06/02/2016	16.9 (135)	15.9 (135)	1.0, 15.8% (135)	21.5 (228)	18.3 (228)	3.2, 14.9% (228)	20.3 (228)
	06/15/2016	18.0 (239)	16.2 (239)	1.8, 9.8% (239)	20.5 (244)	17.6 (244)	2.9, 13.9% (244)	21.8 (244)

(Number of flights considered in the simulation is shown in parentheses)

Mesoscopic Models of EWR

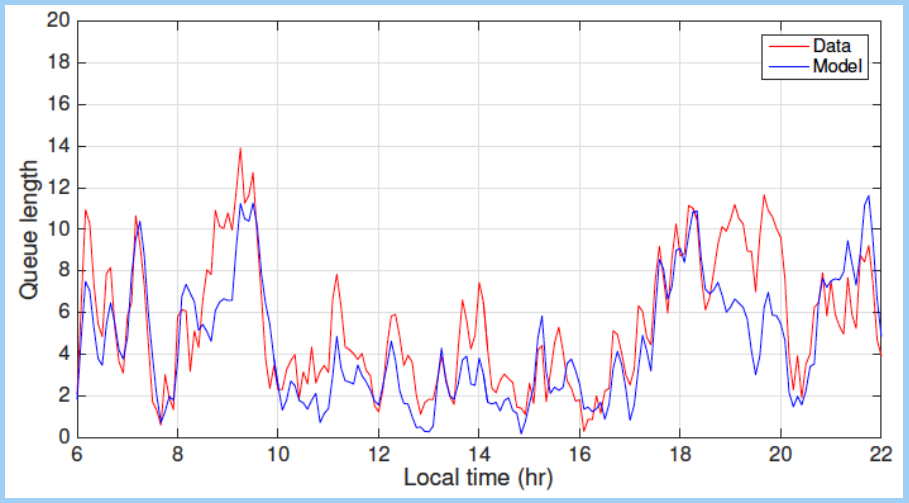
- Baseline (no metering)

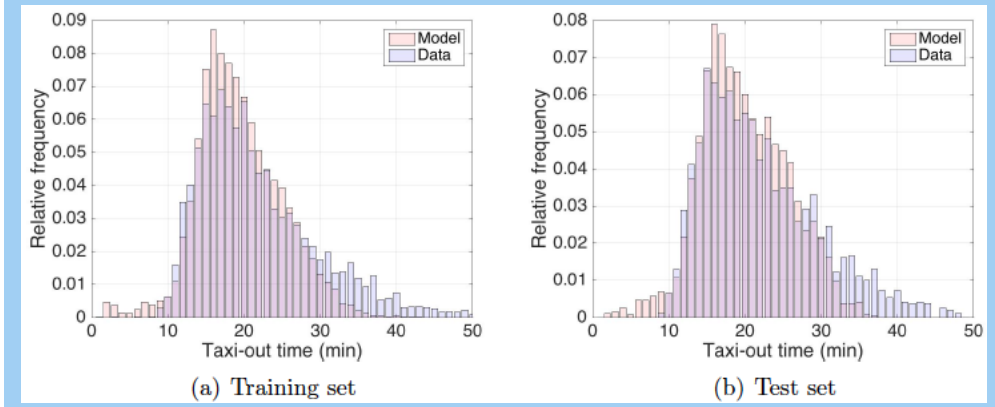


(a) Arrival spot assignment (b) Departure spot assignment

North Flow	Actual	Error
	Avg. (min)	
Taxi-out (9,251 flights)	21.3	0.2
Taxi-in (8,123 flights)	9.4	-0.1

South Flow	Actual	Error
	Avg. (min)	
Taxi-out (16,349 flights)	20.1	0.6
Taxi-in (15,753 flights)	9.4	-0.5

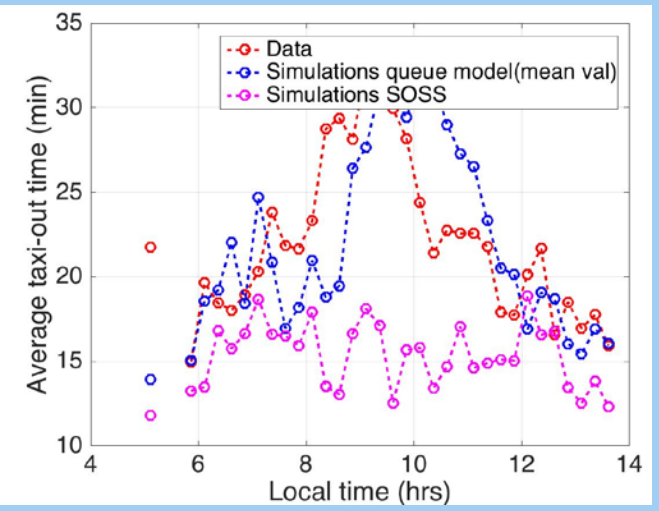


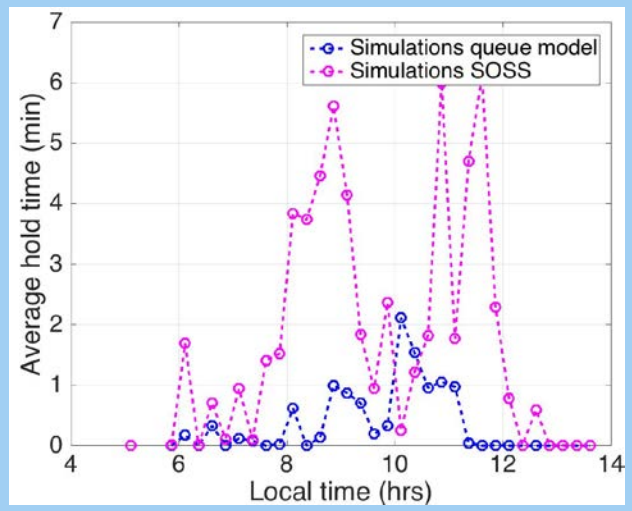


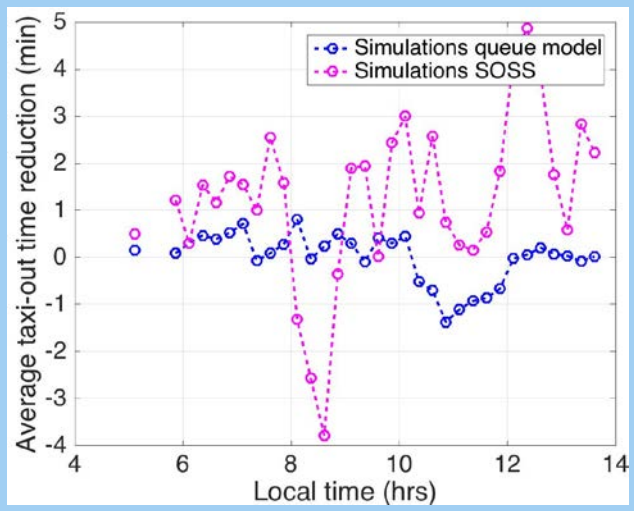
(a) Training set (b) Test set

EWR Metering Scenario: 07/29/2016

- Estimate taxi-out time reduction from ATD-2
- North Flow
- Excess queue parameter: 15 min

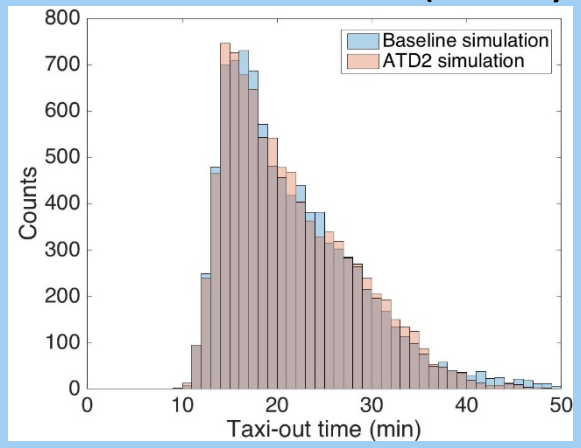


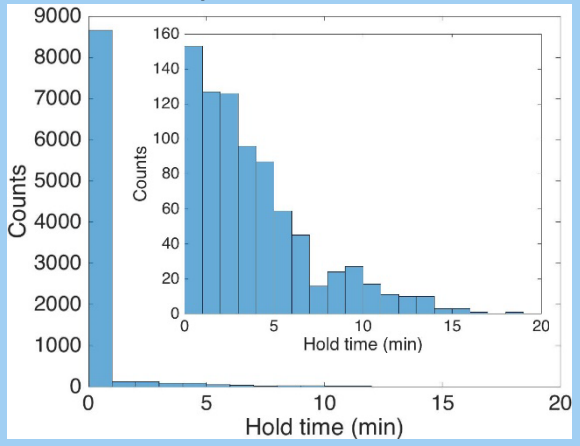


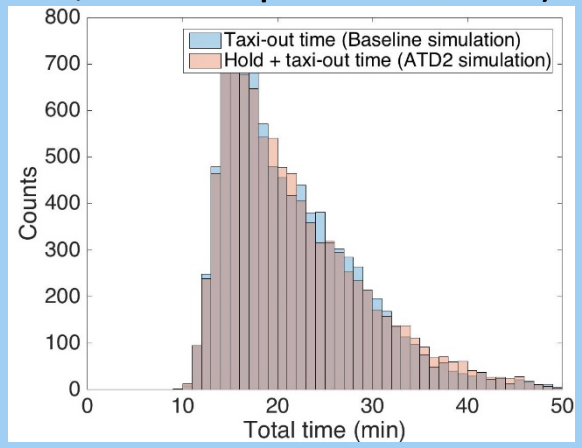


EWR Metering Impacts

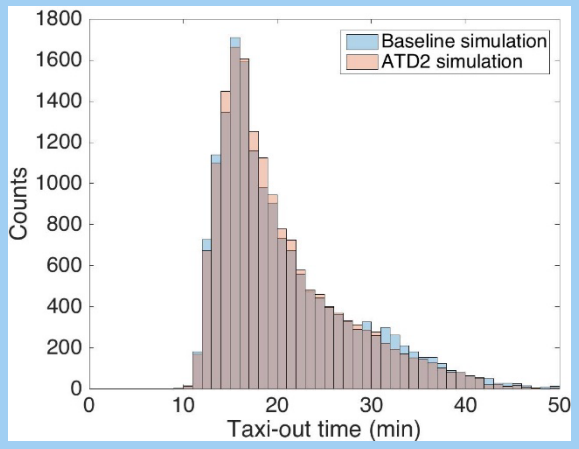
- North Flow (40 days; 9,251 departures; 8,123 arrivals; excess queue: 15 min)

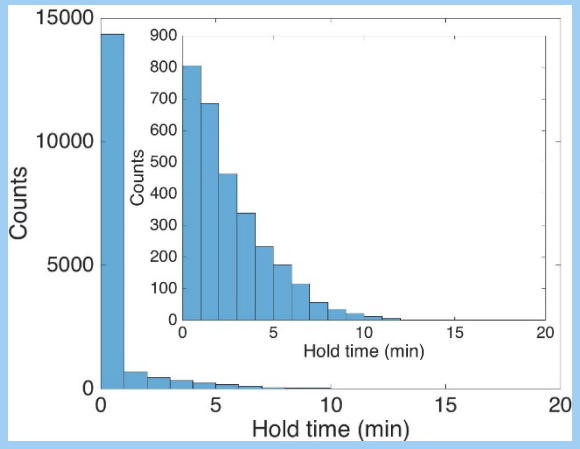


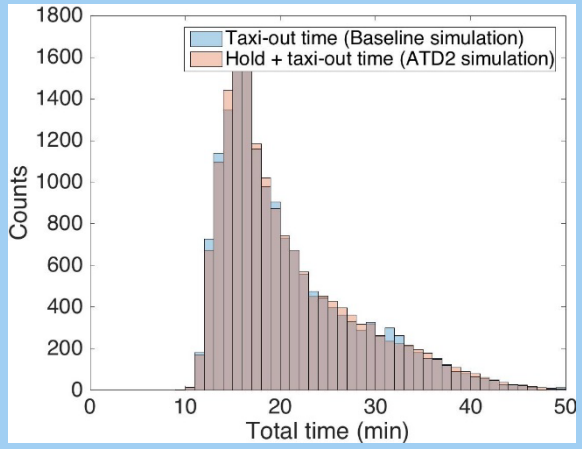




- South Flow (48 days; 16,349 departures; 15,753 arrivals; excess queue: 12 min)







SOSS vs. Queuing Model Simulations: EWR

- ATD-2 benefits in terms of taxi-out time reduction

Taxi-out time (in minutes)

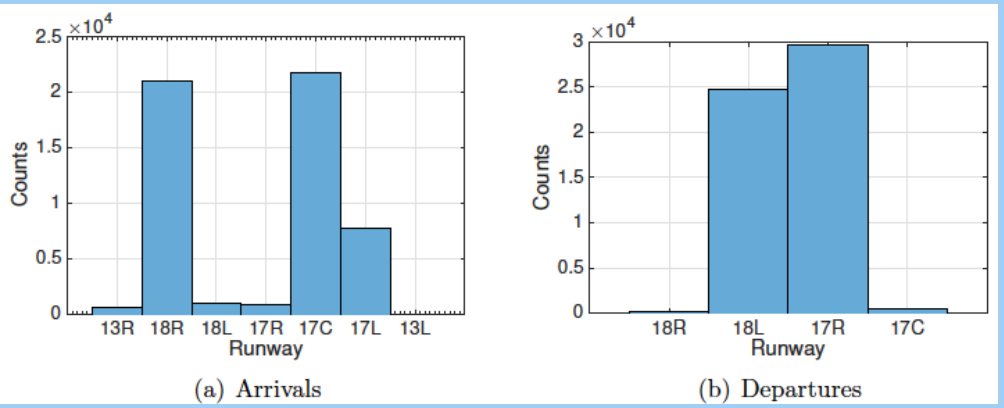
	Date	SOSS			Queuing model			Actual
		Baseline	ATD-2	Reduction	Baseline	ATD-2	Reduction	Baseline
North Flow	05/06/2016	15.0 (171)	13.6 (171)	1.4, 9.7% (171)	19.8 (199)	19.6 (199)	0.2, 1.3% (199)	20.6 (199)
	07/29/2016	15.6 (260)	14.5 (260)	1.1, 7.2% (260)	22.0 (260)	22.0 (260)	0, 0.1% (260)	22.4 (260)
South Flow	07/03/2016	20.0 (175)	15.6 (175)	4.4, 21.8% (175)	15.9 (154)	15.8 (154)	0.1, 0.6% (154)	15.9 (154)
	07/21/2016	17.0 (286)	15.9 (286)	1.1, 6.6% (286)	28.0 (292)	25.8 (292)	2.2, 7.8% (292)	18.2 (292)

(Number of flights considered in the simulation is shown in parentheses)

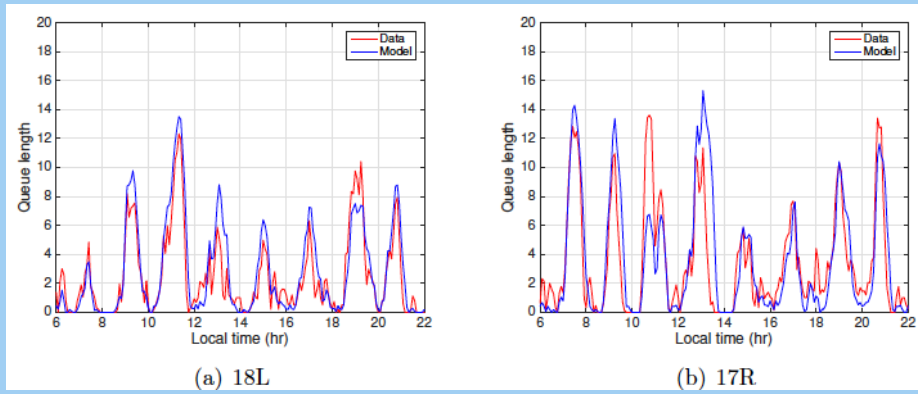
Mesoscopic Models of DFW

- Baseline (no metering)

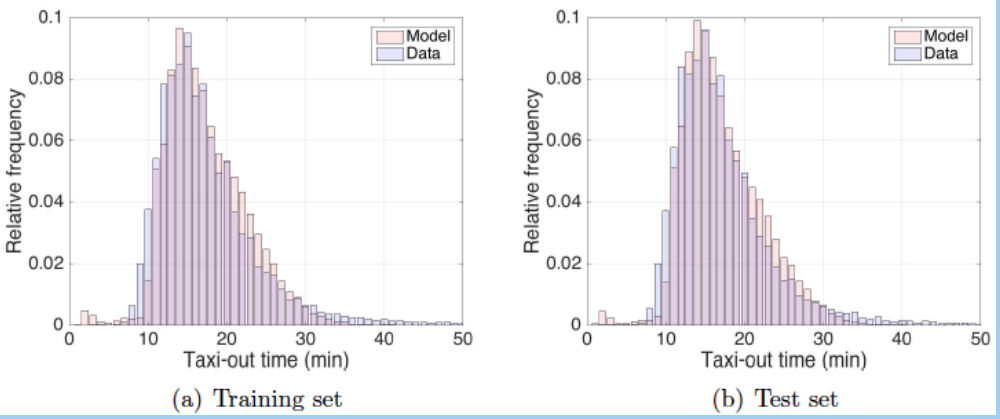
Operates in South Flow 80% of the time



(a) Arrivals (b) Departures



(a) 18L (b) 17R



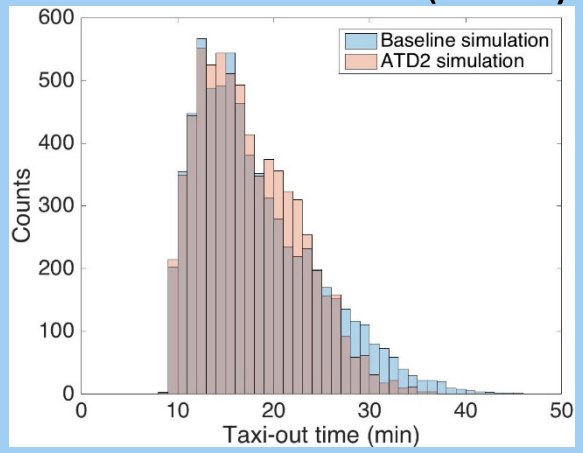
(a) Training set (b) Test set

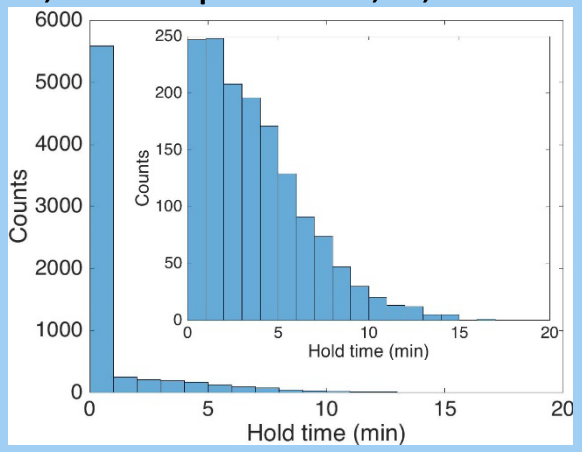
North Flow	Actual	Error
	Avg. (min)	
Taxi-out (6,788 flights)	18.7	-0.6
Taxi-in (6,349 flights)	10.1	-0.0

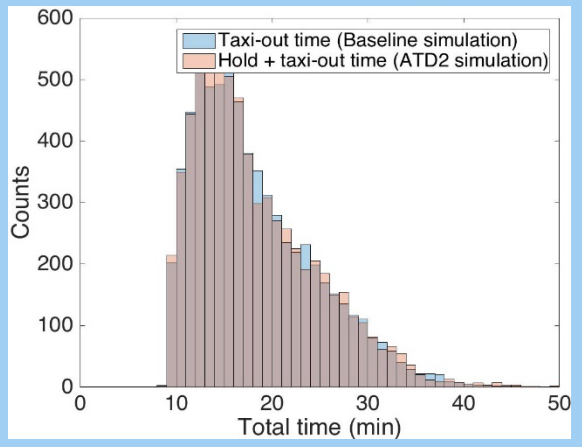
South Flow	Actual	Error
	Avg. (min)	
Taxi-out (53,513 flights)	16.8	0.0
Taxi-in (51,577 flights)	11.2	0.2

DFW Metering Impacts

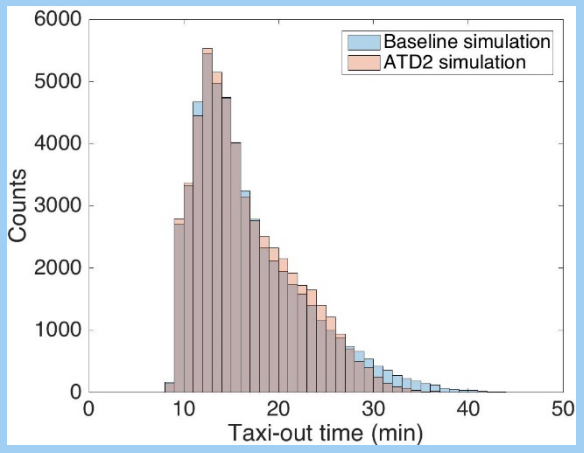
- North Flow (11 days; 6,788 departures; 6,349 arrivals; excess queue: 10 min)

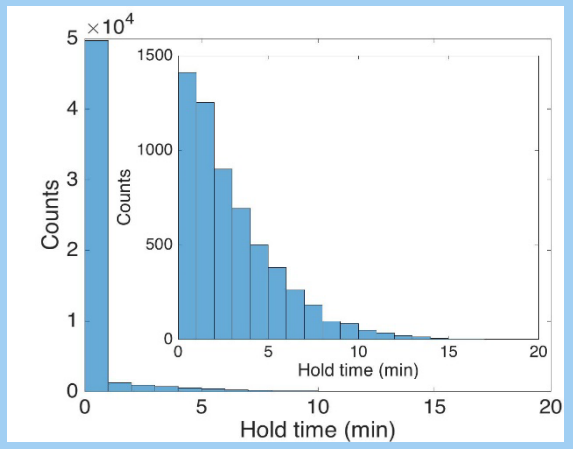


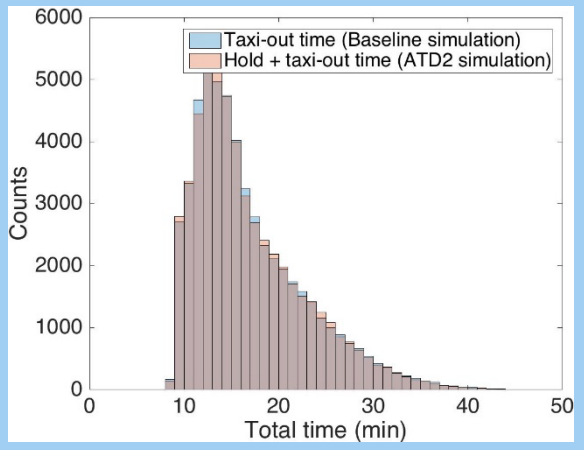




- South Flow (72 days; 53,513 departures; 51,577 arrivals; excess queue: 12 min)







SOSS vs. Queuing Model Simulations: DFW

- ATD-2 benefits in terms of taxi-out time reduction

Taxi-out time (in minutes)

	Date	SOSS			Queuing model			Actual
		Baseline	ATD-2	Reduction	Baseline	ATD-2	Reduction	Baseline
North Flow	05/12/2016	22.3 (302)	20.5 (302)	1.8, 8.2% (302)	19.4 (305)	18.3 (305)	1.1, 5.6% (305)	20.0 (305)
	06/04/2016	20.9 (297)	18.0 (297)	2.9, 14.0% (297)	16.5 (327)	16.3 (327)	0.2, 1.3% (327)	17.8 (327)
South Flow	06/03/2016	19.6 (382)	17.9 (382)	1.7, 8.4% (382)	16.0 (386)	15.9 (386)	0.1, 0.6% (386)	16.2 (386)
	07/05/2016	19.6 (350)	17.6 (350)	2.0, 10.6% (350)	16.3 (337)	16.0 (337)	0.3, 1.4% (337)	22.5 (337)
	07/17/2016	18.8 (254)	16.8 (254)	2.0, 10.7% (254)	19.2 (259)	18.3 (259)	0.9, 4.6% (259)	16.6 (259)
	07/28/2016	17.8 (254)	16.7 (254)	1.1, 6.4% (254)	16.0 (266)	15.9 (266)	0.1, 0.5% (266)	19.6 (266)

(Number of flights considered in the simulation is shown in parentheses)

Summary of Taxi-out Time Reduction Benefits

	Config.	Excess queue (min)	Mean taxi-out time savings (min)	# deps in sims	Total taxi-out time savings (min)	Avg. daily deps	Estim. daily taxi-out time savings (hours)
CLT	N Flow	8	2.1	15,718	33,008	707	**24.4**
	S Flow	5	2.0	7,069	14,138		
EWR	N Flow	8	1.2	9,251	11,101	615	**7.6**
	S Flow	12	0.4	7,069	925		
DFW	N Flow	10	0.8	6,788	5,430	969	**7.2**
	S Flow	12	0.4	53,513	21,405		

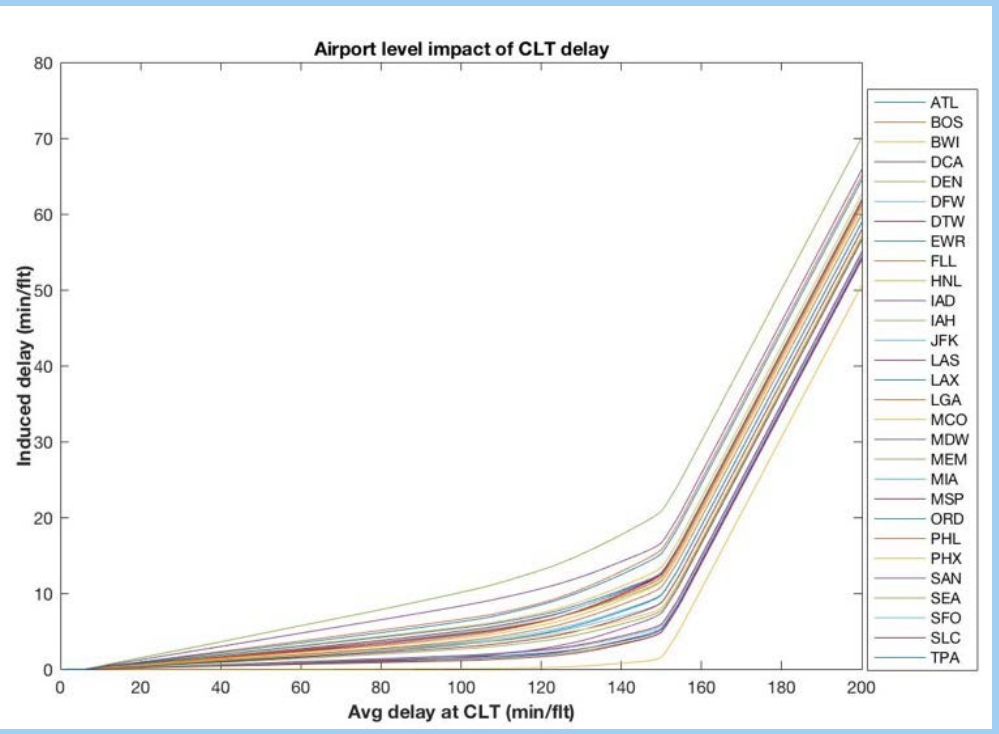
		Date	% taxi-out time reduction				Scaling factor	Median
			Queue model		SOSS			
CLT	N Flow	5/06/2016	10.7	13.4	15.1	7.4	1.4	**0.6**
		5/31/2016	14.4		3.8		0.3	
		6/01/2016	12.8		9.0		0.7	
	S Flow	5/17/2016	12.2		5.7		0.5	
		6/02/2016	14.9		5.8		0.4	
		6/15/2016	13.9		9.8		0.7	
DFW	N Flow	5/12/2016	5.6	1.4	8.2	9.5	1.5	**6.8**
		6/04/2016	1.3		14.0		10.5	
	S Flow	6/03/2016	0.6		8.4		13.1	
		7/05/2016	1.4		10.6		7.7	
		7/17/2016	4.6		10.7		2.3	
		7/28/2016	0.5		6.4		11.7	
EWR	N Flow	5/06/2016	1.3	1.0	9.7	8.5	7.5	**8.5**
		7/29/2016	0.1		7.2		91.9	
	S Flow	7/03/2016	0.6		21.8		34.9	
		7/21/2016	7.8		6.6		0.8	
Other airports (Median)			5.1		8.7		**1.9**	**1.9**

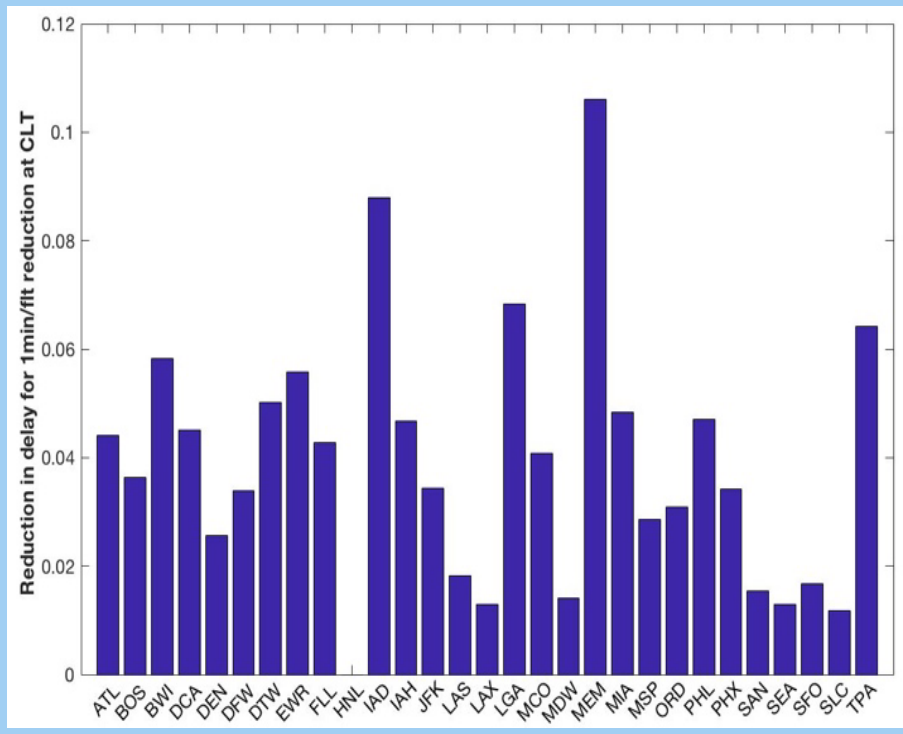
Extrapolation to Core 30 Airports

Apt.	% TFDM benefits	Normalized TFDM benefits	[SB10] & [Fornes15]	Med-fidelity benefits	SOSS scaling	Extrapolation factor	% extrapolated benefit
ATL	10.9	**1.3**			1.9	2.6	6.7%
ORD	10.1	**1.2**			1.9	2.4	6.2%
JFK	10.0	1.2	**1.5**		1.9	2.9	7.5%
EWR	8.1	1.0	1.0	**1.0**	8.5	8.5	22.3%
LGA	7.5	0.9	**0.8**		1.9	1.6	4.1%
PHL	6.4	0.8	**1.4**		1.9	2.7	7.0%
DEN	4.7	**0.6**			1.9	1.1	2.9%
CLT	4.0	0.5		**3.2**	0.6	1.8	4.6%
DTW	3.7	**0.5**			1.9	0.9	2.2%
MSP	3.5	**0.4**			1.9	0.8	2.1%
IAH	3.1	**0.4**			1.9	0.7	1.9%
DFW	3.1	0.4		**0.9**	6.8	6.4	16.9%
BOS	3.1	0.4	**0.4**		1.9	0.8	2.0%
SFO	2.9	**0.4**			1.9	0.7	1.8%
DCA	2.6	**0.3**			1.9	0.6	1.6%
LAX	2.6	**0.3**			1.9	0.6	1.6%
PHX	2.5	**0.3**			1.9	0.6	1.5%
MIA	1.7	**0.2**			1.9	0.4	1.0%
LAS	1.6	**0.2**			1.9	0.4	1.0%
SEA	1.4	**0.2**			1.9	0.3	0.9%
IAD	1.3	**0.2**			1.9	0.3	0.8%
SLC	1.2	**0.1**			1.9	0.3	0.7%
BWI	1.1	**0.1**			1.9	0.3	0.7%
MDW	0.9	**0.1**			1.9	0.2	0.6%
FLL	0.9	**0.1**			1.9	0.2	0.5%
MCO	0.8	**0.1**			1.9	0.2	0.5%
SAN	0.7	**0.1**			1.9	0.2	0.4%

Decrease in Propagated Delays

- By deploying ATD-2 at an airport, the departure delays at that airport are likely to decrease
- **2nd order effects:** Decrease in departure delays will imply less propagation of delays to other airports in the system





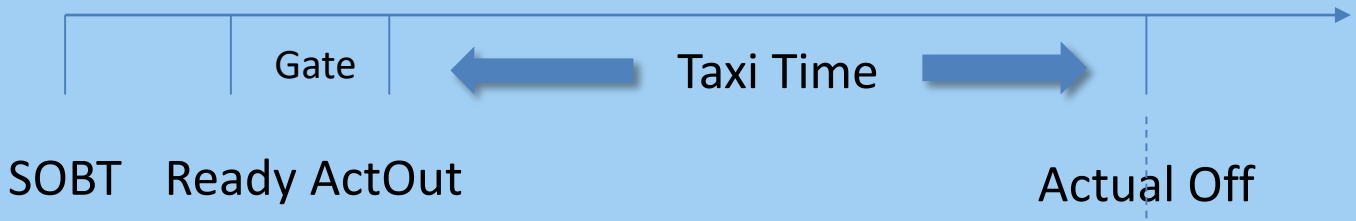
BENEFITS MONETIZATION AND ANNUALIZATION

Mechanisms

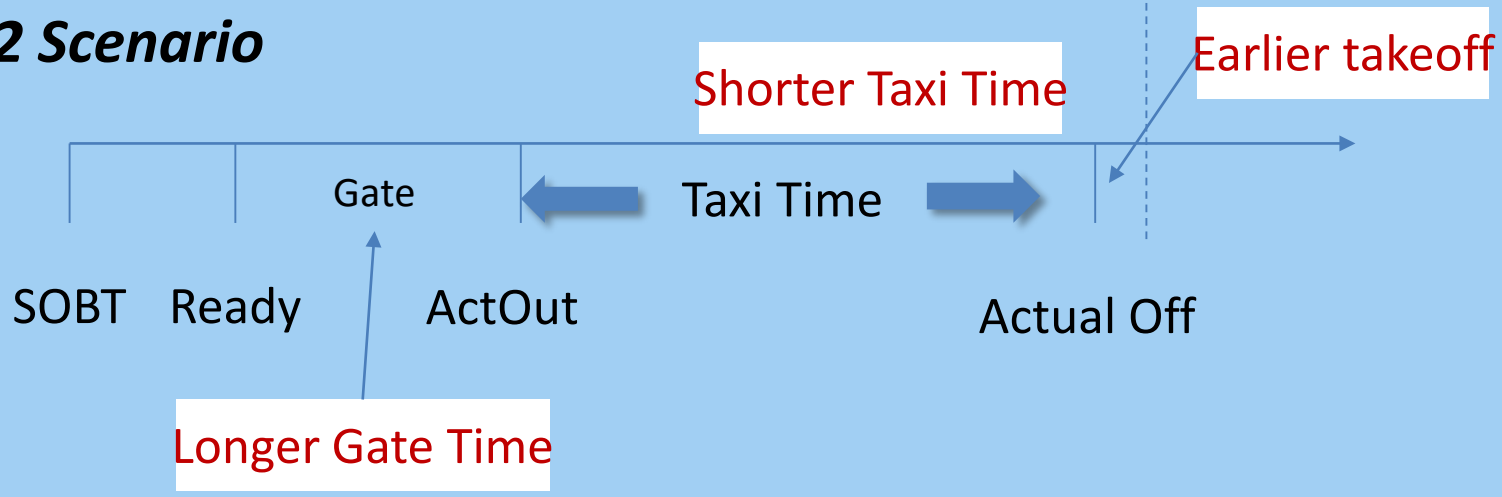
- Two primary benefits
  1) Increased time at gate
     a) Fuel Savings for reduced taxi time
  2) Earlier off time (increase in thru-put)
     a) Airline Direct Operating Costs (ADOC)
     b) Passenger Value of Time (PVT)
- Secondary benefits
  1) Improved compliance with EDCT/APREQs
     a) Captured due to earlier off time impact
  2) Emissions due to reduced fuel burn

Benefit Timeline

Baseline Scenario



ATD-2 Scenario



Of note is that in some cases the off time could be greater for the ATD-2 scenario due to error (e.g., excess gate hold)

Benefits Inputs

- Flight Level Data Provided (Departures only)
  - Scheduled Off Block Time (SOBT)
  - Ready Off Block Time (Ready)
  - Actual Off Block Time (ActOut)
    - Generally in the baseline scenario, Ready = ActOut
  - Runway Off Time (ActOff)
  - Numerous other fields not used in calculation
- Summary level data for arrivals
  - Average Taxi In time

Benefits Calculations

Due to potential shifts in Out and Off times, need to avoid double counting:

Define: F_r as $/fuel burn rate during taxi

A as ADOC/min

P as PVT/min

C_i as Cost of surface trajectory

$$C_i = \{\min(t^0_{off}, t^i_{off}) - t^i_{out}\} * F_r + (t^i_{off} - t^o_{off}) * (A + P)$$

The Benefits of the $\imath^{th}$ flight are then

$$B_i = C_0 - C_i$$

Economic Values

- Baseline values are provided by the Investment Analysis and Planning (IP&A) directorate of the FAA:
  - Average Fuel burn on the surface
  - Average ADOC (Cargo, Pax, Air Taxi, and GA)
  - PVT (policy value from DoT guidance)
  - Average passenger load/flight

Value per hour as used in the TFDM analysis

Airport	Fuel ($/hr)	PVT ($/hr)	ADOC ($/Hr)
CLT	$605.28	$3,844.69	$1,748.68
DFW	$645.45	$4,318.48	$1,865.14
EWR	$638.15	$4,220.87	$1,844.03

Extrapolation to Full Year

- Simulation Date selection is based on frequency of occurrence of "similar" days
  - This will be used as a first-order approximation methodology
- Second-Order variable will be taxi-out delay as highly correlated with the dominant benefit mechanisms
- Benefits:
  - 1 June is similar to 11.6% of the days compared days (112). Benefits for all similar days is thus 112*11.6%*Benefits(1 Jun)
  - Combined with the other days and scaled to 366 operational days
  - Alternate methodology would be to use the modeled dates and extrapolate using taxi-out delay
- These results would then be extended to the NAS using methods described earlier

Cost Analysis

- Examine major cost drivers within the TFDM program
- Apply risk reduction to impact the “high confidence” results
  - Reduce estimation parameter variance
  - Assume a small decrease in the point estimate due to NASA ATD-2 work
- Risk parameter adjustments
  - Reduced the variance parameter within a triangular distribution by 5%
  - Mode decreased by 2.5%

Cost Risk Parameters

- Major Cost Drivers
  - Prime Mission Product Application Software
  - Prime Mission Product Platform Integration
  - Prime Mission Product Management
- Base risk elements
  - Triangular: min/mode/max
- SME based estimate of impact
  - Mode-Min/Max-mode reduced by 5%
  - Mode reduced by 2.5%
- Only impacts F&E (Capital) budget items. Operations are assumed to be unaffected

NAS-wide Cost Results

- Overall impact was to reduce cost by 3.5%
- Costs dropped from $1.3 B (RATY$) to $1.25 B a savings of $50 M (life-cycle)
- We consider this a conservative estimate
  - ATD-2 will help with development costs
  - Define interfaces
  - Provide direction based on proto-types

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BENEFITS COSTS ANALYSIS

Economic Analysis

- Apply changes to cost & benefits to the base TFDM B/C ratio and NPV metrics
- Methodology
  - $(B/C)_{TFDM}$ =1.03, gets adjusted via
    - $(B/C)_{ATD2}=(B_{TFDM}*B_{ATD2}\%)/(C_{TFDM}*C_{ATD2}\%)$ is the adjusted 20th percentile Benefits to Cost ratio
  - No change in schedule assumed
  - $B_{ATD2}\%=1.77$; $(B/C)_{ATD2}$ ATD2%=0.965
  - $(B/C)_{ATD2}$ = 1.77/0.965*1.03 = 1.89
- NPV is calculated similarly and changes from
  - $17M to nearly $500 M (PV$)

Large improvement in ROI metrics

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CONCLUSIONS, LESSONS LEARNED, AND FUTURE WORK

Conclusions

- ATD-2 offers significant taxi-out time savings benefits at congested airports in the NAS, without having negative impact on taxi-in times, OFF time performance and airport throughput
- Annual total of 3.5 million minutes of reduced taxi-time and nearly 400K minutes of early off times (delay savings) at CLT, EWR, and DFW
- $2.6 Billion in monetary benefits nationwide due to significant reduction in delay as well as gate hold time
- ATD-2 benefits significantly outweigh the implementation costs, NPV increased from $17M to $500M (PV$)
- Incorporation of ATD-2 into the FAA's TFDM system significantly improves the B/C ratio of the TFDM program from 1.03 to 1.89

Lessons Learned

- ATD-2 benefits can be enhanced by making adjustments to scheduling algorithms, prediction methods, and implementation procedures
  - ERUT estimation accuracy hinders ATD-2 benefits at EWR and DFW
  - Taxi-out time uncertainty results in inefficient computation of TOBTs
  - Certain runway configurations present unique challenges
  - Prioritization rules result in sequence jumps when a departure flight transitions from “Uncertain” to “Planned” status and from “Planned” to “Ready” status
  - New York TRACON needs a multi-airport, hierarchical departure scheduling solution

Future Work Ideas

- Simulation based assessments to evaluate ATD-2 enhancement alternatives for
  - ATD-2 spacing algorithms, especially for parallel dependent runways
  - Managing uncertainty in taxi-out times
  - Prioritization rules changes
  - Hierarchical multi-airport scheduling
- Operational data analysis (Benefits computation from operational data)
  - Pre- versus post- implementation comparison for “similar” time-periods
  - Measure other benefits, e.g., ON-time performance, NAS network predictability, throughput
- Simulation based analysis of extending ATD-2 and TBFM type scheduling to multiple Centers and metroplexes, e.g., Northeast Corridor
- Leverage analysis framework for assessing technologies in other NASA research areas
  - Integrated Demand Management (IDM)
  - Increasing Diverse Operations (IDO)

Acknowledgements

- Thanks to Rich Coppenbarger and the rest of the NASA ATD-2 team for support of this research work

- Thanks to the NASA ATD-2 research group and ATD-2 fast time analytics research group for their feedback and support throughout the project

- Thanks to Eric Chevalley, Todd Callantine, and Al Capps for sharing airspace configuration data and information on airspace procedures

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QUESTIONS

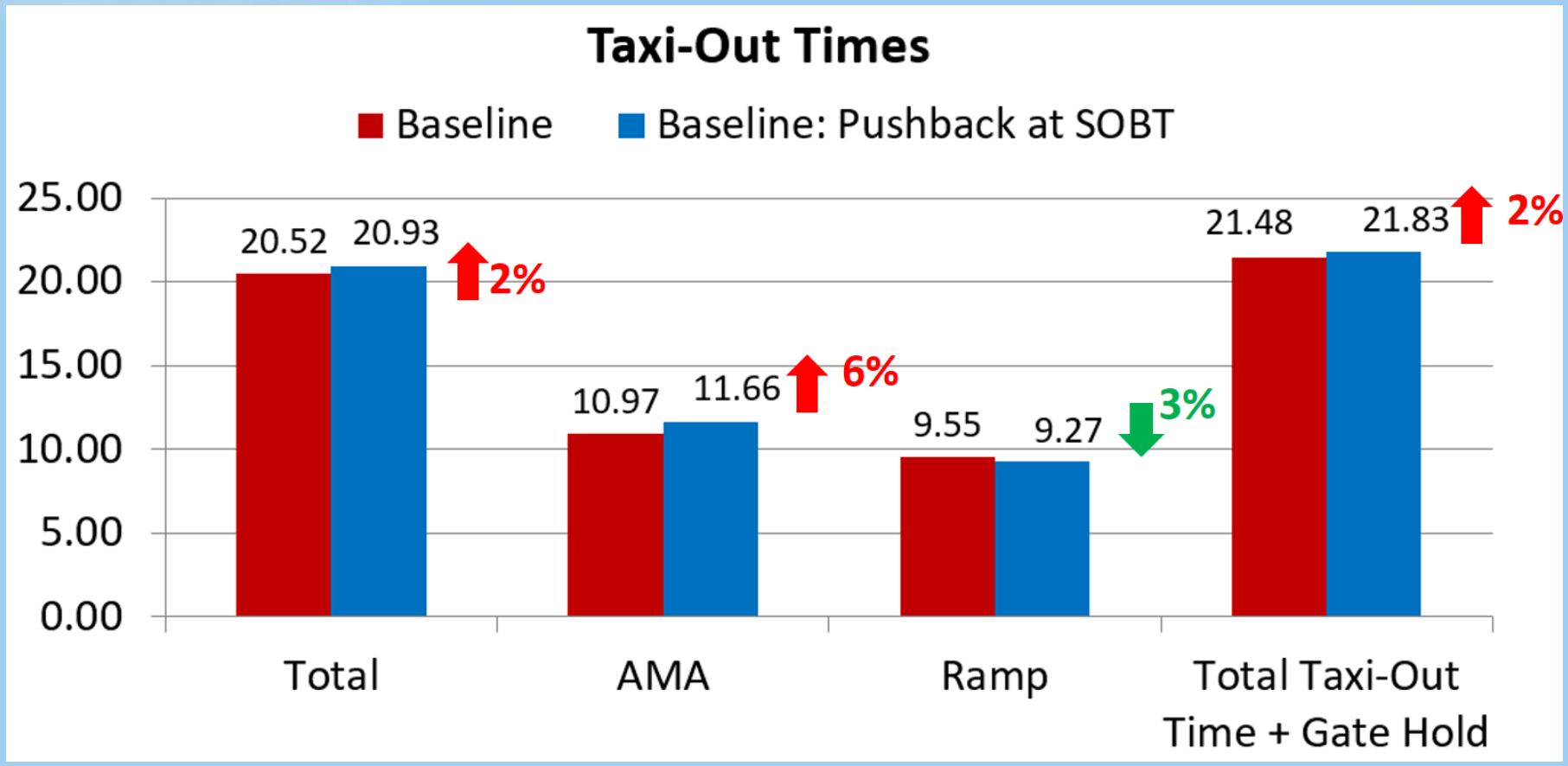
Sensitivity Tests

1. Assess the effects of departure flights pushing back at exactly their Scheduled Off Block Times

2. Assess the benefits of adding Phase II functionality: Strategic Scheduler for optimum queue delay buffer parameter setting, and

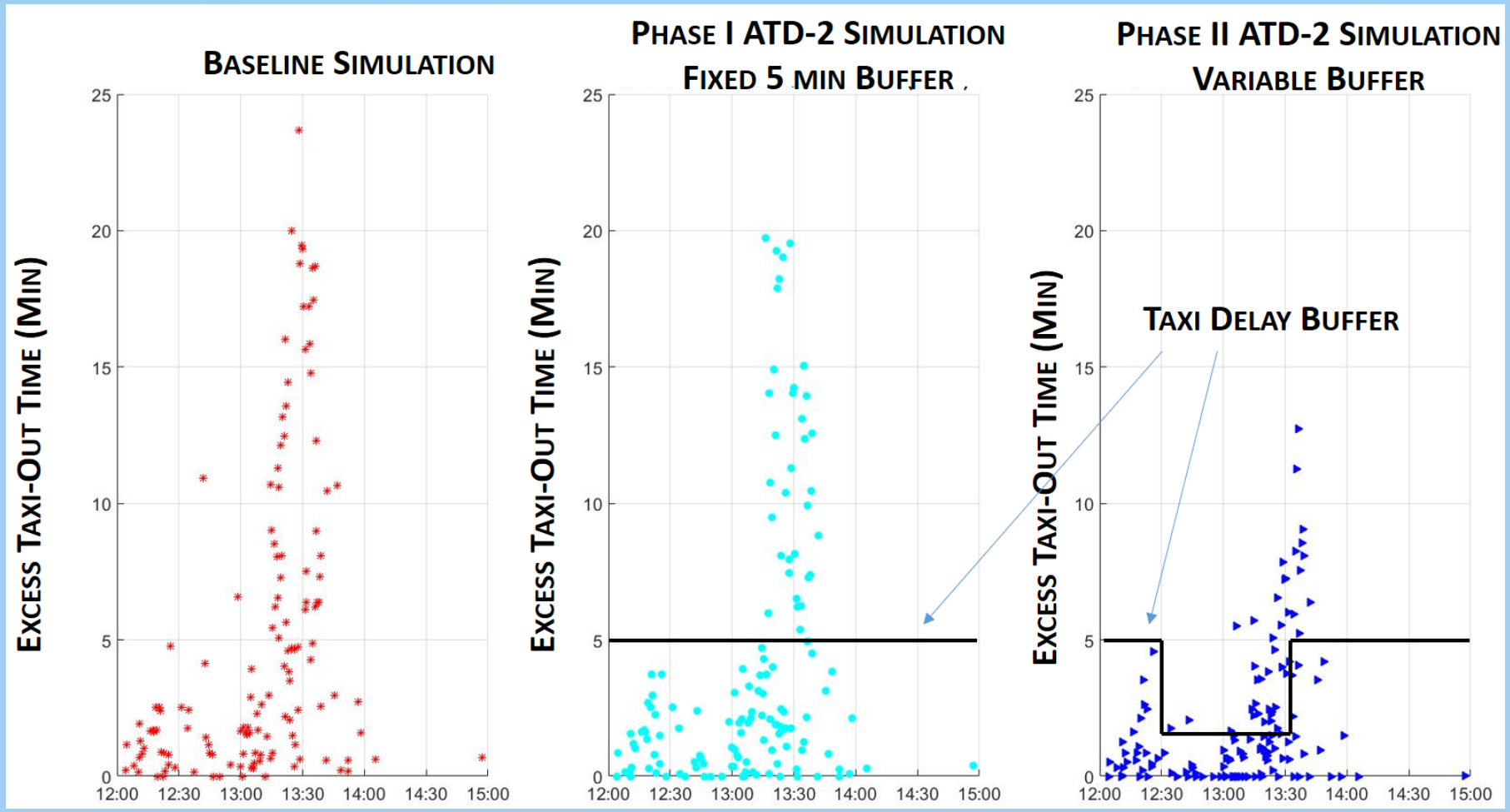
3. Leverage a past simulation study to assess the benefits of adding Phase III Integrated Airspace Scheduling capability, focused on the New York airspace

Sensitivity Test # 1: Pushback at SOBT

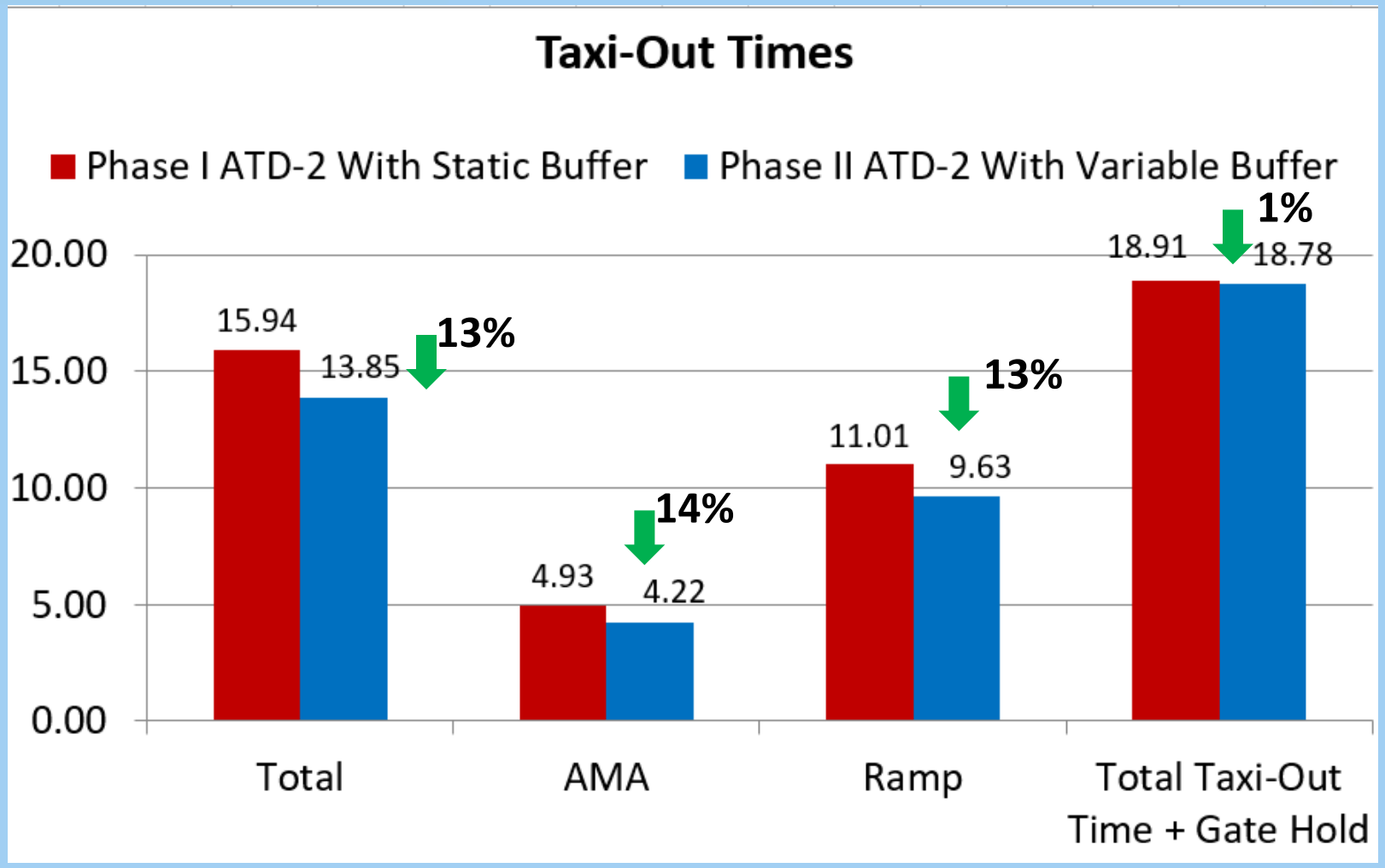


All departure flights pushing back exactly at their SOBTs increased the taxi-out times by around 2%, with 6% increase in AMA taxi-out times

Sensitivity Test 2: ATD-2 Phase II Benefits

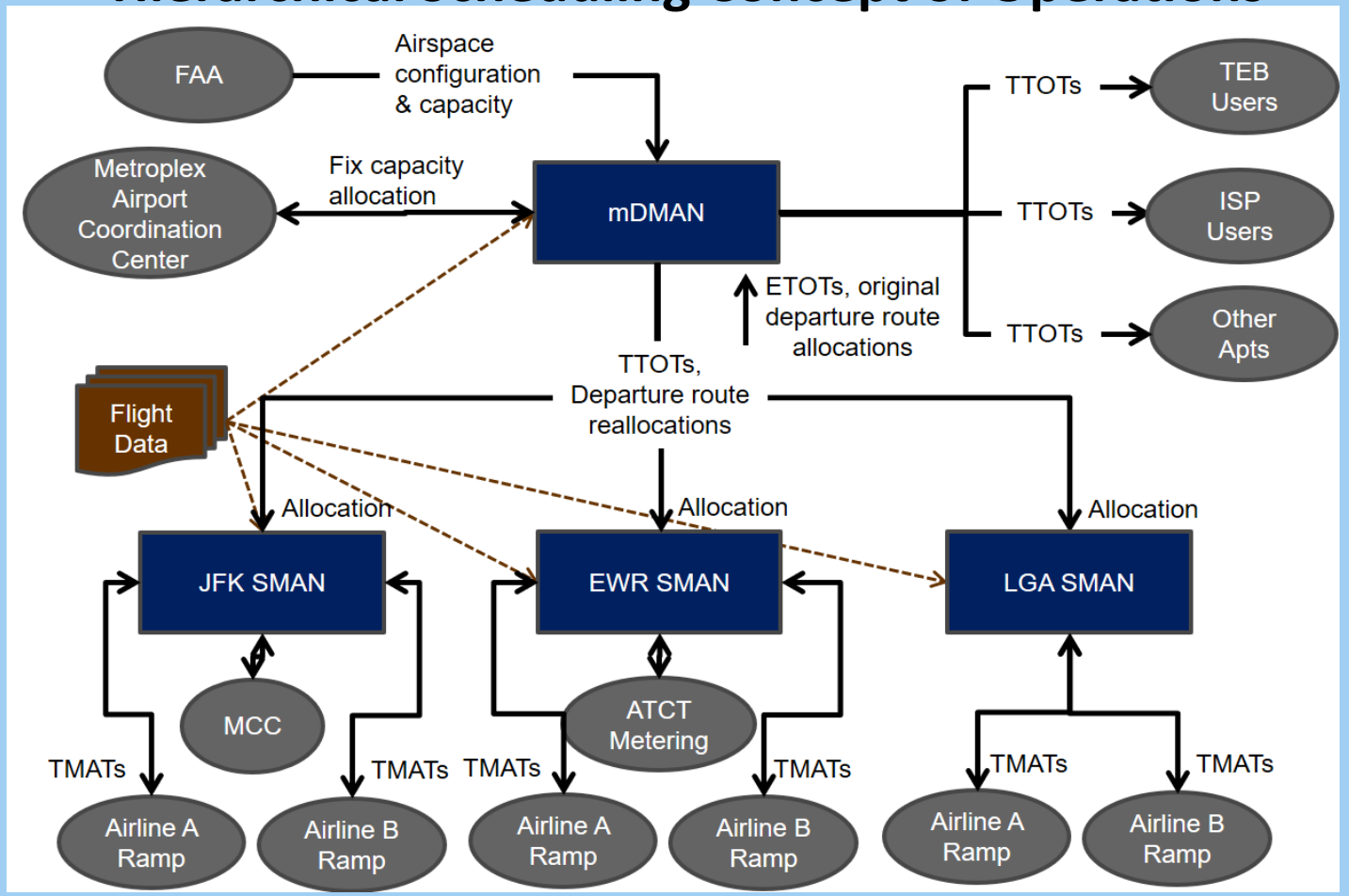


Sensitivity Test 2: ATD-2 Phase II Benefits



Sensitivity Test 3: Phase III Airspace Scheduling Benefits

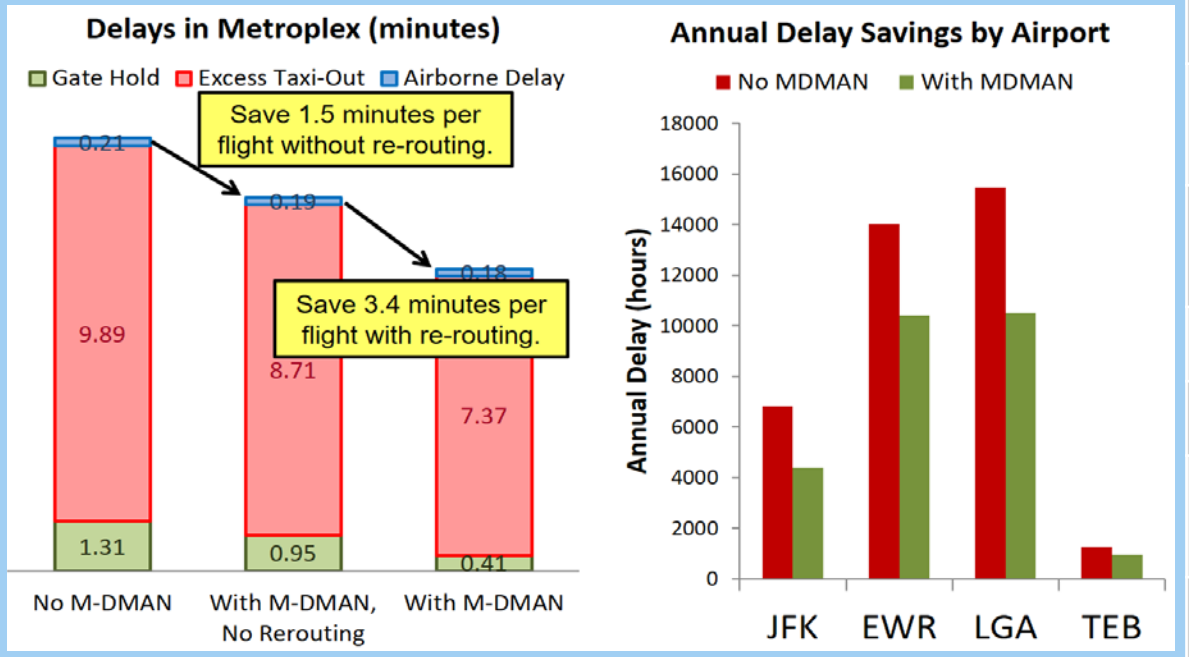
Hierarchical Scheduling Concept of Operations*



**Leverages past study: [SL14] Saraf, A., Levy, B., Stroiney, S., Griffin, K., "Metroplex Departure Management," Final presentation for Saab Sensis R&D project.*

Sensitivity Test 3: Phase III Airspace Scheduling Benefits*

Simulation-based Benefits Estimates



**Leverages past study:*
[SL14] Saraf, A., Levy, B., Stroiney, S., Griffin, K., "Metroplex Departure Management," Final presentation for Saab Sensis R&D project.

Annual Benefits

Quantity	Savings
Taxi-Out Duration	8,300 hours
Total Delay in Metroplex	11,400 hours
Fuel	1.4 million gallons
Fuel Cost	$ 4.2 million
Operating Costs	$ 26 million
CO_2 Emissions	13,500 metric tons
Passenger Time	34,000 person-days
Passenger Time @ $30/hr	$ 25 million
Passenger Time NAS-wide	$ 36 million

Top Delay Locations (Baseline North Flow)

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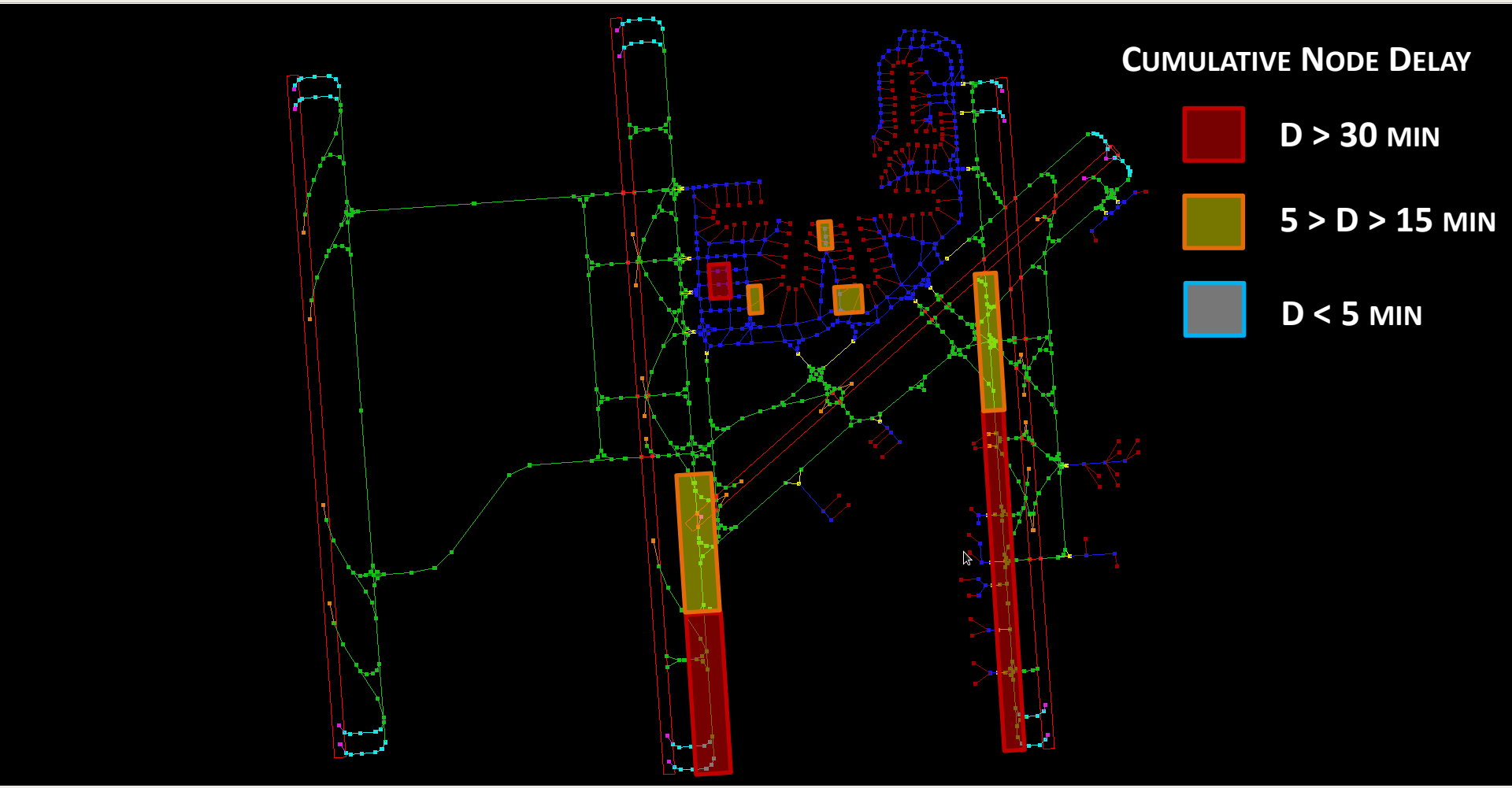
File Configuration View Preferences Tools Help Mode



CLT3, south_flow1, /scenario_data_official/CLT_20160602_0110000_012_15_south_flow1_Scenario_data.list_data_pushTimes

Simulation time and FTG info

Mouse Position: (578.76, -1697.27)

Top Delay Locations (ATD-2 North Flow)

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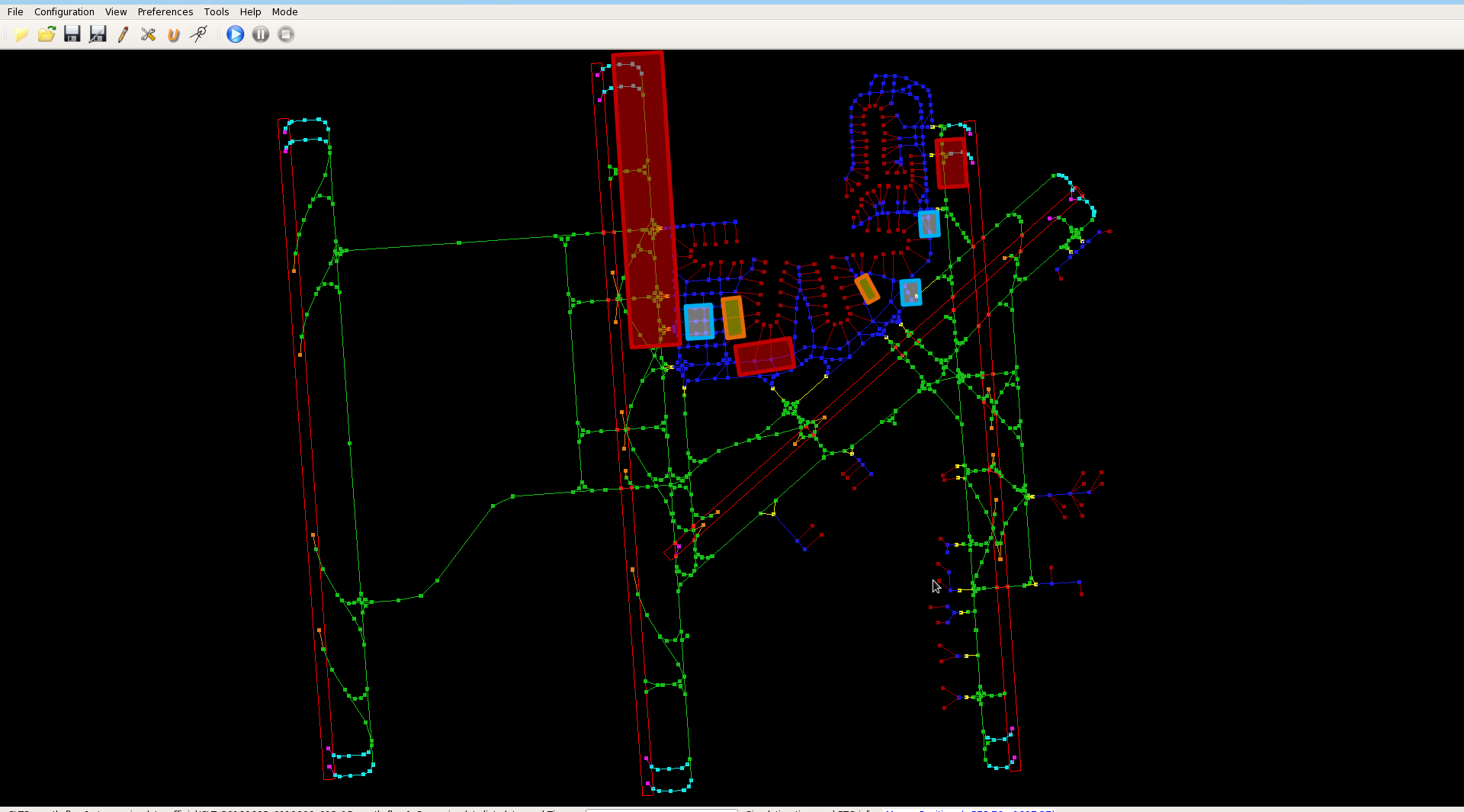
File Configuration View Preferences Tools Help Mode

CLT3, south_flow1, /scenario_data_official/CLT_20160602_0110000_012_15_south_flow1_Scenario_data.list_data_pushTimes

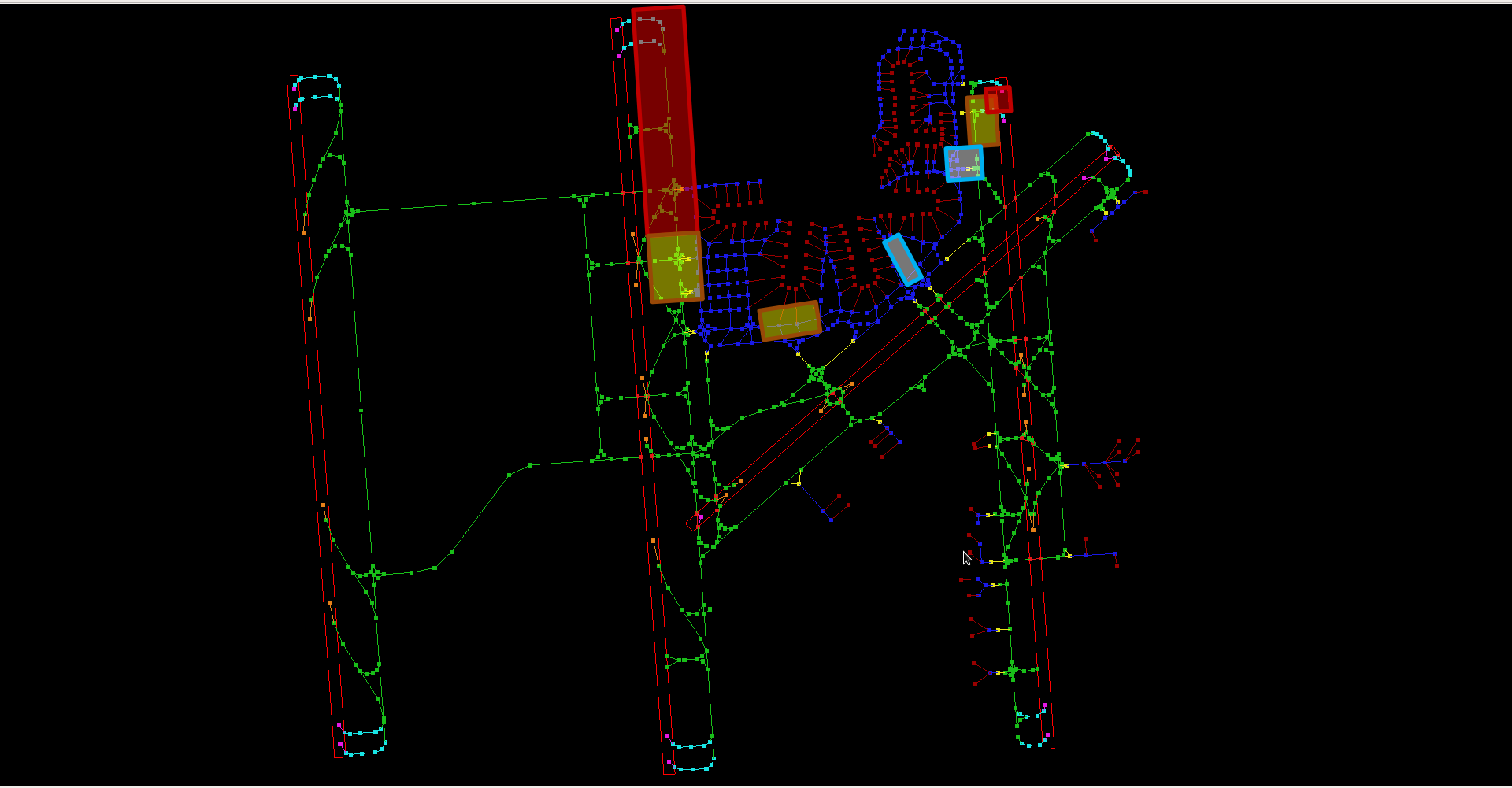
Simulation time and FTG info

Mouse Position: (578.76, -1697.27)

Top Delay Locations (Baseline South Flow)



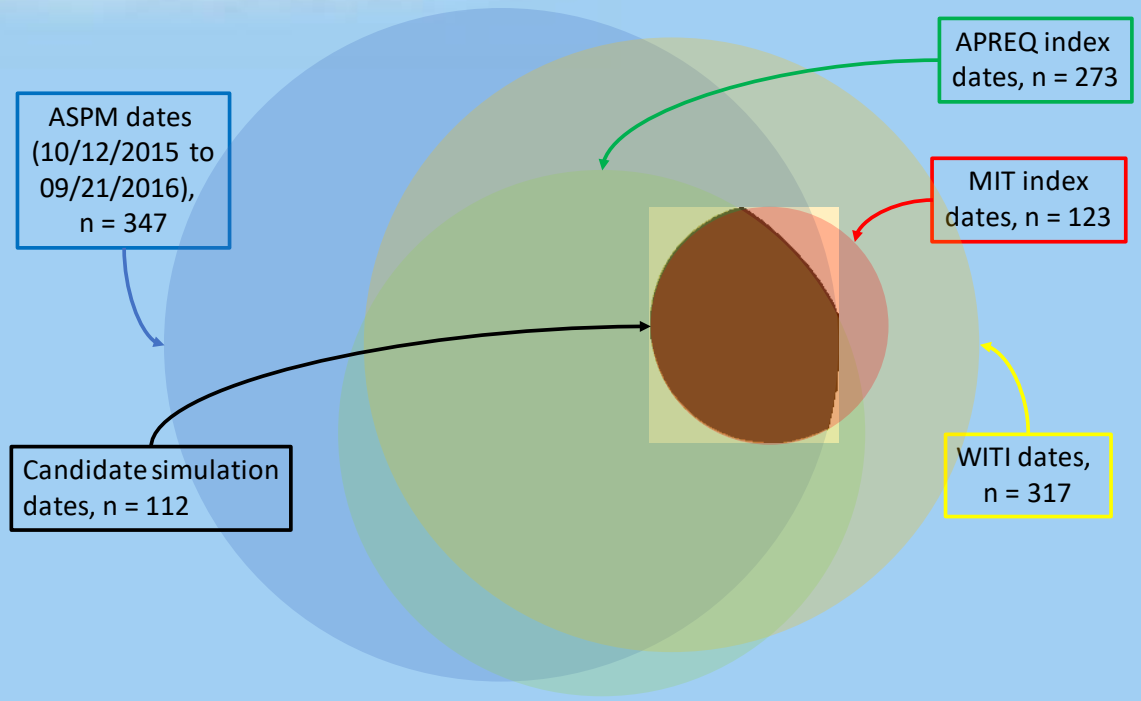
Top Delay Locations (ATD-2 South Flow)



SOSS Problems

- Gridlock – multiple gridlock situation types
- SOSS not holding flights on departure runway queue nodes and departure node
- SOSS not able to change taxi route and hold flight at gate, at the same time
- SOSS misses sending certain delayed flights' information to the scheduler at consecutive scheduler calls, although the flights are active (i.e., at gate)
- Strange behavior by certain arrival flights – they just stop at a node and don't move (even when there is no active STR)
- Cancelling an STR by using -2 doesn't always work

Venn Diagram of Simulation Data



MIT Indices (n = 123)

APREQ Indices (n = 273)

Sort, Rank
n = 1 .. 123
$0 \le Pr(R_i) \le 1$

Sort, Rank
n = 1 .. 273
$0 \le Pr(R_i) \le 1$

ASPM Data (n = 347)

Sort, Rank
n = 1 .. 347
$0 \le Pr(R_i) \le 1$

WITI Scores (n = 317)

Sort, Rank
n = 1 .. 317
$0 \le Pr(R_i) \le 1$

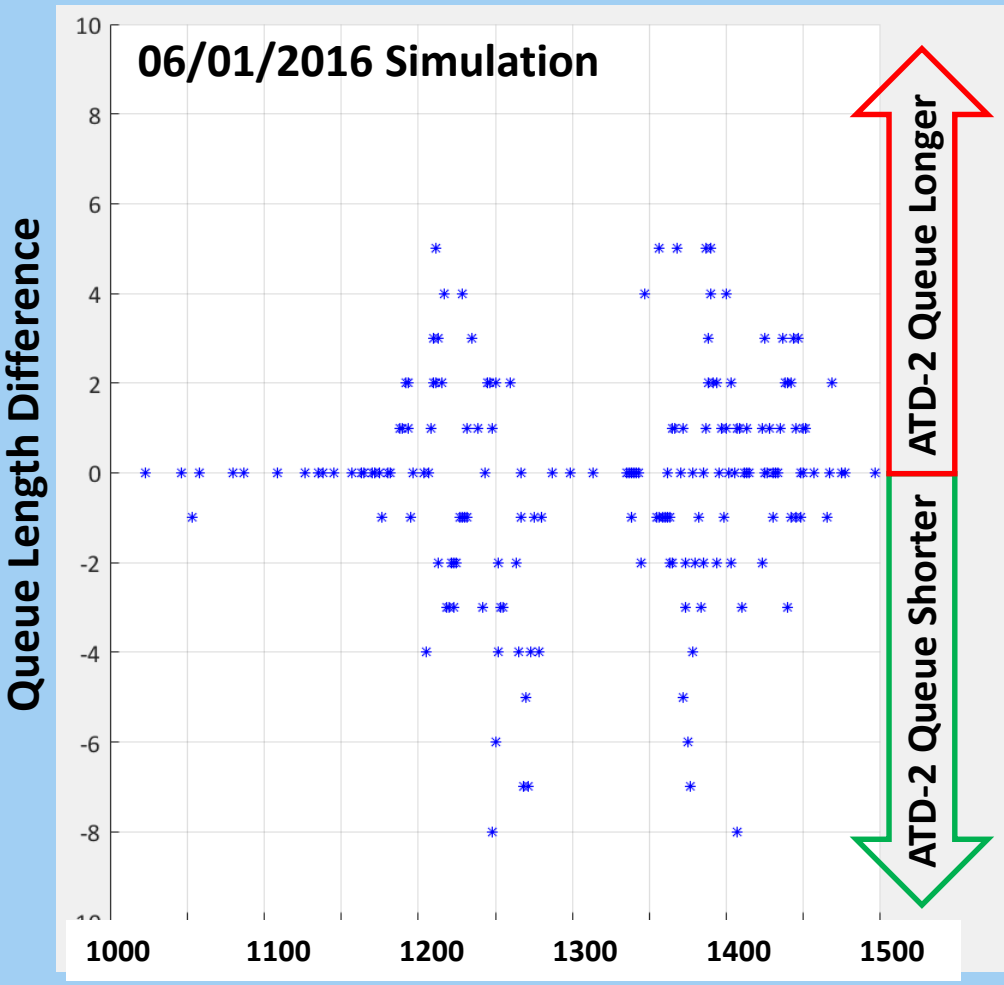
Intersection Set (n = 112)

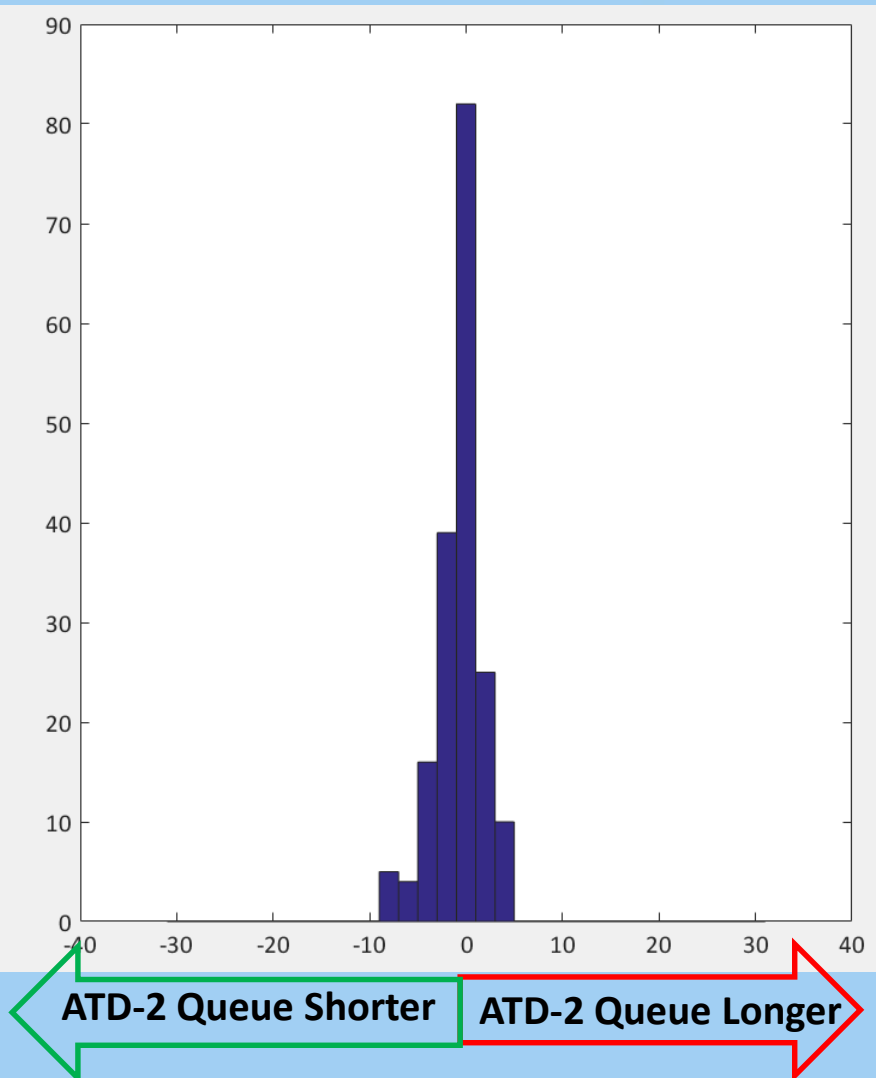
$R_i = Rank(Pr_{i,j})$ (n = 112)

Tercile Grouping

Departure Queue Length Comparison

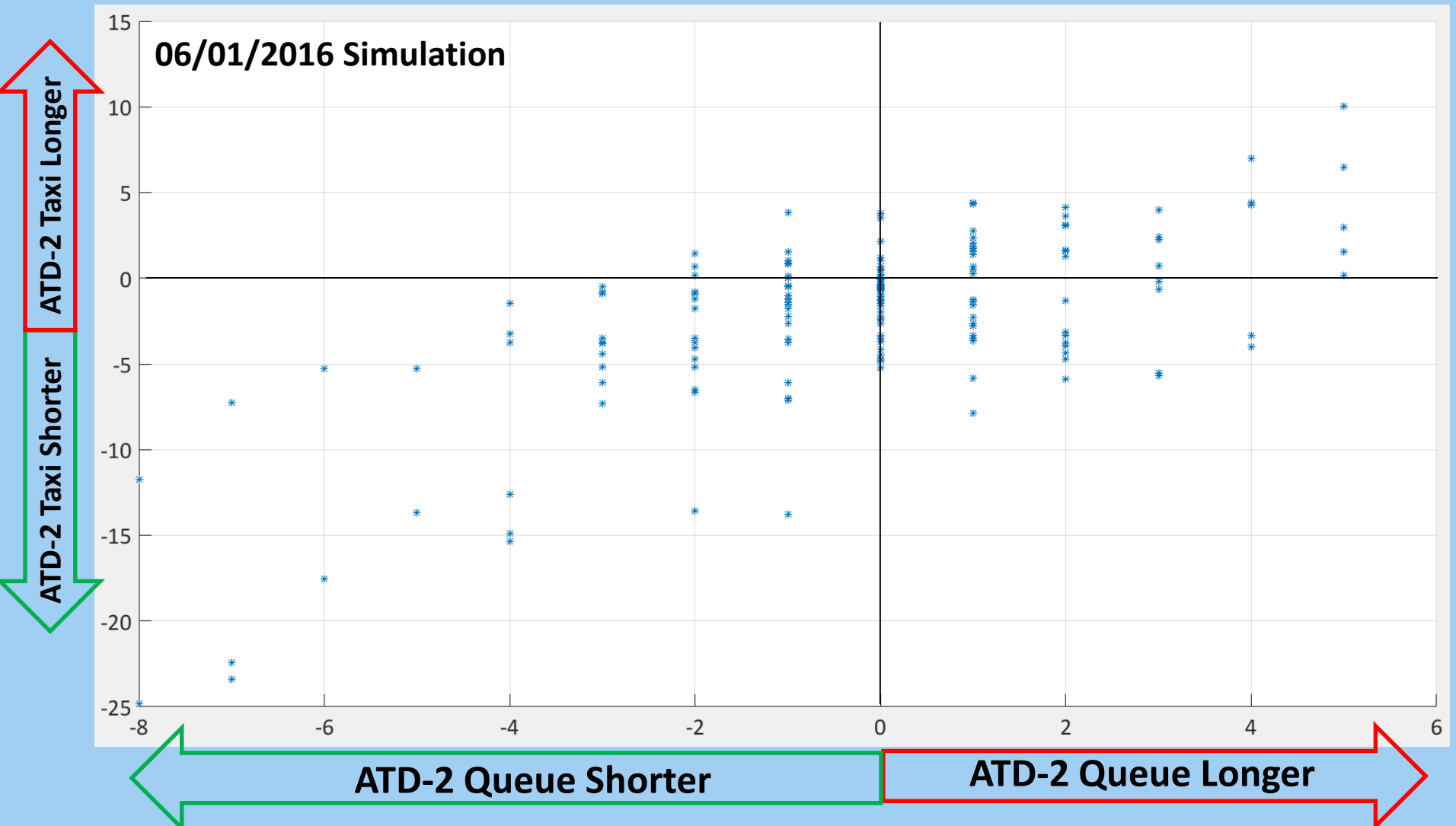
Simulated Departure Queue Length Experienced Difference
ATD-2 Sim Flight – Baseline Sim Flight





Taxi Out Time VS Departure Queue Length

Taxi Out Time Difference as a function of Departure Queue Length Experienced Difference



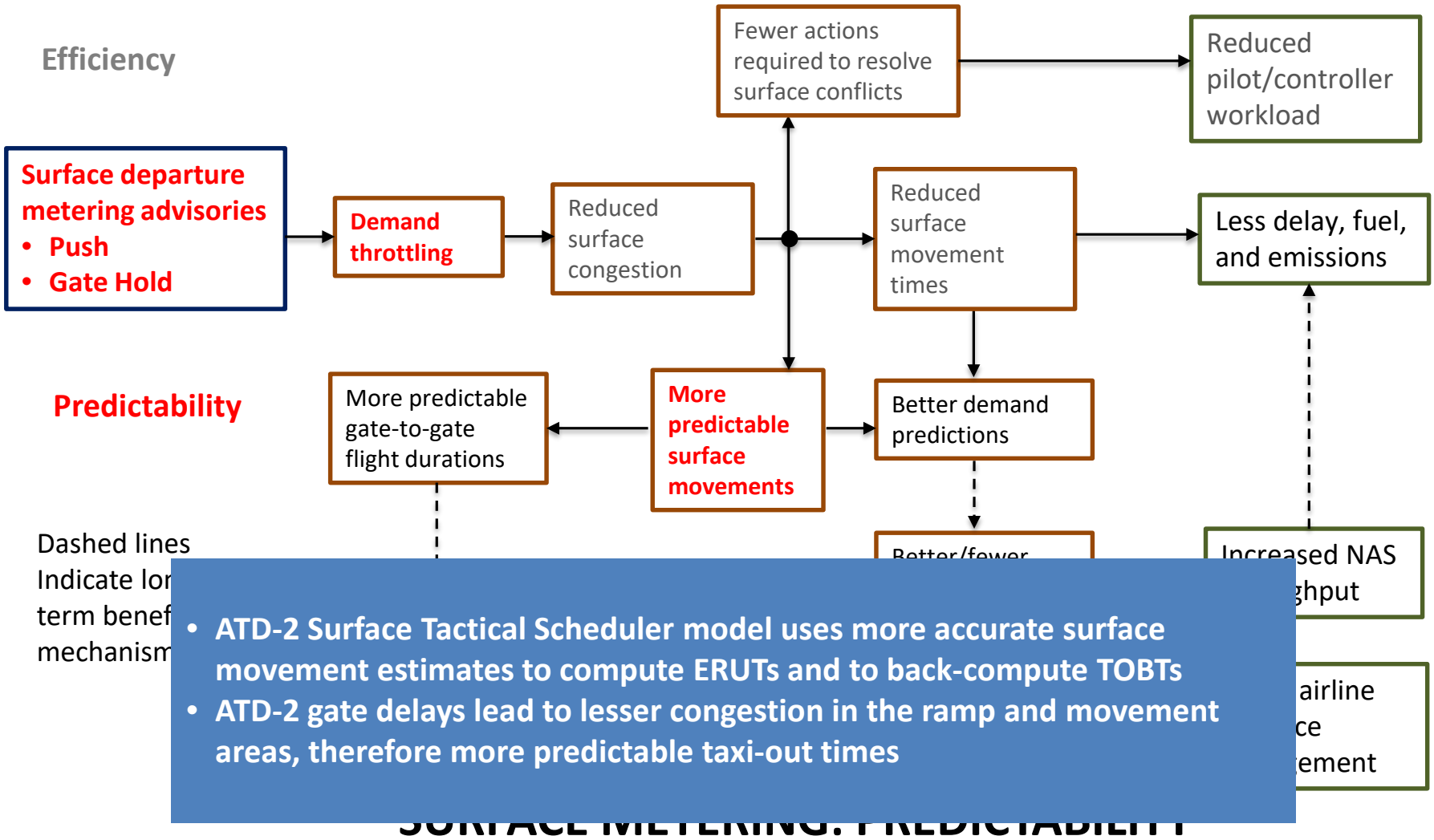
Forecast – Future Years

- FAA Policy Office (APO)
  - Provides forecast for future demand at annual airport level
    - AJR (SysOps) provides a flight level forecast if needed
  - Due to unknown changes in capacity (e.g., new runways, NextGen, etc) growth is generally capped at 10 years by IP&A Policy
  - Apply simple queuing theory algorithm

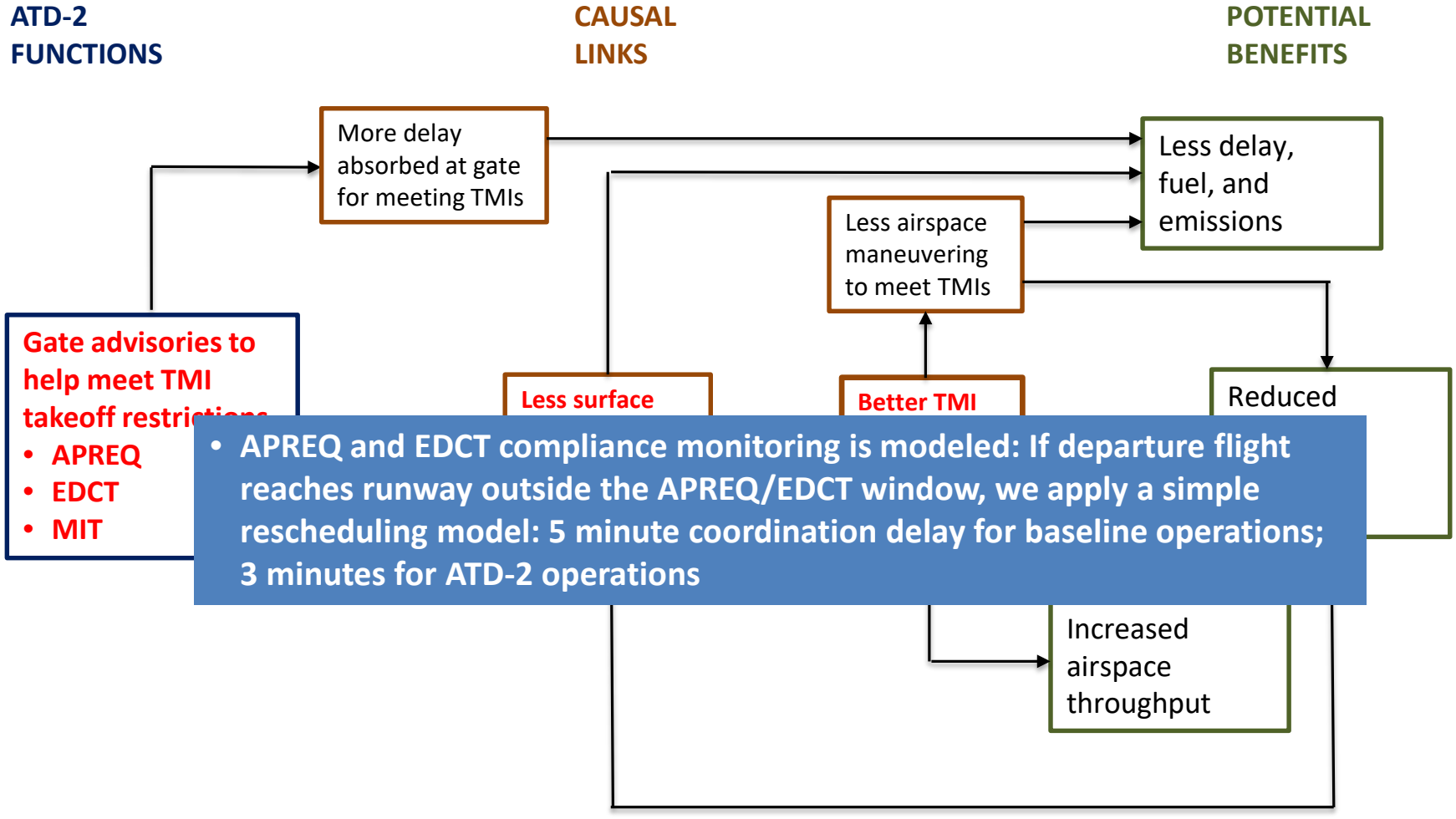
$$Delay \cong Delay_{Base} * \frac{(1-\frac{\sigma}{\mu})}{(1-\frac{\sigma_2}{\mu_2})}$$ where

σ is the demand and μ is the capacity. Capacity generally is assumed constant, or adjusted only if "known" changes

Modeling of ATD-2 Benefit Mechanisms

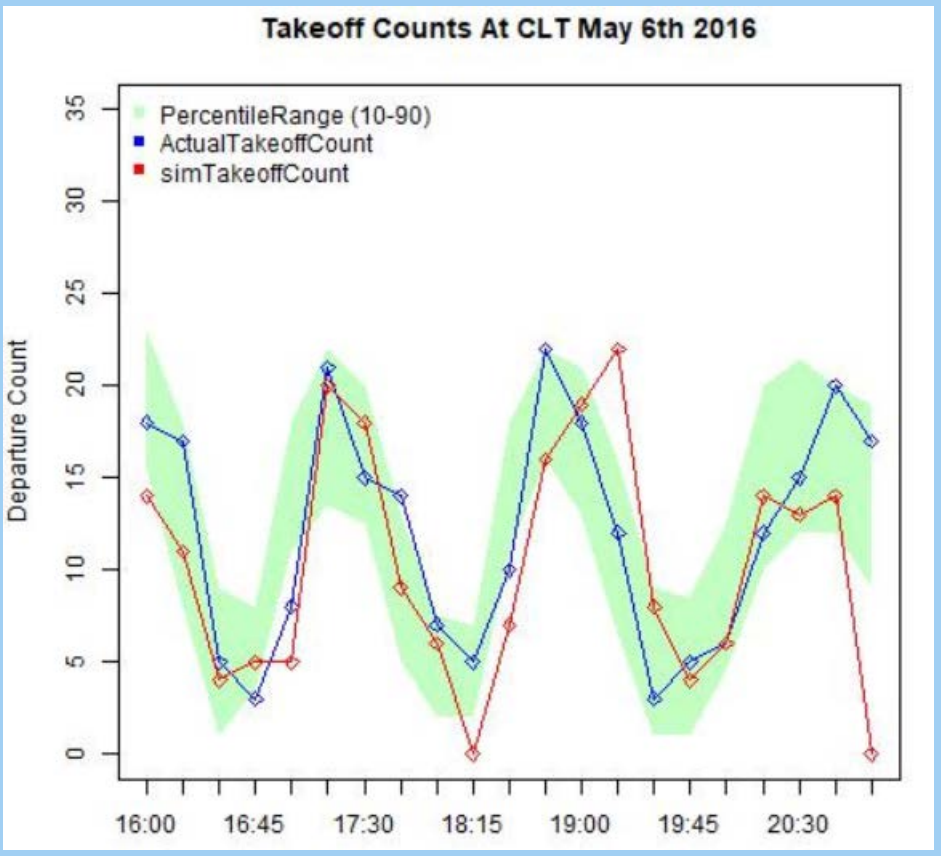


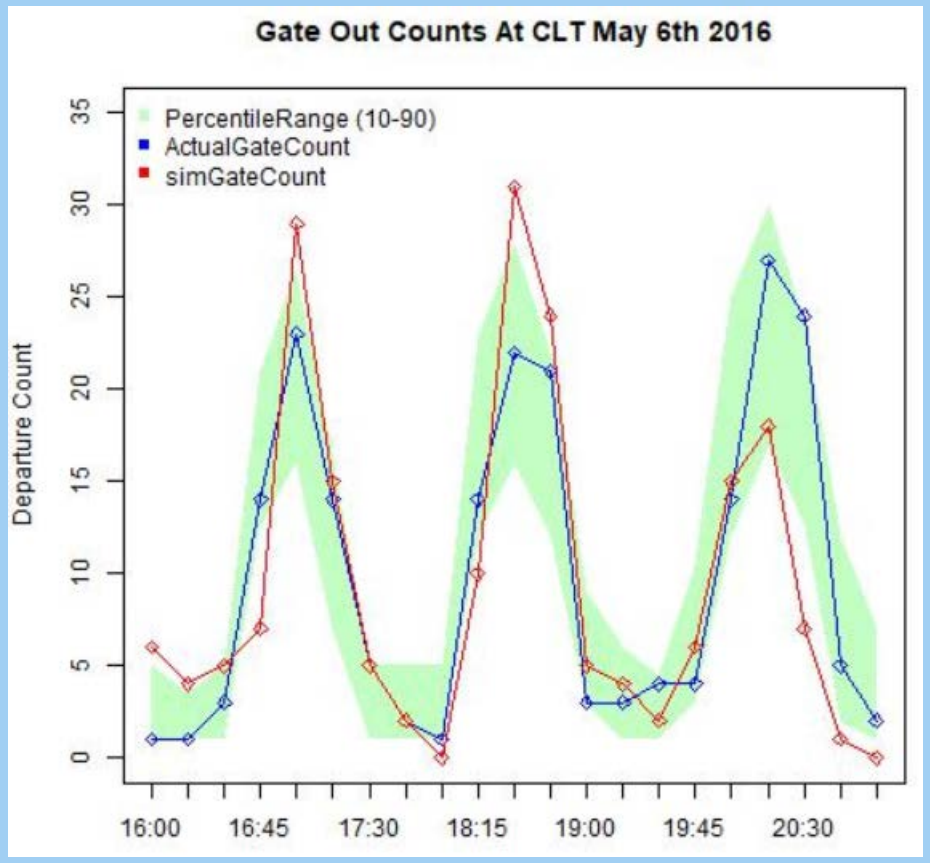
Modeling of ATD-2 Benefit Mechanisms



Validation: Runway and Gate Counts

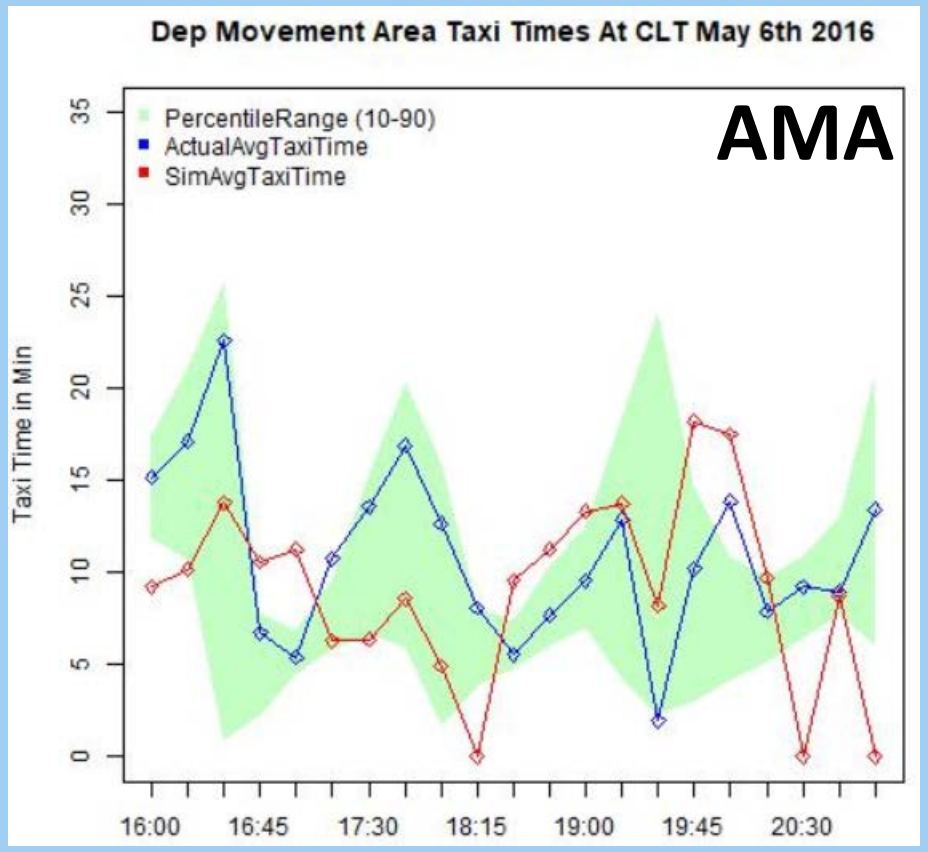
Sim #2: 05/06/2016, North Flow, 1600-2100 UTC

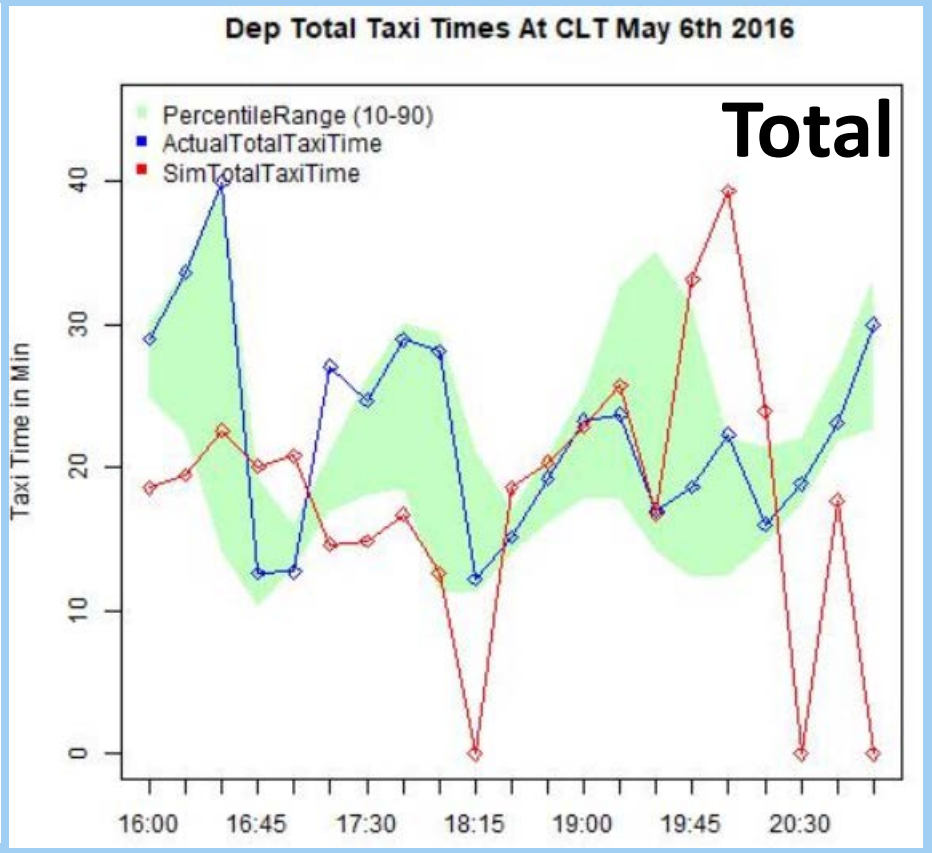




Validation: Taxi-Out Time

Sim #2: 05/06/2016, North Flow, 1600-2100 UTC





Technical Tasks

Task 1: Identify Operational Shortfalls and Benefit Mechanisms
- Stakeholder interviews, Data Analysis, Causality Analysis

Task 2: Site selection
- Operational data analysis for Core 30 FAA airports

Identified Benefit Mechanisms, Shortfalls, Benefit Metrics for modeling in Simulation Platform

Additional Simulation Modeling Requirements

Three Selected airports for high-fidelity simulation

Task 3: Simulation Platform Development
- Airport surface (SOSS) and Airspace (AOSS) subsystems
- Baseline operations (current-day procedures)
- ATD-2 Operations (Tactical Scheduling Algorithm, Data Exchange)

Task 4.1: Experiment Design
- Sim Day Selection from Annualization Perspective
- Sim Scenario Selection Per Selected Day

Surface-Airspace Simulation Platform
- Airport and Airspace Transit
- ATD-2 Departure Metering, Current-day and ATD-2 APREQ/EDCT Procedures

Selected Simulation Days/Scenarios
- Realistic gate, runway, dep fix, meter arc allocations
- Frequency of occurrence of similar days over the entire year

Task 4.2: Conduct Simulation Experiments
- Multiple sims per scenario to select appropriate taxi delay buffer

Per Airport Per Scenario Benefit Estimates

Technical Task (Cont.)