

# Distributed Schemes for Integrated Arrival Departure Surface (IADS) Scheduling

## NRA Year 1 Final Briefing

Husni Idris and Ni Shen  
(TASC an Engility Company)

Jason Bertino, Natasha Luch, Aditya Saraf  
(ATAC Corporation)

21 October, 2015

# Outline

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- Research Motivation and Objectives
- Recap of Year One Activities and Progress
- Discussion of Focus Areas of Year One
  - Integrated Scheduling between Surface and Airspace
  - Identification of Queue/Delay Buffer Sizes for Departure Metering
  - Integration of Arrival and Departure Scheduling
  - High-Fidelity Fast-Time Simulation Modeling
- Proposed Year 2 Work

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# Motivation and Background

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- Solutions to mitigate delays focused historically on components of the system and resulted in separate tools, for example:
  - Traffic Management Advisor for arrival metering at TRACON entry points
  - Departure metering to absorb delay at gate/ramp rather than on airport movement area
  - Departure precision release to merge in overhead streams, etc.
- Integration is needed in order to reap the benefits envisioned by the isolated systems
- NASA is undertaking major efforts to demonstrate and mature integrated packages of decision support tools
  - ATD-1 focused on integrated arrival management
  - ATD-2 focused on integrated departure management, in addition to ATD-1

# Motivation and Background – What is ATD-2

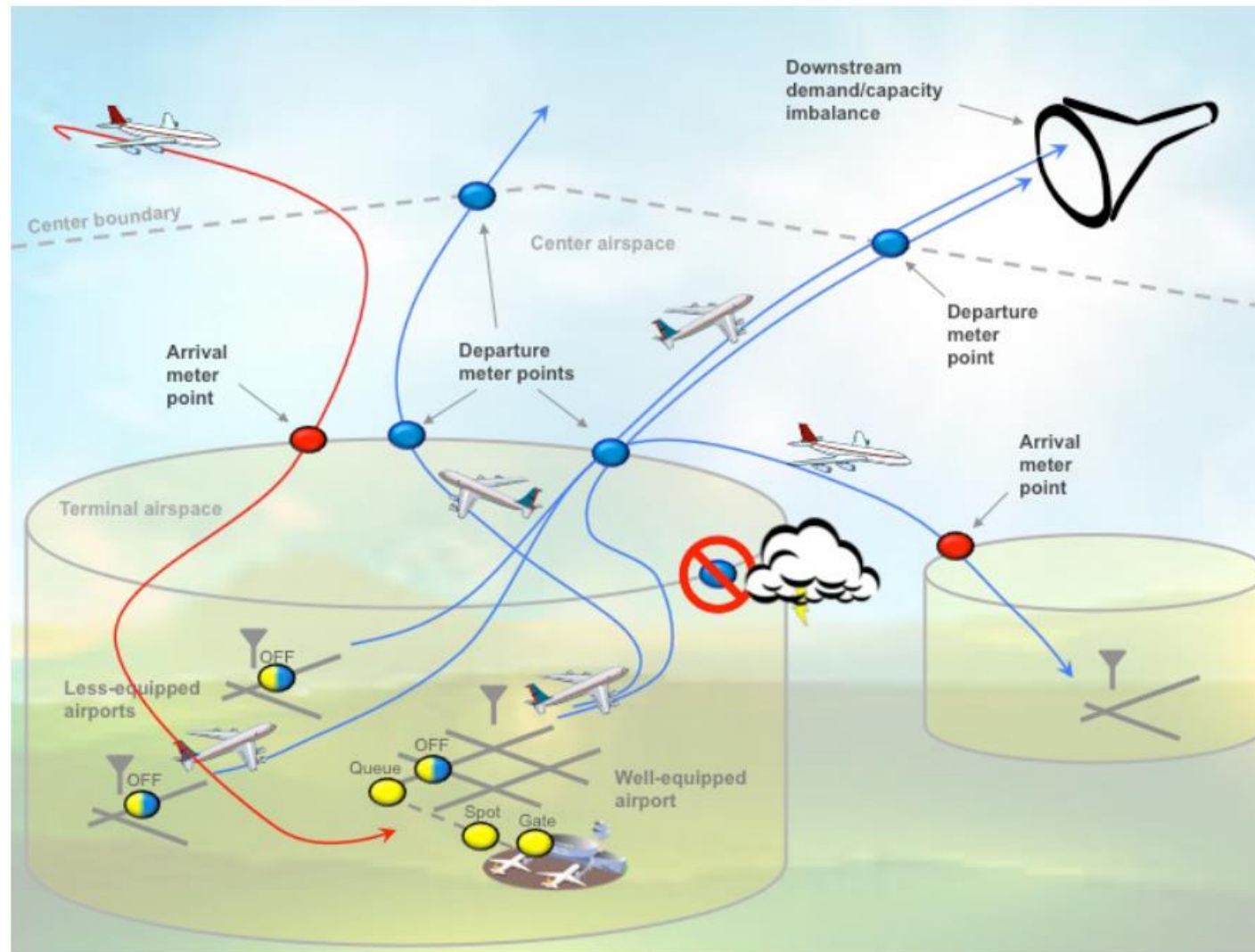


Figure taken from NASA ATD-2 team presentation

# Objectives and Scope

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- Investigate and develop integrated scheduling solutions for arrival, departure and surface operations
  - Identify and address gaps and needs associated with integrating arrival, departure and surface operations
  - Develop methods for integrating arrival, departure and surface operations
  - Analyze benefit cases of new methods relative to current operations
  - Investigate technology and human factor requirements for new methods

# Objectives and Scope

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- Main tasks
  - Identify gaps and needs based on literature review
  - Identify and model real-world cases
  - Develop concepts and architectures for distributed scheduling
  - Prototype concepts in Matlab environment
  - Implement concepts in high fidelity fast-time simulation platform
  - Conduct performance analysis of concepts

# NRA Year 1 Tasks

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- Task 1: Literature Review
- Task 2: Identify and Downselect Real-world Arrival-Departure-Surface Interaction Cases
- Task 3: Concept and Algorithm Development
  - Terminal scheduling algorithm development
  - Prototype model development
  - SOSS (high-fidelity) model development
- Task 4: Prototype Simulation-based Assessments



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# Literature Review

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- Delivered in October 2014
- Focused on scheduling algorithms that integrated arrivals and departures
- Twenty approaches reviewed and ranked based several criteria
- Key insights:
  - Most approaches were centralized, limited consideration of collaboration with users
  - Most approaches were static, some were dynamic
  - Most approaches were deterministic, few handled uncertainty with buffers and few with statistical averaging of possible scenarios
  - Computational issues handled mostly through multiple problem stages, windowing, limited position shifting
  - Increased interest in genetic algorithm approaches

# Selection of Real World Interaction Cases

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- Original requirements included at least one case from NY metroplex and at least one case outside it
- Conducted site visits to NY: JFK, EWR, LGA and ZNY and subject matter expert (SME) interviews
- Conducted site visits to ATL, A80 and ZTL and SME interviews
- Conducted SME interviews with CLT, NoCal and SoCal in collaboration with subtopic one.
- Analyzed PDARS data to visualize interactions
- Identified and down-selected cases focusing on major airports and arrival-departure interaction, included in delivered report

# NASA's Feedback

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- Focus on ATL and then CLT as sites for analysis
  - NY may be of interest later in project but not in near term
- Focus on departure scheduling algorithms primarily
  - Consider ATD-2 relevant approaches in near term
  - Consider arrival-departure interactions from departures' perspective
- Perform preparatory tasks to support potential use of SOSS simulation in Year 2
  - Develop ATL model in SOSS
  - Leverage NASA's work on interfacing SOSS and ACES
  - Learn building scheduling models in SOSS

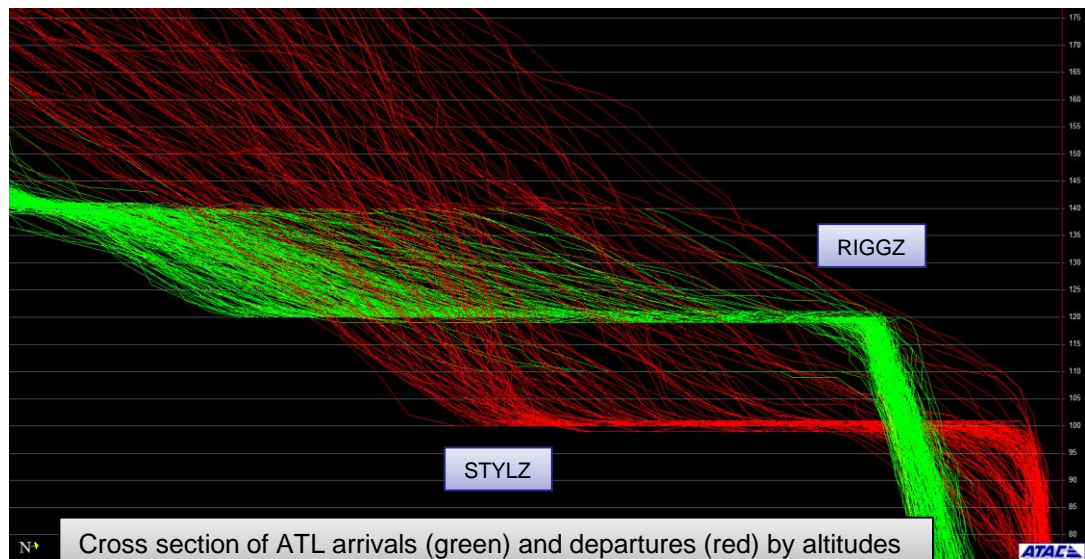
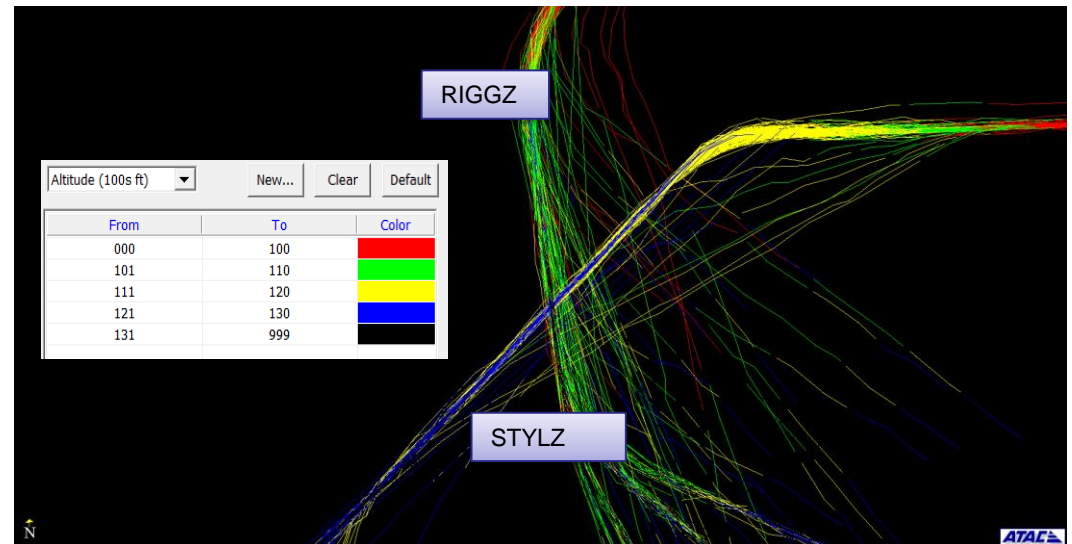
# Selection of Real World Interaction Cases

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- NY was not selected as site for analysis, however, insights gained were relevant to ATD-2, for example:
  - JFK experience with departure metering including
    - Proper sizing of queue buffers set originally at eight aircraft, resulting in runway starvation, then reset at twelve aircraft
    - Transparency to air traffic controllers to avoid impacting their workload
    - Collaboration using ‘snow desk’ approach
  - LGA constraints limiting departure metering application
    - Limited availability of gate/ramp to hold metered departures
    - One-to-one arrival departure operation
  - Lack of ability to conform to restrictions
    - Main concern is to keep flow of traffic moving
    - Make best effort to comply with restrictions
  - Interactions with secondary airports are significant (some cases are included in delivered report)

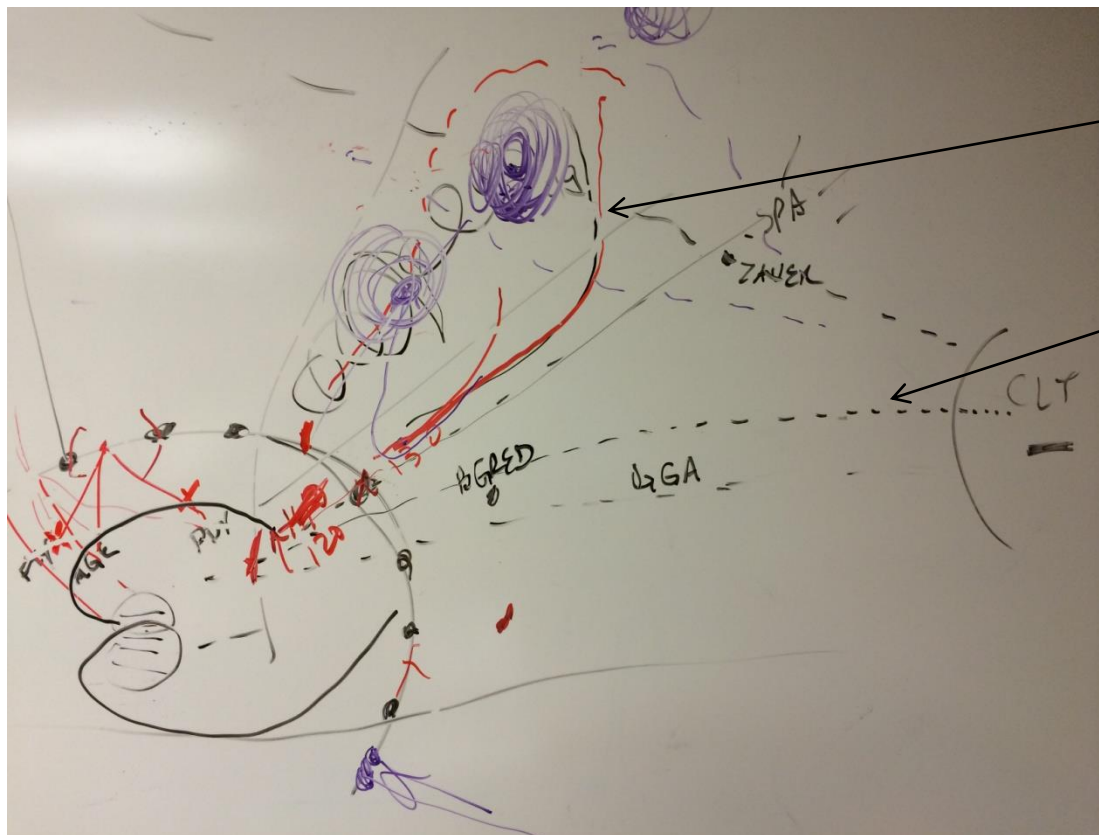
# Selection of Real World Interaction Cases

- ATL metroplex was recommended as potential site and selected with CLT as second site
- Initial analysis identified key arrival-departure interactions



# Selection of Real World Interaction Cases

- ATL metroplex was recommended as potential site and selected with CLT as second site
- Additional SME feedback identified key ATL-CLT interactions



Arrival holding and deviation infringes on departure flow and makes situation more constraining

CLT departure flow sandwiched between two major ATL flows to northeast – makes sector 28 very complex

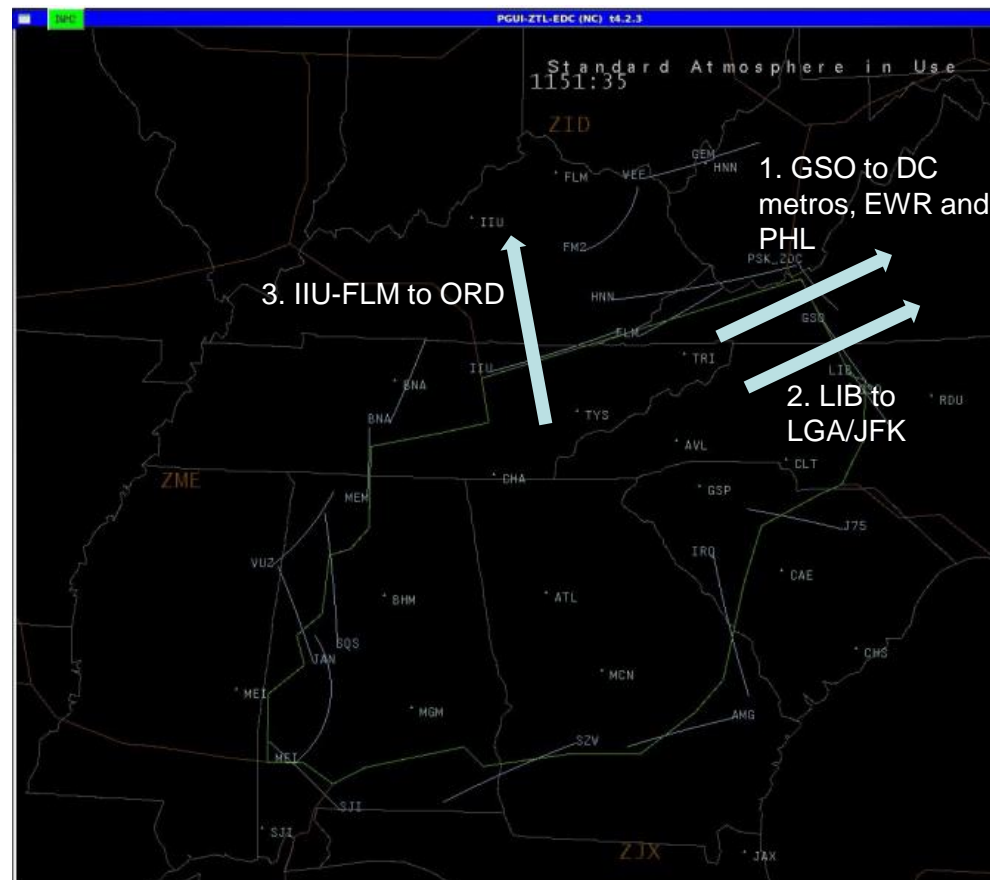
Deviations from ZID / VULKN reroute over ATL push traffic south (from ZID into ZTL to J22 and then J22 to J75) creating complex interactions

# Selection of Real World Interaction Cases

- ATL metroplex was recommended as potential site and selected with CLT as second site
- Additional SME feedback identified key en-route restricted flows

Busiest and most restricted gates are:

1. GSO
2. LIB
3. IIU/FLM

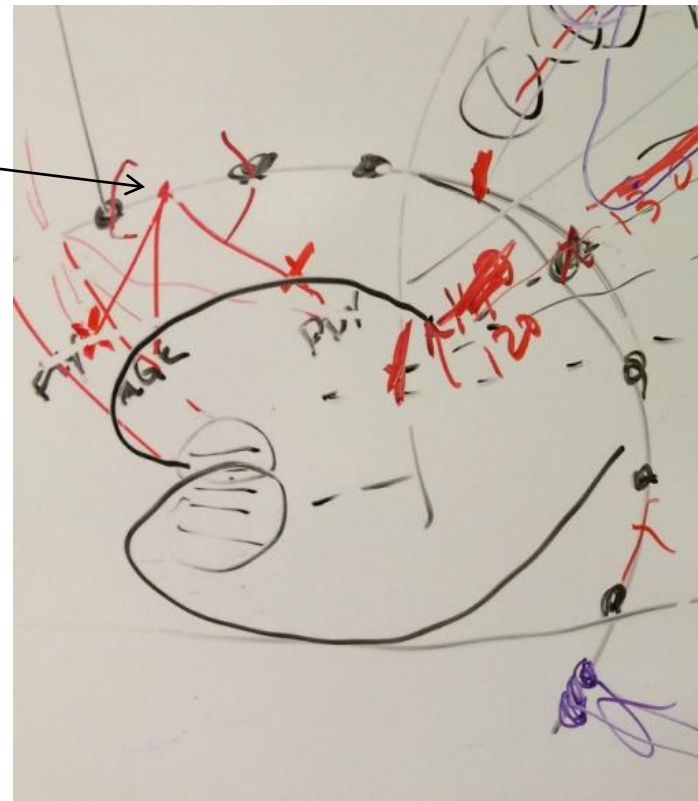




# Selection of Real World Interaction Cases

- ATL metroplex was recommended as potential site and selected with CLT as second site
- Additional SME feedback identified key interactions with secondary airports

Some jets from FLY/RQE/PDK share the northern gates with ATL at similar altitude. Issue is that distance between gates does not allow fitting the secondary traffic in without impacting ATL traffic



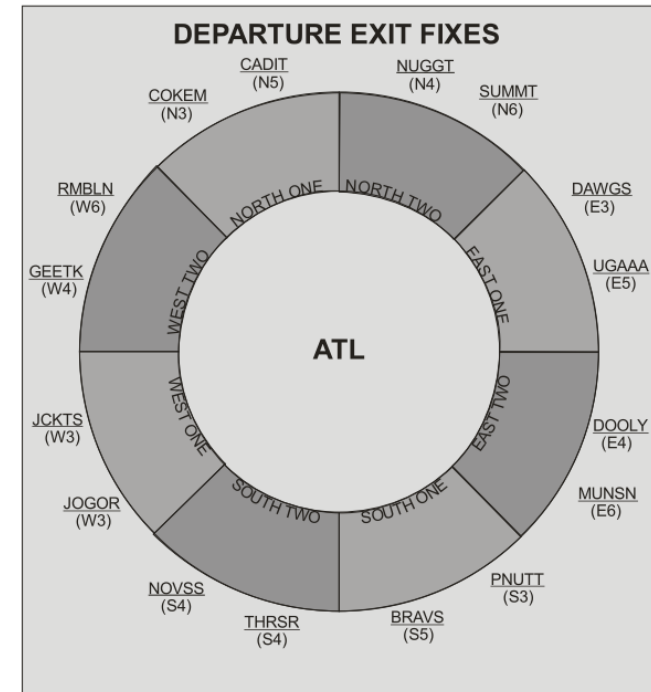
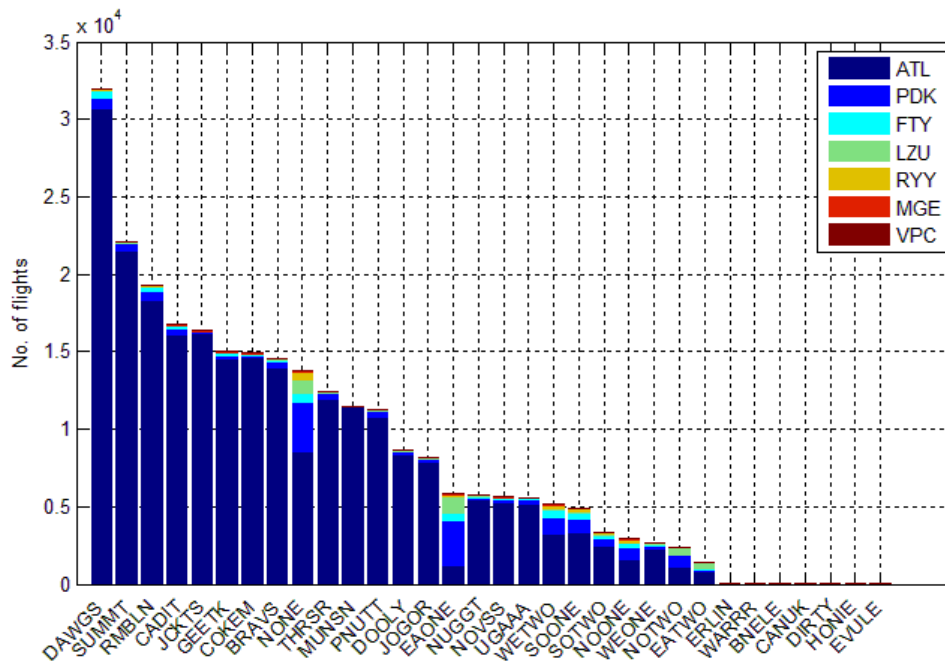
# Selection of Real World Interaction Cases

- ATL metroplex was recommended as potential site and selected with CLT as second site
- Analysis of departure fix sharing

ATL 7110.65C

April 1, 2014

FIG 1-3-14  
Departure Exit Fixes



# Selection of Real World Interaction Cases

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- ATL metroplex was recommended as potential site and selected with CLT as second site
- Analysis of departure fix sharing

Origin Airport	Number of Flights	Minimum Fix Crossing Altitude	Average Fix Crossing Altitude	Maximum Fix Crossing Altitude
'ATL'	30677	120	215	300
'FTY'	435	120	190	270
'LZU'	44	120	130	163
'MGE'	27	120	188	250
'PDK'	729	120	143	232
'RYY'	83	120	181	257
'VPC'	1	226	226	226

# First Year Focus Areas

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- Base on feedback, identified few areas for near term focus
  - Integration of surface and airspace scheduling
    - Using TMA-like algorithm adopted to departures
    - With consideration of downstream restrictions
  - Queue/delay buffers for departure metering
    - Identification of queue/buffer sizes from historical data
    - Integration of buffers into the scheduler
  - Integration of arrivals
    - As constraints to departure scheduling – arrival sensitive departure scheduling (ASDS)
    - With limited arrival time adjustment to consider departure concerns – Departure sensitive arrival scheduling (DSAS)
- Started development of ATL model in SOSS
- Decided to pursue prototyping in MATLAB rather than SOSS to be able to accomplish first year deliverable:
  - Prototype analysis of one case

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# Task 3: IADS Scheduling & Simulation Development

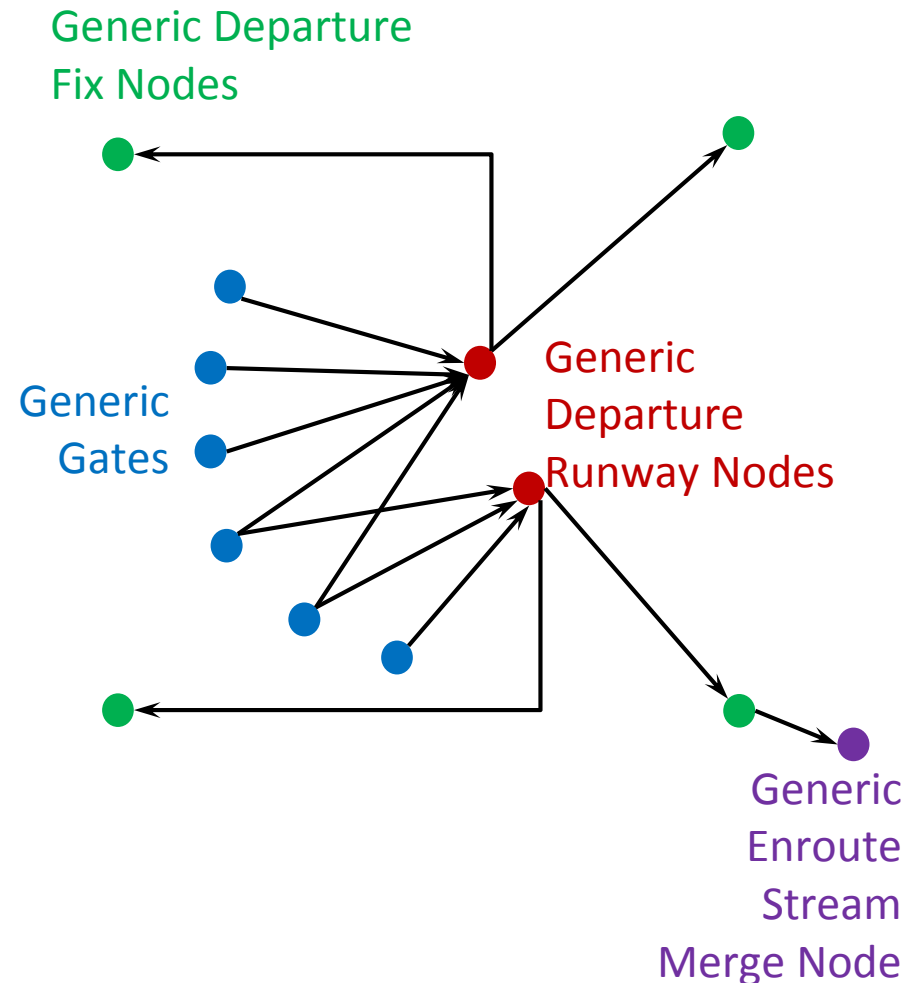
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This task has three components

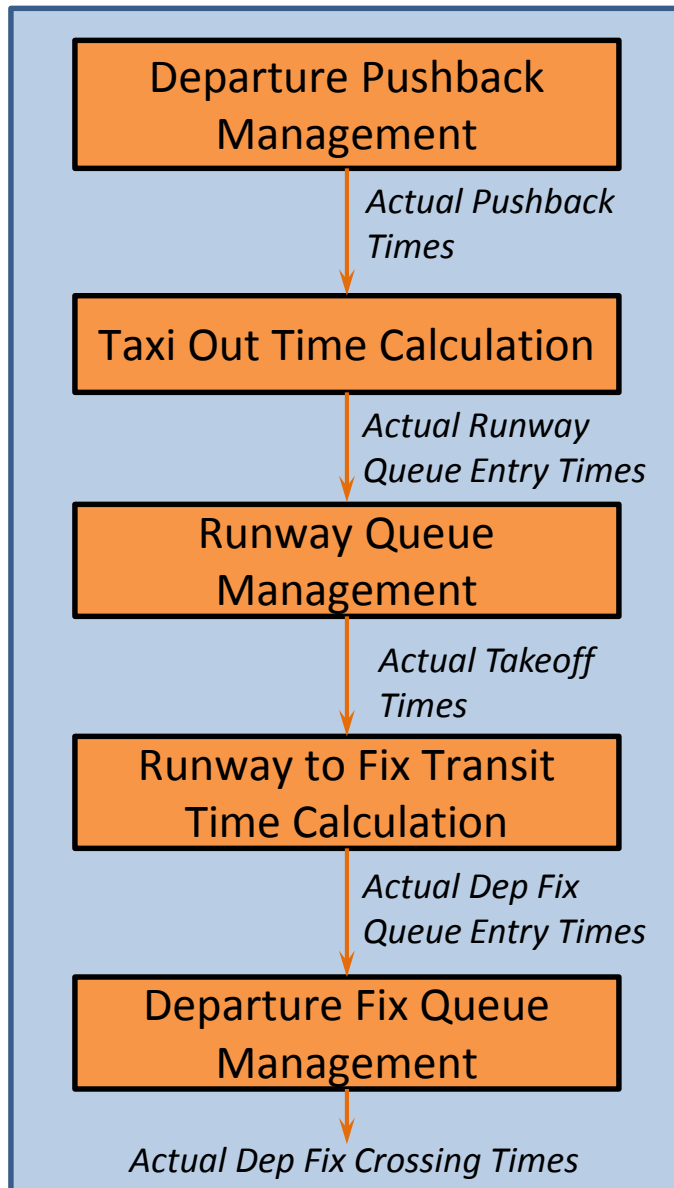
- Prototype Simulation Platform
- IADS Scheduling Algorithm Development
- Baseline VS ATD-2 Benefits Assessment Methodology

# Simulation Methodology: Medium Fidelity Queuing Model

- Link-node representation of Airport Surface –Terminal Airspace
- Queuing simulation with key control nodes located at
  - Terminal gate areas (groups of gates in the same geographical region of the airport) at major and satellite airports
  - Departure runways at major and satellite airports
  - Departure fixes (metering fixes at the boundary of the TRACON)
  - Center-center boundary metering fixes (merge-fixes for the overhead enroute traffic stream)



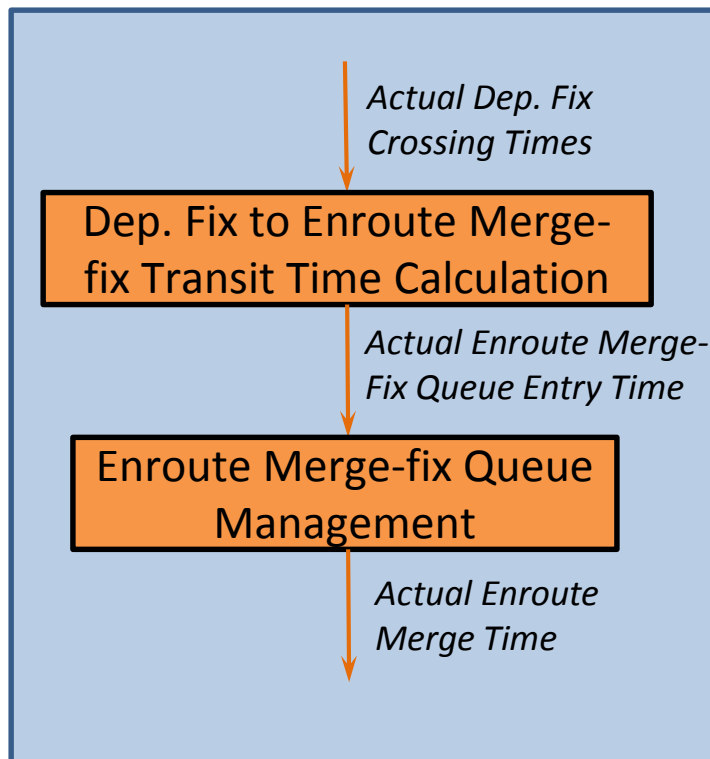
# Simulation Process



- Flights pushback at or around their scheduled gate departure time (or **TOBT**)
- **Pre-pushback process uncertainty model: Three levels of uncertainty**
- ASQP data based model for the primary airport. Separate taxi-time calculation for each airline (accounts for differing terminal-gate area usage)
- Constant taxi time model for smaller airports
- Prior to entering the queue, Ground Controller may modify the order slightly for **departure fix sequencing**
- Flights leave the queue in the same order as they enter it
- Queue leader flight cannot leave (i.e., takeoff) until a time-slot is available on the runway AND until it satisfies **runway MIT restrictions** that may be active
- **Spacing w.r.t. landings on the same or closely spaced parallel or intersecting runway applied before the queue leader is allowed to leave (i.e., takeoff)**
- Transit times computed using a physics based model
- **Models departure-fix merging**
- Flights leave the queue in the same order as they enter it
- Queue leader flight cannot leave (i.e., cross the fix) until a time-slot is available at the fix AND until it satisfies **same-fix MIT restrictions** that may be active



# Simulation Process (Cont.)



- *Transit times computed using physics-based model*
- ***Models en route traffic stream merging for departures from the primary airport***
- *Flights leave the queue in the same order as they enter it*
- *Queue leader flight cannot leave (i.e., merge into the overhead traffic stream) until a gap is available in the enroute stream*
- *Assume Poisson distributed enroute stream gaps with a defined arrival rate*

# Terminal Departure Scheduling

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- Scheduler computes Target Off Block Times (TOBTs\*) for departure flights in order to
  - Absorb as much delay as possible at the gate, minimize taxi times, departure queue waiting times and airborne transit times
  - Perform integrated sequencing of departures across all airports for satisfying multiple interconnected constraints
    - Runway capacity
    - Departure-fix merging under fix-capacity constraints
    - En route traffic stream merging subject to availability of gaps

*\*TOBTs are target gate pushback times*

# ATD-2 Scheduling Algorithm: Emulates TMA's Dynamic Planner Algorithm

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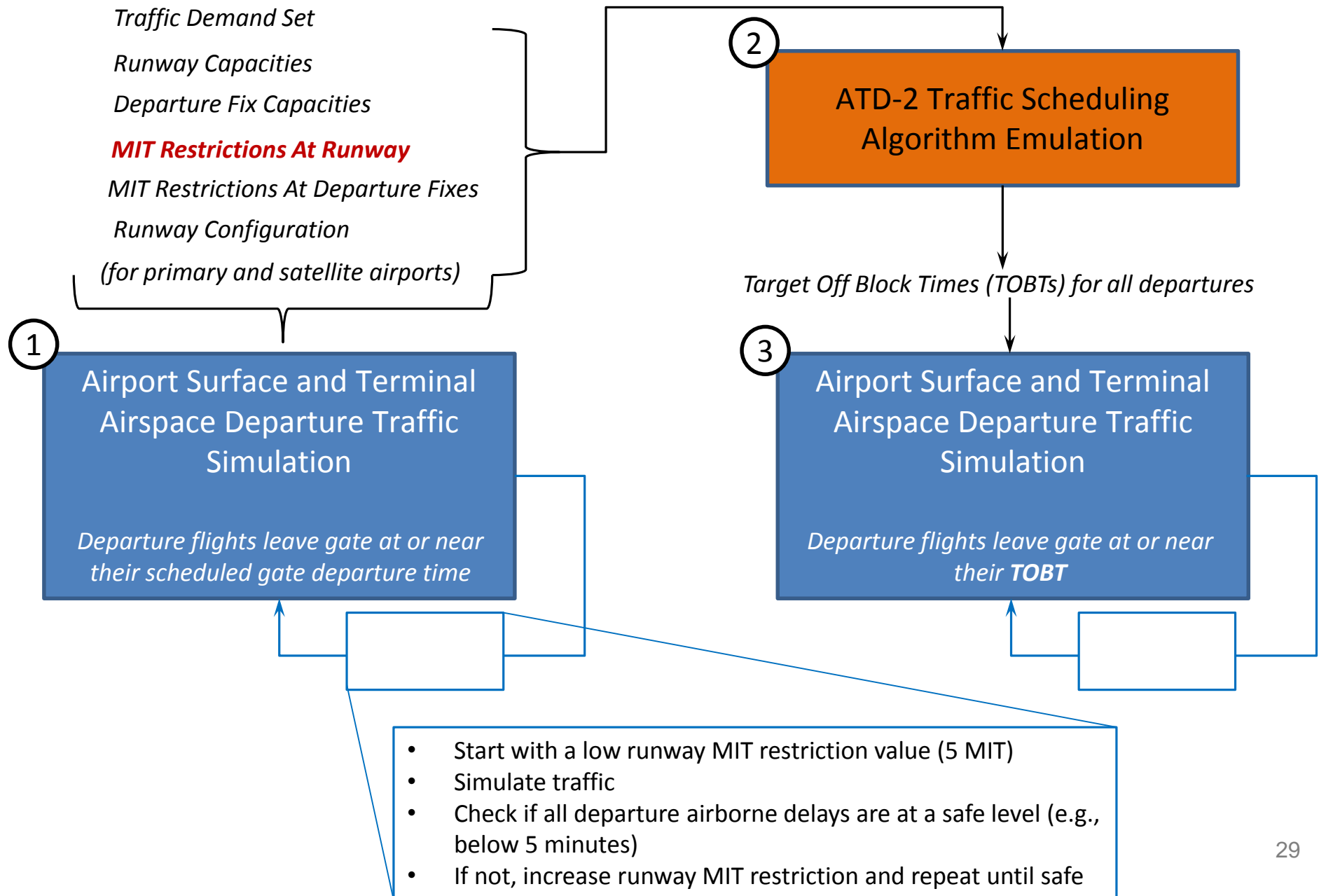
- Step 1: Predict unimpeded times to the runway, departure-fix and enroute stream merge point
- Step 2: Determine earliest possible runway departure times
  - Space flights sufficiently at the runway according to runway capacity
  - Delay runway takeoff time to “hit” enroute merge stream gaps
- Step 3: Apply Order of Consideration algorithm to determine the next flight to “consider” for scheduling
  - (1) Select lead departure of each runway; (2) Select lead departure of each departure fix from runway leaders; (3) Select from these departures one with earliest fix crossing time as next flight to schedule
- Step 4: “Fit” the selected departure in the departure-fix crossing sequence at the proper position
  - Back propagate excess delays to the surface
    - Apply delay buffers as amount of delay to absorb in airspace and on surface
  - May check back for runway time-slot availability after fixing departure-fix time-slot

# ATD-2 Test Scenario

- Analysis of one day at ATL
  - July 15, 2015, west configuration
  - Actual PDARS/ASDE-X demand
  
- Modeled restrictions
  - Runway capacity: 20 per 15 min for ATL, 8 per 15 min at other airports
  - 50% fix capacity degradation from 15:00 to 19:00 UTC at JCKTS and JOGOR departure-fixes

Airports	Departure Fixes	Enroute Merge Points	Departure Merge Point Mapping	Airport-Merge Point Mapping
ATL, PDK, FTY, RYY, LZU, CSG	BRAVS, CADIT, COKEM, DAWGS, DOOLY, GEETK, JCKTS, JOGOR, MUNSN, NOVSS, NUGGT, PNUTT, RMBLN, SUMMT, THRSR, UGAAA'	SPA, GRD, IRQ	SUMMT-SPA, DOOLY-GRD, MUNSN-IRQ	ATL – SPA, ATL – GRD, ATL – IRQ

# Assessment Methodology



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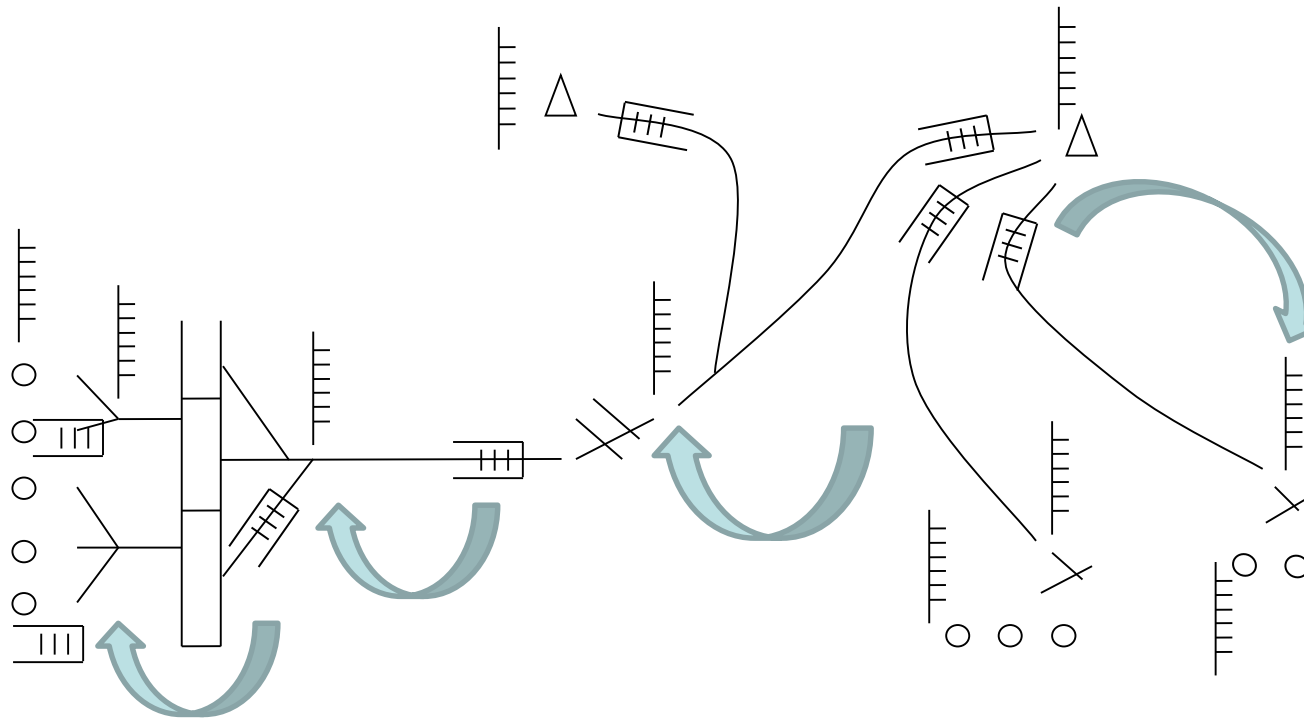
# Configurable Delay Buffers - Motivation

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- Queue/delay buffers are needed to maintain pressure on resources to avoid losing precious throughput due to uncertainty
  - Aircraft need to be queued to take advantage of any opening opportunity due to uncertainty in travel and service times
  - Queues provide controllers ability to sequence departures optimally
- Buffers provide flexibility and controllability in conformance to prescribed schedule at resources
  - If schedule assumed fastest travel between resources with zero buffers it would be violated due to any disturbance that results in longer travel time
- Only sufficient buffers for throughput and conformance should be maintained by departure metering
  - Additional delay should be absorbed at gate more efficiently and with less workload
- What are the appropriate buffer values to target?

# Configurable Delay Buffers - Motivation

- Buffers are needed for scheduling algorithm to decide on distribution of delay and flexibility between resources
  - What desired queue sizes should the scheduler target?
  - Scheduler moves additional queues/delay upstream from airspace to surface and from surface to gate to save on fuel and emission





# Configurable Delay Buffers - Motivation

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- Lessons from JFK experience with departure metering
  - Proper sizing of queue buffers is critical
    - Original system: Desired queues originally set at eight departures which resulted in controller complaint about starving runways and lack of ability to sequence with only three departures in queue at times
    - Current system: Desired queues reset at twelve departures
  - Transparent to air traffic controllers
    - Original system: required controllers to stage departures according to release times from the taxi spots resulting in high workload
    - Current system: departure metering completely transparent to controllers
  - Collaborative using “snow-desk” approach
    - Each airline or terminal participates with representative to negotiate and allocate available slots

# Configurable Delay Buffers - Methodology

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- Identification of buffer size necessary for throughput saturation from historical data analysis
  - Applicable in nominal and off-nominal conditions that manifest in historical data
  - Can be used to complement subject matter expert feedback on buffer size needed to avoid the JFK experience
  - Can be used to validate simulation models
- Use of historical data to validate simulation models
- Identification of buffer size necessary for throughput saturation from validated simulation
  - Useful particularly for conditions that do not manifest in historical data
- Application of queue/delay buffers in scheduling algorithm
  - Queue versus delay target buffers

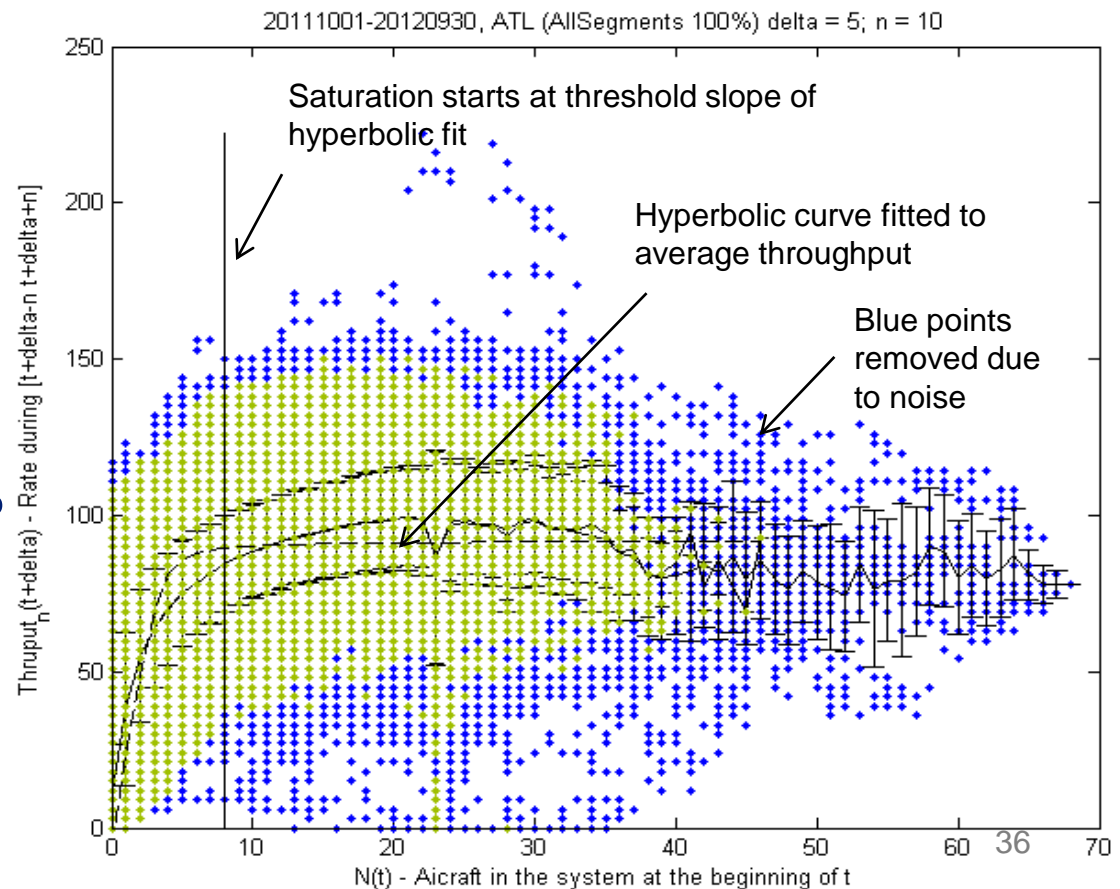
# Configurable Delay Buffers - Methodology

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- Identification of buffer size necessary for throughput saturation from historical data analysis
- Adapted and extended MATLAB utilities to analyze terminal airspace and airport surface using PDARS/ASDE-X data
- Analyses include:
  - Throughput saturation – identifies queue size that results saturation
  - Queuing analysis – identifies correlation between delay and queue size
  - Service rate analysis – identifies distributions of inter-departure times
  - Arrival departure interactions – for example pareto curves
- Utilities suite for airport and sector analysis delivered to NASA (under choke point NRA)
  - Delivered suite works with ASPM and ASDI data
  - Versions under this project can be delivered extending capabilities to terminal airspace and airport resources using PDARS/ASDE-X data

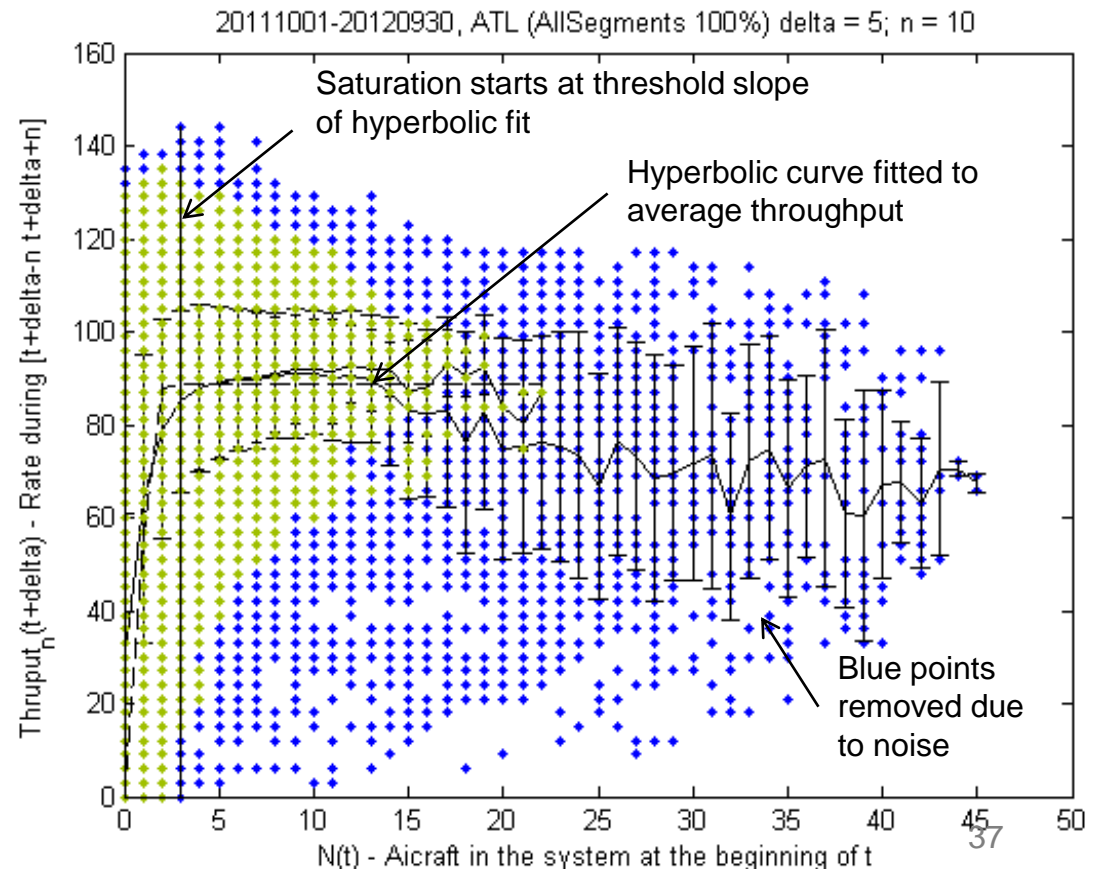
# Throughput Saturation Analysis

- Throughput at time  $t+\delta$  plotted versus demand  $N(t)$  at time  $t$ 
  - $N(t)$  = number of aircraft with  $\text{OUT} < t \leq \text{OFF}$  (due to takeoff by  $t$  but have not yet)
  - Throughput = number of takeoffs in 20 minute window around  $t$
  - Delta selected as value resulting in best correlation between demand and throughput
  - Least frequent 0.5% of data filtered out (blue dots) to remove rare events
- Saturation criterion
  - Saturation starts at slope of fitted hyperbolic curve = 0.5% (vertical line)
  - Other criteria can be used



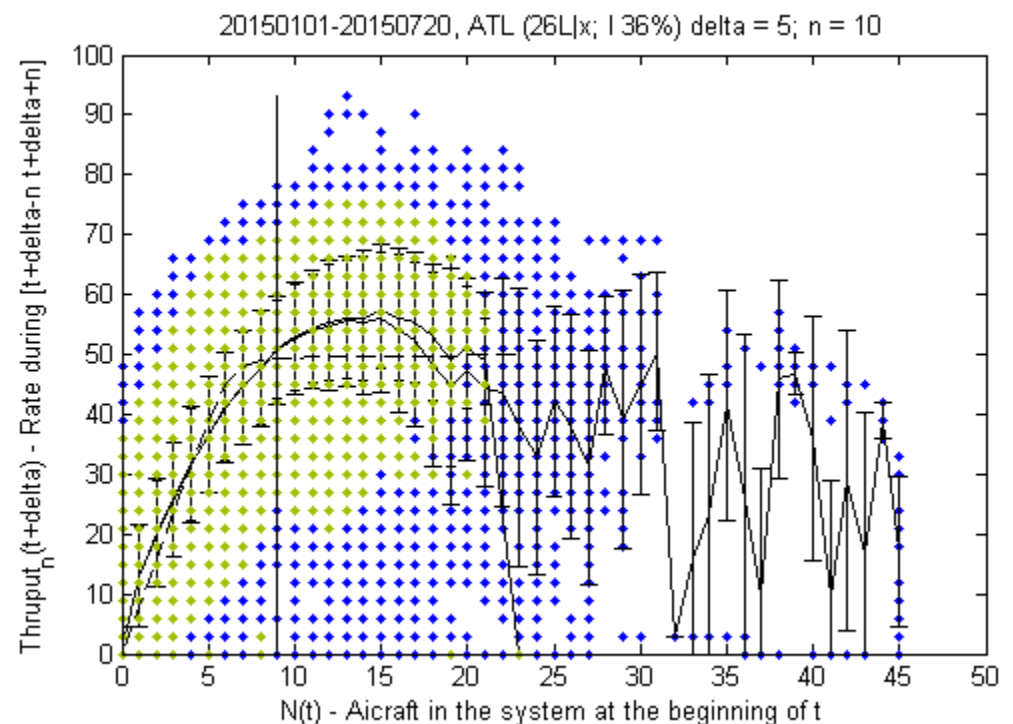
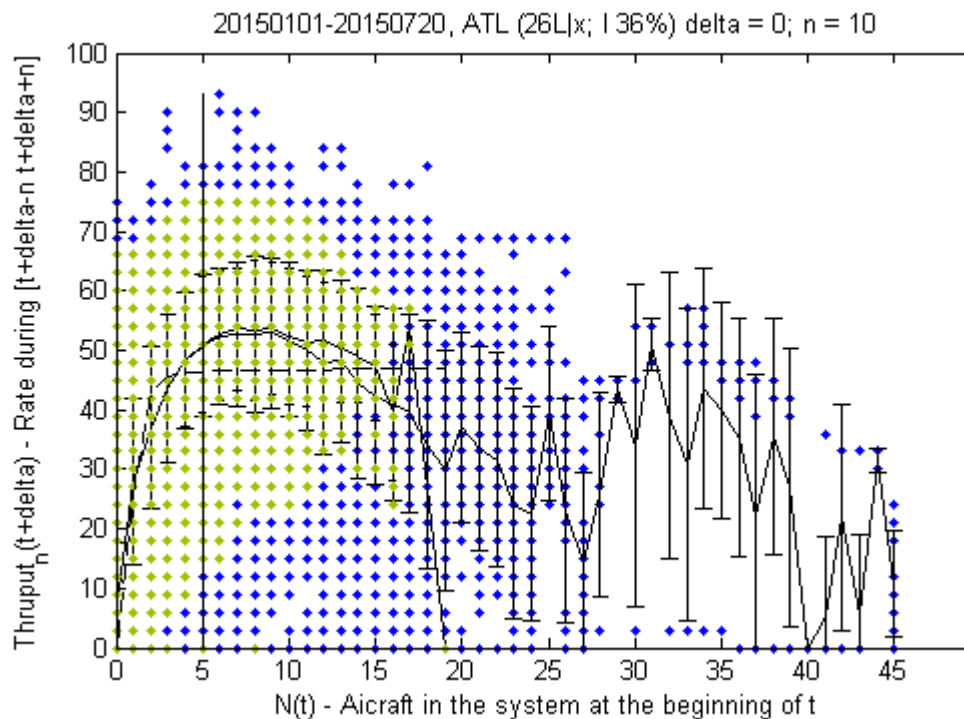
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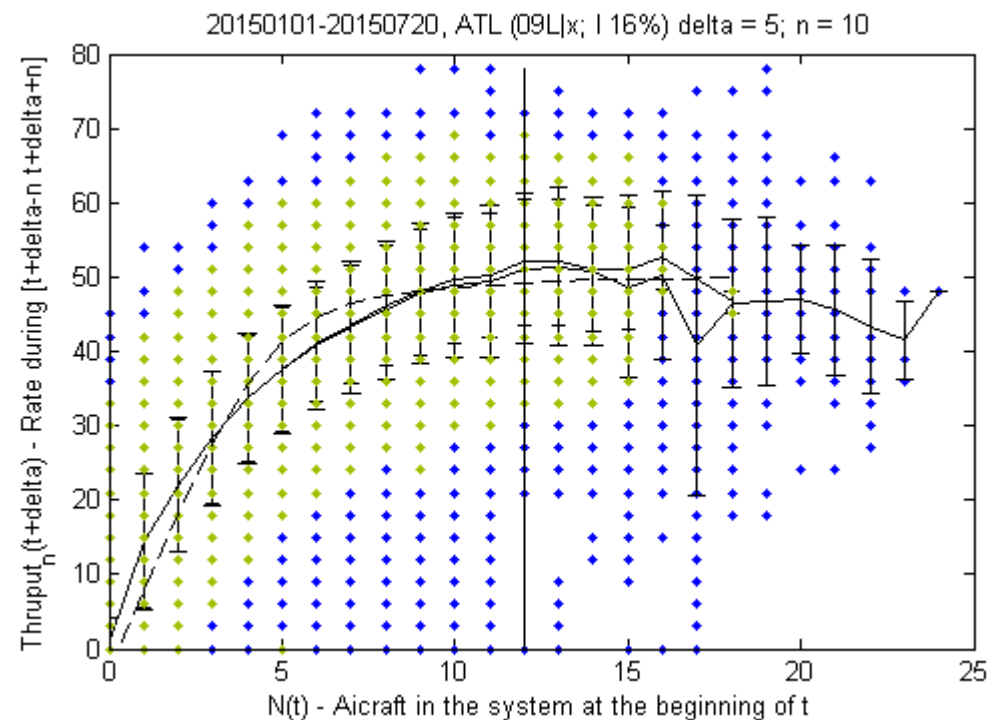
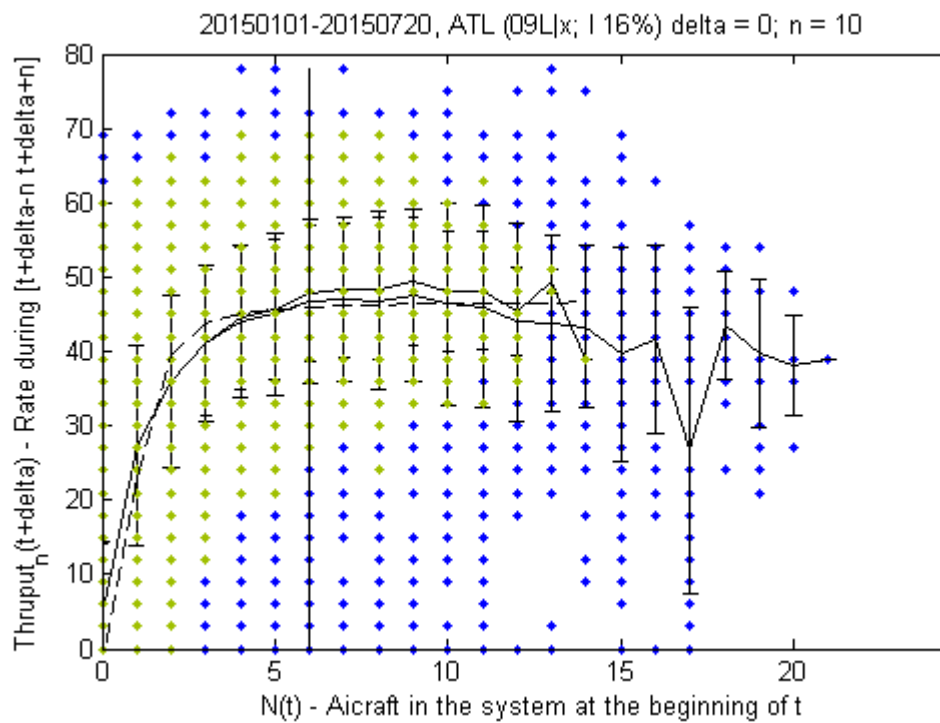
# Throughput Saturation Analysis

- Throughput saturation applied to all runways at ATL
- All runways used for departure exhibited saturation



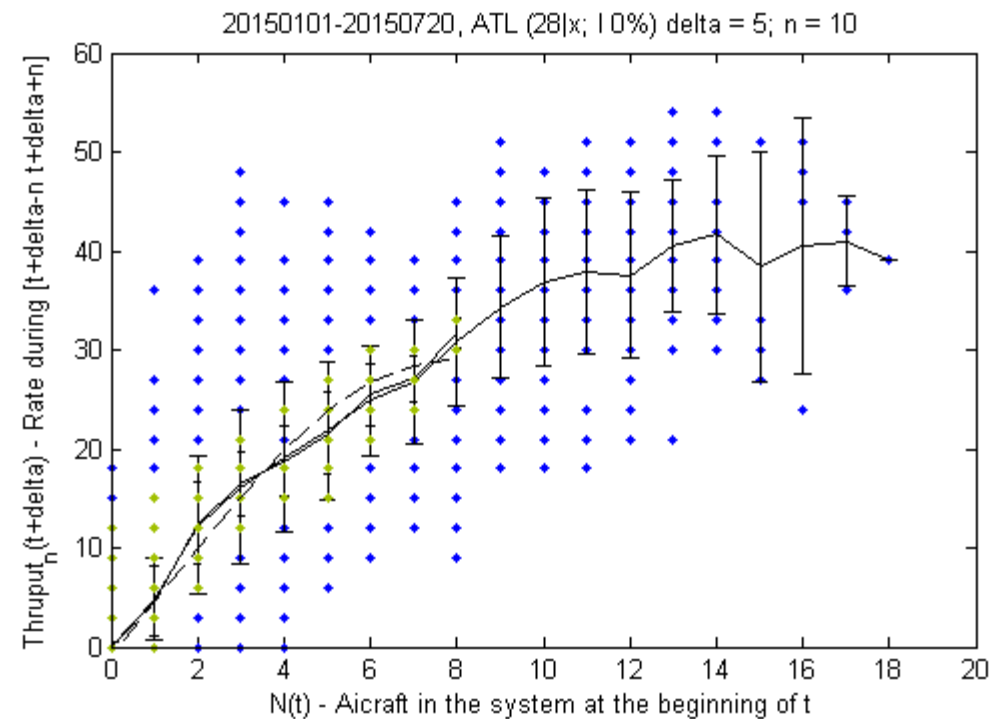
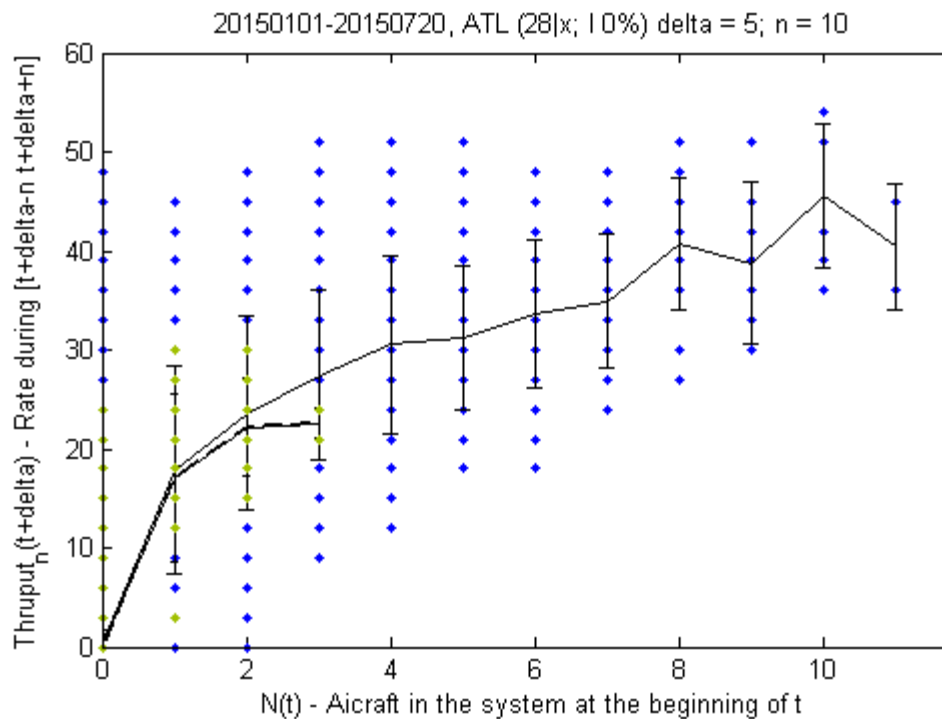
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- Throughput saturation applied to all runways at ATL
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# Throughput Saturation Analysis

- Throughput saturation applied to all runways at ATL
- Runways used mainly for arrivals did not exhibit departure saturation

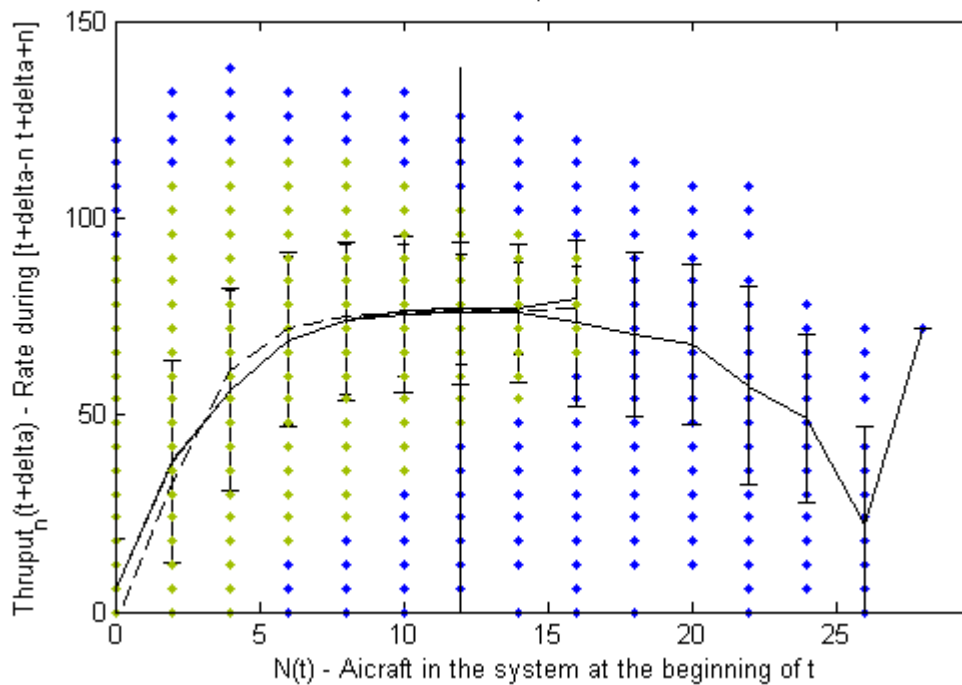




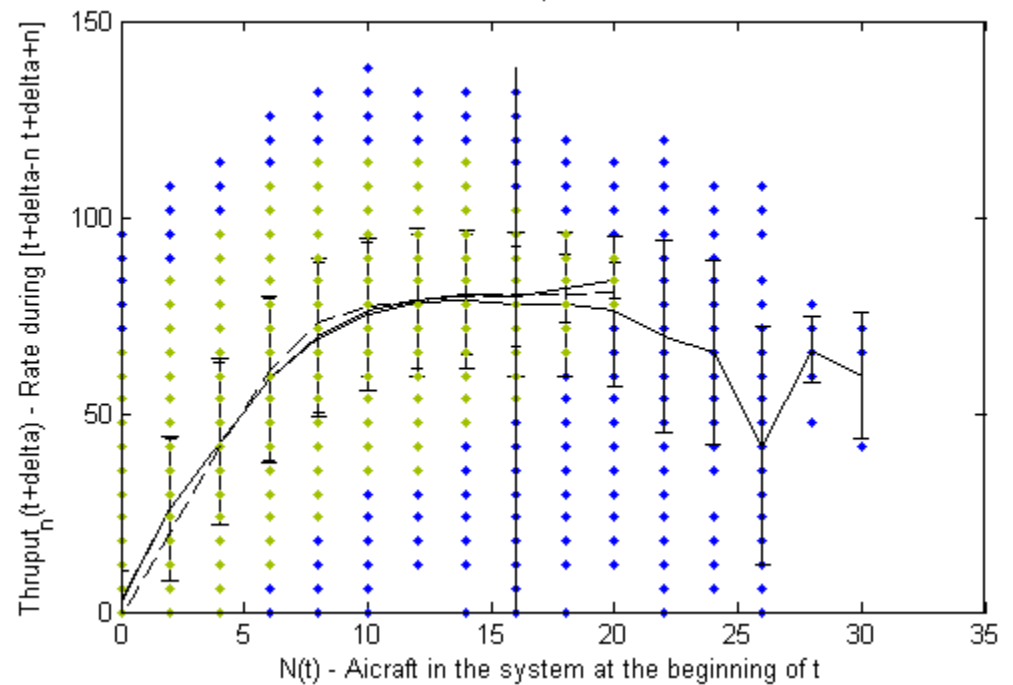
# Throughput Saturation Analysis

- Throughput saturation applied to all runways at CLT

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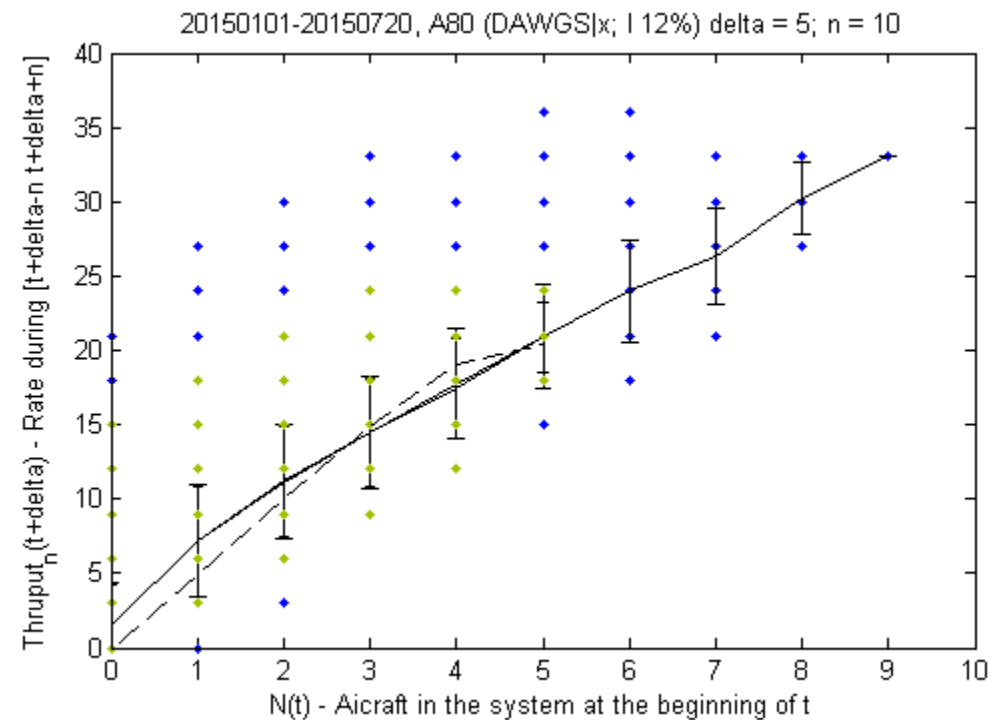
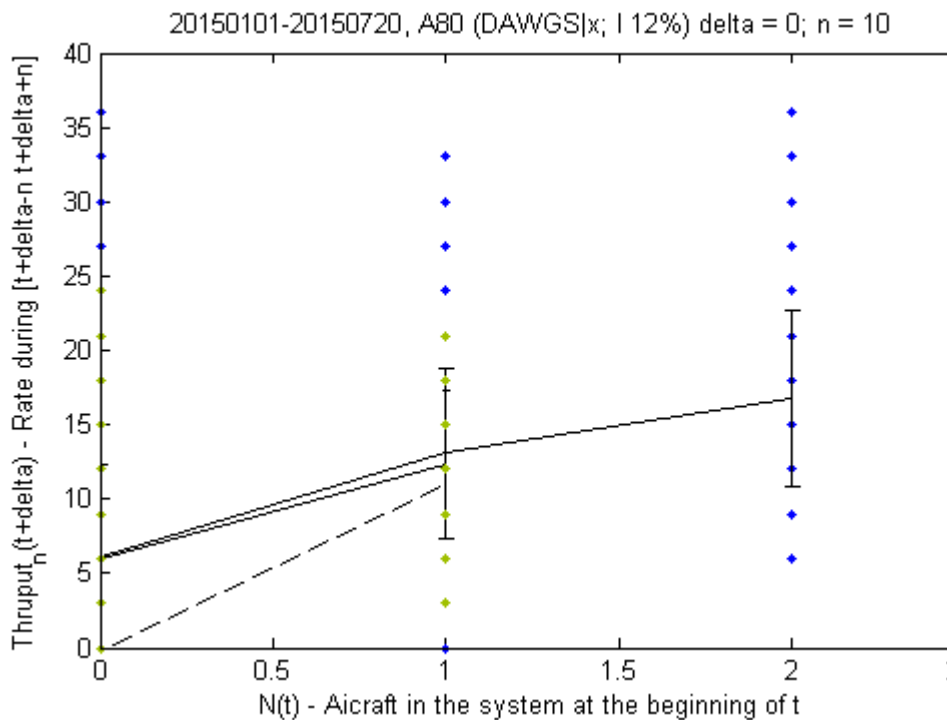


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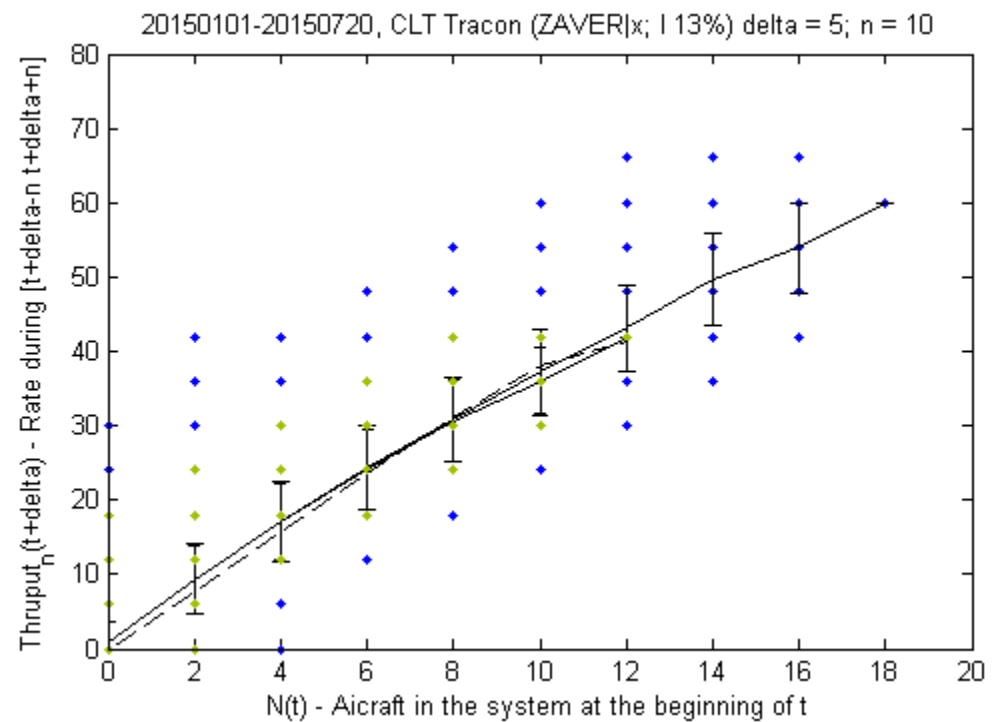
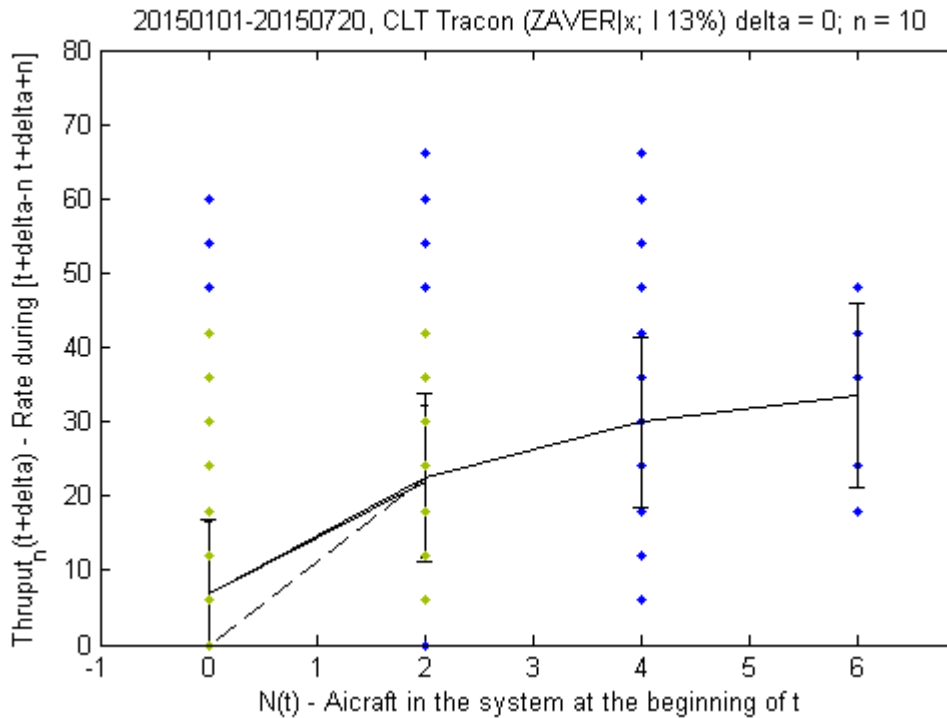
# Throughput Saturation Analysis

- Throughput saturation applied to all departure fixes at ATL and CLT
- None of the fixes exhibited saturation at the criteria used



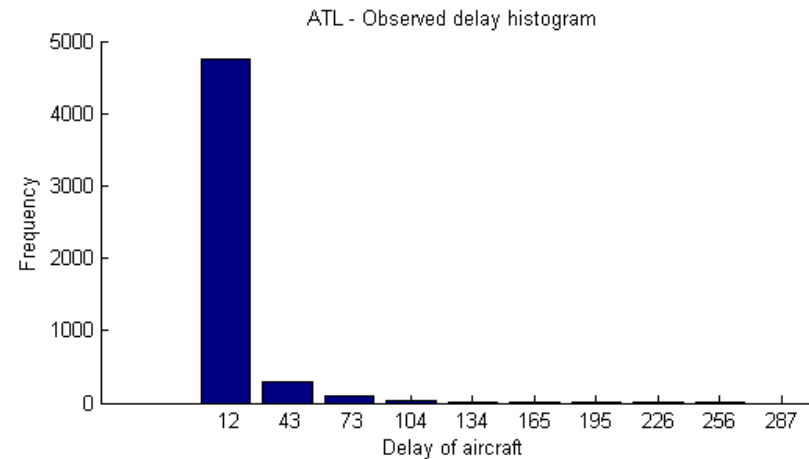
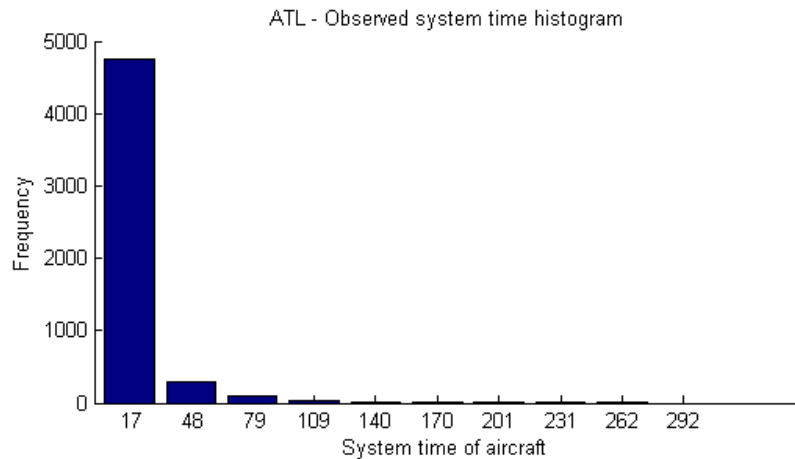
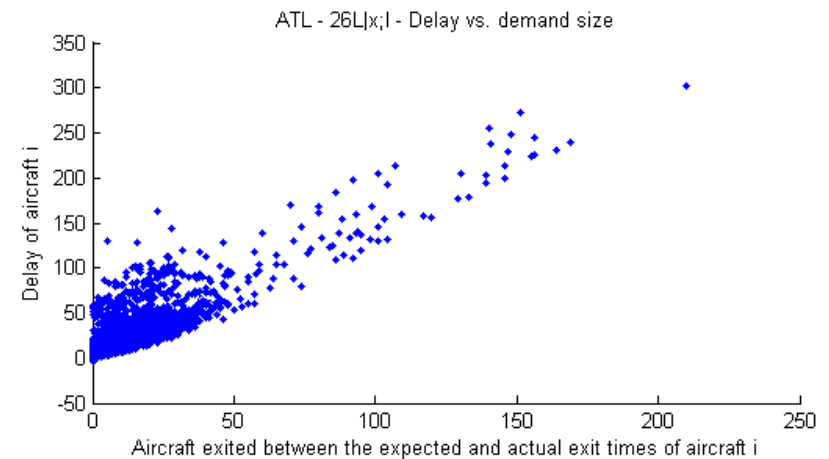
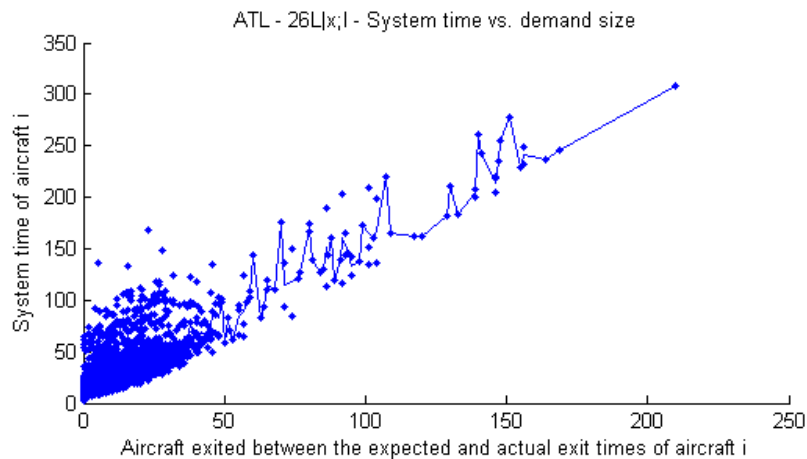
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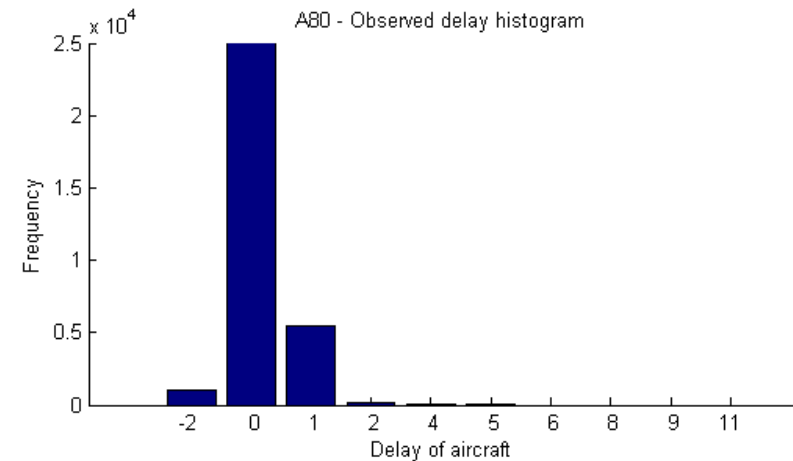
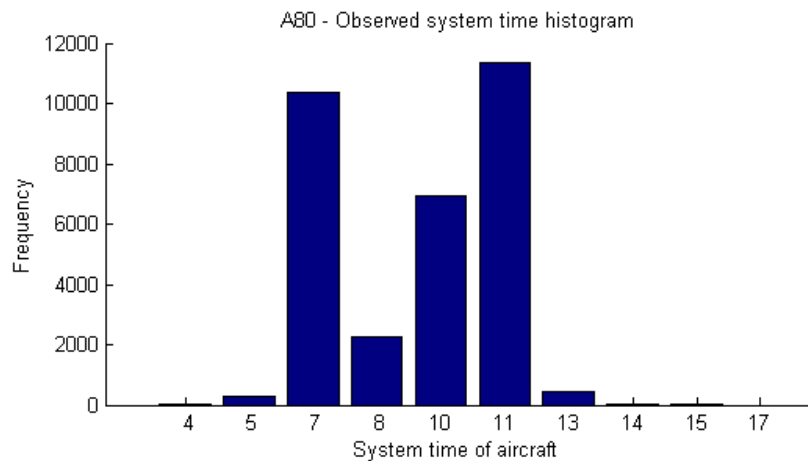
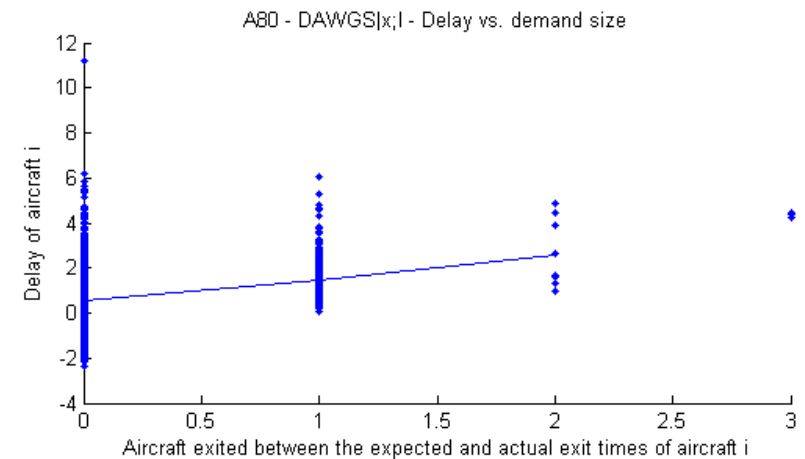
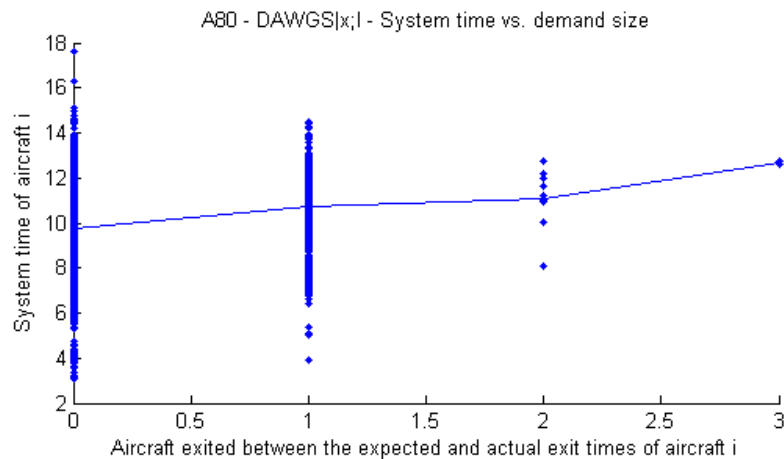
# Queuing Analysis

- System time and delay versus queue size for runways
- System time and delay distributions for runways



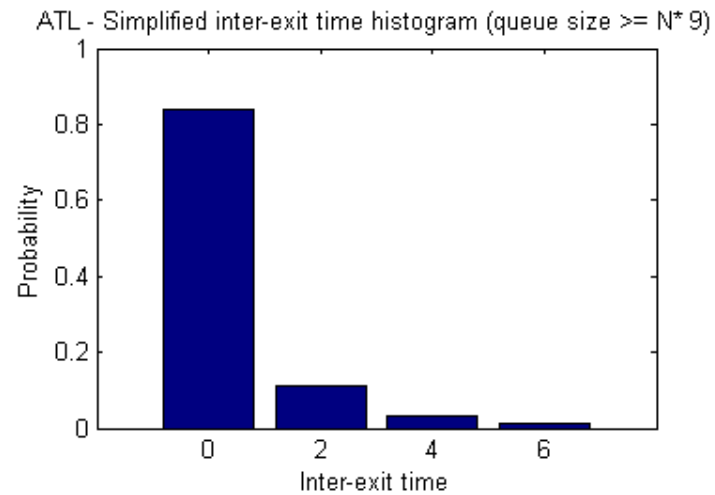
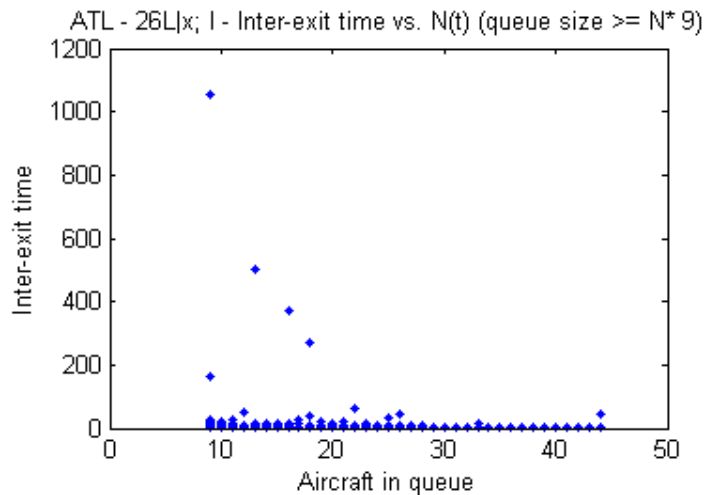
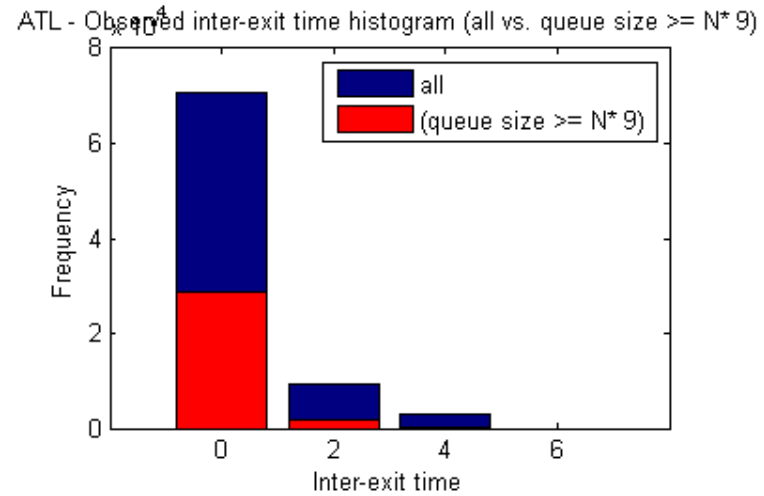
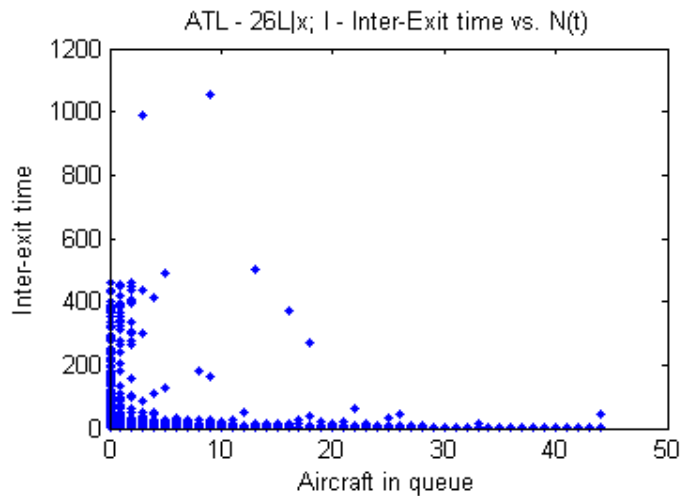
# Queuing Analysis

- System time and delay versus queue size for departure fixes
- System time and delay distributions for departure fixes



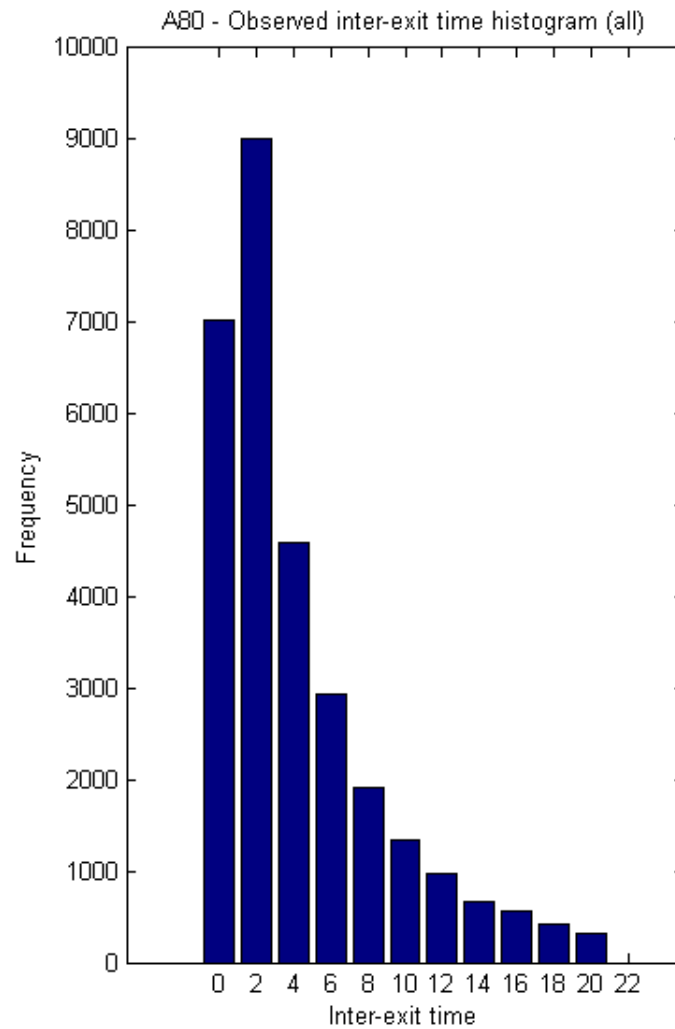
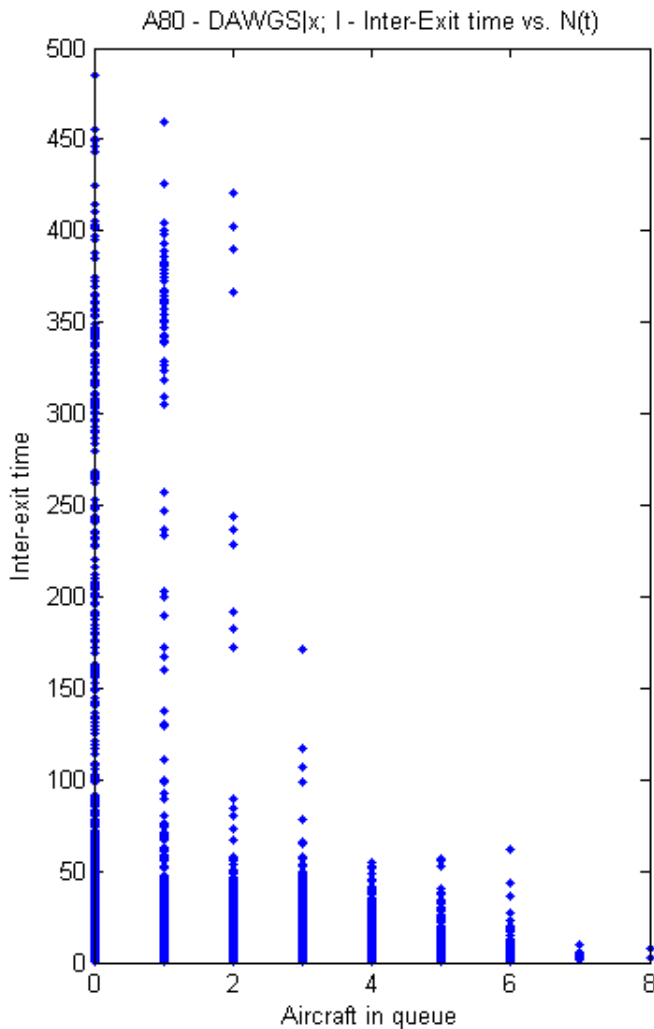
# Service Rate Analysis

- Inter-exit time versus queue size for runways
- Inter-exit time distributions for runways



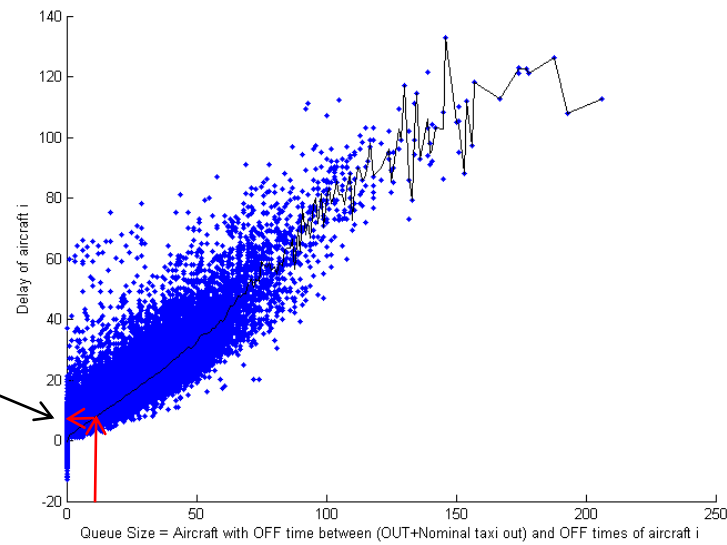
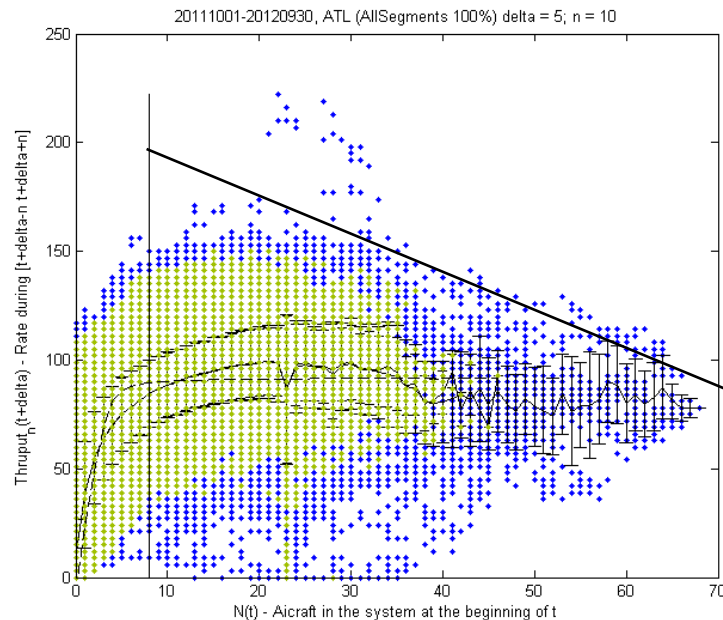
# Service Rate Analysis

- Inter-exit time versus queue size for departure fixes
- Inter-exit time distributions for departure fixes



# Application of Configurable Delay Buffers

- Current application
  - Target desired delay value  $D^*$  for each flight - Similar to TMA approach
  - $D(i)$  is delay estimated by scheduler for flight  $i$
  - Allocate  $\min(D^*$  and  $D(i))$  to local queue (runway or fix) and remaining delay to upstream resource (runway or gate, respectively)
- $D^*$  may be deduced from saturation and queuing analyses

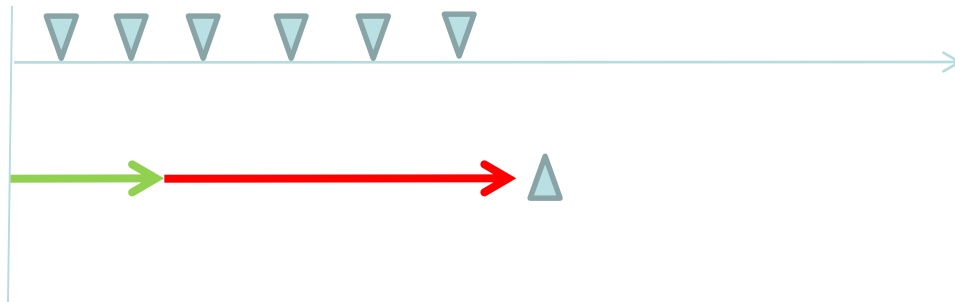


Determine delay buffer that corresponds to queue buffer from queuing dynamics



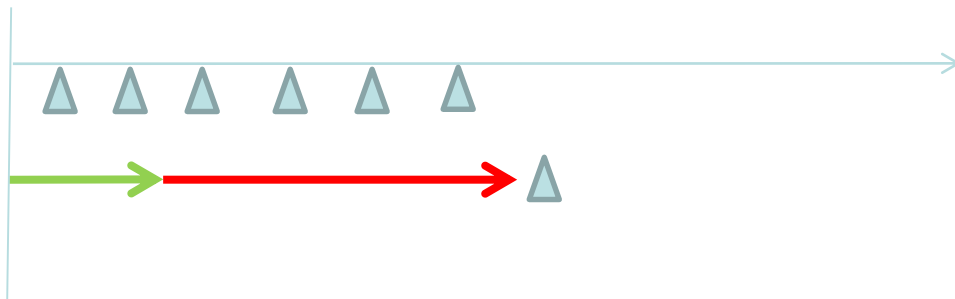
# Application of Configurable Delay Buffers

- Using  $D^*$  may not guarantee desired queue pressure on resource



$N^* = 4$  aircraft  
 $D^* = 4$  minutes  
 $Q(i) = 0$   
 $D(i) = 6$  minutes

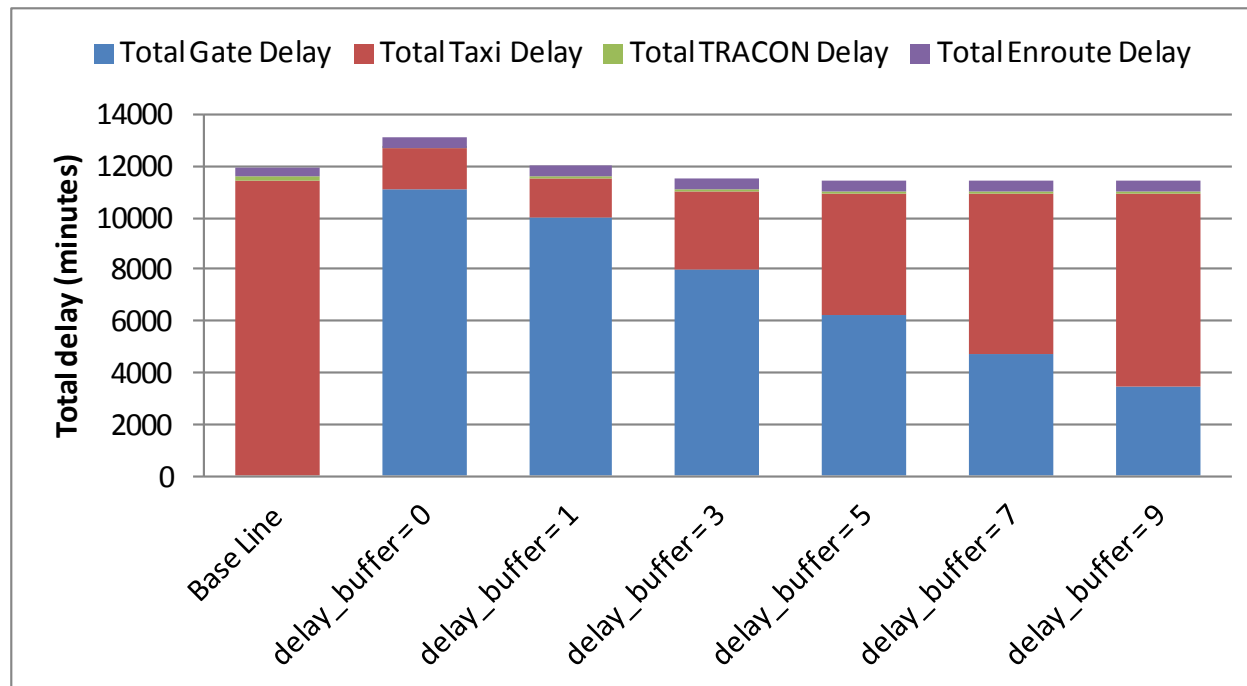
- Alternatively can use  $N^*$  which guarantees desired queue pressure on resource
  - $Q(i)$  number of departures scheduled ahead of flight  $i$
  - Schedule target release time when  $Q(i) < N^*$



$N^* = 4$  aircraft  
 $D^* = 4$  minutes  
 $Q(i) = 6$  aircraft  
 $D(i) = 6$  minutes

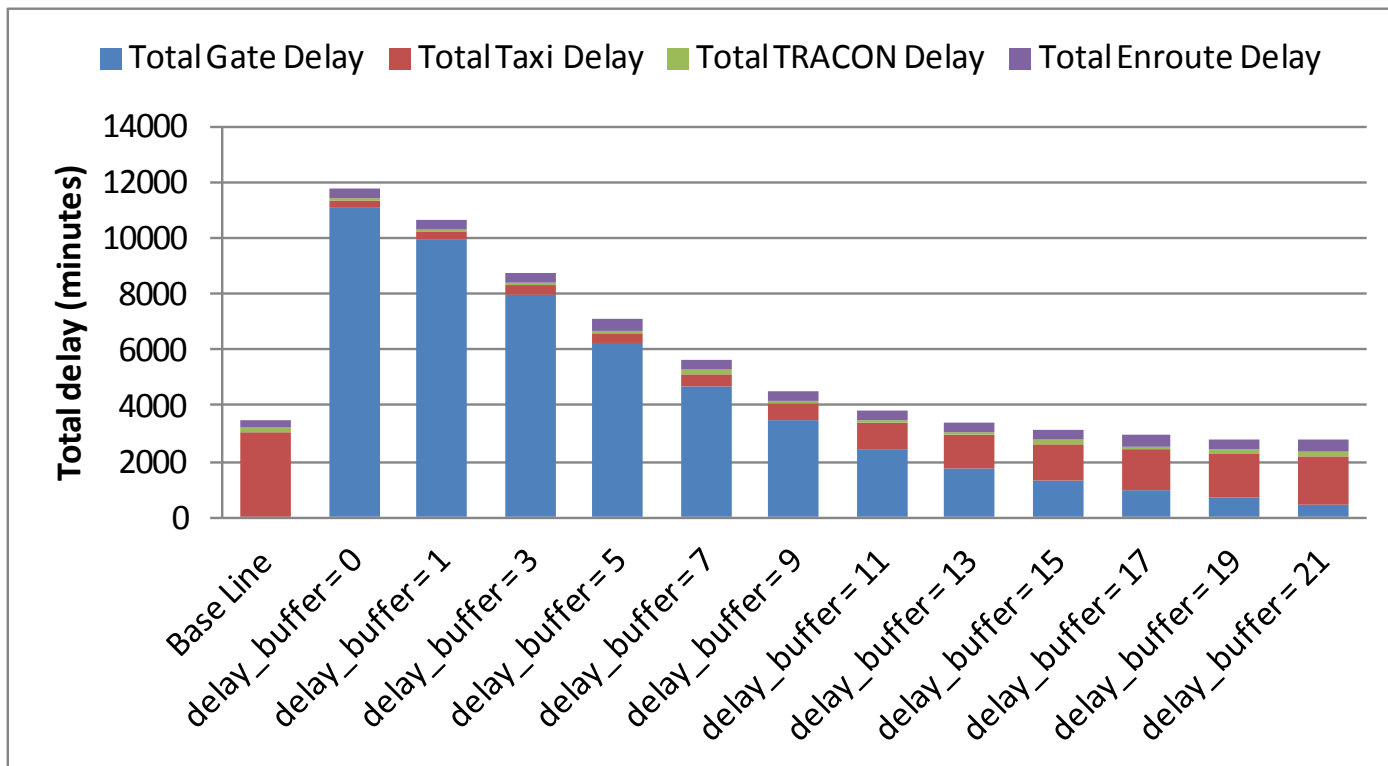
# Simulation-based Buffer Identification

- Small delay buffer needed to accommodate difference between scheduler assumptions and simulation behavior
  - For example, simulation may sequence flights slightly differently
- After buffer of 3 minutes overall delay savings are constant
- Small benefits in terms of overall delay savings but significant benefits in terms of less costly delay at the gate/ramp



# Simulation-based Buffer Identification

- To demonstrate impact of uncertainty, increased runway capacity by 20% relative to scheduler assumed runway capacity
- Larger delay buffer needed to accommodate underestimation of capacity
  - After buffer of 19 minutes overall delay savings are constant



# Outline

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- Research Motivation and Objectives
- Recap of Year One Activities and Progress
- **Discussion of Focus Areas of Year One**
  - Integrated Scheduling between Surface and Airspace
  - Identification of Queue/Delay Buffer Sizes for Departure Metering
  - **Integration of Arrival and Departure Scheduling**
  - High-Fidelity Fast-Time Simulation Modeling
- Proposed Year 2 Work

# Integrating Arrival Scheduling – Motivation

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- Integrate arrivals into departure scheduling in small gradual steps since ATD-2 focus is on departure control with arrival consideration
- Focus initially on integrated scheduling of dependent runways where most critical interaction takes place
- Consider heuristic approaches with simple applications considered by ATD-2
  - Arrival Sensitive Departure Scheduling (ASDS)
  - Departure Sensitive Arrival Scheduling (DSAS)
  - Full arrival-departure integration may be considered in future years
- Are there potential impacts/benefits of applying DSAS at ATL or CLT?

# Integrating Arrival Scheduling – Concept

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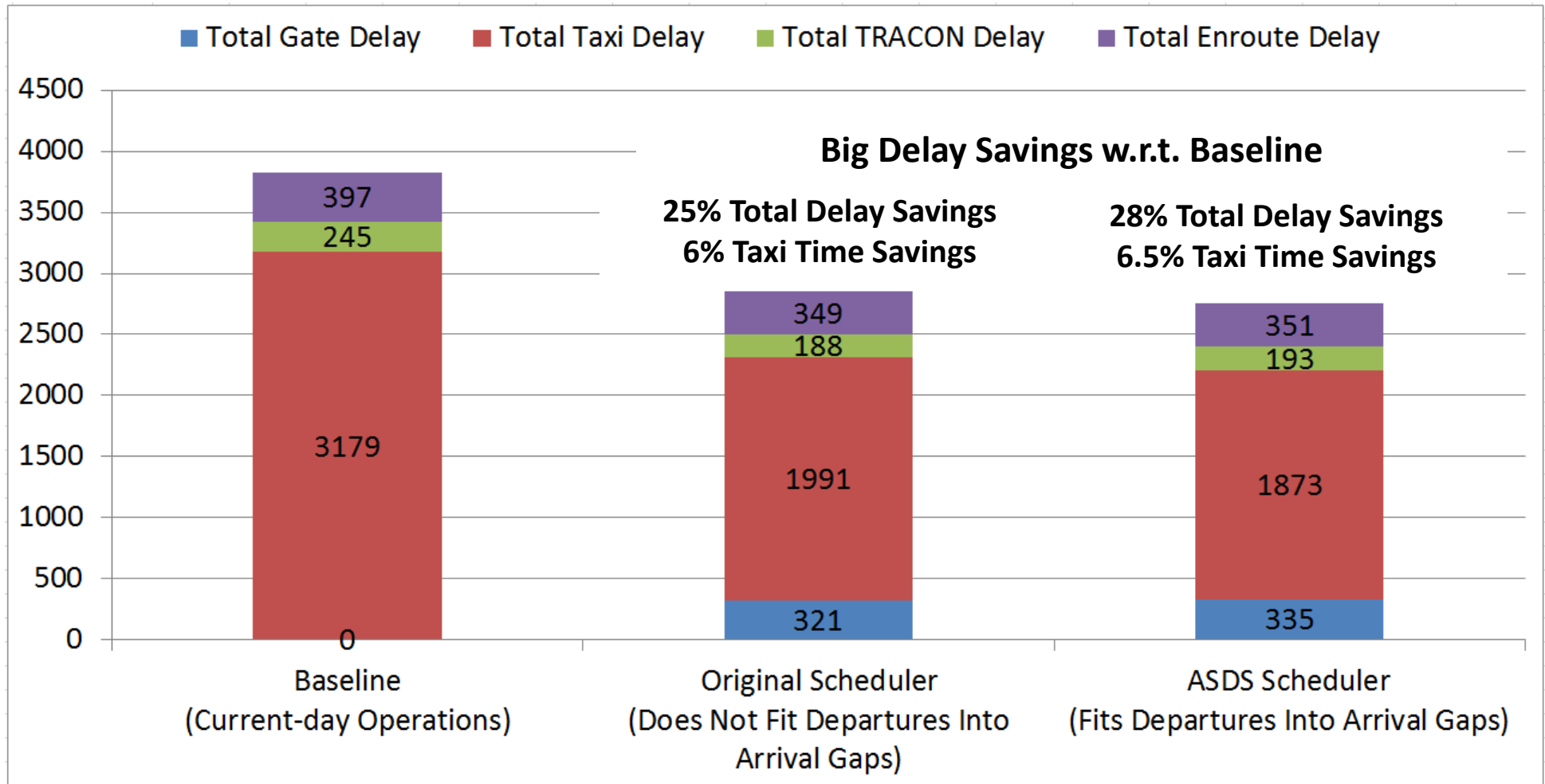
- **ASDS:** Take arrivals into account when scheduling departures
  - Typical of today's operations since arrivals are given priority
  - Extreme condition: Schedule arrivals independently of departures and then schedule departures between arrivals with arrivals as constraints
- **DSAS:** Take departures into account when scheduling arrivals
  - Less common in today's operations since arrivals are given priority
  - Small adjustments in the arrival schedule to accommodate departures when there is a departure queue
  - Motivated by highly dependent arrival-departure runway operations, for example, LGA with two crossing runways and one-to-one operations
  - Gaps between arrivals often accommodate partial departures, for example 1.5 departures, resulting in wasted throughput
  - Slight movement of arrivals in these cases to accommodate two or three departures can benefit departures greatly with minimal arrival impact

# Integrating Arrival Scheduling – Concept

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- DSAS: Take departures into account when scheduling arrivals
  - Often spacing between successive arrivals is sufficient to insert one departure
  - Therefore, TSS arrival schedule, which is independent of departures, can mostly accommodate one departure between successive arrivals
  - DSAS identifies opportunities for making inter-arrival spacing accommodate two or three departures, when there is departure queue
  - HITL showed potential benefits at LGA
    - DSAS opportunities identified and advised at en-route TMA position and made manually in TMA schedule
    - TSS slot markers reflect DSAS schedule and ensure gaps are created at runways
    - If gap does not materialize, departure is not cleared by tower controller

# ASDS Scheduler Analysis





# DSAS Scheduler Analysis – Methodology

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- Compare the following baselines to identify DSAS opportunities and benefits on departures
  - Actual operations: Schedule departures within the actual arrival times
    - Eliminates causes of departure delay other than runway capacity
    - Can be used for calibrating separations requirements to match runway throughput
  - TSS operations: Schedule departures within TSS-like arrival schedule
    - Schedule arrivals by delaying actual arrival times to establish arrival-arrival required spacing
    - Identical to actual arrival times if arrival-arrival required spacing always satisfied
    - Arrival-arrival spacing should be sufficient for inserting one departure
    - Establishes benefits of TSS scheduling
  - DSAS operations: Schedule departures within DSAS generated arrival schedule to accommodate two or three departures
    - Delay-only: generate gaps by delaying arrivals
    - Delay-advance: generate gaps by delaying or advancing arrivals
    - No-slack: generate gaps by delaying or advancing without leaving any slack

# DSAS Scheduler Analysis – Methodology

- Generate separation matrix for dependent runways based on historical PDARS data
- Table shows tenth percentile of observed separation from ASDEX data, in seconds

Runway	Number of Departures	Land-Land	Land-Depart-Land	Land-Depart	Depart-Depart	Depart-Land-Depart	Depart-Land
26L-26R	86226	67	67	7	41	44	7
27R-27L	68528	71	74	8	43	47	8
08R-08L	41050	102	134	111	42	121	31
09L-09R	36975	74	76	8	42	48	7

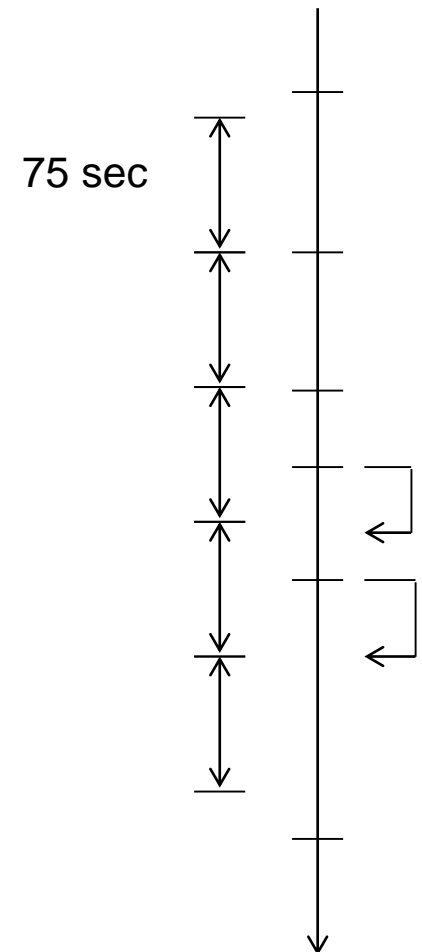
# DSAS Scheduler Analysis – Methodology

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- Generate demand for dependent runways
  - Arrival demand – used actual landing times from PDARS
  - Departure demand – used actual runway entry times from ASDE-X plus ten percent of travel time between runway entry and takeoff
- Schedule arrivals and departures according to algorithms described on next slides

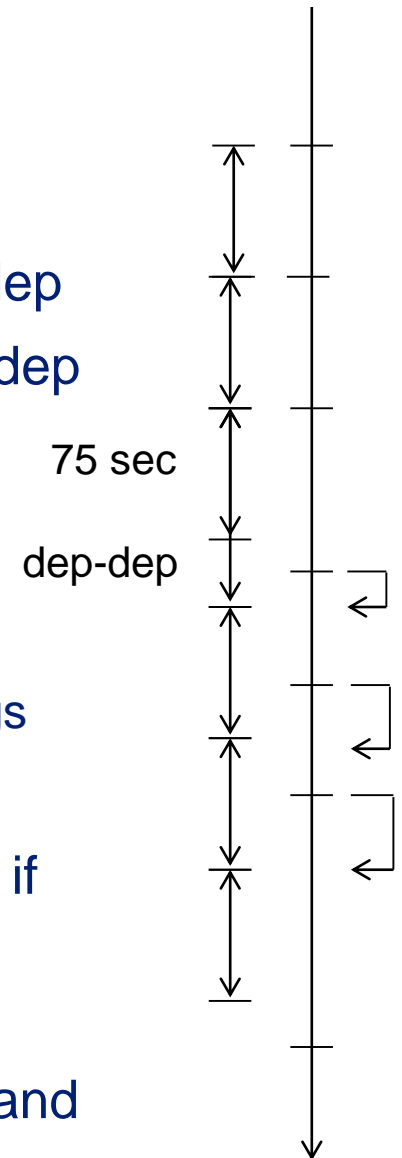
# TSS Algorithm

- Inputs:
  - Actual arrival landing times
  - One-departure spacing: spacing required between arrivals to insert one departure
    - Currently using 75 seconds between arrivals, with no consideration of landing runway or aircraft type
    - 75 seconds is conservative and accommodates all arr-dep + dep-arr spacings
- Logic: For each arrival  $i$  in FCFS order
  - delay arrival  $i$  to previous arrival  $i-1$  plus required one-departure spacing if
    - gap from previous arrival is less than required spacing
    - delay is less than a threshold currently set at 120 seconds



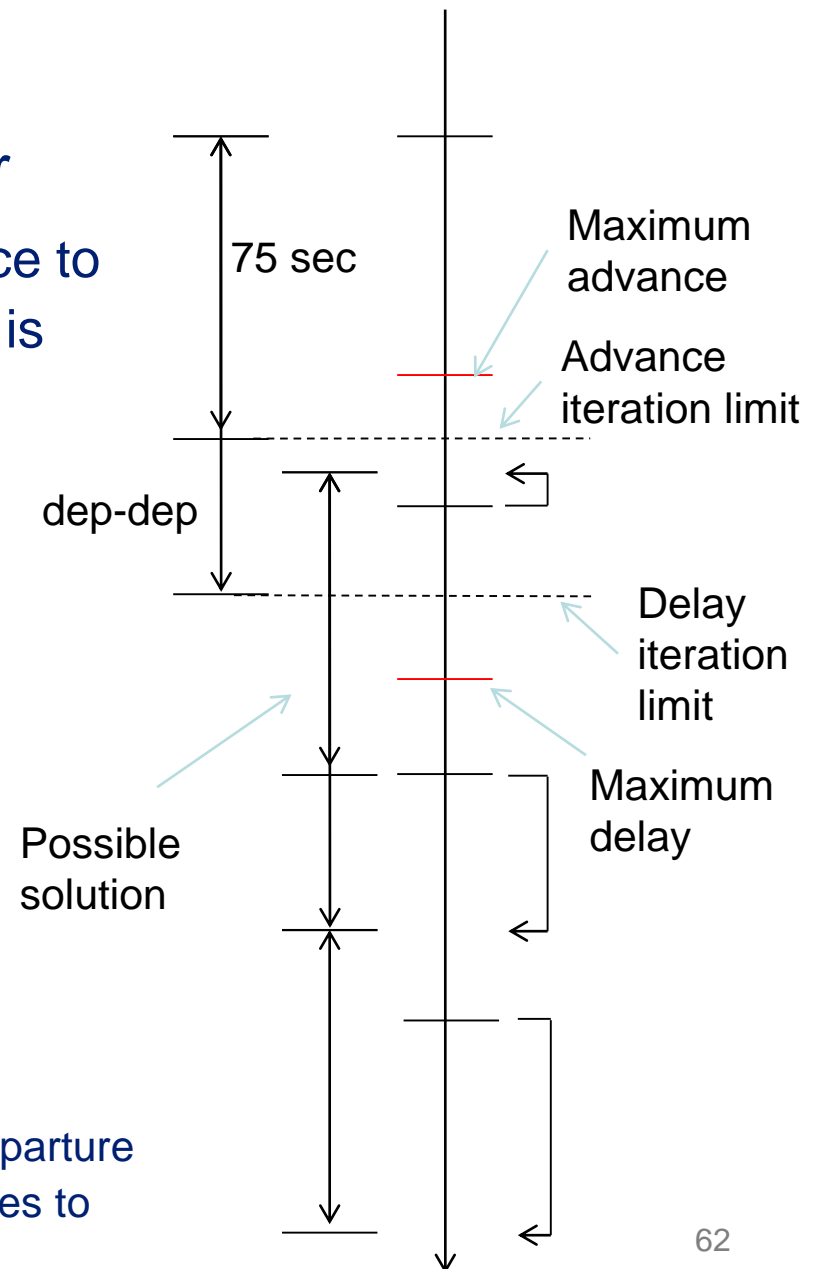
# DSAS Delay-Only Algorithm

- Inputs:
  - TSS schedule
  - Required spacing: arr-dep, dep-dep and dep-arr
  - Two-departure spacing = One-departure spacing + dep-dep
  - Three-departure spacing = two departure spacing + dep-dep
- Logic: For each arrival  $i$  in FCFS order
  - Delay arrival  $i$  to previous arrival  $i-1$  plus two-departure spacing (or three-departure spacing) if
    - Original spacing is between one- and two-departure spacings
    - Required delay is less than threshold (120 sec)
    - There is a set of following arrivals that can be delayed if needed with each delay under the threshold (120 sec) and with one-departure spacing in between
    - There is at least one departure that can be advanced and cumulative departure advance is larger than the cumulative arrival delay



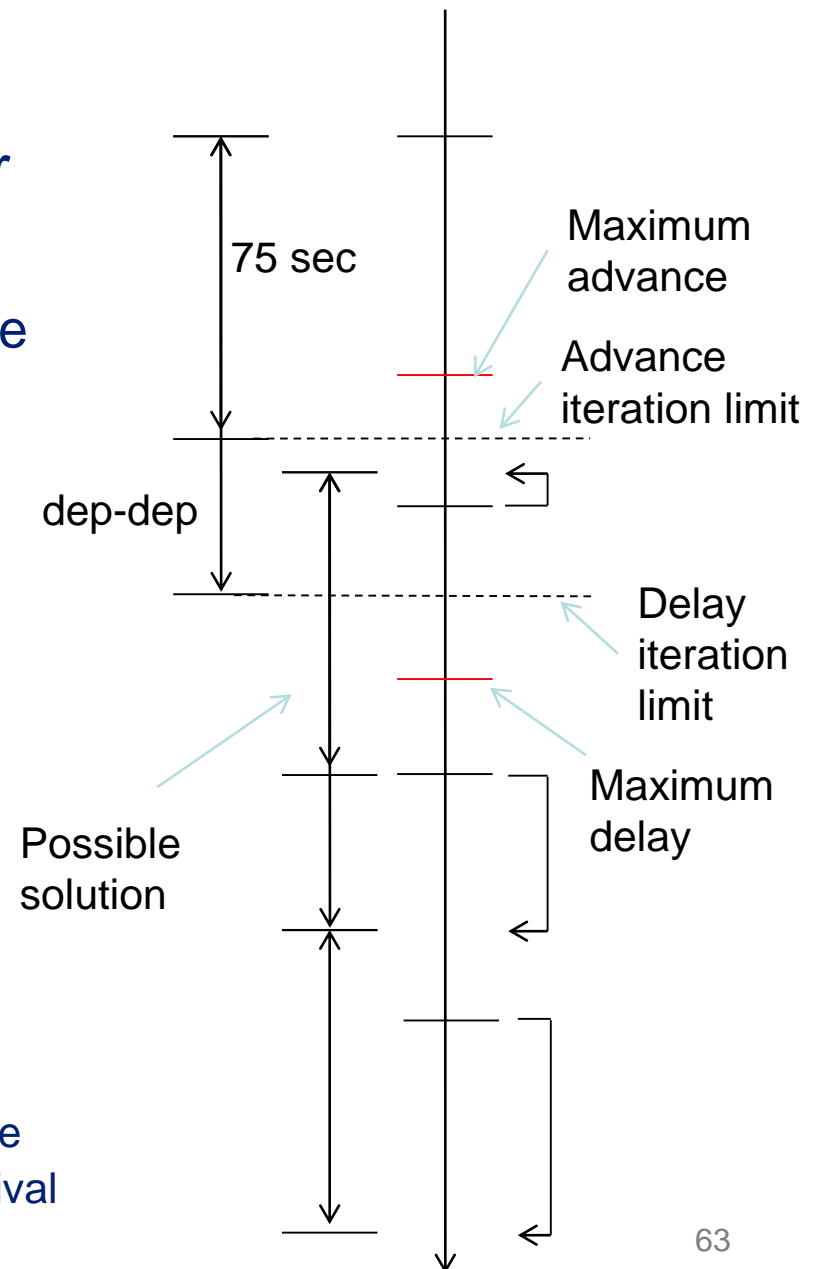
# DSAS Advance-Delay Algorithm

- Inputs: Same as Delay-Only algorithm
- Logic: For each arrival  $i$  in FCFS order
  - Iterate backwards to find minimum advance to create two-departure gap, if advance limit is reached, iterate forward to find the two-departure gap until delay limit is reached
  - Advance limit is set at maximum of:
    - Advance threshold set at 45 seconds
    - One-departure gap from previous arrival
    - Two-departure gap from following arrival
  - Delay limit is set at minimum of
    - Delay threshold set at 120 seconds
    - Two-departure spacing from previous arrival
  - At each iteration
    - Set following arrival to iterated value plus two-departure spacing and accept solution if there are departures to advance more than cumulative arrival delay



# DSAS Advance-Delay No-Slack Algorithm

- Inputs: Same as Delay-Only algorithm
- Logic: For each arrival  $i$  in FCFS order
  - Iterate forwards from advance limit to find maximum advance to create two-departure gap, until delay limit is reached
  - Advance limit is set at maximum of:
    - Advance threshold set at 45 seconds
    - One-departure gap from previous arrival
    - Two-departure gap from following arrival
  - Delay limit is set at minimum of
    - Delay threshold set at 120 seconds
    - Two-departure spacing from previous arrival
  - At each iteration
    - Set following arrival to iterated value plus two-departure spacing and accept solution if there are departures to advance more than cumulative arrival delay



# DSAS Departure Scheduling Algorithm

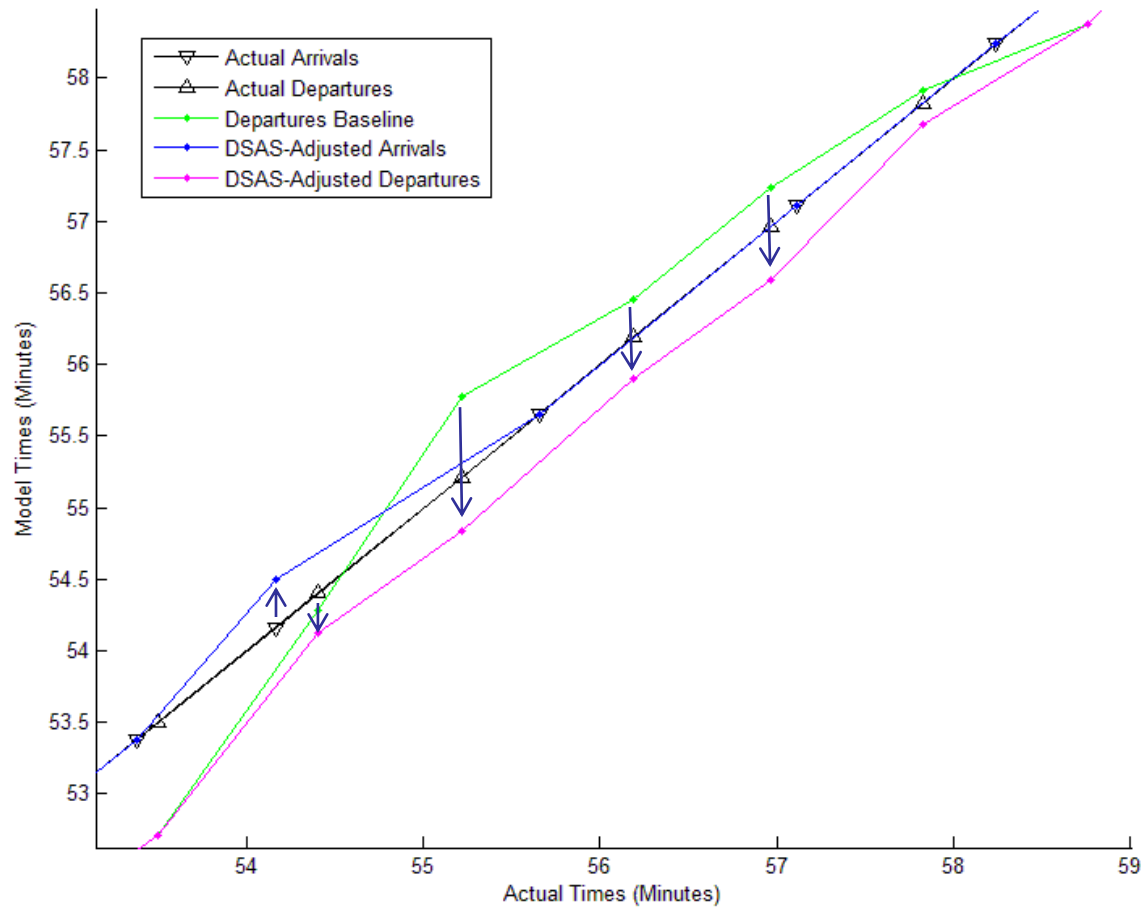
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- Inputs:
  - Arrival schedule to fit departures in between
  - Required spacing: arr-dep, dep-dep and dep-arr
  - Departure demand: expected departure times EDT
  - Reference departure time to be used if only benefit is acceptable
- Logic: For each departure  $i$  in FCFS order according to expected departure times
  - Starting from arrival gap that brackets expected departure time search forward until a schedule departure time ( $dep\_sch$ ) satisfies the following
    - If gap has no departures,  $dep\_sch = \max(\text{leading arrival} + \text{arr-dep}, \text{EDT})$
    - If gap has departures already scheduled,  $dep\_sch = \max(\text{latest departure} + \text{dep-dep}, \text{EDT})$
    - If reference time is given,  $dep\_sch = \min(dep\_sch, \text{reference time})$
    - Trailing arrival  $> dep\_sch + \text{dep-arr}$



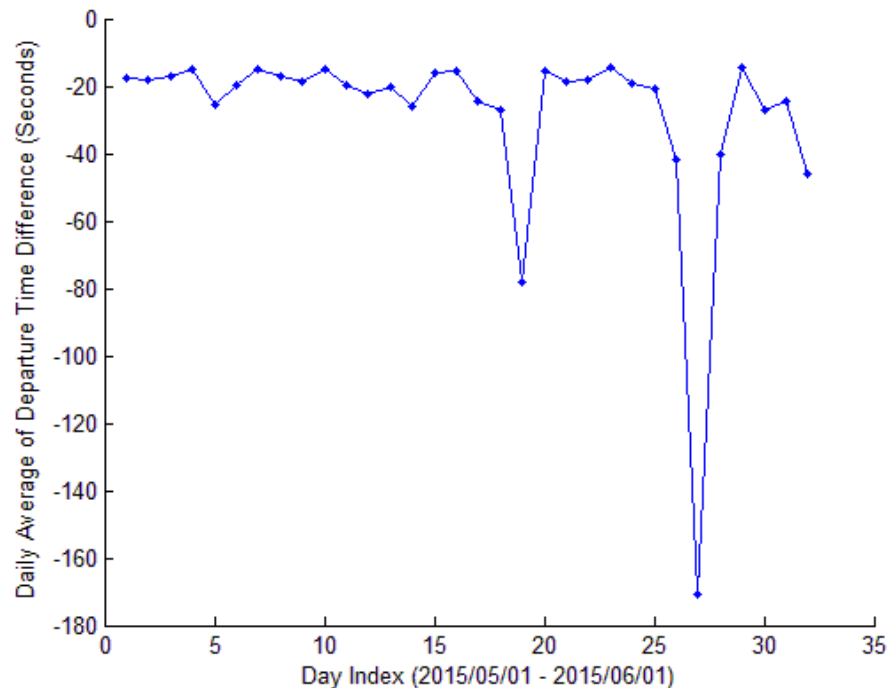
# DSAS Scheduler Analysis – Results

- Mechanism of TSS and DSAS scheduling
- One arrival adjustment can cause several departure adjustments



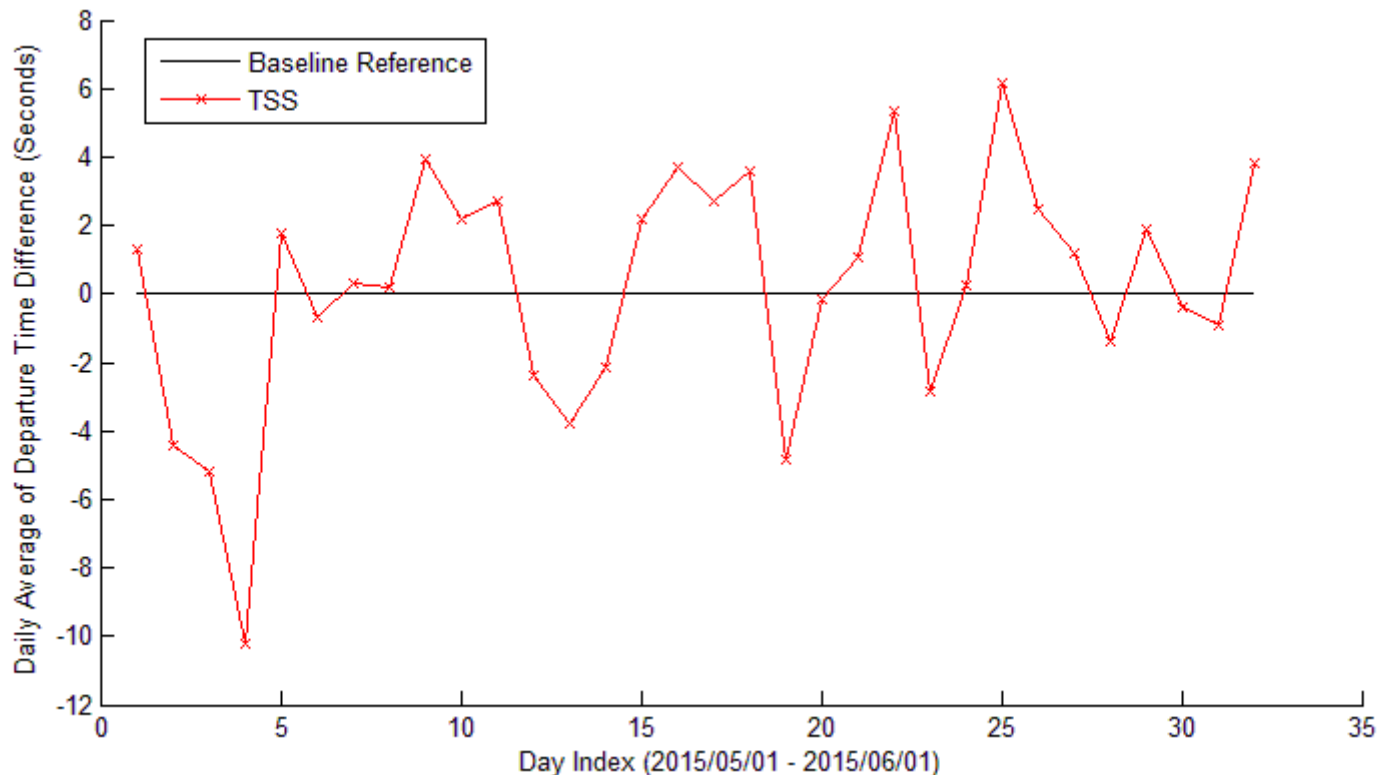
# DSAS Scheduler Analysis – Results

- Departure baseline validation
  - Departures inserted within actual arrival times to establish ideal baseline
  - Baseline error depends on model parameters including nominal travel time and separation requirements
    - Departures assumed ready at actual runway entry time plus 10% of entry to takeoff times
    - Separation matrix assumed at 10<sup>th</sup> percentile of historical inter-operation times
    - Resulted in baseline error of about -20 seconds for most days



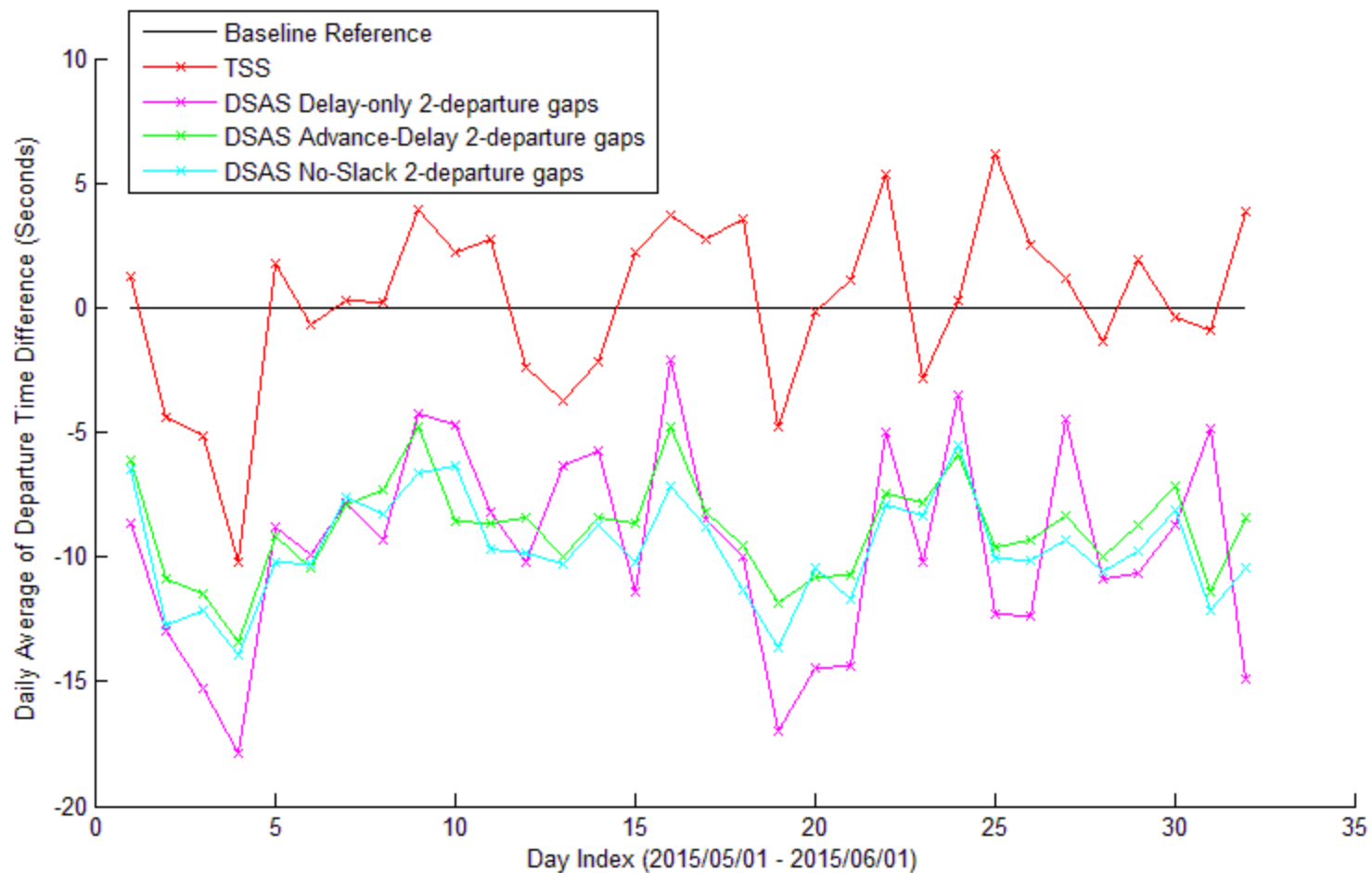
# DSAS Scheduler Analysis – Results

- TSS performance relative to baseline varied around zero
  - TSS only re-establishes required separations between landings, which should be mostly satisfied in baseline’s actual landing times
  - TSS spacing is not coordinated with departures (spacing adjusted even if no departure may take advantage of it)



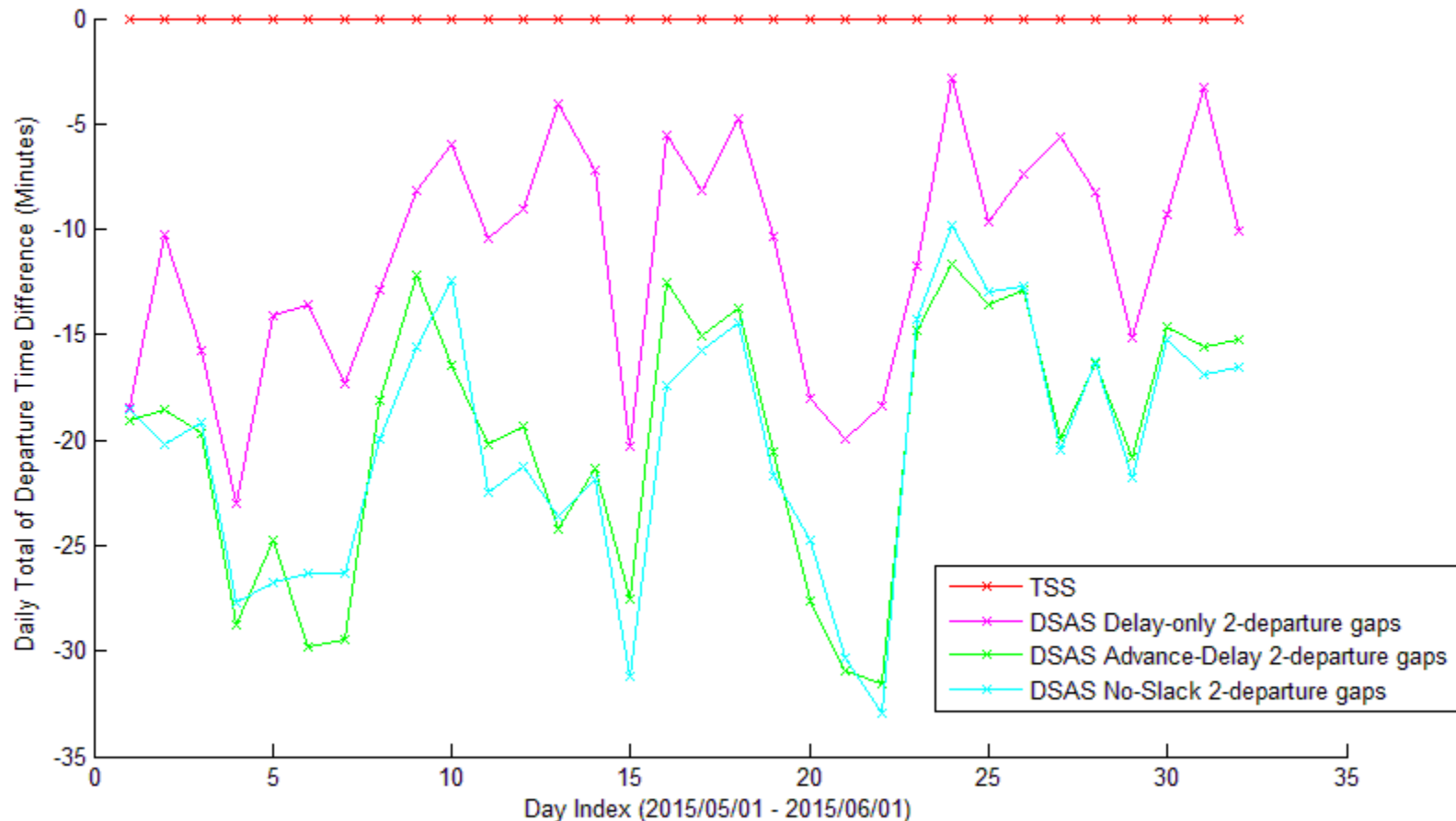
# DSAS Scheduler Analysis – Results

- DSAS performance relative to TSS
  - All DSAS algorithms show savings relative to the TSS



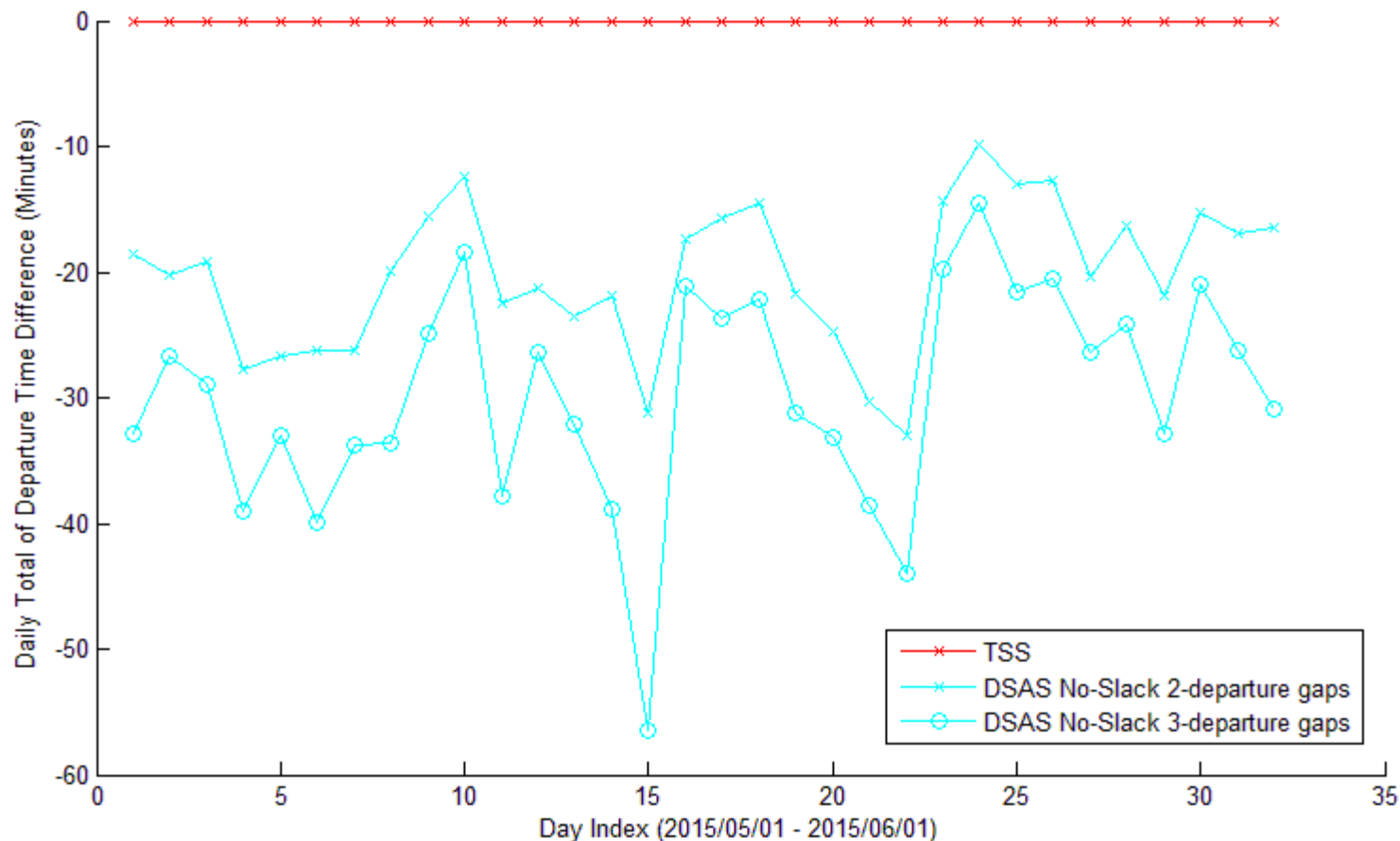
# DSAS Scheduler Analysis – Results

- DSAS performance relative to TSS
  - Total daily delay savings relative to TSS between five and thirty minutes
  - DSAS with Advance and with No-Slack results in higher savings than with Delay-Only



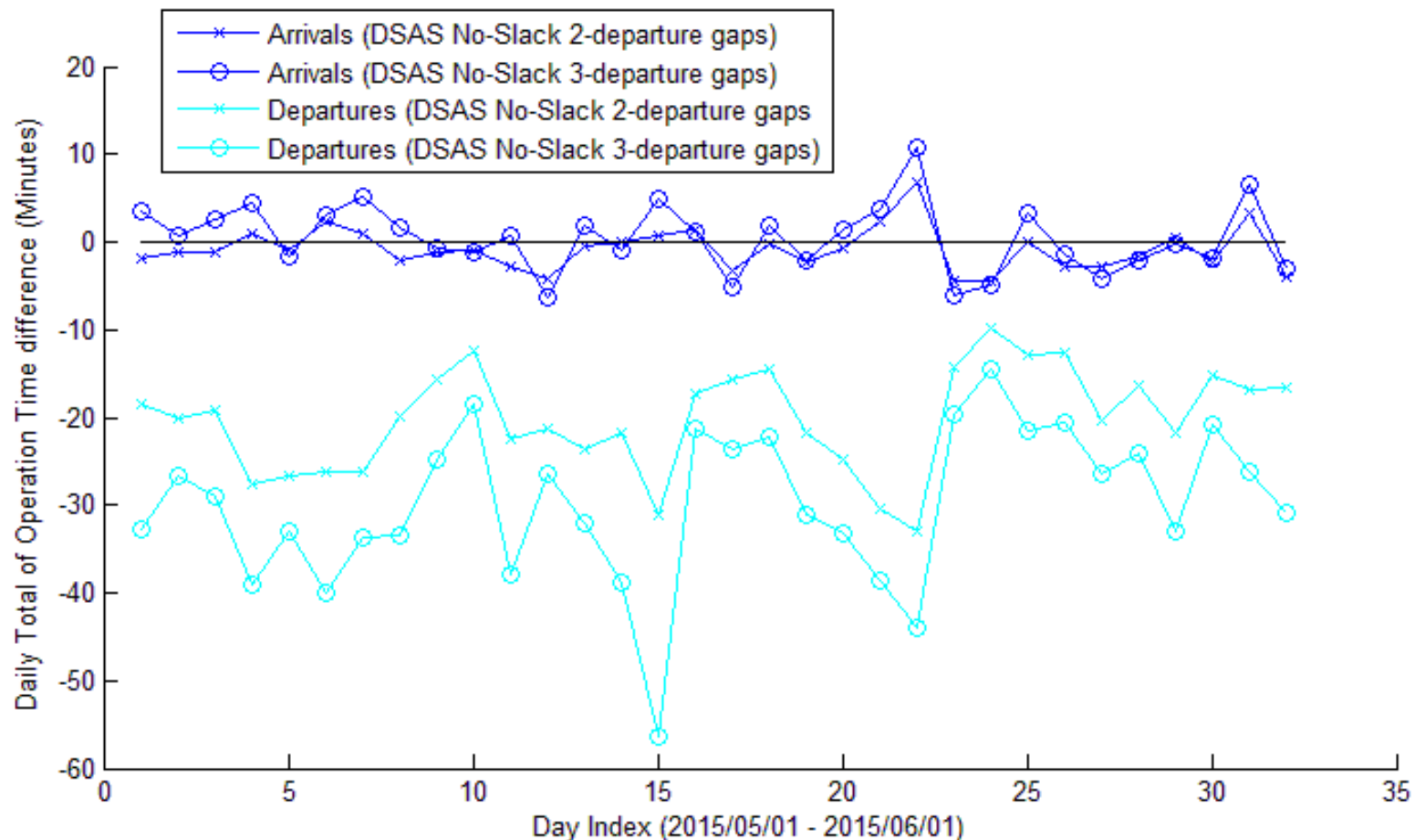
# DSAS Scheduler Analysis – Results

- DSAS performance relative to TSS
  - Savings increase when DSAS finds gaps for three departures in addition to gaps for two departures



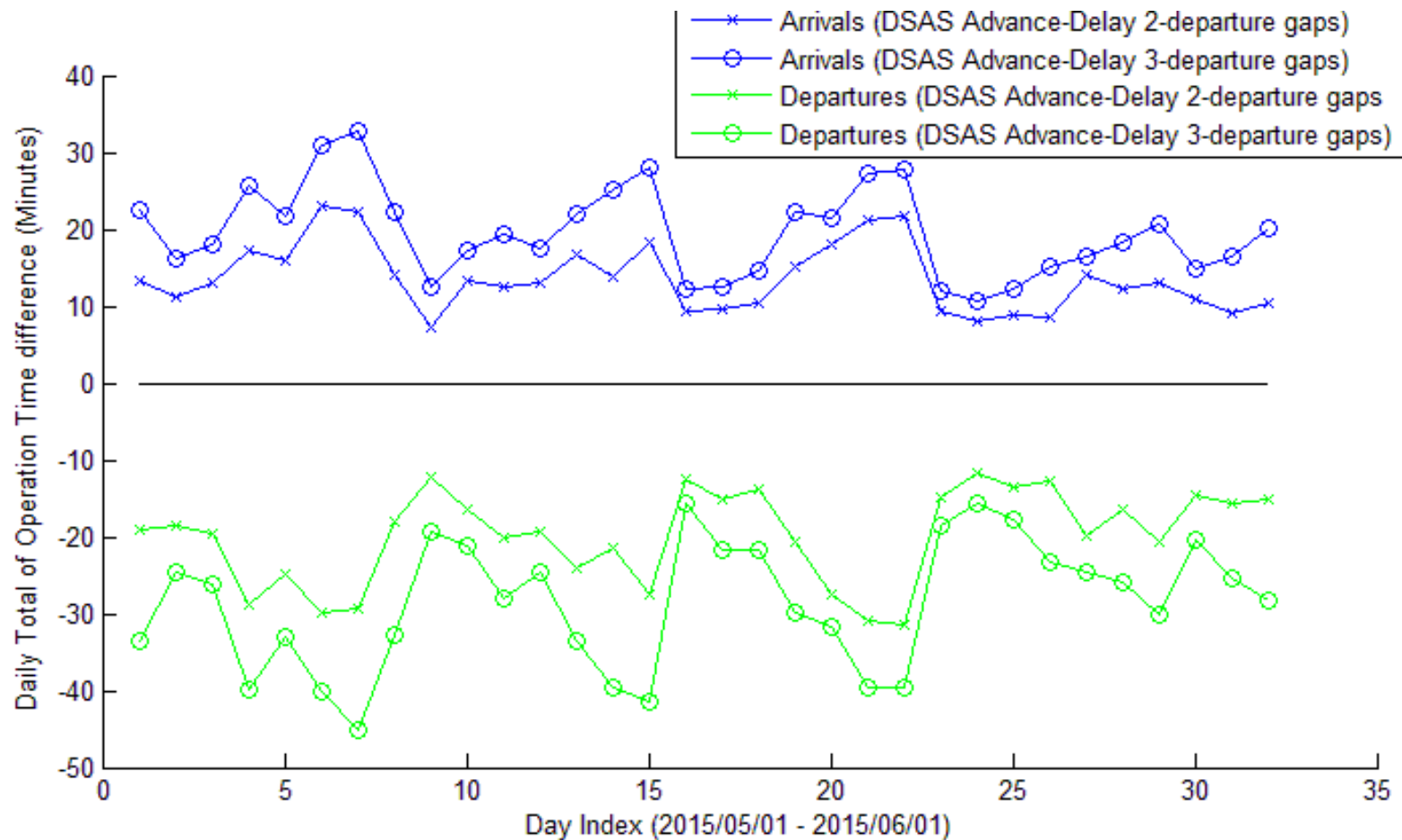
# DSAS Scheduler Analysis – Results

- Negative impact on arrivals is guaranteed to be lower than positive impact on departures



# DSAS Scheduler Analysis – Results

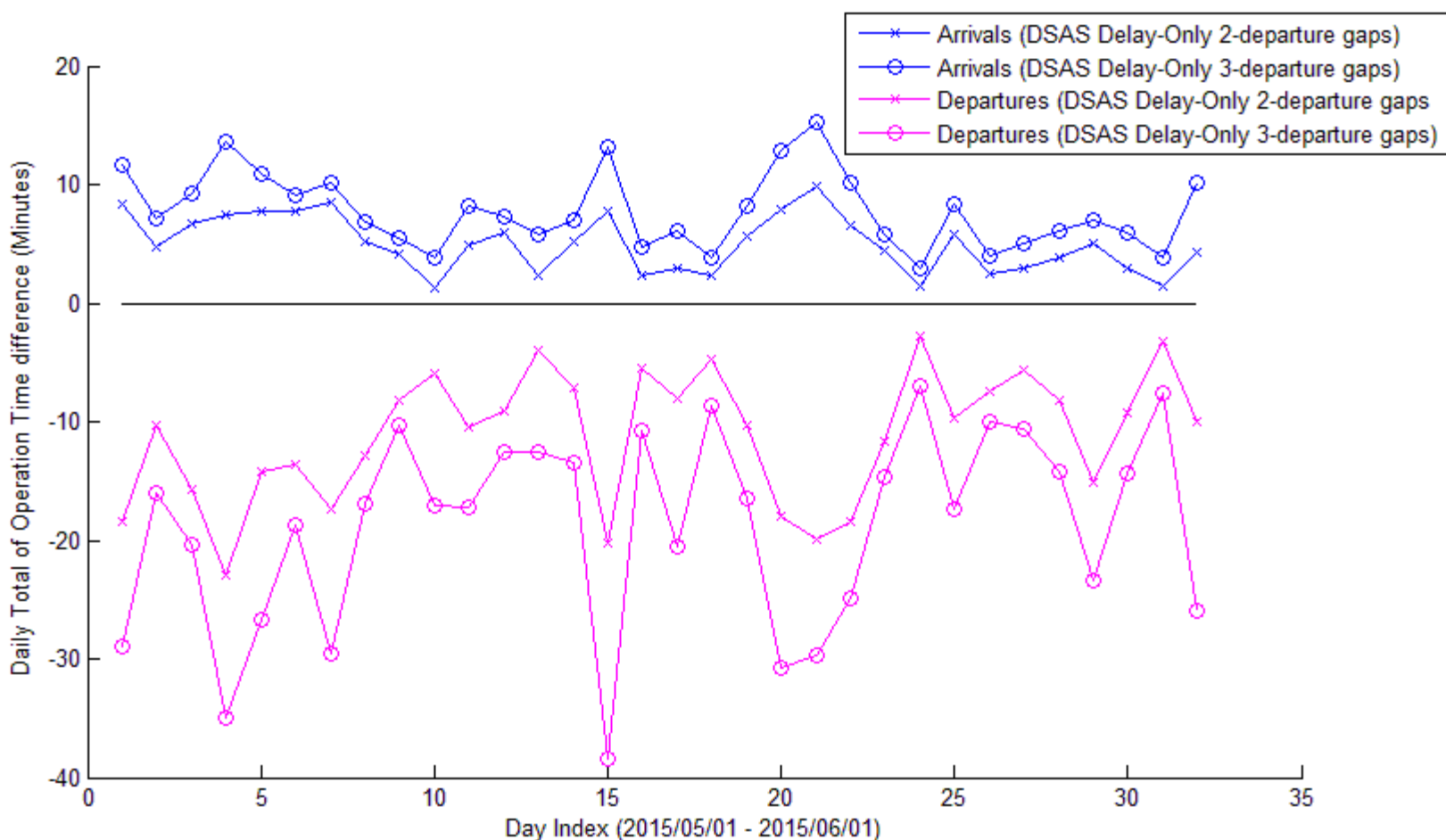
- Negative impact on arrivals is guaranteed to be lower than positive impact on departures





# DSAS Scheduler Analysis – Results

- Negative impact on arrivals is guaranteed to be lower than positive impact on departures

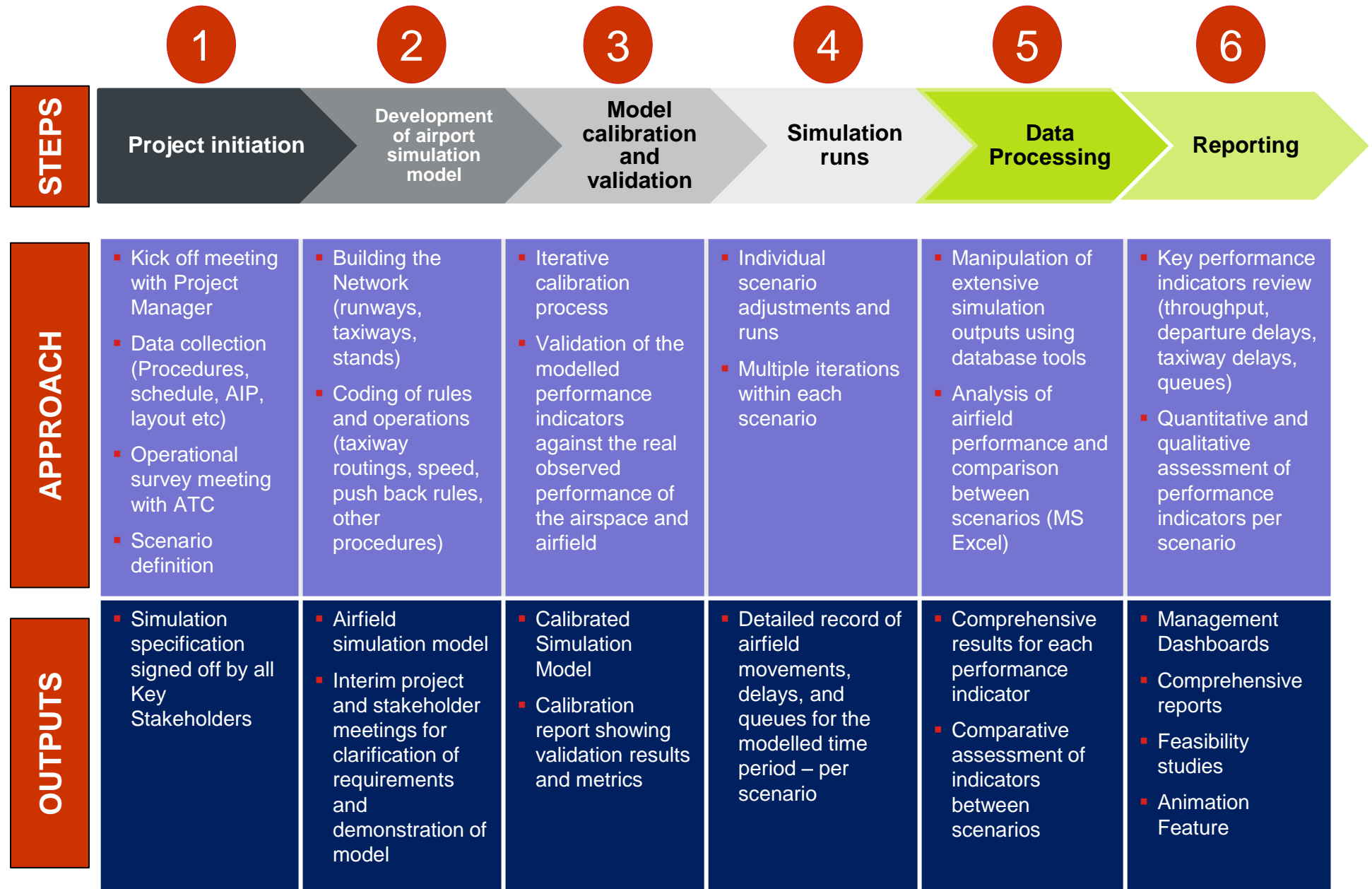


# Outline

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- Research Motivation and Objectives
- Recap of Year One Activities and Progress
- **Discussion of Focus Areas of Year One**
  - Integrated Scheduling between Surface and Airspace
  - Identification of Queue/Delay Buffer Sizes for Departure Metering
  - Integration of Arrival and Departure Scheduling
  - **High-Fidelity Fast-Time Simulation Modeling**
- Proposed Year 2 Work

# 6 Stage Approach to the Simulation Process




# Calibration Process

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- Simulation built based on West Flow
  - Analysis of entire year of operations
  - Demand Schedules (MS Excel)
- Models built based on current gate assumptions (simplified gate areas to start) and taxiway structure
- Comparisons to real world data (truth data)
  - A80 TRACON Data – Performance Data Analysis and Reporting System (PDARS)
  - Surface Data Metrics (PDARS)
- Iterative process

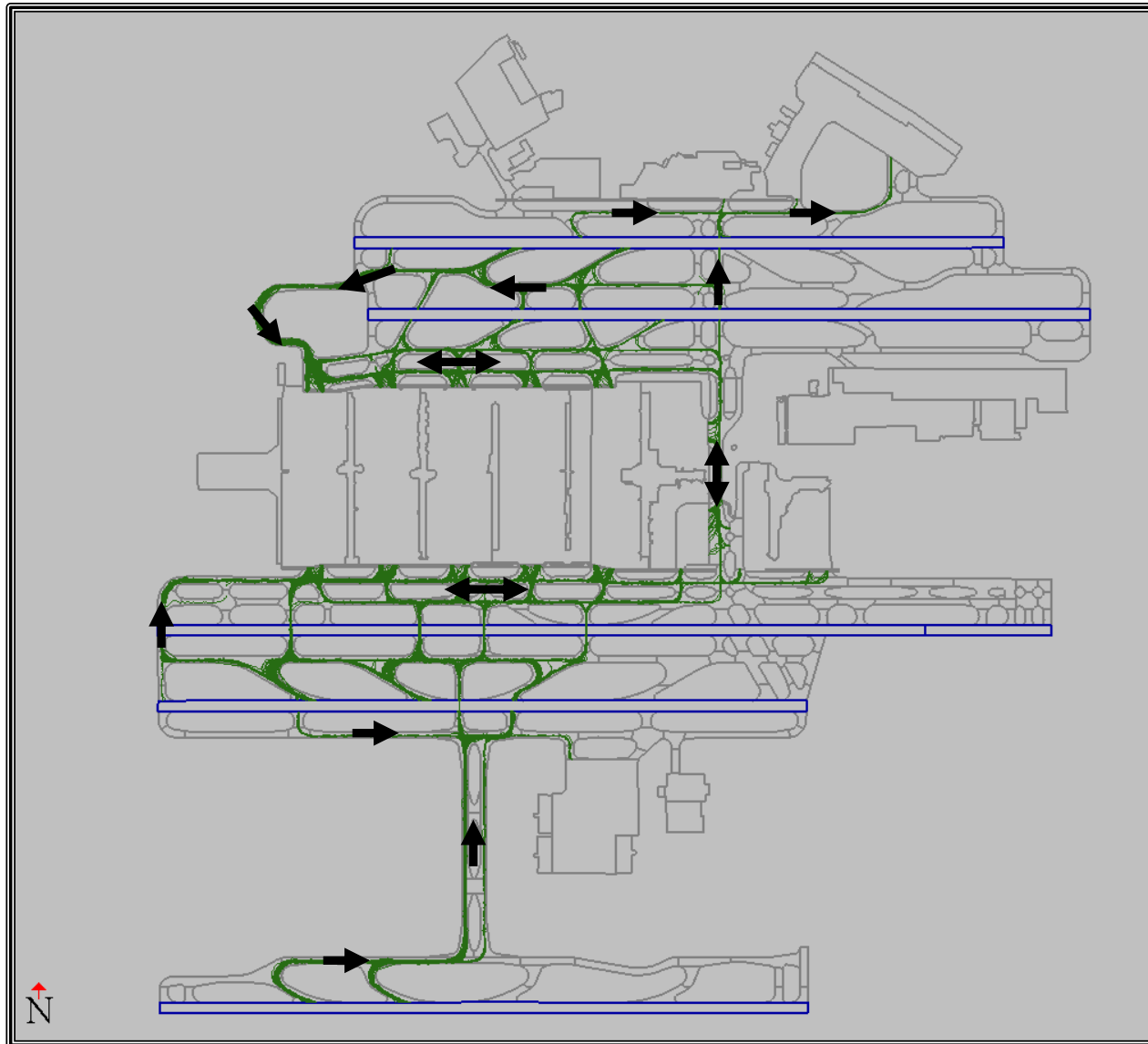
# ATL Runway Flow Analysis

- Year's Worth of PDARS Shows ATL Primarily Uses West Flow Configuration
- Arrival Runways = 26R, 27L, 28
- Departure Runways = 26L and 27R

 Runway Usage For A80 from 01/01/2014 to 12/31/2014			
Airport		ATL	▼
Operation		Arrival	▼
Sum			
Flow	Runway	Total	
East Flow	08L	48,415	
	08R	3,628	
	09L	344	
	09R	45,935	
	10	30,943	
<b>East Flow Total</b>		<b>129,265</b>	<b>29.89%</b>
West Flow	26L	5,829	1.92%
	26R	123,726	40.80%
	27L	109,884	36.23%
	27R	1,353	0.45%
	28	62,471	20.60%
<b>West Flow Total</b>		<b>303,263</b>	<b>70.11%</b>
<b>Grand Total</b>		<b>432,528</b>	
Airport		ATL	▼
Operation		Departure	▼
Sum			
Flow	Runway	Total	
East Flow	08L	467	
	08R	67,261	
	09L	60,770	
	09R	250	
	10	75	
<b>East Flow Total</b>		<b>128,823</b>	<b>29.85%</b>
West Flow	26L	162,523	53.68%
	26R	2,049	0.68%
	27L	913	0.30%
	27R	134,126	44.30%
	28	3,165	1.05%
<b>West Flow Total</b>		<b>302,776</b>	<b>70.15%</b>
<b>Grand Total</b>		<b>431,599</b>	

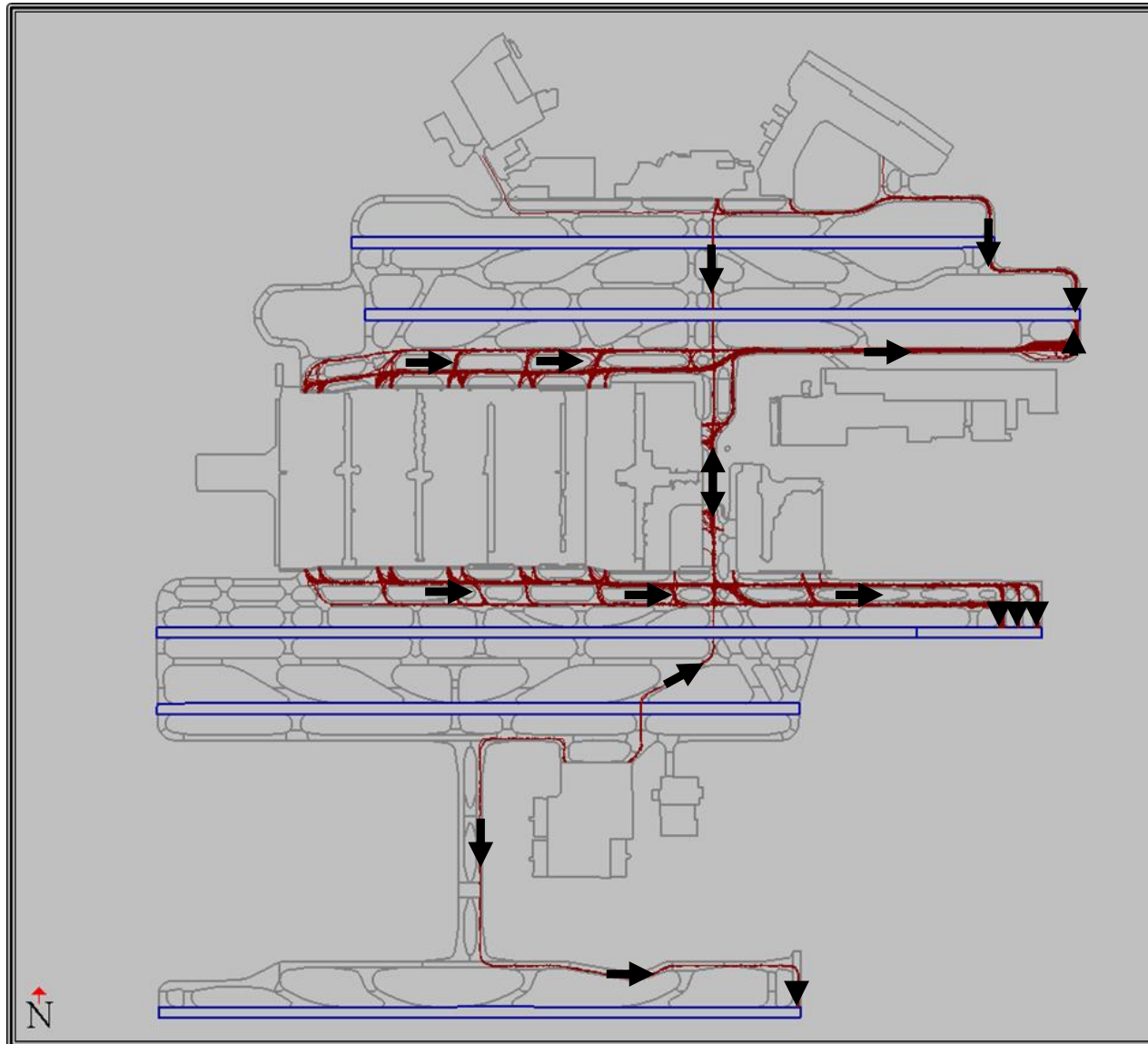
# ATL West Flow - Arrivals

- West Flow ASDE-X PDARS Reviewed for Arrival Taxi Flows



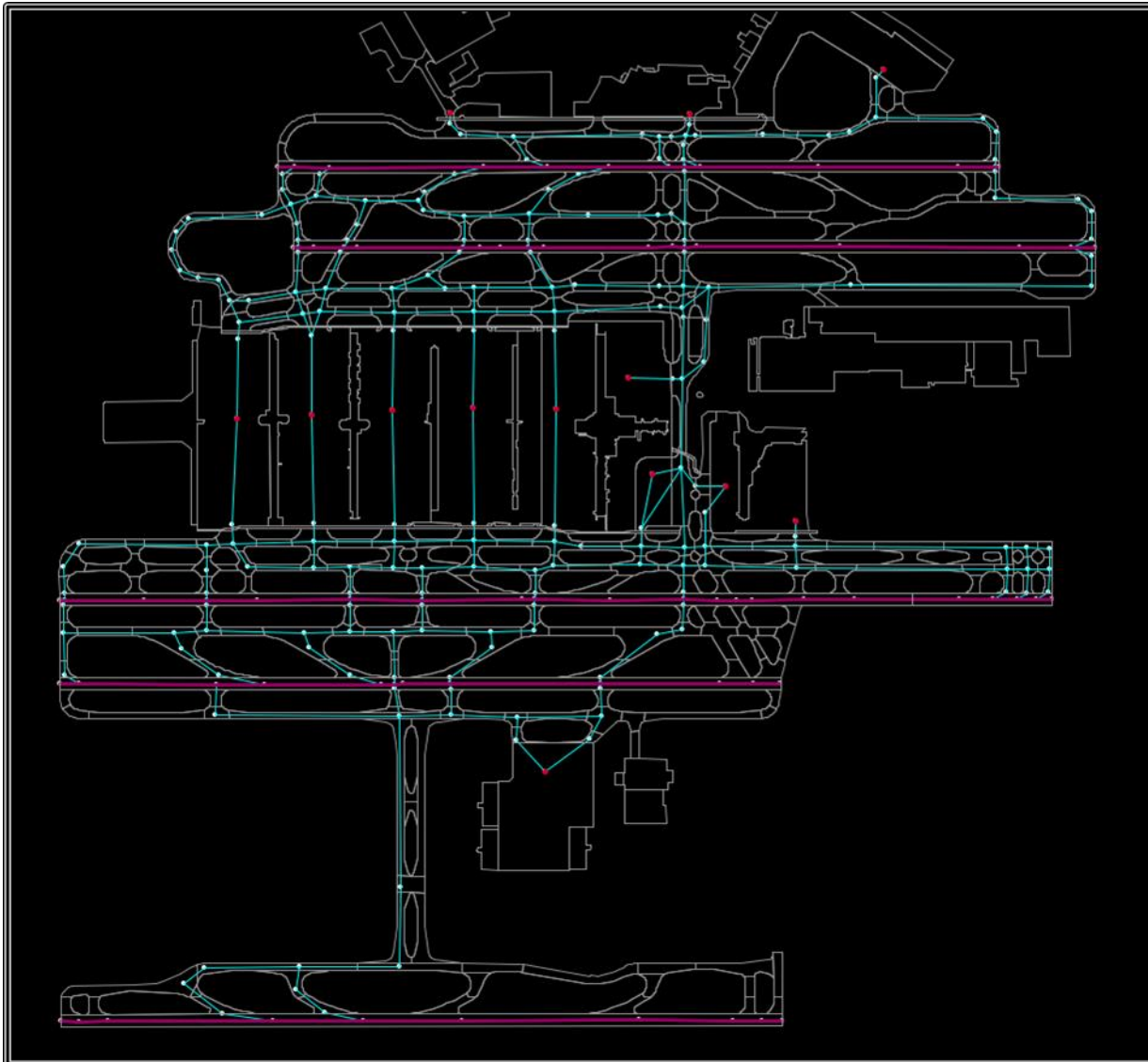
# ATL West Flow Departures

- West Flow ASDE-X PDARS Reviewed for Departure Taxi Flows



# ATL Model Build

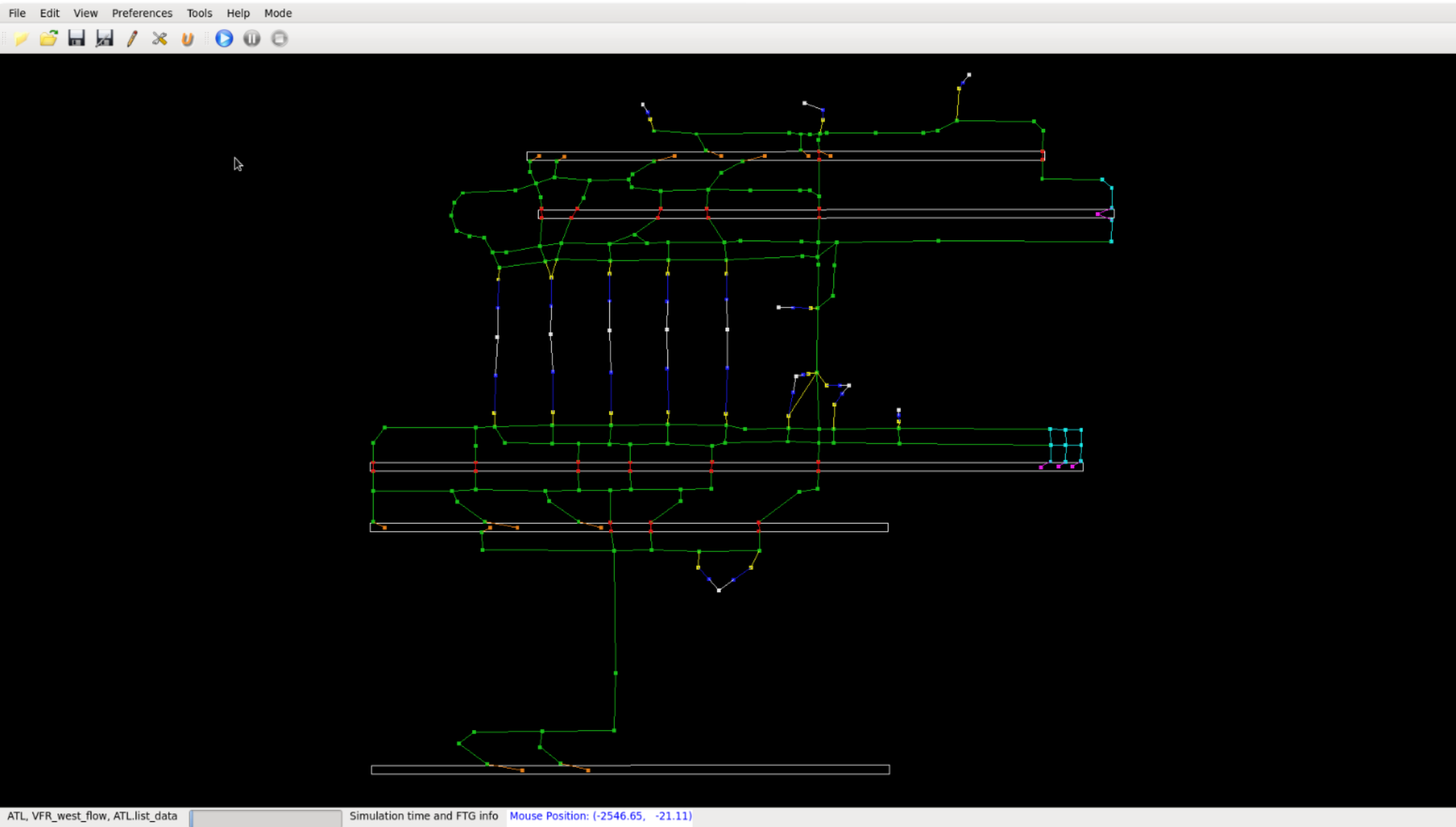
- Node/Link Structure Creation






# ATL Model Build in SOSS

- Node/Link Structure in SOSS



# Example Calibration Metric – Taxi Time

- Taxi Time Calibration - West Flow Configuration Days



## Average Taxi Time

For ATL+ASDEX - 2014\*

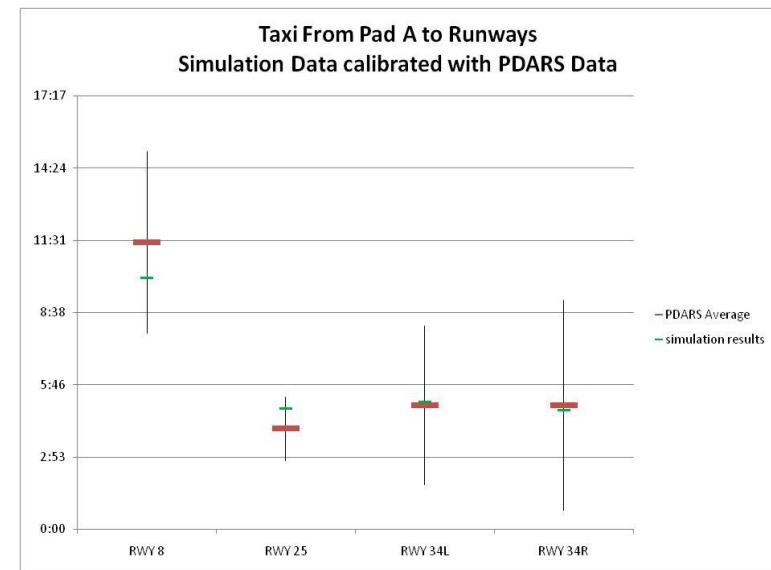
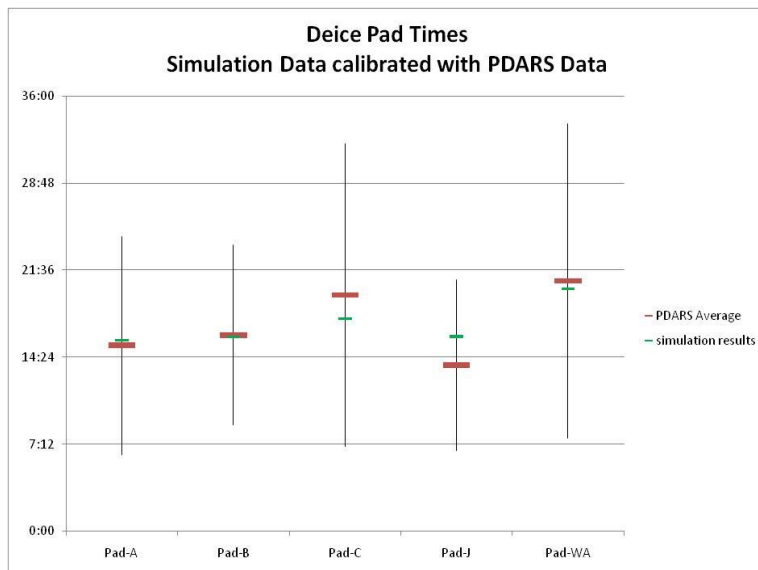
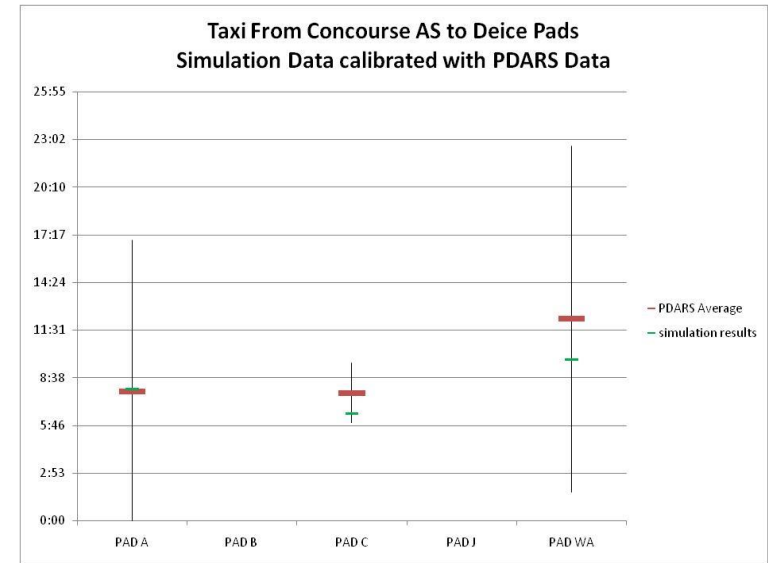
Month	Arrivals		Departures		Total Acft Count	Total Avg Taxi Time
	Acft Count	Avg Taxi Time	Acft Count	Avg Taxi Time		
January	17,235	05:10	17,208	08:44	34,443	06:57
February	16,554	04:51	16,550	08:22	33,104	06:36
March	14,980	04:48	14,966	08:16	29,946	06:32
April	13,670	04:53	13,705	08:33	27,375	06:43
May	21,719	04:59	21,660	09:11	43,379	07:05
June	24,483	05:20	24,520	09:52	49,003	07:36
July	15,652	05:00	15,643	09:27	31,295	07:14
August	12,950	04:56	13,042	10:33	25,992	07:45
September	4,272	05:11	4,455	10:43	8,727	08:00
October	26,895	05:01	28,275	09:18	55,170	07:13
November	19,646	04:26	20,491	07:58	40,137	06:14
December	17,754	04:32	18,318	08:07	36,072	06:21
<b>Grand Total</b>	<b>205,810</b>	<b>04:56</b>	<b>208,833</b>	<b>09:00</b>	<b>414,643</b>	<b>06:59</b>

\* Data represents 176 days of West Flow configuration only; no configuration changes during the day

# Calibration of fast time model with PDARS

Simulation Times calibrated with PDARS  
(ASDE-X) recorded data

- Concourses to Pads
- Within Pads
- From Pads to Runways



# Example Calibration Metric – Runway Throughput

- Hourly Runway Throughput – West Configuration, Single Day

**PDARS**

## Daily Runway Throughput - Hour Bins

For ATL+ASDEX - January 7, 2014 (UTC)

Time	Arrivals				Departures			
	26R	27L	28	Total	26R	26L	27R	Total
4:00	4	2		6		8		8
5:00	14	8		22		30	2	32
6:00	2	2		4		8	4	12
7:00	4	2		6		2		2
8:00	4			4				0
9:00	6			6	1	2		3
10:00	12	10		22		2		2
11:00	18	16		34		6	2	8
12:00	36	36		72		28	32	60
13:00	66	66		132		50	50	100
14:00	63	54	28	145		64	58	122
15:00	50	34		84		76	80	156
16:00	67	68		135		82	64	146
17:00	58	50		108		74	60	134
18:00	63	64	12	139		66	76	142
19:00	73	58	20	151		65	68	133
20:00	75	68	26	169		74	82	156
21:00	60	64	4	128		80	76	156
22:00	62	58	8	128		100	58	158
23:00	62	62	52	176		62	50	112
0:00	70	46	46	162		78	68	146
1:00	76	60	36	172		64	60	124
2:00	64	50	22	136		90	46	136
3:00	42	14		56		64	56	120
4:00	10	4		14		58	36	94
<b>Total</b>	<b>1,061</b>	<b>896</b>	<b>254</b>	<b>2,211</b>	<b>1</b>	<b>1,233</b>	<b>1,028</b>	<b>2,262</b>

# Outline

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- Research Motivation and Objectives
- Recap of Year One Activities and Progress
- Discussion of Focus Areas of Year One
  - Integrated Scheduling between Surface and Airspace
  - Identification of Queue/Delay Buffer Sizes for Departure Metering
  - Integration of Arrival and Departure Scheduling
  - High-Fidelity Fast-Time Simulation Modeling
- **Proposed Year 2 Work**

# Proposed Year 2 Work

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- Extending the scheduling algorithms to support ATD-2 activities, along four main tracks
  - Investigate limited distributed schemes
  - Increase incorporation of arrivals
  - Improve optimality while maintaining practical real time application
  - Improve robustness and flexibility to mitigate uncertainties
- Assess scheduling schemes performance using higher fidelity simulation using NASA's SOSS and/or ACES trajectory-based simulation platforms

# Proposed Year 2 Work: Distributed Schemes

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- Current year one approach:
  - Centralized integrated scheduler
- Year two extensions:
  - Collaborative centralized scheduling
    - Centralized scheduler incorporating user /airport preferences
  - Limited distributed scheduling:
    - Centralized scheduler computes desired time slots
    - Distributed allocation of flights to available time slots by users and/or airports
- Potential third year extensions:
  - Additional distributed schemes with user/airport agents generating time slots

# Proposed Year 2 Work: Increase Arrival Incorporation

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- Current year one approach:
  - ASDS – Arrivals as constraints at dependent runways
  - DSAS – Arrival schedule adjustment to accommodate departure queues
- Year two extensions:
  - Arrival constraints at gates/ramp for departure metering
  - Additional control points to schedule departures while de-conflicting with arrivals sharing intersections points in the airspace
    - Tradeoff between added flexibility through delay buffers in the airspace and added control through scheduling at more control points



# Proposed Year 2 Work: Improve Optimality

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- Current year one approach:
  - Dynamic planner for integrated scheduling is suboptimal because of Flight by flight and FCFS scheduling
  - ASDS and DSAS remove some slack opportunistically
- Year two extensions:
  - Relax FCFS approach – Find opportunities to swap flights with maximum position shifts to accommodate
    - User preferences for flight priorities
    - Fair sharing of delay among airports/flights
  - Relax FCFS and flight by flight approaches using optimization methods
    - Use as benchmark for optimality because it may be impractical to use as solution

# Proposed Year 2 Work: Improve Robustness

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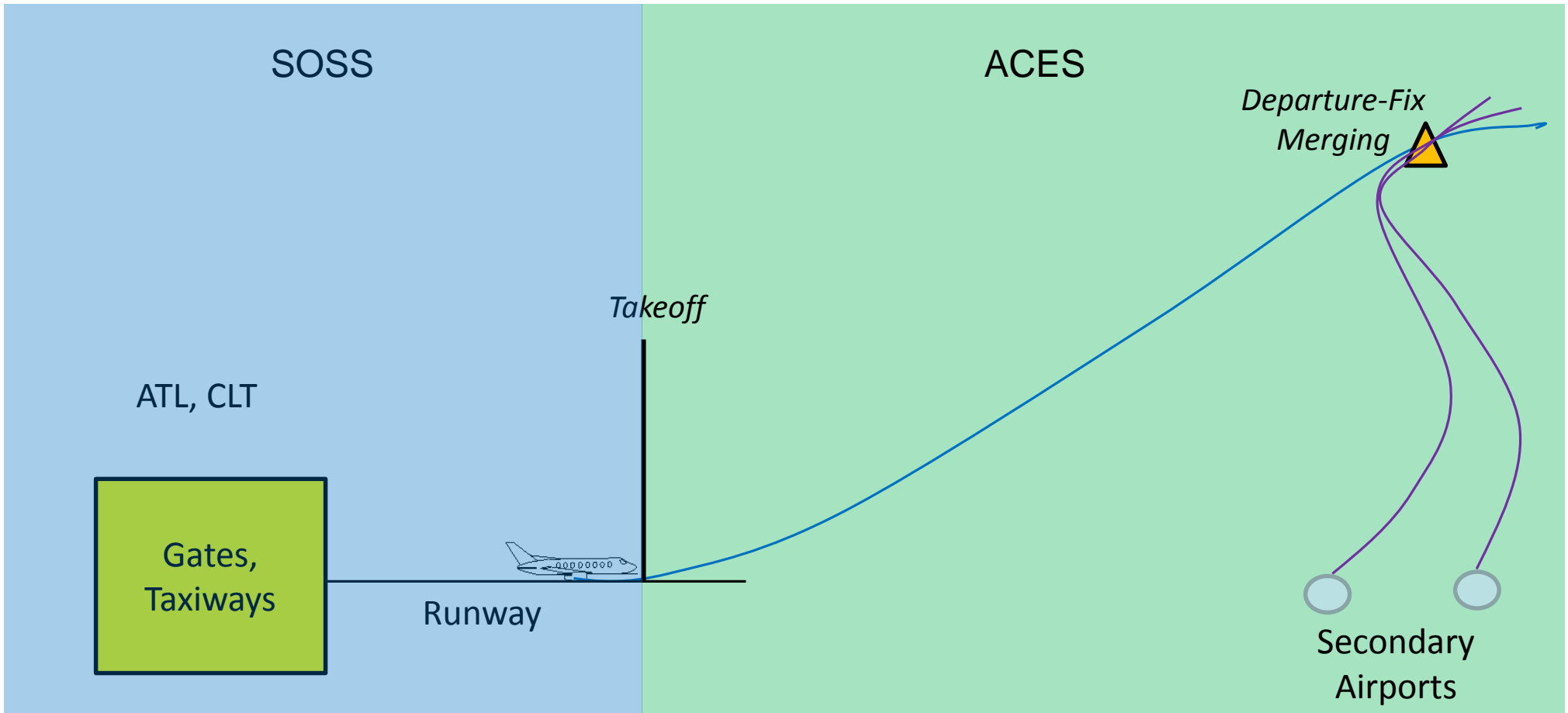
- Current year one approach:
  - Delay buffer sizing based on historical data and based on simulation
- Year two extensions:
  - Extend historical and simulation based buffer sizing
    - Use historical data based models to validate the simulation
    - Assess effectiveness of applying historical-based buffers using simulation
    - Estimate buffers under different conditions using validated simulation
  - Tailor delay buffer size
    - Dynamic buffer sizes over time based on varying conditions
    - Tradeoff between delay on ground or in the air
    - Tailor delay absorption by flight based on flight conditions and user preference
- Third year potential: stochastic modeling and optimization

# Proposed Year 2 Work

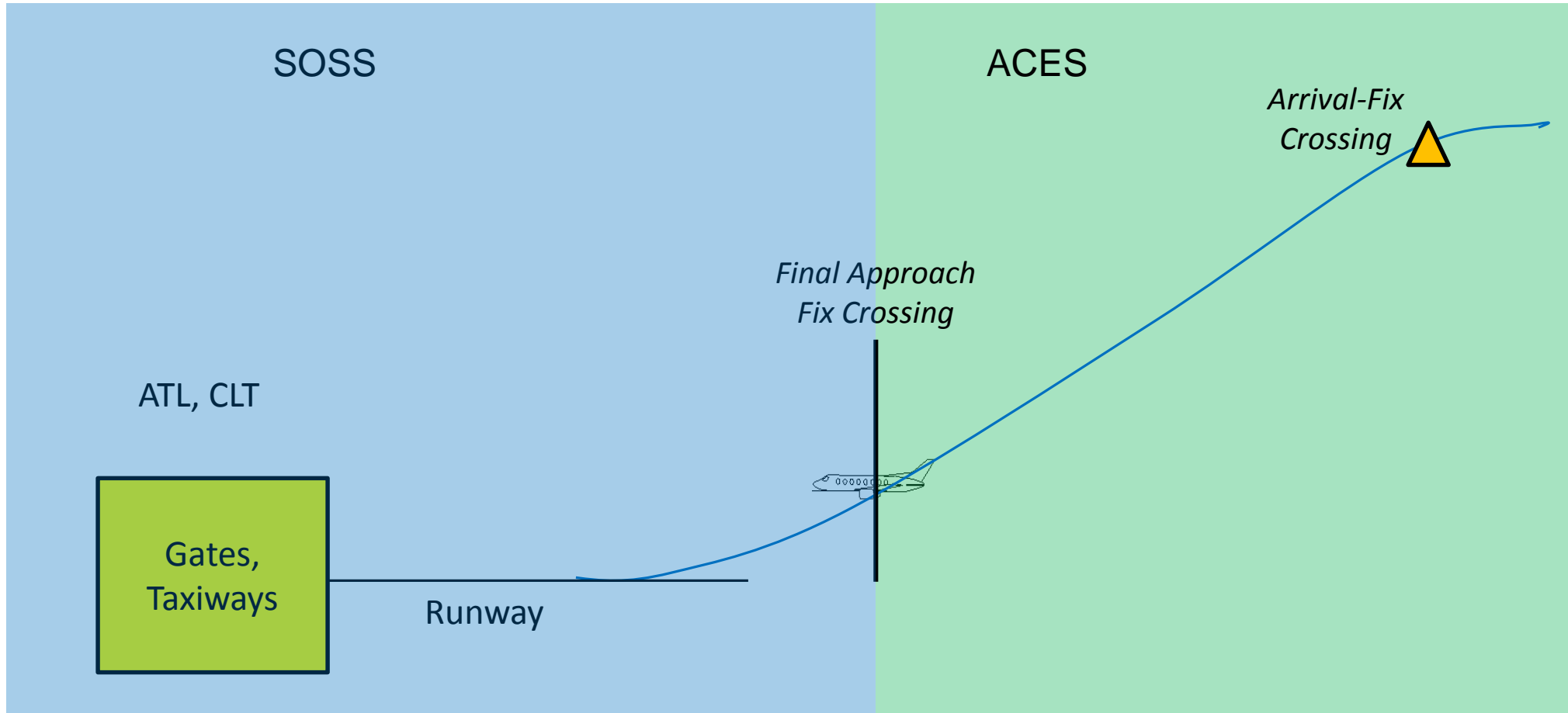
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- Assess scheduling schemes performance using higher fidelity simulation using NASA's SOSS and/or ACES trajectory-based simulation platforms

# Departure Flight Modeling

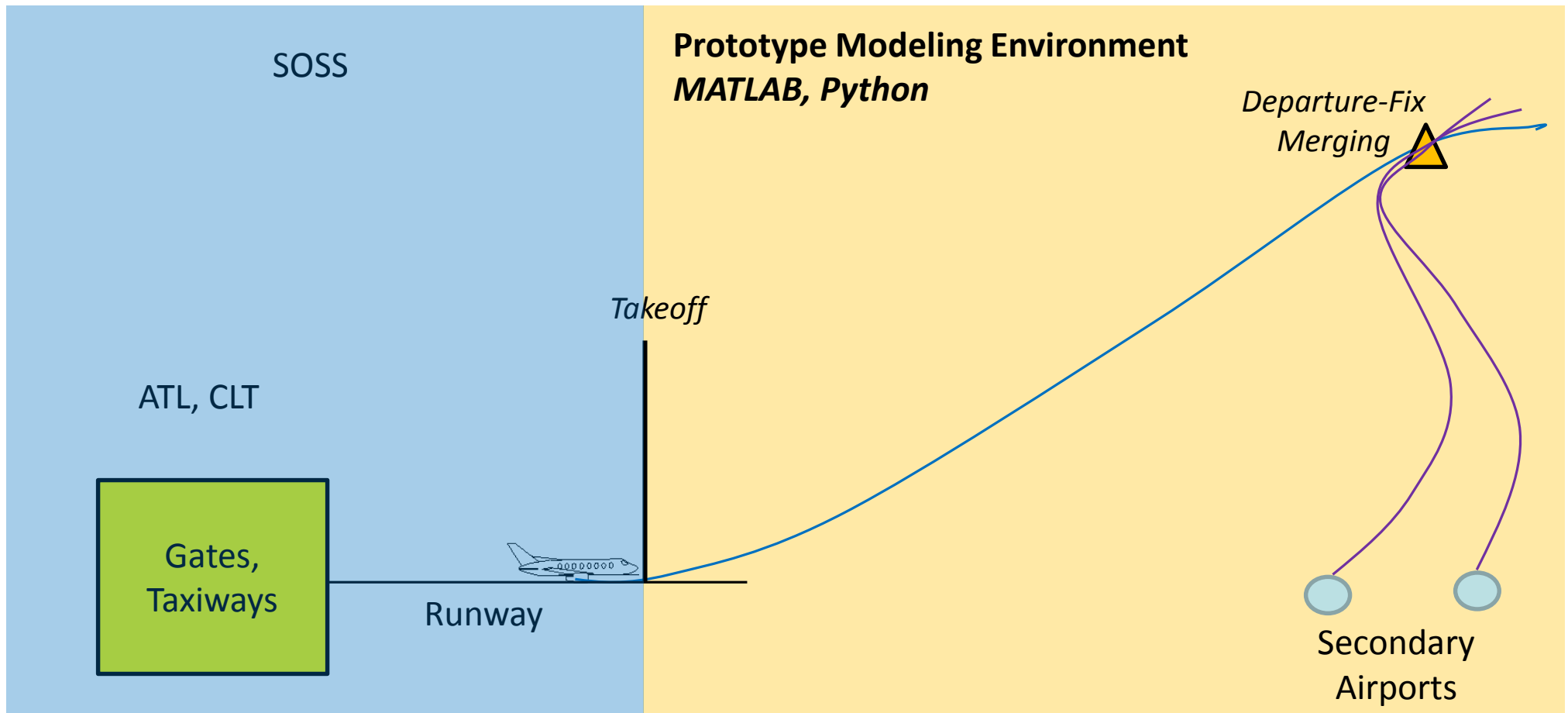


# Arrival Flight Modeling



# Another Option

## Departure Flight Modeling







Offers flexibility in modeling key features such as

- TMA at destination airports controlling departures at CLT/ATL
- En route stream merging
- Different departure-fix merging altitudes
- Arrival-departure interactions in the airspace

# Task Timelines

Task	Qtr1	Qtr2	Qtr3	Qtr4
Enhance scheduling algorithms	[Orange bar spanning Qtr1 and Qtr2]			
Develop new airport surface-terminal airspace models using SOSS and ACES, <b>ATL</b>	[Orange bar in Qtr1]			
Develop new airport surface-terminal airspace models using SOSS and ACES, <b>CLT</b>		[Orange bar in Qtr2]		
Integrate scheduling algorithms with simulation platform		[Orange bar spanning Qtr2 and Qtr3]		
Conduct simulation experiments			[Orange bar spanning Qtr3 and Qtr4]	
Analyze simulation output and quantify benefits				[Orange bar in Qtr4]

-  Algorithms report
-  Integration report
-  Modeling report
-  Final Year 2 report

# Proposed Year 2 Work

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- It is our understanding that NASA wants us to continue work on ATL traffic scenario in Year 2, plus add two more scenarios. Is this correct?
  - Proposed scenarios: CLT, another scenario?
- We would like to propose a quick-turnaround evaluation of different simulation architectures for modeling the ATD-2 scenarios, with SOSS-ACES being our first choice and MATLAB/Python-SOSS being two other options. Is NASA ok with this?
- How does NASA envision the results of this NRA being integrated into the ATD-2 decision support tools?



# Proposed Year 2 Work

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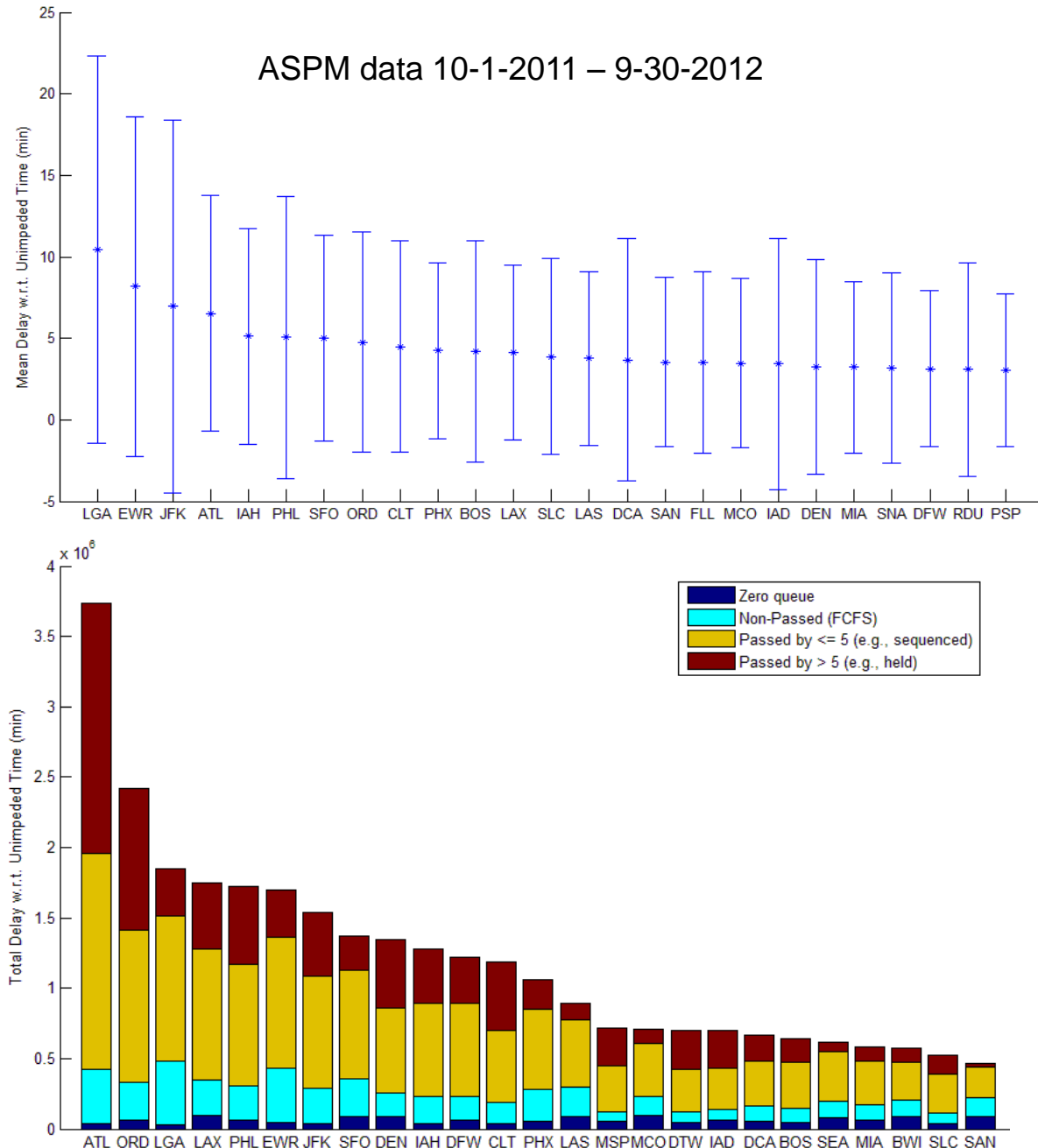
- Questions

# Back up slides

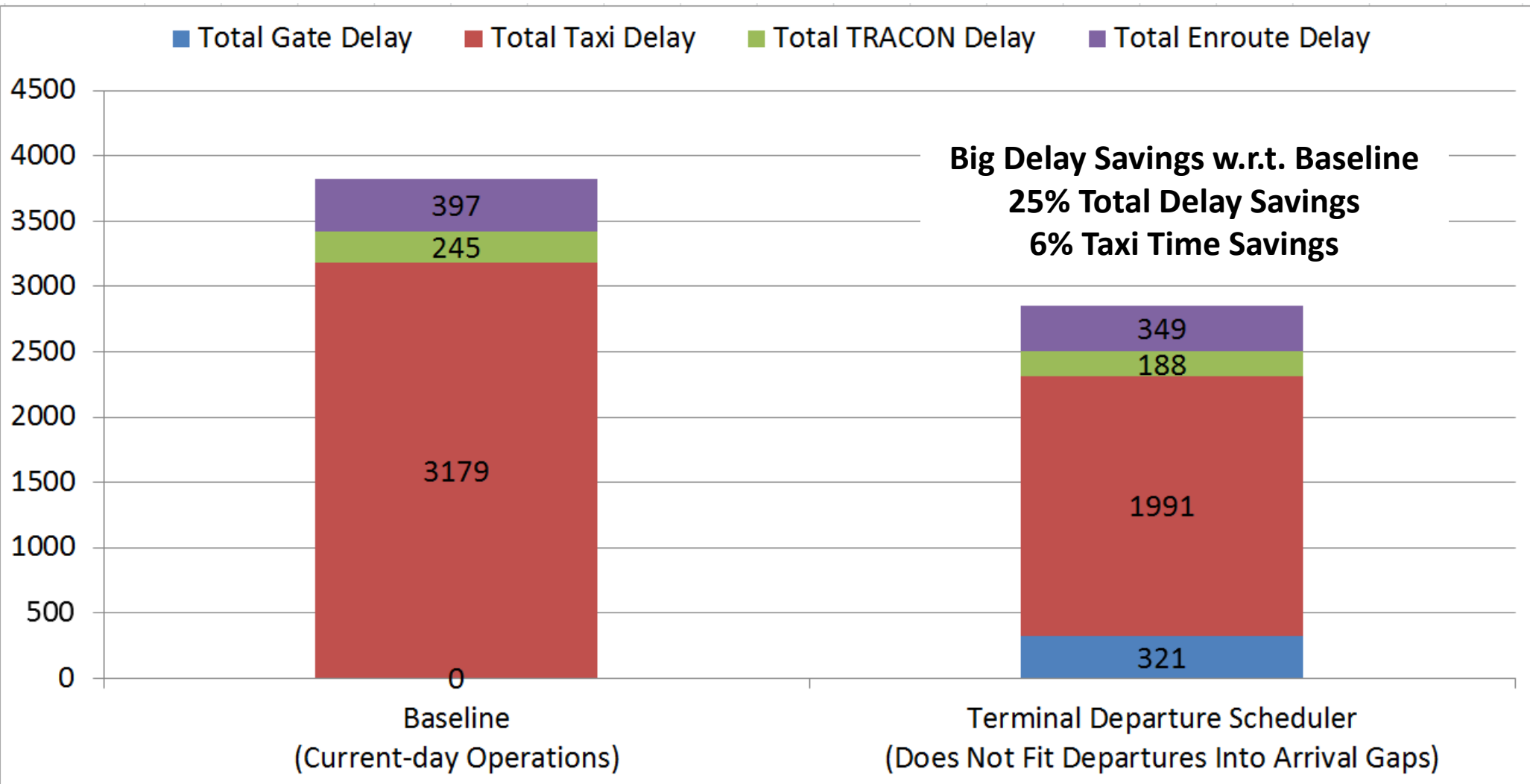
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# Motivation and Background

- Delays are generated mostly at major metroplex systems and incurred mostly by departure operations on the airport surface
- LGA, EWR and JFK rank highest based on average delay due to local queuing constraints
- ATL and ORD rank highest based on total delay due to their high traffic volume



# ATD-2 Case Study 1: Baseline VS Scheduler



# Assessment Methodology

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- Simulate current-day and ATD-2 operations
  - Simulations performed under modeled constrained departure conditions conducive to the usage of ATD-2
  - Reduction in capacity and application of MIT restrictions at some fixes selected to produce significant airborne and taxi delays in the baseline
- Main ATD-2 benefit mechanisms analyzed
  - Assess impacts of integrated scheduling with consideration of throughput and workload
  - Assess impacts of configurable delay buffers on handling uncertainty
  - Assess impacts of arrival consideration
- Caveats
  - Benefit estimates dependent upon severity of modeled constraints
  - Impacts reported represent demonstrations of benefit mechanisms in isolated situations rather than validated benefit assessment

# Throughput Saturation Analysis

- JFK shows saturation at more than 12 departure on surface

