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

NRA Final Briefing

ATAC Corporation, MCR Federal, Massachusetts Institute Of Technology

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  - Husni Idris
Outline

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

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

- Identify *operational shortfalls* that ATD-2 can address and associated ATD-2 *benefit mechanisms* and *benefit metrics*

- Develop a *combined airspace-surface simulation platform* that can simulate key operational shortfalls and benefit mechanisms

- Conduct *high-fidelity surface-airspace simulations* for simulating current-day and future ATD-2 operations at *three airport sites* and *carefully selected simulation days*

- Extrapolate results to FAA Core 30 airports using *medium-fidelity queuing simulation models* and FAA *TFDM benefits analysis results*

- Extrapolate to annualized benefits by conducting medium-fidelity simulations at a larger set of days and by using carefully generated “*similar number of days in a year*” *based multipliers*

- Follow *FAA-recommended processes* for cost analysis

- Compute *advantages to the FAA’s TFDM program*: enhancement in benefits, reduction in costs, overall a *beneficial impact on the TFDM B/C ratio*
COMBINED SURFACE-AIRSPACE SIMULATION PLATFORM
Combined Airspace-Surface Simulation Platform Architecture

**SOSS**
- Added models
  - Push readiness
  - EOBT uncertainty
  - Taxi rerouting

**AOSS**: Surface TFM
- Existing processes for handling APREQ, EDCT constraints
- Sequence changes for miles-in-trail impacted departure fixes
- Surface traffic state
- Taxi routes

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

**AOSS**: ATD-2 Tactical Surface Scheduler
- APREQ takeoff time window constraints
- Gate delays for APREQ/EDCT flights
- Surface delays for MIT flights

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

*AOSS: Airspace Operations Simulator & Scheduler*
**SURFACE MODEL FEATURES:**
- Controller surface conflict resolution model
- Model of coordination with receiving center: APREQ and EDCT implementation model incl. uncertainties
- Runway separations, sequencing for miles-in-trail restriction adherence
- ATD-2 departure metering emulation

**AIRSPACE MODEL FEATURES:**
- Departure fix and enroute merging model
- Model of coordination with surface departure traffic mgmt: timeline-based electronic APREQ requests (TBFM IDAC integration)
- Sector transit time uncertainty models
- Model of airborne delays for center miles-in-trails

**ATAC AOSS MODELS**
Airspace transit from runway takeoff to TBFM meter arc crossing

**NASA SOSS MODELS**
Surface trajectories

**CLT**
Combination of all the models

**NY Area Airports**
- DYL
- VCN
- HOG

**DC Area Airports**
- TER
- DC Arc

**Simulation Injection Arcs for Non-CLT Flights**
Modeling of ATD-2 Benefit Mechanisms

ATD-2 FUNCTIONS

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

CAUSAL LINKS

- Improved awareness of flight status and intent
- More accurate demand predictions

POTENTIAL BENEFITS

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

DATA EXCHANGE

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

- **Efficiency**
  - Surface departure metering advisories
    - Push
    - Gate Hold
  - Demand throttling
  - Reduced surface congestion
  - Fewer actions required to resolve surface conflicts
  - Reduced surface movement times
  - Potential benefits: Reduced pilot/controller workload, Less delay, fuel, and emissions

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

ATD-2 FUNCTIONS

- Improved takeoff time predictions using EOBT
- Timeline-based electronic APREQ request (TBFM IDAC integration)

CAUSAL LINKS

- More efficient and achievable APREQ times, with earlier awareness by airlines
- More accurate taxi-out time estimates lead to efficient runway release time request which may result in frequent need for rescheduling
- ATD-2: more accurate taxi-out time estimates lead to efficient runway release time request and therefore, less frequent need for rescheduling
- No APREQ release coordination time benefit assumed

POTENTIAL BENEFITS

- Better airline resource management
- Improved airline schedule integrity
- Improved airline resource management
- Reduced controller workload

INTEGRATED AIRSPACE SCHEDULING

- TMI COMPLIANCE
SIMULATION DAYS/SCENARIOS SELECTION
Simulation Days Selection

Considers Weather and Traffic Demand Impacts

- **Goal**
  - Select a set of simulation dates for benefits estimation ATD-2
  - Support extrapolation across the CONUS on an annual basis

- **Local and national weather/traffic demand conditions considered for days selection**
  - Weather impact traffic index (WITI) computation for NAS-wide and regional weather impact
  - Traffic Management Initiative (TMI) impact on departure airport also captured using APREQ and MIT impact indices
## Simulation Dates for KCLT

<table>
<thead>
<tr>
<th>Condition</th>
<th>TMI/APREQ Indices</th>
<th>Weather</th>
<th>Recom. Date</th>
<th># Days</th>
<th>% Occur.</th>
<th>Total Daily Precip (in)</th>
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### Tercile grouping rules

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<th>Condition</th>
<th>Good (0)</th>
<th>Fair (1)</th>
<th>Poor (2)</th>
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<td>APREQ/MIT indices</td>
<td>Both &lt; 50%</td>
<td>One &gt; 50%</td>
<td>Both &gt; 50%</td>
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<td>CONUS WITI</td>
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<td>(&gt; 33% \text{ and } \leq 66%)</td>
<td>(&gt; 66%)</td>
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<tr>
<td>Local WITI</td>
<td>(\leq 33%)</td>
<td>(&gt; 33% \text{ and } \leq 66%)</td>
<td>(&gt; 66%)</td>
</tr>
<tr>
<td>Departure index</td>
<td>(\leq 33%)</td>
<td>(&gt; 33% \text{ and } \leq 66%)</td>
<td>(&gt; 66%)</td>
</tr>
</tbody>
</table>

**Σ % Occur. = 80%**

Encompasses 80% of operational conditions for FY2015
## Experiment Matrix

<table>
<thead>
<tr>
<th>Airport</th>
<th>Simulation Day</th>
<th>Annualization Day Rank</th>
<th>Runway Config</th>
<th>Simulation Timeframe (UTC)</th>
<th>Baseline Sim #</th>
<th>ATD-2 Sim #</th>
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<td>1500-2100</td>
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<td>1000-1600</td>
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<td>South</td>
<td>0900-1600</td>
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<td>North</td>
<td>0900-1800</td>
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<td>32</td>
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</tbody>
</table>

Three sensitivity studies: (1) Push at SOBT, (2) Phase II benefits, (3) Phase III benefits
RESULTS FROM HIGH-FIDELITY SIMULATIONS
Simulation Scenarios

- **Sim #1**: 06/15/2016, 1000-1600 UTC
  - South Flow
  - APREQs for LGA, EWR, DCA, ORD, DTW flights
  - No GDP

- **Sim #2**: 05/06/2016, 1600-2100 UTC
  - North Flow
  - APREQs for LGA, EWR, JFK, ORD flights
  - GDP for SFO flights

**Graph Details**:
- **Y-axis**: Wheels-Off Counts Per Minute
- **X-axis**: Time of the Day (Local Time)
- **Legend**: Loess Curve Fit
- **Banks at CLT**: 1 2 3 4 5 6 7 8 9
Efficiency: Taxi-Out Time Savings

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

Sim #2: 05/06/2016
North Flow
1600-2100 UTC
Impact on Taxi-In Times

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

Sim #2: 05/06/2016
North Flow
1600-2100 UTC
Impact on OFF-Time Performance

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

Difference in Actual Takeoff Time between ATD2 and Baseline Sim

Sim #1: 06/15/2016
South Flow
1000-1600 UTC
Impact on OFF-Time Performance

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

**Histograms showing delay distribution:**
- **Total Taxi Out Time + Gate Hold Time**
  - **Baseline Sim**
    - Delay <= 15 min
      - Mainline 87%
      - Regional 87%
      - Total 87%
    - Takeoff Delay = 15 min
    - Taxi Time Within Budget:
      - Mainline 78%
      - Regional 67%
      - Total 73%
  - **ATD-2 Sim**
    - Delay <= 15 min
      - Mainline 83%
      - Regional 80%
      - Total 82%
    - Taxi Time Within Budget:
      - Mainline 70%
      - Regional 63%
      - Total 67%
Impact on Airport Throughput

Cumulative Runway Takeoff Counts
Red – Baseline (current-day) operations
Blue – ATD-2 operations

Sim #1: 06/15/16
South Flow

Runway Throughput, 18C

Cumulative Throughput (
# Takeoffs Until Time t)

Minutes Past Midnight on 6/15/2016 (600 = 10:00 AM)
Benefit Mechanism: Demand Throttling

Sim #1: 06/15/16
South Flow
Benefit Mechanism: APREQ Coordination

**BASELINE**

- **All Departures**
  - Mean = 22.65
  - STD = 8.71

- **APREQ Departures**
  - Mean = 26.82
  - STD = 10.85

- **Non-APREQ Departures**
  - Mean = 21.92
  - STD = 8.1

**ATD-2**

- **All Departures**
  - Mean = 20.62
  - STD = 6.47

- **APREQ Departures**
  - Mean = 22.37
  - STD = 6.39

- **Non-APREQ Departures**
  - Mean = 20.31
  - STD = 6.45

**Taxi Out Times (min)**

Sim #2: 05/06/2016, North Flow, 1600-2100 UTC
**Benefit Mechanism: TMI Compliance**

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

<table>
<thead>
<tr>
<th>Simulated Takeoff Times As Compared to the APREQ Window</th>
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<tbody>
<tr>
<td>*</td>
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<tr>
<td><strong>Baseline</strong></td>
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<tr>
<td>-------------</td>
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<tr>
<td><strong>Beyond -15 min</strong></td>
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<tr>
<td>0</td>
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<td>8</td>
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<td>15</td>
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<td>18</td>
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</table>

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

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

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

Sim #1: 06/15/2016, CLT South Flow, 1000-1600 UTC
## Summary of Taxi-Out Time Saving Benefits

### Full Day Benefits (min)

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<th>CLTN</th>
<th>DFWN</th>
<th>DFWS</th>
<th>EWRS</th>
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### Average Per Departure Taxi-Out Time Saving (Min) =

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<th>CLT</th>
<th>DFW</th>
<th>EWR</th>
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<td>1.72</td>
<td>1.89</td>
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Benefits Analysis & Extrapolation

**Baseline**
- CLT1
- CLT2
- CLT6

**ATD-2**
- CLT1
- CLT2
- CLT6

**High Fidelity Sims**
- DFW1
- DFW2
- DFW6
- EWR1
- EWR4

**Nationwide Extrapolation**

**Performance Metrics from High-fidelity Sims at 3 Study Airports**

**Other Medium Fidelity Sims Models**
- PHL
- BOS
- JFK
- TFDM BCA Results

**Model Validation**

**Performance Metrics from Medium-fidelity Sims at 3 Study Airports over a Wider Set of Days**

**Annualization & Monetization**

- Scale individual airport benefits results to an annualized level
- Convert taxi time savings to $ savings using Cost of Fuel, Airline Direct Operating Cost and Cost of Passenger Time
BENEFITS NATIONALIZATION
Benefits Nationalization

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

- Baseline (no metering)

<table>
<thead>
<tr>
<th></th>
<th>Departures</th>
<th>Actual</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(14,122 flts)</td>
<td>Avg. (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxi-out time</td>
<td>20.2</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Gate to spot</td>
<td>9.7</td>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>Spot to runway</td>
<td>10.5</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

Arrivals (16,383 flts) 10.2 0.5
CLT Metering Scenario: 05/06/2016

- Estimate taxi-out time reduction from ATD-2
Impact of Excess Queue Parameter

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

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

Suitable choice of excess queue parameter
CLT Metering Impacts

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

- **South Flow** (20 days; 7,069 departures; 7,499 arrivals; excess queue: 5 min)
## SOSS vs. Queuing Model Simulations: CLT

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

### Taxi-out time (in minutes)

<table>
<thead>
<tr>
<th>Date</th>
<th>North Flow</th>
<th>South Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOSS</td>
<td>Queuing model</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>ATD-2</td>
</tr>
<tr>
<td>05/06/2016</td>
<td>20.5 (228)</td>
<td>17.4 (228)</td>
</tr>
<tr>
<td>05/31/2016</td>
<td>18.5 (222)</td>
<td>17.8 (222)</td>
</tr>
<tr>
<td>06/01/2016</td>
<td>22.7 (181)</td>
<td>20.6 (181)</td>
</tr>
<tr>
<td>05/17/2016</td>
<td>20.1 (283)</td>
<td>19.0 (283)</td>
</tr>
<tr>
<td>06/02/2016</td>
<td>16.9 (135)</td>
<td>15.9 (135)</td>
</tr>
<tr>
<td>06/15/2016</td>
<td>18.0 (239)</td>
<td>16.2 (239)</td>
</tr>
</tbody>
</table>

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

- Baseline (no metering)

<table>
<thead>
<tr>
<th>Flow</th>
<th>Actual</th>
<th>Error</th>
<th>Avg. (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxi-out</td>
<td>21.3</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Taxi-in</td>
<td>9.4</td>
<td>-0.1</td>
<td></td>
</tr>
<tr>
<td>South Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxi-out</td>
<td>20.1</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Taxi-in</td>
<td>9.4</td>
<td>-0.5</td>
<td></td>
</tr>
</tbody>
</table>
EWR Metering Scenario: 07/29/2016

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

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

- South Flow (48 days; 16,349 departures; 15,753 arrivals; excess queue: 12 min)
SOSS vs. Queuing Model Simulations: EWR

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

### Taxi-out time (in minutes)

<table>
<thead>
<tr>
<th>Date</th>
<th>South Flow</th>
<th>SOSS Baseline</th>
<th>SOSS ATD-2</th>
<th>SOSS Reduction</th>
<th>Queuing model Baseline</th>
<th>Queuing model ATD-2</th>
<th>Queuing model Reduction</th>
<th>Actual Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/06/2016</td>
<td>07/29/2016</td>
<td>15.0 (171)</td>
<td>13.6 (171)</td>
<td>1.4, 9.7% (171)</td>
<td>19.8 (199)</td>
<td>19.6 (199)</td>
<td>0.2, 1.3% (199)</td>
<td>20.6 (199)</td>
</tr>
<tr>
<td>07/03/2016</td>
<td>07/21/2016</td>
<td>20.0 (175)</td>
<td>15.6 (175)</td>
<td>4.4, 21.8% (175)</td>
<td>15.9 (154)</td>
<td>15.8 (154)</td>
<td>0.1, 0.6% (154)</td>
<td>15.9 (154)</td>
</tr>
<tr>
<td>07/29/2016</td>
<td></td>
<td>17.0 (286)</td>
<td>15.9 (286)</td>
<td>1.1, 6.6% (286)</td>
<td>28.0 (292)</td>
<td>25.8 (292)</td>
<td>2.2, 7.8% (292)</td>
<td>18.2 (292)</td>
</tr>
</tbody>
</table>

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

- Baseline (no metering)
  Operates in South Flow 80% of the time

<table>
<thead>
<tr>
<th></th>
<th>North Flow</th>
<th>Actual</th>
<th>Error Avg. (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi-out</td>
<td>18.7</td>
<td>-0.6</td>
<td></td>
</tr>
<tr>
<td>Taxi-in</td>
<td>10.1</td>
<td>-0.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>South Flow</th>
<th>Actual</th>
<th>Error Avg. (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi-out</td>
<td>16.8</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Taxi-in</td>
<td>11.2</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>
DFW Metering Impacts

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

- **South Flow** (72 days; 53,513 departures; 51,577 arrivals; excess queue: 12 min)
# SOSS vs. Queuing Model Simulations: DFW

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

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

(Number of flights considered in the simulation is shown in parentheses)
# Summary of Taxi-out Time Reduction Benefits

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

<table>
<thead>
<tr>
<th>Date</th>
<th>% taxi-out time reduction</th>
<th>Scaling factor</th>
<th>Median</th>
</tr>
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<tbody>
<tr>
<td>CLT</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5/06/2016</td>
<td>10.7</td>
<td>15.1</td>
<td>1.4</td>
</tr>
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<td>5/31/2016</td>
<td>14.4</td>
<td>3.8</td>
<td>0.3</td>
</tr>
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<td>6/01/2016</td>
<td>12.8</td>
<td>9.0</td>
<td>0.7</td>
</tr>
<tr>
<td>5/17/2016</td>
<td>12.2</td>
<td>5.7</td>
<td>0.5</td>
</tr>
<tr>
<td>6/02/2016</td>
<td>14.9</td>
<td>5.8</td>
<td>0.4</td>
</tr>
<tr>
<td>6/15/2016</td>
<td>13.9</td>
<td>9.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

| DFW      |                            |                |        |
| 5/12/2016| 5.6                        | 8.2            | 1.5    |
| 6/04/2016| 1.3                        | 14.0           | 10.5   |
| 6/03/2016| 0.6                        | 8.4            | 13.1   |
| 7/05/2016| 1.4                        | 10.6           | 7.7    |
| 7/17/2016| 4.6                        | 10.7           | 2.3    |
| 7/28/2016| 0.5                        | 6.4            | 11.7   |
| EWR      |                            |                |        |
| 5/06/2016| 1.3                        | 9.7            | 7.5    |
| 7/29/2016| 0.1                        | 7.2            | 91.9   |
| 7/03/2016| 0.6                        | 21.8           | 34.9   |
| 7/21/2016| 7.8                        | 6.6            | 0.8    |

| Other airports (Median) | 5.1 | 8.7 | 1.9 | 1.9 |
## Extrapolation to Core 30 Airports

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ATL</td>
<td>10.9</td>
<td>1.3</td>
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<td>2.6</td>
<td>6.7%</td>
<td></td>
</tr>
<tr>
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<td>10.1</td>
<td>1.2</td>
<td></td>
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<td>2.4</td>
<td>6.2%</td>
<td></td>
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<tr>
<td>JFK</td>
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<td>1.5</td>
<td>1.9</td>
<td>2.9</td>
<td>7.5%</td>
<td></td>
</tr>
<tr>
<td>EWR</td>
<td>8.1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>8.5</td>
<td>8.5</td>
<td>22.3%</td>
</tr>
<tr>
<td>LGA</td>
<td>7.5</td>
<td>0.9</td>
<td></td>
<td>1.9</td>
<td>1.6</td>
<td>4.1%</td>
<td></td>
</tr>
<tr>
<td>PHL</td>
<td>6.4</td>
<td>0.8</td>
<td>1.4</td>
<td>1.9</td>
<td>2.7</td>
<td>7.0%</td>
<td></td>
</tr>
<tr>
<td>DEN</td>
<td>4.7</td>
<td>0.6</td>
<td></td>
<td>1.9</td>
<td>1.1</td>
<td>2.9%</td>
<td></td>
</tr>
<tr>
<td>CLT</td>
<td>4.0</td>
<td>0.5</td>
<td></td>
<td>3.2</td>
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<td>4.6%</td>
<td></td>
</tr>
<tr>
<td>DTW</td>
<td>3.7</td>
<td>0.5</td>
<td></td>
<td>1.9</td>
<td>0.9</td>
<td>2.2%</td>
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</tr>
<tr>
<td>MSP</td>
<td>3.5</td>
<td>0.4</td>
<td></td>
<td>1.9</td>
<td>0.8</td>
<td>2.1%</td>
<td></td>
</tr>
<tr>
<td>IAH</td>
<td>3.1</td>
<td>0.4</td>
<td></td>
<td>1.9</td>
<td>0.7</td>
<td>1.9%</td>
<td></td>
</tr>
<tr>
<td>DFW</td>
<td>3.1</td>
<td>0.4</td>
<td>0.9</td>
<td>6.8</td>
<td>6.4</td>
<td>16.9%</td>
<td></td>
</tr>
<tr>
<td>BOS</td>
<td>3.1</td>
<td>0.4</td>
<td>0.4</td>
<td>1.9</td>
<td>0.8</td>
<td>2.0%</td>
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<tr>
<td>SFO</td>
<td>2.9</td>
<td>0.4</td>
<td></td>
<td>1.9</td>
<td>0.7</td>
<td>1.8%</td>
<td></td>
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<tr>
<td>DCA</td>
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<td></td>
<td>1.9</td>
<td>0.6</td>
<td>1.6%</td>
<td></td>
</tr>
<tr>
<td>LAX</td>
<td>2.6</td>
<td>0.3</td>
<td></td>
<td>1.9</td>
<td>0.6</td>
<td>1.6%</td>
<td></td>
</tr>
<tr>
<td>PHX</td>
<td>2.5</td>
<td>0.3</td>
<td></td>
<td>1.9</td>
<td>0.6</td>
<td>1.5%</td>
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</tr>
<tr>
<td>MIA</td>
<td>1.7</td>
<td>0.2</td>
<td></td>
<td>1.9</td>
<td>0.4</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>LAS</td>
<td>1.6</td>
<td>0.2</td>
<td></td>
<td>1.9</td>
<td>0.4</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>SEA</td>
<td>1.4</td>
<td>0.2</td>
<td></td>
<td>1.9</td>
<td>0.3</td>
<td>0.9%</td>
<td></td>
</tr>
<tr>
<td>IAD</td>
<td>1.3</td>
<td>0.2</td>
<td></td>
<td>1.9</td>
<td>0.3</td>
<td>0.8%</td>
<td></td>
</tr>
<tr>
<td>SLC</td>
<td>1.2</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.3</td>
<td>0.7%</td>
<td></td>
</tr>
<tr>
<td>BWI</td>
<td>1.1</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.3</td>
<td>0.7%</td>
<td></td>
</tr>
<tr>
<td>MDW</td>
<td>0.9</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.2</td>
<td>0.6%</td>
<td></td>
</tr>
<tr>
<td>FLL</td>
<td>0.9</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.2</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>MCO</td>
<td>0.8</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.2</td>
<td>0.5%</td>
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<tr>
<td>SAN</td>
<td>0.7</td>
<td>0.1</td>
<td></td>
<td>1.9</td>
<td>0.2</td>
<td>0.4%</td>
<td></td>
</tr>
</tbody>
</table>
Decrease in Propagated Delays

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

- Two primary benefits
  1) Increased time at gate
     a) Fuel Savings for reduced taxi time
  2) Earlier off time (increase in thru-put)
     a) Airline Direct Operating Costs (ADOC)
     b) Passenger Value of Time (PVT)

- Secondary benefits
  1) Improved compliance with EDCT/APREQs
     a) Captured due to earlier off time impact
  2) Emissions due to reduced fuel burn
Of note is that in some cases the off time could be greater for the ATD-2 scenario due to error (e.g., excess gate hold)
Benefits Inputs

- **Flight Level Data Provided (Departures only)**
  - Scheduled Off Block Time (SOBT)
  - Ready Off Block Time (Ready)
  - Actual Off Block Time (ActOut)
    - Generally in the baseline scenario, Ready = ActOut
  - Runway Off Time (ActOff)
  - Numerous other fields not used in calculation

- **Summary level data for arrivals**
  - Average Taxi In time
Benefits Calculations

Due to potential shifts in Out and Off times, need to avoid double counting:
Define: $F_r$ as $$/fuel burn rate during taxi
$A$ as ADOC/min
$P$ as PVT/min
$C_i$ as Cost of surface trajectory

$$C_i = \{\min(t_{off}^0, t_{off}^i) - t_{out}^i\} \times F_r + (t_{off}^i - t_{off}^0) \times (A + P)$$

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

$$B_i = C_0 - C_i$$
Economic Values

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

Value per hour as used in the TFDM analysis

<table>
<thead>
<tr>
<th>Airport</th>
<th>Fuel ($/hr)</th>
<th>PVT ($/hr)</th>
<th>ADOC ($/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT</td>
<td>$605.28</td>
<td>$3,844.69</td>
<td>$1,748.68</td>
</tr>
<tr>
<td>DFW</td>
<td>$645.45</td>
<td>$4,318.48</td>
<td>$1,865.14</td>
</tr>
<tr>
<td>EWR</td>
<td>$638.15</td>
<td>$4,220.87</td>
<td>$1,844.03</td>
</tr>
</tbody>
</table>
Extrapolation to Full Year

- Simulation Date selection is based on frequency of occurrence of "similar" days
  - This will be used as a first-order approximation methodology

- Second-Order variable will be taxi-out delay as highly correlated with the dominant benefit mechanisms

- Benefits:
  - 1 June is similar to 11.6% of the days compared days (112). Benefits for all similar days is thus \( 112 \times 11.6\% \times \text{Benefits(1 Jun)} \)
  - Combined with the other days and scaled to 366 operational days
  - Alternate methodology would be to use the modeled dates and extrapolate using taxi-out delay

- These results would then be extended to the NAS using methods described earlier
Cost Analysis

- Examine major cost drivers within the TFDM program

- Apply risk reduction to impact the “high confidence” results
  - Reduce estimation parameter variance
  - Assume a small decrease in the point estimate due to NASA ATD-2 work

- Risk parameter adjustments
  - Reduced the variance parameter within a triangular distribution by 5%
  - Mode decreased by 2.5%
Cost Risk Parameters

- **Major Cost Drivers**
  - Prime Mission Product Application Software
  - Prime Mission Product Platform Integration
  - Prime Mission Product Management

- **Base risk elements**
  - Triangular: min/mode/max

- **SME based estimate of impact**
  - Mode-Min/Max-mode reduced by 5%
  - Mode reduced by 2.5%

- **Only impacts F&E (Capital) budget items. Operations are assumed to be unaffected**
NAS-wide Cost Results

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

- Apply changes to cost & benefits to the base TFDM B/C ratio and NPV metrics

Methodology

- \((B/C)_{\text{TFDM}} = 1.03\), gets adjusted via
  - \((B/C)_{\text{ATD2}} = (B_{\text{TFDM}} \times B_{\text{ATD2}}\%)/(C_{\text{TFDM}} \times C_{\text{ATD2}}\%)\) is the adjusted 20\(^{th}\) percentile Benefits to Cost ratio

- No change in schedule assumed

- \(B_{\text{ATD2}}\% = 1.77\); \((B/C)_{\text{ATD2}}\) \(\text{ATD2}\% = 0.965\)

- \((B/C)_{\text{ATD2}} = 1.77/0.965 \times 1.03 = 1.89\)

- NPV is calculated similarly and changes from
  - $17M to nearly $500 M (PV$)

Large improvement in ROI metrics
CONCLUSIONS, LESSONS LEARNED, AND FUTURE WORK
Conclusions

- ATD-2 offers significant taxi-out time savings benefits at congested airports in the NAS, without having negative impact on taxi-in times, OFF time performance and airport throughput

- Annual total of 3.5 million minutes of reduced taxi-time and nearly 400K minutes of early off times (delay savings) at CLT, EWR, and DFW

- $2.6 Billion in monetary benefits nationwide due to significant reduction in delay as well as gate hold time

- ATD-2 benefits significantly outweigh the implementation costs, NPV increased from $17M to $500M (PV$)

- Incorporation of ATD-2 into the FAA’s TFDM system significantly improves the B/C ratio of the TFDM program from 1.03 to 1.89
Lessons Learned

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

- Simulation based assessments to evaluate ATD-2 enhancement alternatives for
  - ATD-2 spacing algorithms, especially for parallel dependent runways
  - Managing uncertainty in taxi-out times
  - Prioritization rules changes
  - Hierarchical multi-airport scheduling

- Operational data analysis (Benefits computation from operational data)
  - Pre- versus post- implementation comparison for “similar” time-periods
  - Measure other benefits, e.g., ON-time performance, NAS network predictability, throughput

- Simulation based analysis of extending ATD-2 and TBFM type scheduling to multiple Centers and metroplexes, e.g., Northeast Corridor

- Leverage analysis framework for assessing technologies in other NASA research areas
  - Integrated Demand Management (IDM)
  - Increasing Diverse Operations (IDO)
Acknowledgements

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

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

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

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

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

3. Leverage a past simulation study to assess the benefits of adding Phase III Integrated Airspace Scheduling capability, focused on the New York airspace
Sensitivity Test # 1: Pushback at SOBT

All departure flights pushing back exactly at their SOBTs increased the taxi-out times by around 2%, with 6% increase in AMA taxi-out times.
Sensitivity Test 2: ATD-2 Phase II Benefits

**Baseline Simulation**

**Phase I ATD-2 Simulation**
- Fixed 5 min Buffer

**Phase II ATD-2 Simulation**
- Variable Buffer

**Excess Taxi-Out Time (Min)**

- **12:00** to **15:00**
  - Baseline Simulation
  - Phase I Simulation (Fixed 5 min Buffer)
  - Phase II Simulation (Variable Buffer)

**TAXI DELAY BUFFER**
Sensitivity Test 2: ATD-2 Phase II Benefits

Taxi-Out Times

- Phase I ATD-2 With Static Buffer
- Phase II ATD-2 With Variable Buffer

<table>
<thead>
<tr>
<th>Component</th>
<th>Phase I Time</th>
<th>Phase II Time</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>15.94</td>
<td>13.85</td>
<td>13%</td>
</tr>
<tr>
<td>AMA</td>
<td>4.93</td>
<td>4.22</td>
<td>14%</td>
</tr>
<tr>
<td>Ramp</td>
<td>11.01</td>
<td>9.63</td>
<td>13%</td>
</tr>
<tr>
<td>Total Taxi-Out</td>
<td>18.91</td>
<td>18.78</td>
<td>1%</td>
</tr>
</tbody>
</table>

Time + Gate Hold
Hierarchical Scheduling Concept of Operations*

Sensitivity Test 3: Phase III Airspace Scheduling Benefits*

Simulation-based Benefits Estimates

Annual Benefits

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi-Out Duration</td>
<td>8,300 hours</td>
</tr>
<tr>
<td>Total Delay in Metroplex</td>
<td>11,400 hours</td>
</tr>
<tr>
<td>Fuel</td>
<td>1.4 million gallons</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>$ 4.2 million</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>$ 26 million</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>13,500 metric tons</td>
</tr>
<tr>
<td>Passenger Time</td>
<td>34,000 person-days</td>
</tr>
<tr>
<td>Passenger Time @ $30/hr</td>
<td>$ 25 million</td>
</tr>
<tr>
<td>Passenger Time NAS-wide</td>
<td>$ 36 million</td>
</tr>
</tbody>
</table>

*Leverages past study:
Top Delay Locations (Baseline North Flow)
Top Delay Locations (ATD-2 North Flow)
Top Delay Locations
(Baseline South Flow)
Top Delay Locations (ATD-2 South Flow)
SOSS Problems

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

ASPM dates (10/12/2015 to 09/21/2016), n = 347

WITI dates, n = 317

APREQ index dates, n = 273

MIT index dates, n = 123

Candidate simulation dates, n = 112

MIT Indices (n = 123)

APREQ Indices (n = 273)

Sort, Rank n = 1 .. 123
0 ≤ Pr(Ri) ≤ 1

Sort, Rank n = 1 .. 273
0 ≤ Pr(Ri) ≤ 1

Ri = Rank( Pr_i,j) (n = 112)

Tercile Grouping
Departure Queue Length Comparison

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

06/01/2016 Simulation

Queue Length Difference

ATD-2 Queue Shorter

ATD-2 Queue Longer
Taxi Out Time VS Departure Queue Length

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

06/01/2016 Simulation

ATD-2 Queue Shorter

ATD-2 Queue Longer

ATD-2 Taxi Shorter

ATD-2 Taxi Longer
Forecast – Future Years

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

\[
Delay \approx Delay_{Base} \times \frac{(1 - \frac{\sigma}{\mu})}{(1 - \frac{\sigma^2}{\mu^2})}
\]

where

- \(\sigma\) is the demand and \(\mu\) is the capacity. Capacity generally is assumed constant, or adjusted only if “known” changes
Modeling of ATD-2 Benefit Mechanisms

### ATD-2 FUNCTIONS

Efficiency

- Surface departure metering advisories
  - Push
  - Gate Hold

Predictability

- More predictable gate-to-gate flight durations
- More predictable surface movements

### CAUSAL LINKS

- Demand throttling
- Reduced surface congestion
- Reduced surface movement times
- Better demand predictions
- Better/fewer TMIs

### POTENTIAL BENEFITS

- Reduced pilot/controller workload
- Less delay, fuel, and emissions
- Increased NAS throughput
- Better airline resource management
- Shorter airline-scheduled block times

**Dashed lines Indicate longer-term benefit mechanisms**

- ATD-2 Surface Tactical Scheduler model uses more accurate surface movement estimates to compute ERUTs and to back-compute TOBTs
- ATD-2 gate delays lead to lesser congestion in the ramp and movement areas, therefore more predictable taxi-out times
Modeling of ATD-2 Benefit Mechanisms

- **Gate advisories to help meet TMI takeoff restrictions**
  - APREQ
  - EDCT
  - MIT

- **More delay absorbed at gate for meeting TMIs**
- **Less delay, fuel, and emissions**
- **Less airspace maneuvering to meet TMIs**
  - Better TMI
  - Reduced
  - Increased airspace throughput

- **Less airspace through**

- **CAUSAL LINKS**

- **POTENTIAL BENEFITS**

- **TMI COMPLIANCE**

- APREQ and EDCT compliance monitoring is modeled: If departure flight reaches runway outside the APREQ/EDCT window, we apply a simple rescheduling model: 5 minute coordination delay for baseline operations; 3 minutes for ATD-2 operations.
Validation: Runway and Gate Counts

Sim #2: 05/06/2016, North Flow, 1600-2100 UTC
Validation: Taxi-Out Time

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

**TASK 1: IDENTIFY OPERATIONAL SHORTFALLS AND BENEFIT MECHANISMS**
- Stakeholder interviews, Data Analysis, Causality Analysis

**TASK 3: SIMULATION PLATFORM DEVELOPMENT**
- Airport surface (SOSS) and airspace (AOSS) subsystems
- Baseline operations (current-day procedures)
- ATD-2 Operations (Tactical Scheduling Algorithm, Data Exchange)

**TASK 2: SITE SELECTION**
- Operational data analysis for Core 30 FAA airports

**TASK 4.1: EXPERIMENT DESIGN**
- Sim day selection from annualization perspective
- Sim scenario selection per selected day

**SURFACE-AIRSPACE SIMULATION PLATFORM**
- Airport and airspace transit
- ATD-2 departure metering, current-day and ATD-2 AREQ/EDCT procedures

**SELECTED SIMULATION DAYS/SCENARIOS**
- Realistic gate, runway, dep fix, meter arc allocations
- Frequency of occurrence of similar days over the entire year

**TASK 4.2: CONDUCT SIMULATION EXPERIMENTS**
- Multiple sims per scenario to select appropriate taxi delay buffer

**PER AIRPORT PER SCENARIO BENEFIT ESTIMATES**
**Technical Task (Cont.)**

**TASK 5: BENEFITS ANALYSIS & EXTRAPOLATION**
- **EXTRAPOLATE TO NAS**
- **QUANTIFY/MONETIZE BENEFITS**
- **EXTRAPOLATE TO ANNUAL SCALE**

**PER AIRPORT PER SCENARIO BENEFIT ESTIMATES**

**SELECTED SIMULATION DAY ANNUAL FREQUENCIES**

**TASK 6: COST ANALYSIS**
- **USE FAA METHODOLOGY**
- **ESTIMATE COST REDUCTION IN TFDM IMPLEMENTATION DUE TO RISK MITIGATION**

**ATD-2 NAS-WIDE BENEFIT ESTIMATE**
- **INCREMENT IN TFDM BENEFITS**

**ATD-2 NAS-WIDE COST ESTIMATE**
- **REDUCTION IN TFDM IMPLEMENTATION COST**

**IMPROVED BENEFITS/COSTS RATIO**