ATD-2
Integrated Arrival/Departure/Surface

NASA

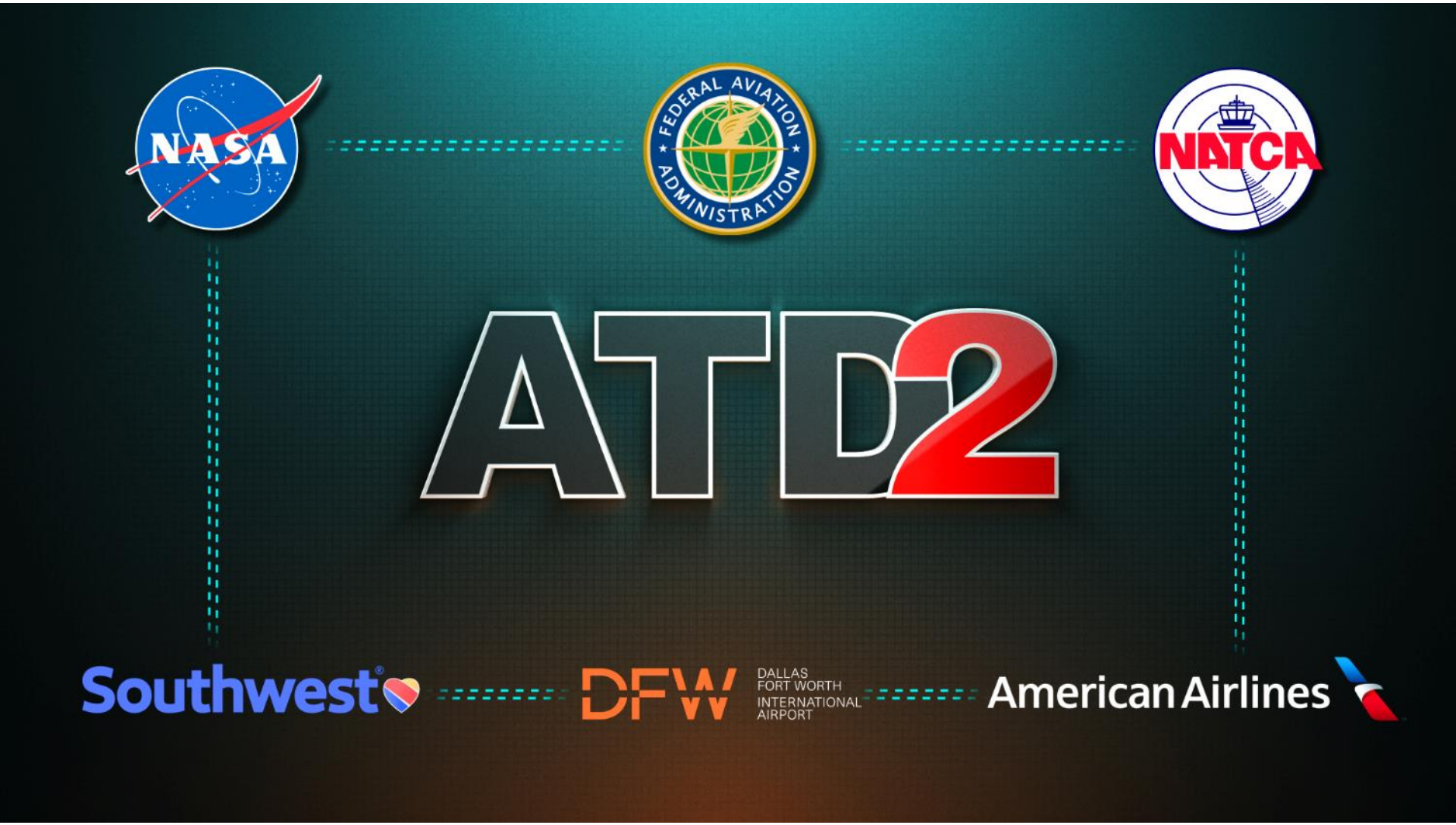
ATD-2 Briefing for Southwest Data Science Community

Aug 21, 2018

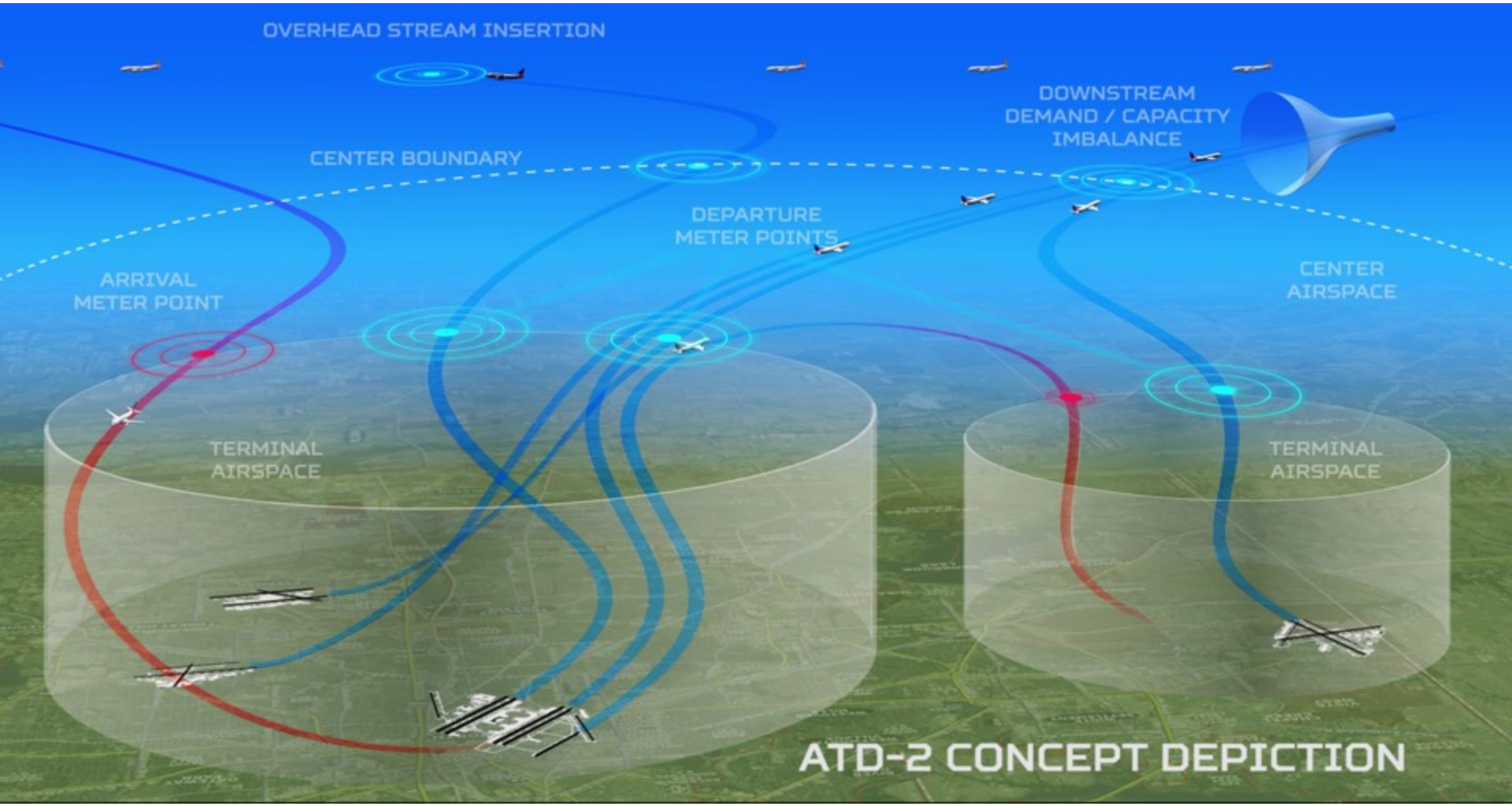
Agenda

- Background
  - *Al Capps*
- Data Availability and Analysis Framework
  - *Dr. Andrew Churchill*
- Taxi Time Prediction Model
  - *Dr. Hanbong Lee*
- Surface Metering Fundamentals
  - *Isaac Robeson*
- Benchmarking and Characterizing Operational Days
  - *Dr. Jeremy Coupe*
- Using Trajectory Options Sets to Reduce Delay
  - *Dr. Eric Chevalley*

ATD-2 Phase 3 Field Demo Partners



Integrated Arrival/Departure/Surface (IADS) Concept Overview



See the ATD-2 Concept Animation Video and Latest Updates here:
https://www.aviationsystemsdivision.arc.nasa.gov/research/atd2/index.shtml

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Data in ATD-2: Inputs & Outputs

- **ATD-2 has many sources of input data!**
  - *Challenge 1*: Fusing these sources to collect all related information about each individual “flight”
  - *Challenge 2*: Applying logic to ensure the most accurate or timely source is being prioritized
- **ATD-2 has many kinds of output data!**
  - Primarily built on PostgreSQL, supporting consumers with different needs

Analysts: flight-level summaries, deep-dive ability	*Project managers*: aggregated metrics, example flights	*Developers*: diagnostic logs, message-by-message debugs
Ramp controllers: push regular flight-level performance detail	*Ramp supervisors*: status dashboards	*Airline analysts*: performance and diagnostic data

Input Data Sources

ATD-2 takes input from SWIM and other sources…

- TFM Flights – all kinds of flight-related data
- ASDE-X – surface surveillance
- TBFM/TMA/IDAC – terminal-area flight data
- TFM Terminal – EOBTs, etc.
- OIS – TMIs around the NAS
- TFM Flow – ground stops, etc.
- Proprietary airline feed – gates, registrations, etc.
- FlightStats – gates
- Ramp controllers & TMCs – clearances, etc.

Each source provides slightly different identifying information, requiring complex logic to fuse these messages to a single flight:

- For example, a flight operates YYY-ZZZ-YYY with same callsign. TFM Flights will give ACID, IGTD, orig/dest, but ASDE-X only gives callsign (and not on every message!). When seen on surveillance, which “flight” is it?

Input Data Mediation

Many data sources provide similar information…

- So how do we know which to use?
- For example, when is a flight going to be ready to pushback? Use the first non-null entry in this list.
  1. Ramp controller entry
  2. EOBT
  3. LTIME/LGTD
  4. FlightStats estimated time
  5. Flight plan time
  6. Scheduled time
  7. Initial time
- Similar rules exist for many other data elements
- These are being regularly updated, as we learn more, get feedback from users, and observe changes in the data feeds themselves.

Output Data Description & Challenges

Output data are verbose…

- Full state of flight inserted in db each time some update/action happens on that flight
- Main table includes 222 columns, ~400k rows/hour (~50% are surveillance updates)
  - Departure generates ~5k rows in the hour before takeoff.

However, scale (compute power) is not the issue…

- Many analysts contributing to this research, often working on closely-related questions
- Many possible angles for misinterpretation of data, requiring specific business rules

Aggregated Flight-level Reporting

- We have developed a daily report, with one row per flight (284 columns), cover many categories of data
- Includes numerous business rules / conventions
- Constantly adding new fields to support analyst/user requests, all from primary db to allow backward-compatibility
  - Identifying info
  - Scheduled, proposed, etc. times/routes
  - Actual times/resources
  - Actual, unimpeded, excess taxi times
  - Surface metering
  - EOBT/LTIME info
  - Controller clearances
  - Gate conflicts
  - Bank info
  - Resource predictions at events
  - EDCT info
  - APREQ info
  - Other TMIs
  - Various AOBTs
  - Airport configuration

Example Rules & Analyses

- ***AOBTs***: Which systems provided actual out times, and how do these times differ from one another?
- ***Resource predictions***: Just before flight pushes back, what spot and runway are expected?
- ***Return to gate flights***: What data to report on these flights? Last AOBT & AMAT (this part is easy!). But also need to capture when first were ready.
- ***EOBT accuracy***: At m minutes before pushback, what is current airline-provided EOBT? How far from actual is it?
- ***APREQs***: How many times did the APREQ time change? Were any of these changes associated with IDAC? Was the first APREQ negotiated while flight still at the gate?
- ***Airport configuration***: Was airport in north or south when flight pushed back? What about at takeoff?

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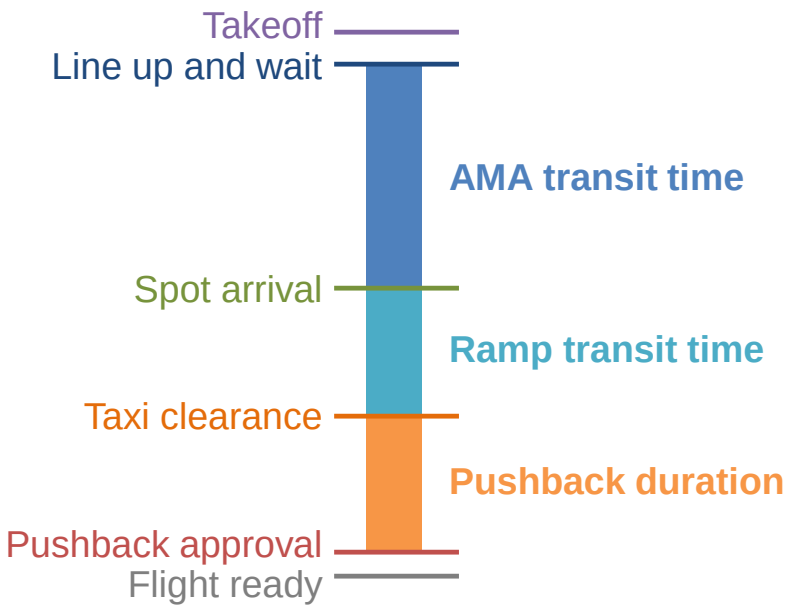
Taxi Time Prediction

- Objectives of taxi time prediction
  - To estimate the earliest possible takeoff times of departures, which are used for runway scheduling in Tactical Scheduler
  - To predict a possibility of gate conflicts for arrivals

- Taxi time calculation for departures

Taxi-out time = Pushback duration + Ramp transit time + AMA transit time



Trajectory Based Model

- Compute taxi distances along taxi routes
  - Ramp taxi distances for gate-spot pairs
  - AMA taxi distances for spot-runway pairs

- Calculate taxi speeds in ramp and AMA for individual flights

  Taxi speed = Taxi distance / Actual transit time, for ramp and AMA each

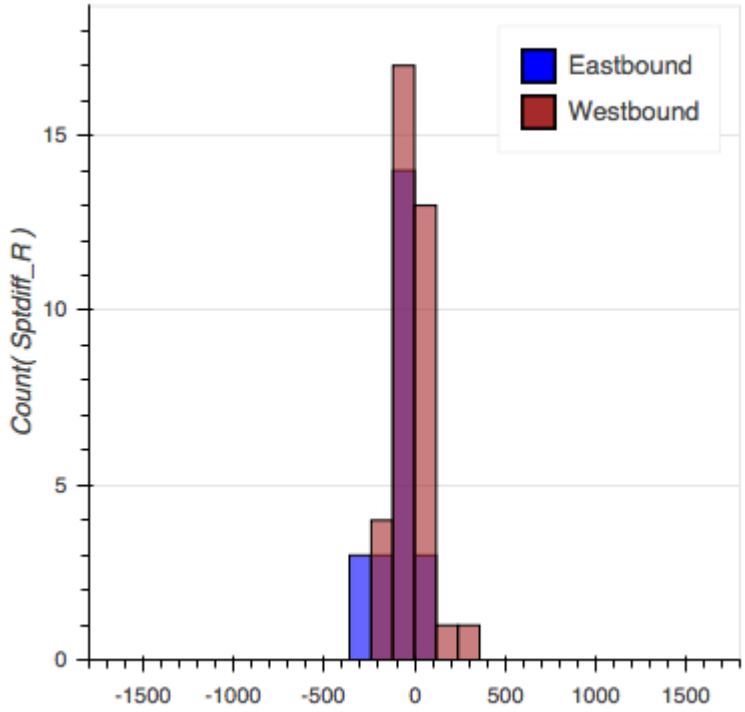
- Provide default taxi speed and pushback duration values in decision trees
  - Ramp and AMA taxi speeds
  - Pushback duration by ramp area (gate group) and aircraft type

- This model is currently used in the field and can update undelayed spot/runway arrival times in real time, based on current positions and remaining taxi distance.

Prediction Results for a Sample Date

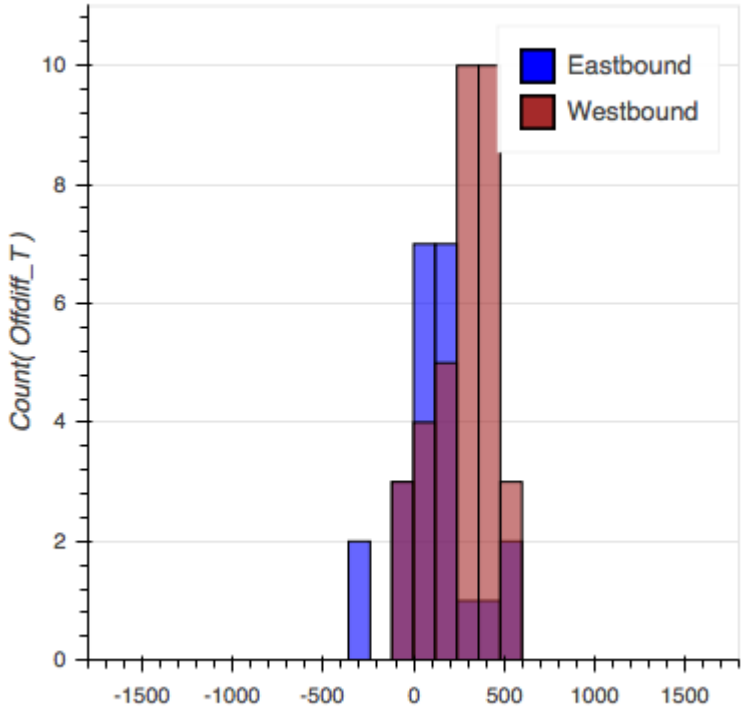
- Taxi time prediction example from trajectory based model
  - Positive gaps between undelayed runway arrival times and actual takeoff times due to runway separations

Taxi Time Difference (Actual – Predicted) (in seconds)



Spot arrival time when start taxiing

Taxi Time Difference (Actual – Predicted) (in seconds)



Runway arrival time when passing spot

Machine Learning Based Model

- Features (variables):
  - Terminal concourse, spot, runway, departure fix, aircraft model
  - Taxi distance, unimpeded taxi time
  - Scheduled OUT time of day
  - Number of departures and arrivals on the surface

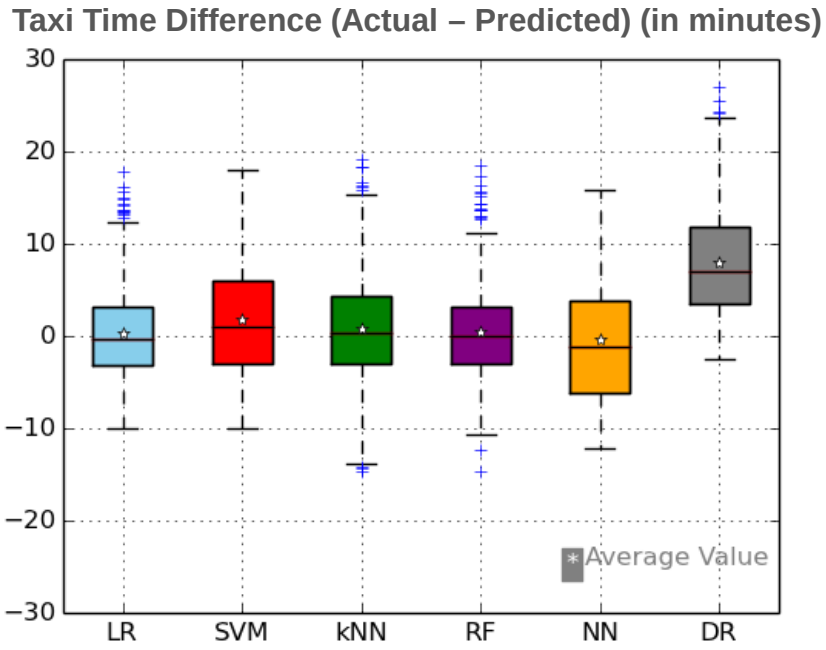
- Machine learning techniques tested
  - Linear Regression (LR)
  - Support Vector Machines (SVM)
  - *k*-Nearest Neighbors (*k*NN)
  - Random Forest (RF)
  - Neural Networks (NN)

- Coded in Python using *sklearn* and *PyBrain* libraries

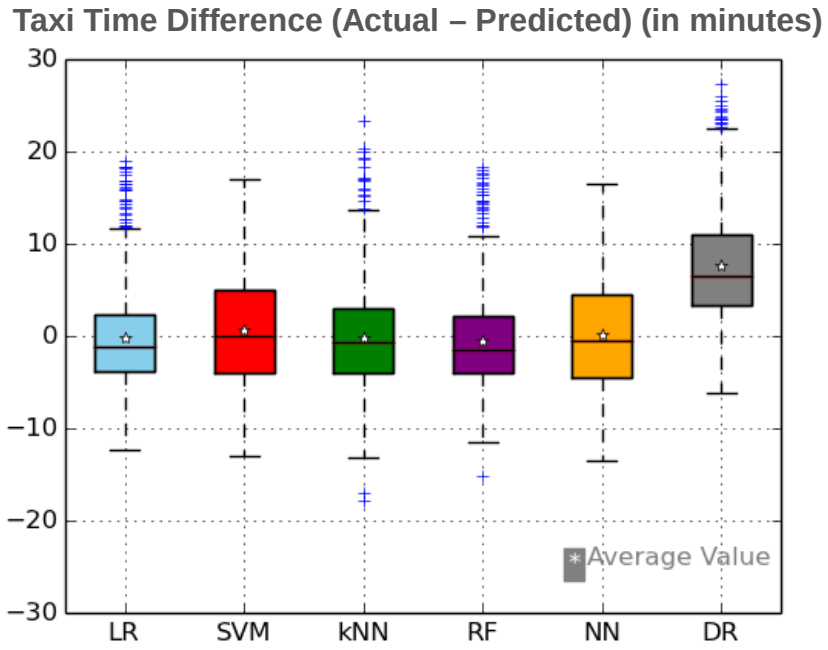
- Trained with actual flight data at CLT

Prediction Results for Test Dataset

- Machine learning algorithms showed better performance than Dead Reckoning (DR) method based on unimpeded taxi times.
- However, there is still room for improvement.



South-flow traffic, good weather



South-flow traffic, heavy rain

Future Work

- Decision tree updates for pushback duration and taxi speeds in the ATD-2 model
  - Keep collecting more accurate taxi time data from CLT field

- Further investigation on machine learning algorithms
  - Improve prediction accuracy both in pushback duration and ramp transit time
  - Achieve better maintainability in the long term
  - Apply a common approach to multiple airports, including DFW and DAL

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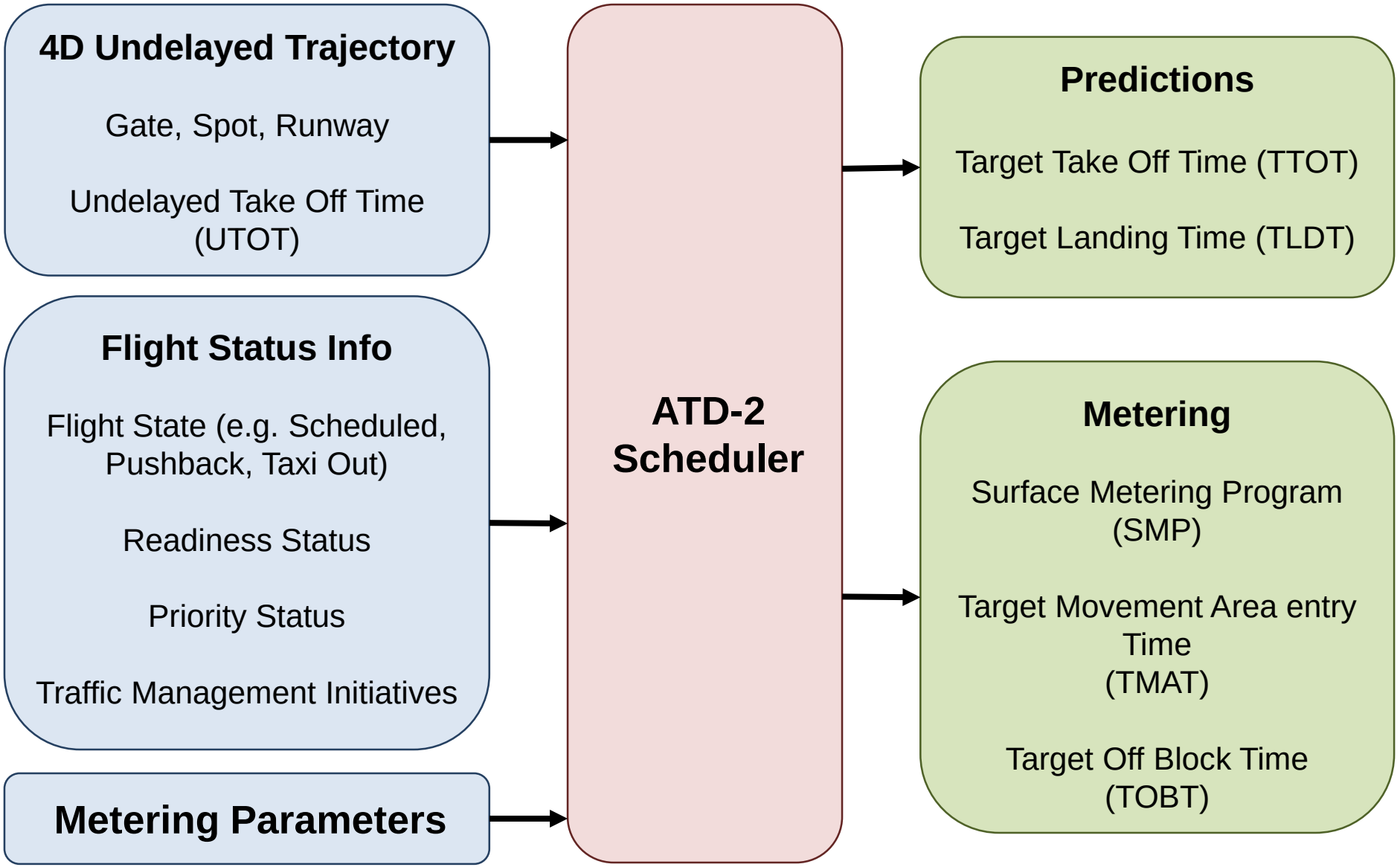
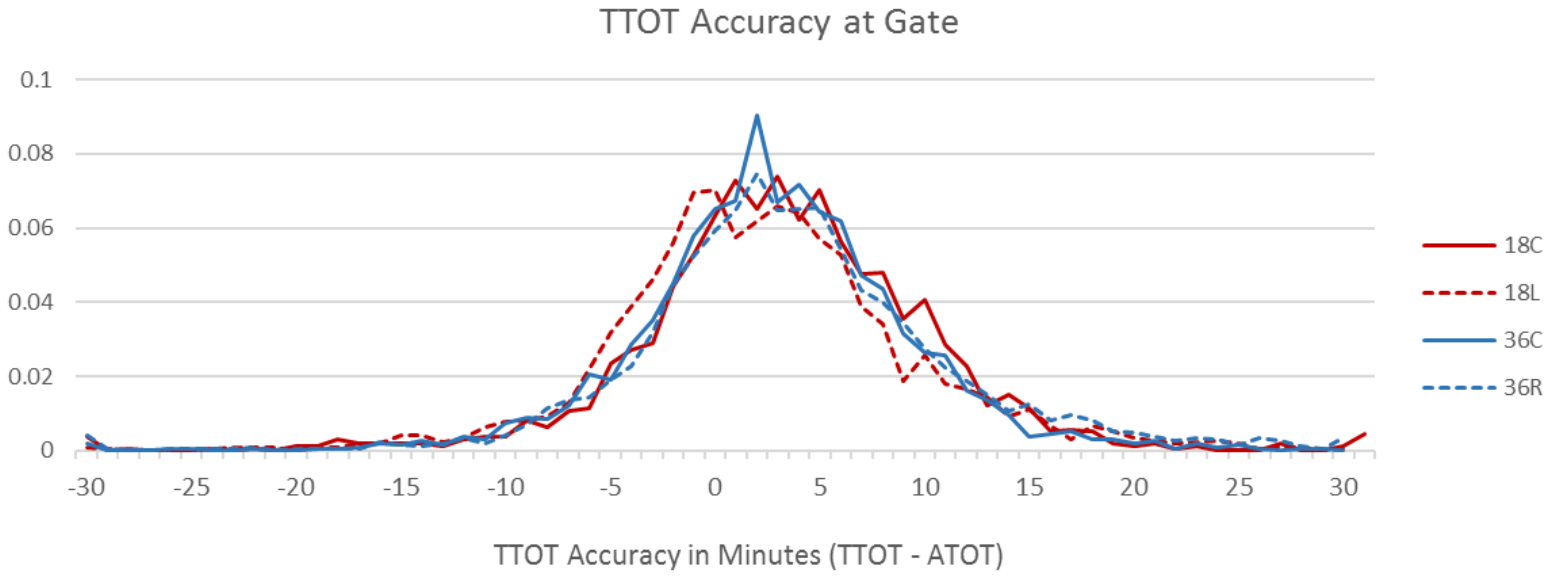
SMP Briefing Outline

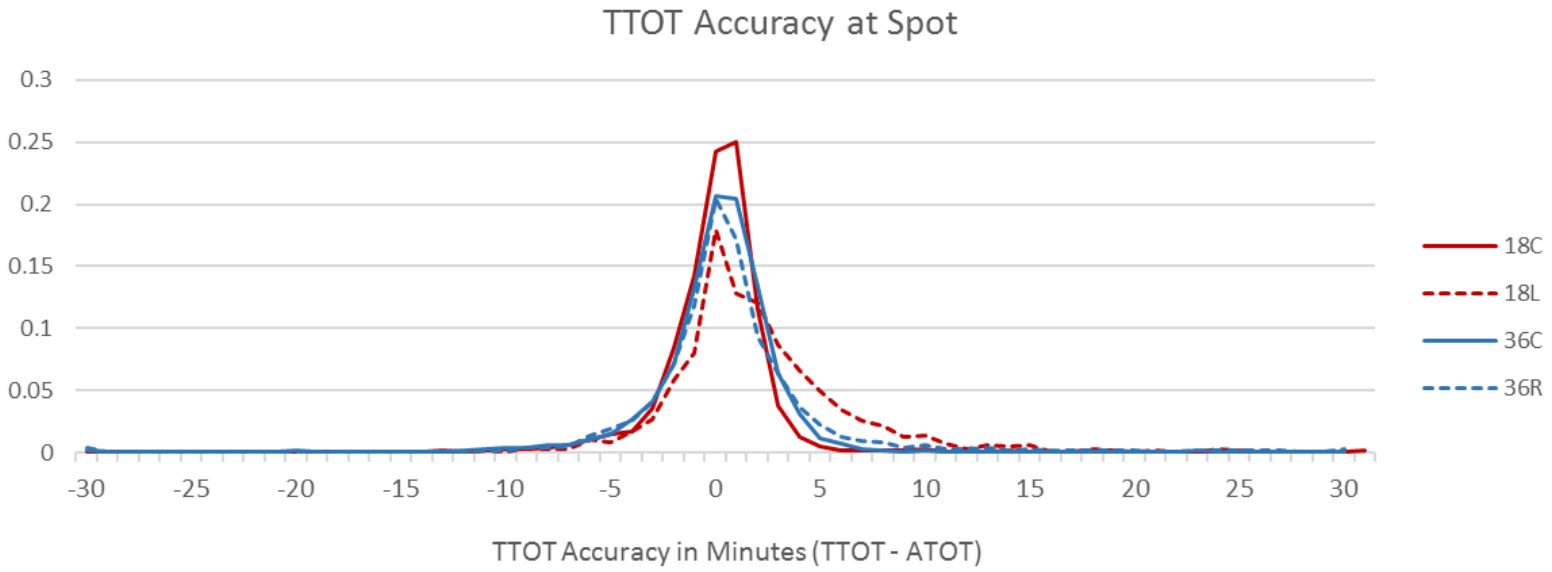
- Overview of ATD-2 scheduler
- Tactical Surface Metering
- Transition to Strategic Surface Metering
- Future of Surface Metering in the NAS

ATD-2 Scheduler Overview



ATD-2 Scheduler Prediction Accuracy





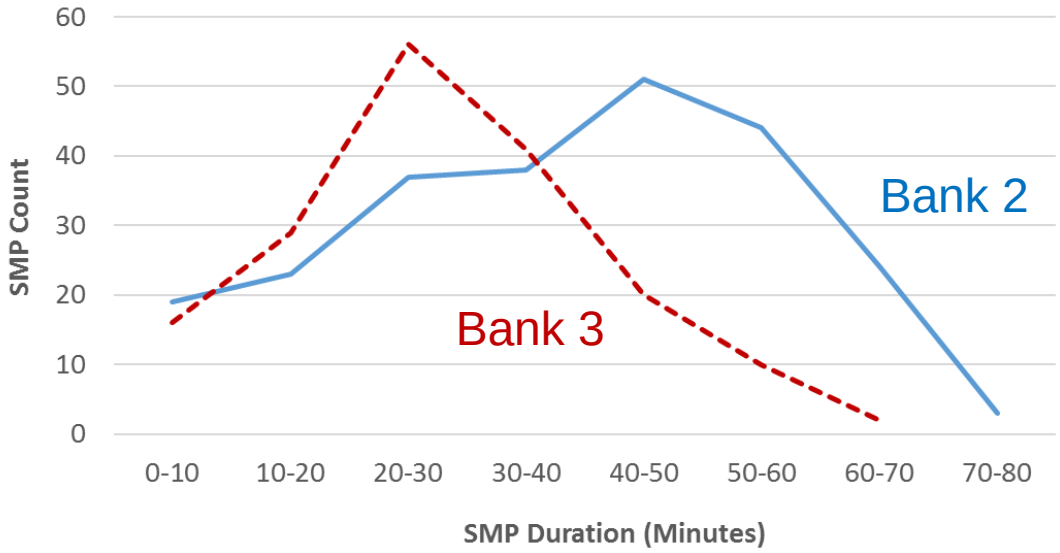
Tactical Surface Metering

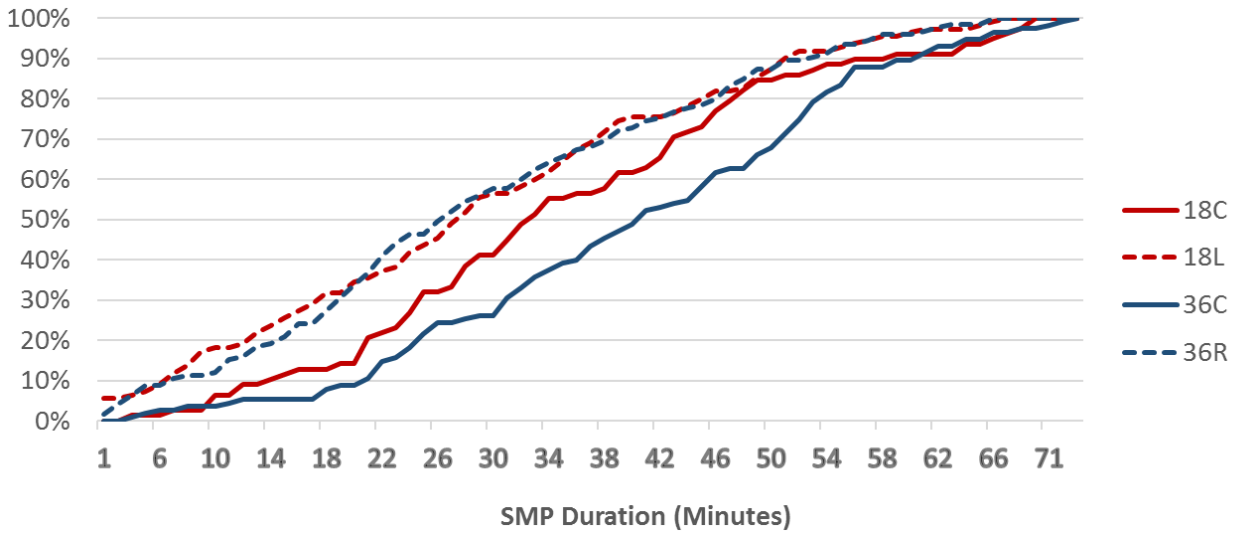
- Capability is enabled during the 2nd and 3rd departure bank at CLT
- Scheduler predicts the amount of excess taxi time (i.e. taxi time beyond unimpeded = TTOT - UTOT)
- The schedule will trigger surface metering if it predicts that
  - A departure off the gate will have an excess taxi time > the target excess taxi time
  - And a departure at the gate will have an excess taxi time > the upper threshold
- When metering triggers, the scheduler passes back excess taxi time over the target to the gate
  - Gate Hold = (TTOT – UTOT) – Target Excess Taxi Time
- Gate hold advisories displayed to ramp controllers

Tactical Metering Statistics from the start of April 2018

Tactical SMP Counts

Runway	Bank 2	Bank 3
18C	39	37
18L	53	45
36C	70	42
36R	62	53
Total	224	167

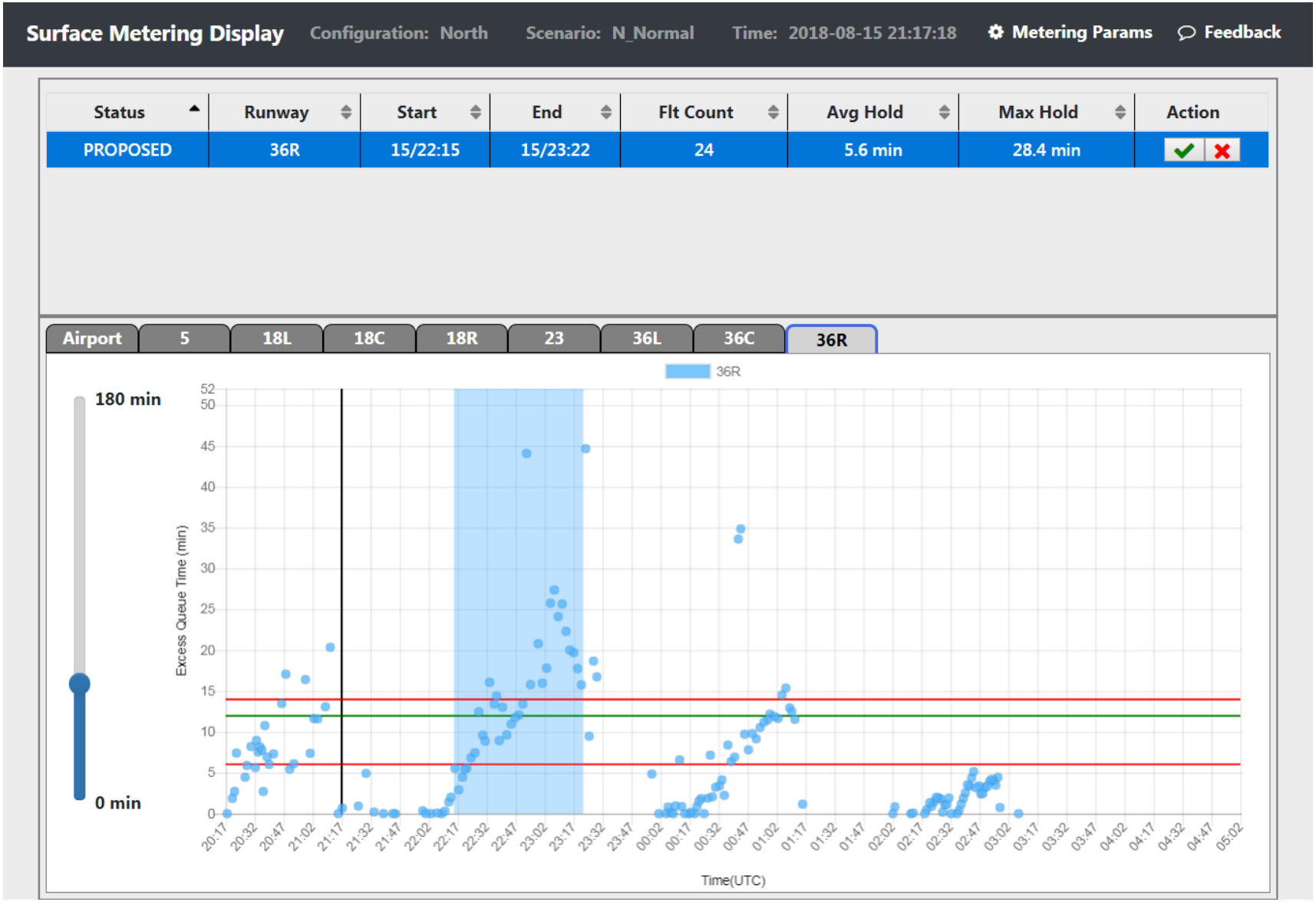




Transition to Strategic

- Predict when metering will be needed in advance
- Scheduler recommends a Surface Metering Program (SMP)
- Allows users at CLT to collaborate on recommended metering
  - Affirm or reject the recommended SMP
- SMP is adjusted at regular intervals based the latest data

Surface Metering Program



Future of Surface Metering

- Terminal Flight Data Manager (TFDM)
  - Electronic Flight Data
  - Traffic Flow Management
  - Collaborative Decision Making for the Surface
    - Surface Metering Programs (SMPs)
  - Systems Consolidation

- TFDM Terminal Publication (TTP) SWIM Service
  - Surface metering information
  - Shared situational awareness
    - Airport configuration
    - Runway assignments
    - TMI data per flight
    - Airport metrics

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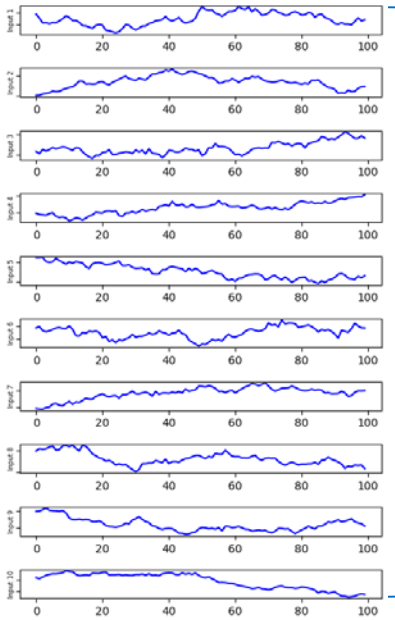
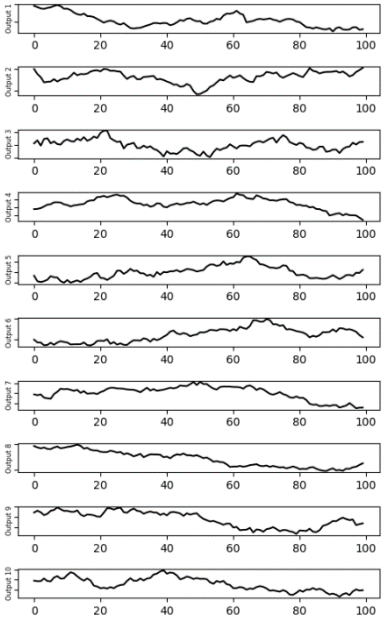
Challenges of Operational Data

Multiple Inputs



Complex System

Multiple Outputs



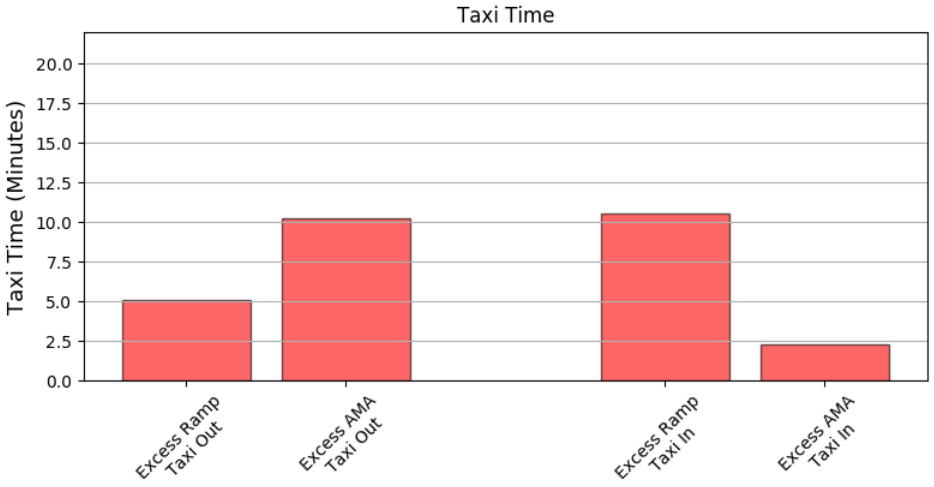
Motivation

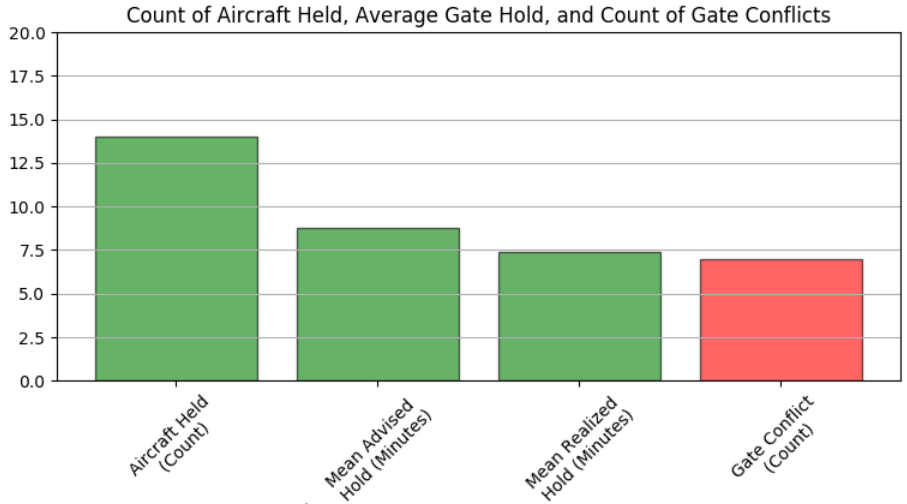
- **Operational views:** Identify important outputs / metrics that are relevant to the users and allow us to quantify the overall health of the surface system

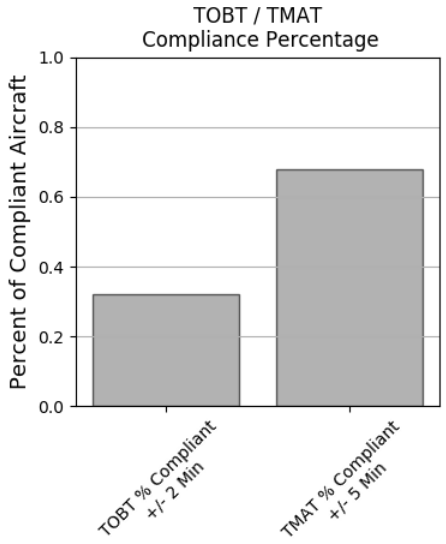
- **System views:** Identify important outputs / metrics that allow us to understand if the system is working as expected, calibrate the parameters, and diagnose problems

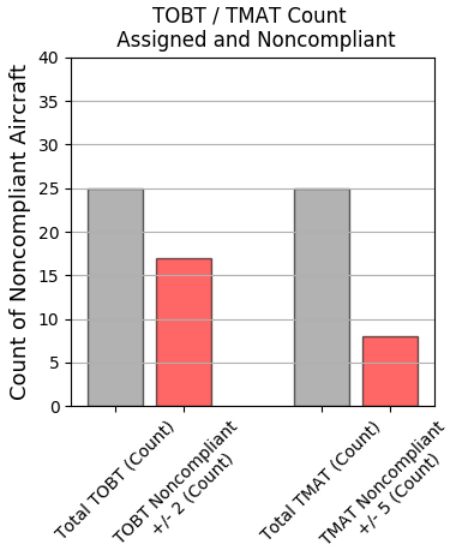
Post Bank Operational Summary

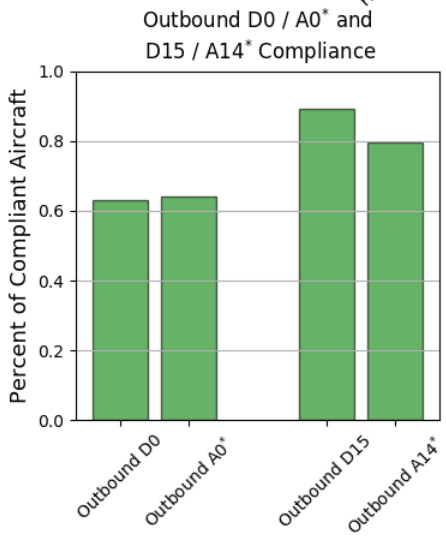
2018-1-24 North Flow Bank 2

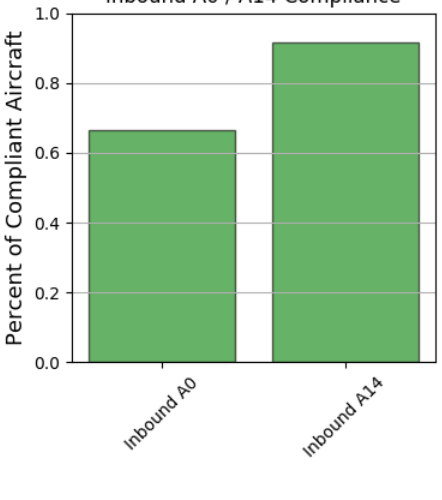








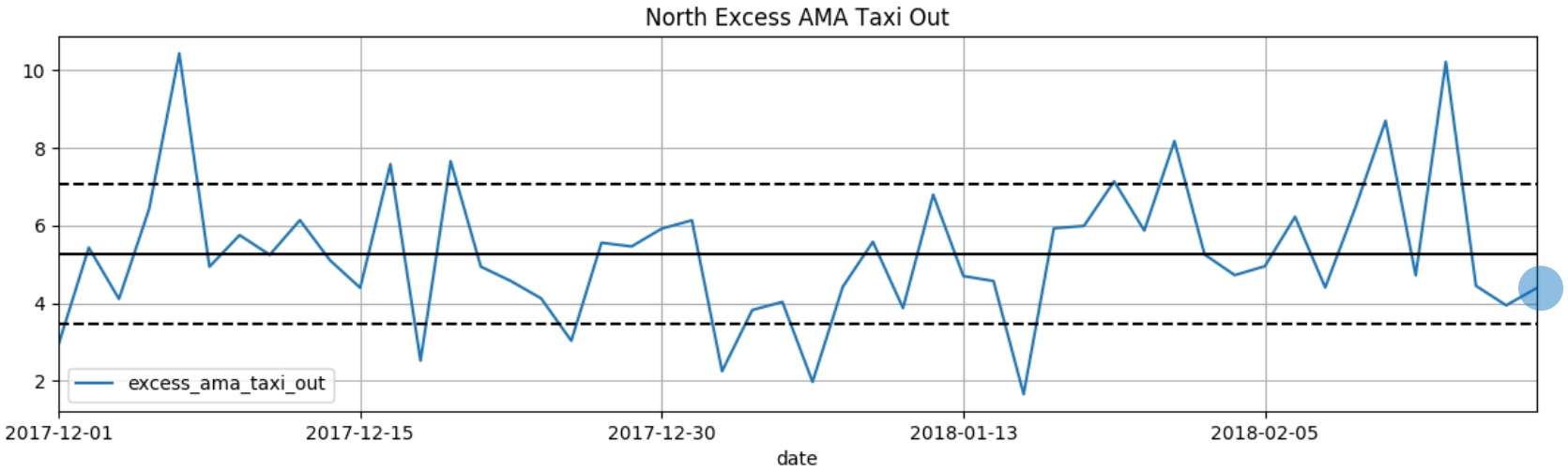




Providing Context to the Data

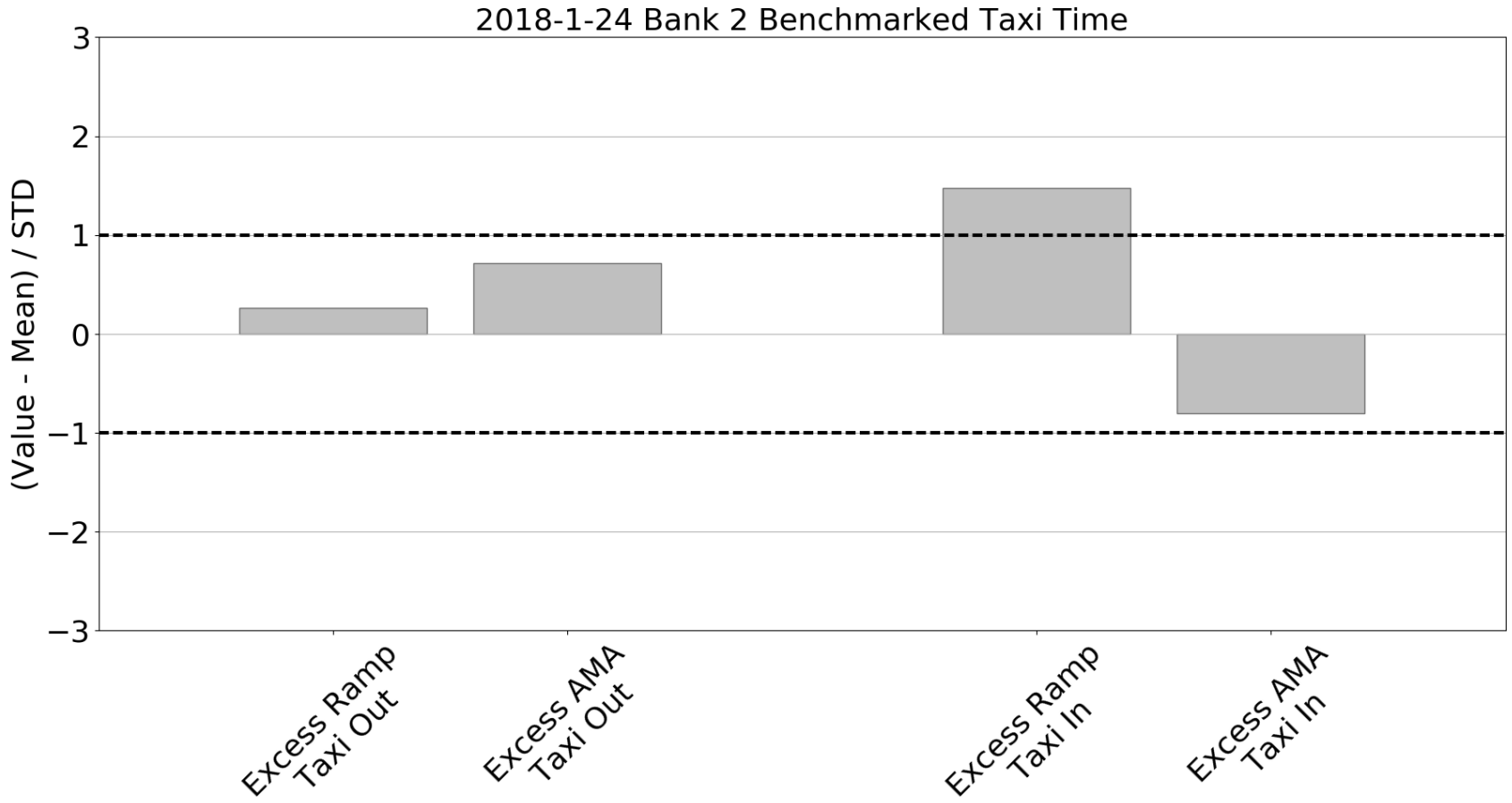
- **Problem:** How to understand the data and metrics in context

- **Solution:** Benchmark single day data against the average and standard deviation of metered days in the same flow

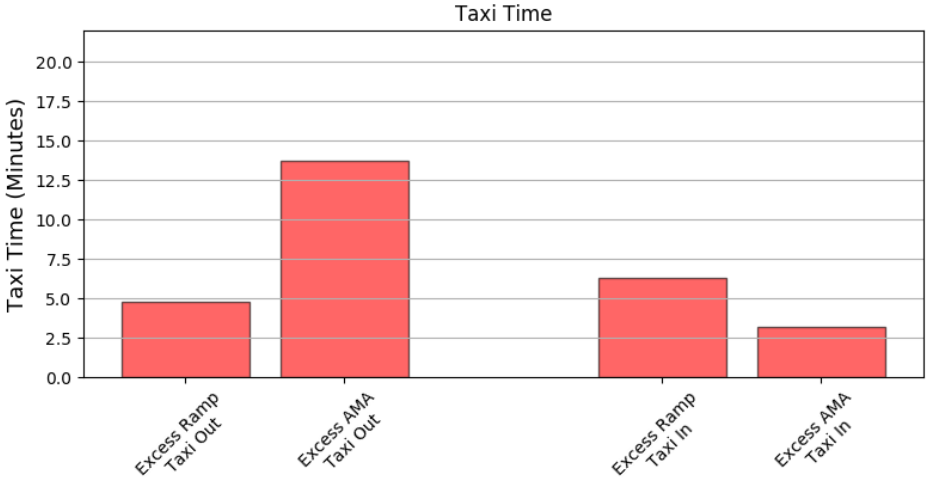


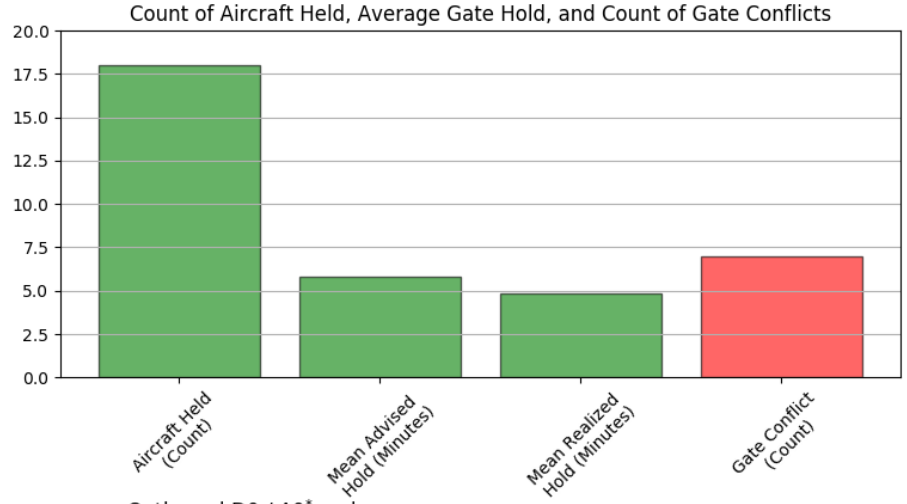
Benchmarked Value = (value – average) / standard deviation

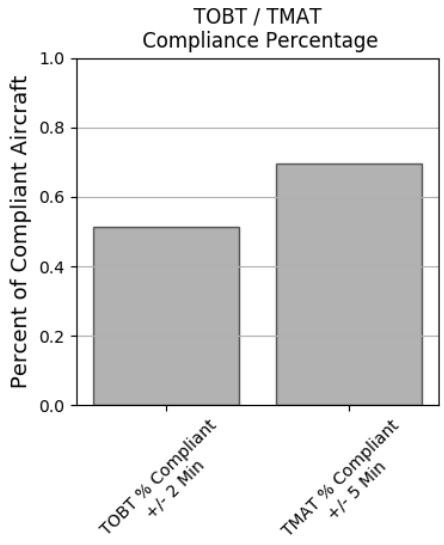
Benchmarked Taxi Data

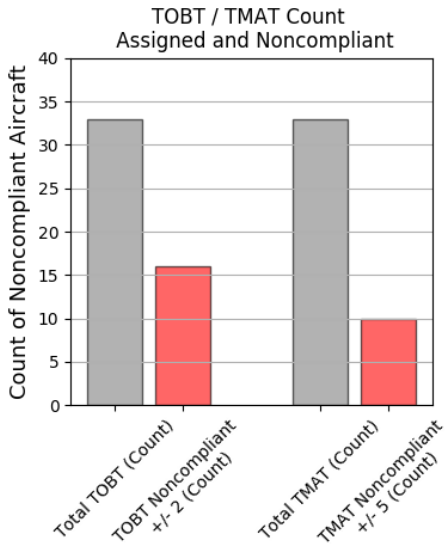


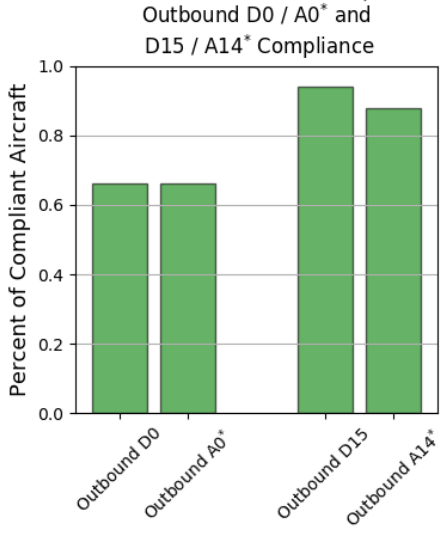
Question

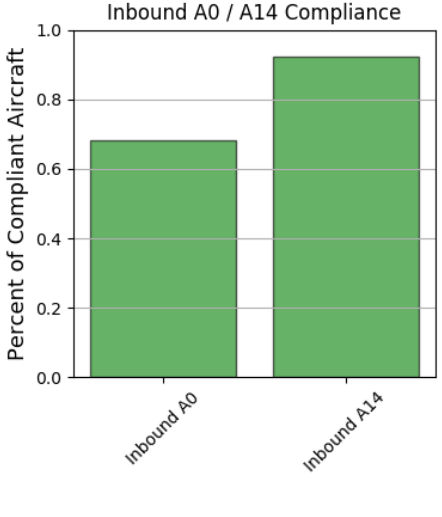






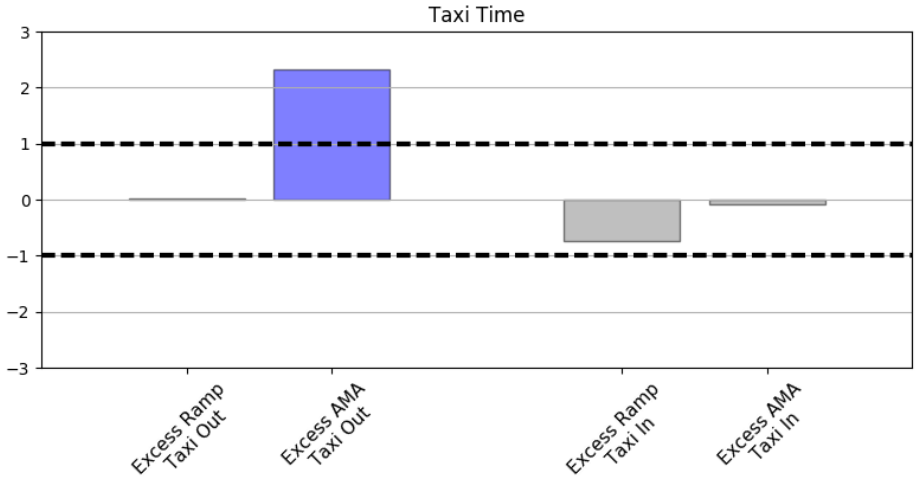


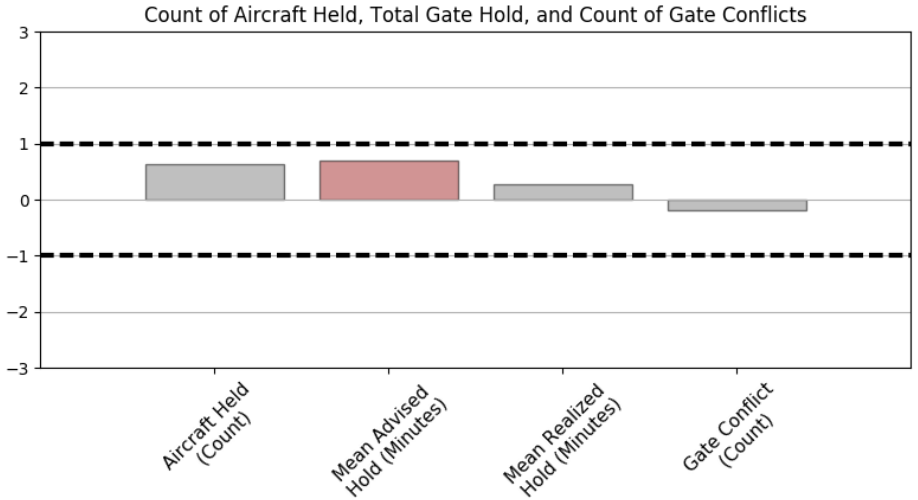


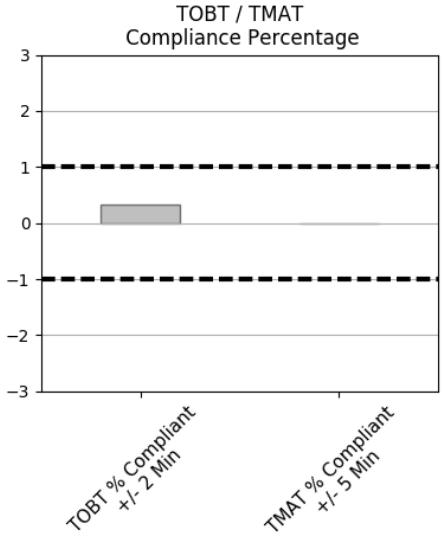


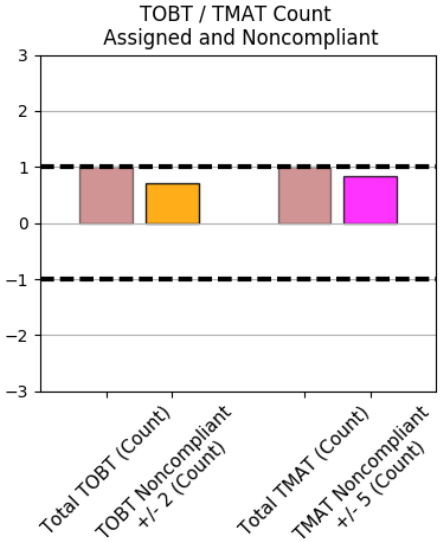
Can the benchmarked data provide additional insights that are not apparent when looking at the summary data?

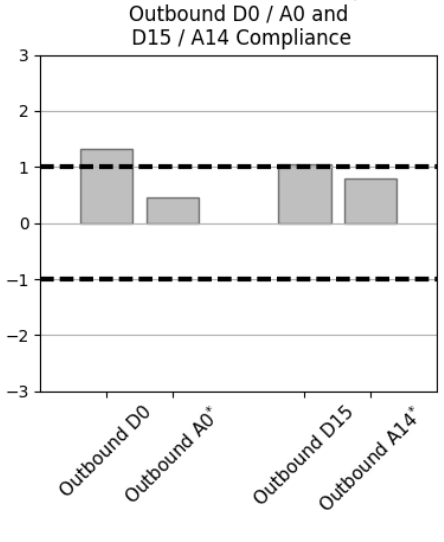
Analyzing the Benchmarked Data

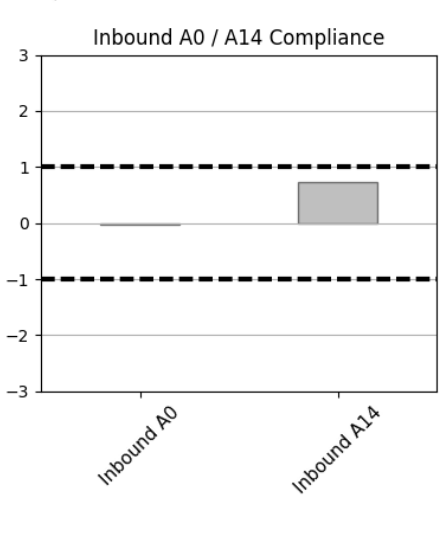












Above average AMA taxi time driven by above average demand capacity imbalance and above average count of aircraft noncompliant to the assigned TOBT and TMAT

Research Question

- What is the best benchmark to use?
  - Cluster of “similar” days
  - Data from same month of previous year
  - Metered vs. Non-metered data

- Can the individual benchmarked metrics be rolled up into a single metric that summarizes the overall performance?

- Is the classification of a good / bad day the same for the ramp compared to ATC?

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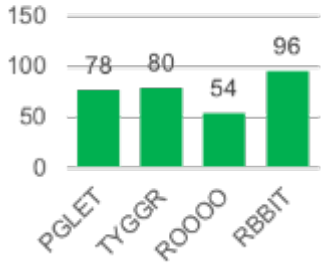
D10 Airspace and Departure Demand

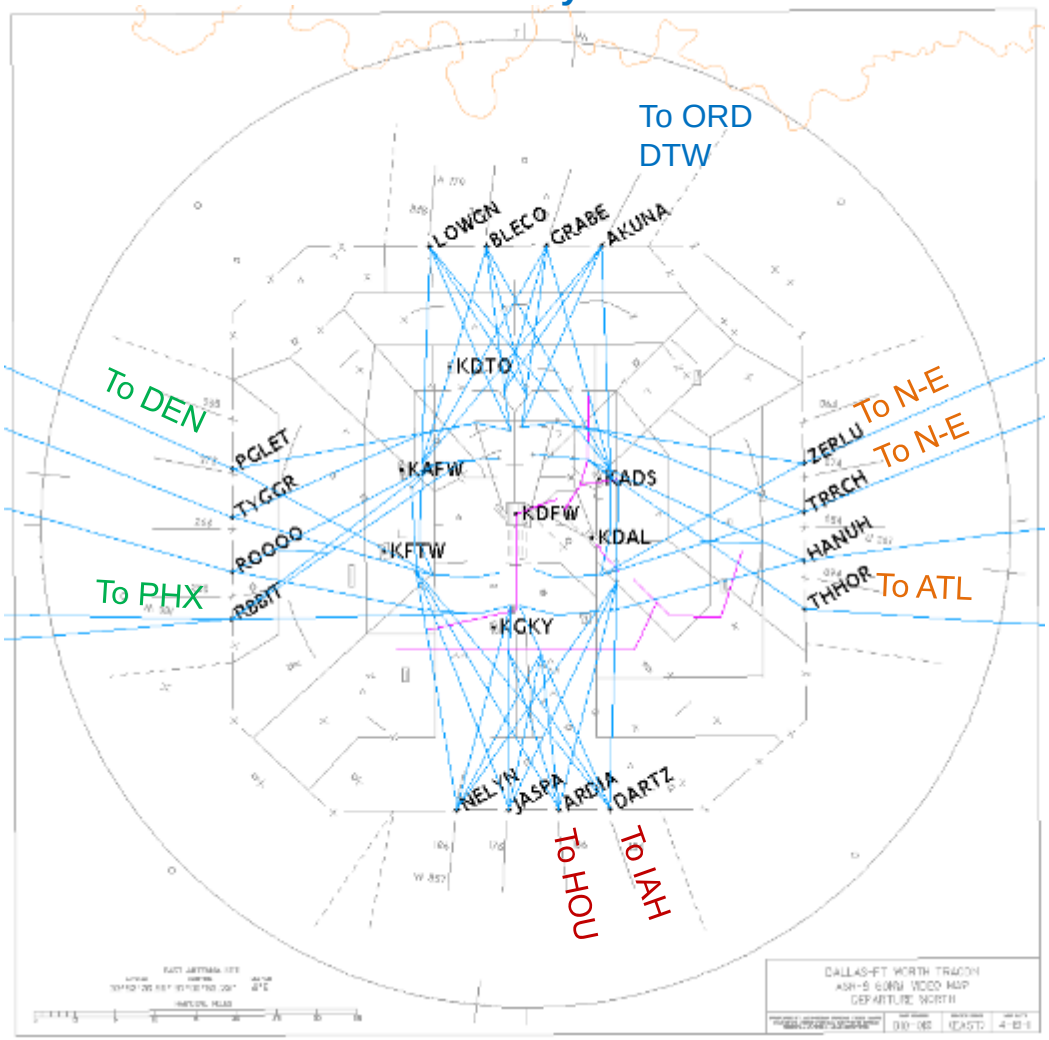
October 2017 departures above 11,000ft

North Gate
252/day

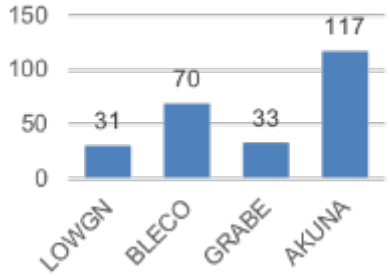
West Gate



West Gate
306/day

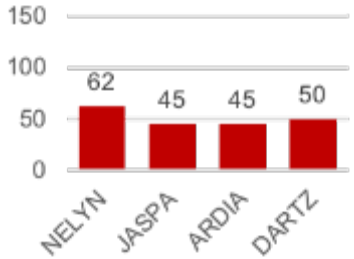


North Gate

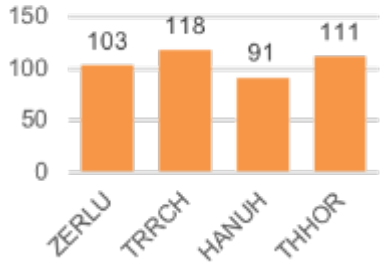


East Gate
435/day

South Gate



East Gate

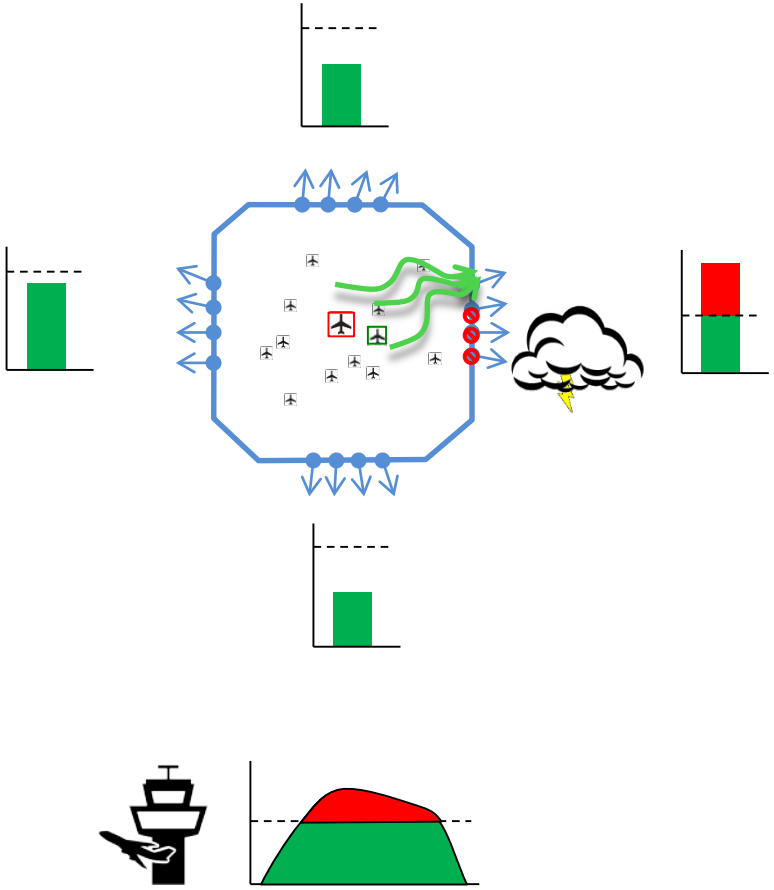


South Gate
201/day

Demand Capacity Imbalances in D10 TRACON Airspace

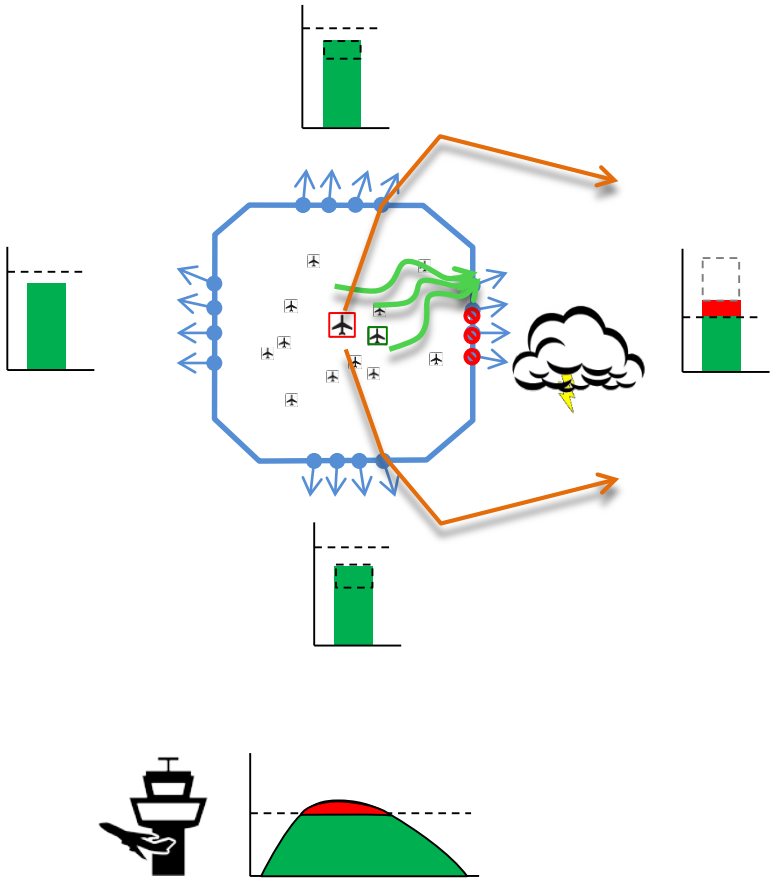
Fix compression caused by weather events near TRACON airspace

Currently

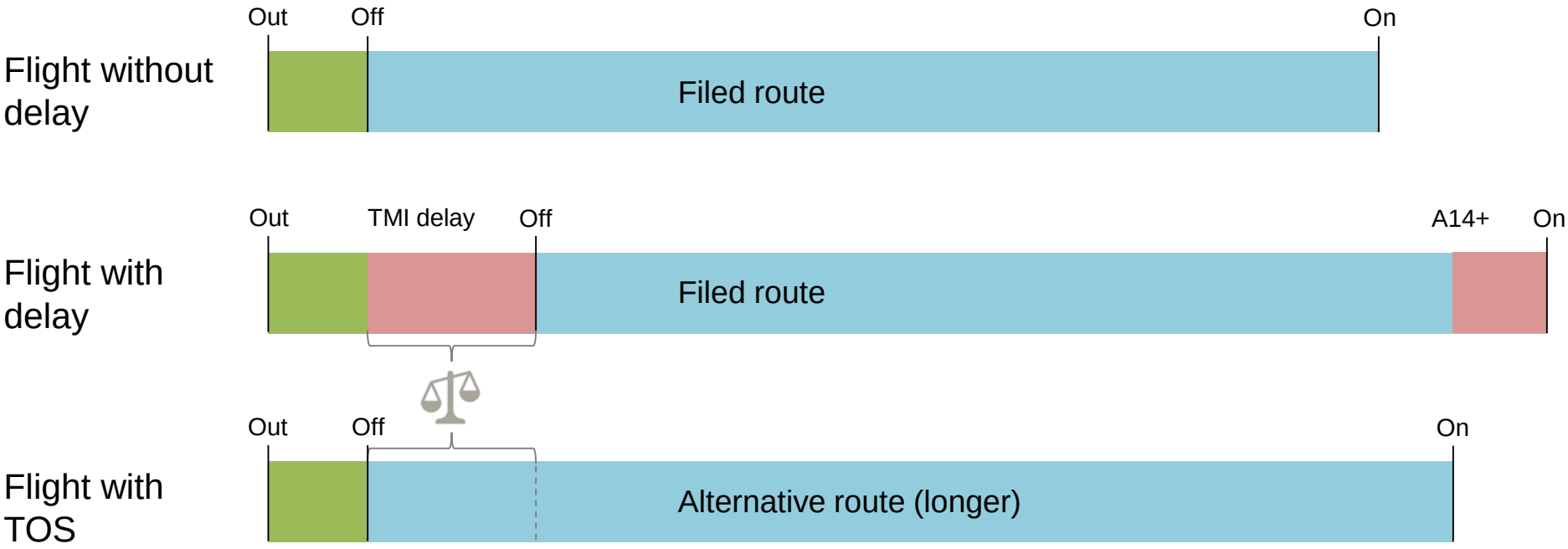


Load Balancing With TOS

(Trajectory Option Set)



TOS Trade-Off



Trajectory Option Set		Relative Trajectory Cost
Route 1	650nm (filed)	0min
Route 2	680nm	10min
Route 3	720nm	20min
Route 4	750nm	30min
Route 5	780nm	45min

Benefit Case

Using TOS for SWA at DAL during an inclement weather day

With terminal restrictions resulting in surface delay

Method – Data & Scenario

- July 11th: Day with terminal restrictions and surface delays at DAL and DFW
  - Terminal restriction
    - 1 Flow to the East gate with 10MIT from 16:58 to 20:07
  - Tower restriction
    - Flow rate passed back to DFW and departure stops at DAL

- Collected the departure demand of D10 departures
  - Actual off-block times
  - Estimated take-off times
  - Actual take-off times
  - Actual times at departure fix
  - Estimated surface delays
  - Reported surface delays

- Built a schedule based on the restriction that was applied at the terminal boundary and passed to the towers

- Computed delays due to the restrictions

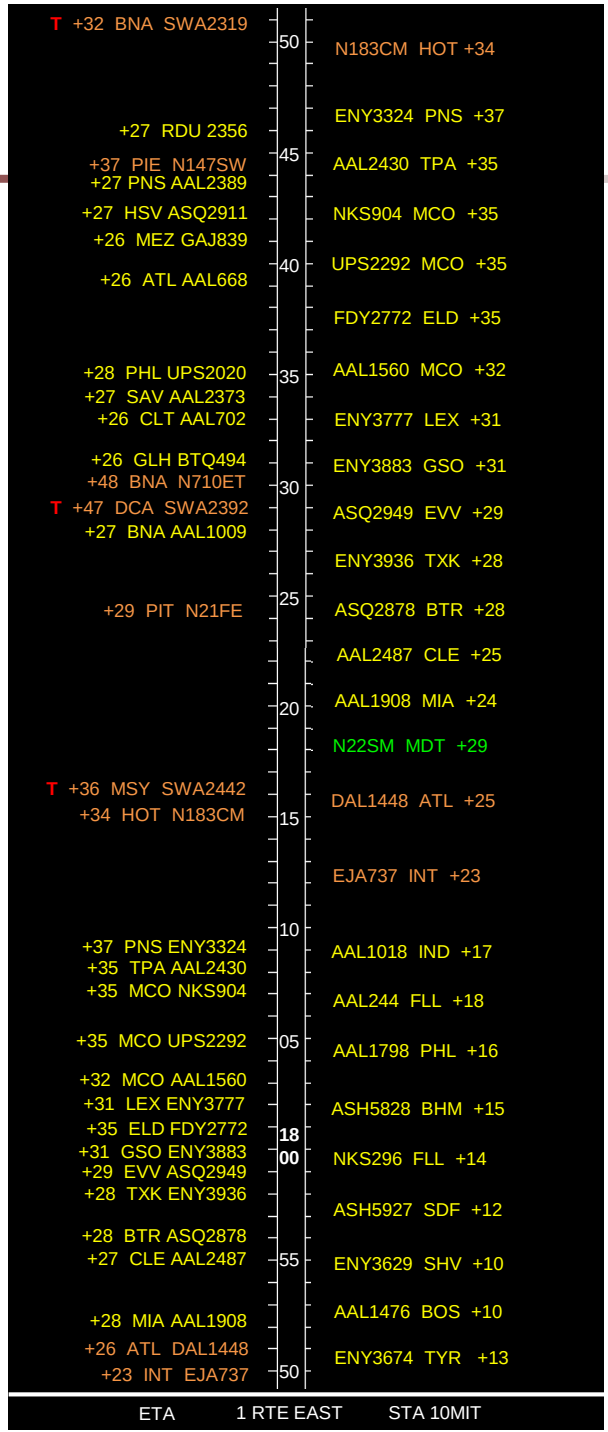
Method – Use of TOS

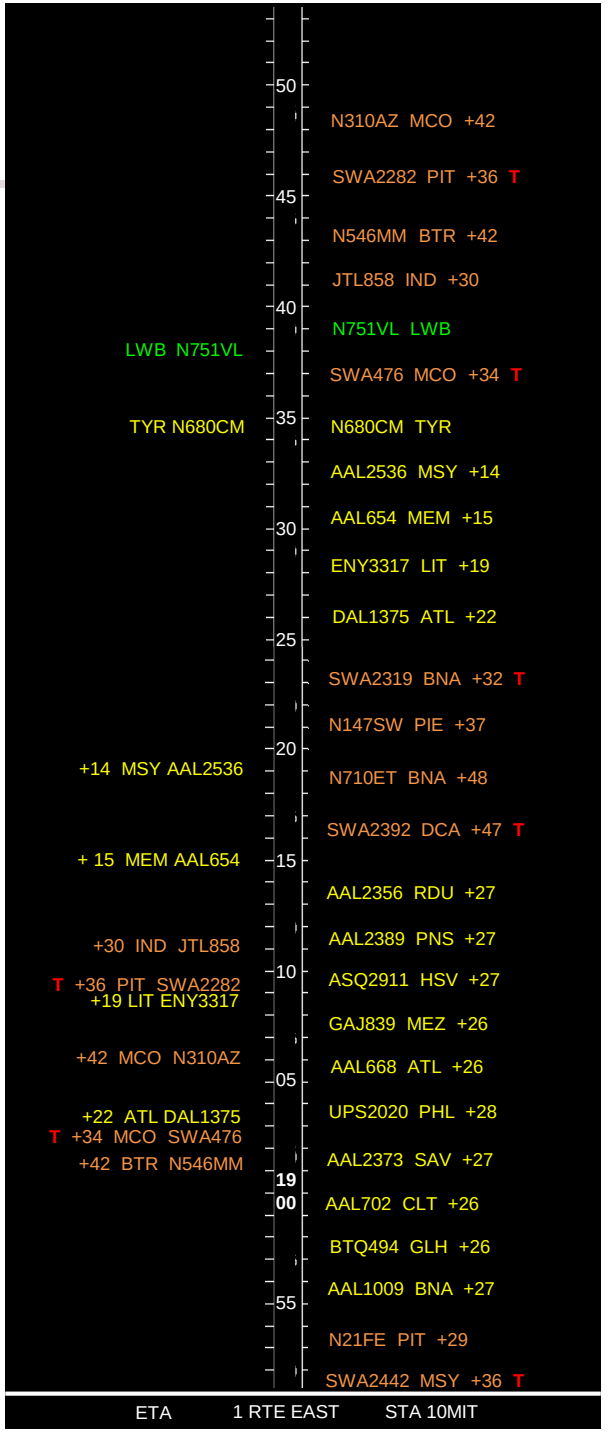
- Only SWA flights
- All SWA flights with TOS and RTC values
- TOS used when the RTC value matches the surface delay (driven by the terminal restriction)
- First Come First Served allocation
  - First aircraft with RTC value matching delay
  - Repeat until no more aircraft with matching delay
  - Reallocated the TOS flights to the same RWY

ETAs and STAs at the East Gate

Before TOS assignments

DAL Flights in **orange**
DFW Flights in **yellow**
ADS Flights in **green**





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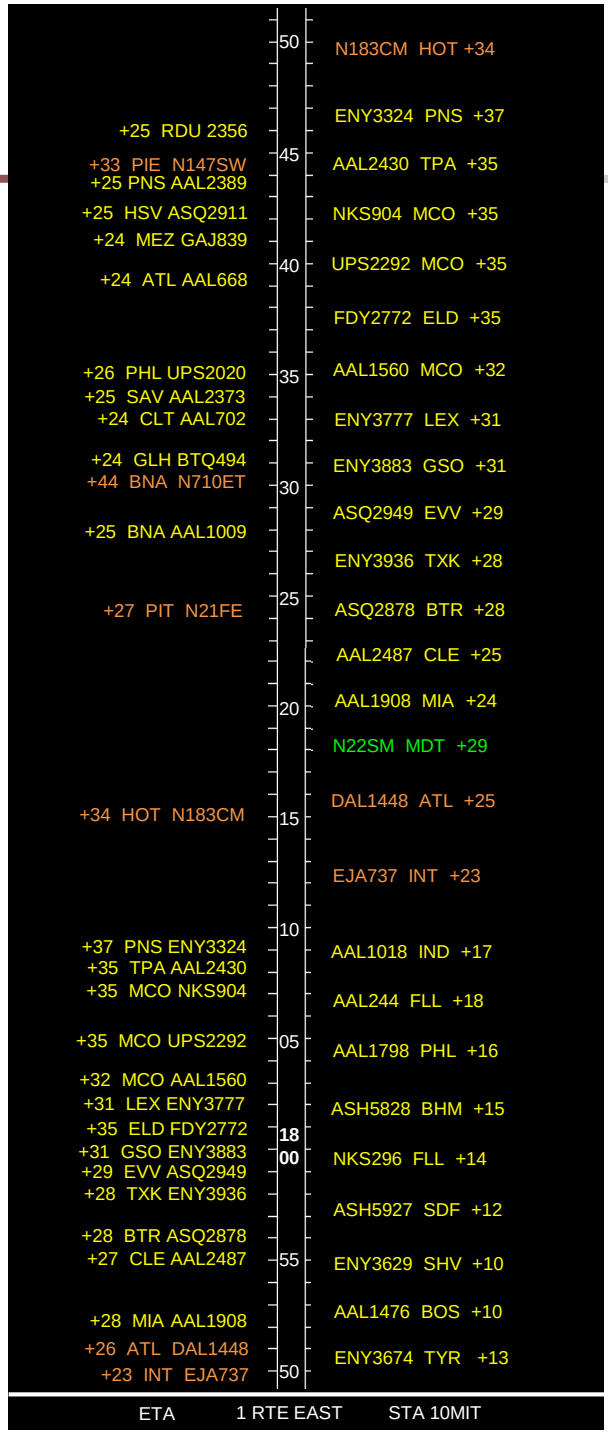
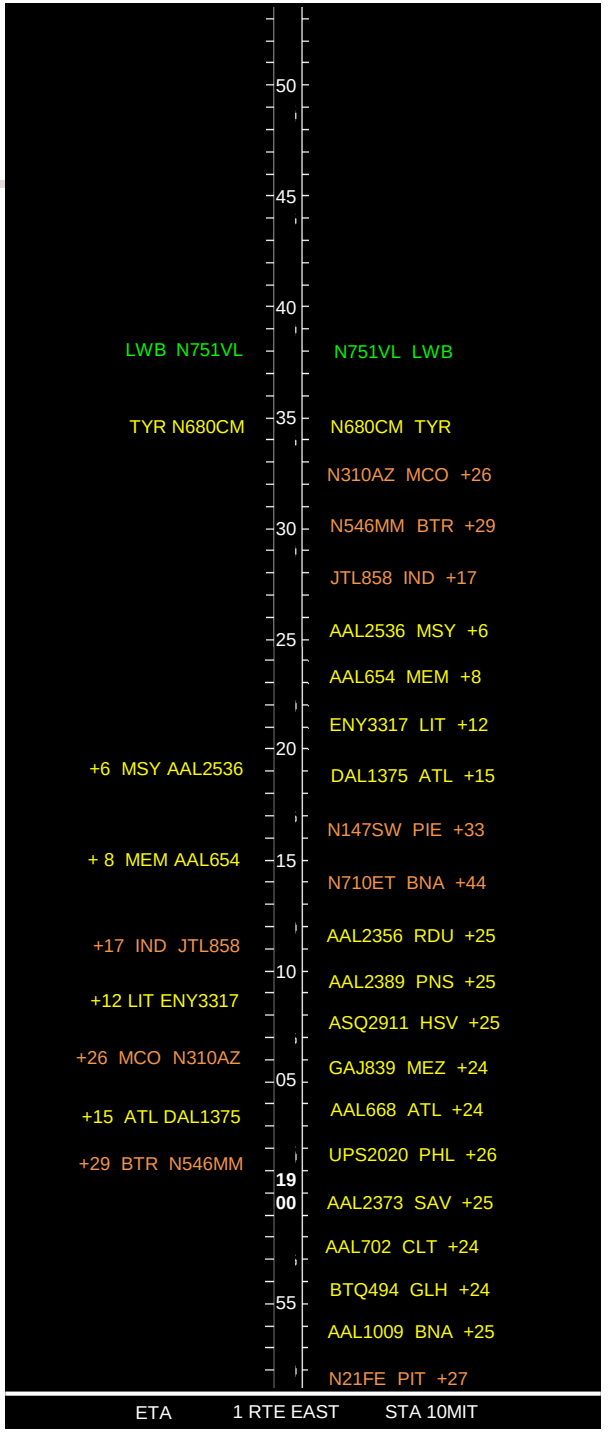
19:50

ETAs and STAs at the East Gate

After TOS assignments

DAL Flights in **orange**
DFW Flights in **yellow**
ADS Flights in **green**





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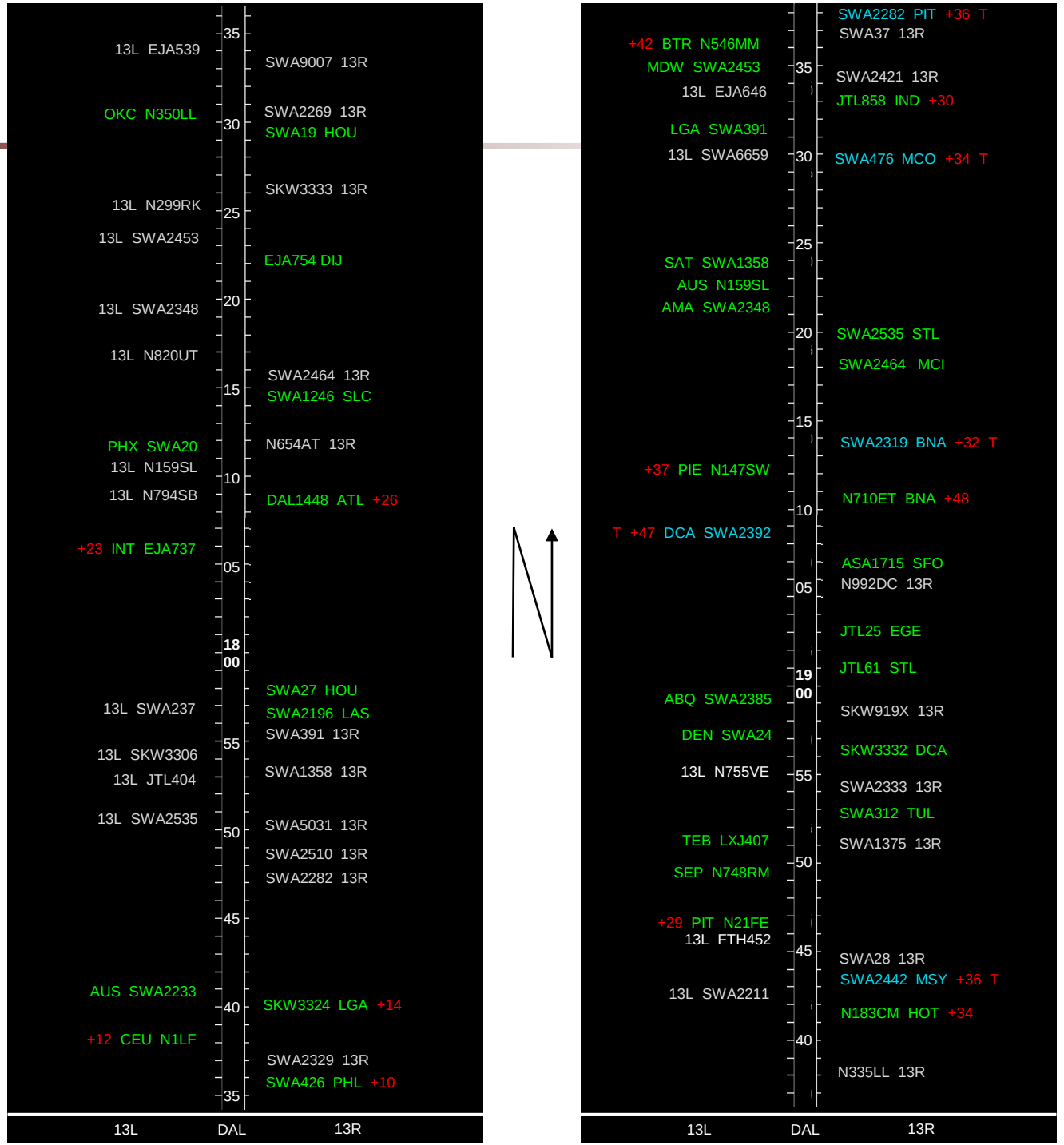
19:50

RWY Demand at Love Field

Before TOS assignments

TOS Flights in cyan



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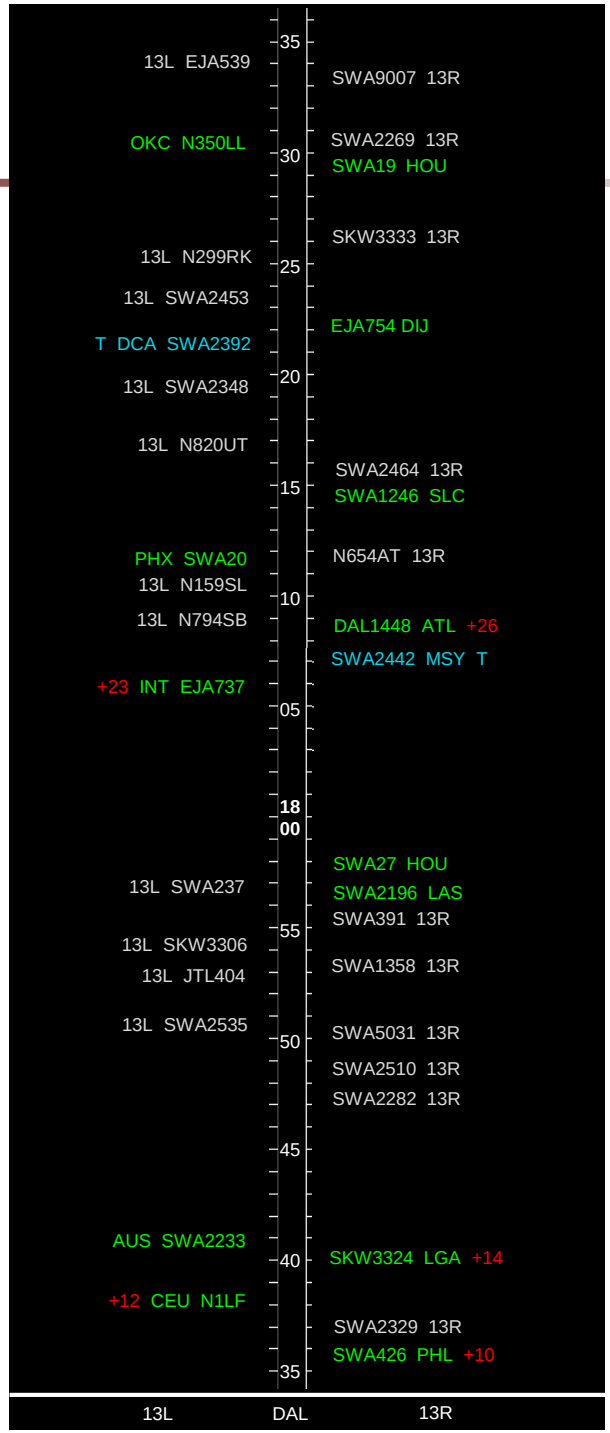
ATD-2 Integrated Arrival/Departure/Surface

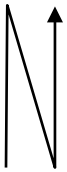
RWY Demand at Love Field

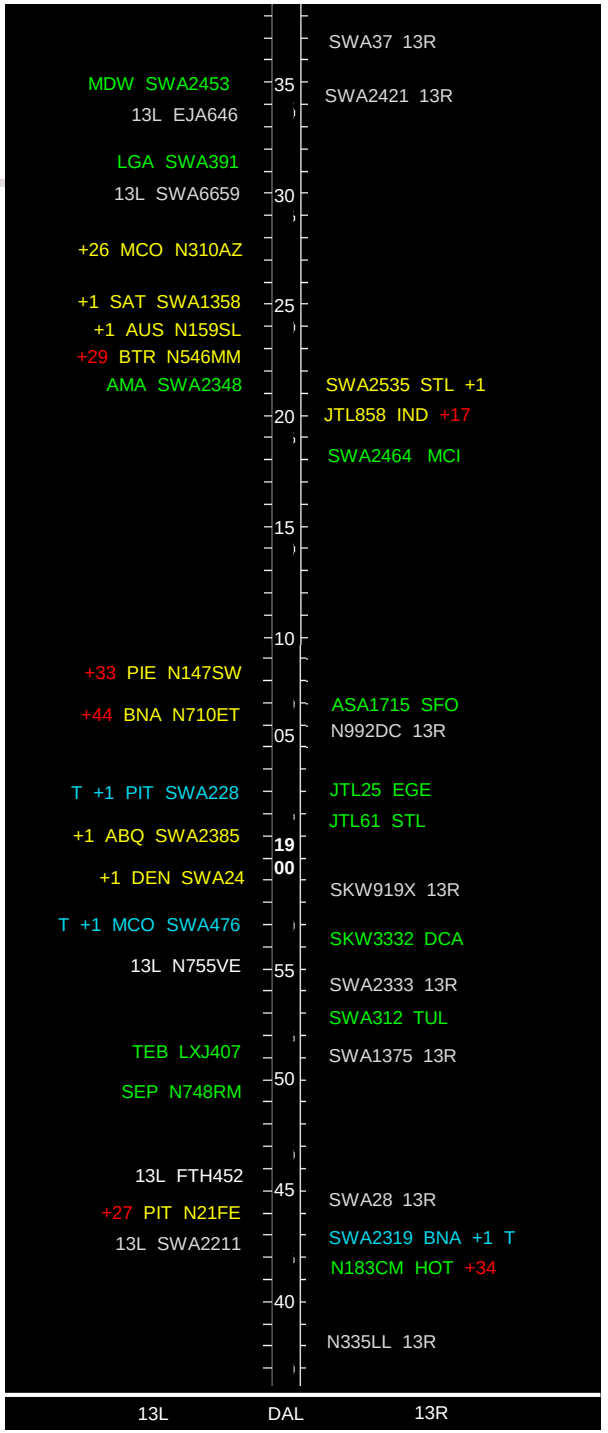
After TOS assignments

TOS flights in **cyan**

Other flights benefitting in **yellow**







17:35
19:35

Result of TOS Assignments for SWA at DAL

DAL SWA Flights	Dest	Est. RTC	Reroute via	Delay was	Delay now	Gain	Sub-totals
SWA2442	MSY	10	South gate	36	0	-36	
SWA2392	DCA	20	North gate	47	0	-47	
SWA2319	BNA	25	South gate	32	0	-32	
SWA476	MCO	20	South gate	34	1	-33	
SWA2282	PIT	25	North gate	36	1	-35	
SWA24	DEN			0	2	+2	
SWA2385	ABQ			0	2	+2	
SWA1358	SAT			0	1	+1	
SWA2535	STL			0	1	+1	177 min
DAL NON-SWA							
N21FE	PIT			29	27	-2	
N710ET	BNA			48	44	-4	
N147SW	PIE			37	33	-4	
N546MM	BTR			42	29	-13	
N3210AZ	MCO			42	26	-16	
JTL858	IND			30	17	-13	
N159SL	AUS			0	1	+1	51 min
DAL flights				**413 min**	**185 min**	**228 min**	
DFW Flights				**337 min**	**289 min**	**48 min**	
D10 Flights				**750 min**	**474 min**	**276 min**	

Conclusion

- Direct benefit
  - Using TOS to reroute departures can lead to a significant delay reduction for TOS flights and subsequent departures for the airline

- Indirect benefit
  - Other airlines (not using TOS) may also benefit from airlines using TOS

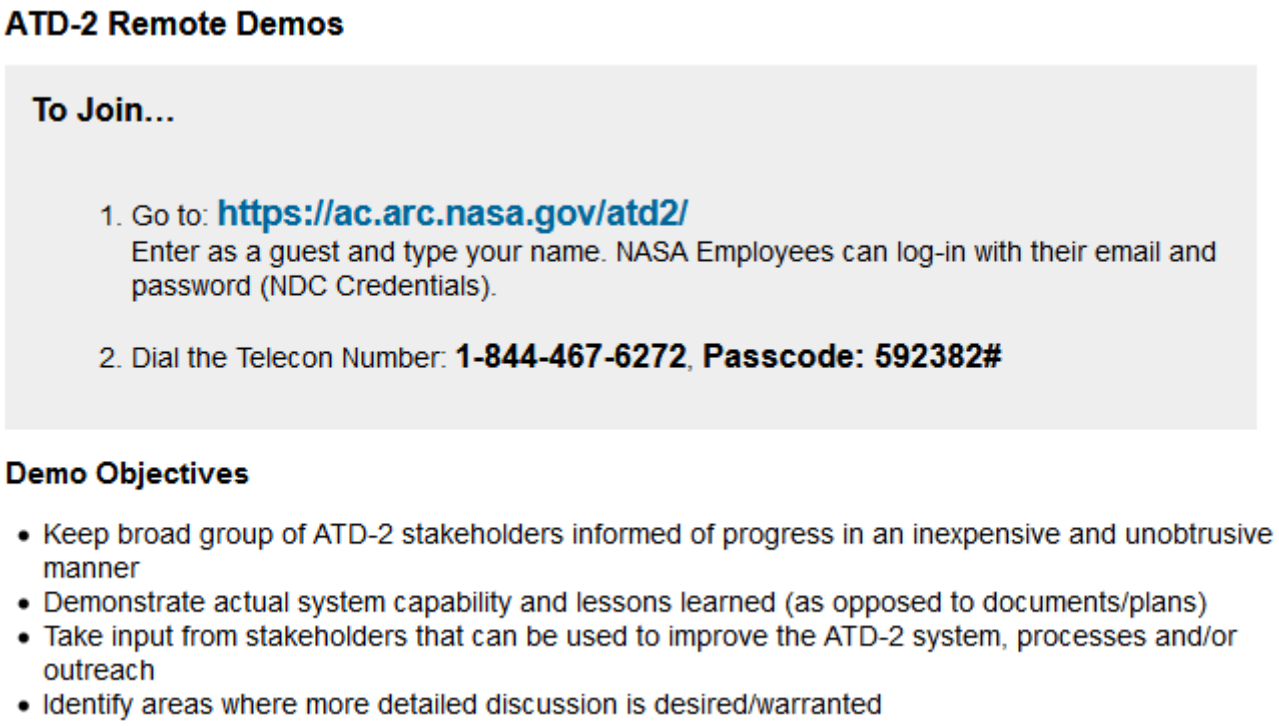
Questions

- Questions?
- Email Al.Capps@nasa.gov or William.J.Coupe@nasa.gov
- To learn more visit…
  - https://www.aviationsystemsdivision.arc.nasa.gov/research/atd2/index.shtml
- Or attend a webinar, stream a pre-recorded webinar at
  - https://aviationsystemsdivision.arc.nasa.gov/research/atd2/remote_demos.shtml

Remote Demos / Webinars

- Approximately one webinar per month
- Routinely host 60-80 attendees
- Eight sessions recorded and available for replay
- Latest schedule, access info, and recorded sessions online at:

https://aviationsystemsdivision.arc.nasa.gov/research/atd2/remote_demos.shtml



ATD-2 Remote Demos

To Join…

1. Go to: **https://ac.arc.nasa.gov/atd2/**
   Enter as a guest and type your name. NASA Employees can log-in with their email and password (NDC Credentials).
2. Dial the Telecon Number: **1-844-467-6272**, **Passcode: 592382#**

Demo Objectives

- Keep broad group of ATD-2 stakeholders informed of progress in an inexpensive and unobtrusive manner
- Demonstrate actual system capability and lessons learned (as opposed to documents/plans)
- Take input from stakeholders that can be used to improve the ATD-2 system, processes and/or outreach
- Identify areas where more detailed discussion is desired/warranted

Backup

Surface Predictive Engine

ATC TMC Runway Utilization Intent

TRACON controller runway intent

TBFM de-conflicted ON time estimate

TFM SWIM ETAs

TMIs. Controlled Take Off Times (CTOT)

Airline provided EOBTs

Tactical airline intent (ramp controller)

Surface Predictive Engine

Surface modeling logic

- Earliest IN time estimate
- Earliest OFF time estimate
- Latest OUT estimate
- Pushback duration model
- Ramp and AMA taxi time
- Hovering logic

Scheduling Logic

- Converging runways
- Flight spacing requirements
- Dual use runways
- Runway crossing delays
- Departure fix separation
- Use of flight state

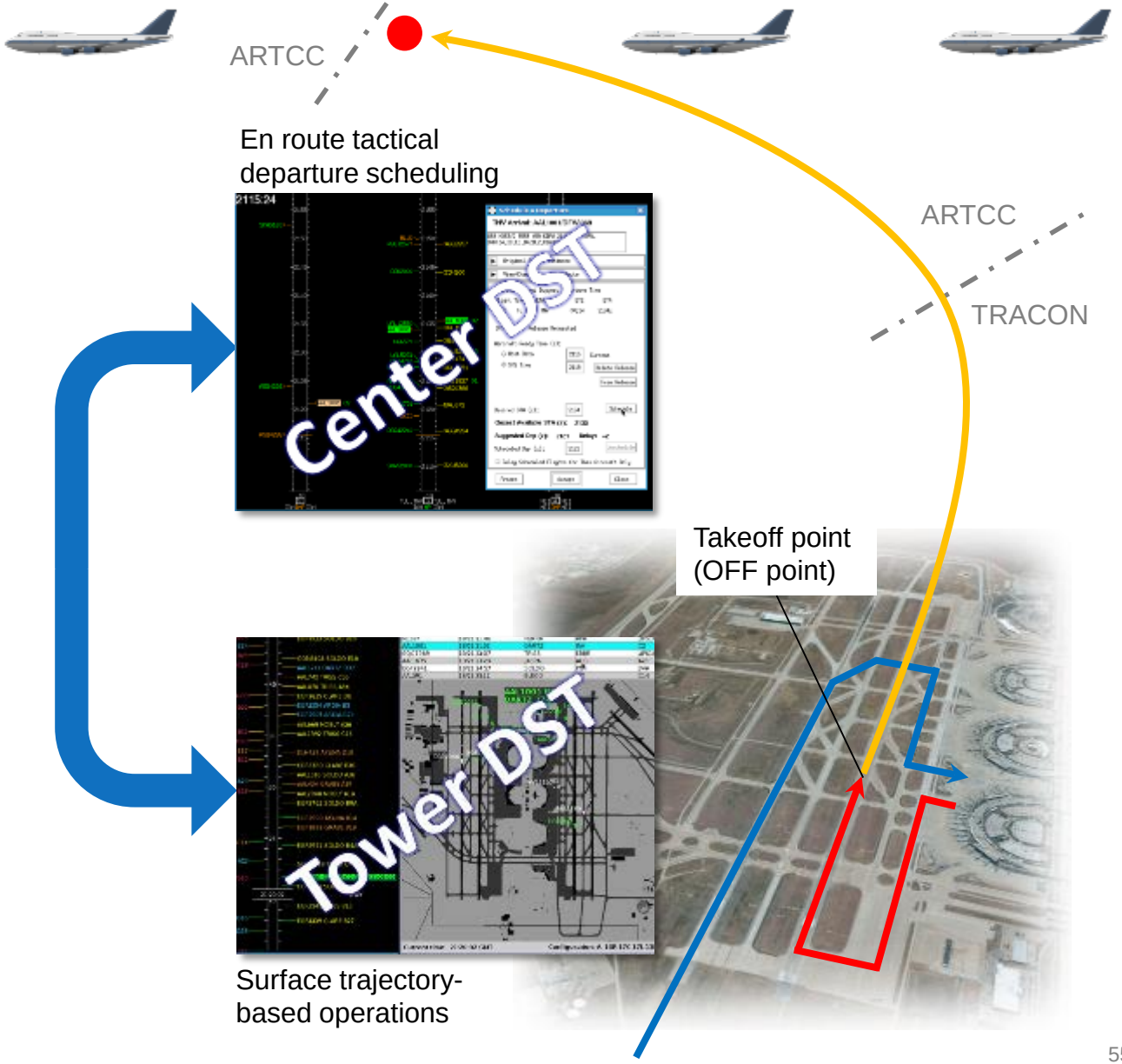
Links to Other Presentations/Webinars

- ATD-2 Surface metering
  - https://aviationsystemsdivision.arc.nasa.gov/research/atd2/remote-demos/ATD2_remote_briefing_20180321_SurfaceMetering.pdf
- Latest ATD-2 IADS Capabilities
  - https://aviationsystemsdivision.arc.nasa.gov/research/atd2/remote-demos/ATD2_remote_briefing_20180314_LatestCapabilities.pdf
- New Surface SWIM feed – TFDM Terminal Publication (TTP)
  - https://aviationsystemsdivision.arc.nasa.gov/research/atd2/remote-demos/ATD2_remote_briefing_20180712_TTP.pdf
- Understand and Process Restrictions in the NAS (Part 1 – Stream)
  - https://ac.arc.nasa.gov/pok8rxacq45g/?OWASP_CSRFTOKEN=205edc6ee12cbf81ae6b17d3d523b0b250eff34d152ff1c368f6d0eb3425452d
- Understand and Process Restrictions in the NAS (Part 2 – Stream)
  - https://ac.arc.nasa.gov/pok8rxacq45g/?OWASP_CSRFTOKEN=205edc6ee12cbf81ae6b17d3d523b0b250eff34d152ff1c368f6d0eb3425452d

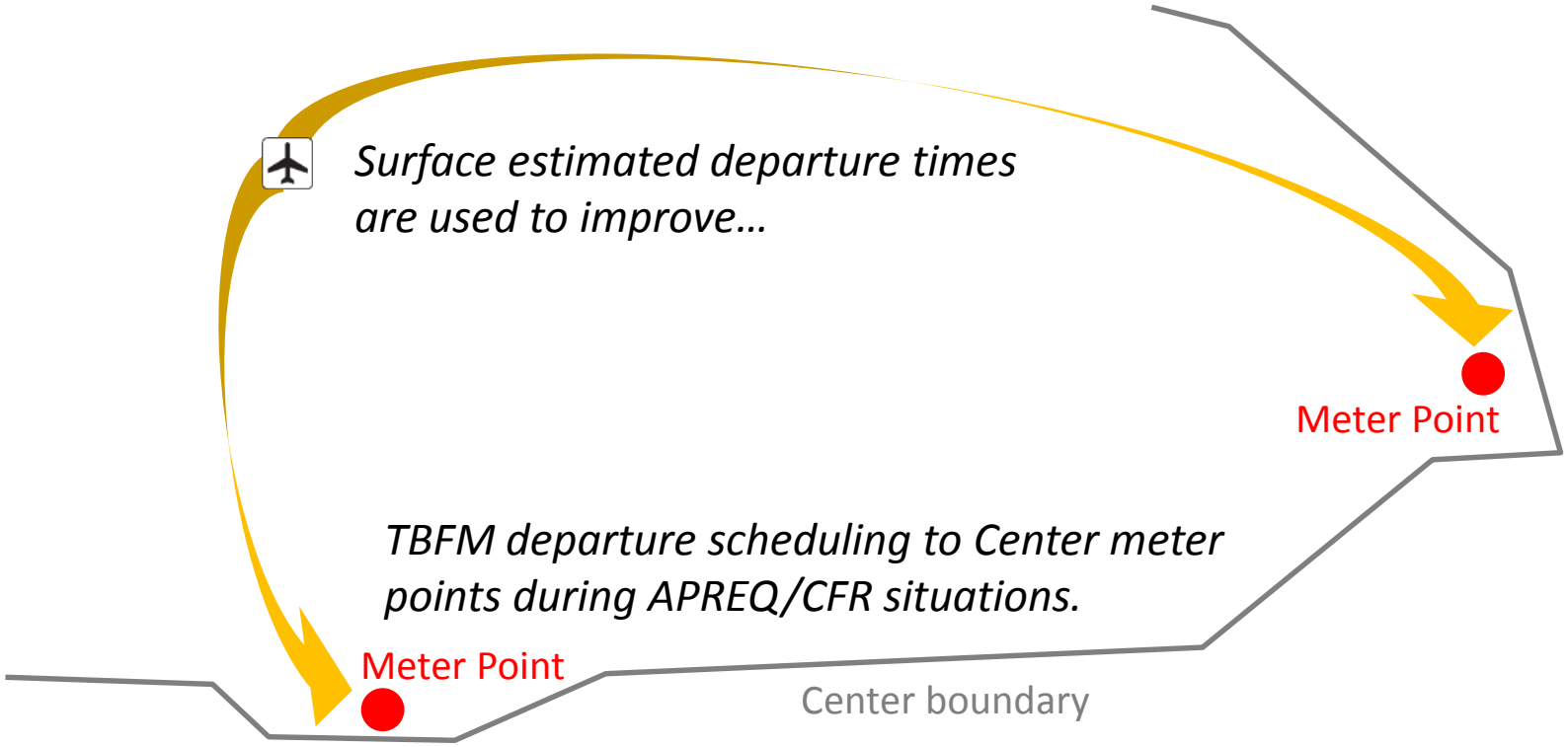
Tactical Departure Scheduling – Prior Research

En route system uses information from surface system for more precise tactical departure scheduling.

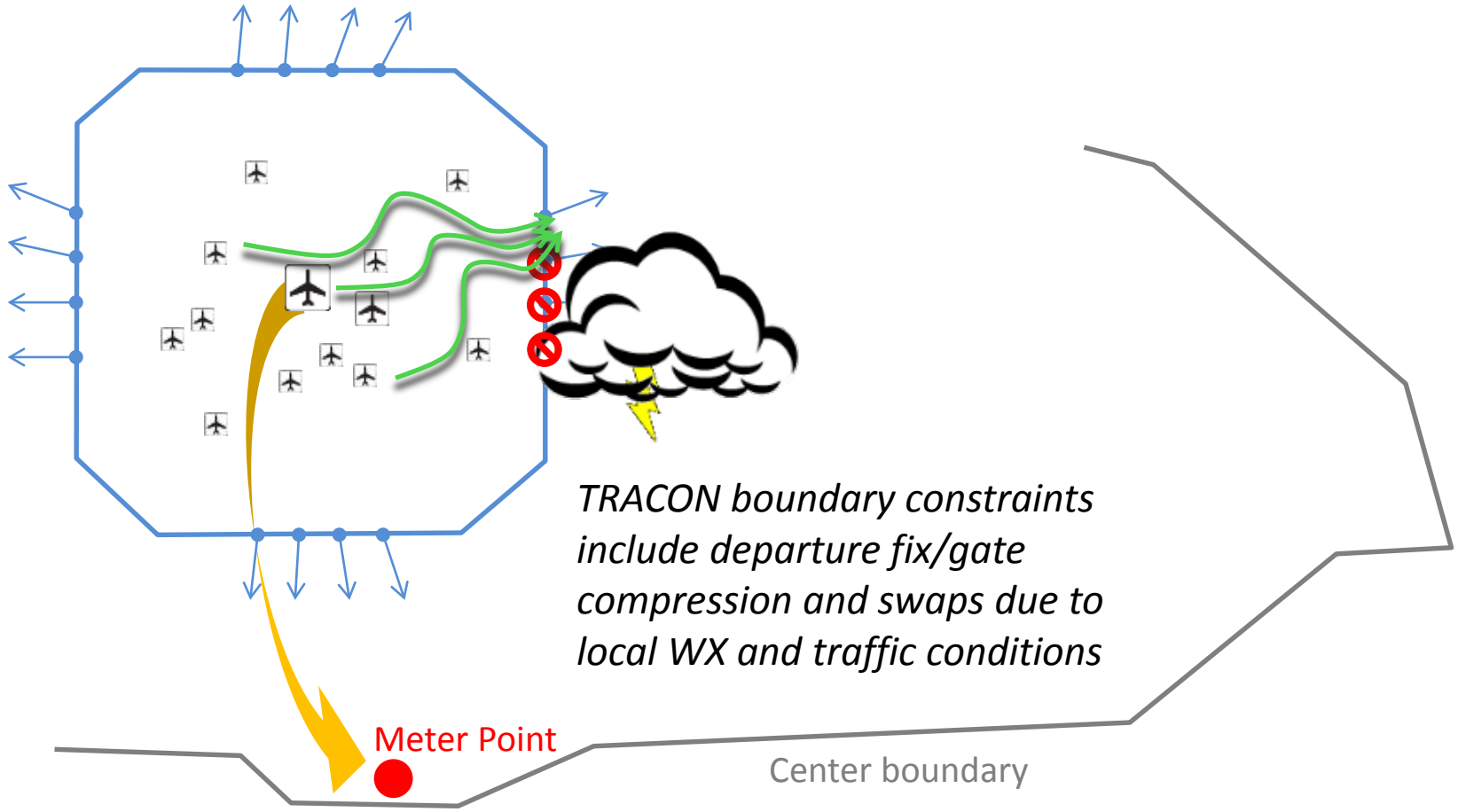
Surface system predicts OFF times and runway assignments for use by the en route scheduling system.



TFDM/TBFM Departure Scheduling



Adding in the Terminal Layer



Terminal Departure Coordination

- Enable time-based control of Terminal departures
- Schedules from multiple airports with various automation equipage
- Simultaneously satisfies local, regional, and national traffic constraints

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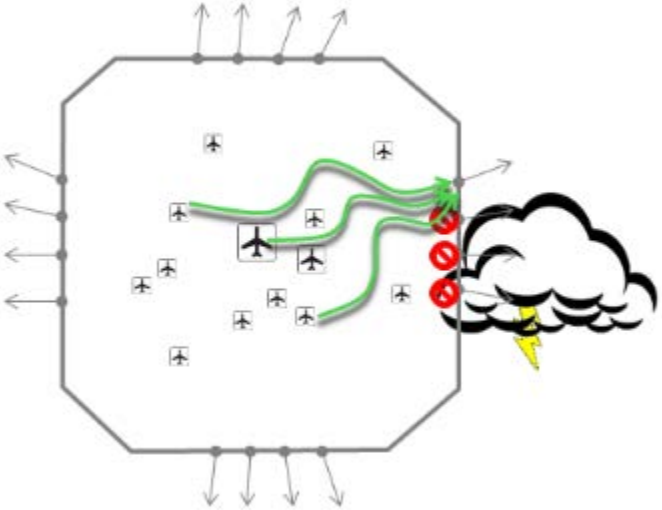
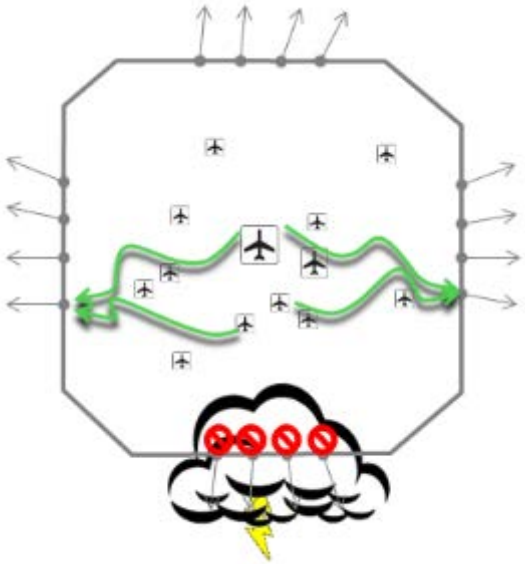
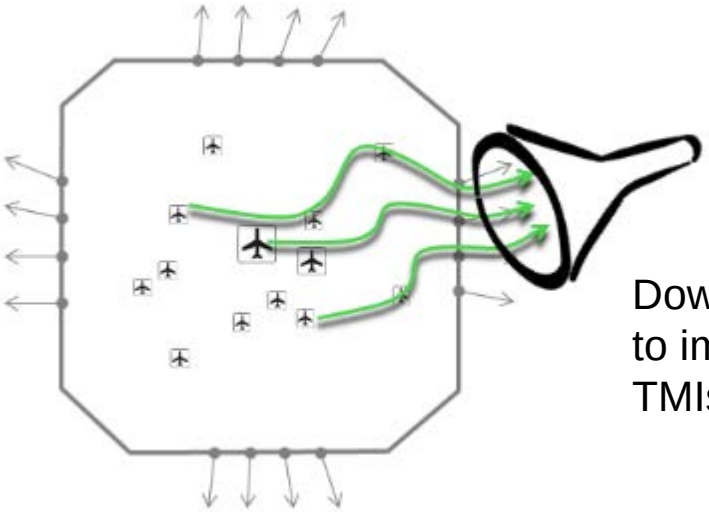
Common Terminal Departure Scenarios



Fix compression caused by weather events in or near TRACON airspace

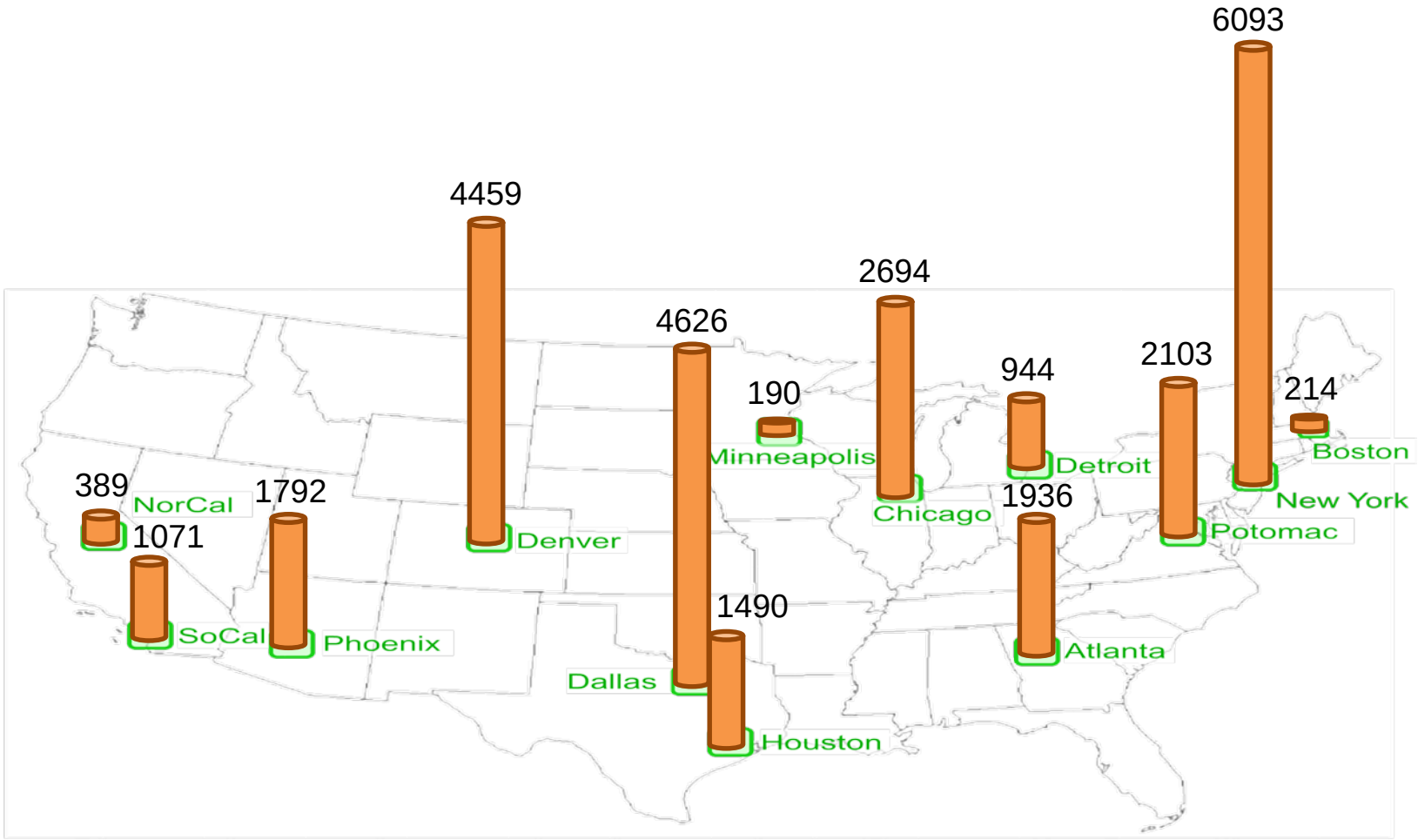


Complete blockage of departure fixes or gates may lead to fix/gate swaps



Downstream constraints may lead to implementation of TRACON TMIs

Count of Flights in Terminal Restrictions

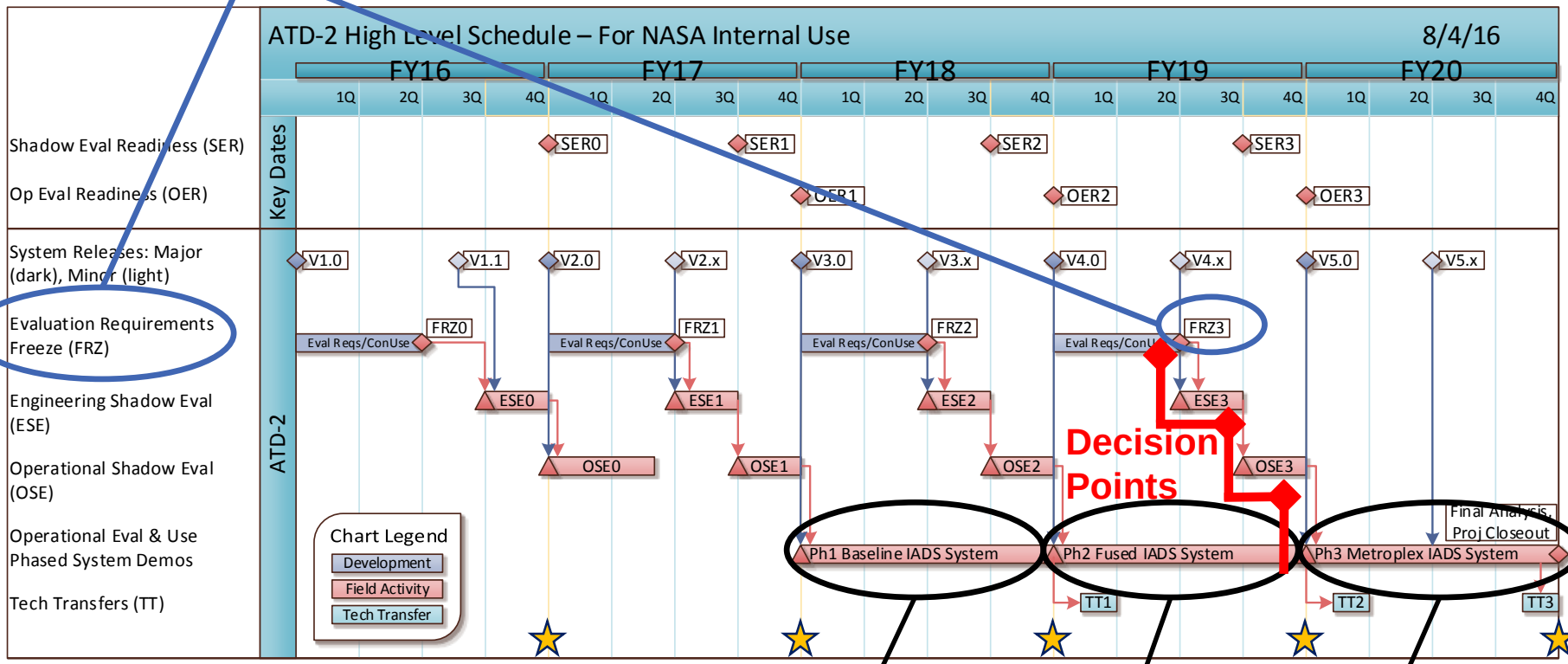


Number of flights involved in a Terminal constraint in July 2013

Kistler, Capps & Engelland, AIAA-2014-2019

Timeline and Field Demonstration Strategy

Evaluation Requirements Freeze (FRZ) assesses current system capability against Field Demo Partner desires and constraints. A joint decision establishes parameters for the upcoming demonstration phase.



Commitments to Demo Partners

- ✓ Sep 2016 ATD-2 system installation at CLT
- ✓ Sep 2017 ATD-2 demonstration commences
- Sep 2018 interim technology transfer
- Sep 2019 interim technology transfer
- Sep 2020 final technology transfer

Phase 1: Baseline IADS

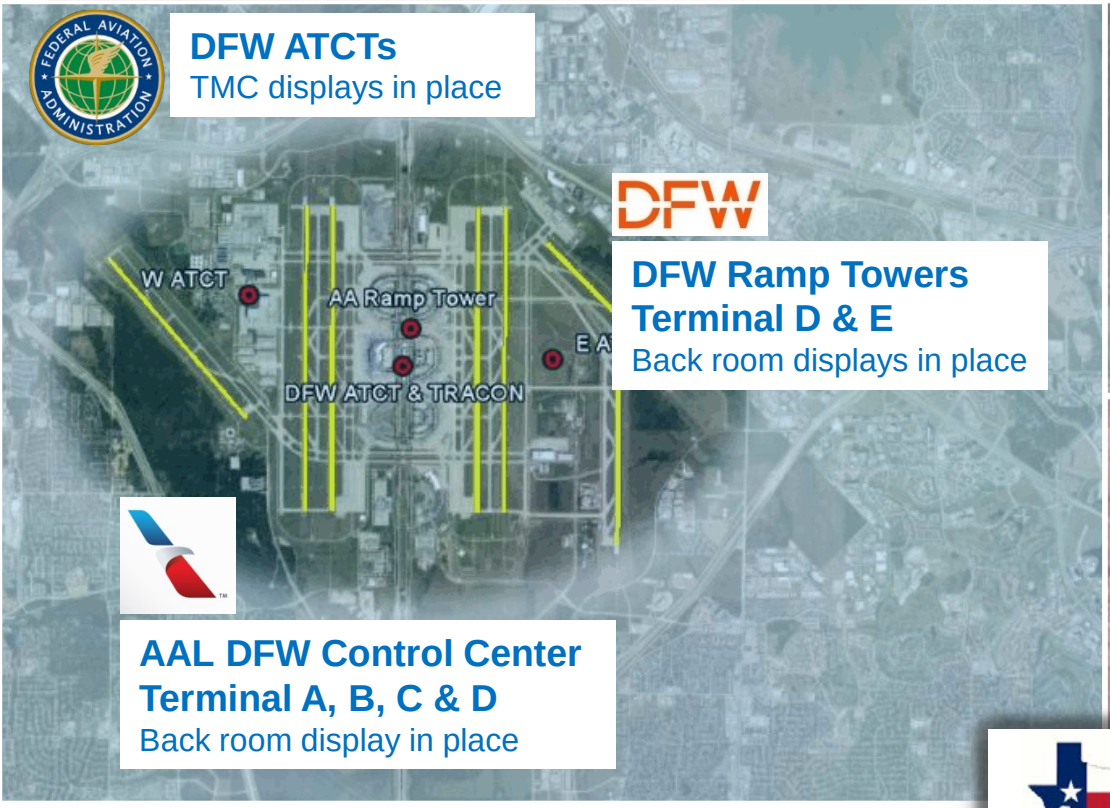
Phase 2: Fused IADS

Phase 3: Terminal Departure IADS

Phase 3 Deployment Status

DFW ATCTs
TMC displays in place

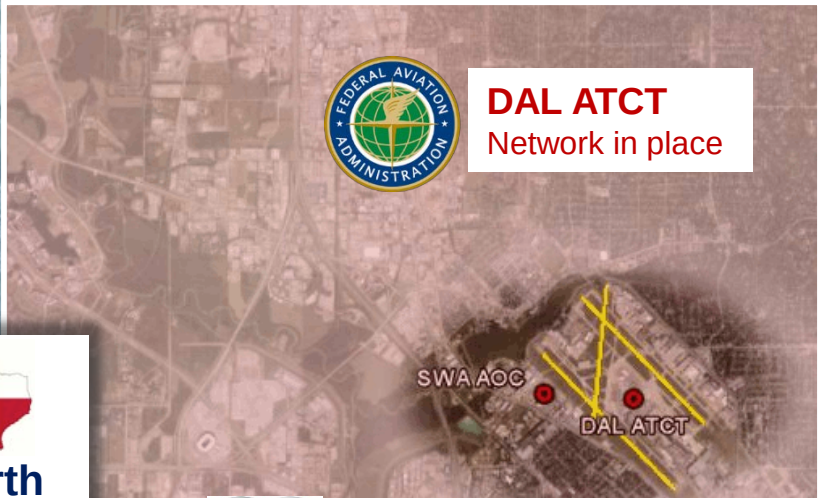
DFW Ramp Towers
Terminal D & E
Back room displays in place



AAL DFW Control Center
Terminal A, B, C & D
Back room display in place

D10 TRACON TMU
TMC displays in place

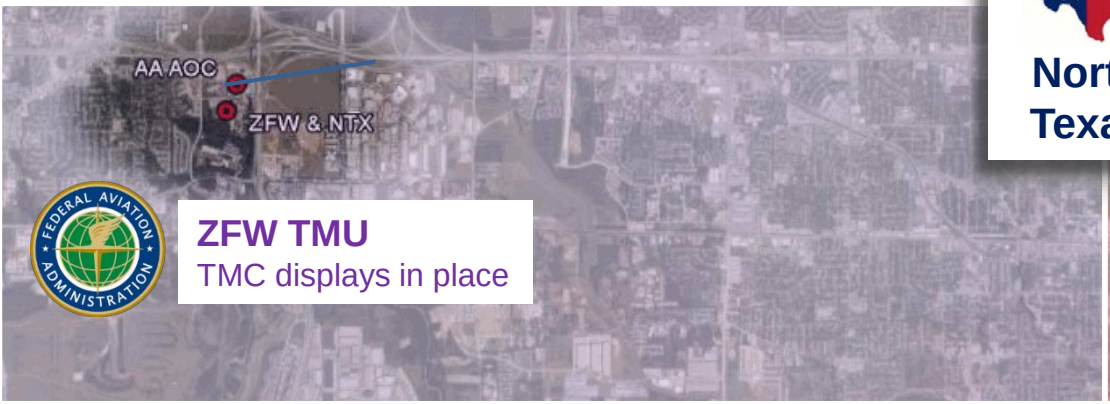
DAL ATCT
Network in place



SWA Control Center
Requirements evaluation

General Aviation
Discussing with Mobile App partners

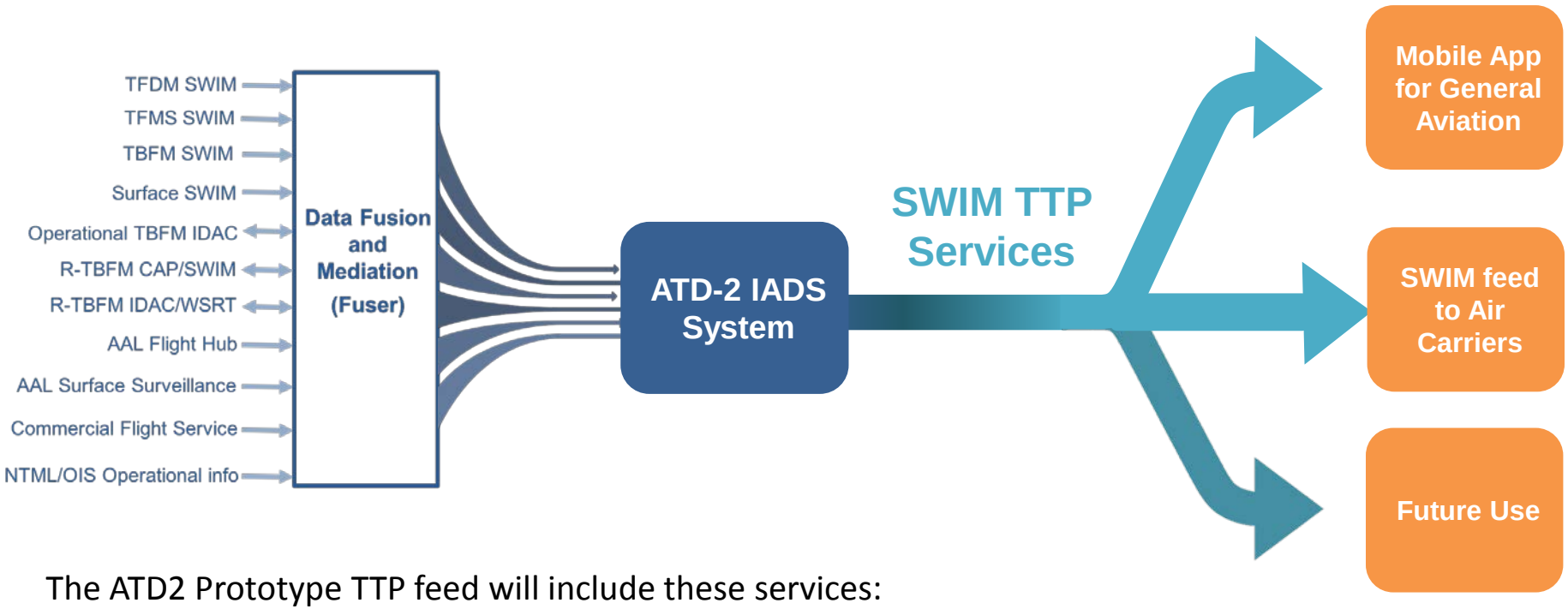
North Texas



ZFW TMU
TMC displays in place

IADS Data Sharing via Prototype TTP

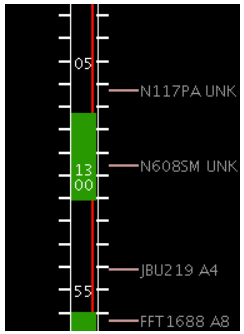
NASA and the FAA are collaborating to provide a prototype TFDM Terminal Publication (TTP) feed via SWIM R&D network as part of the ATD-2 Field Demonstration



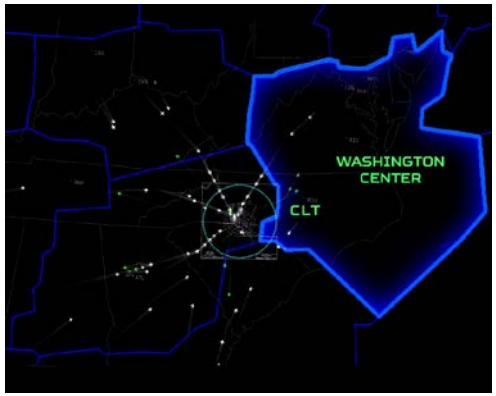
The ATD2 Prototype TTP feed will include these services:

- Flight Data
- Airport Information
- Traffic Management Restrictions
- Flight Delay
- Operational Metrics

Overhead Stream Insertion Collaboration



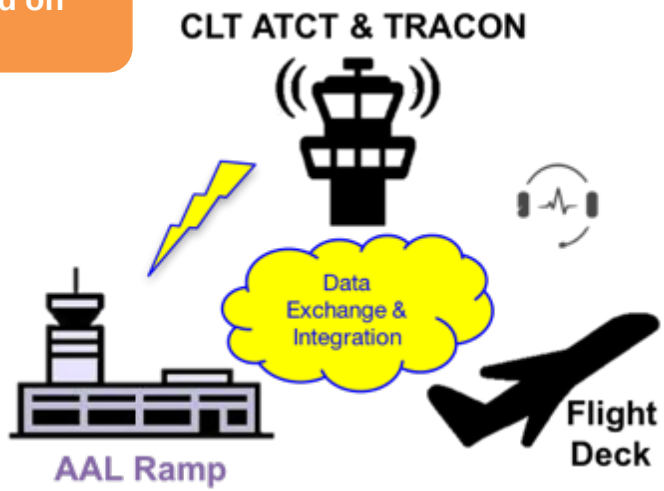
Washington ARTCC (ZDC)



IDAC-style scheduling between IADS at CLT and TBFM at ZDC

2) TMC electronically negotiates with ZDC for a time based on red/green space

3) ZDC TMC approves or adjusts the time based on center constraints



4) Ramp utilizes the now visible APREQ time on their strips and pushback advisories

1) Pilot calls into clearance delivery approximately 10 min prior to push back for APREQ times