Airspace Technology Demonstration 2 (ATD-2)

Charlotte – EDC Evaluation & Demonstration (CEED)
Human-In-The-Loop

Results Briefing
to ATD-2 FAA Partners

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Team

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ATD-2 Goal, Objectives and Outcomes

GOAL ATD-2 will improve the predictability and the operational efficiency of the air traffic system in metroplex environments through the enhancement, development and integration of the nation's most advanced and sophisticated arrival, departure and surface prediction, scheduling and management systems.

- **Predictability**: Reduce the variability of aircraft movement times
- **Efficiency**: Manage and schedule operations to reduce aircraft movement times and fuel burn by leveraging enhanced predictability
- **Throughput**: Maintain or improve metroplex airspace throughput

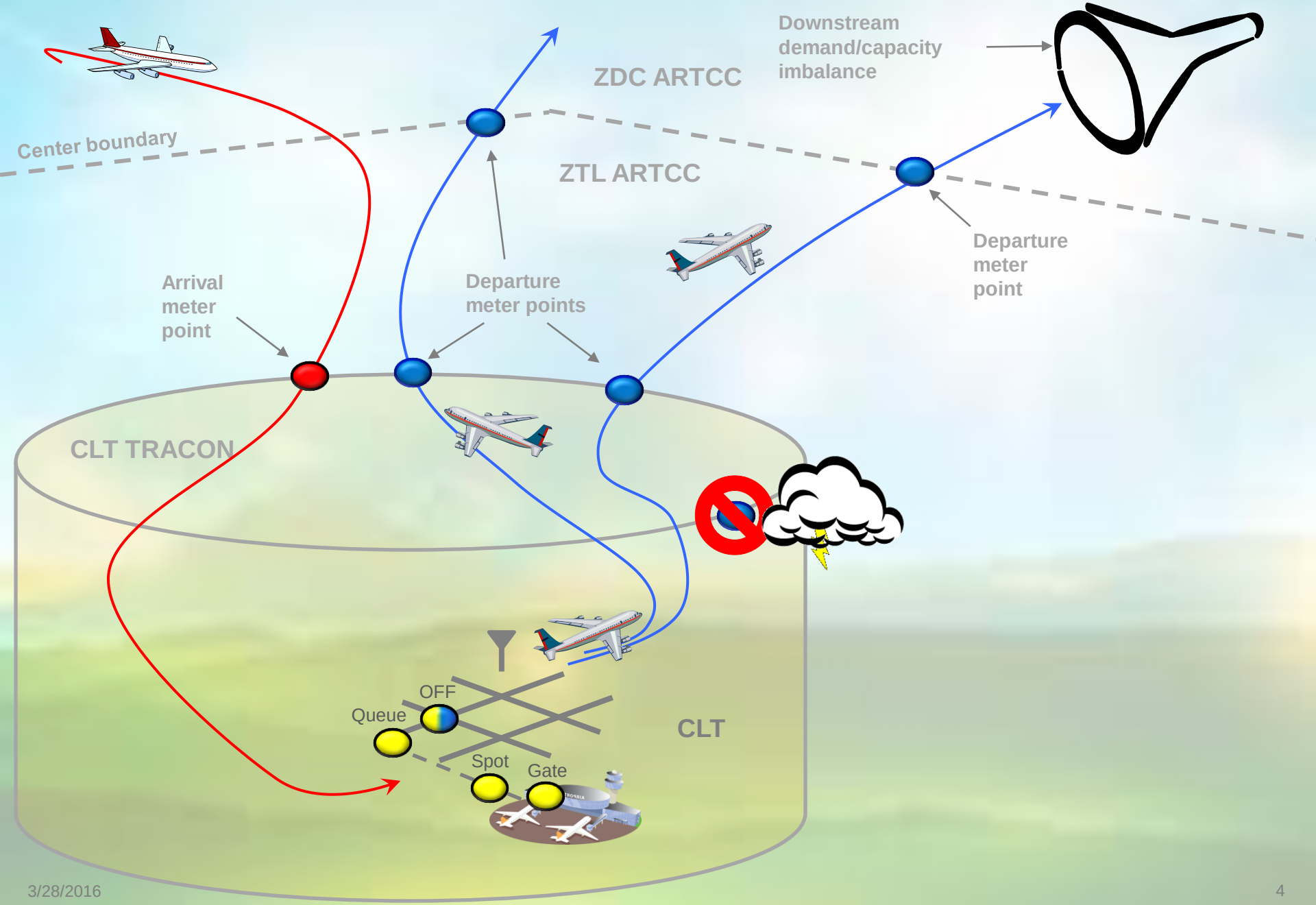
OBJECTIVES

- Demonstrate **improved aircraft arrival, departure and surface movement predictability and efficiency** by integrating evolving collaborative decision-making capabilities with state-of-the-art air traffic management scheduling technologies.
- Enable effective use of collaborative decision making by demonstrating efficiency gains through enhanced two-way sharing of prediction and scheduling information.
- Demonstrate Integrated Arrival/Departure/Surface (IADS) traffic management for metroplex environments.

OUTCOMES

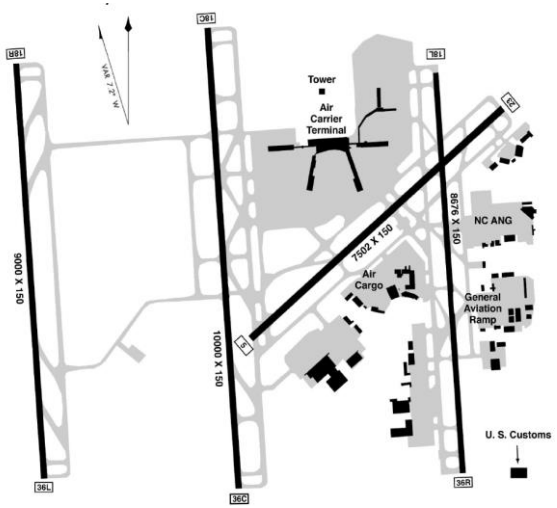
- Demonstrate the ATD-2 technologies in an operationally relevant environment
- Quantify the benefits, performance, acceptability, and limitations of the ATD-2 technology
- Transfer an integrated set of technology to the FAA and airlines, airports, and suppliers.

Operational Environment for 2017 ATD-2



ATD-2 Field Demonstration Site

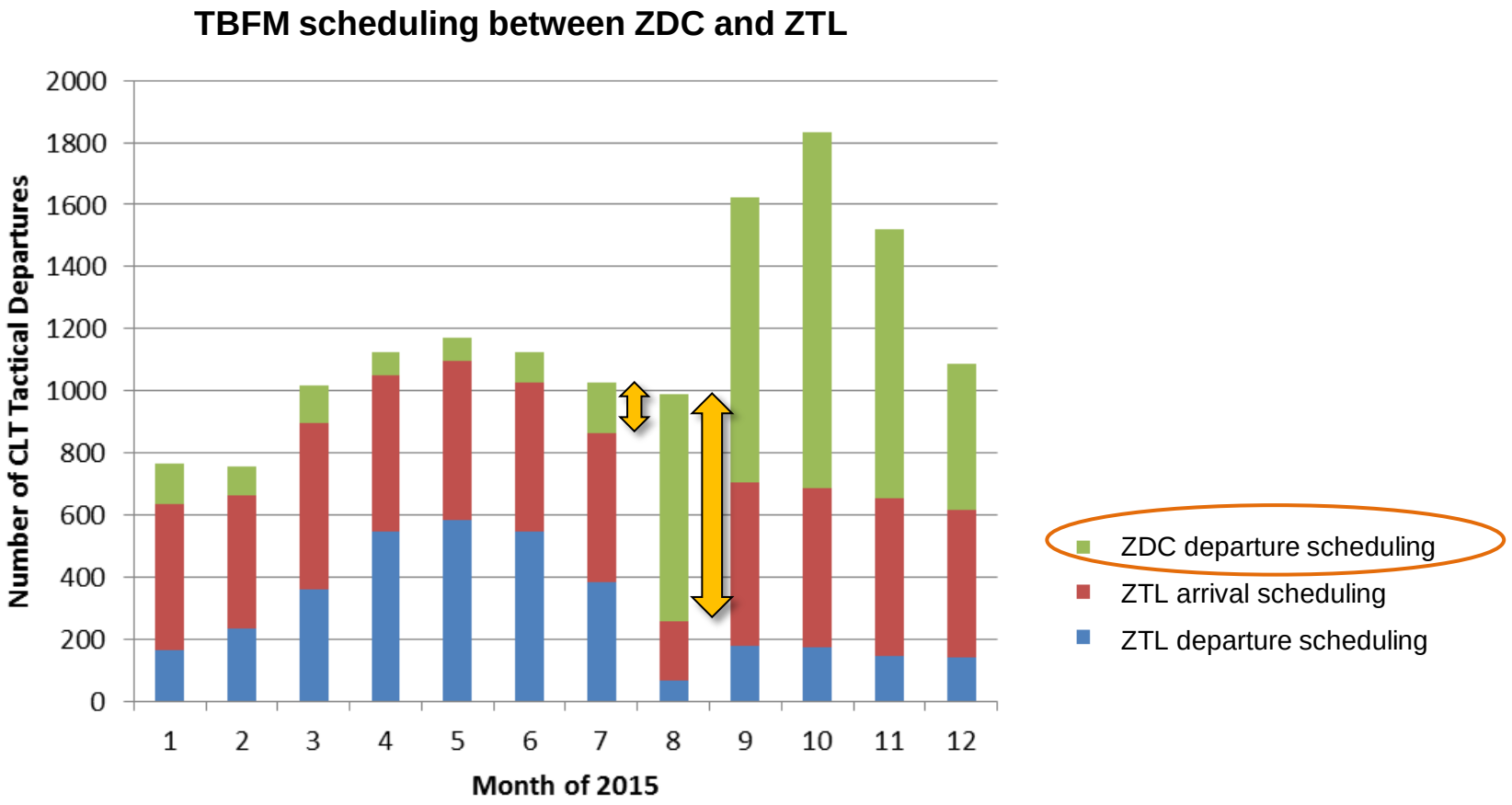
- Charlotte Douglas International Airport (CLT)
  - Large volume of operation (~1500 ac/day)
  - Subject to surface delays due to tactical Traffic Management Initiatives (TMI) issued by Atlanta and Washington Centers:
    - MIT
    - Call For Release (CFR)



Number of Tactical Departures scheduled with TBFM in 2015

Before August 2015, most CFR were scheduled by ZTL. Since then, about 60% of CFR have been scheduled by ZDC. The number of departures also increased, suggesting an increased need of ZDC to control the CLT releases.

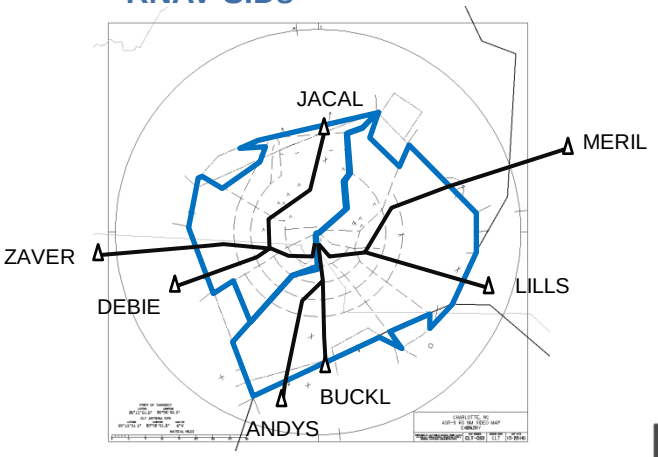
All the flights ZDC scheduled flew the MERIL departure route.



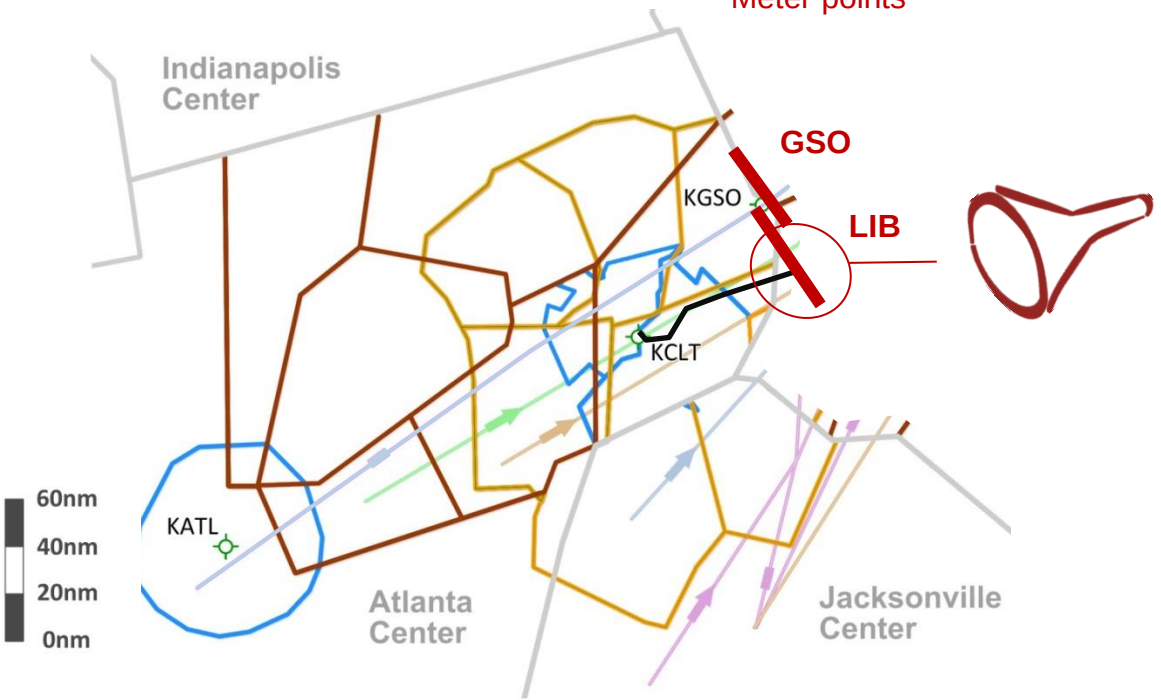
Test Airspace and ZTL Meter Points

- Atlanta Center schedules ATL and CLT departures to LIB and GSO meter points:
- Overhead and ATL streams fly through:
  - GSO Meter Point: PHL, IAD, BWI, DCA, EWR, TEB, BOS
  - LIB Meter Point: LGA, HPN, JFK
- All CLT departures fly through LIB
- Thus, overhead traffic and CLT departures to LGA and JFK are scheduled at LIB
- Thus, overhead traffic and CLT departures to EWR are not scheduled to the same meter points (GSO vs LIB)

CLT TRACON Departure sectors and RNAV SIDs

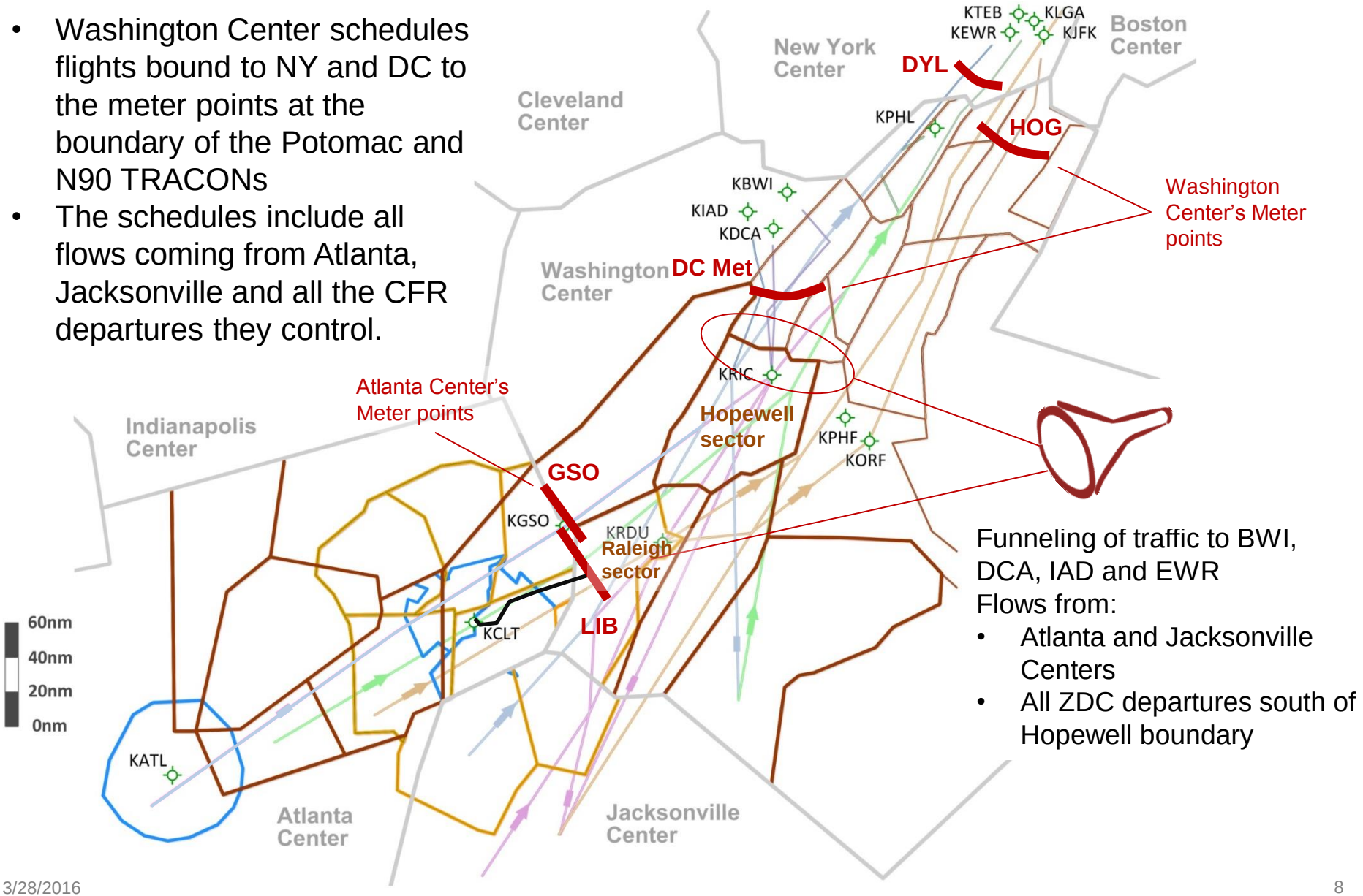


Atlanta Center's Meter points



Test Airspace and ZDC Meter Points

- Washington Center schedules flights bound to NY and DC to the meter points at the boundary of the Potomac and N90 TRACONs
- The schedules include all flows coming from Atlanta, Jacksonville and all the CFR departures they control.



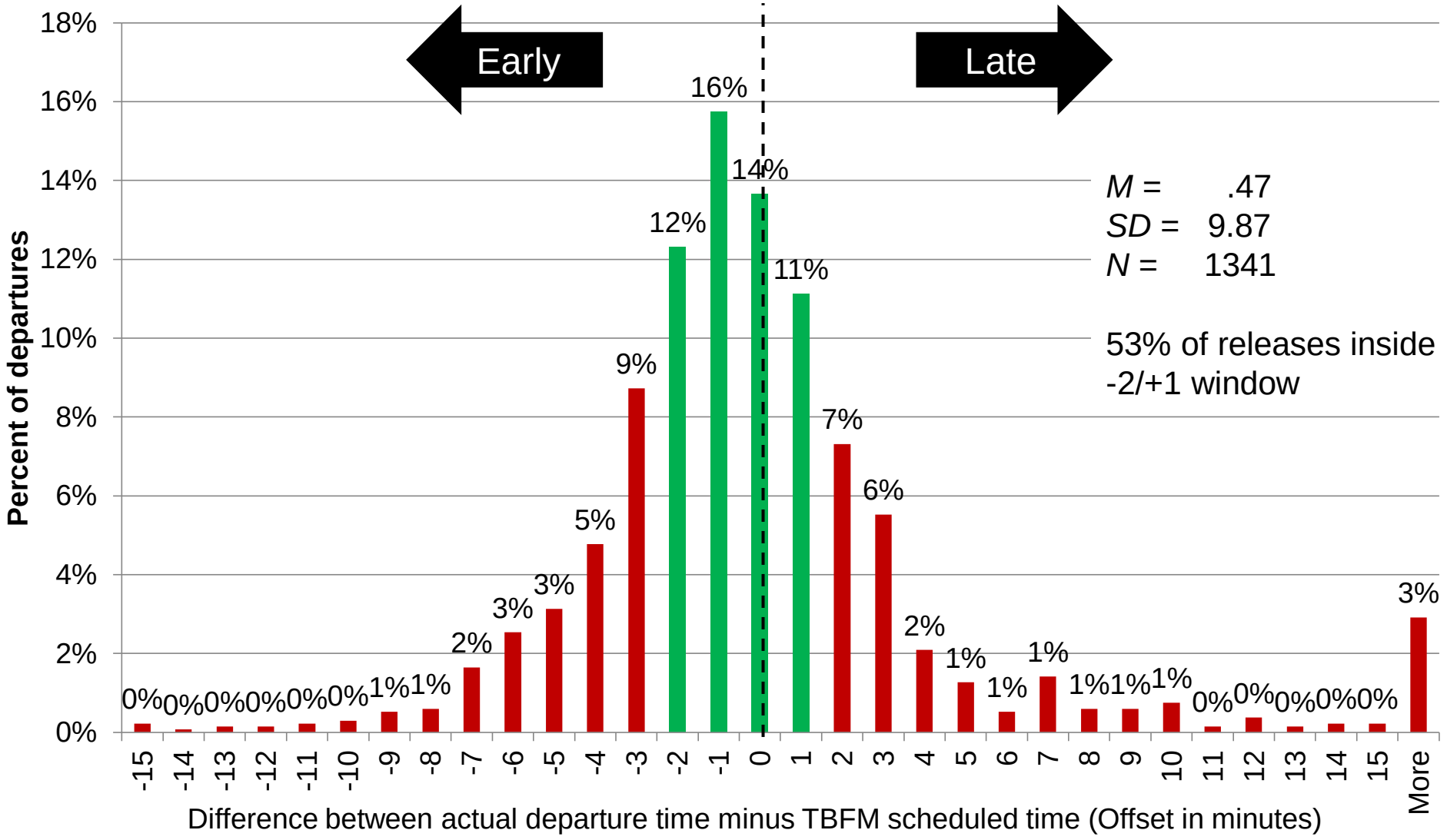
Funneling of traffic to BWI, DCA, IAD and EWR
Flows from:

- Atlanta and Jacksonville Centers
- All ZDC departures south of Hopewell boundary

Summary of Problems

- Lack of predictability and efficiency
  - Independent scheduling at GSO and LIB by ZTL
  - Lack of coordinated schedules across ZTL and ZDC creating conflicting demand
  - Unreliable high demand from ZTL and ZJX making demand capacity imbalances difficult to manage
  - Low takeoff compliance of CLT departure times create additional uncertainties and inefficiencies
  - Likely inefficient flow insertions beyond ZTL's meter point (LIB)
  - No compliance to assigned times at meter points

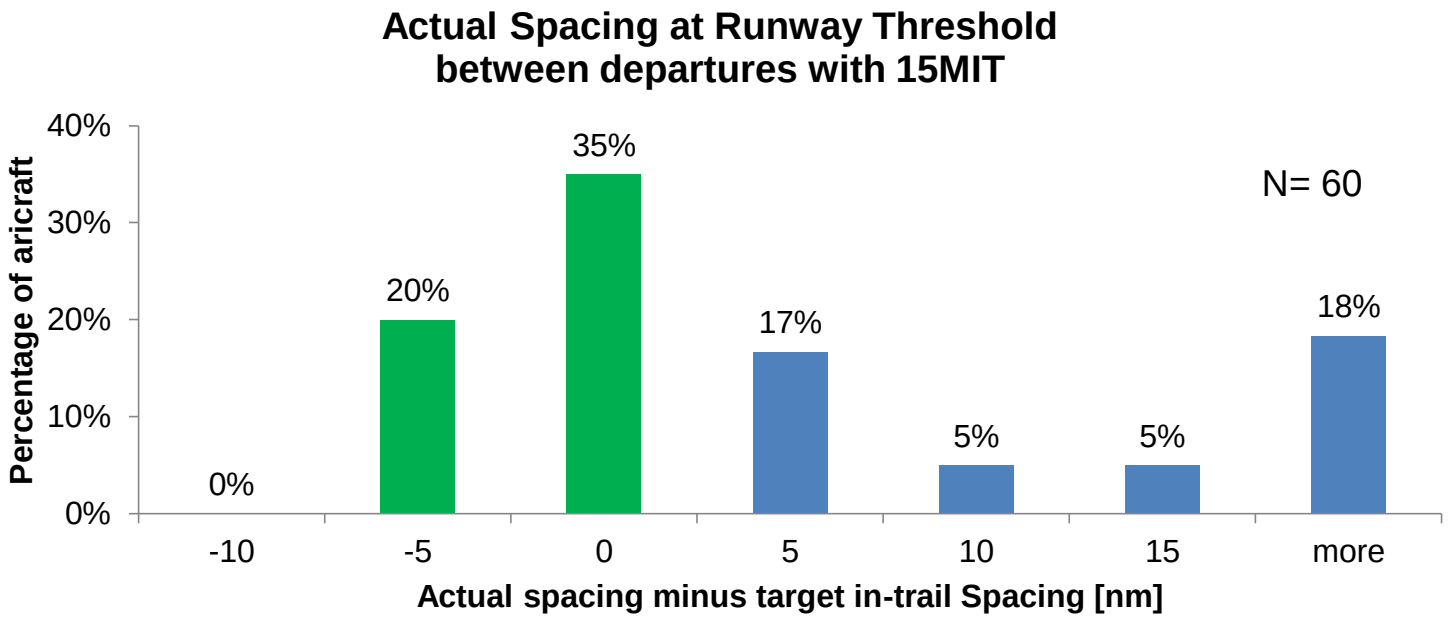
Departure Compliance with Scheduled Takeoff Time (MERIL Departures only during 2014)



Data source: NTX OTTR EDC output, 12 months in 2014

Compliance to 15MIT Restrictions at the Departure Runway

- Tower aims to deliver departures with 15 or 10 MIT to support the TRACON's delivery of MIT at its boundary
- Analyzed 5 days of departures from RWY18L with 15MIT restrictions (April 2015)
- 50% of departures with desired spacing



Objectives for HITL

1. Establish simulation environment for ATD-2 airspace operations
2. Simulate current-day departure operations with current technology
3. Assess current Traffic Management Initiatives on departure flows and control operations
4. Assess impact of compliance of departure release times on stream insertion in en route airspace

Research Questions

- What are the advantages and disadvantages of ZDC versus ZTL managing CFR for the MERIL departures?
- What are the impact of CFR and MIT on delay, throughput, and effectiveness of stream insertion?
- What is the impact of takeoff compliance on stream insertion?

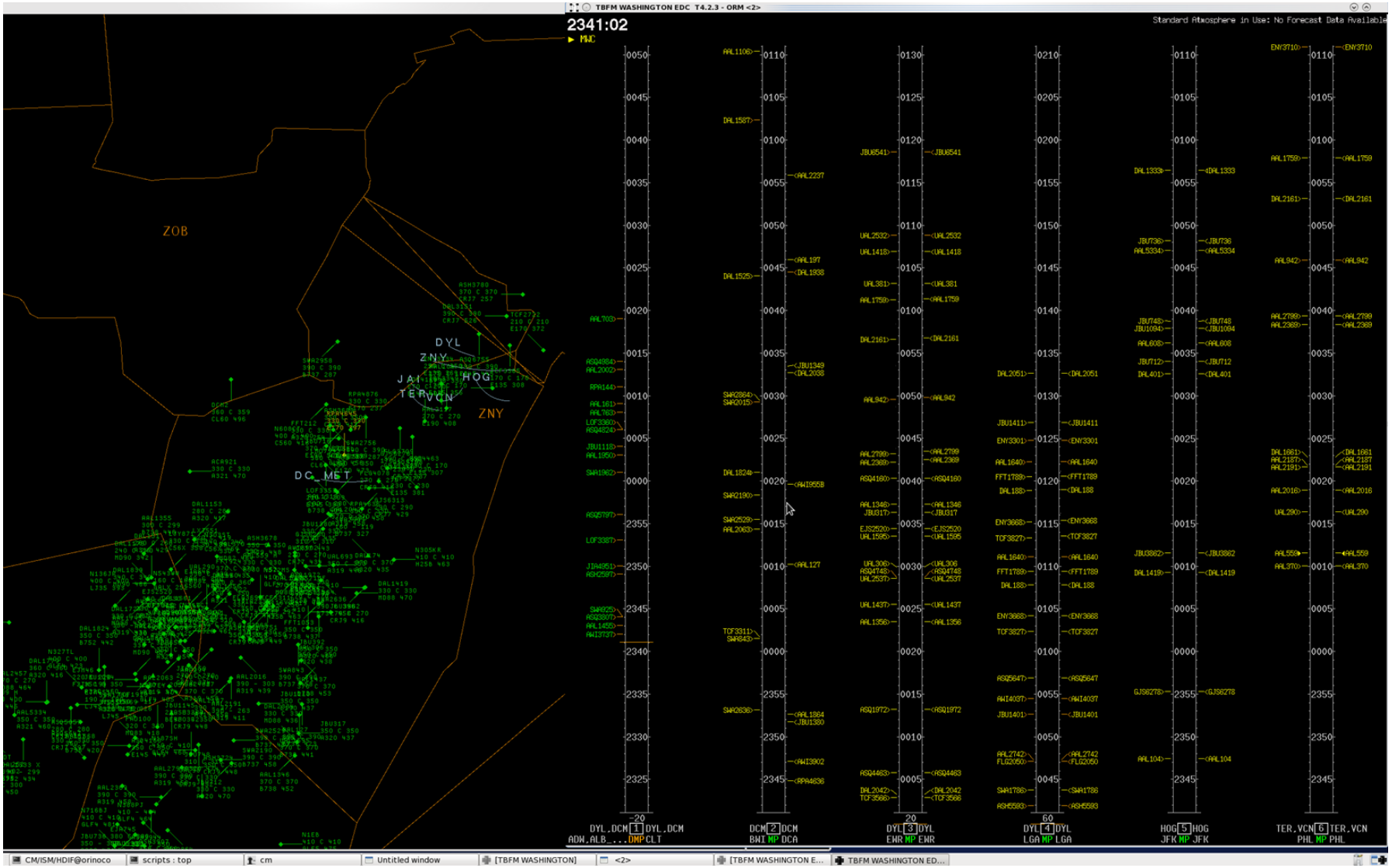
Experiment

Technologies

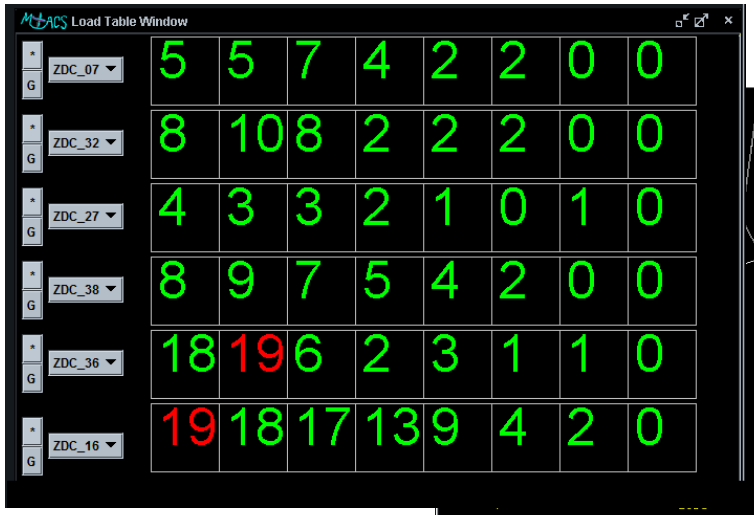
- TBFM 4.2.3 En route Departure Capability (EDC)
  - ZTL & ZDC adaptations
  - Version from the field as of August 2015
  - Both adaptations running at the same time

- MACS tools functions
  - Traffic Situation Display (TSD)
  - Flow Evaluation Area (FEA)
  - Monitor Alert Parameter (MAP)
  - User Request and Evaluation Tool (URET)

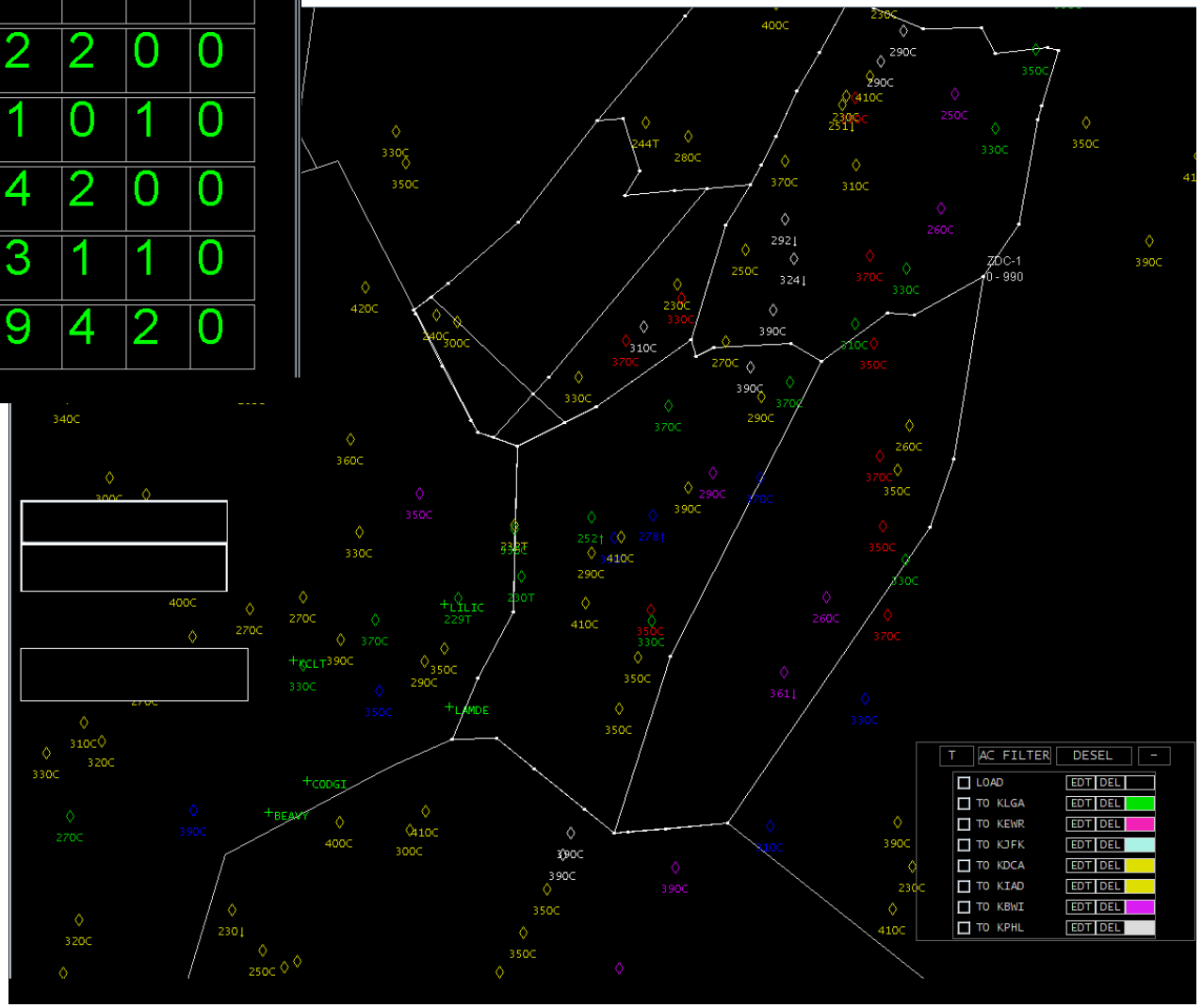
Example of ZDC TBFM PGUI and TGUI



Example Traffic in ZDC

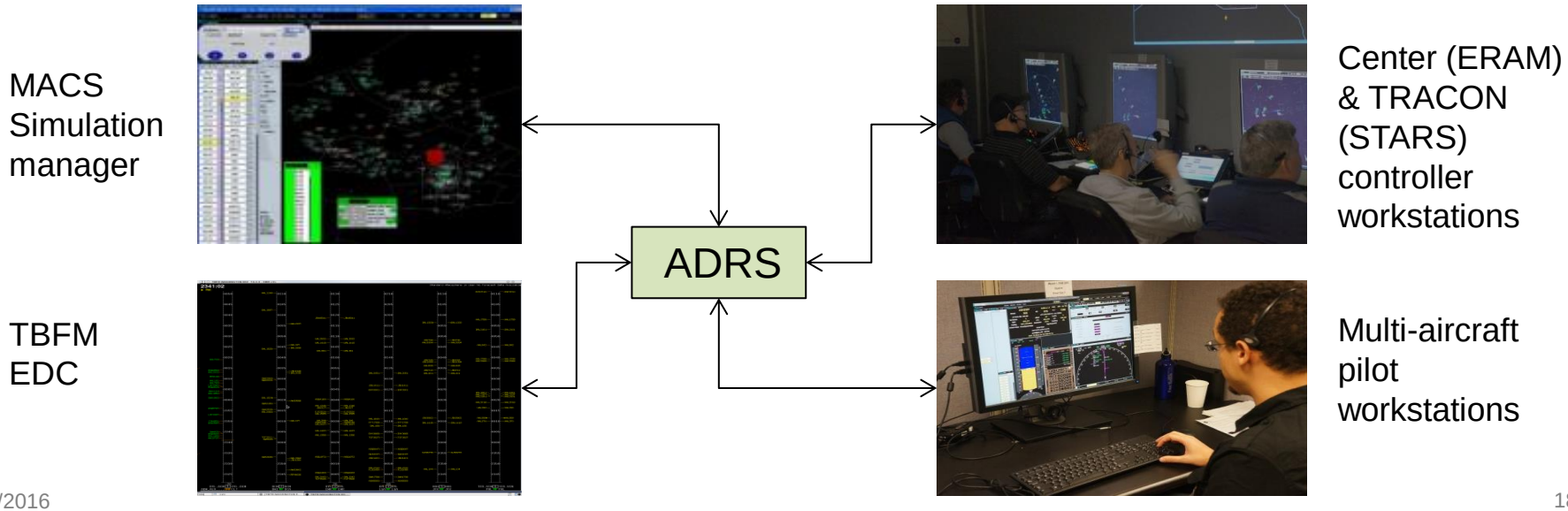


MACS Monitor Alert Parameter



Resources

- MACS and ADRS simulation architecture
- Software: Multi-Aircraft Control System (MACS)
  - Controllers: STARS & ERAM radar display
  - Pseudo-pilots: Multi-aircraft control stations
- Hardware:
  - Radar Scope sized monitors
  - En route and TRACON keyboards, mice, and foot pedals
  - VoiP voice comm system for Air-Ground and Ground-Ground communication



Participants

14 controllers with experience in the test position

9 Test sectors
- 1 CLT TRACON
- 3 ZTL en route controllers (1 low, 2 highs)
- 5 ZDC en route controllers (1 low, 4 highs)

3 Ghost (non-test) sectors
- 1 Ghost en route arrival controller (2 lows)
- 1 Ghost TRACON arrival (feeder + final)
- 1 Ghost for ZJX (all sectors)

3 TMC/FLM
- 1 STMC from ZDC
- 1 TMC from ZTL
- 1 ZDC supervisor

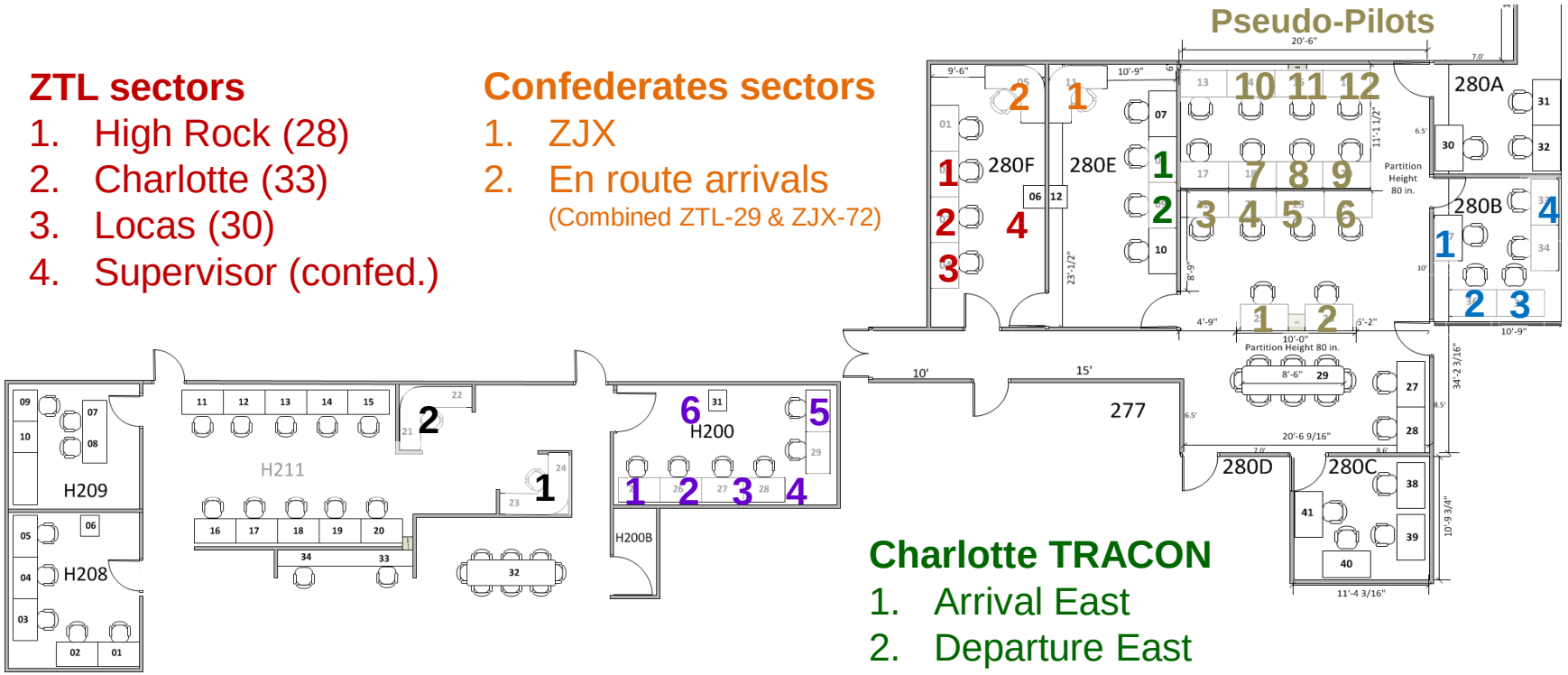
- Averages: 28 years of experience and 5 years of retirement

12 Pseudo-pilots (SJSU Aviation students), 1 for each sector

Airspace Operation Laboratory Layout

ZTL sectors
1. High Rock (28)
2. Charlotte (33)
3. Locas (30)
4. Supervisor (confed.)

Confederates sectors
1. ZJX
2. En route arrivals
(Combined ZTL-29 & ZJX-72)



Charlotte TRACON
1. Arrival East
2. Departure East

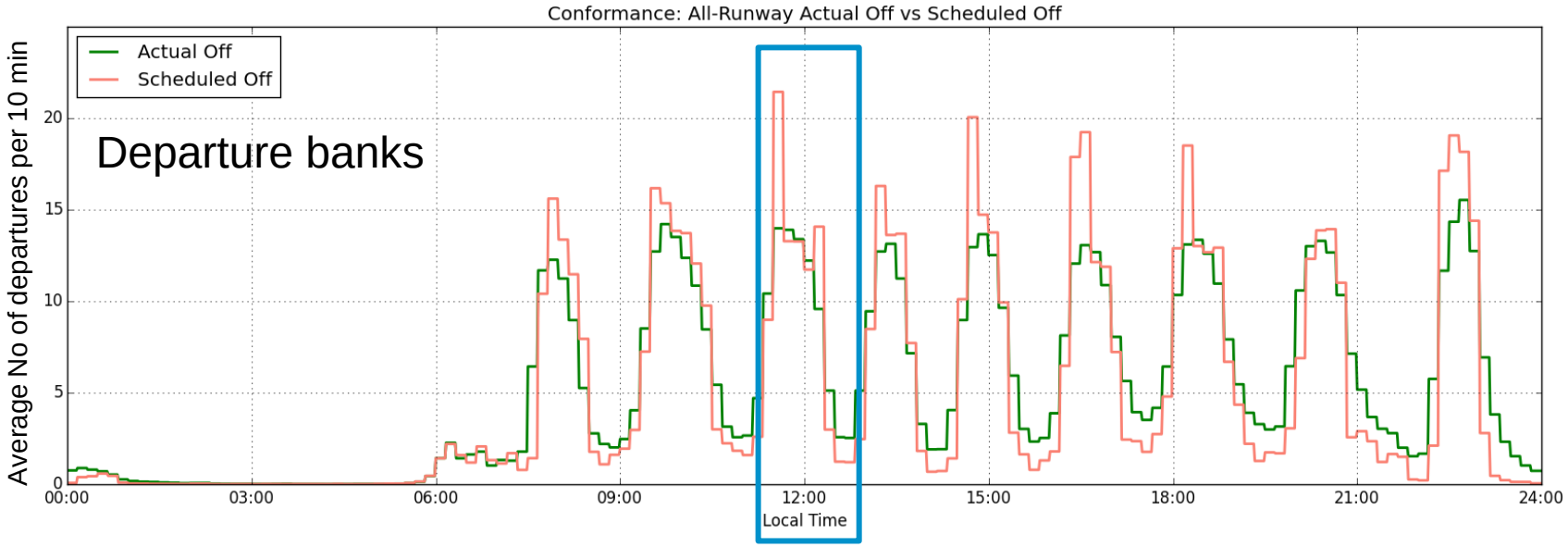
TMC Stations
1. ZDC TGUIs
2. ZTL TGUIs

ZDC sectors
1. Hopewell (16)
2. Raleigh (36)
3. Liberty (27)
4. Gordonsville (32) & Wahoo (07)
5. Tar River (38) & Dixon (09)
6. Supervisor

Simulation Control Room
1. Researcher
2. CLT release Confederate
3. TBFM ZDC Main
4. TBFM ZTL Main

Scenario Design – CLT Traffic

- 90min runs: Departure push + climb-out phase
- CLT East side, south configuration
  - Flights and fleet mix matching current operations
  - 29 Departures from RWY 18L
    - Heavy departure push
    - 19 MERIL departures + 10 other departures
  - 27 Arrivals to RWY 23



Scenario Design – En Route traffic

- Scenario with 480+ aircraft
- Realistic traffic with excess demand, which justified TMI restrictions
  - Excess demand for key sectors and meter point capacity
  - Based on current ZDC STMC's input

- Sector capacity
  - Target demand: 25-30 peak traffic load into key sectors (RDU & HPW)
  - Capacity: MAP value of 17 (official) + acceptable margin of 2

Scenario Design – Basis for Restrictions

- Downstream flow restrictions for EWR, LGA and JFK
  - Demand:
    - 30 aircraft /hour to EWR & LGA
    - <30 aircraft /hr to PHL (16), JFK (20), BWI (17), DCA (19), IAD (26)
  - TBFM stream class values determined by the TMC:
    - EWR, LGA: Needed 15, but entered 20 in the stream class
    - JFK: Needed 15, entered 20 in the stream class
    - BWI, DCA, IAD: Needed 15, entered 18 in the stream class

- Restrictions:
  - 15MIT for CLT dep at LIB
  - 30MIT for overhead from ZTL and ZJX
  - 20MIT sector to sector in ZDC
  - CFR for CLT, GSO, RDU, RIC for departures to EWR, LGA and JFK

- Exploratory run:
  - Same as above, except
  - 15MIT sector to sector and
  - 15 at MP for EWR, LGA and JFK

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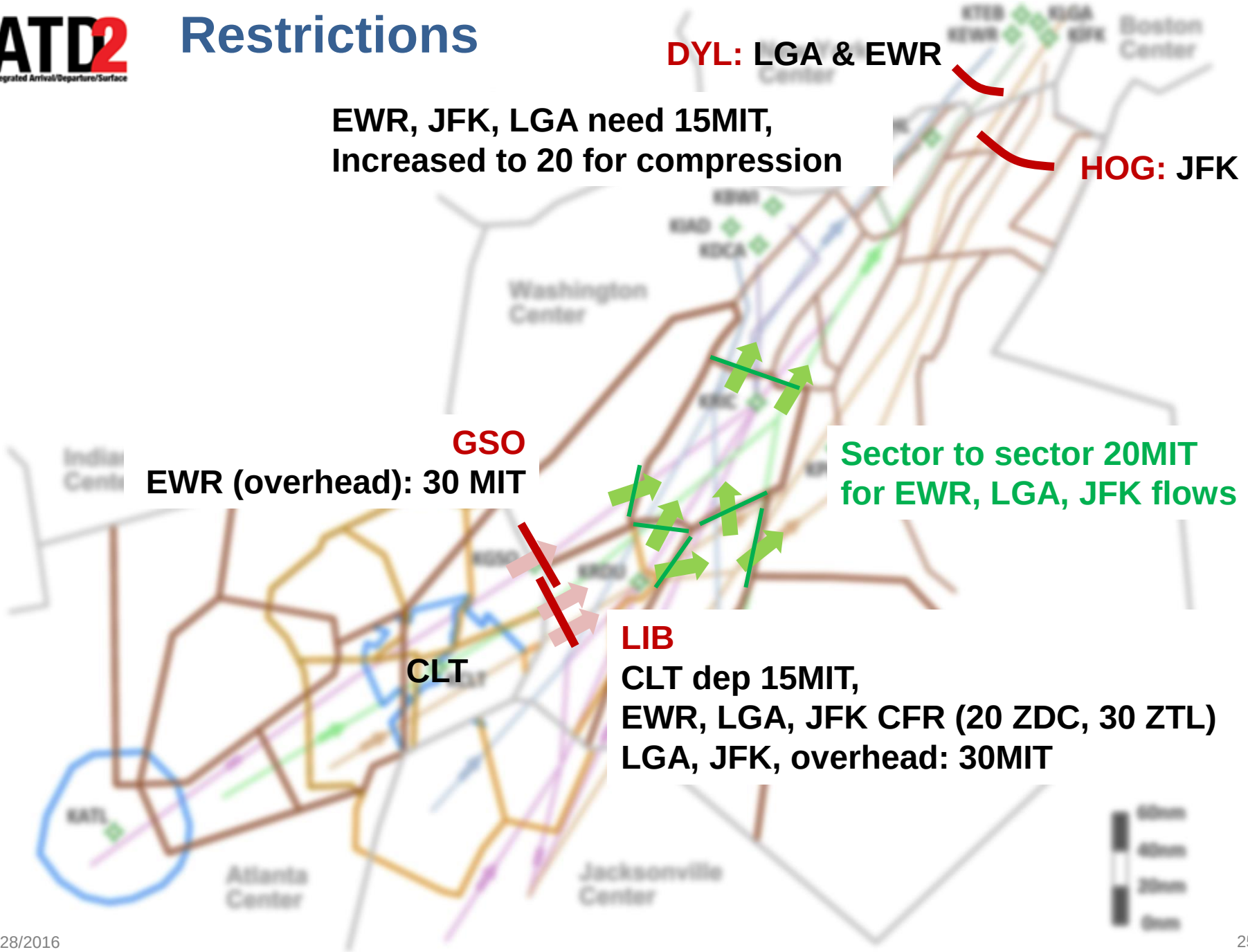
Restrictions



Experimental Plan Overview

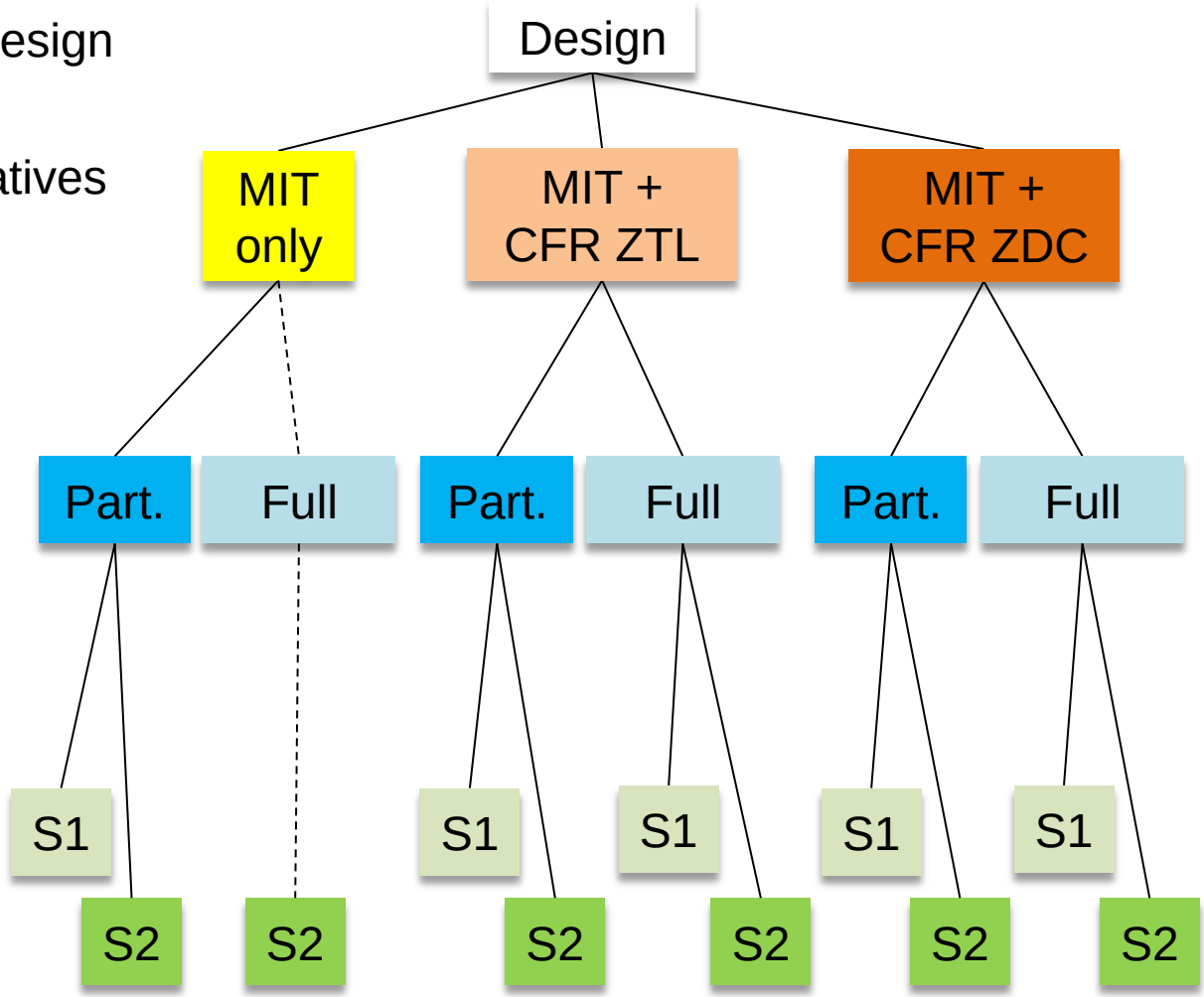
- Compare 3 current-day Traffic Management Initiatives imposed on CLT
  - MIT for all MERIL departures
  - MIT for all MERIL departures, except CFR by ZTL for flights to EWR, LGA, JFK
  - MIT for all MERIL departures, except CFR by ZDC for flights to EWR, LGA, JFK

- Compare 2 Takeoff Compliance Level to Controlled TakeOff Times
  - Partial current-day compliance (53%)
  - Full compliance (100%)

- Evaluate surface and airborne delays, throughput, airborne compliance, control efficiency, workload, safety, acceptability.

Experimental Design

- 3 x 2 x 2 Mixed Factorial Design
- 3 Traffic Management Initiatives
  - MIT Only
  - MIT + CFR by ZTL
  - MIT + CFR by ZDC
- 2 Compliance levels
  - Partial (Current day)
  - Full compliance
- 2 scenarios of equal demand and complexity



Data Collection Design Matrix

4 practice runs
10 data collection runs
1 extra run

Order of runs counter-balanced

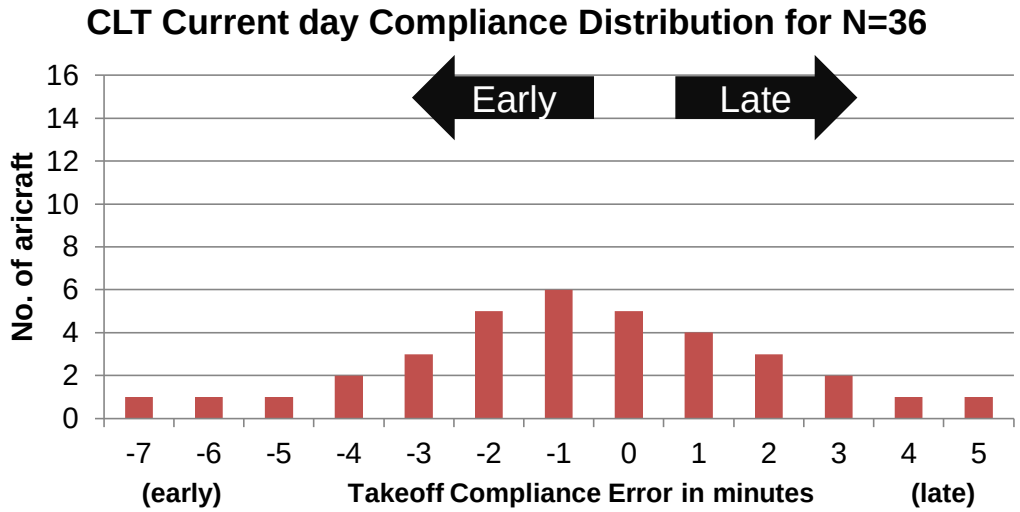
Days	Runs	Compliance	TMI	Scenario
Monday	Practice	Partial	MIT	P2
	Practice	Partial	ZDC CFR	P1
Tuesday	Practice	Partial	ZTL CFR	P2
	Practice	Full	MIT	P2
	1	Full	ZTL CFR	2
	2	Partial	ZDC CFR	1
Wednesday	3	Partial	MIT	2
	4	Partial	ZTL CFR	1
	5	Full	ZDC CFR	2
	6	Partial	ZTL CFR	2
Thursday	7	Full	ZDC CFR	1
	8	Partial	MIT	1
	9	Partial	ZDC CFR	2
	10	Full	ZTL CFR	2
Friday	Re-run1	Full	ZTL CFR	2
	Re-run3	Partial	MIT	2
	Exploratory	Full 15 MIT at MP + Sector to sector	ZDC CFR	1

Practice Runs

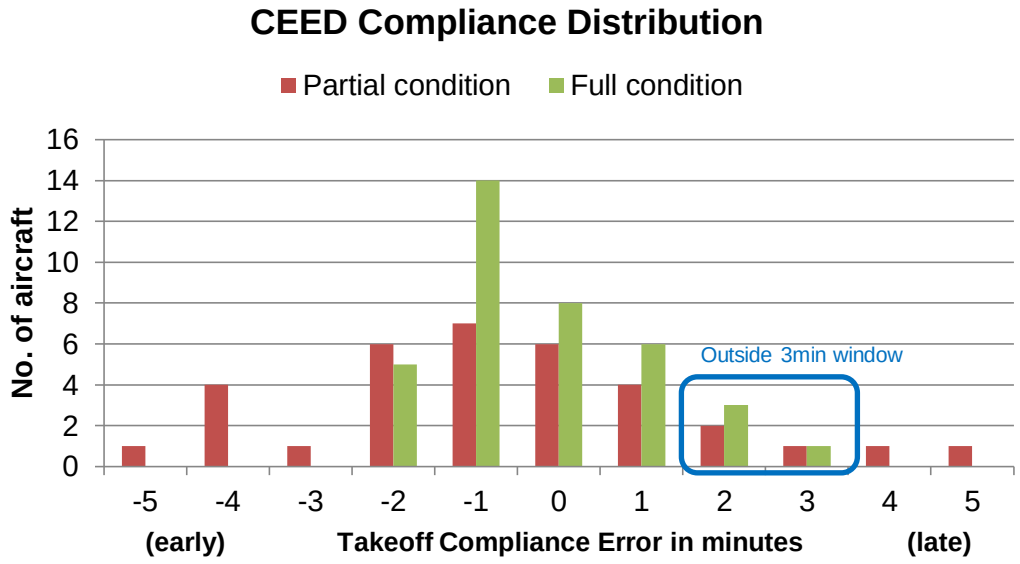
Data collection Runs

Bonus Run

Distribution of Compliance Error



	Current day
N	36
Mean	-.53
Std. Deviation	2.97



	Partial condition	Full condition
N	36	37
Mean	-.58	-.24
Std. Deviation	2.27	1.28

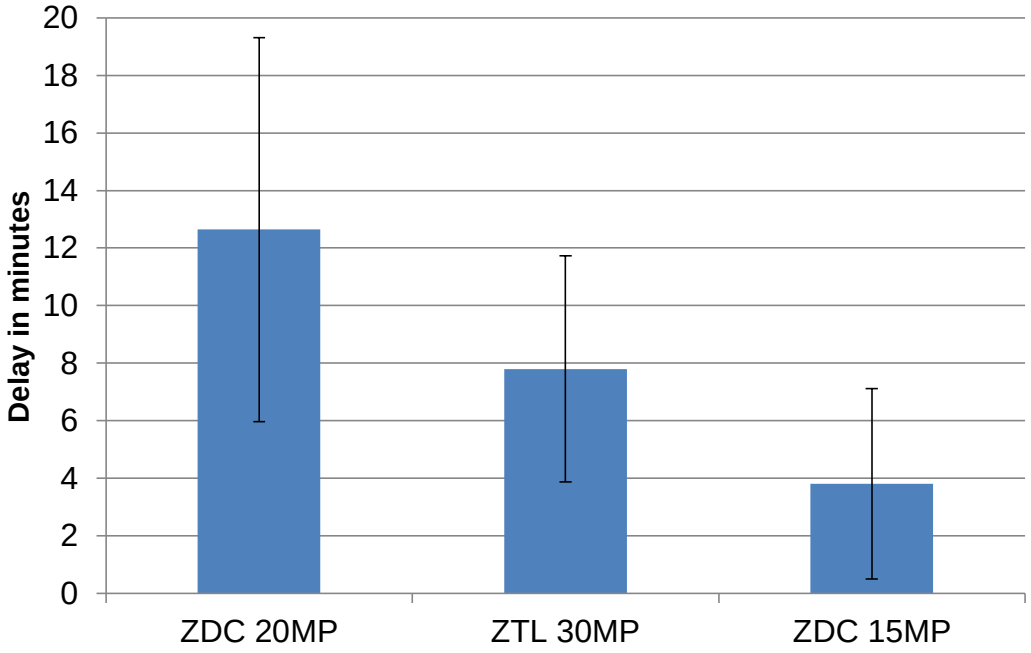
Limitations of the HITL

- The results may not reflect reality
  - Traffic scenarios were modified from actual radar track data
  - Participants were retired from the facility
- The results are the product of a small sample from the operations
  - The data is limited to the scenario and the duration of the simulation

Results

ZDC CFR tended to generate higher tactical delays

- When ZDC scheduled with 20 MIT at the MP, it tended to generate the highest amount of delay due to higher demand at the meter points compared to ZTL.
- When ZTL scheduled with 30MIT at the MP) it tended to generate a high amount of delays, because of higher in-trail restrictions.
- The lack of delays for the departures to EWR in the ZTL condition also contributes to a lower average mean in ZTL.
- When ZDC scheduled with 15MIT at the MP (exploratory run), it tended to generate the least amount of delay, due to lower in-trail restriction and thus accommodating more departures.

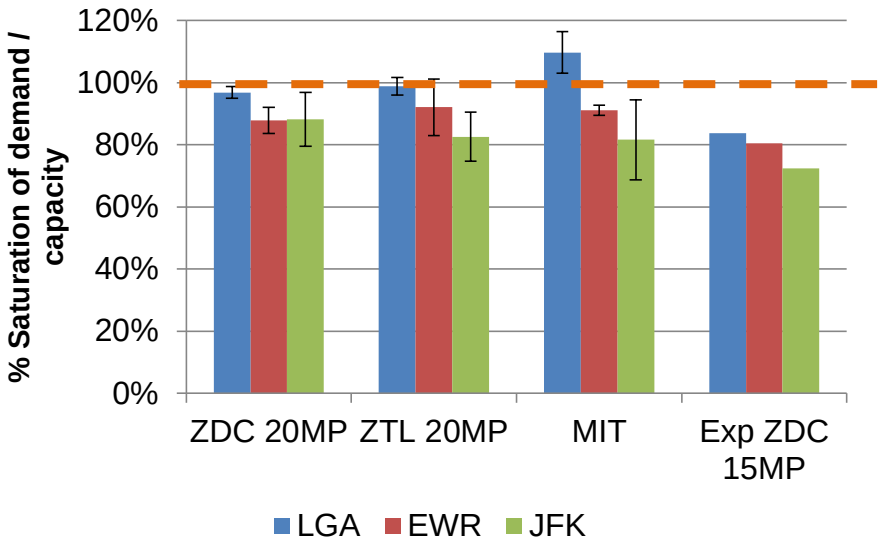


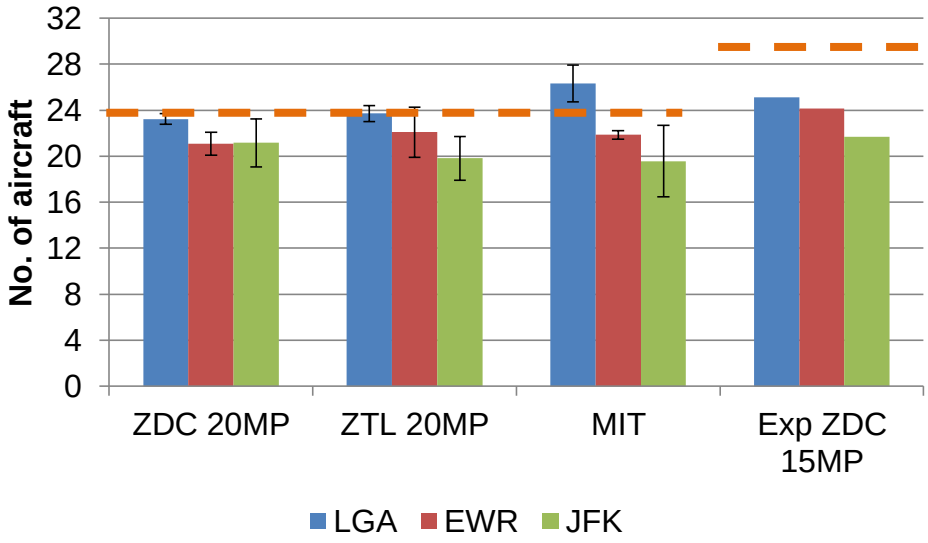
TBFM $F(2,82)= 1.56$, p .21

Impact of TMI Manipulations on Demand Capacity / Balance

- The average demand reached near saturation of capacity in all TMI conditions, except in the Exploratory run (Exp ZDC 15MP).
- In the MIT runs, the demand to LGA flow at the ZDC MP exceeded capacity. This is because there were more CLT departures to LGA than those to EWR and JFK. In the MIT, none of the departure to LGA were not delayed on the surface.
- In the exploratory run, when the capacity increased from 24 aircraft per hour to 30 aircraft per hour (due to the decreased minimum spacing at the MP between aircraft) the saturation dropped by about 10%, and throughput was slightly higher than in the two other CFR conditions.

20MIT at MP = ~2.5min spacing between STAs = ~24 aircraft per hour
15MIT at MP = 2min spacing between STAs = ~ 30 aircraft per hour





TMI $F(3,21) = 3.85$, $p = .024$
Destination $F(2,21) = 12.30$, $p = .000$

Composition of flows with CFR

Flow	Total	CLT departures	Internal departures (GSO, RDU, RIC)	Overhead traffic
LGA	25-28	7	5-6	13-16
EWR	21-22	4	1-2	16
JFK	20	2	1	17

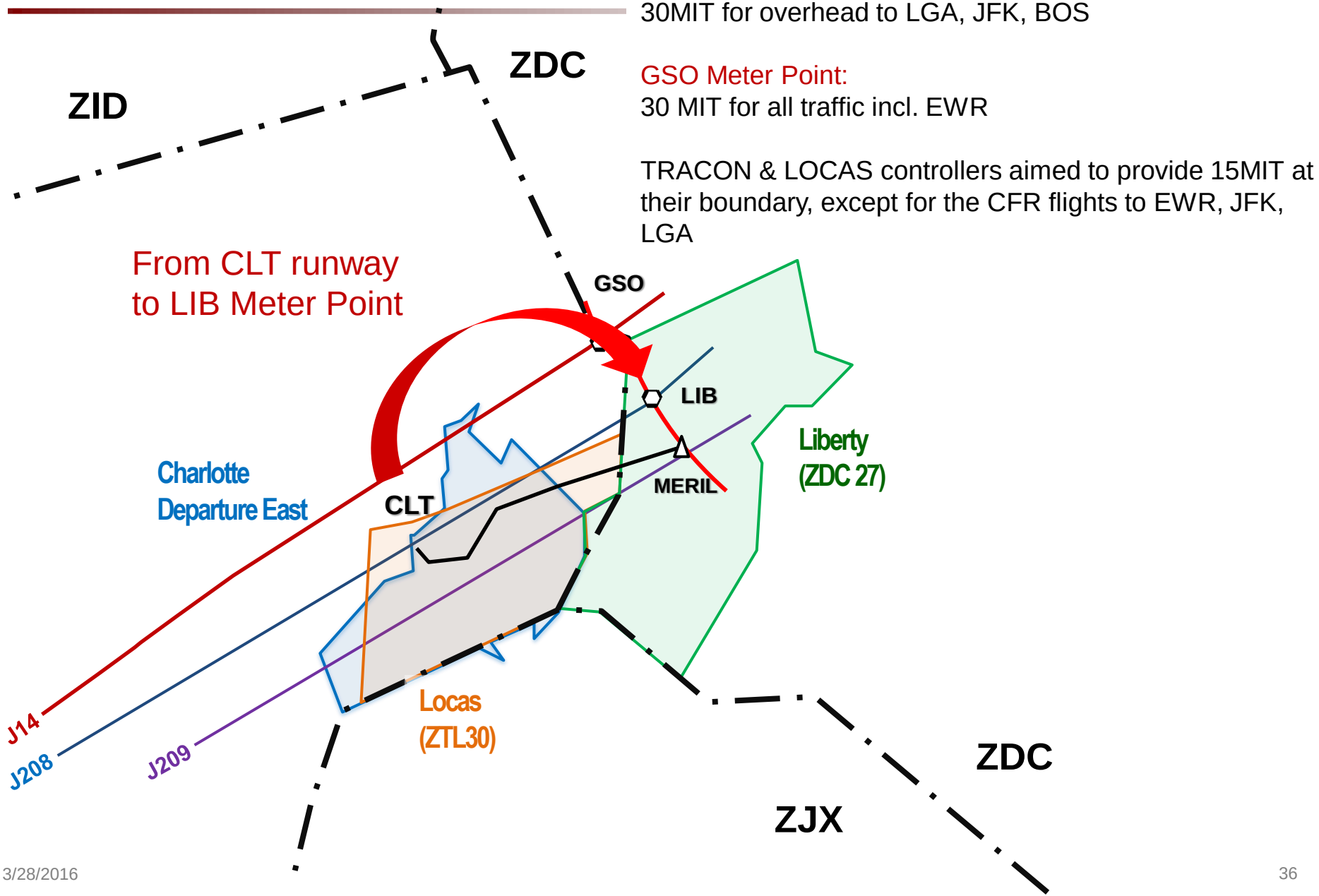
Flights to LIB

Flights to LIB

LIB Meter Point:
15MIT for CLT departures, except CFR
CFR for departure to EWR, LG and JFK
30MIT for overhead to LGA, JFK, BOS

GSO Meter Point:
30 MIT for all traffic incl. EWR

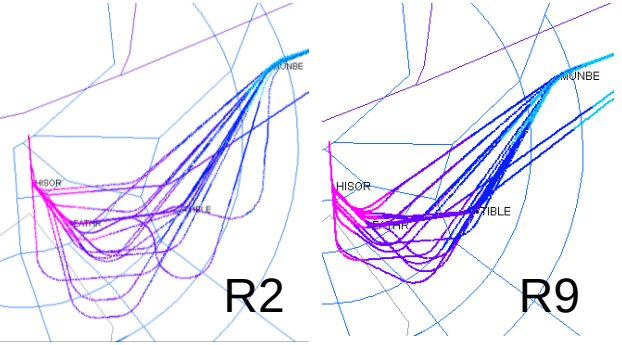
TRACON & LOCAS controllers aimed to provide 15MIT at their boundary, except for the CFR flights to EWR, JFK, LGA



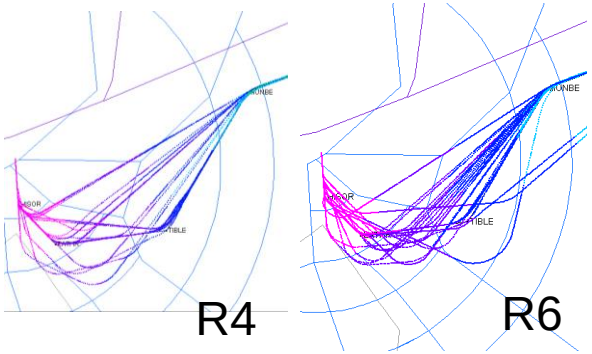
Visual of Key Tracks in the TRACON

- Vectoring seemed more extensive during the MIT runs than in the ZTL and ZDC conditions.
- Partial CFR compliance did not seem to increase vectoring in the TRACON airspace.
- Unfortunately, the TRACON controller mistakenly treated the exploratory run as MIT run and spaced all departures with 15MIT (confirmed). This resulted in heavier vectoring than expected.

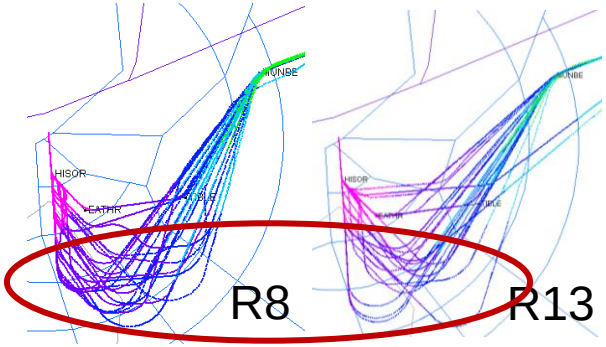
ZDC 20MP
Partial Compliance



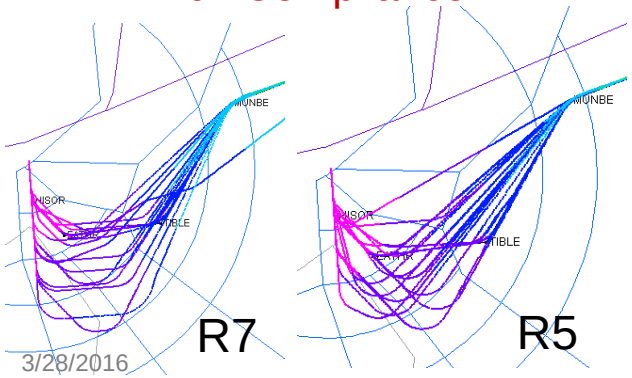
ZTL 30MP
Partial Compliance



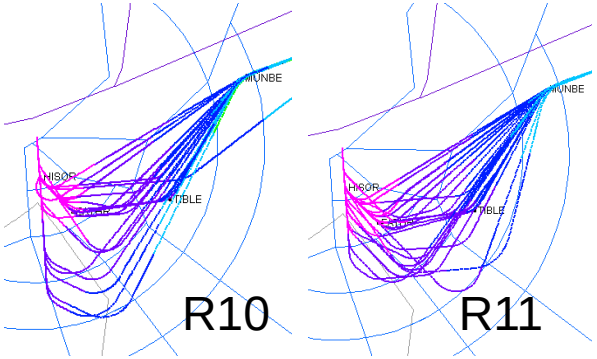
MIT
Partial Compliance



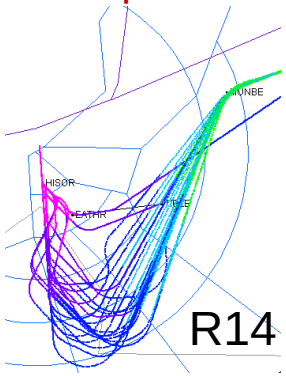
ZDC 20MP
Full Compliance



ZTL 30MP
Full Compliance

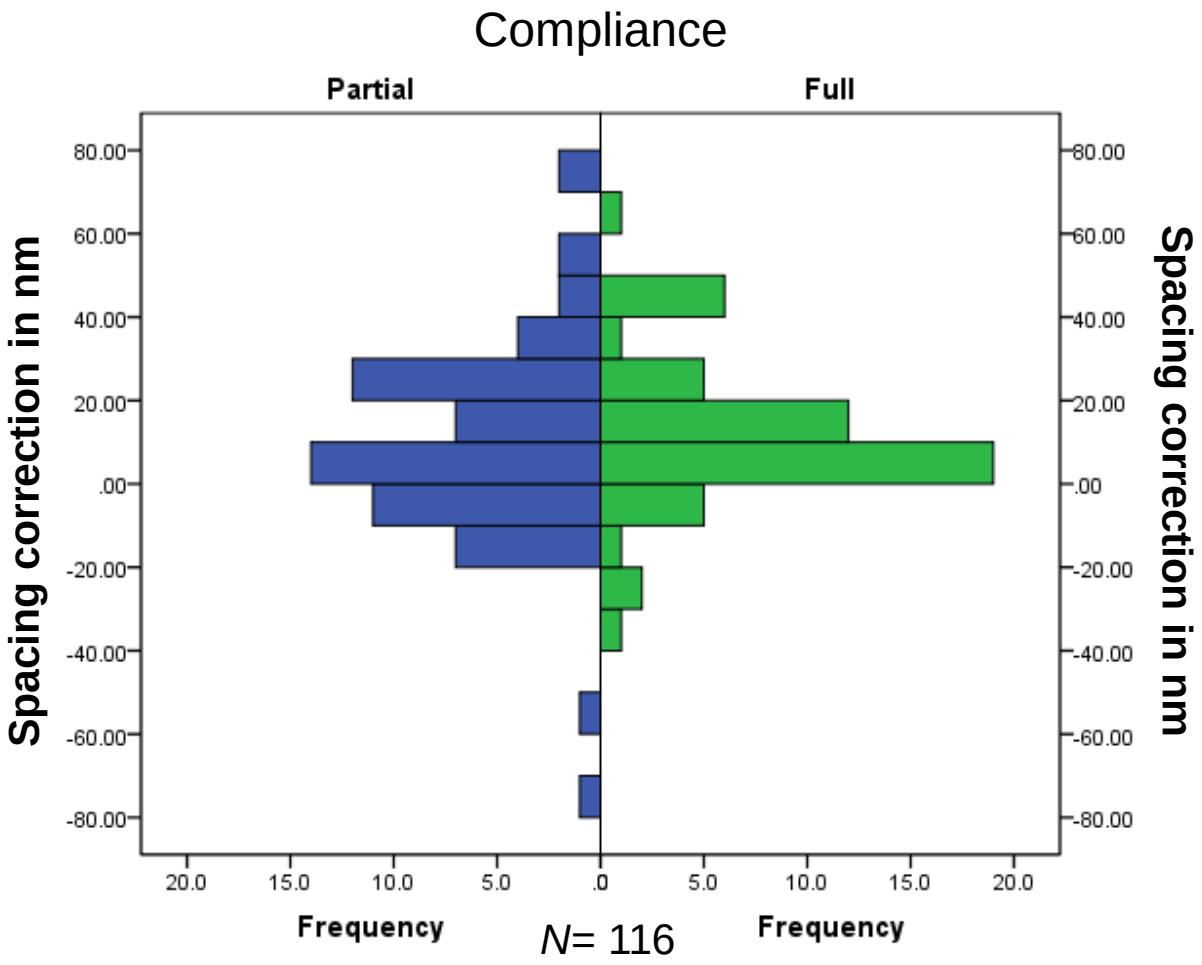


Expl. ZDC full
Compliance



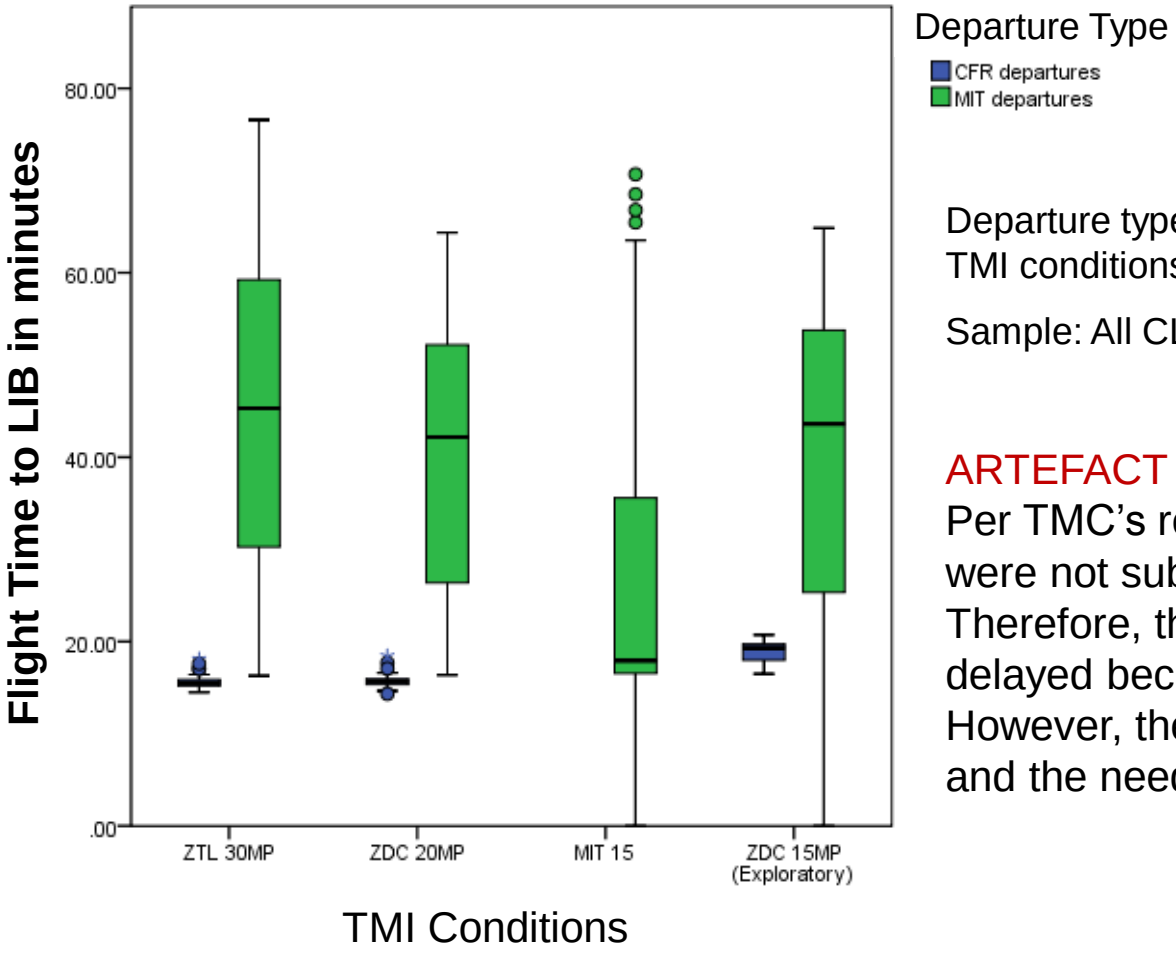
Partial Compliance Increased Workload to Space MIT Departures Compared to the Full Compliance Condition

There was a larger variance of spacing corrections in the partial compliance condition compared to the full compliance condition, suggesting a high workload for the TRACON controller.



CFR Flights Reached LIB Faster Than The MIT Flights Did

- Flight times of departures with MIT were twice as large as departures with CFR (in the same run).
- They also ranged more widely.
- This indicates a reduction of workload for the CFR flights for the TRACON controller.
- Note there were no mean differences between the two Compliance conditions (Partial and Full)



Departure type $F(1,245)= 96.11$, p .000
TMI conditions $F(1,245)= 10.46$, p .000

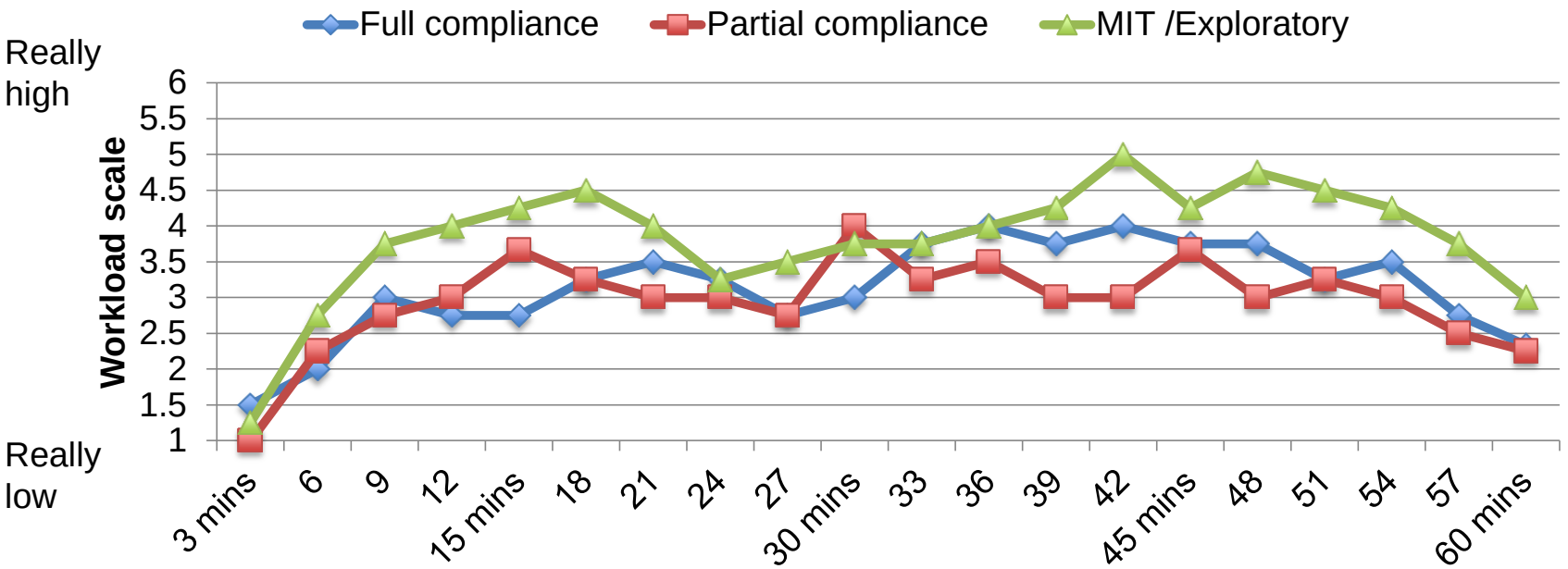
Sample: All CLT dep

ARTEFACT

Per TMC's restrictions, the CFR departures were not subject to an in-trail spacing at LIB. Therefore, they were less likely going to be delayed because of the MIT restrictions. However, the impact of the mix of departures and the need for separation was not known.

The TRACON controller rated workload higher in the MIT conditions

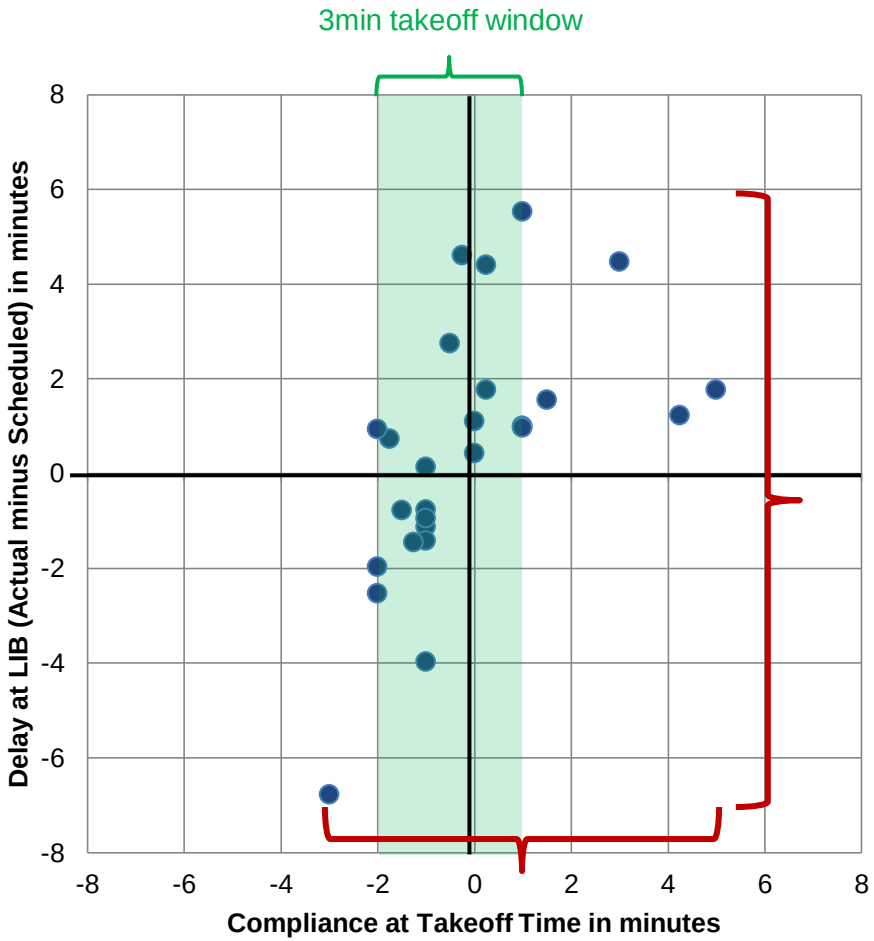
- Workload was self reported by controllers on a 6-point scale every 3minutes during the runs.
- TRACON controller's mean scores in the MIT/Exploratory conditions are significantly higher than the means score in the partial and full compliance conditions



Conditions $F(2,6)= 12.07$, p .022

Takeoff Time Delay at the Runway Seemed to Increase at LIB Meter Point

The variance of delay was larger than the variance of the takeoff compliance error, suggesting a lack of control action to correct the takeoff delay.



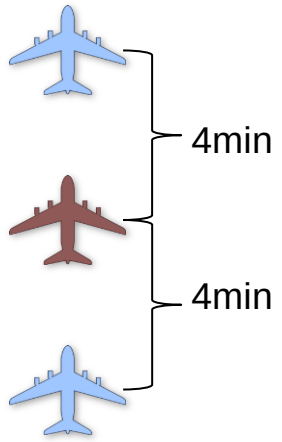
Departure to LGA
$r(28) = .578$, p .002

Very Good Stream Insertion Rate at LIB

- Slots in the overhead stream are bounded by a lead and a trail aircraft.
- Successful stream insertion means the departure is in between the correct lead and trail aircraft at the meter point
- “Hit scheduled slot” means the departure ended up in the slot that was intended when the departure release time was scheduled
- “Hit slot after takeoff” means the departure ended up in the slot that was determined once the departure was actively tracked by TBFM after takeoff.
- The 14% difference between the hit slot after takeoff and the scheduled slot represents the loss due to the lack of compliance at takeoff time. In this study, the 4 departures that took off 2 minutes early or more were not successfully inserted.
- It can be seen that that the rates increase when the correct lead is considered only (88% & 100%)
- These high rates are in part due to the large spacing restriction imposed on aircraft at LIB (30MP = 4min between each aircraft = 8min window). The larger the window, the less precision is required to merge a departure in the overhead stream.

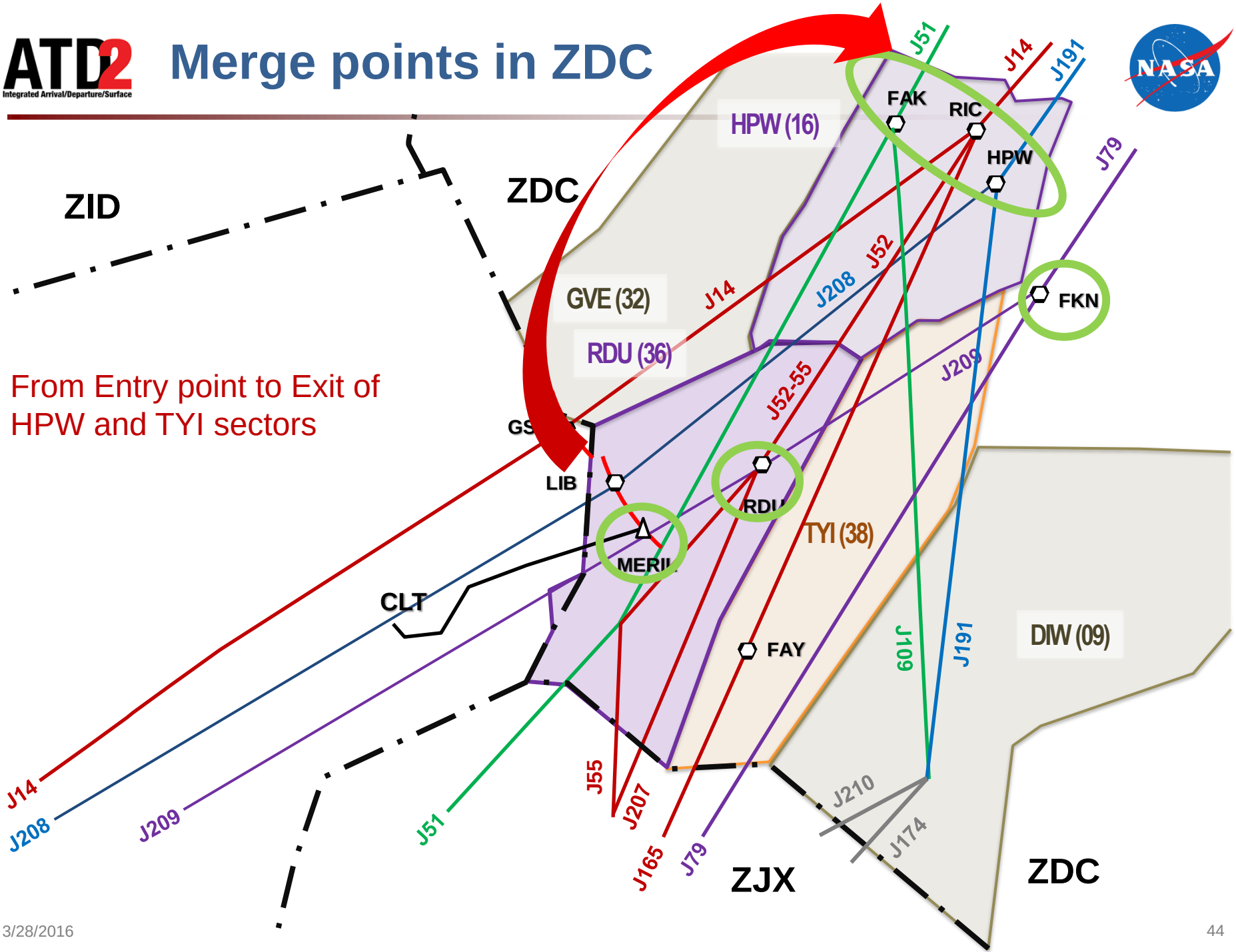
Stream Insertion at LIB meter point (Scheduled by ZTL)

Planned TBFM Sequence	% Hit scheduled slot	% Hit slot after takeoff	Difference
Correct lead and trail aircraft	81%	95%	14%
Correct lead aircraft	88%	100%	12%



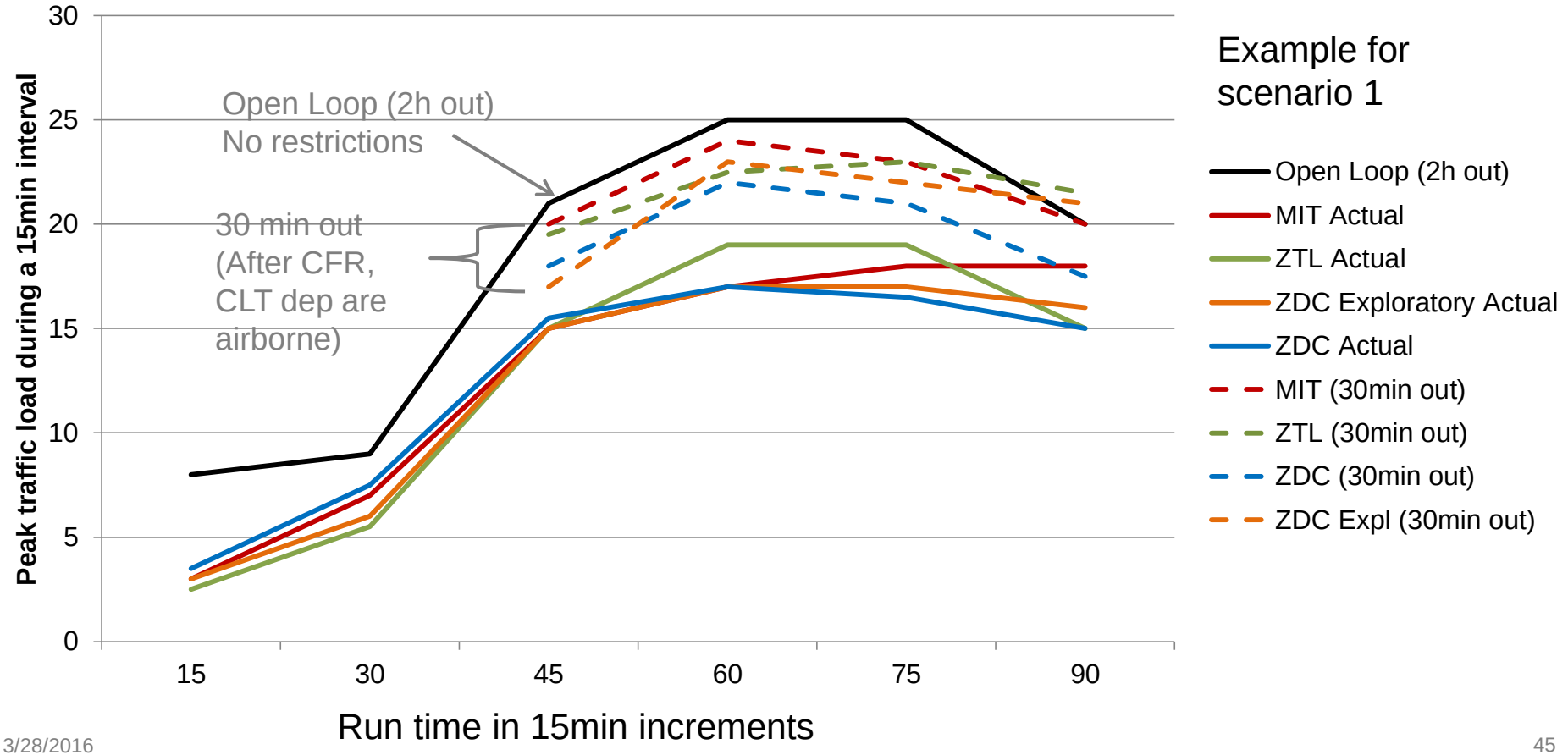
Analysis of flights in ZDC airspace

Merge points in ZDC



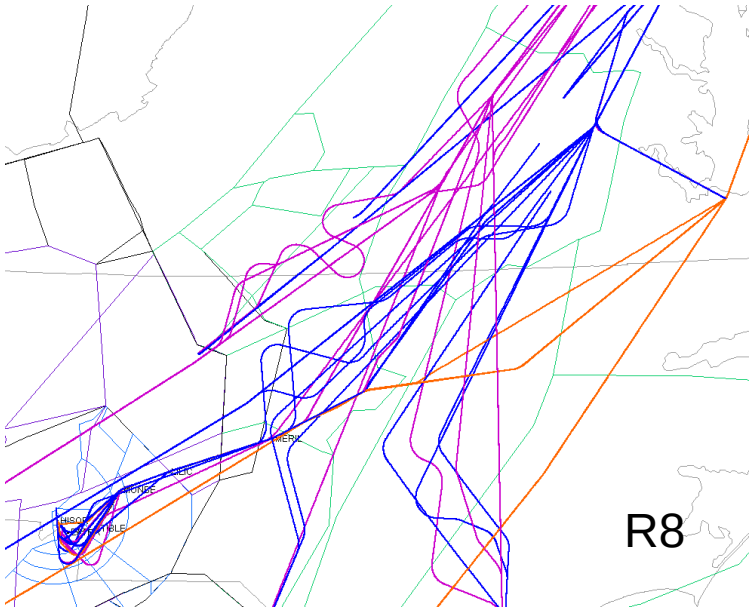
TMI initiatives mitigated the excess demand in Hopewell by 30% only, compared to the unrestricted demand in the open loop run

- 2h out shows the demand before any restrictions are applied
- 30min out shows the demand of traffic once inside ZDC
- MIT run shows a longer sustained demand in the last 15min of the run comapred to the other conditions



Tracks in the MIT Conditions

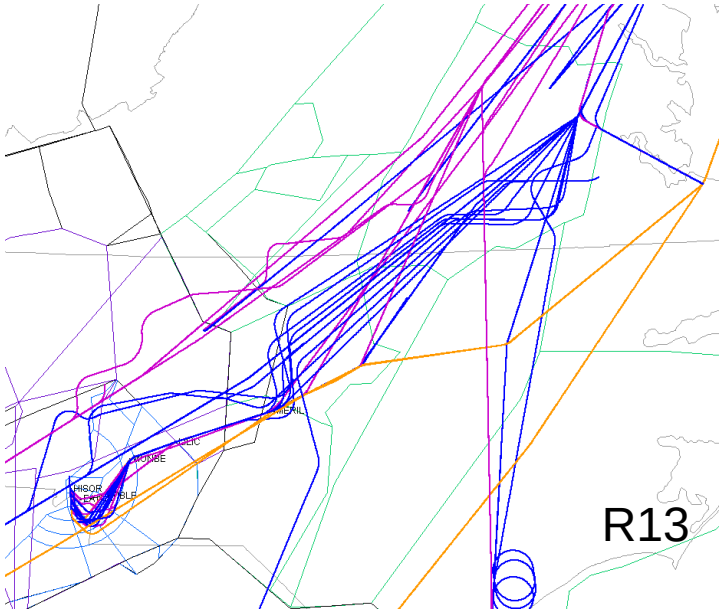
Sc1



41 vectors

Lines color code
Magenta = flow to EWR
Blue = flow to LGA
Orange = flow to JFK

Sc2

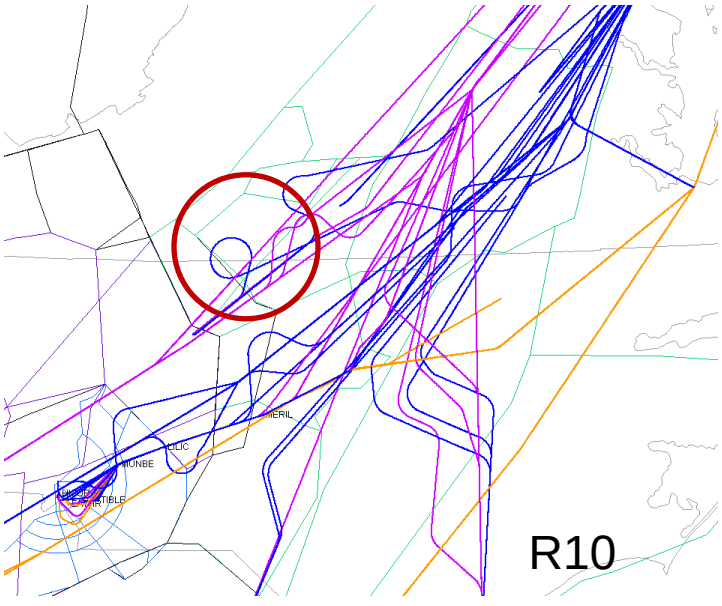


A comparison between the main conditions indicate that:
There were more vectoring in MIT, than in the ZTL, and than in ZDC conditions.
The main reason is the increased demand in the MIT saturating the airspace.
In the ZTL conditions, there were notably more vectoring taking place with the EWR flow (circled in red), than compared to the ZDC conditions.
In the exploratory run, there drastically less vectoring (2) compared to all other conditions.
It also seems that the full and partial compliance of the CLT departures may have influenced the number of vectors in ZDC.

Tracks in the ZTL Conditions

Sc1

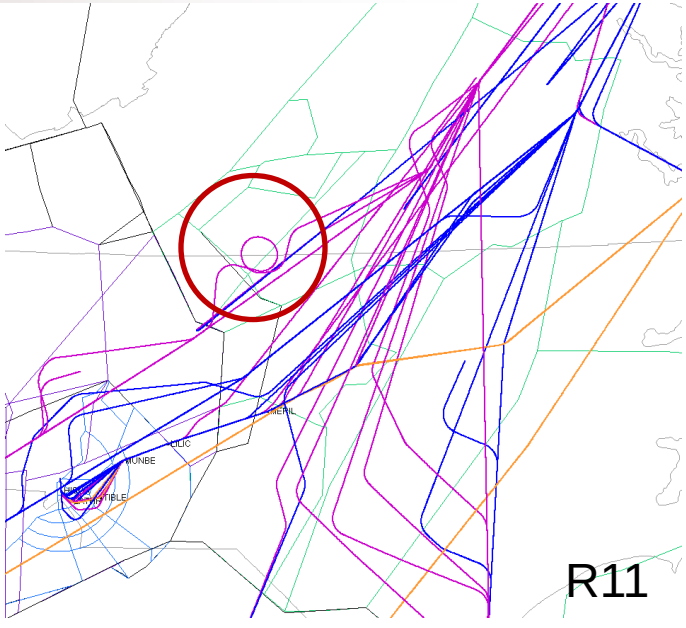
Sc2



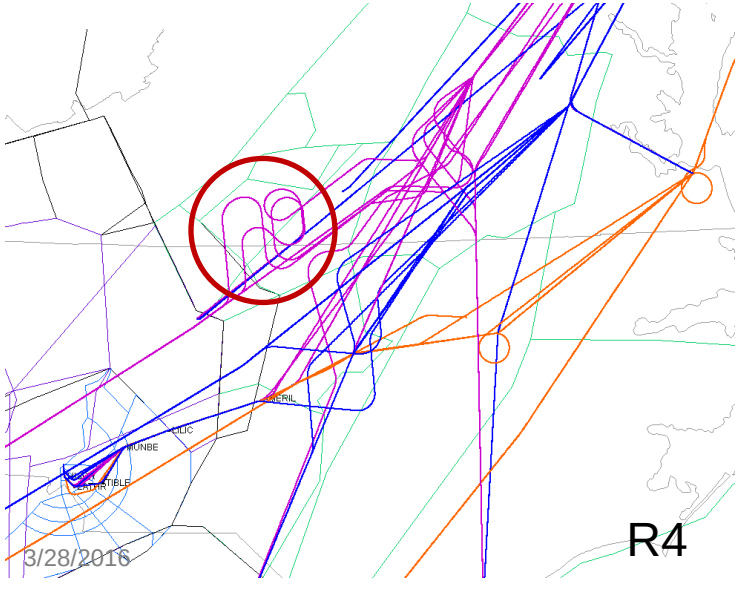
R10

ZTL
Full Compliance

33 vectors



R11

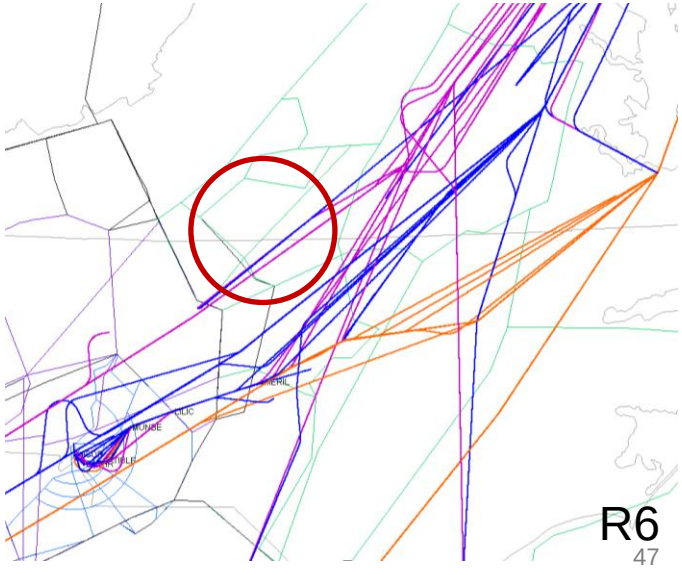


R4

ZTL
Partial Compliance

28 vectors

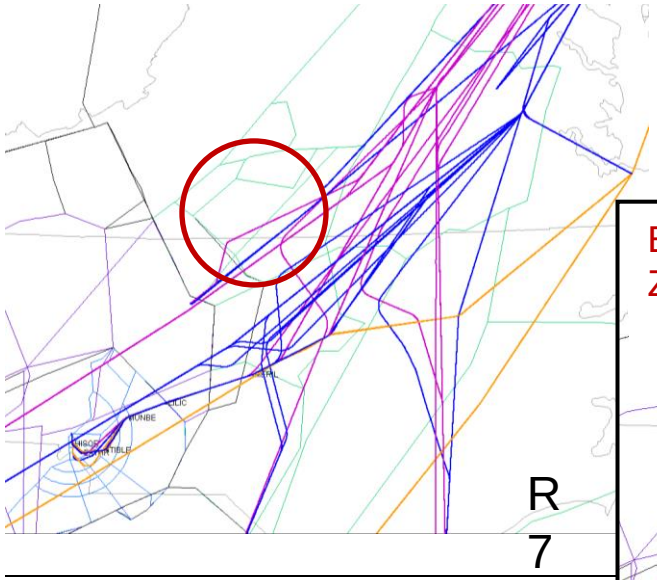
Lines color code
Magenta = flow to EWR
Blue = flow to LGA
Orange = flow to JFK



R6

Tracks in the ZDC Conditions

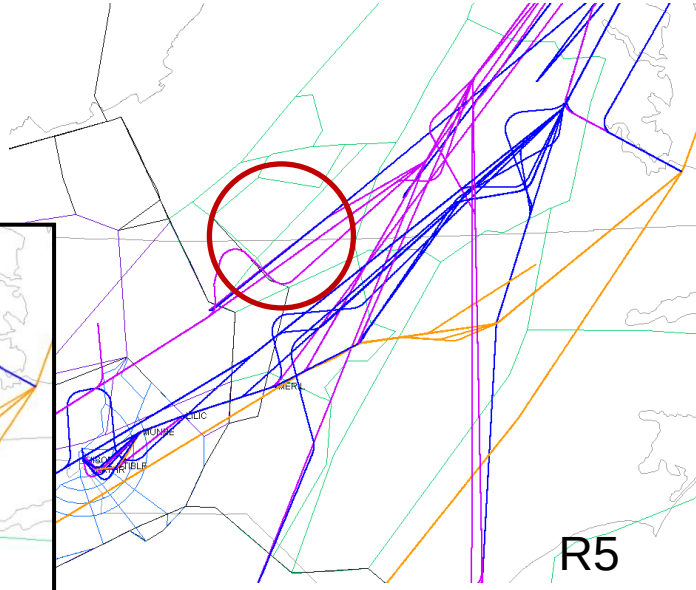
Sc1



ZDC
Full Compliance

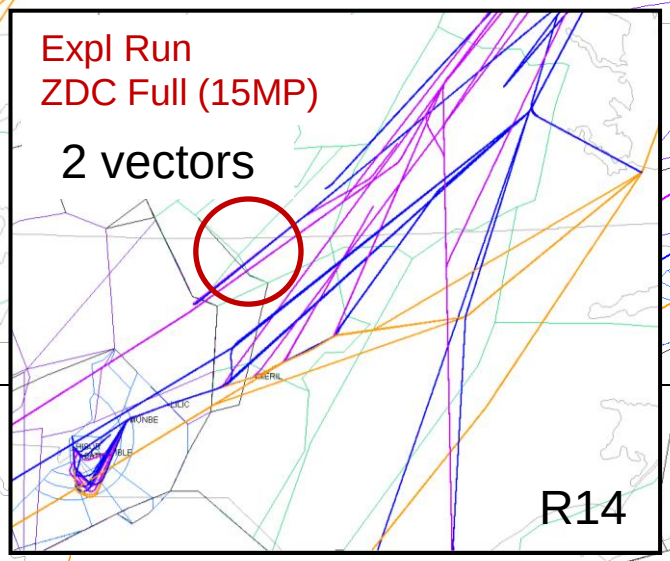
20 vectors

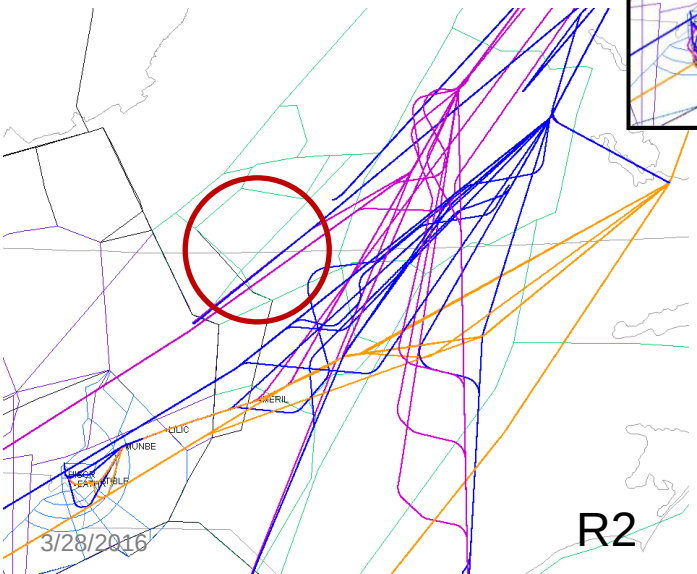
Sc2



Expl Run
ZDC Full (15MP)

2 vectors

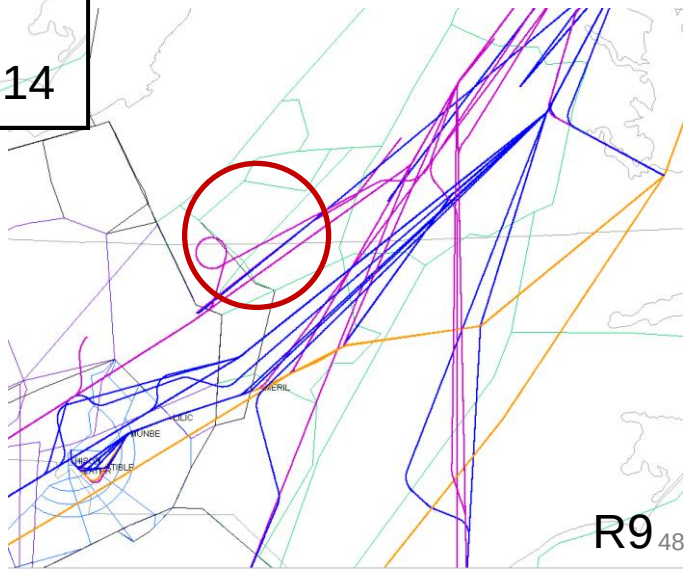




ZDC
Partial Compliance

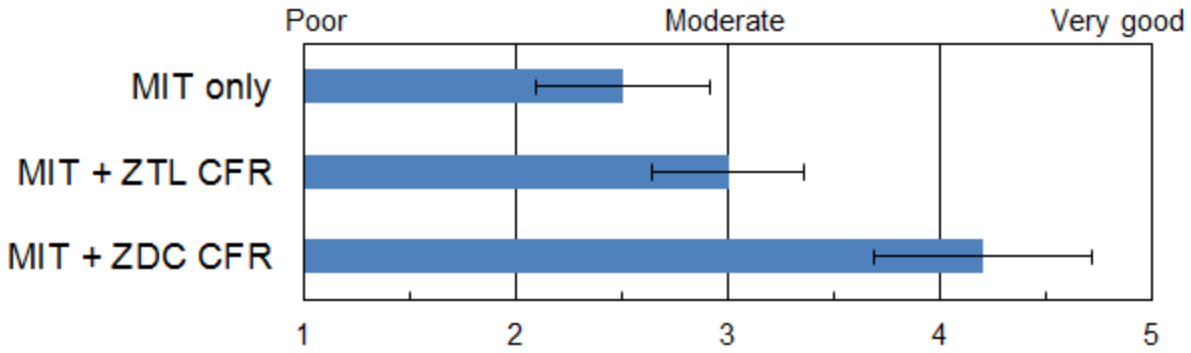
26 vectors

Lines color code
Magenta = flow to EWR
Blue = flow to LGA
Orange = flow to JFK



LGA Flow: Those Who Noticed a Difference in the LGA Flow Entering their Sector or Center Rated the MIT + ZDC CFR Condition as the Best Flow

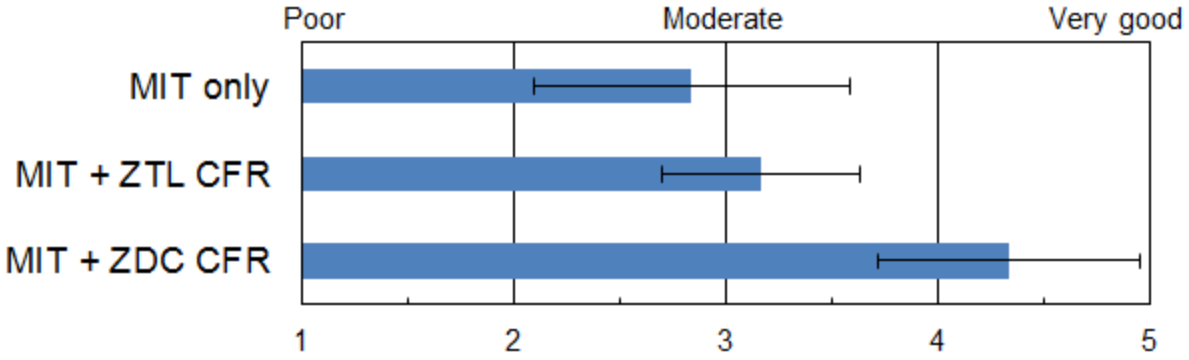
Question: "If you noticed a difference in the quality of the LGA flows entering your sector, please rate the flows in the different conditions."



Raters were 4 ZDC controllers (excluding Tar River) and the ZDC TMC and FLM. Means were 2.5, 3.0, 4.17, *SD*s = .55, .63, .41, Repeated measures *MS* 4.4, $F(2,10) = 17.2$, $p = .001$. Error bars are 95% Confidence Intervals adjusted for repeated measures ANOVA per Loftus & Masson (1994). Conditions 1 & 2 significantly different only at $p = .08$.

EWR Flow: Those Who Noticed a Difference in the EWR Flow Entering their Sector or Center Rated the MIT + ZDC CFR Condition as the Best Flow

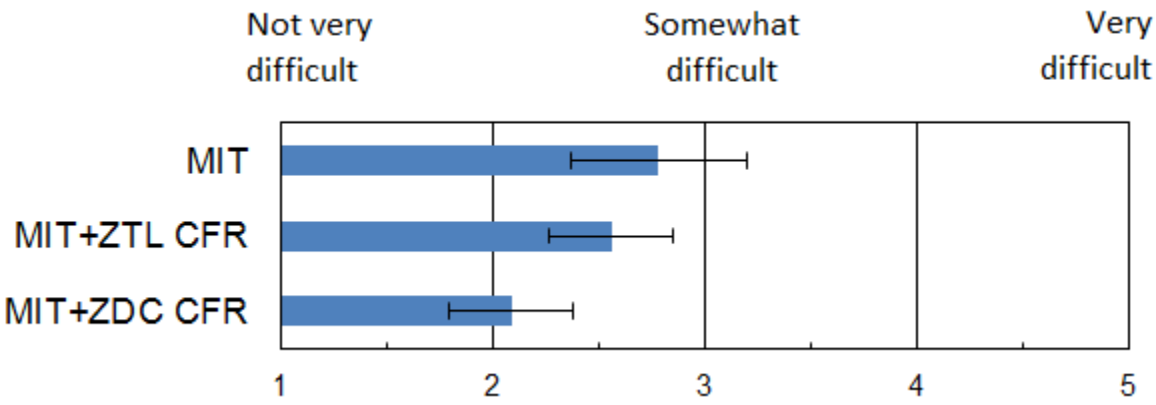
Question: "If you noticed a difference in the quality of the EWR flows entering your sector, please rate the flows in the different conditions."



Raters were 4 ZDC controllers (excluding Tar River) and the ZDC TMC and FLM. Means were 2.8, 3.2, 4.3, *SD*s = 1.3, .98, .52, Repeated measures *MS* 3.7, $F(2,10) = 7.1$, $p = .012$. Error bars are 95% *CI*s adjusted for repeated measures.

What was Different was the Difficulty Providing LGA Flows: ZDC CFR Least Difficult

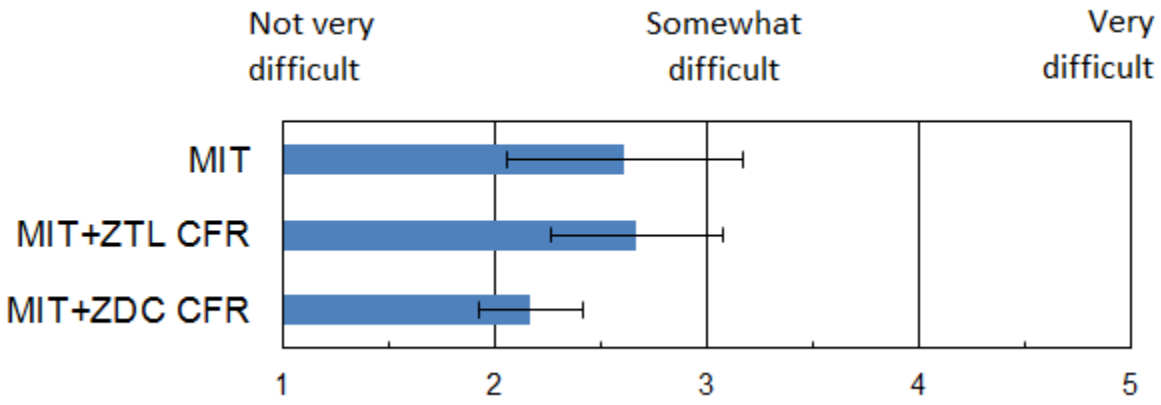
In this run, how difficult was it to provide the LGA flows?



Means 2.8, 2.6, 2.1, *MS* .39, $F(2,7) = 6.4$, $p = .026$. Error bars 95% CIs. Note: Comparing schedule conditions only in a 2 X 2 repeated measures design (with compliance), ZTL CFR is significantly different from ZDC CFR (means 2.6 & 2.1) at *MS* 2.0, $F(1,8) = 8.9$, $p = .018$.

Similar Results for Providing EWR Flows: ZDC CFR Condition Less Difficult than ZTL CFR Condition

In this run, how difficult was it to provide the EWR flows?



Means 2.6, 2.7, 2.2, p = .26. However, comparing the two scheduling conditions only in a 2 X 2 repeated measures (with schedule X compliance) yields p = .015 for the schedule difference. *MS* 2.25, $F(1,8) = 9.6$.

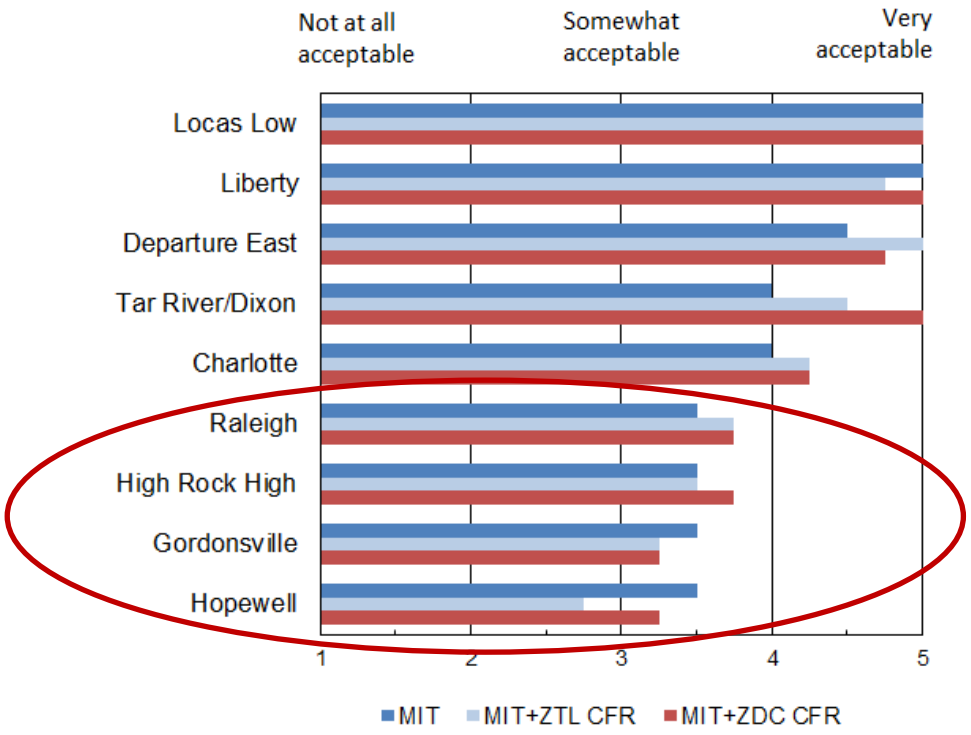
Acceptability of Workload: Workload Least Acceptable for Hopewell, Gordonsville, High Rock High and Raleigh

In this run, how acceptable in terms of workload were operations in your sector?

ZDC controllers

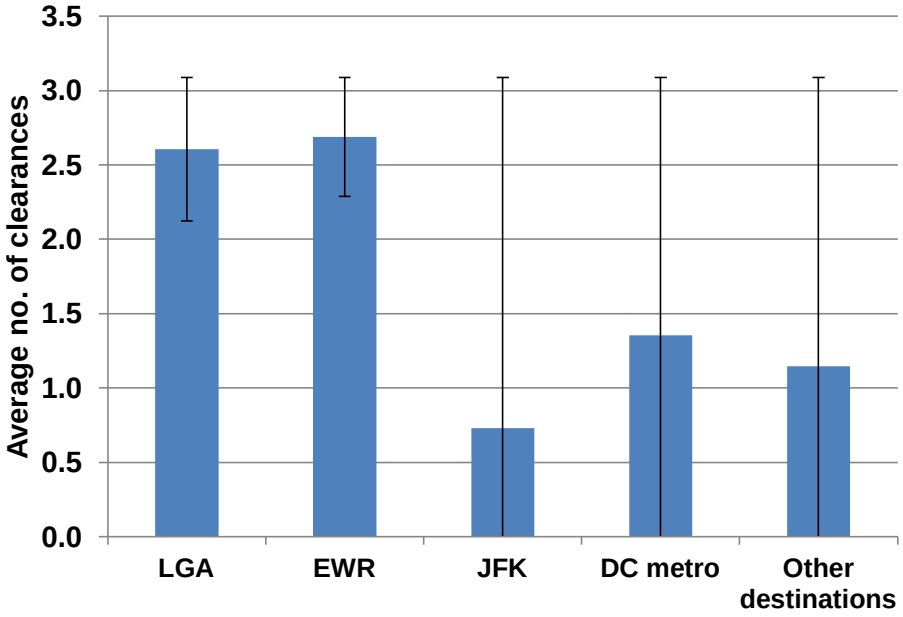
ZDC controllers

ZDC controllers

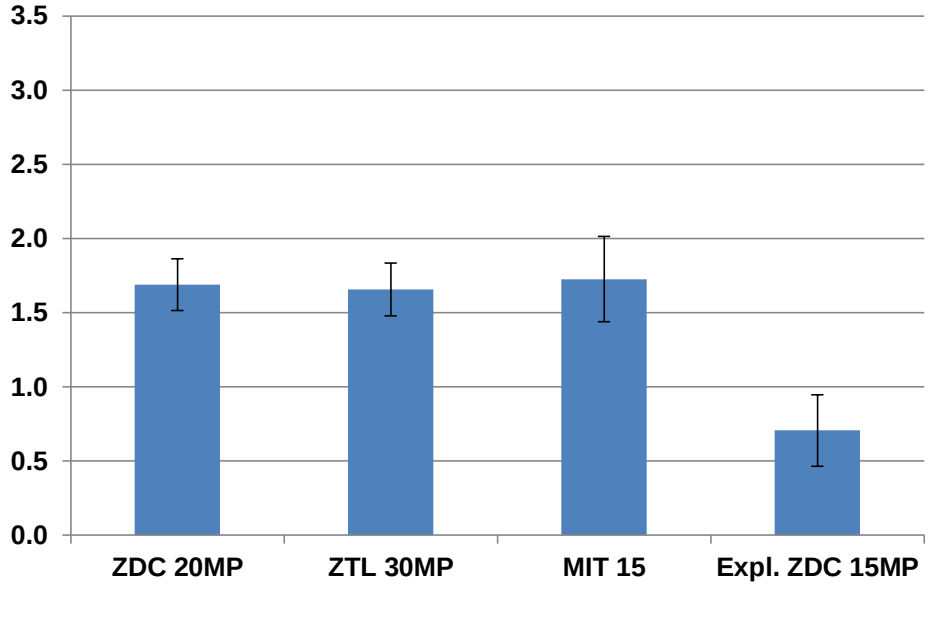


ZDC Controllers Issued Twice More Clearances to Flights to EWR and LGA Than to Other flights

- The number of clearances is an indicator of controllers' workload.
- ZDC Controllers issued twice more clearances flights to EWR and LGA than to flights to other destinations.
- There were also three times less clearances issued in the exploratory run than in the other conditions. This indicate that the lower spacing restrictions reduced workload drastically.
- Other results indicate the speed and heading were 4 times more frequent for the EWR and LGA traffic than the other traffic.
- DC Metro and other destinations received more altitude clearances than the EWR and LGA did. This support the strategy of the supervisor and the TMC to cap the DC metro and other traffic below HPW sector. This was intended to reduce the number of flights in HPW.



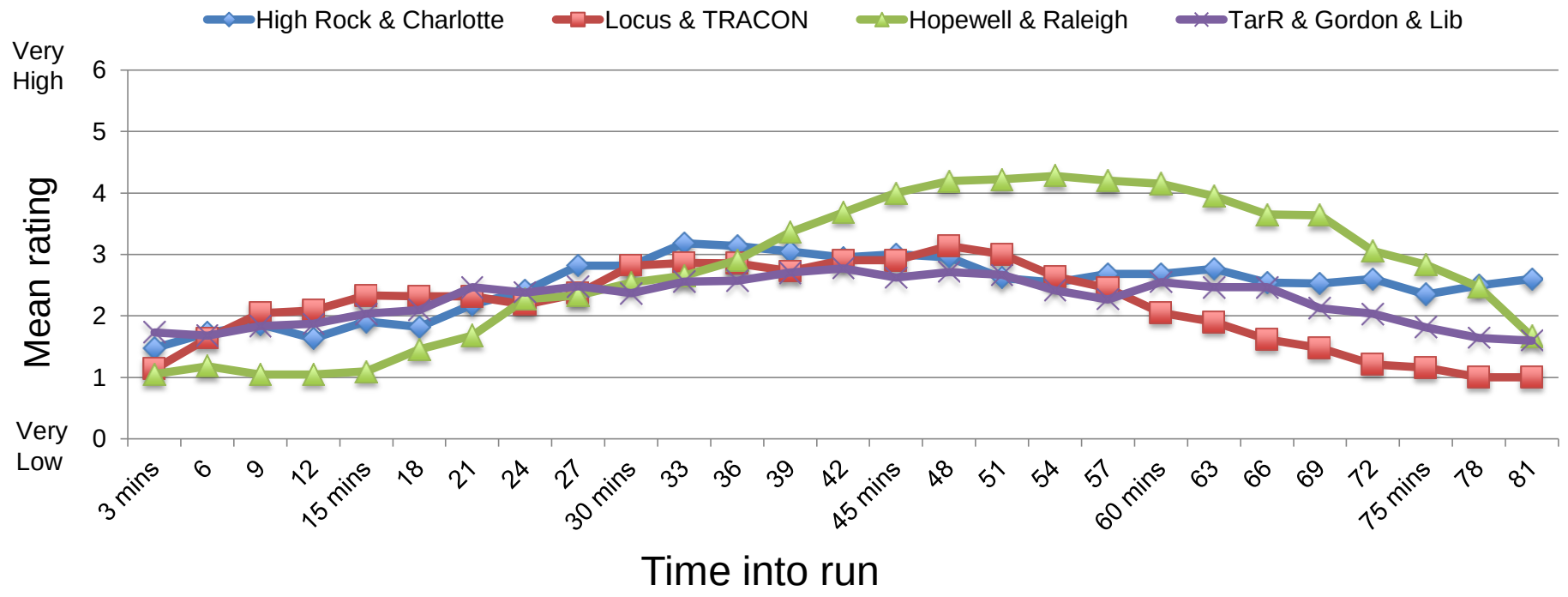
Destination $F(4,1041)= 22.36$, p .000



TMI $F(3,1041)= 3.90$, p .009

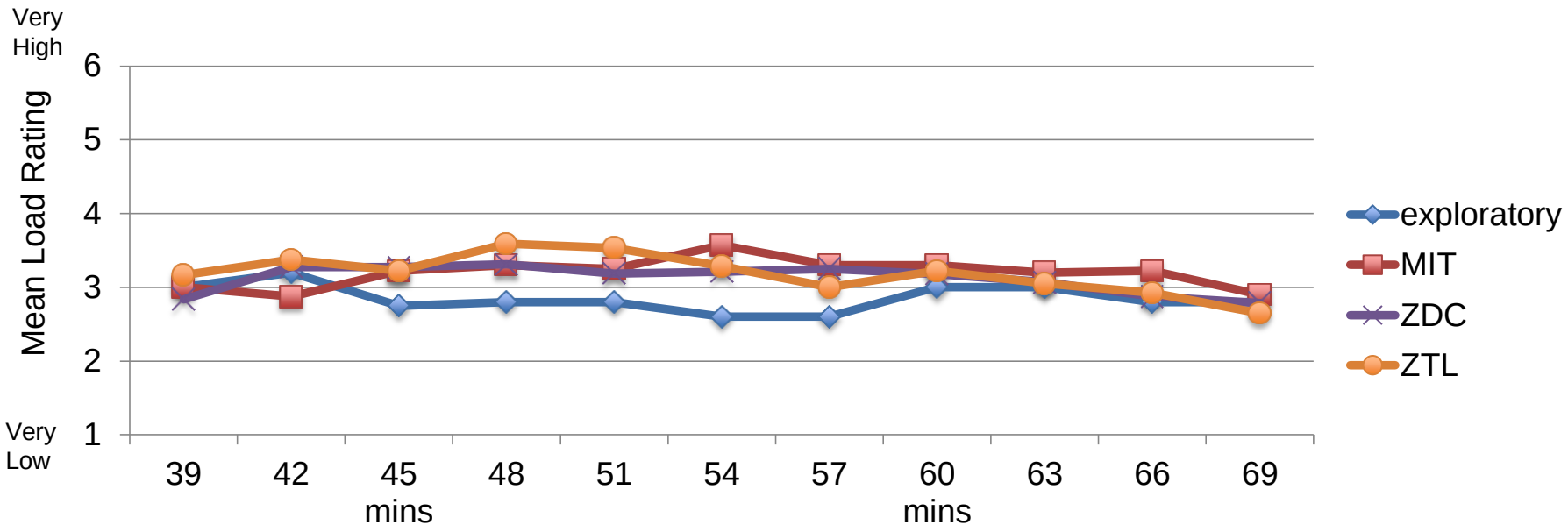
Real Time Workload Charts
Mean Load by Sector/ Position

- Every 3minutes, controllers reported workload on a 6-point scale (WAK).
- Mean Workload ratings ranged from 1 (Very Low workload) to 4.2 (Moderate Workload). Controllers used the entire range (1-6) of ratings.
- Compared to the other sector/position groups Hopewell and Raleigh reported some of the lowest ratings near the beginning of the problems and also some of the highest ratings from about the middle of the runs to near the end.



Workload Reported by the ZDC Controllers During the Last 30min of the Runs

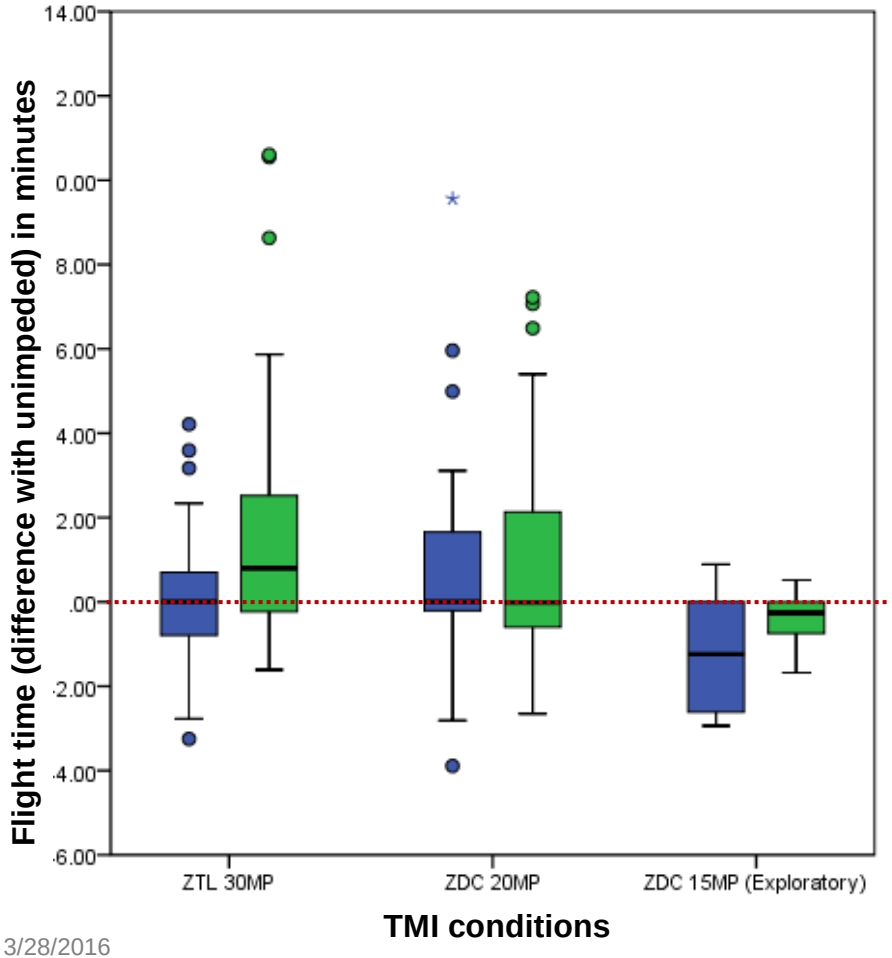
- Workload seemed less high in the Exploratory run compared to the other conditions.
- These averages are high in comparison to other studies (average frequently around 2)



Means not significantly different

Traffic to EWR Flew longer in ZDC Airspace Than Traffic to LGA

- Metric: Difference of flight time between actual and unimpeded for the portion of flight in ZDC (Approximation of airborne delay accrued in ZDC)
- Traffic to EWR (departures and overhead) flew a longer time to reach HPW, compared to traffic to LGA. This was particularly the case in the ZTL and the exploratory conditions.
- The delayed flight time of the EWR traffic in the ZTL condition is due to the lack of insertion of overhead and CLT departures into one stream class at the ZTL boundary.



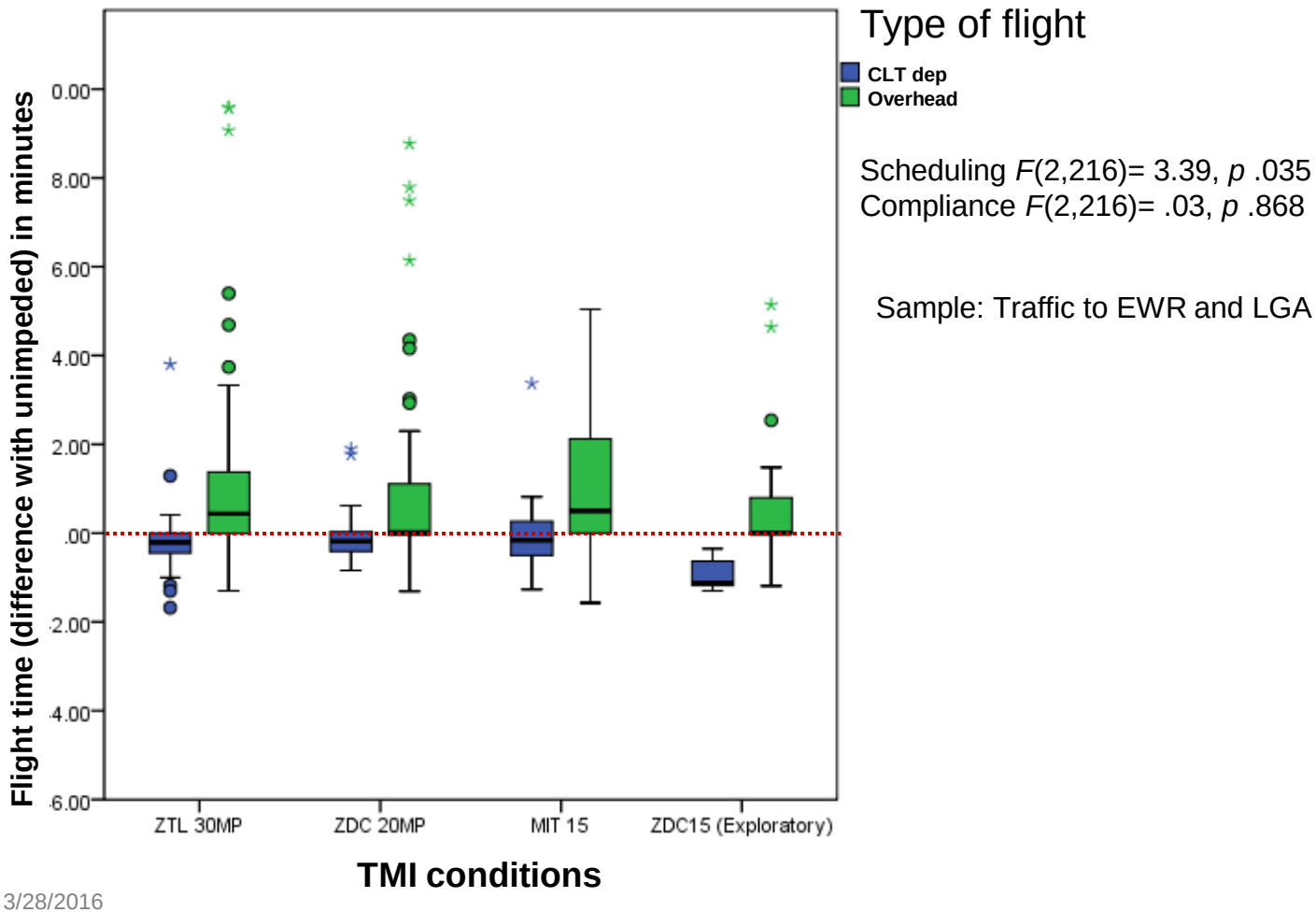
Scheduling $F(3,268)= 3.17$, p .025
Destination $F(1,268)= 12.36$, p .001

Range: -32, +14

Sample: CLT departures + overhead traffic

CLT departures Flight Time to LGA and EWR Was Less Impacted than the Overhead Traffic

- Departures to EWR and LGA were less delayed compared to the overhead traffic
- The variance of the departures were also less large, indicating less frequent interventions by the controllers on this traffic than the overhead. This support the strategies sued by the supervisor. The supervisor anticipated conflicts in HPW, and often reached out to upstream sectors to apply corrections.

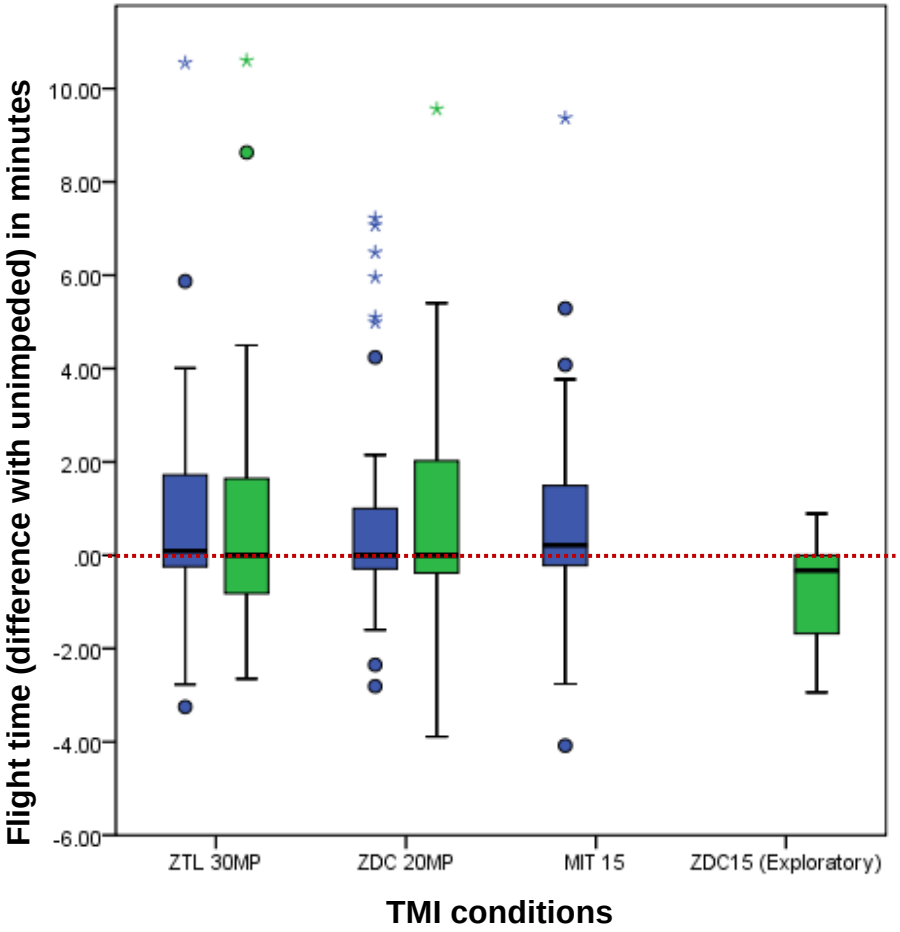


Scheduling $F(2,216)= 3.39$, p .035
Compliance $F(2,216)= .03$, p .868

Sample: Traffic to EWR and LGA

Traffic to EWR and LGA Flew Less Long in the Exploratory condition Compared to the Other Conditions

- Traffic to EWR and LGA (departures and overhead) flew less long in ZDC to reach HPW in the exploratory condition compared to the other conditions.
- The lower spacing restrictions reduced delays.
- There are no significant differences between the partial and the full compliance conditions in ZDC airspace.



Compliance

Partial
Full

TMI $F(3,270)= 3.01$, p .025
Compliance F (1,270)= 0.00, p .960

Range: -32, +14

Sample: CLT departures + overhead traffic to EWR and LGA

Supervisor Helped Controllers Reduce Conflicting Demand in Hopewell

- Transcriptions of the ZDC supervisors indicates that he spent more time resolving problems in the ZTL and MIT conditions than in the ZDC condition
- There were more problems with the EWR flows in the ZTL condition, and there were more problems with the LGA flows in the MIT condition.
- The main reason is that all merge points for the EWR flows are at HPW, compared to LGA the flow that has a merge point in RDU.

Conditions	Sup intervention time (in min)	Problem aircraft LGA flow	Problem aircraft EWR flow
ZDC	47.5	5.5	8.75
ZTL	55.25	2.5	12
MIT	54	9.5	6.5

Main problems:

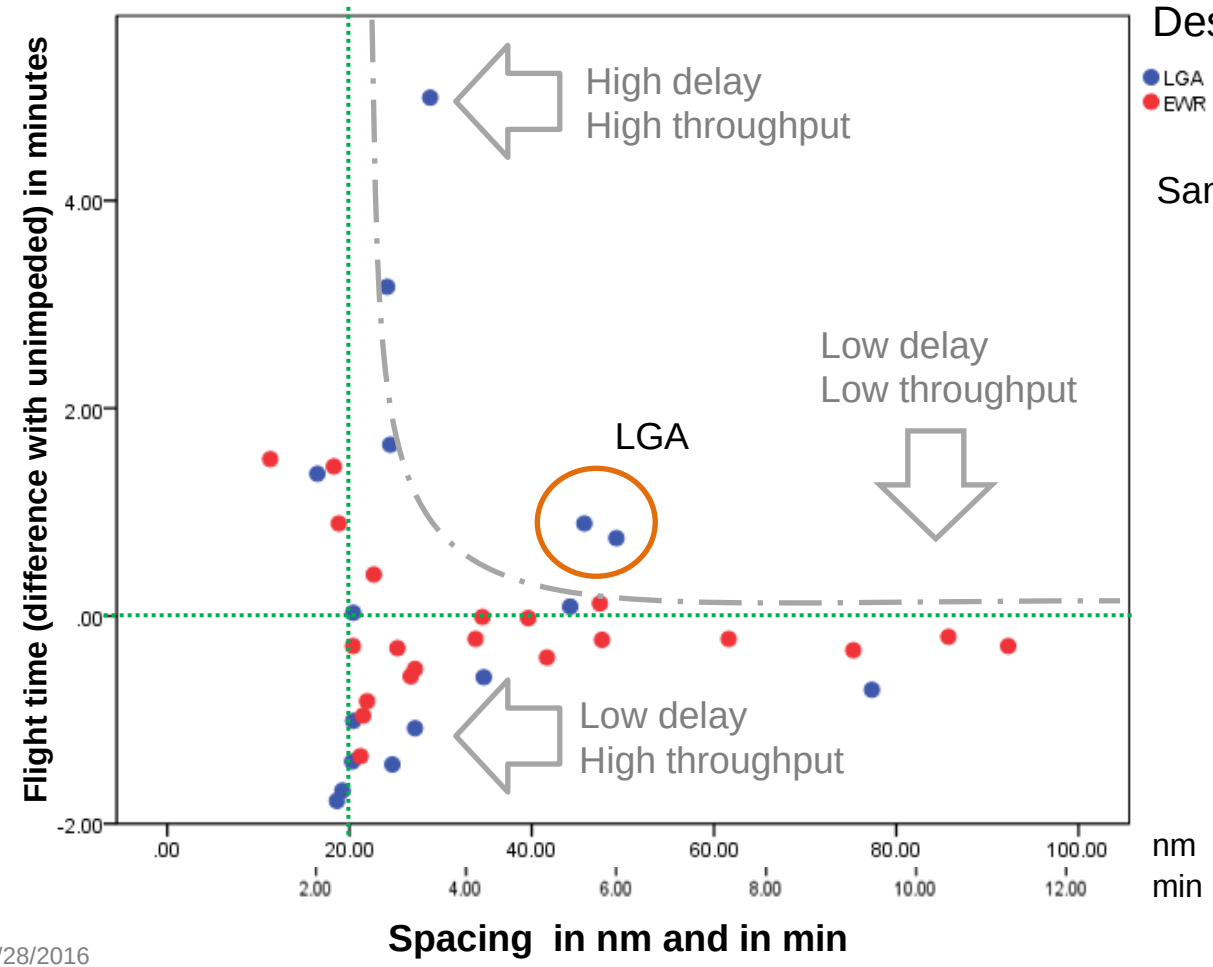
- Aircraft tied at HPW (most often EWR)
- Spacing between aircraft to meet restriction or to merge traffic at RDU or HPW
- Volume

Main Strategies:

- Figured out the required spacing of aircraft across upstream sectors (Gordonsville, Tar River, and Raleigh) and issued guidance to controllers to provide a better spacing and sequence to Hopewell controller

No Wasted Capacity in ZDC

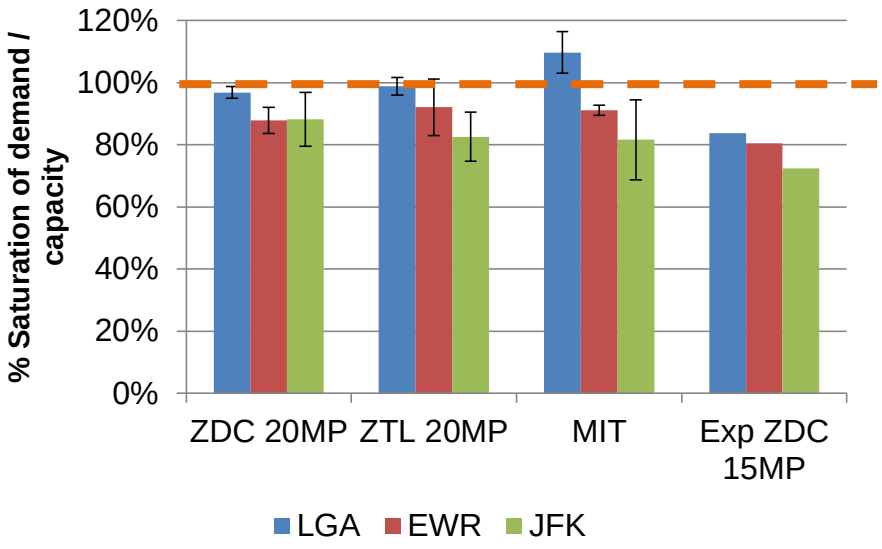
- ZDC controllers aimed to deliver EWR, LGA and JFK streams with 20MIT to downstream sectors
- A large portion of departures were spaced at the HPW boundary with more than 20MIT, however without airborne delay. Only two flights flew longer and were excessively spaced.
- Most of the flights that flew longer were minimally spaced indicating they were delayed to fit into the stream.

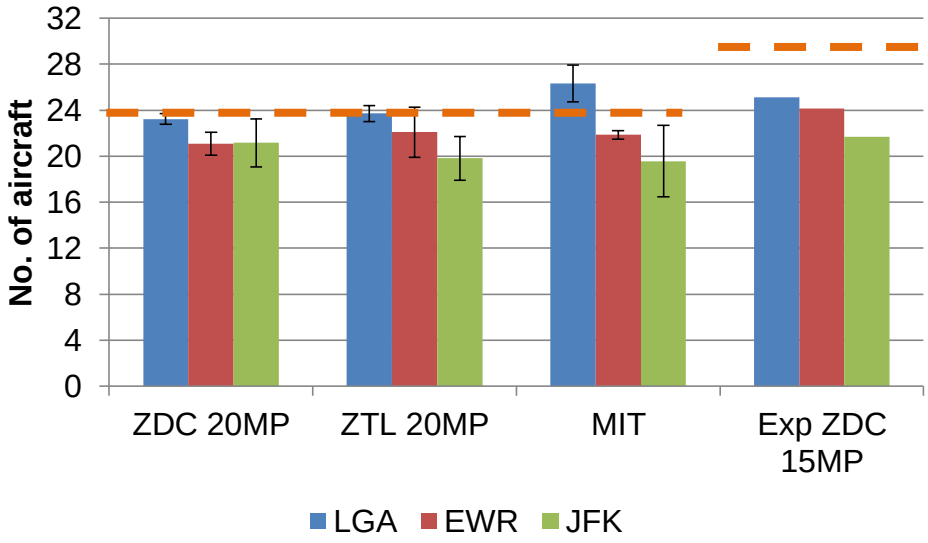


Impact of TMI Manipulations on Demand Capacity / Balance

- The average demand reached near saturation of capacity in all TMI conditions, except in the Exploratory run (Exp ZDC 15MP).
- In the MIT runs, the demand to LGA flow at the ZDC MP exceeded capacity. This is because there were more CLT departures to LGA than those to EWR and JFK. In the MIT, none of the departure to LGA were not delayed on the surface.
- In the exploratory run, when the capacity increased from 24 aircraft per hour to 30 aircraft per hour (due to the decreased minimum spacing at the MP between aircraft) the saturation dropped by about 10%, and throughput was slightly higher than in the two other CFR conditions.

20MIT at MP = ~2.5min spacing between STAs = ~24 aircraft per hour
15MIT at MP = 2min spacing between STAs = ~ 30 aircraft per hour

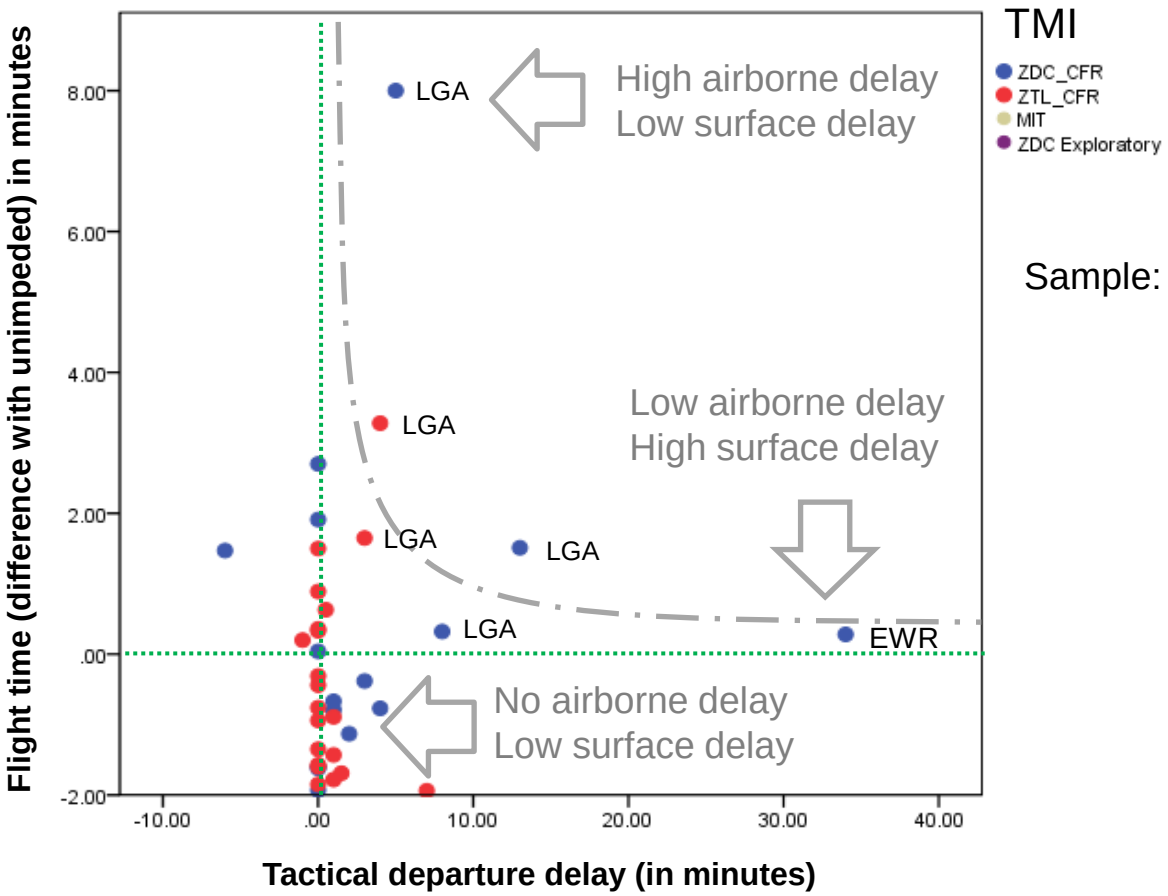




TMI $F(3,21) = 3.85$, $p = .024$
Destination $F(2,21) = 12.30$, $p = .000$

A Large Portion of Departures With TBFM Delay Were Not Impacted by Airborne Delay

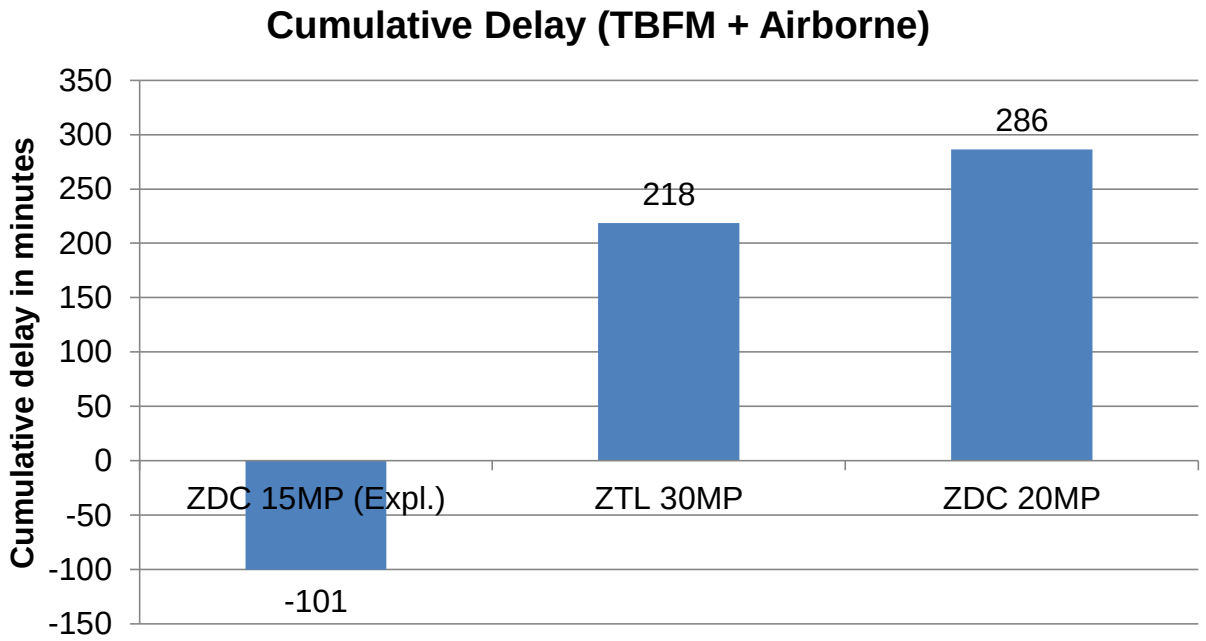
- Tactical departure delay is the delay imposed by TBFM on the departure release time.
- A large portion of departures had both low airborne and tactical delays
- A less significant portion of departures had low tactical delay but then were delayed while airborne.
- There were a few departures to LGA that were delayed tactically and while airborne. This indicates that the restrictions for the LGA flow may not have been sufficient to mitigate the delays in ZDC.



Sample: CLT Departures with CFR

Total Delay was Negative in Exploratory Run and the highest in ZTL Runs

- TBFM and airborne delays were added for all the aircraft to EWR and LGA.
- The exploratory run generated a negative delay. TBFM delays were small and aircraft flew less long than anticipated.
- In comparison, delays accrued in both the ZTL and ZDC conditions. ZTL had more airborne delay than ZDC, but ZDC had more TBFM delay.
- This result indicate how much restrictions at meter points to balance demand and capacity can impact both TBFM (surface) and airborne delays.

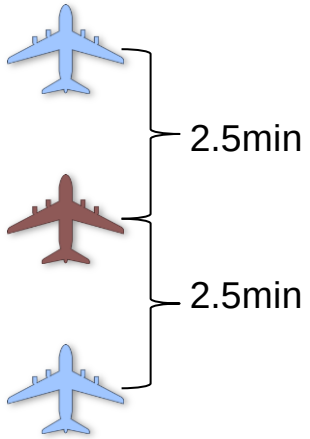


Lower Stream Insertion Success Rates at HPW Boundary

- The stream insertion success rate at HPW is twice less high than at LIB.
- There was a small success rate improvement with slots after departures took off.
- The low rate of success after takeoff is due to:
  - Unpredictability of traffic in ZDC airspace
  - Longer distance to reach HPW
  - Less spacing between aircraft in the schedule
- A high proportion of the departures that hit their slot departed on time (within the 3min window).
- Observations indicate that about a third of the time, the order of aircraft is changed due to the insertion of other departures in between the initial sequence. The other two-third of time is due to aircraft conflicting at merge points.

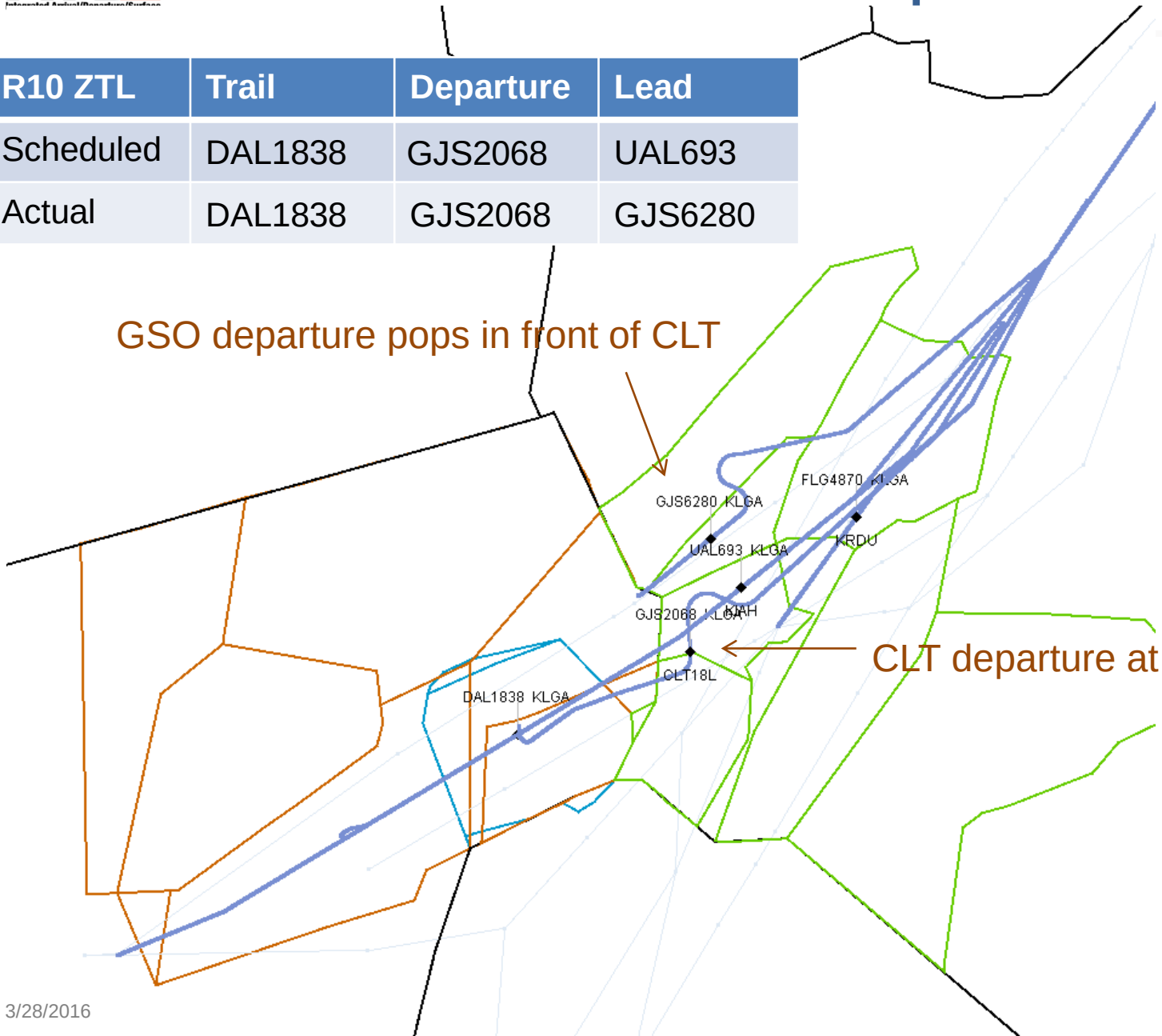
Stream Insertion at HPW boundary (Scheduled by ZDC)

Planned TBFM Sequence	% Hit Scheduled slot	% Hit slot after takeoff	Difference	% departed inside the 3min window for those that hit the slot
Correct lead aircraft	38%	43%	12%	62%
Correct lead and trail aircraft	15%	25%	10%	81%



Example of GSO Departure Being Inserted in in Front of the CLT Departure

R10 ZTL	Trail	Departure	Lead
Scheduled	DAL1838	GJS2068	UAL693
Actual	DAL1838	GJS2068	GJS6280



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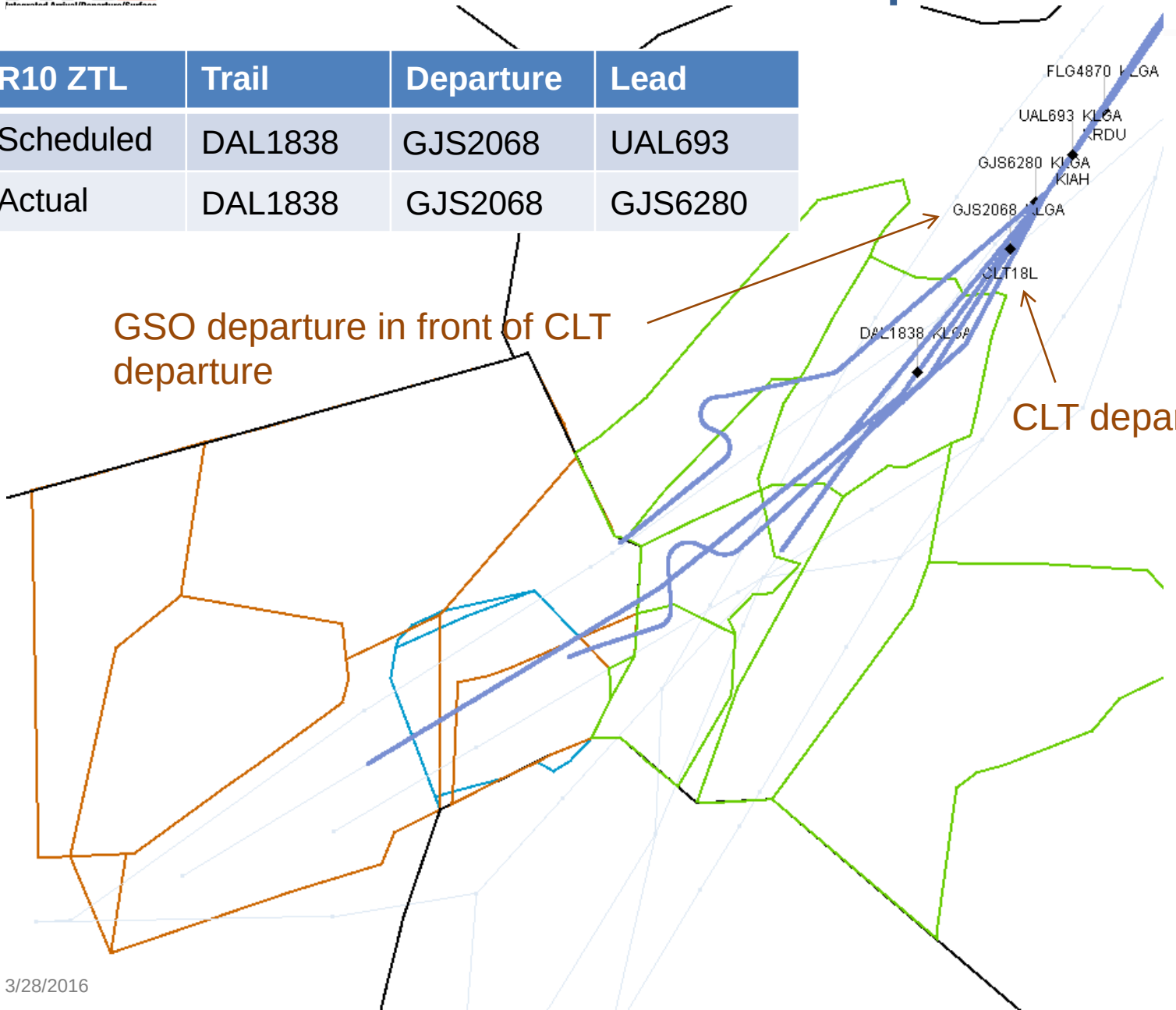


GSO departure in front of CLT departure

CLT departure at HPW

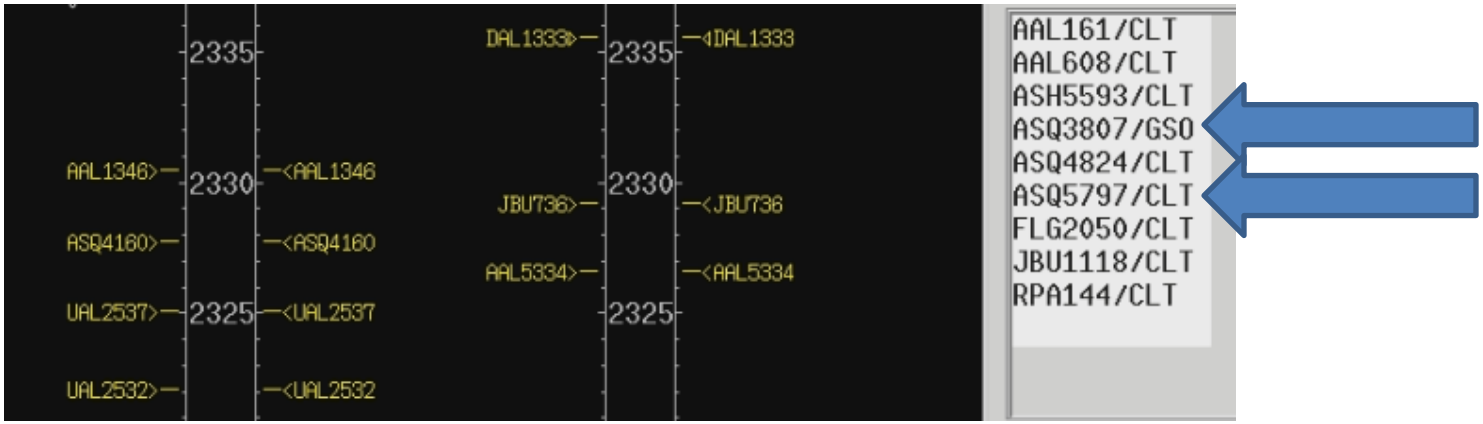
Example of Competitive demand South of Hopewell and how Unreliable the Schedule is

Occasionally other airports compete for the same slots at the ZDC Meter Points

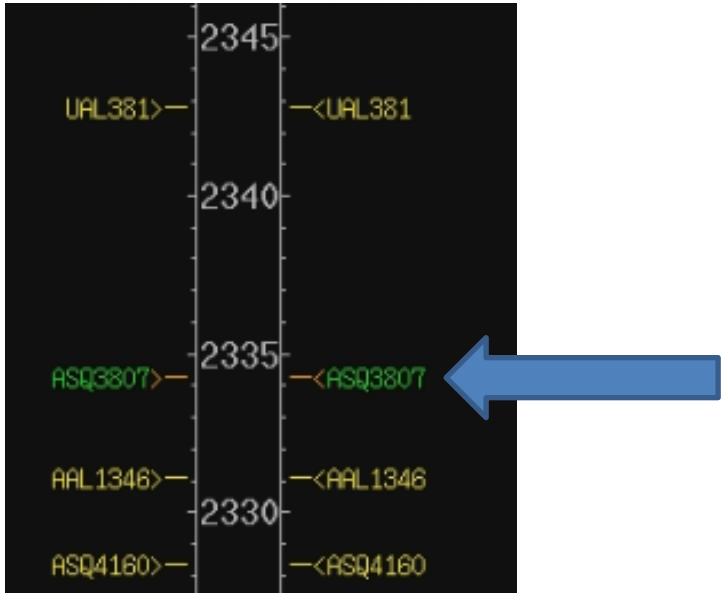
Example of conflicting demand between CLT and GSO across Centers

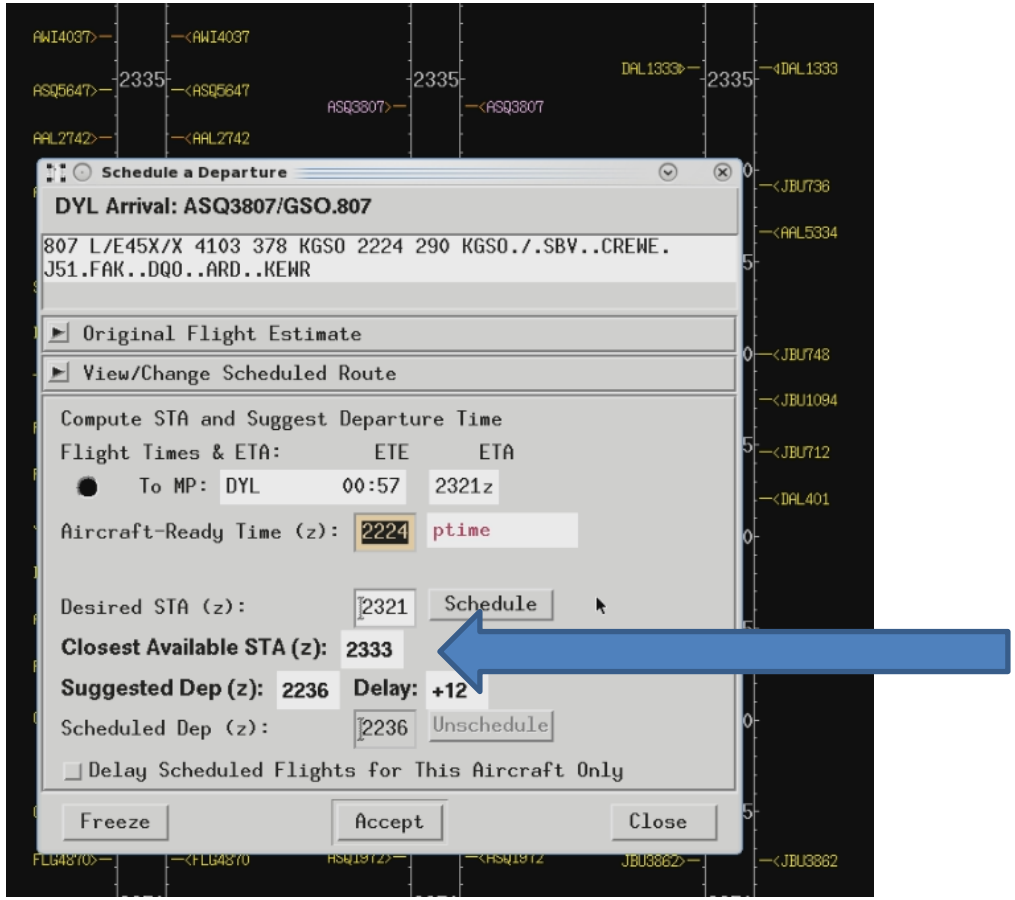
ASQ3807 from GSO & ASQ5797 from CLT

- Both ASQ3807 from GSO & ASQ5797 from CLT are flying to EWR
- ZTL schedules CLT departures at LIB MP
- ZDC schedules GSO departures at DYLIN MP without knowing about ZTL schedule at LIB



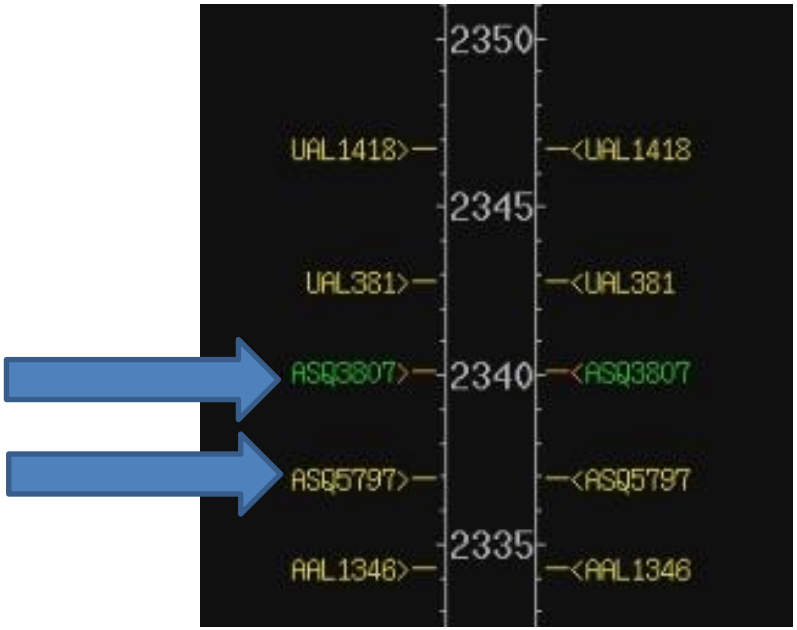
ZDC Schedules GSO Departure to the First Available Slot





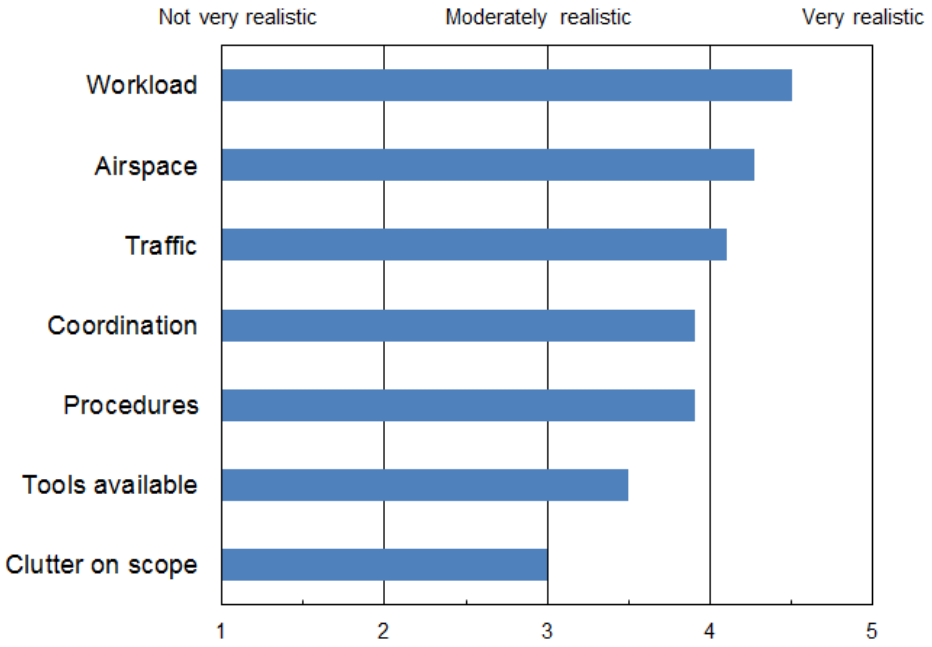
ZTL Scheduled CLT Departure and Conflicts with the GSO Departure

- Later on, CLT Departures ASQ5797 is scheduled by ZTL.
- Once ASQ5797 takes off and becomes active (yellow) it bumps the GSO departure STA, which is not active yet, to the next slot.
- Additionally, notice that AAL1346 is delayed by 4minutes. This further push ASQ5797 and ASQ3807 to a later slot.



Realism: Workload, Airspace, and Traffic were Rated as Most Realistic; Tools and Clutter on Scope were Rated as Least

Question: "How realistic was the modified problem depicted in the simulation in terms of the following factors?"



Out of 12 participants, n's were = 10-12 on each item. "NA/Don't know" was an option. An "other" category was also available, but not used.

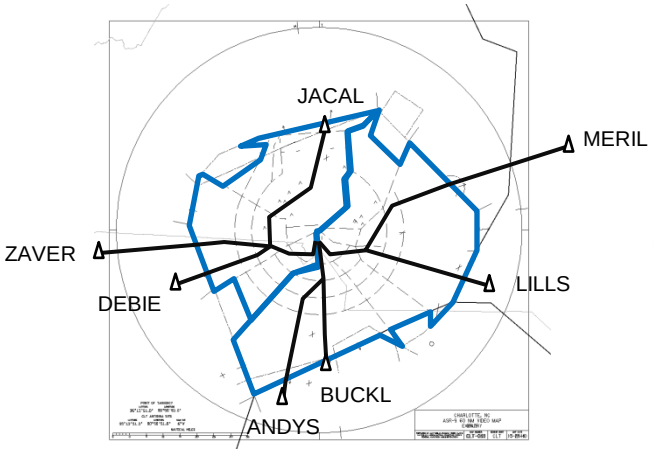
Summary of Findings

- CFR departures had less airborne inefficiencies compared to MIT departures
- Stream insertion was successful at LIB and less so at HPW
- Takeoff compliance did not affect stream insertion at LIB, but helped at HPW
- TMI restrictions were not sufficient to manage the demand in HPW
- ZDC controllers were more impacted when ZTL scheduled departures than when ZDC did (in particular for merging EWR and LGA flows)
- Workload was more acceptable when ZDC scheduled CLT departures than when ZTL did
- The exploratory run with smaller restriction generated less tactical delay on the surface and in the air. It was rated as the best run of the simulation.
- The HITL was overall rated as very realistic. The ZDC STMC stated that the “HITL was 95% realistic.”

Problems to Address

- Provide better control of the restrictions, the schedule, the delays and uncertainties in ZDC to improve predictability and reduce inefficiencies
- Improve ETA predictions of departure routes in TBFM

Test Airspace



KTEB KLGA KEWR KJFK

Boston Center

New York Center

DYL

Cleveland Center

KPHL

HOG

KBWI

KIAD

KDCA

Washington Center

DC Met

Washington Center's Meter points

KRIC

HPW

Atlanta Center's Meter points

Indianapolis Center

KPHF

KORF

GSO

KGSO

KRDU

LIB

KCLT

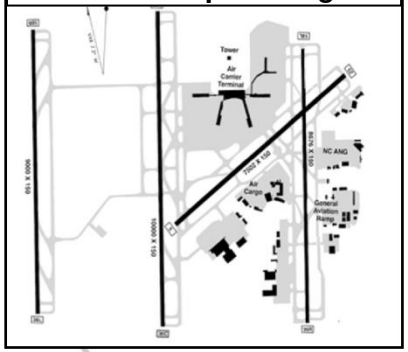
60nm
40nm
20nm
0nm

KATL

Atlanta Center

Jacksonville Center

Charlotte Airport Diagram



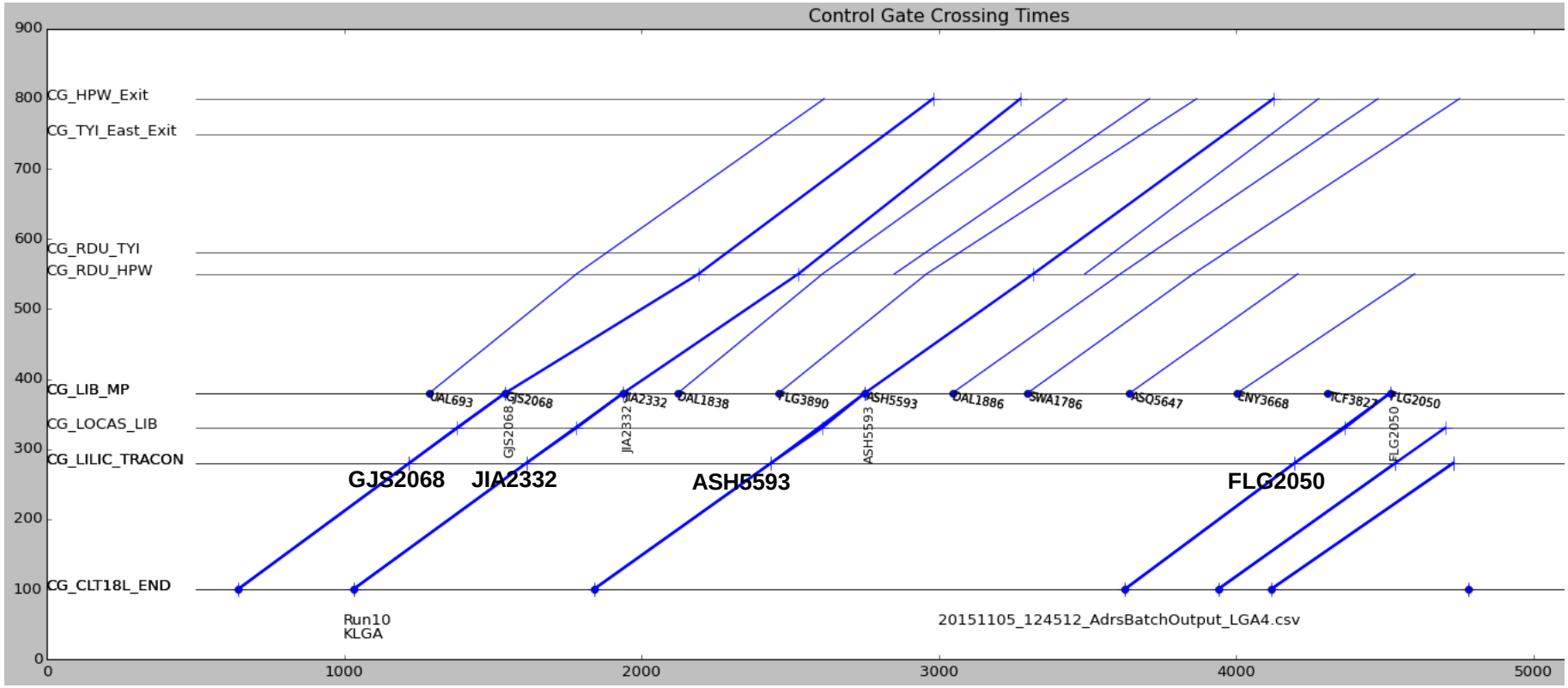
Distances from CLT to	
LIB (ZTL boundary)	90nm
HPW exit boundary	250-260nm
BWI, DCA, IAD MP	310nm
EWR & LGA MP	440-450nm

Back-Up Results

Sequence of aircraft at LIB and HPW for CLT Departures to LGA, scheduled at LIB by ZTL

- Because ZTL schedules with 4min interval between aircraft at LIB (30MIT), and ZDC controllers space aircraft to 2.5min (20MIT), there are often other aircraft inserted in between LGAs at HPW.
- The sequence of the traffic from ZTL remained fairly stable (see example of Run 10 below).

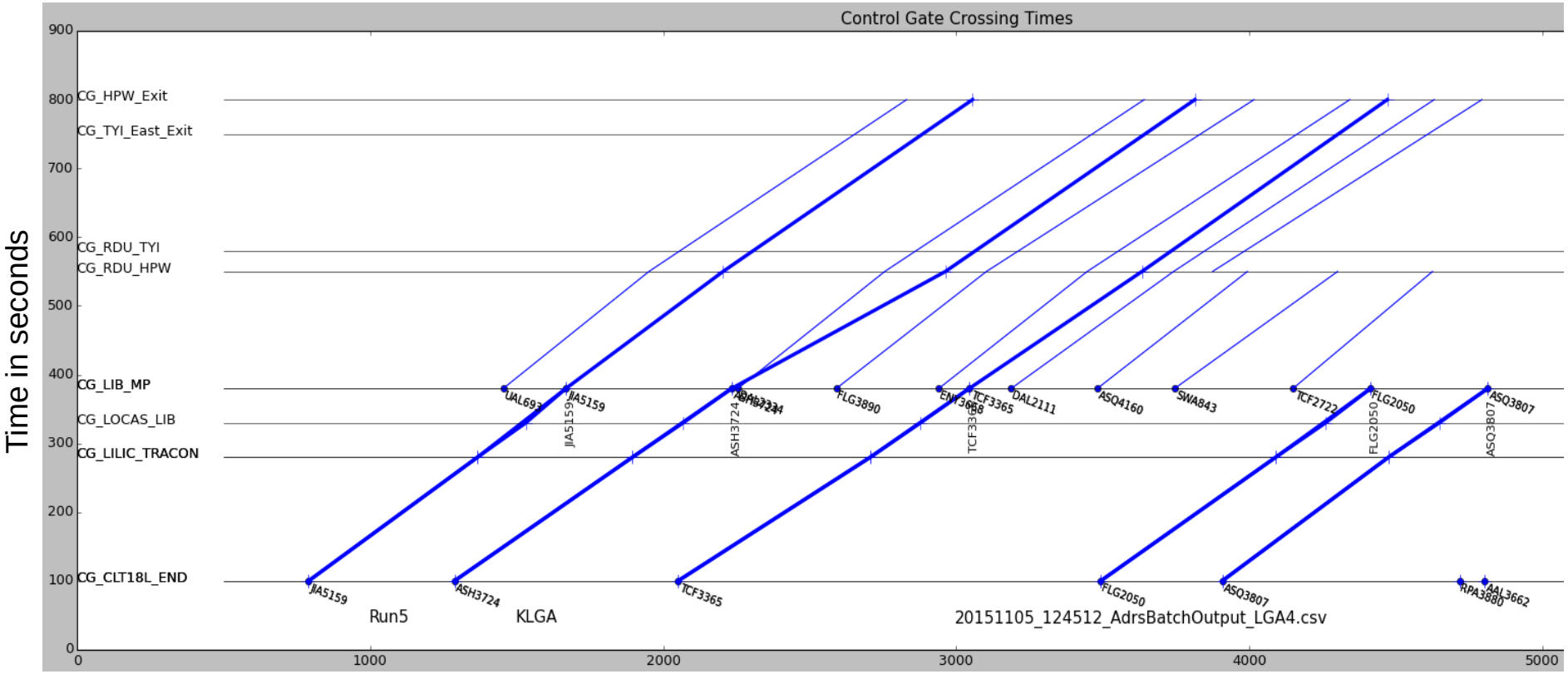
Run 10 – ZTL Full (30MP)



Sequence of aircraft at LIB and HPW for CLT Departures to LGA, scheduled by ZDC

- Stream insertion at LIB is not optimal when ZDC schedules to its own meter point situated 360 nm further away than LIB.
- Once the sequence of traffic is sorted in ZDC, the sequence remains fairly stable (see example of Run 4 below).

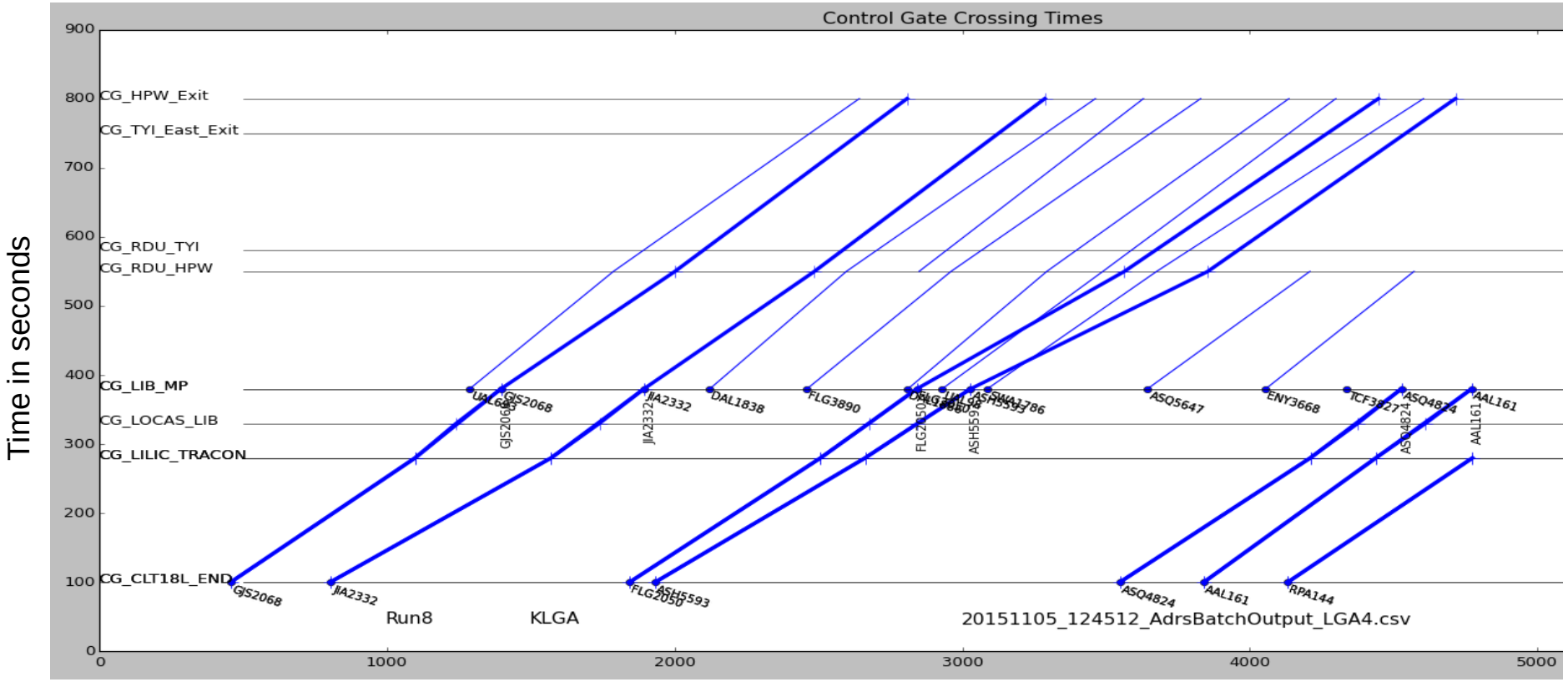
Run 5 – Full ZDC (20MP)



Sequence of aircraft at LIB and HPW for CLT Departures in the MIT condition

- Stream insertion at LIB is not optimal when the departures are only subject to a MIT.
- The demand rate is higher and the ties are more frequent (see example of Run 8 below).

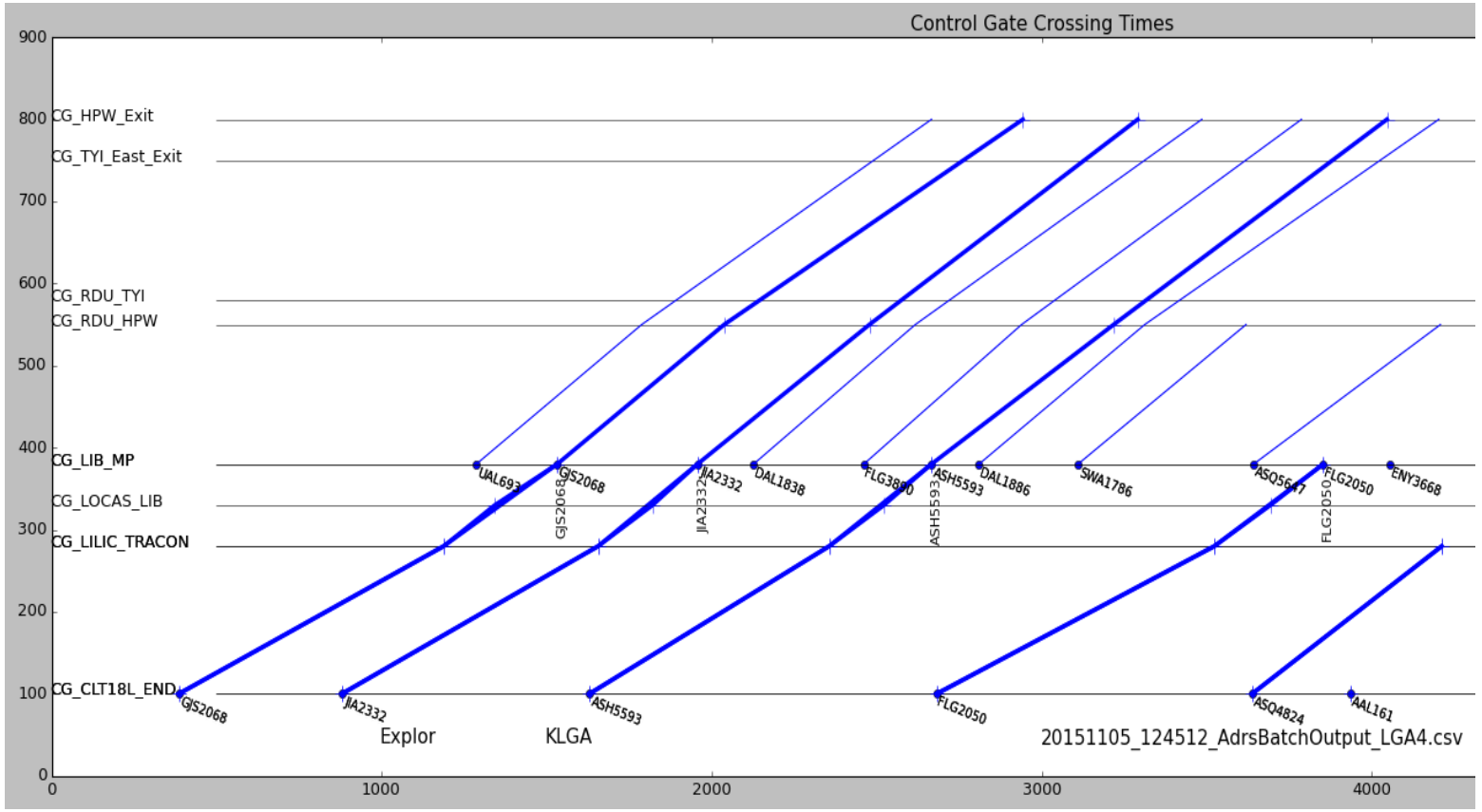
Run 8 – Partial MIT



Sequence of aircraft at LIB and HPW for CLT Departures to LGA scheduled by ZDC (exploratory run)

The delay accrued in the TRACON in the exploratory run seemed to have helped the insertion of traffic in ZDC.

Exploratory Run – Full ZDC (15MP)



Back-Up Slides

The MERIL Departures are the Most Frequently Impacted by CFR

A sample of flight restrictions in April 2015 shows that:

- 19% of CLT departures fly the MERIL departure route
- 18% of the MERIL departures were restricted with a CFR
- 65% of the times, the cause was “volume” in ZDC