Airspace Technology Demonstration 2 (ATD-2)

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

Results Outbrief

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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

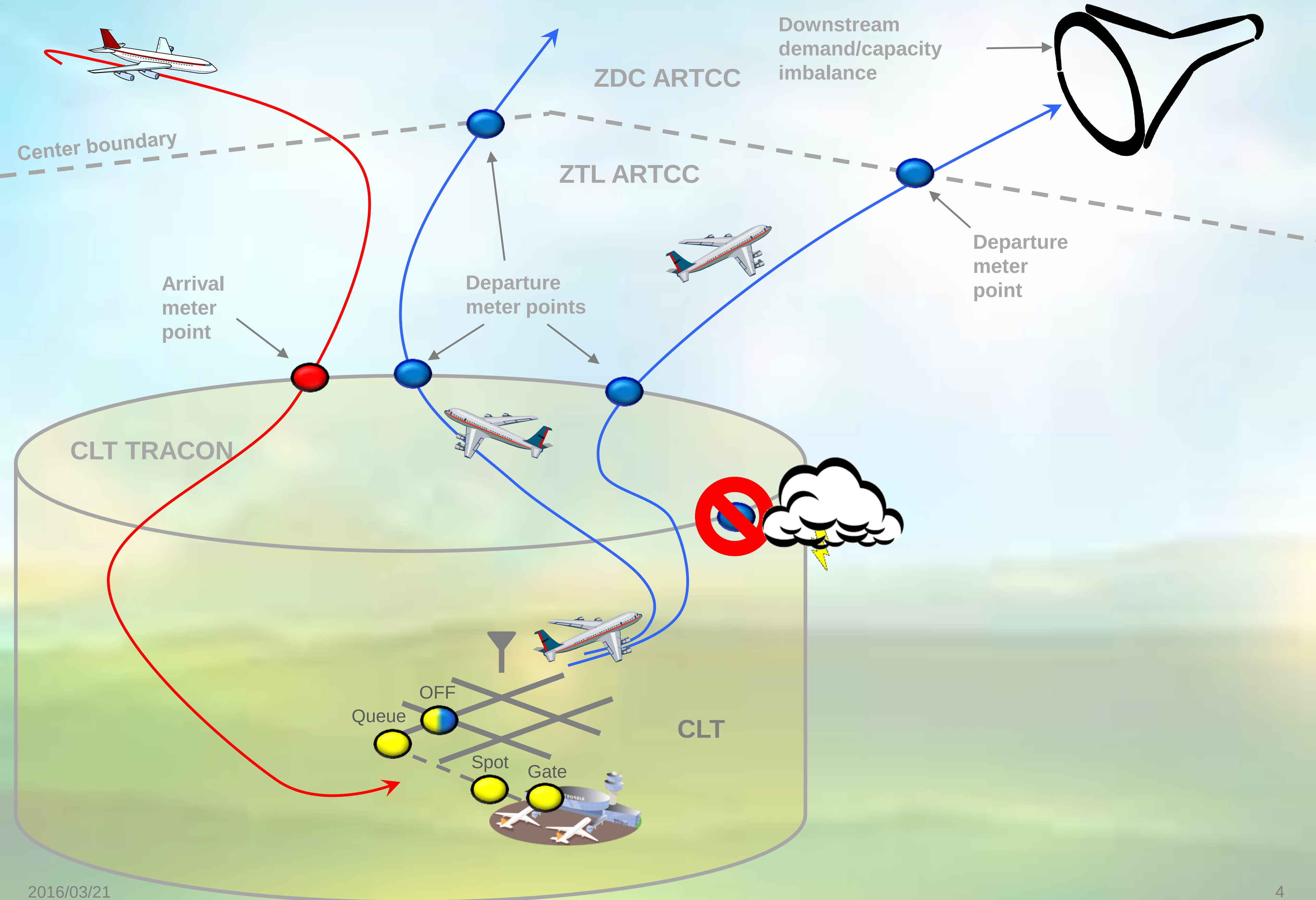
OBJECTIVES

- 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

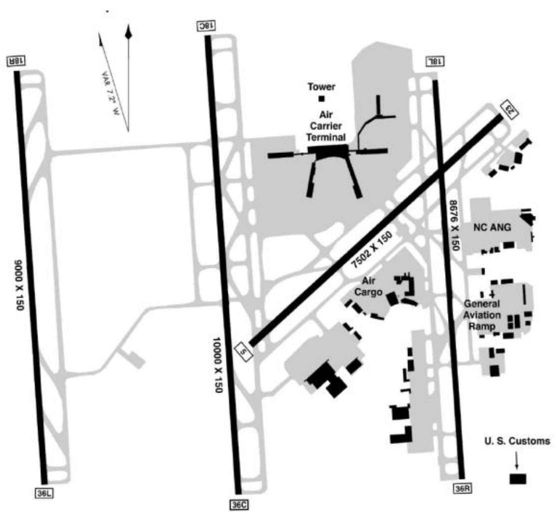
- Demonstrate the ATD-2 technologies in an operationally relevant environment
- Quantify the benefits, performance, acceptability, and limitations of the ATD-2 technology
- Transfer an integrated set of technology to the FAA and airlines, airports, and suppliers.

Operational Environment for 2017 ATD-2



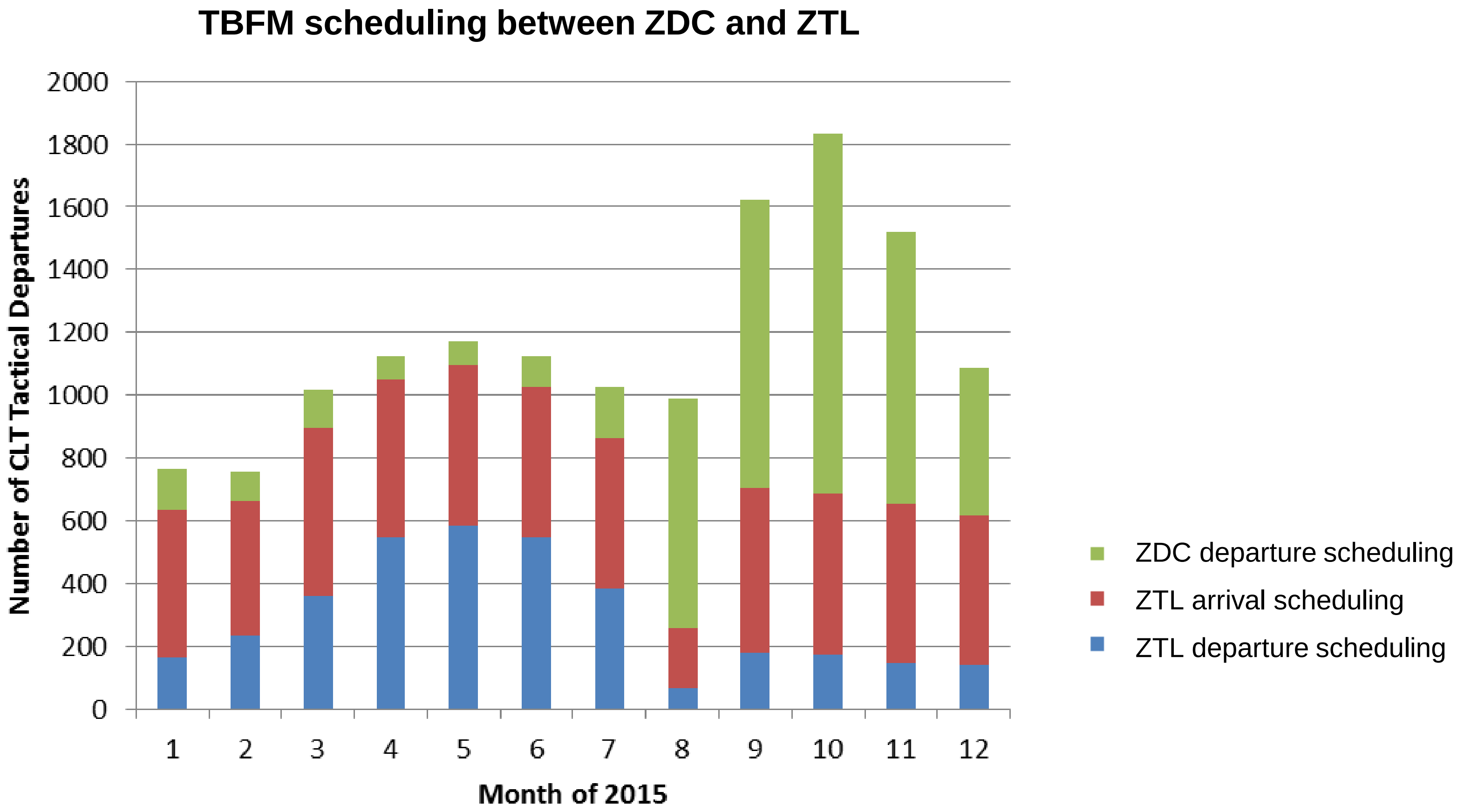
ATD-2 Field Demonstration Site

- Charlotte Douglas International Airport (CLT)
  - Large volume of operation (~1500 ac/day)
  - Subject to surface and tactical departure delays:
    - MIT
    - Call For Release (CFR) for outbound flows scheduled by ZTL or ZDC
    - CFR for inbound flows to ATL arrival metering scheduled by ZTL (Arr. Metering to ATL) by ZTL



Number of Tactical Departures scheduled with TBFM in 2015

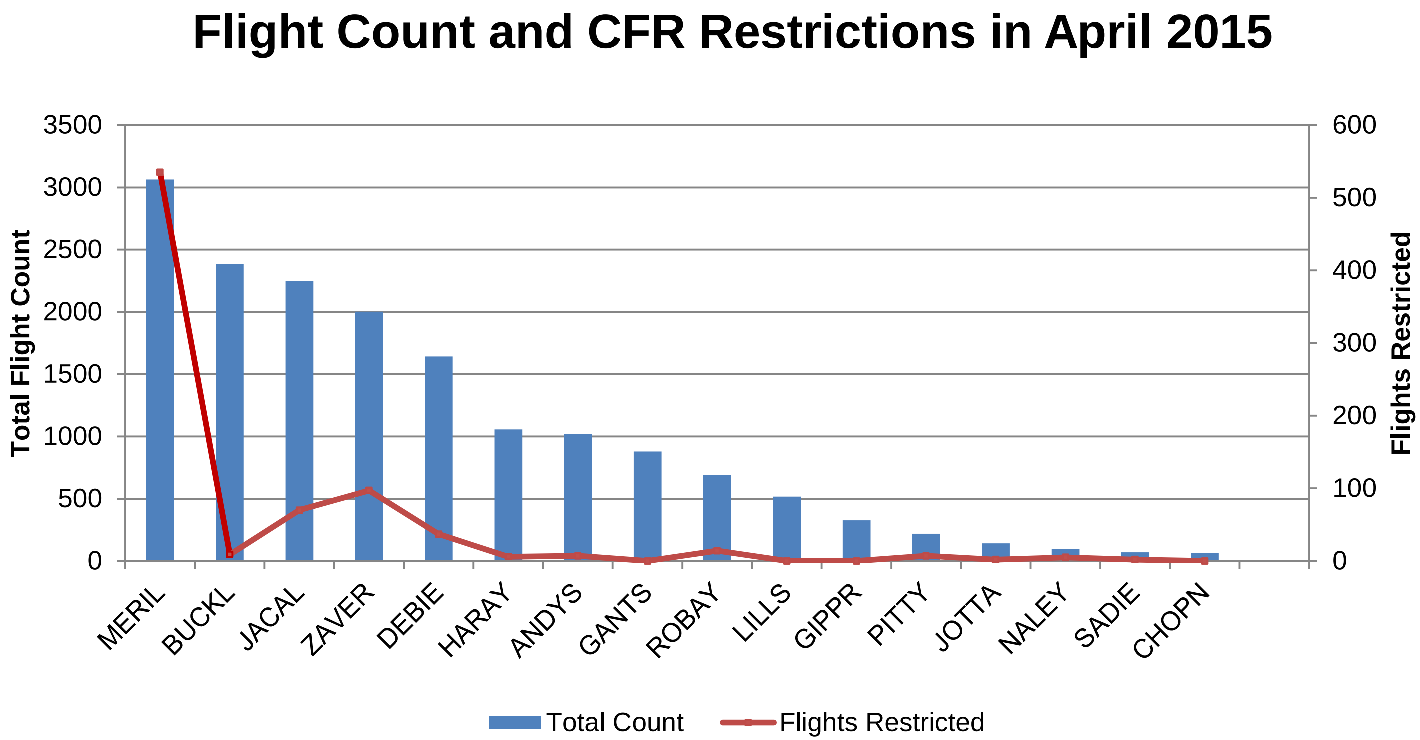
Starting in August 2015, about 60% of departures were scheduled by ZDC. The number of departures also increased, suggesting an increased need of ZDC to control the CLT releases. All the departures ZDC scheduled flew the MERIL departure route.



The MERIL departures are the most frequently impacted by CFR

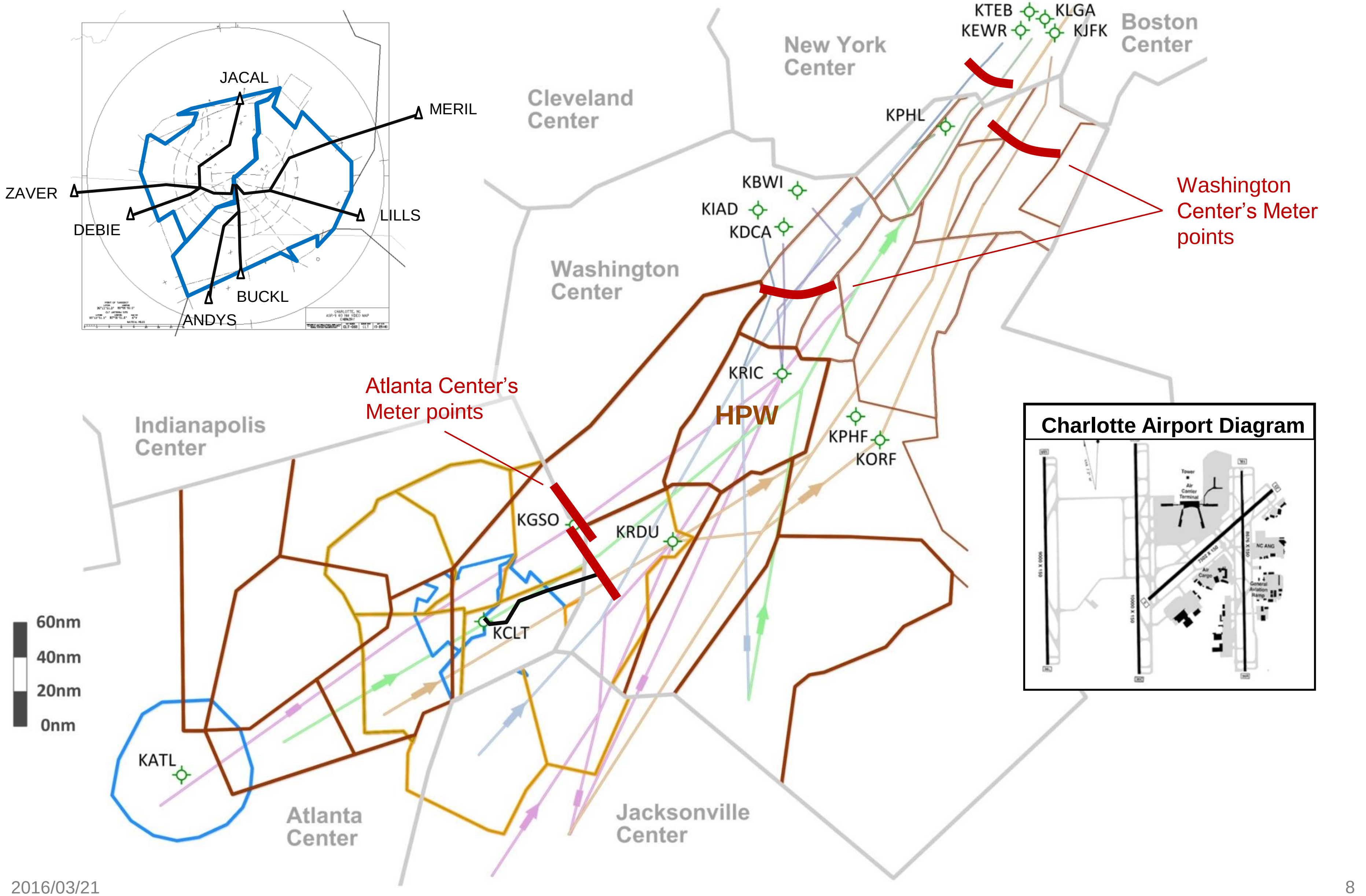
A sample of flight restrictions in April 2015 shows that:

- 19% of CLT departures fly the MERIL departure route
- 18% of the MERIL departures were restricted with a CFR
- 65% of the times, the reason invoked for the restrictions is volume in ZDC



Analysis by M. Kistler

Test Airspace



ZTL Constraints

- Independent scheduling at GSO and LIB
  - All MERIL departures cross LIB meter point.
  - Overhead streams of traffic crosses both LIB and GSO.
  - Notably, ZTL overhead traffic bound to LGA and JFK overhead traffic crosses LIB, and overhead traffic bound to EWR crosses GSO.
  - Thus both the overhead and the departures to LGA and JFK cross LIB. ATL and CLT competes for slots at LIB.
  - Thus when ZTL needs to schedule CLT departures to LGA and JFK, there are less available slots at LIB than there are for EWR. CLT departures to EWR cross LIB, where as the overhead crosses GSO. They are scheduled independently (thought it doesn’t have to).

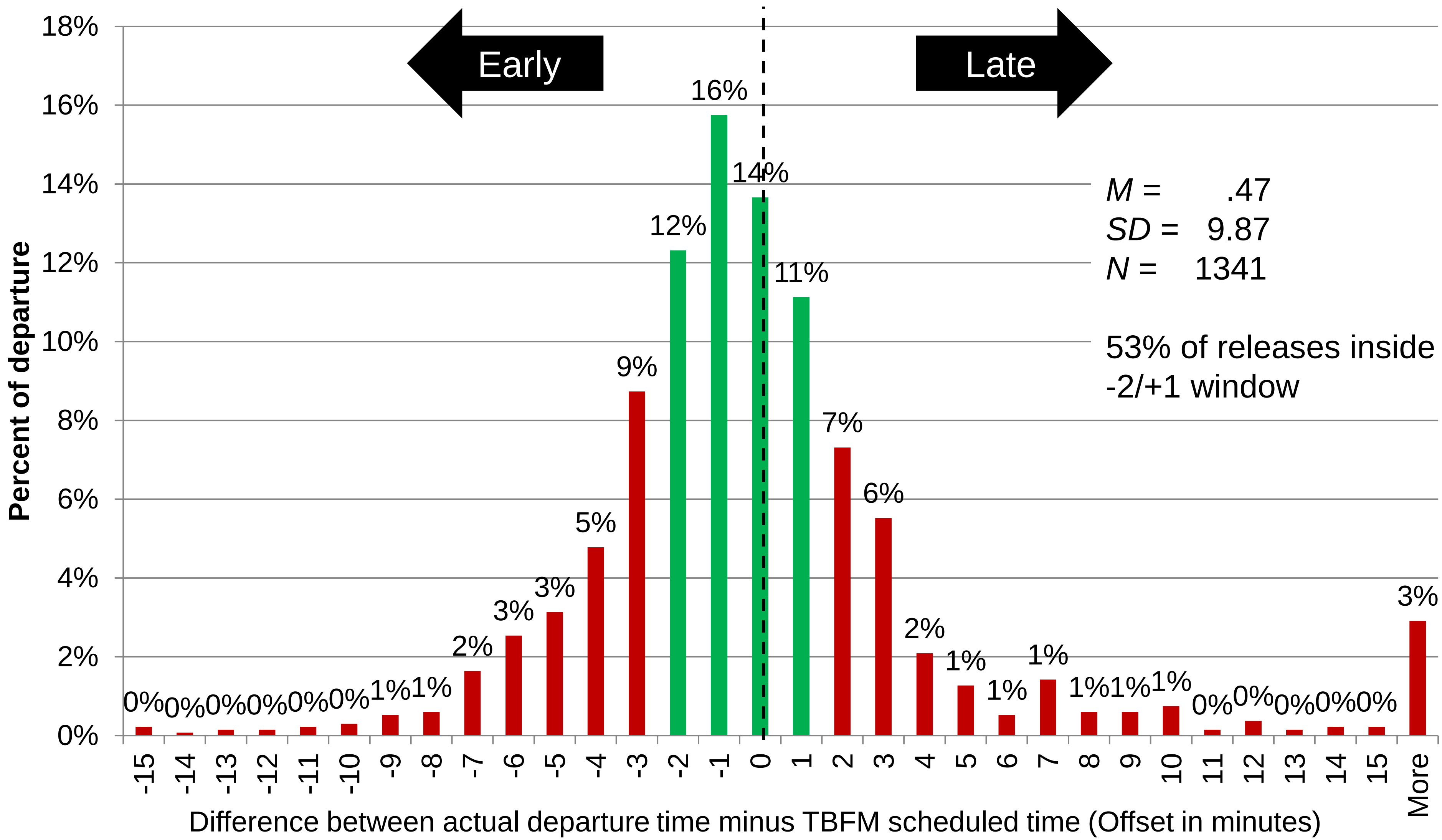
ZDC Constraints

- Lack of coordinated schedules across ZTL and ZDC
  - South of HPW sector, Charlotte (CLT), Greensboro (GSO), Raleigh (RDU, Richmond (RIC), Norfolk (ORF), Newport News (PHF), Wilmington (ILM), Fayetteville (FAY) airports are competing for slots into the overhead streams.
  - ZTL's schedule at LIB is not reflected in ZDC's own schedule at downstream meter points, until departures are airborne. This can make ZDC's schedule unreliable particularly, when there is excess demand.
    - Sometimes CLT departures conflict with another ZDC departures for the same slot in the schedule.
    - Traffic at LIB and GSO is not timed with traffic from ZJX.
- Unreliable high demand from ZTL and ZJX making demand capacity imbalances difficult to manage
  - Traffic from ZTL and ZJX converge into single arrival streams
  - Frequent excess demand for given capacity in ZDC sectors and flows.
- Low compliance of CLT departure times create additional uncertainties and inefficiencies

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 in 2014)

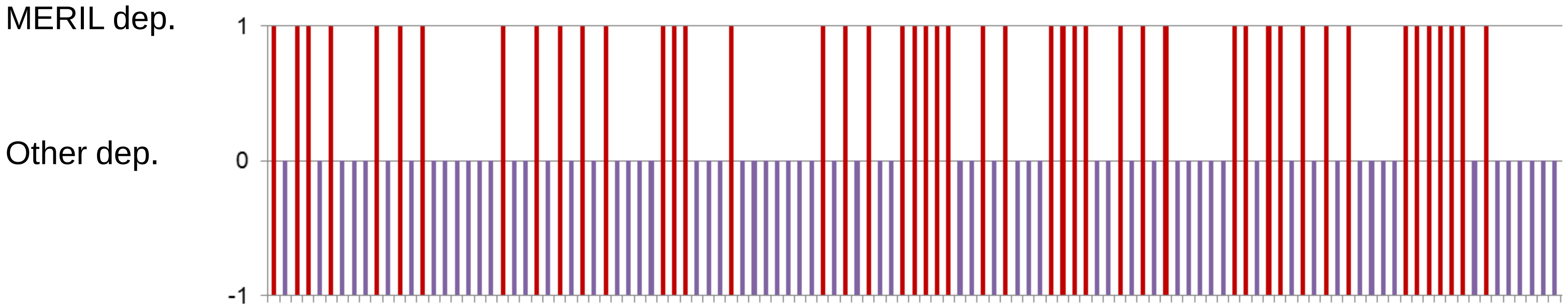


Data source: NTX OTTR EDC output, 12 months in 2014

CLT Tower Sequences Departures to Meet MIT Restrictions at the Runway

- Tower aims to deliver equal spacing or 5nm less than required to support the TRACON's MIT restriction.
- For example, to meet 15MIT, CLT's GC and LC will aim to insert another departure in between the restricted departures. For example, 1 MERIL, 1 BUCKL, 1 MERIL, etc.

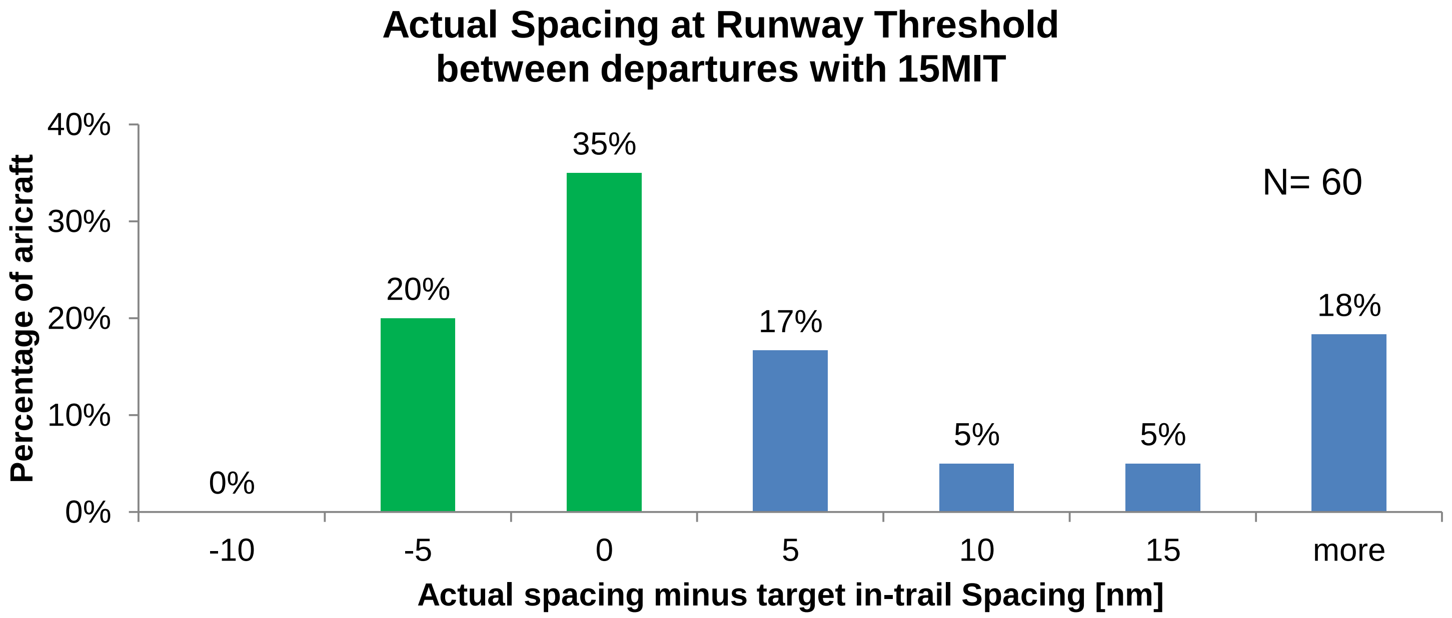
Sequence of departures from RWY 18L during a 15 MIT restriction (April 2nd 2015)



Average of *M*= 1.4 (*SD*= 1.8) aircraft in between each MERIL departures

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



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?

Objectives for HITL

1. Establish simulation environment for airspace operations
2. Simulate current-day departure and arrival 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

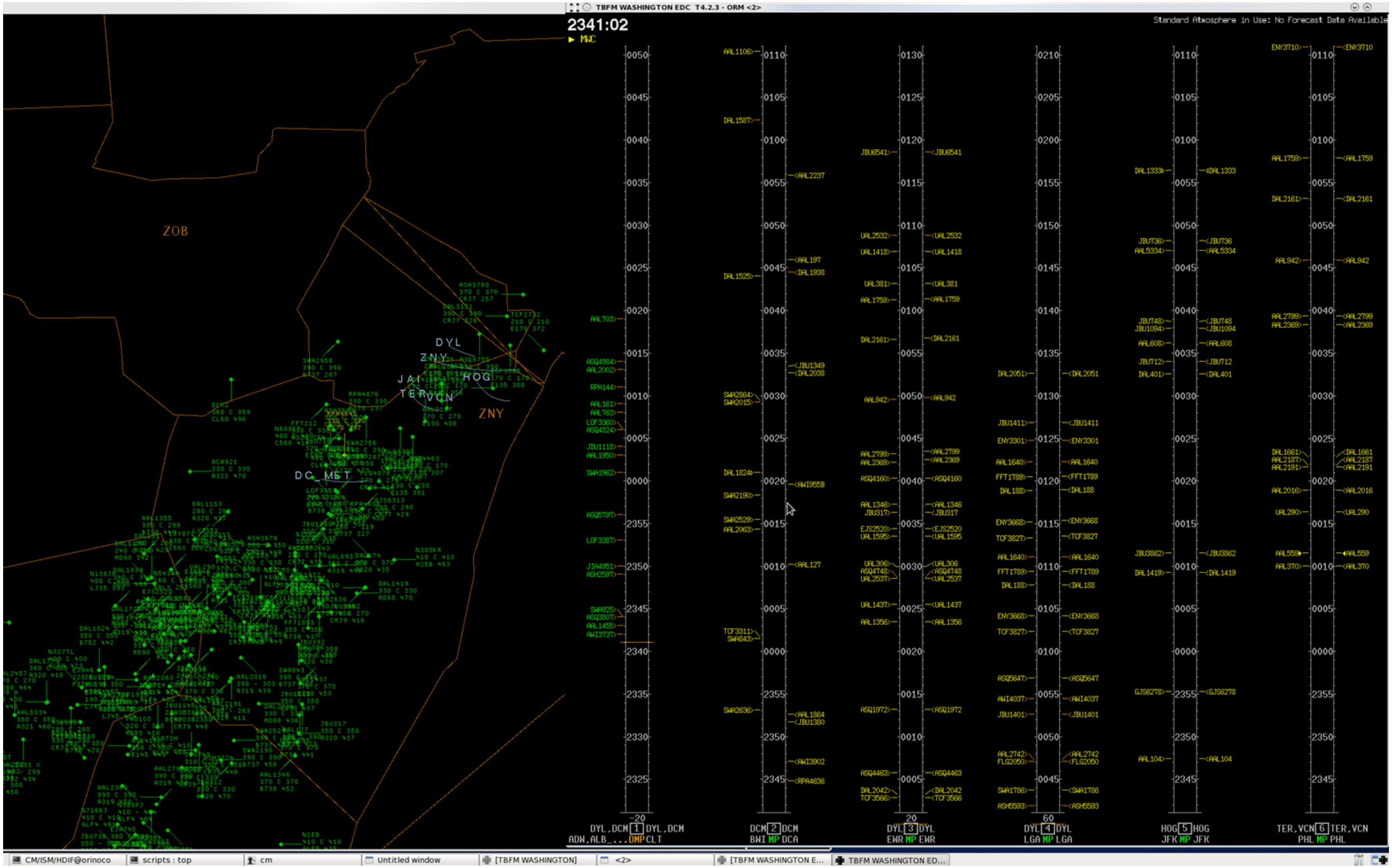
Method

Technologies

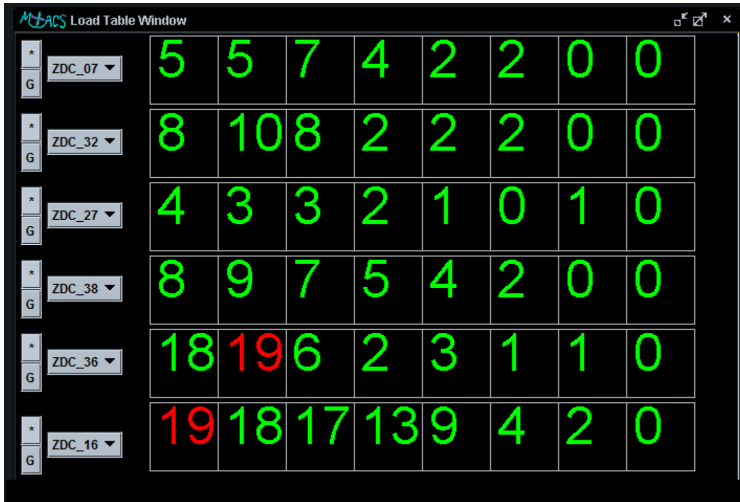
- TBFM 4.2.3 En route Departure Capability (EDC)
  - ZTL & ZDC adaptations
  - Version from the field as of August 2015
  - Both adaptations running at the same time

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

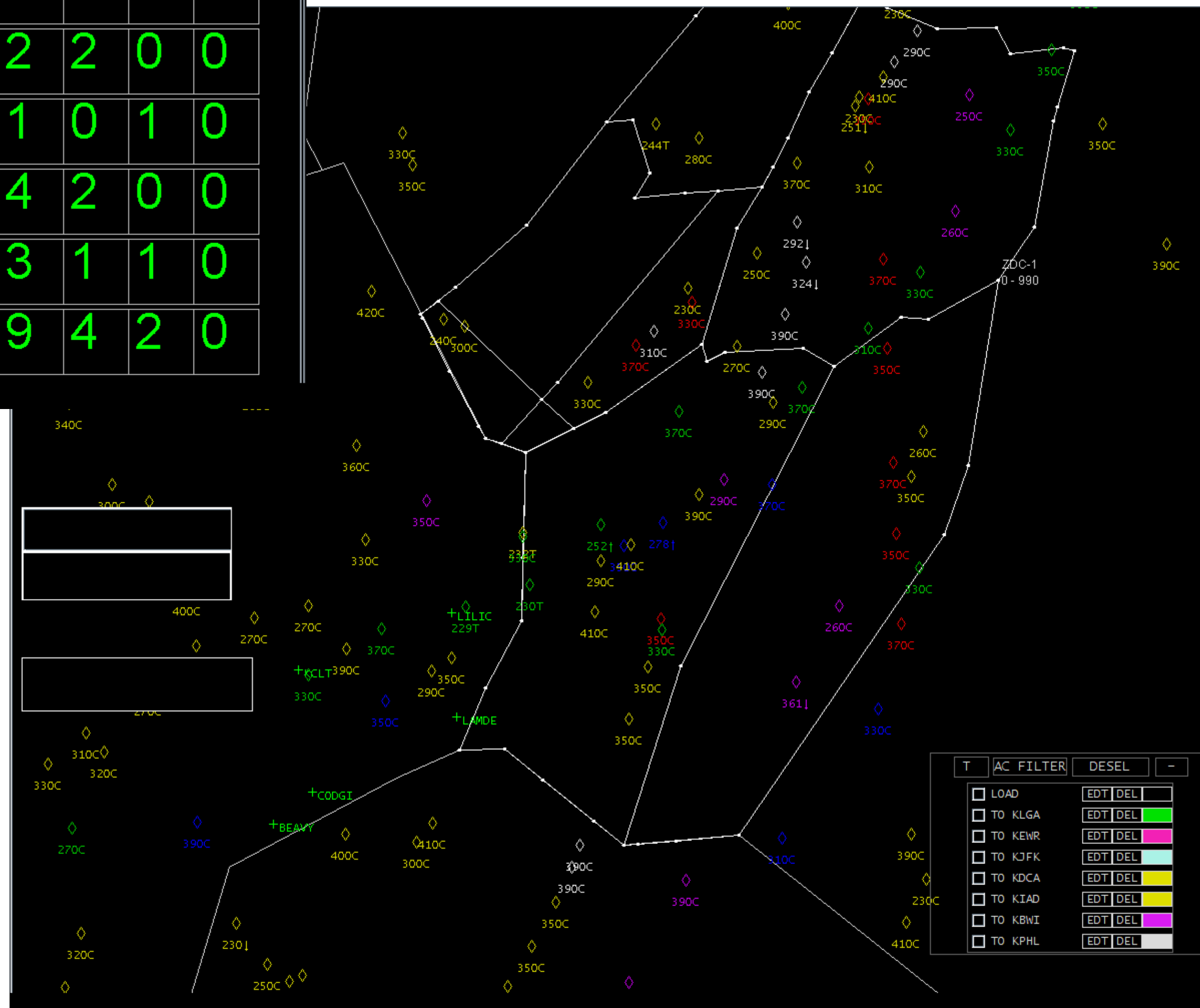
Example of ZDC TBFM PGUI and TGUI



Example Traffic in ZDC

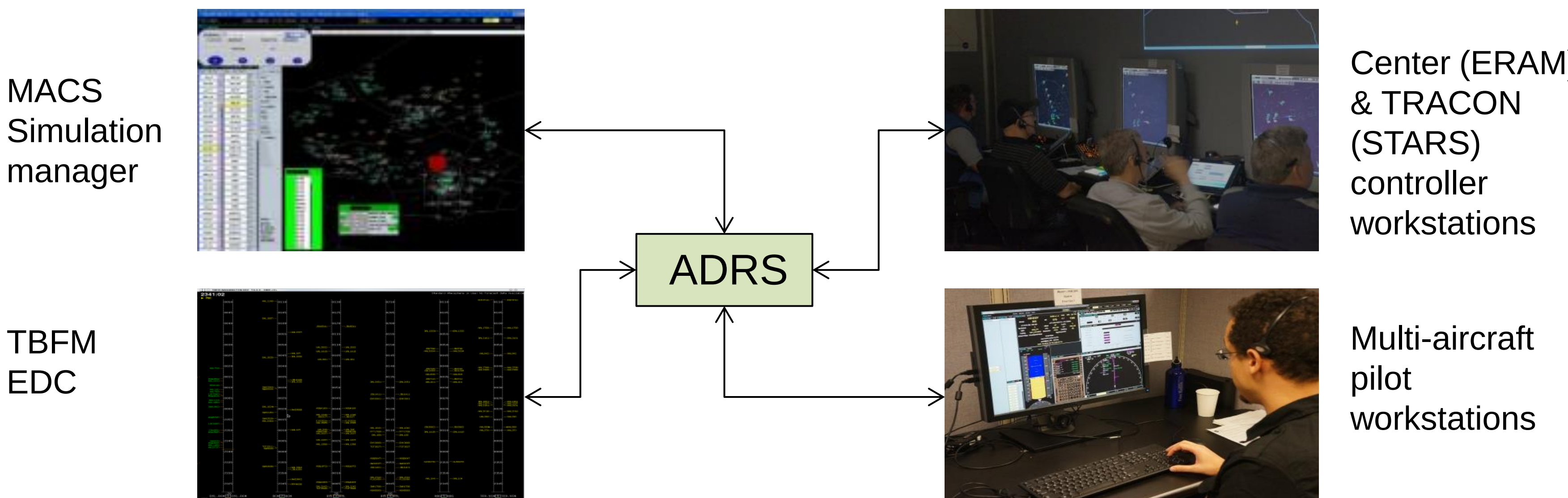


MACS Monitor Alert Parameter

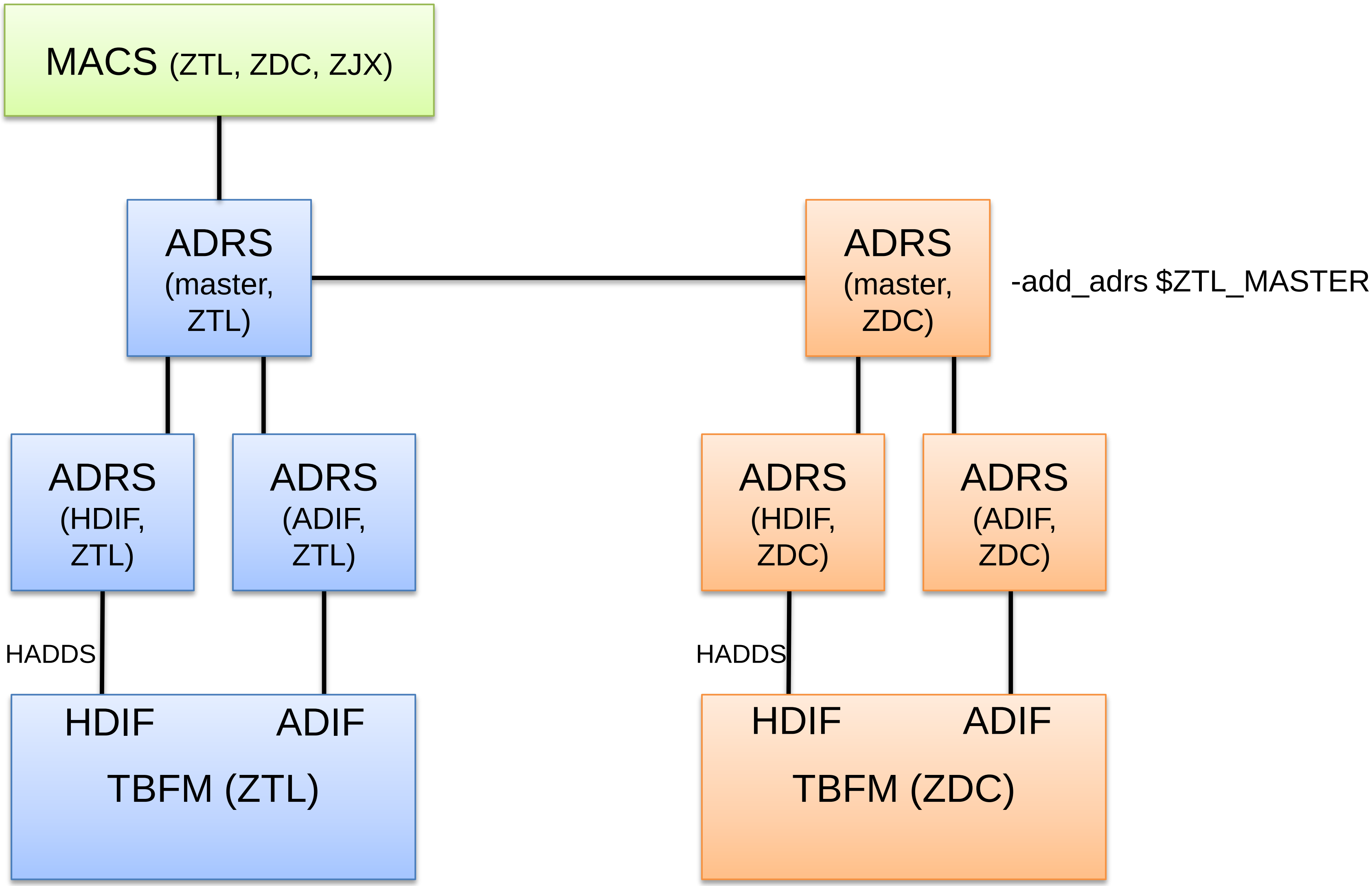


Resources

- 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



Multi-sites TBFM configuration



Participants

13 retired & 1 active controllers with actual 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 active STMC from ZDC
- 1 retired TMC from ZTL
- 1 retired STMC/TMO from ZOA (Sup)

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

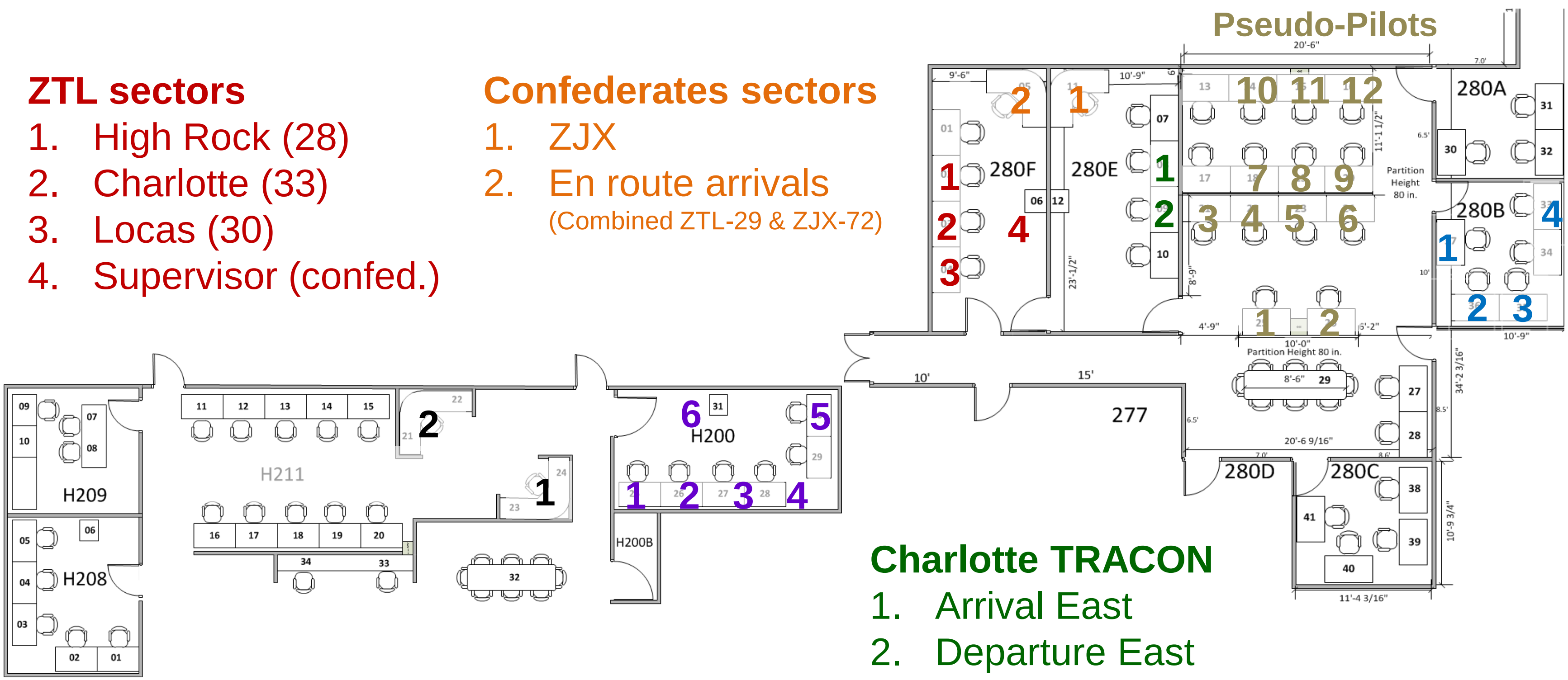
12 Pseudo-pilots (SJSU Aviation students), 1 for each sector

ATD2 Airspace Operation Laboratory Layout

Integrated Arrival/Departure/Surface

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

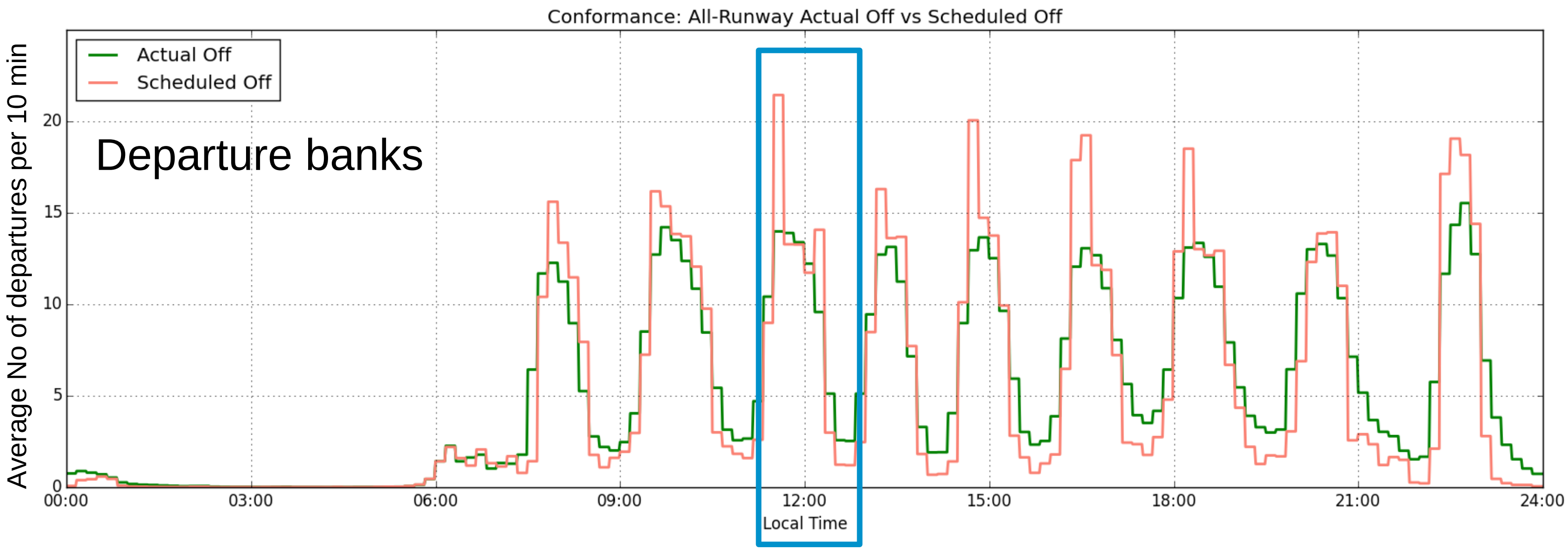
TMC Stations
1. ZDC TGUIs
2. ZTL TGUIs

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

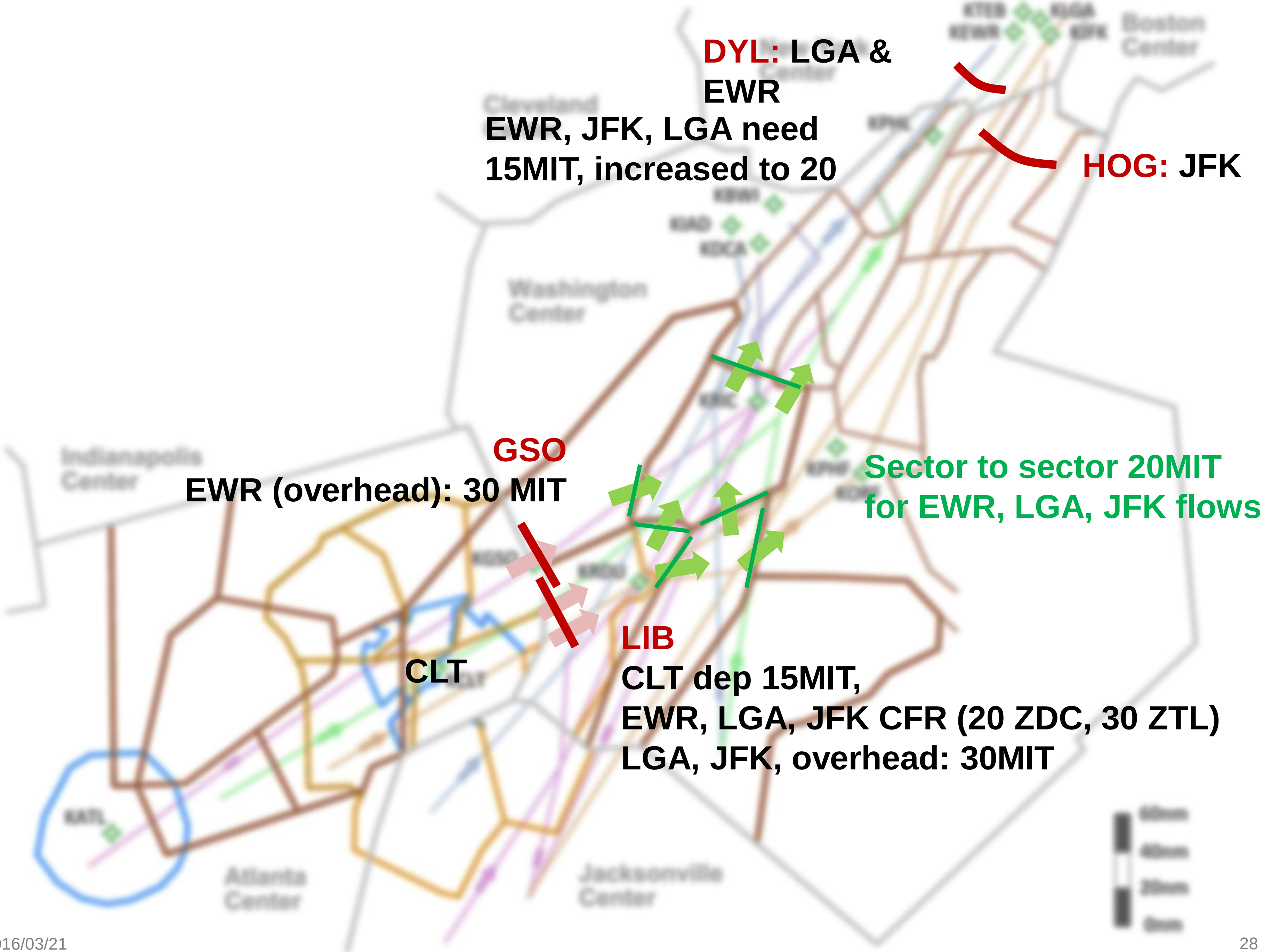
- Sector capacity
  - Target demand: 25-30 peak traffic load into key sectors (RDU & HPW)
  - Capacity: MAP value of 17 (official) to 20 (acceptable)

Scenario Design – En Route traffic

- 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



DYL: LGA &
EWR
EWR, JFK, LGA need
15MIT, increased to 20
HOG: JFK
GSO
EWR (overhead): 30 MIT
Sector to sector 20MIT
for EWR, LGA, JFK flows
CLT
LIB
CLT dep 15MIT,
EWR, LGA, JFK CFR (20 ZDC, 30 ZTL)
LGA, JFK, overhead: 30MIT

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

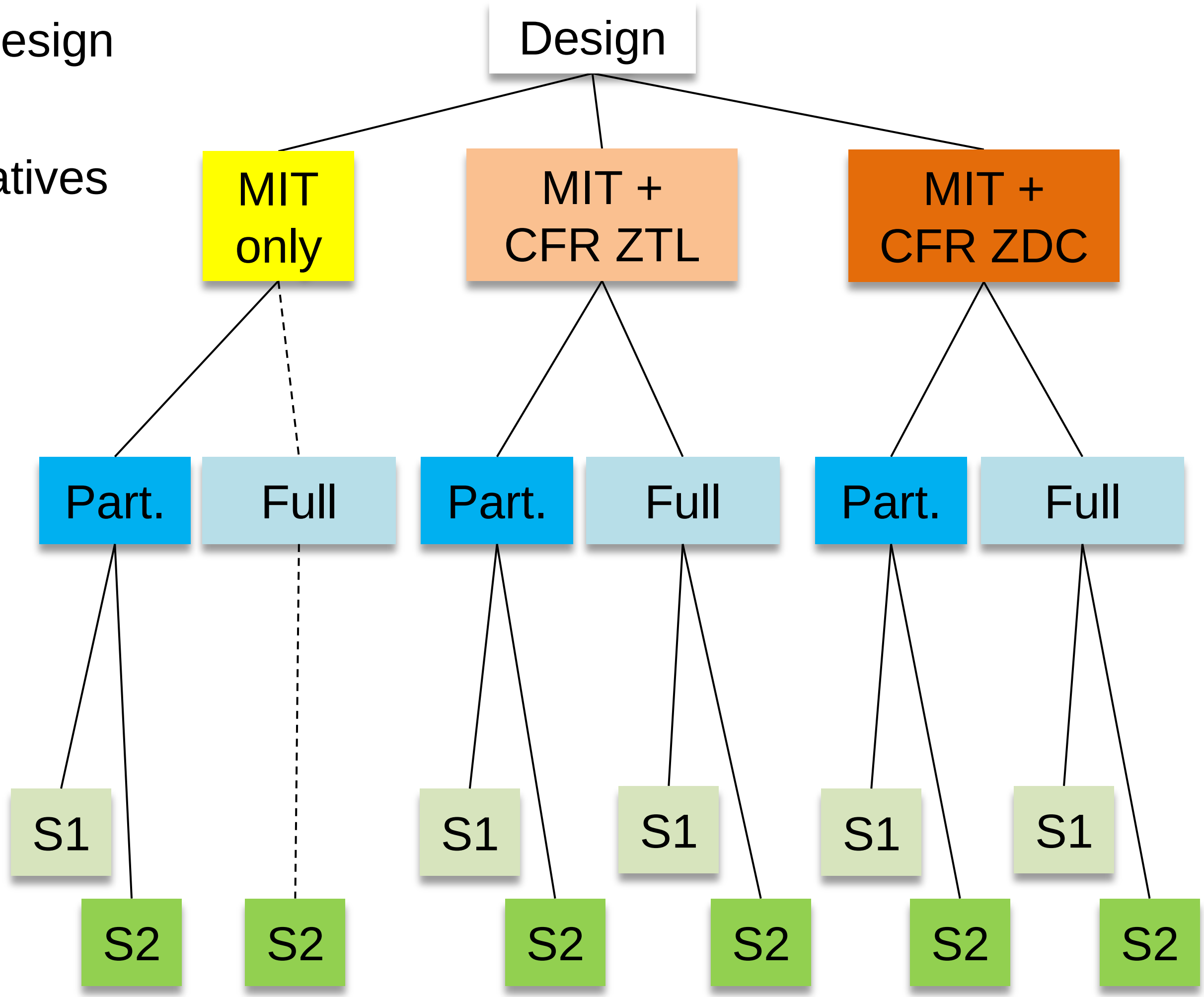
ATD2 Integrated Arrival/Departure/Surface

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 takeoff compliance to Target 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

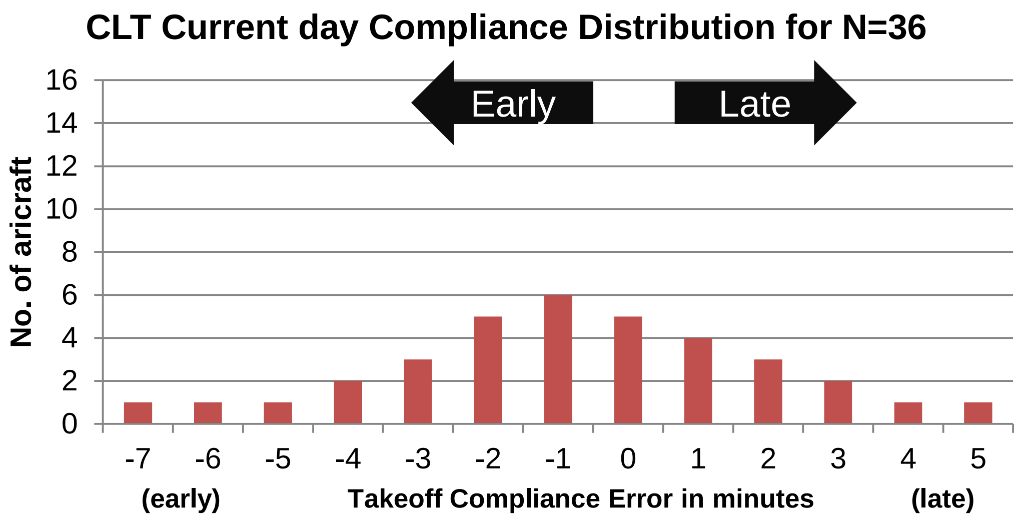
4 practice runs
10 data collection runs
1 extra run

Order of runs counter-balanced

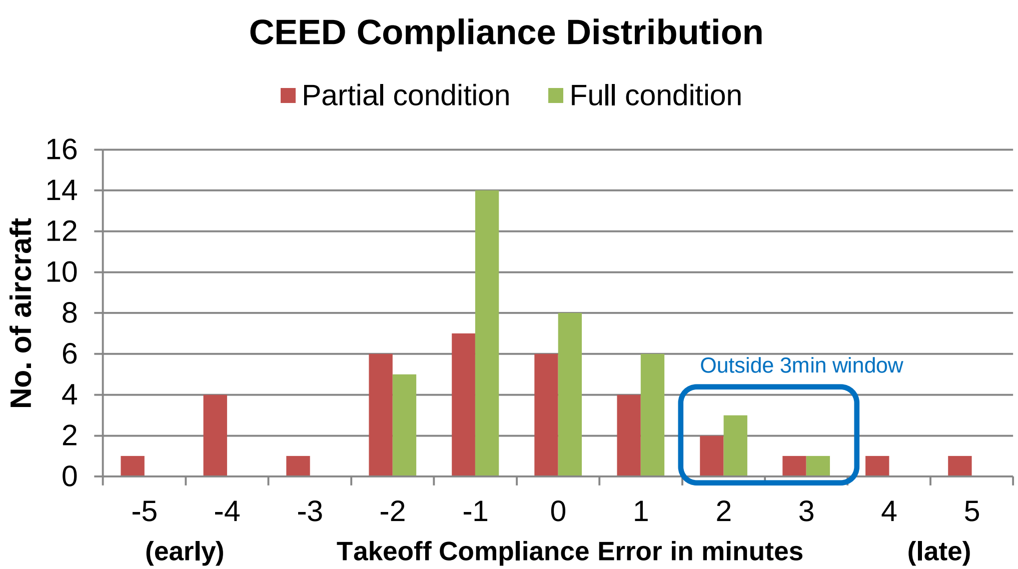
Practice Runs: Monday – Tuesday Practice rows
Data collection Runs: Tuesday run 1 – Friday Re-run3
Bonus Run: Friday Exploratory

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

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

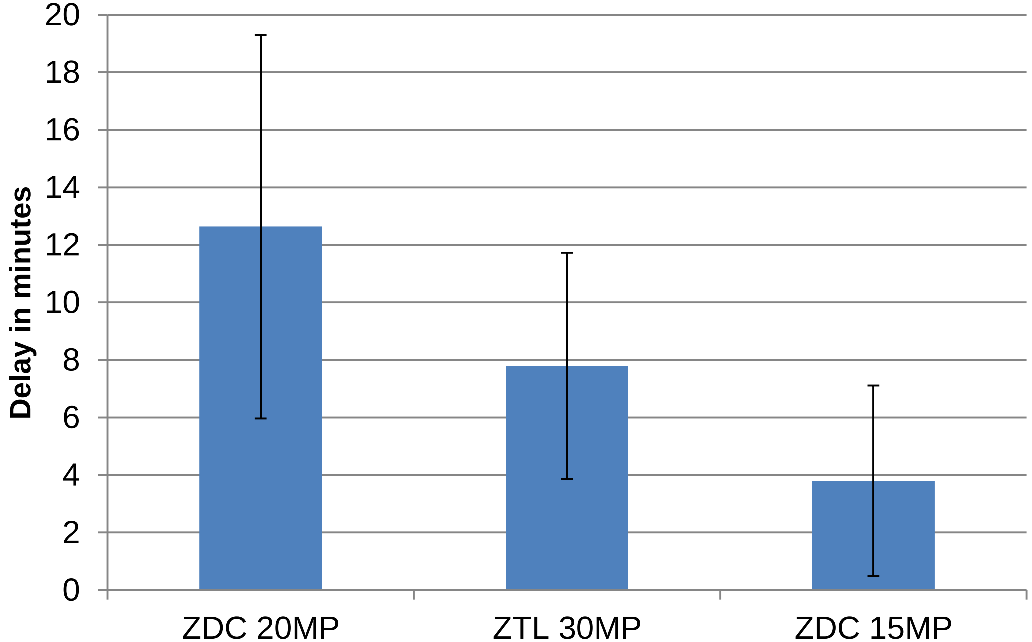
Limitations of the HITL

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

Scheduling and Releasing Departures

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.

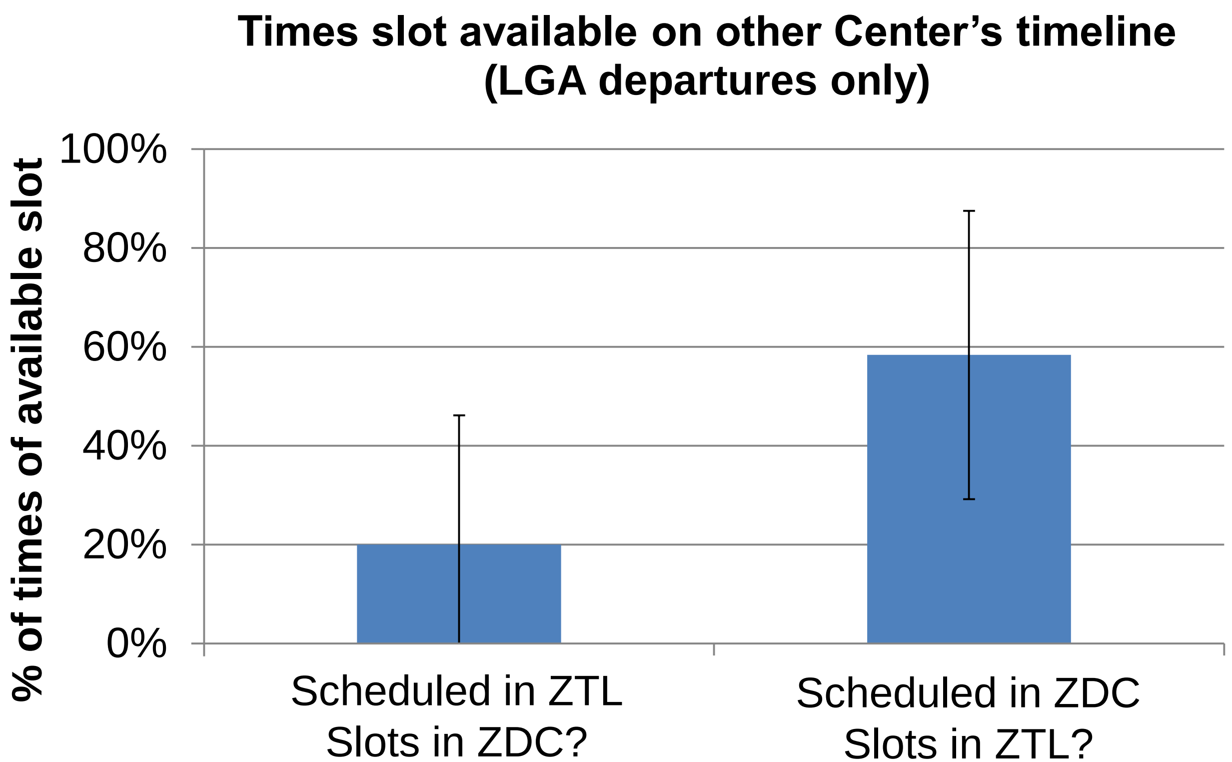


TBFM $F(2,82) = 1.56$, p .21

Slots Were Less Frequently Available at ZDC's MP Schedule When ZTL Scheduled Departures at its MP

ARTEFACT

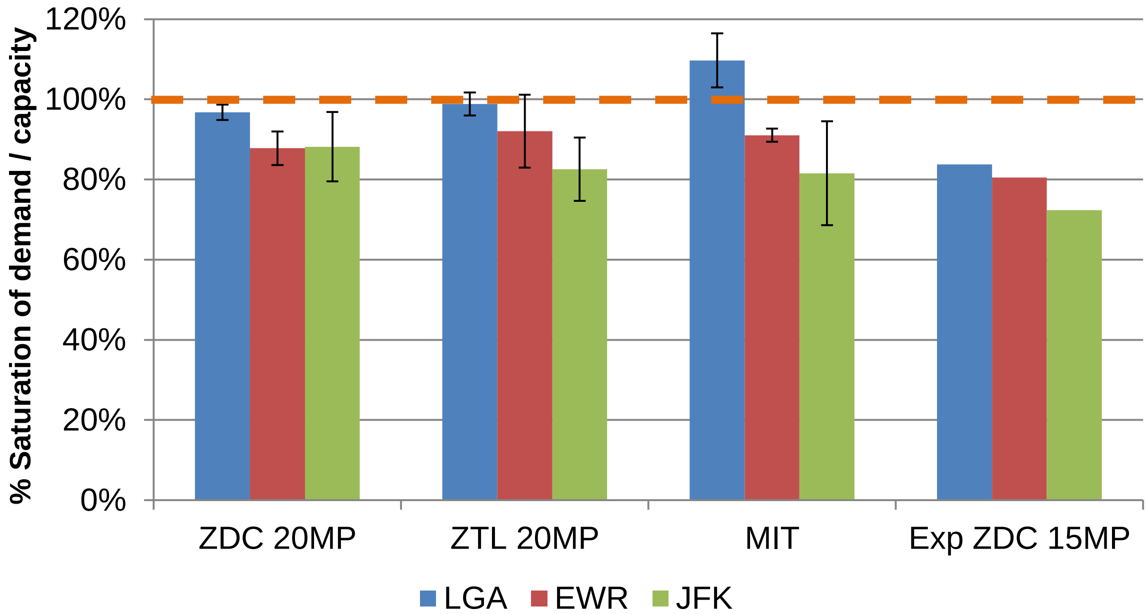
- ZTL scheduling without inclusion of ZDC schedule at LIB can negatively impact ZDC schedule.
- ZDC MP had less slots available because it includes multiple flows, that ZTL MP does not include.
- Vice versa, when ZDC scheduled CLT departures it did not always matched available slots. This is due in part to the difference of MIT restriction at ZDC's and ZTL's MP.



Center *F*(1,20)= 3.5, *p* .074

Impact of TMI Manipulations on Demand Capacity / Balance

- The average demand reached near saturation in all TMI conditions, except in the Exploratory run (Exp ZDC 15MP). ~ 90% = 22/24 aircraft for 20MIT at the MP.
- 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, their departure were not tactically delayed.
- 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%.



Flow capacity

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 $F(2,21) = 12.30$, $p = .000$

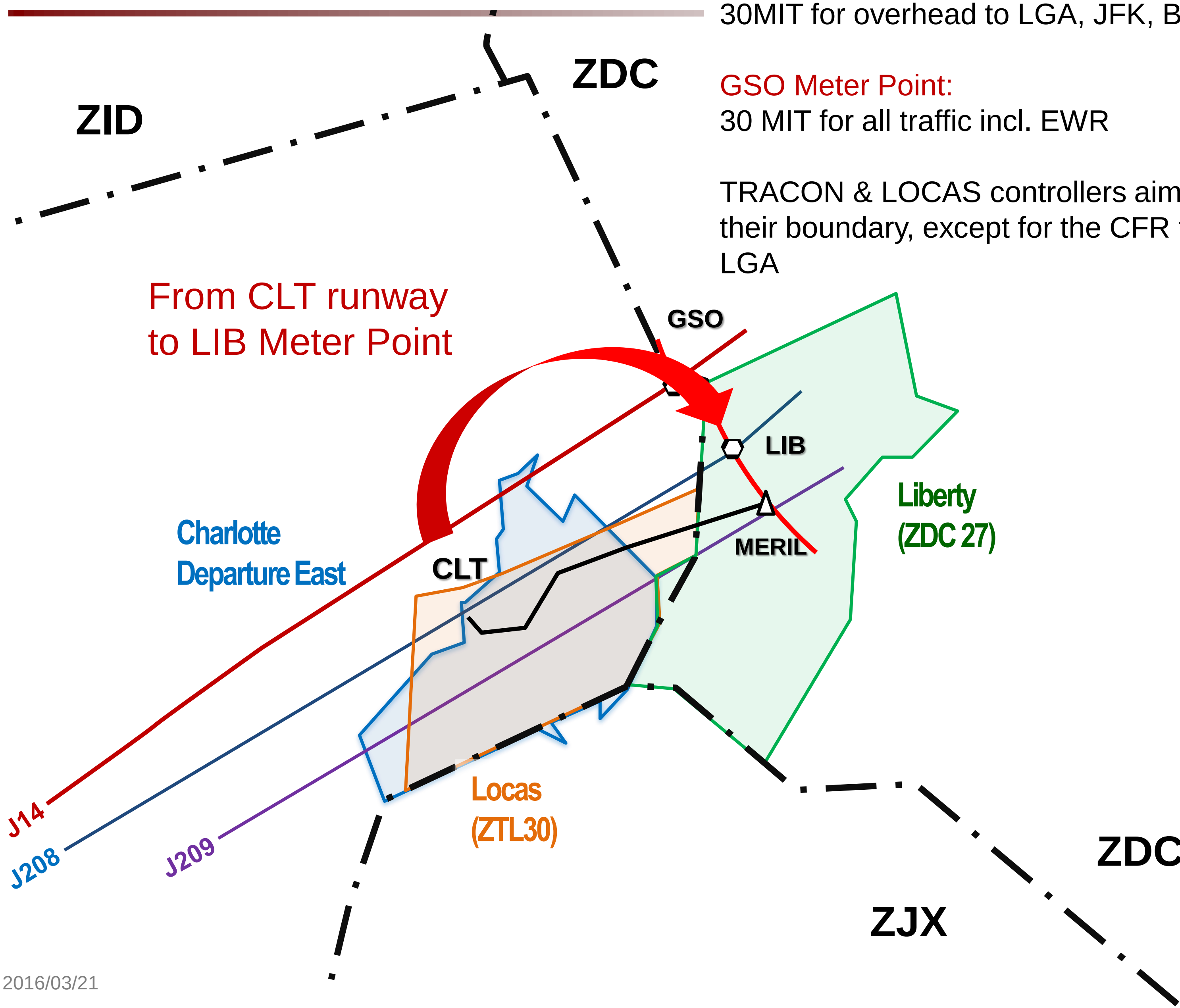
Flights to LIB

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

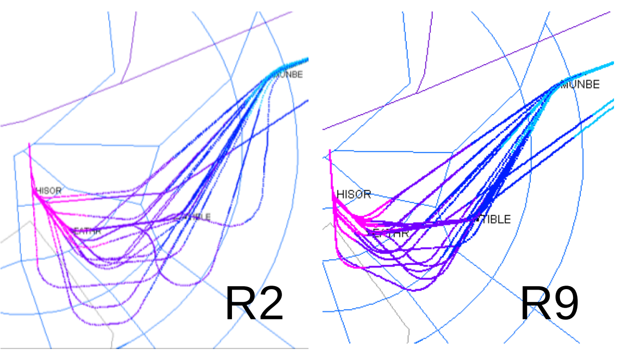
TRACON & LOCAS controllers aimed to provide 15MIT at their boundary, except for the CFR flights to EWR, JFK, LGA



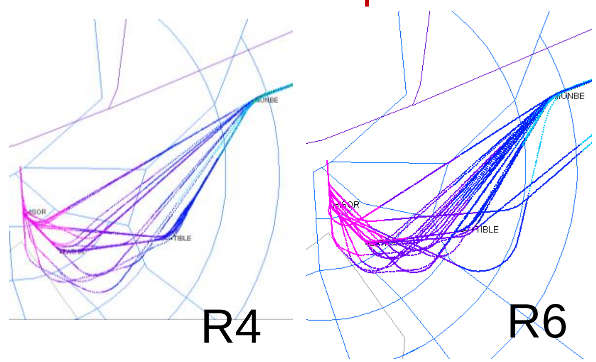
Visual of Key Tracks in the TRACON

- 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.

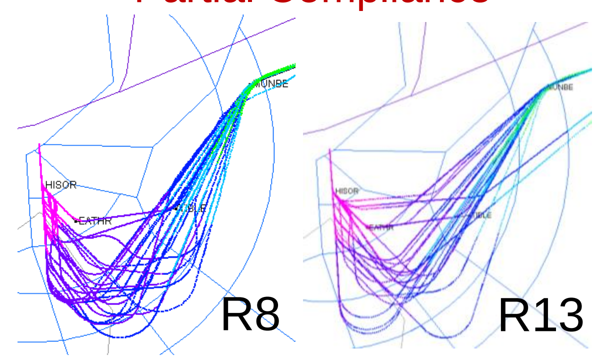
ZDC 20MP
Partial Compliance



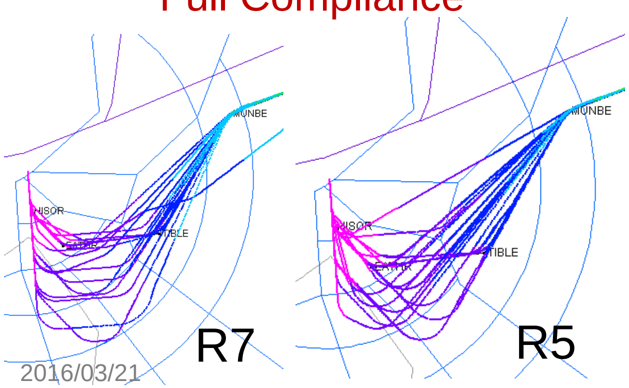
ZTL 30MP
Partial Compliance



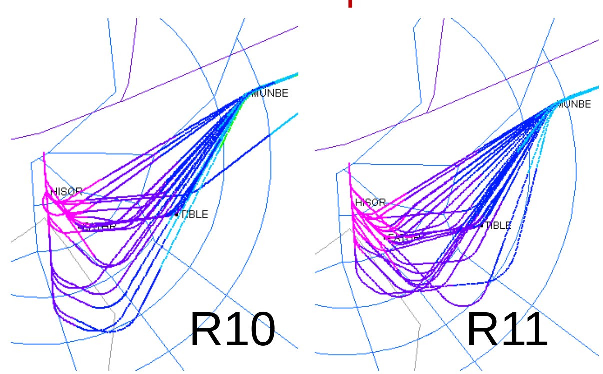
MIT
Partial Compliance



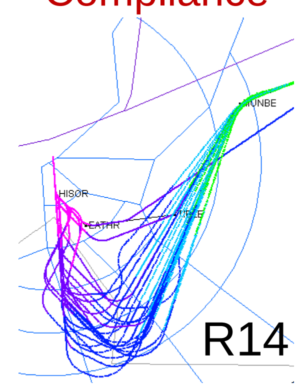
ZDC 20MP
Full Compliance



ZTL 30MP
Full Compliance

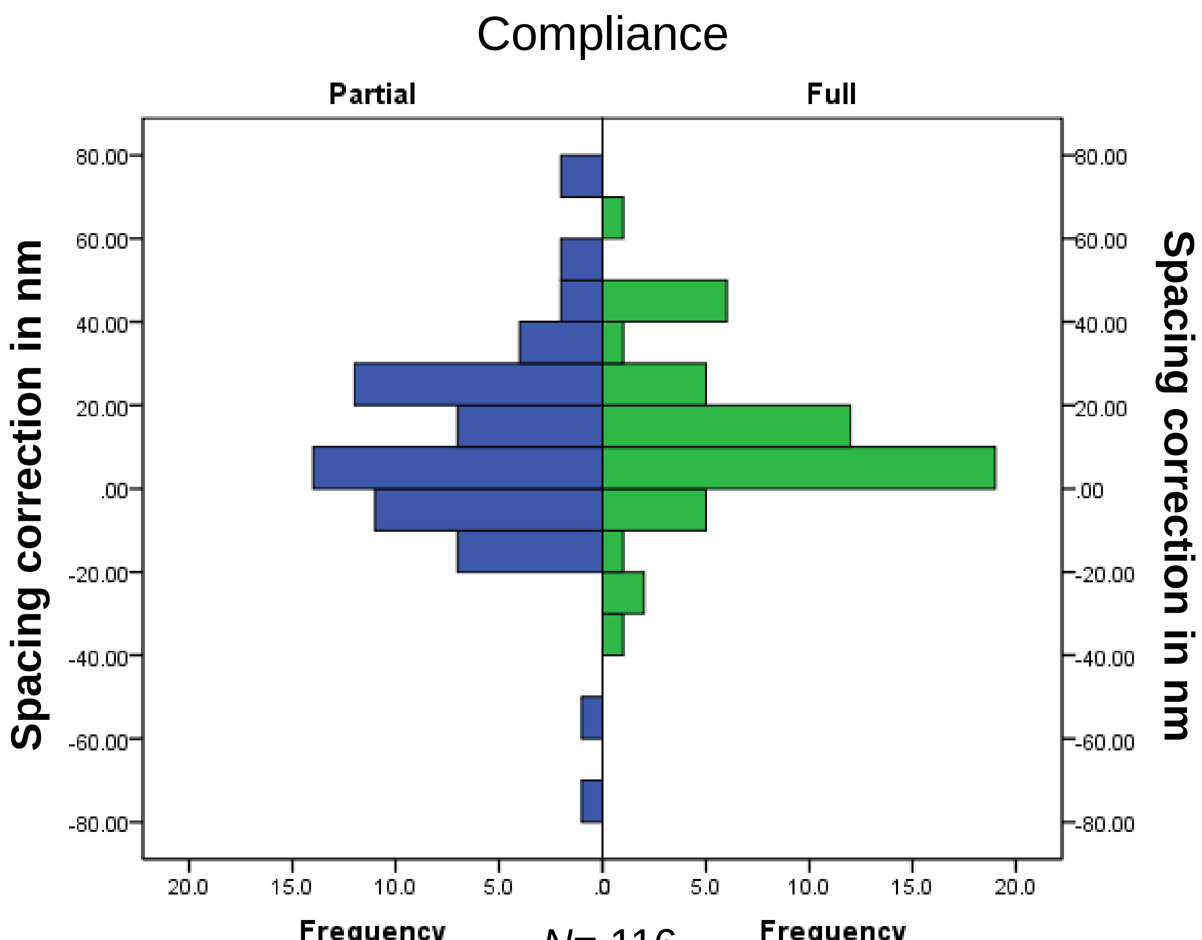


Expl. ZDC full
Compliance



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

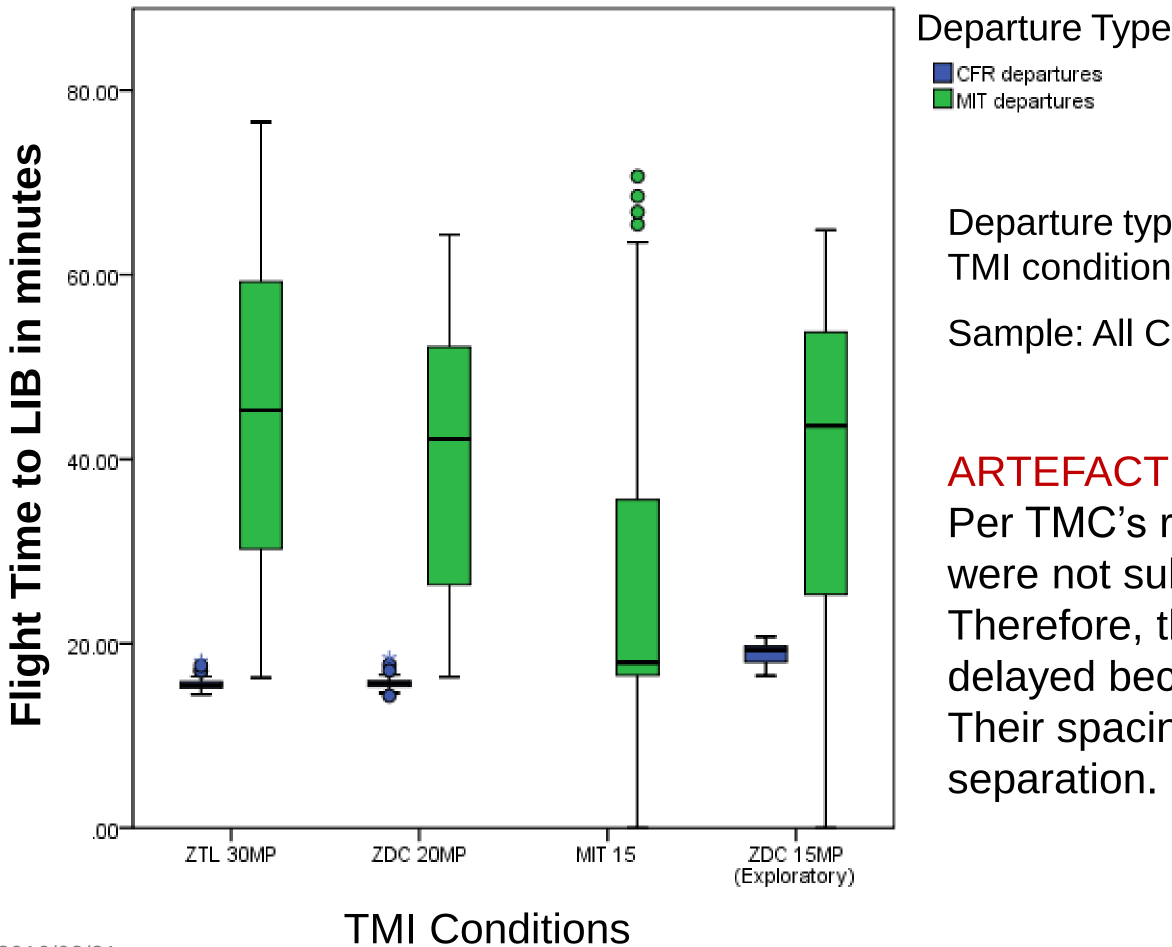
There was a larger variance of spacing corrections in the partial compliance condition compared to the full compliance condition, suggesting a high workload for the TRACON controller.



N= 116

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

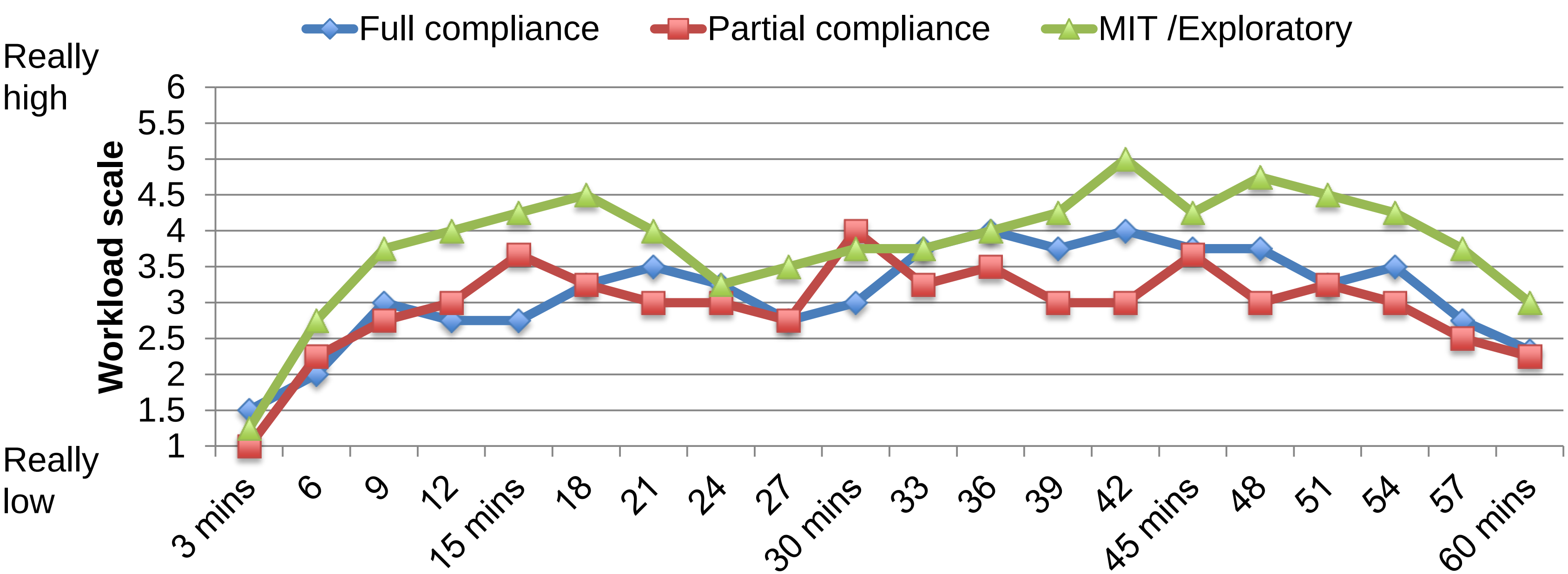
Sample: All CLT dep

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. Their spacing were impacted at times for separation.

The TRACON controller rated workload higher in the MIT conditions

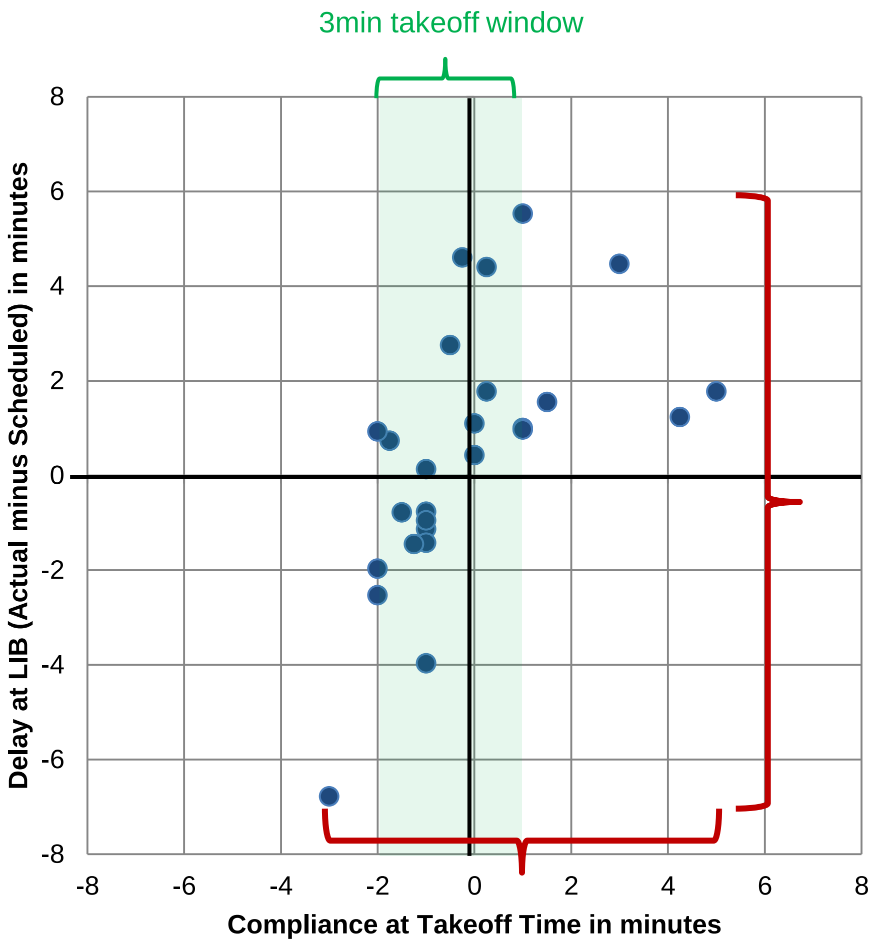
- Workload was self reported by controllers on a 6-point scale every 3minutes during the runs.
- TRACON controller's mean scores in the MIT/Exploratory conditions are significantly higher than the means score in the partial and full compliance conditions



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

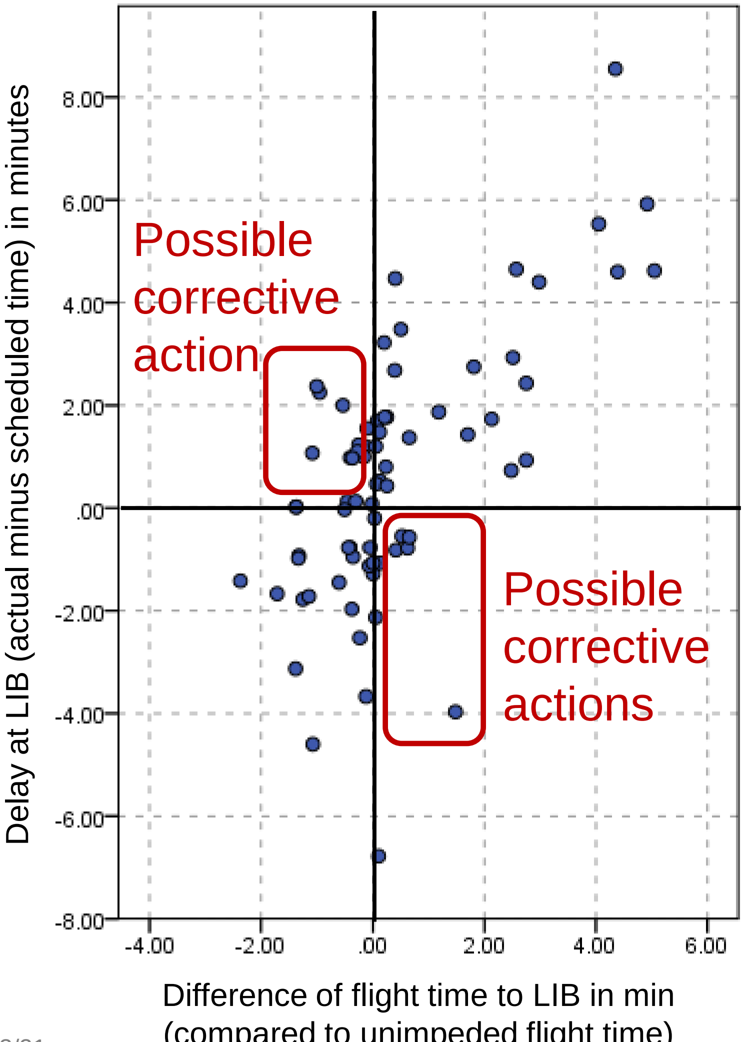
Takeoff Time Delay at the Runway Seemed to Increase at LIB Meter Point

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

Delay seemed to increase rather than decrease

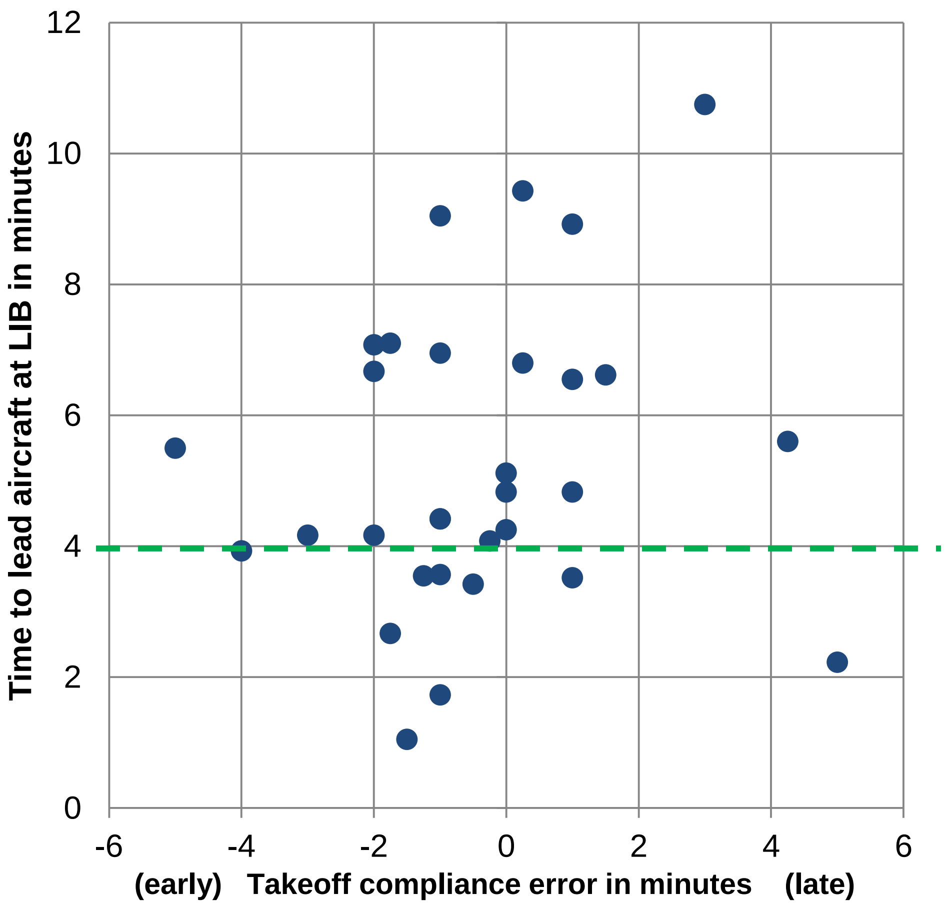


r(74)= .650, *p* .000

- The correlation between flight time and delay at LIB shows that
  - Early flight flew less long to reach LIB
  - Late flight flew longer to reach LIB
- Notes: Unimpeded flight time is ~15min
- Could this result in less optimal stream insertion?

The Compliance of Takeoff time Did Not Seem to Impact Stream Insertions at LIB

- The takeoff compliance error of the departures resulted in various spacing with the lead aircraft at LIB.
- Sample size is not large enough to see a correlation between the takeoff compliance error and the distance between the departure and the lead aircraft at LIB.
- However it can be noted that about 25% of the time the departures were spaced with less than the 4minutes of desired spacing at LIB.



Departures to LGA (*N*= 28)
no significant correlation

Need a larger sample size to draw conclusions

4minutes is the time in between STAs to get 30MIT at LIB

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 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 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. 100% of stream insertion behind the right lead aircraft once the departure was airborne.

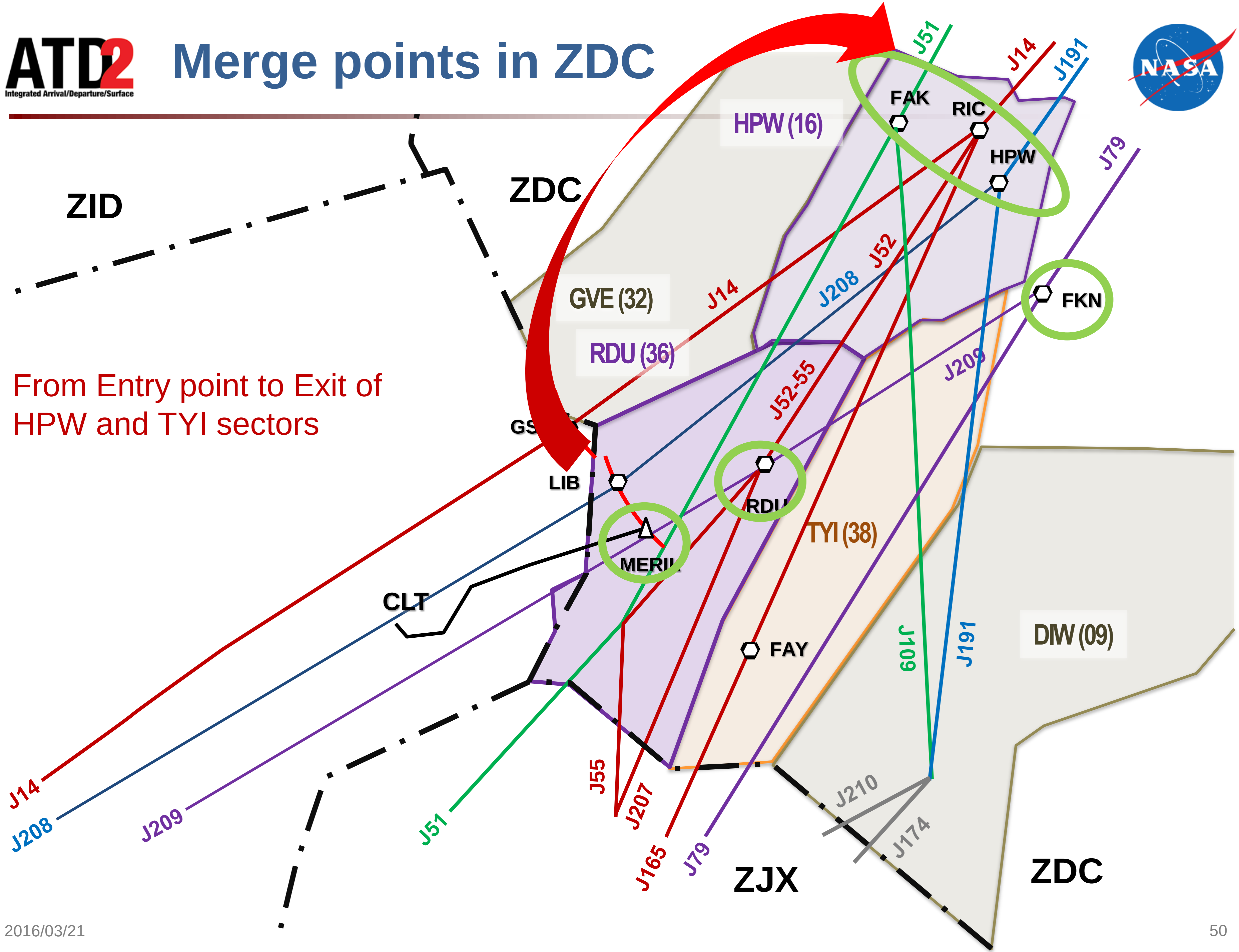
Stream Insertion at LIB meter point (Scheduled by ZTL)

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

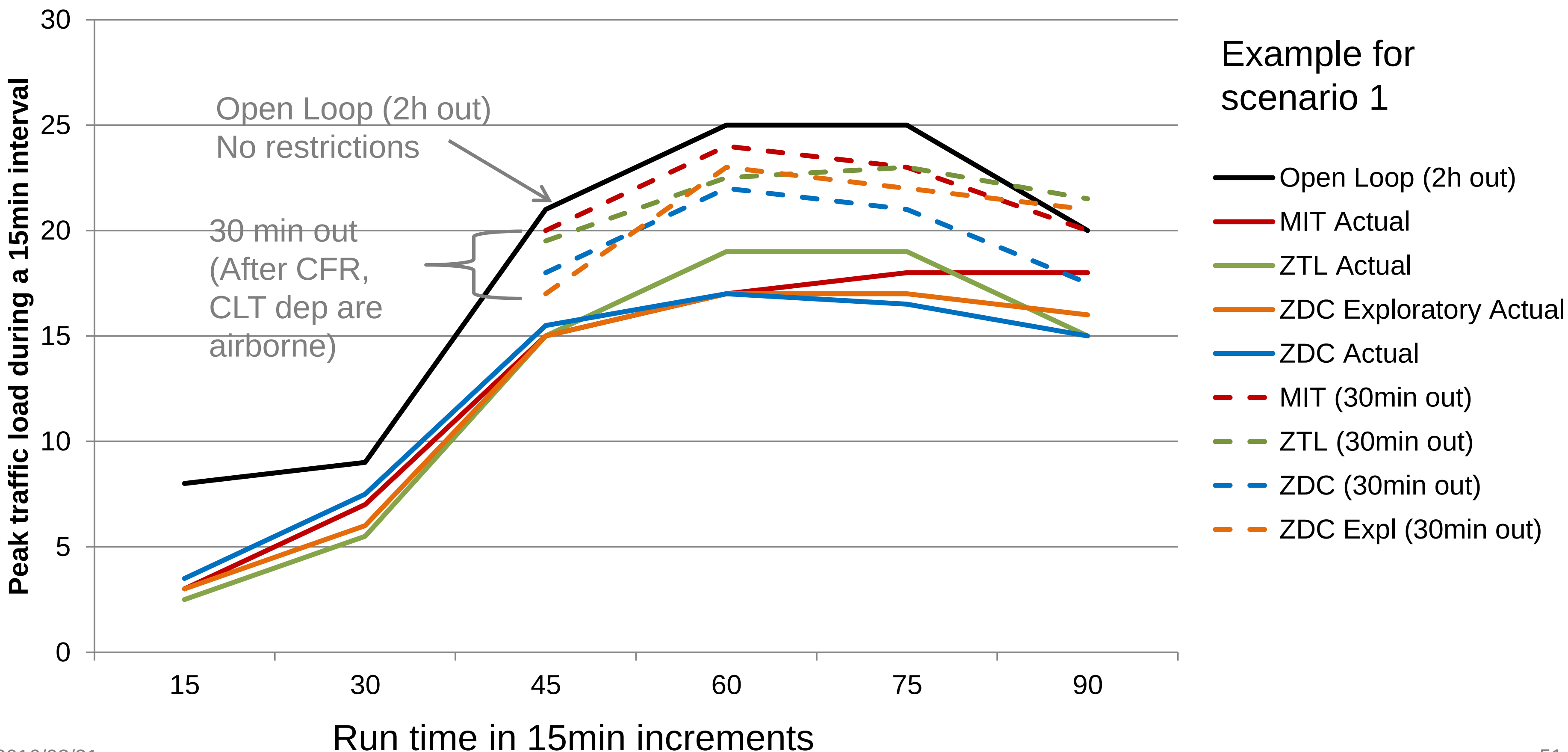
Merge points in ZDC

From Entry point to Exit of HPW and TYI sectors



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

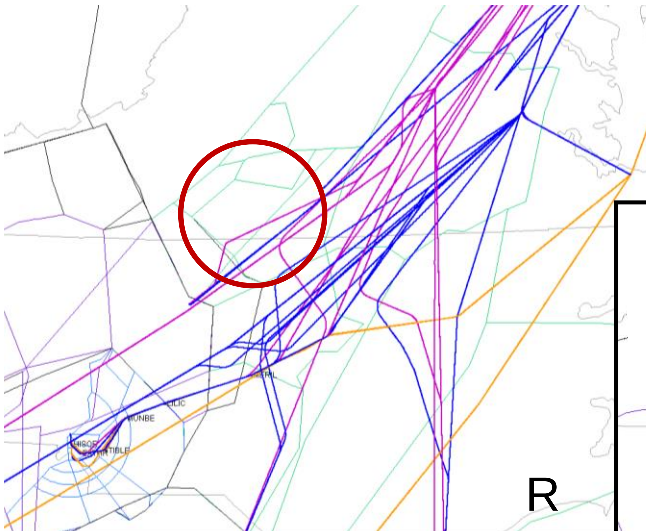
- 2h out shows the demand before any restrictions are applied
- 30min out shows the demand of traffic once inside ZDC
- MIT run shows a longer sustained demand in the last 15min of the run comapred to the other conditions



Tracks in the ZDC Conditions

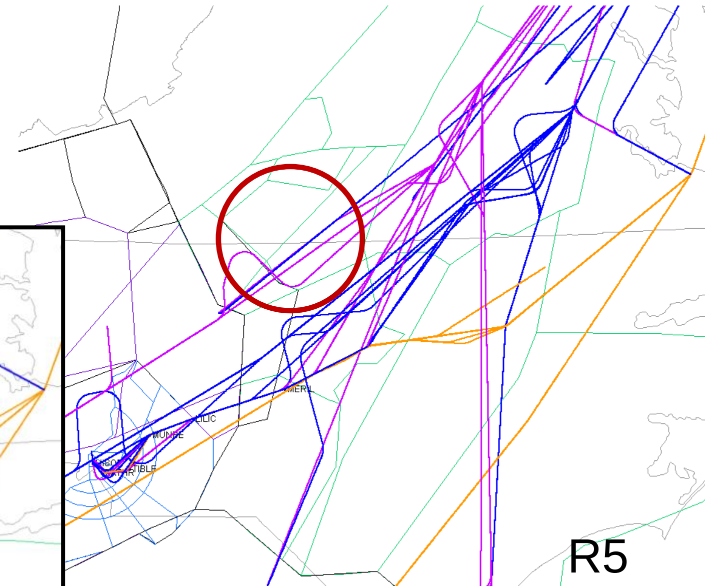
Sc1

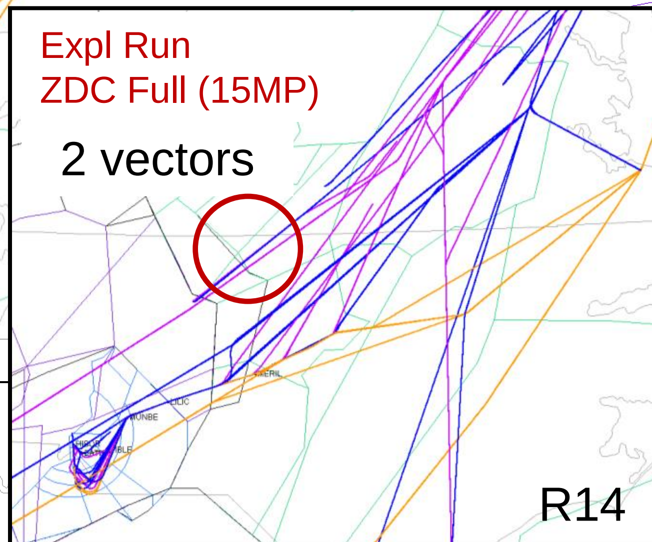
Sc2

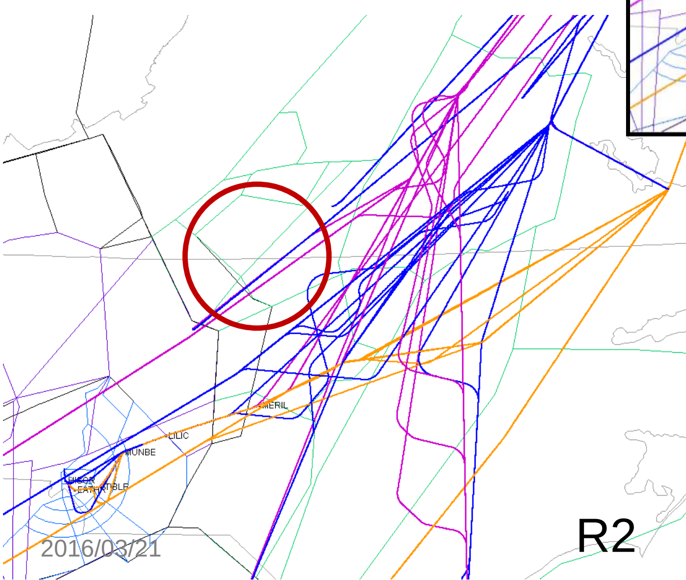


ZDC
Full Compliance

20 vectors

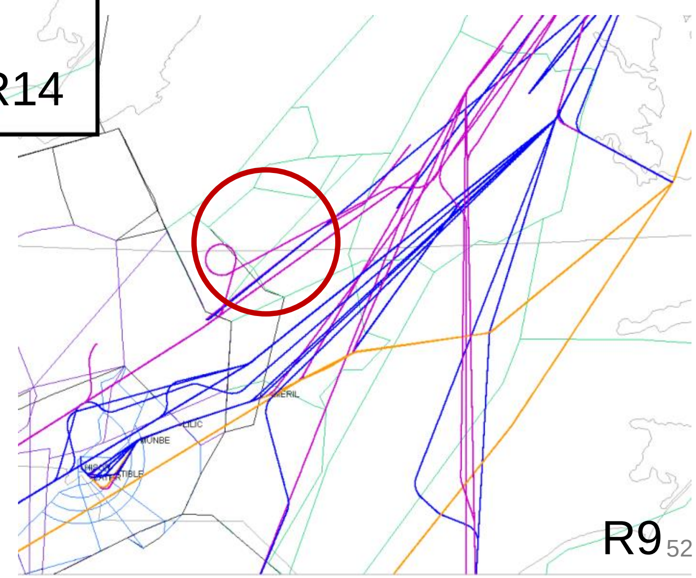






ZDC
Partial Compliance

26 vectors

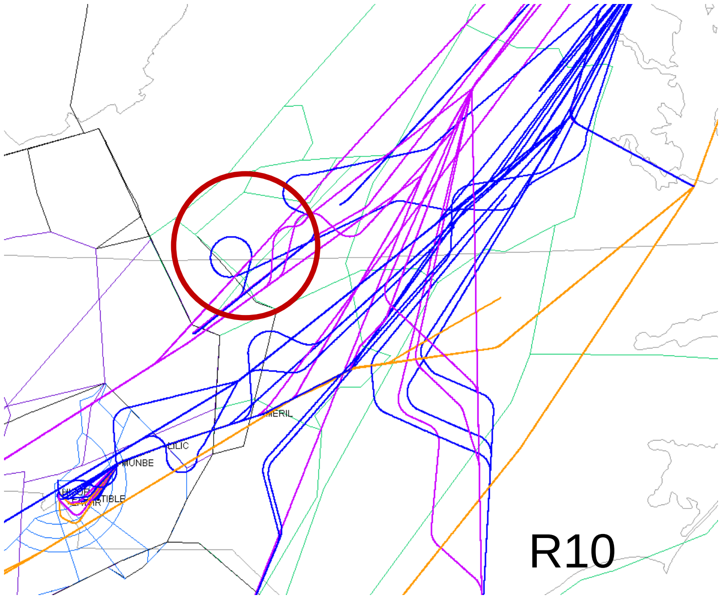


Lines color code
Magenta = flow to EWR
Blue = flow to LGA
Orange = flow to JFK

Tracks in the ZTL Conditions

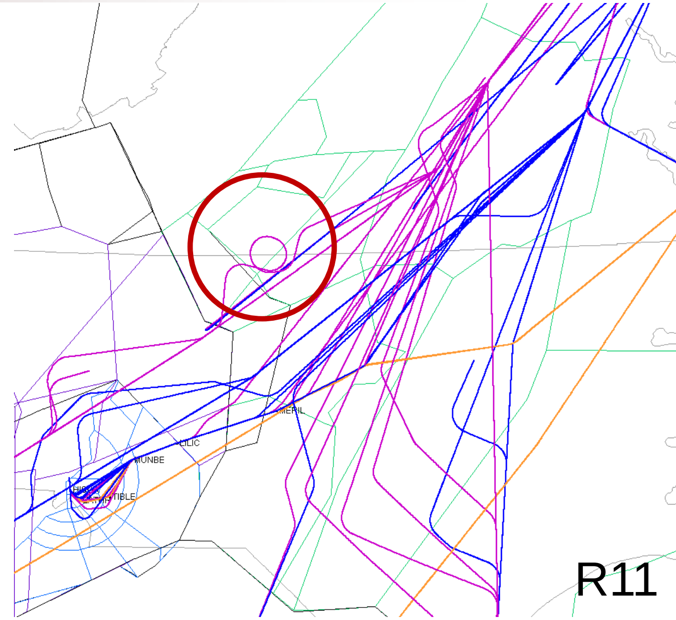
Sc1

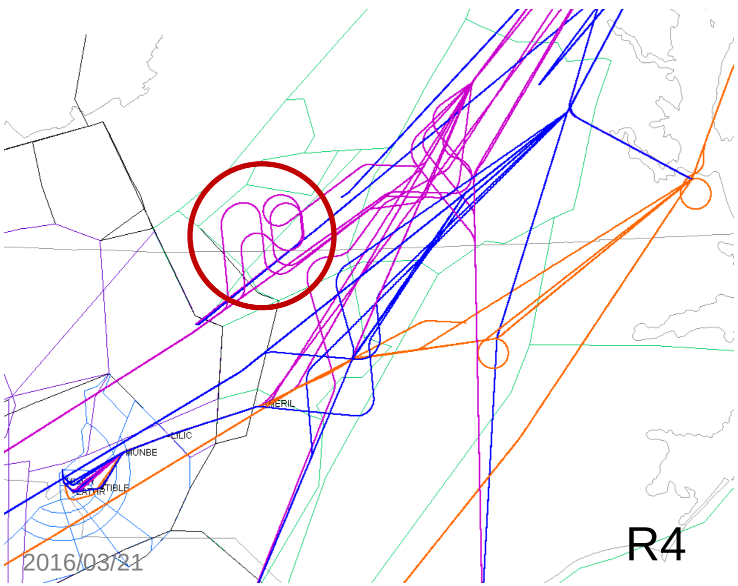
Sc2



ZTL
Full Compliance

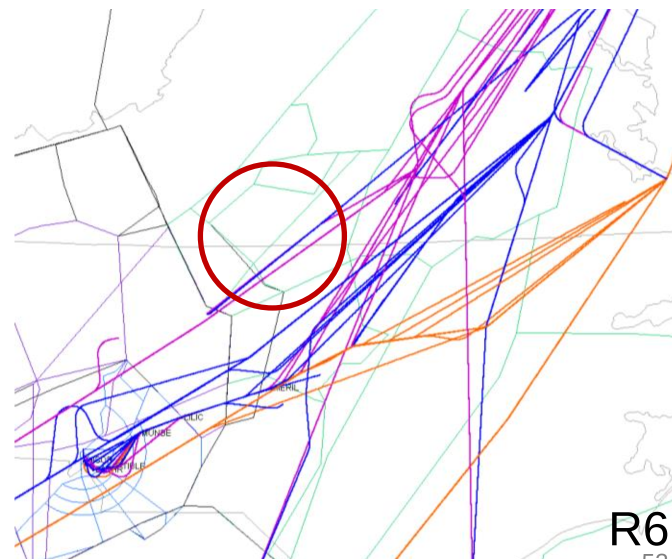
33 vectors





ZTL
Partial Compliance

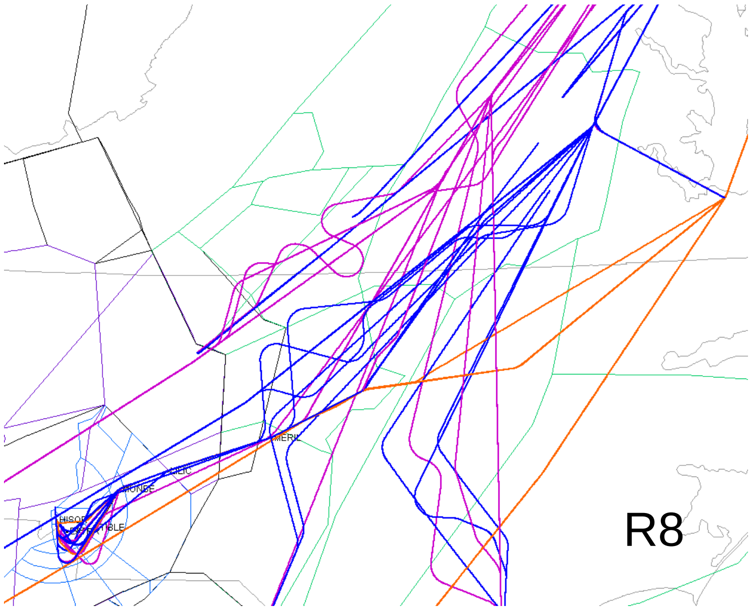
28 vectors



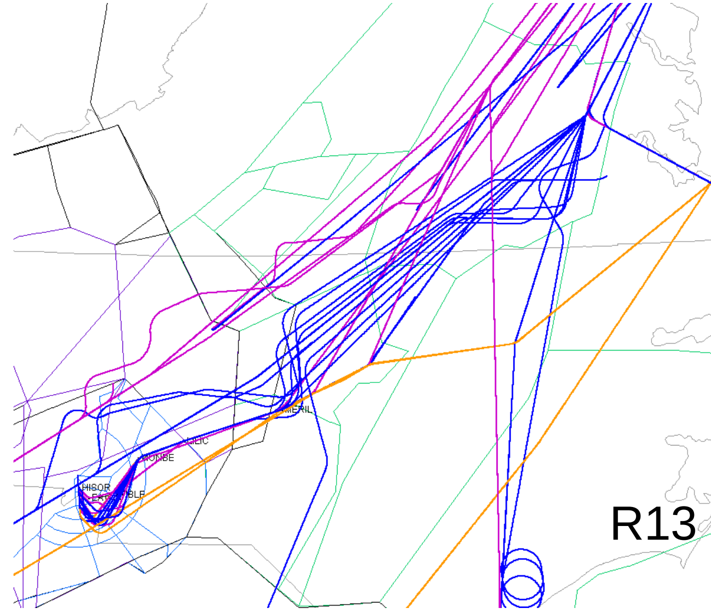
Lines color code
Magenta = flow to EWR
Blue = flow to LGA
Orange = flow to JFK

Tracks in the MIT Conditions

Sc1



Sc2



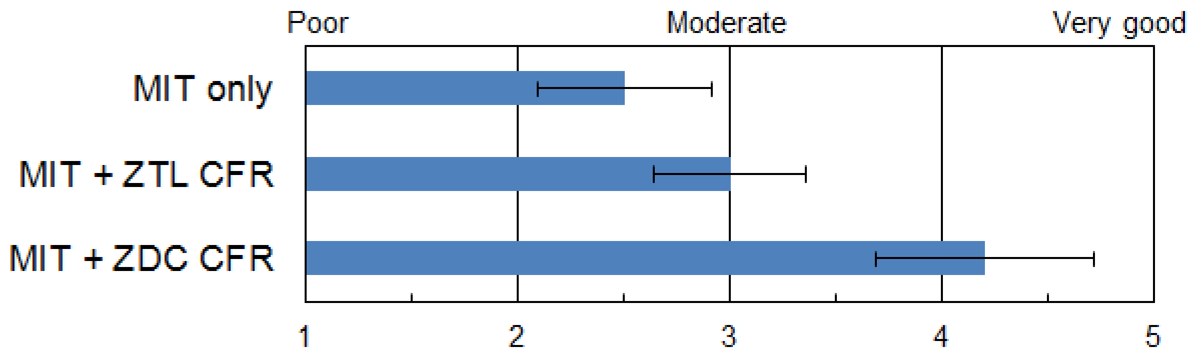
41 vectors

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

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.

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

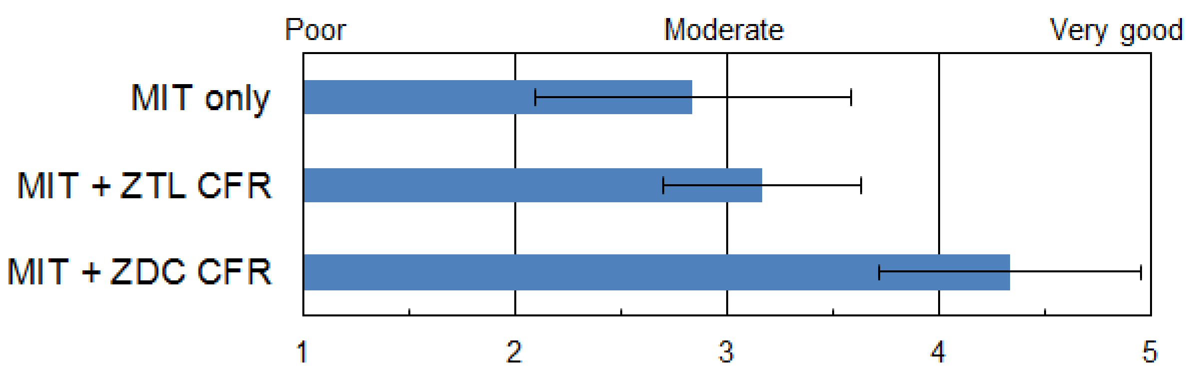
Question: "If you noticed a difference in the quality of the LGA flows entering your sector, please rate the flows in the different conditions."



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

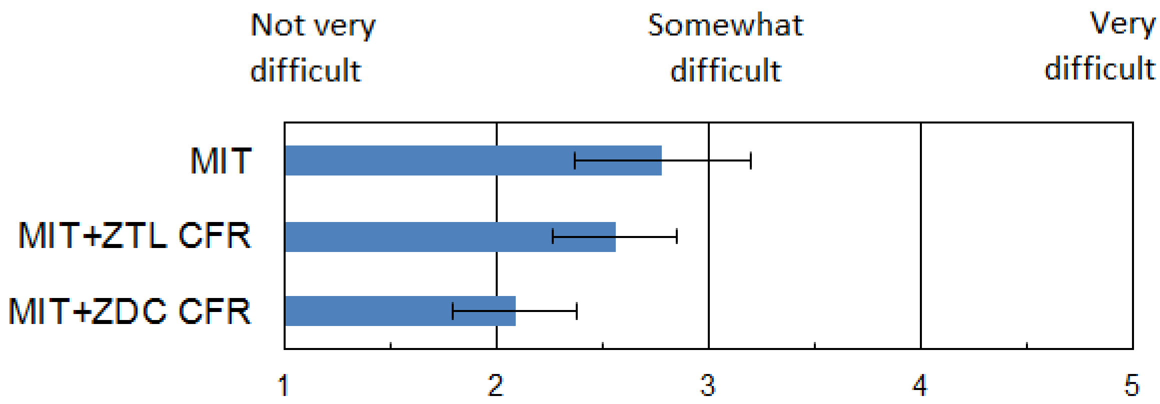
Question: "If you noticed a difference in the quality of the EWR flows entering your sector, please rate the flows in the different conditions."



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

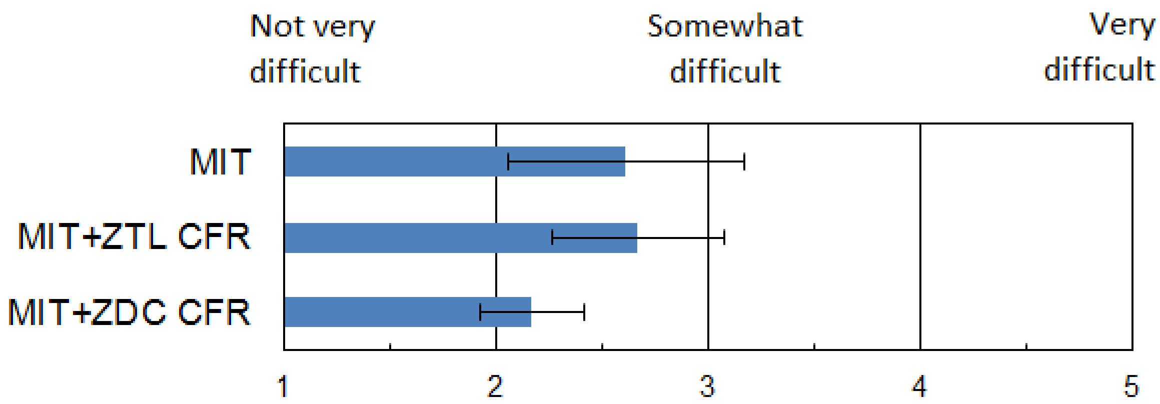
In this run, how difficult was it to provide the LGA flows?



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

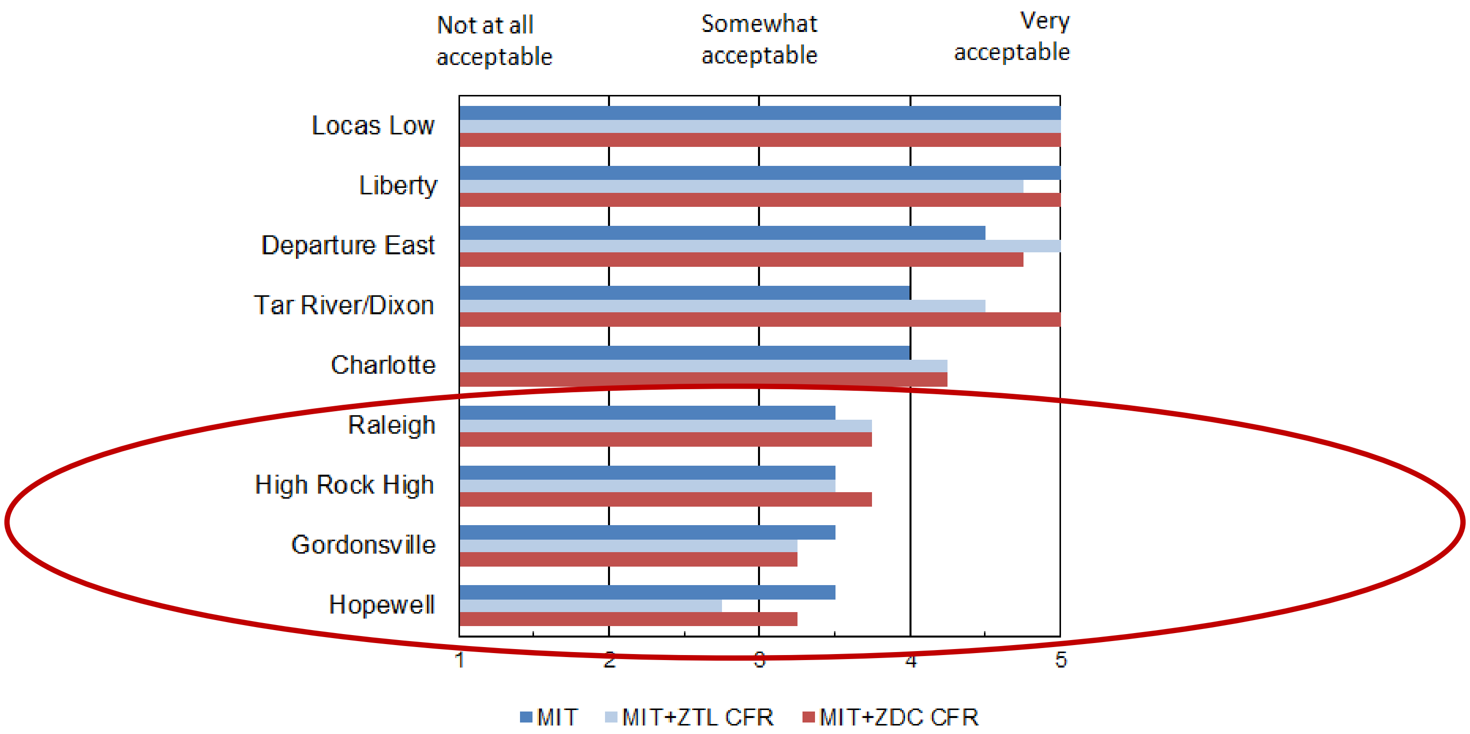
In this run, how difficult was it to provide the EWR flows?



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, $F(1,8) = 9.6$.

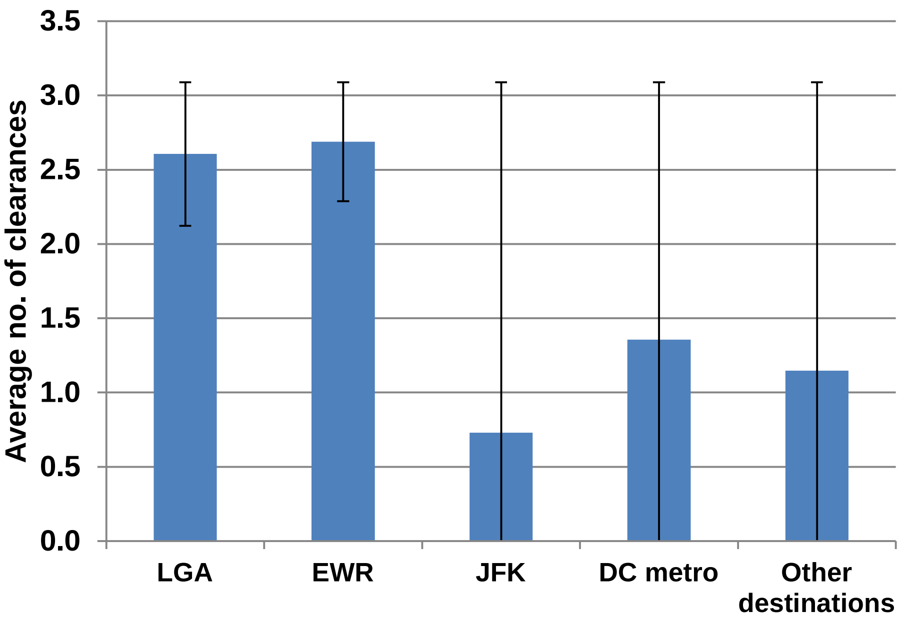
Acceptability of Workload: Workload Least Acceptable for Hopewell, Gordonsville, High Rock High and Raleigh

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

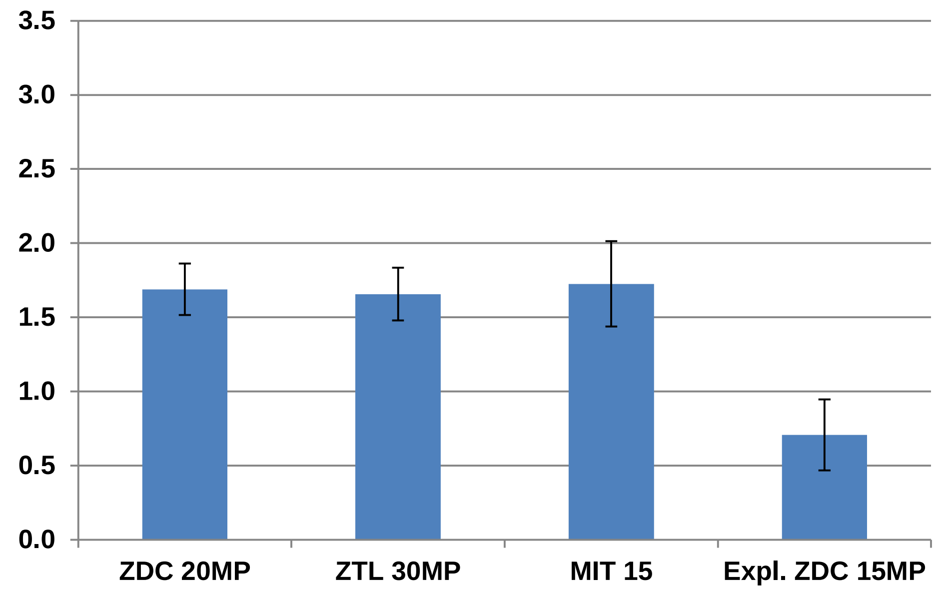


ZDC Controllers Issued Twice More Clearances to Flights to EWR and LGA Than to Other flights

- 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

Highlights of Subjective assessments based on observations, and transcript of ZDC controllers

- Transcriptions of the ZDC supervisors indicates that he spent more time resolving problems in the MIT and ZTL conditions than in the ZTL 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 min	Sup interaction	Aircraft requiring actions	LGA flow	EWR flow
ZDC	47.5	26.5	15.25	5.5	8.75
ZTL	55.25	25	15.5	2.5	12
MIT	54	25.5	17.5	9.5	6.5

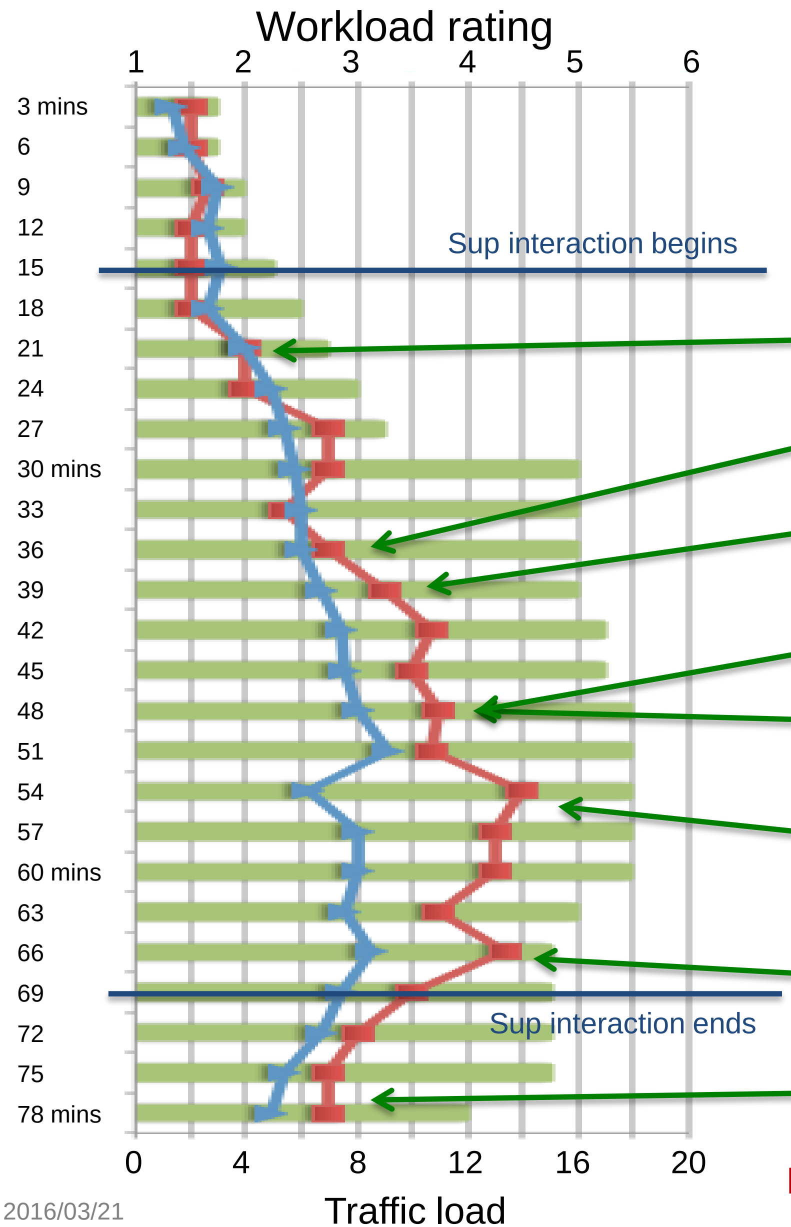
Main problems:

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

Strategies used by the supervisor: (most of the time reached out to upstream sectors)

- Asked for speed changes, vectors and holding for ties and spacing (i.e. bump him up to .75)
- Asked for cap altitude on DC arrivals to reduce volume in HPW
- Asked to lose a distance (i.e. “pull them back a little, they got to lose 10nm”)
- Asked for spacing different between aircraft other than 20 to facilitate merging (i.e. going to need 40nm between your two EWR)
- Asked for a specific sequence (i.e. follow this guy with x in-trail)

Example of HPW workload and traffic load and Supervisor's problem solving activities



4 ZDC
Everyone
HPW traffic load

8 MIT
Scenario 1

Problem: Two aircraft are tied on the LGA flow – need 20nm spacing
Solution: Vectors

Problem: Adjust spacing on EWR flow
Solution: Sup directs speed

Problem: Aircraft are tied on the EWR flow – need 40 nm spacing in GVE
Solution: Sup specifies order. ATC use speed & vectors

Problem: Too much traffic.
Solution: Sup tells HPW 15 MIT for next group

Problem: EWR flow is crowded. Solution: Vectors decided by GVE & Sup

Review: Actions on spacing of EWR aircraft - need more.
Solution: Vectors. Altitude suggested by Sup

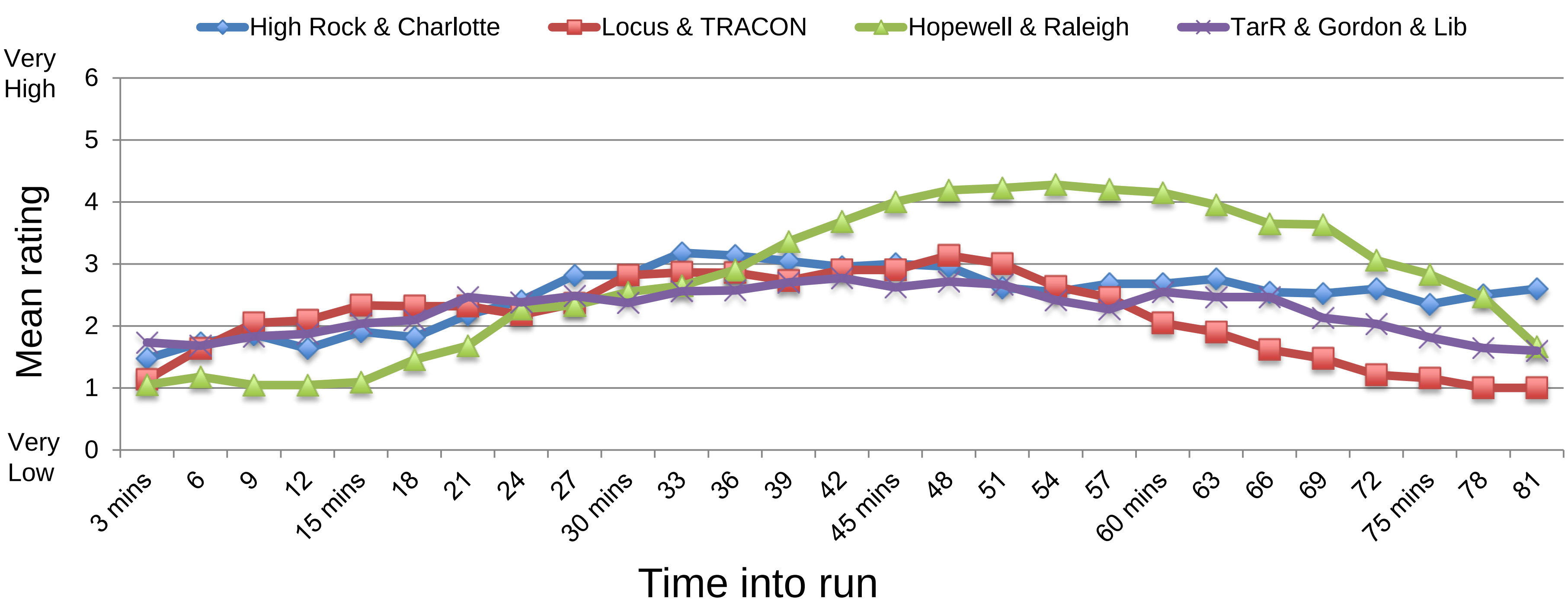
Review 2: Spacing of EWR aircraft - OK
Solution: Back on route – Sup suggestion. Sup to HPW: 15MIT is OK

Review 3: spacing of EWR aircraft - OK
Solution: -

Detailed analyses for each run at the end of the presentation

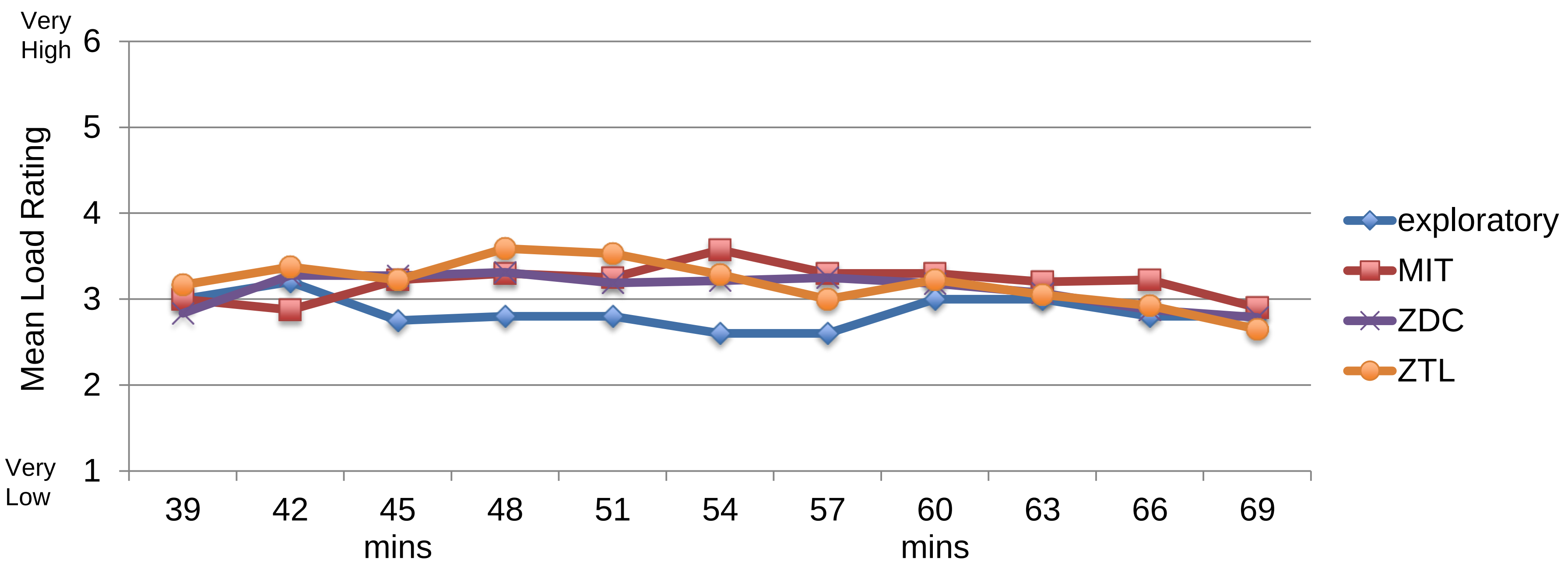
Real Time Workload Charts
Mean Load by Sector/ Position

- 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

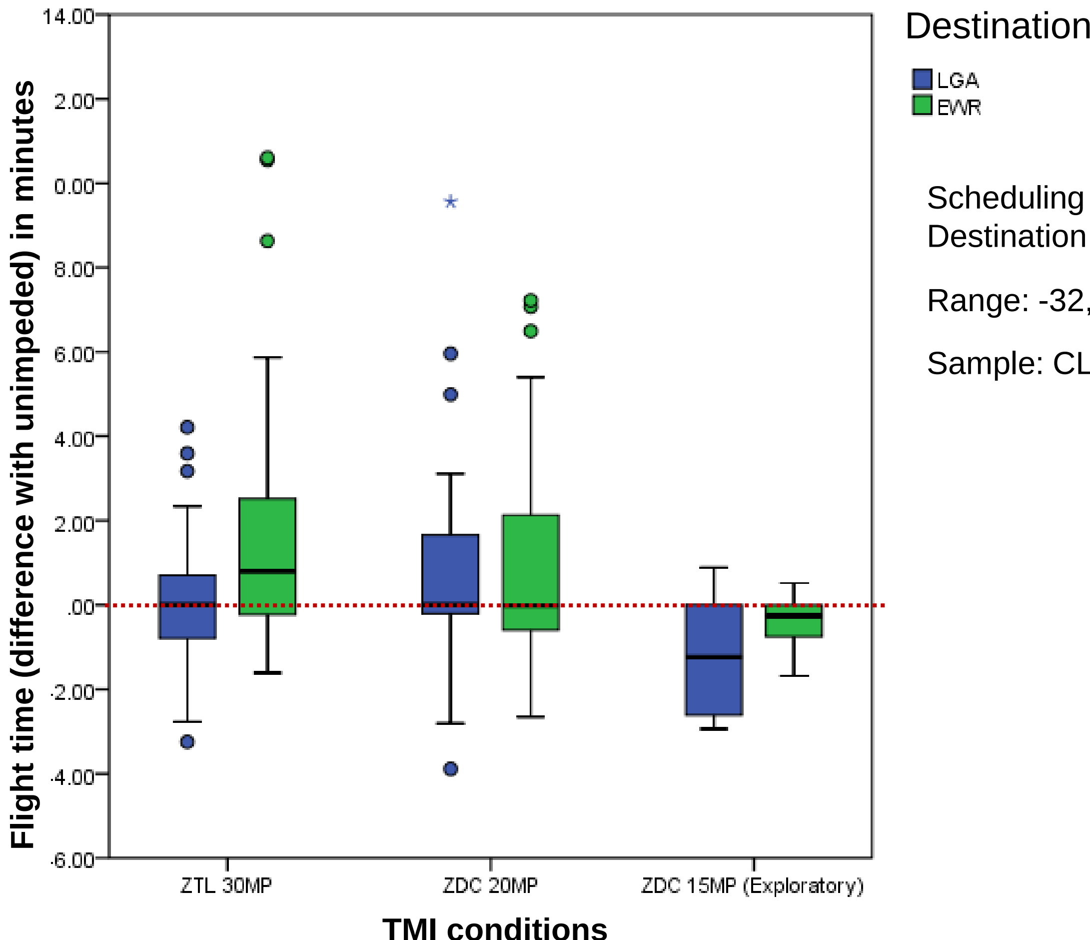
- Workload seemed less high in the Exploratory run compared to the other conditions.
- These averages are high in comparison to other studies (average around 2)



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.



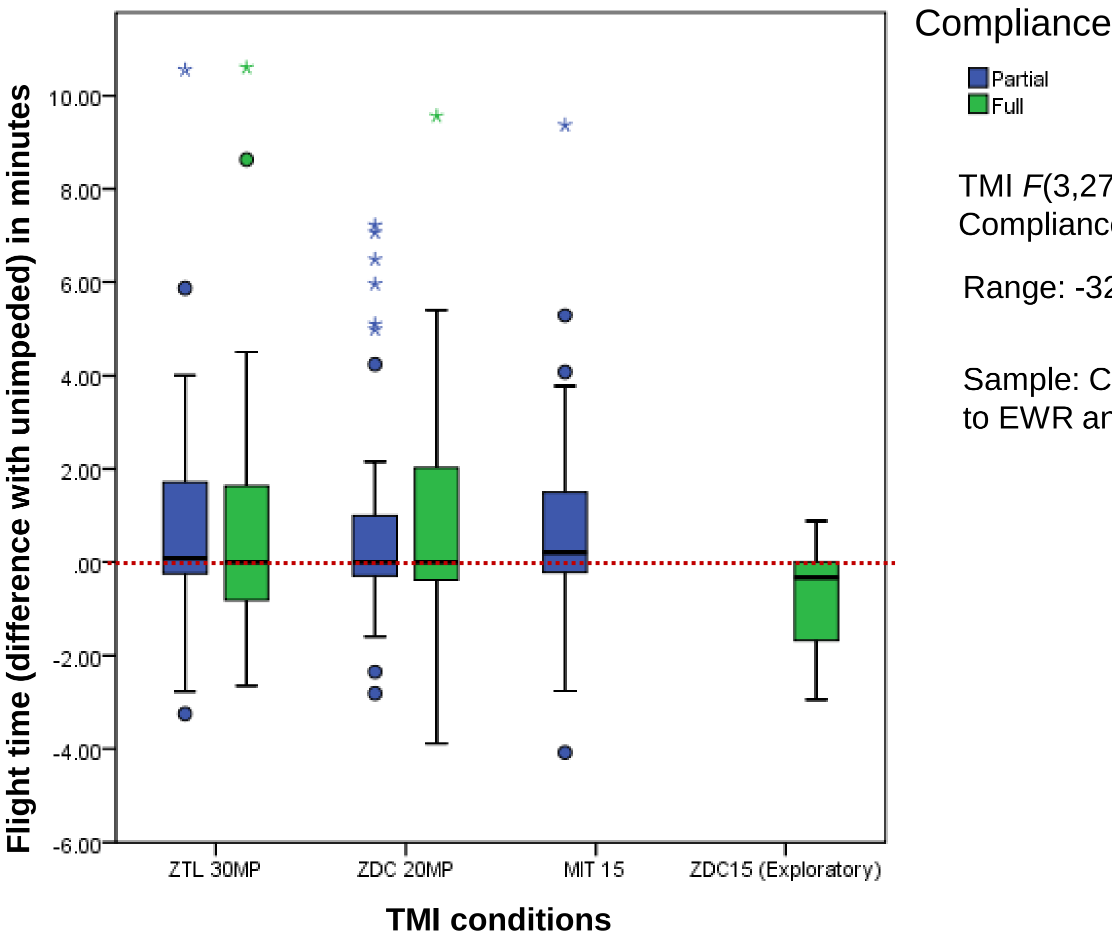
Scheduling $F(3,268)= 3.17$, p .025
Destination $F(1,268)= 12.36$, p .001

Range: -32, +14

Sample: CLT departures + overhead traffic

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.



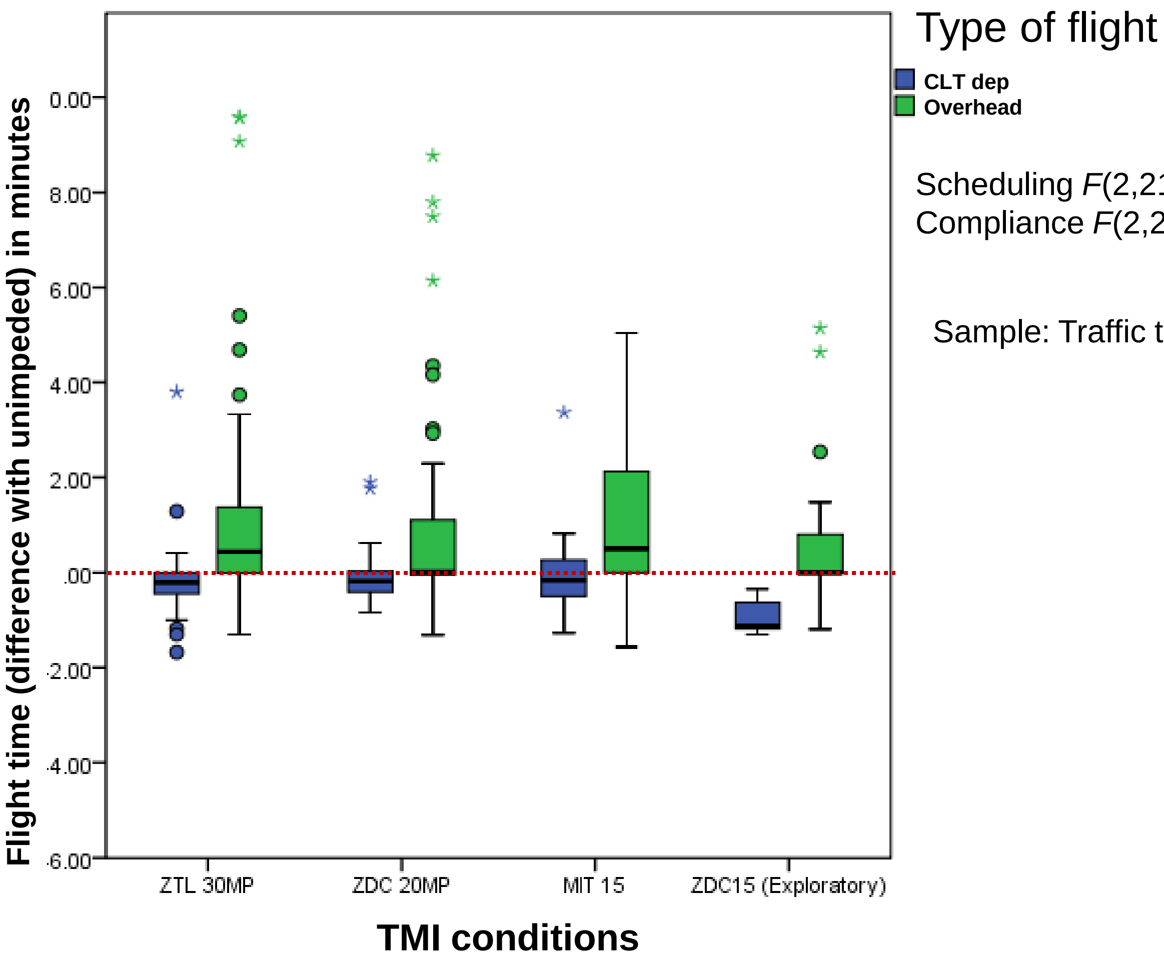
TMI $F(3,270) = 3.01$, p .025
Compliance (1,270)= 0.00, p .960

Range: -32, +14

Sample: CLT departures + overhead traffic to EWR and LGA

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

- Departures to EWR and LGA flew less long in ZDC to reach HPW 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.

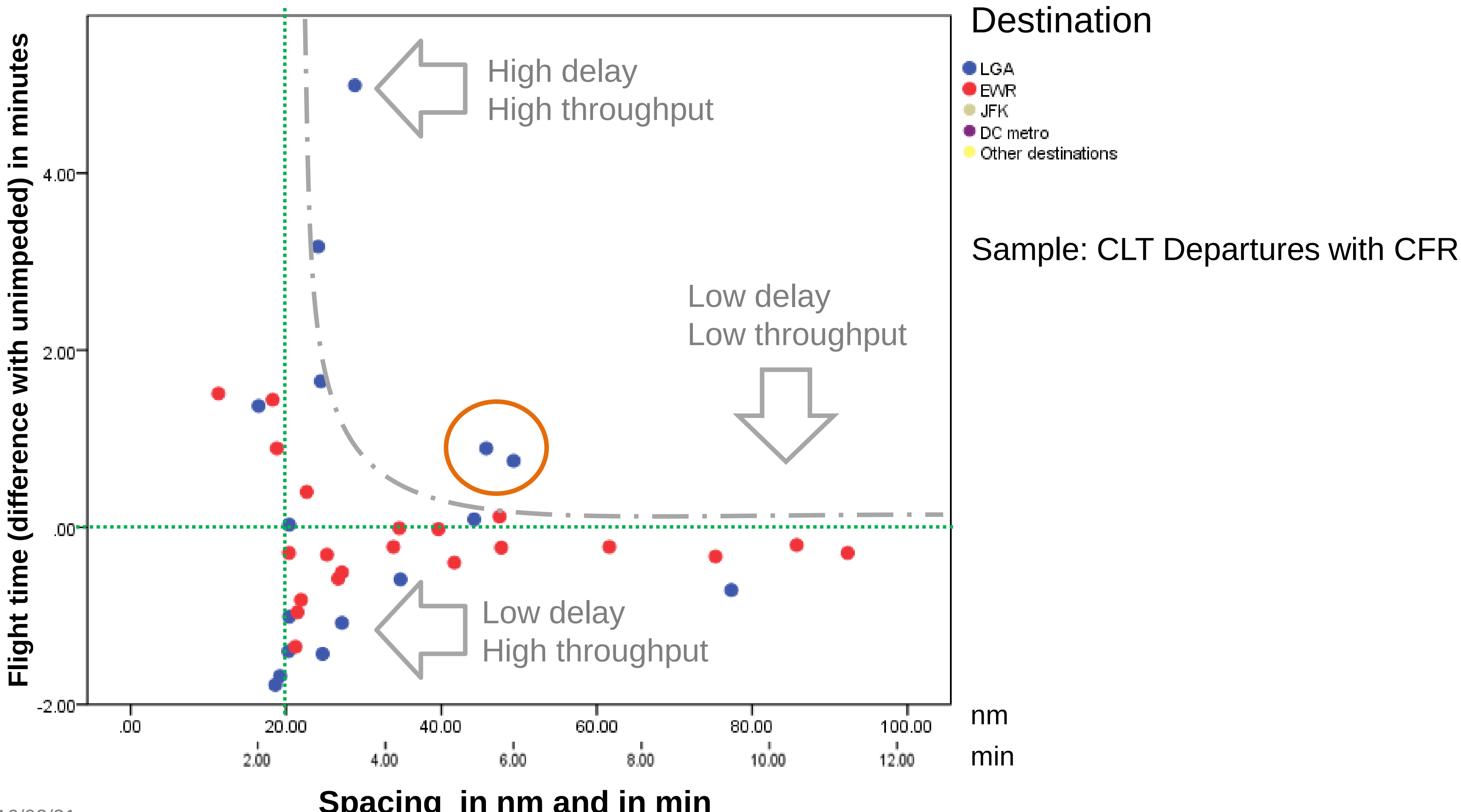


Scheduling *F*(2,216)= 3.39, *p* .035
Compliance *F*(2,216)= .03, *p* .868

Sample: Traffic to EWR and LGA

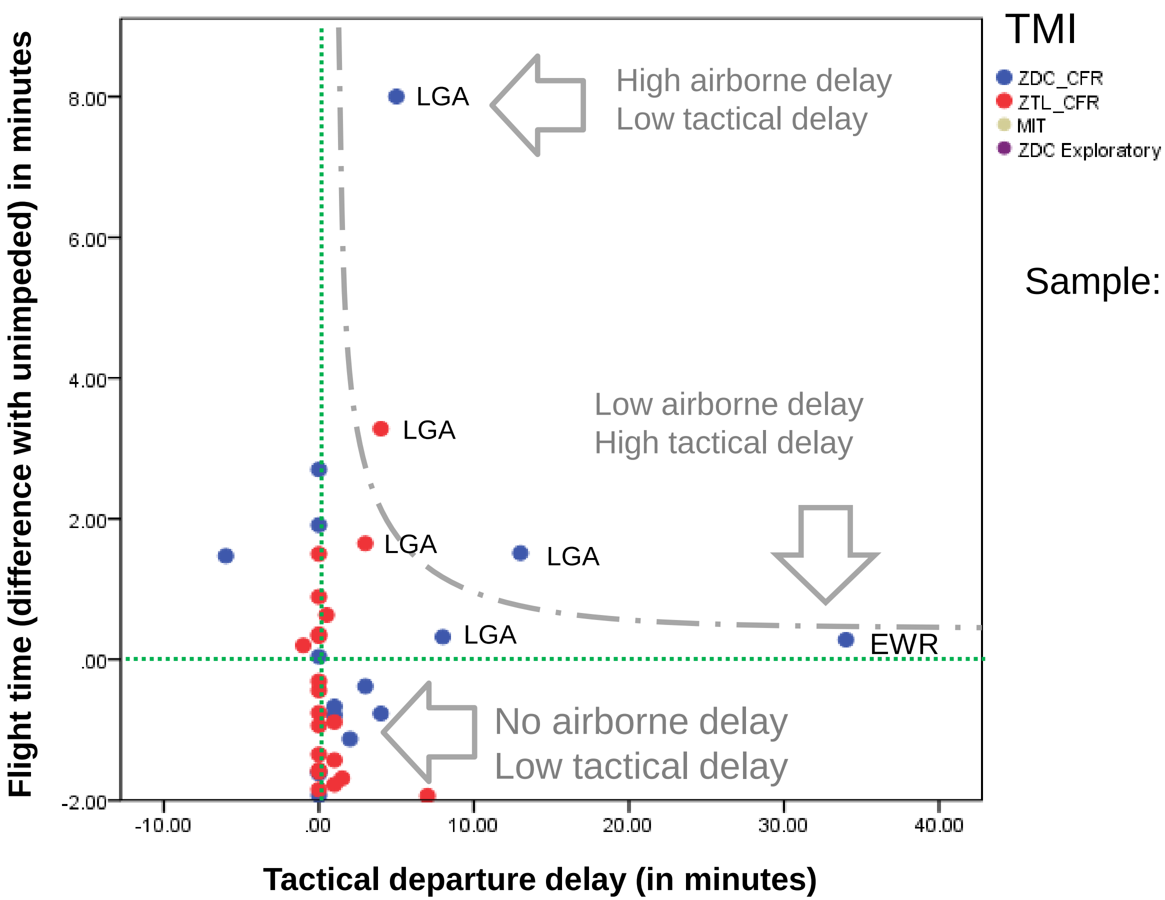
No observed wasted capacity in ZDC

- 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.



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

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 after departure took off. The low rate of success after takeoff is due to the unpredictability of traffic in ZDC airspace.
- This is due to the longer distance to reach HPW but not only.
- Observations indicate that about a third of the time, the order of aircraft is changed due to the insertion of other departures. The other two-third of time is due to aircraft conflicting at merge points

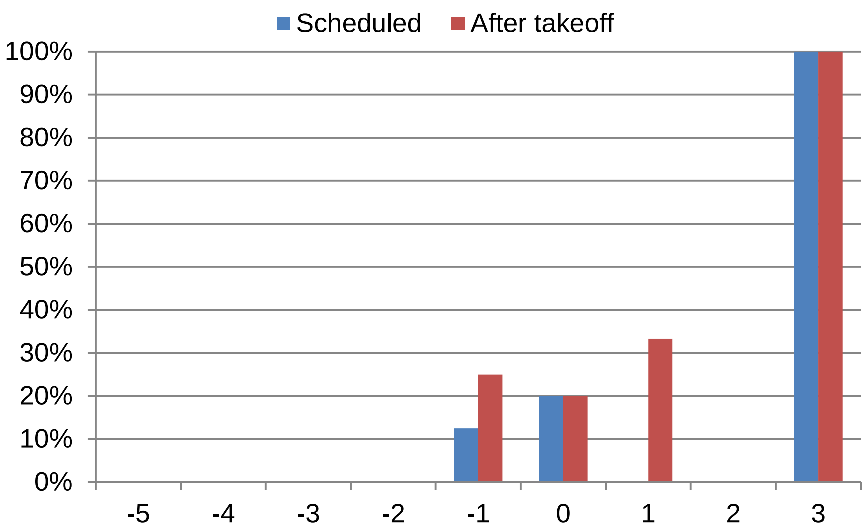
Stream Insertion at HPW boundary (Scheduled by ZDC)			
Planned TBFM Sequence	% Hit Scheduled slot	% Hit slot after takeoff	Difference
Correct lead aircraft	38%	43%	12%
Correct lead and trail aircraft	15%	25%	10%

Stream Insertion at LIB (Scheduled by ZTL)			
Planned TBFM Sequence	% Hit Scheduled slot	% Hit slot after takeoff	Difference
Correct lead aircraft	88%	100%	12%
Correct lead and trail aircraft	81%	95%	14%

Stream Insertion Rate Improved When CLT Departures Departed on Time

- There was a small success rate improvement after departure took off.
- Stream insertion seemed to be improving when departures departed on time.
- A bigger sample size would be useful to show whether stream insertion is more likely with late departures than early departures.

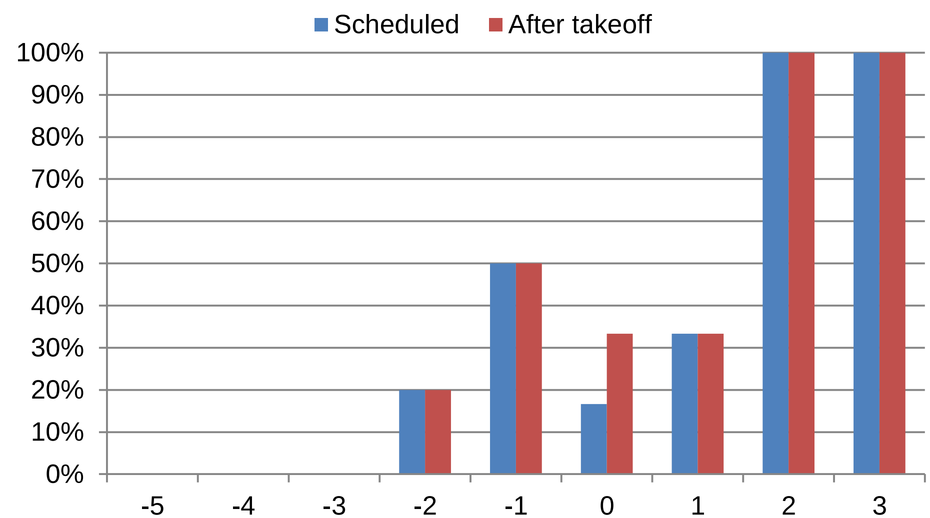
Departure behind planned lead and in front of planned trail



(early) Takeoff compliance error in min (late)

N 26: 1 1 1 5 8 5 3 1 1

Departure behind planned lead



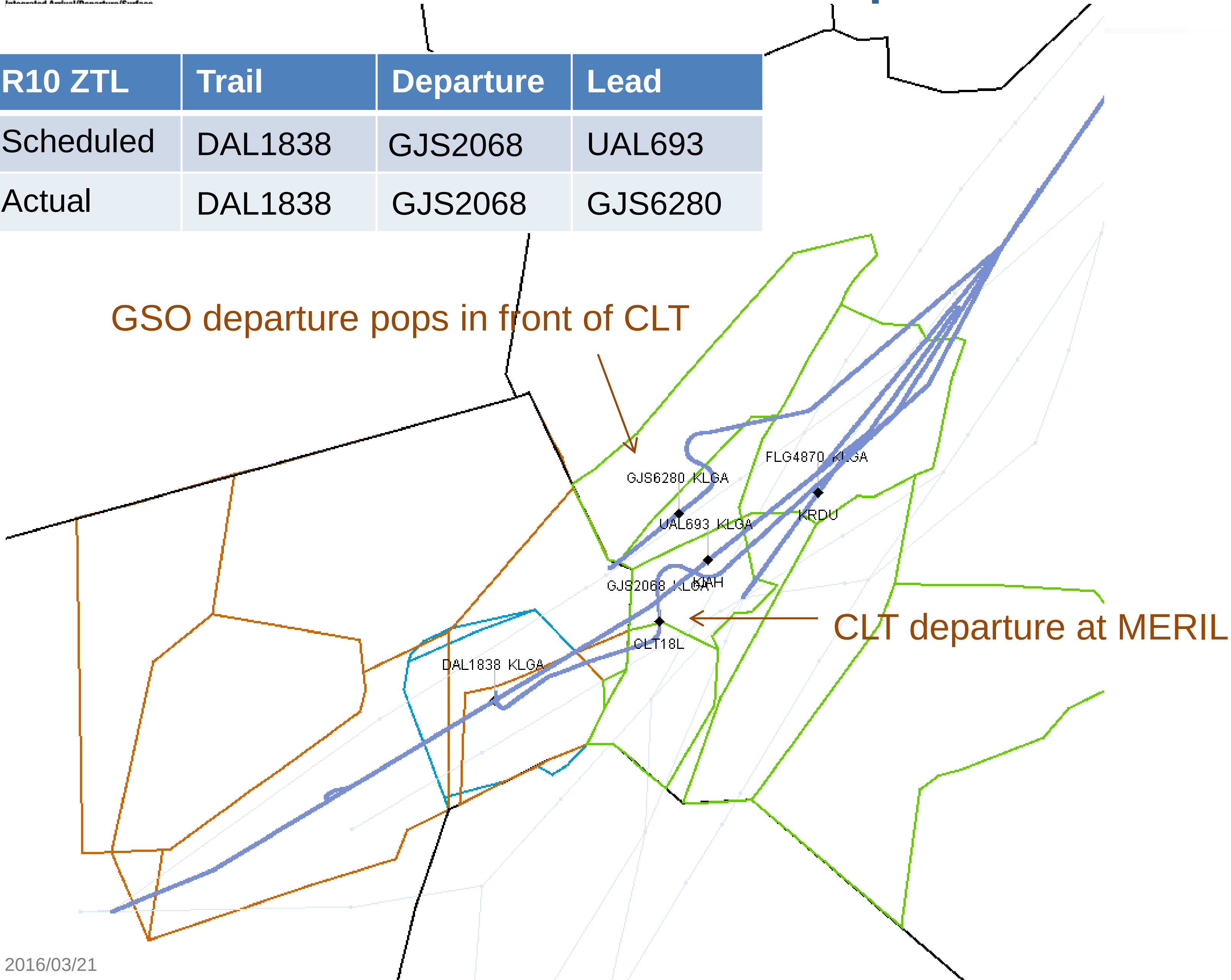
(early) Takeoff compliance error in min (late)

N 27: 1 1 1 5 8 6 3 1 1

Non-significant tests. Sample size is not large enough to draw conclusions

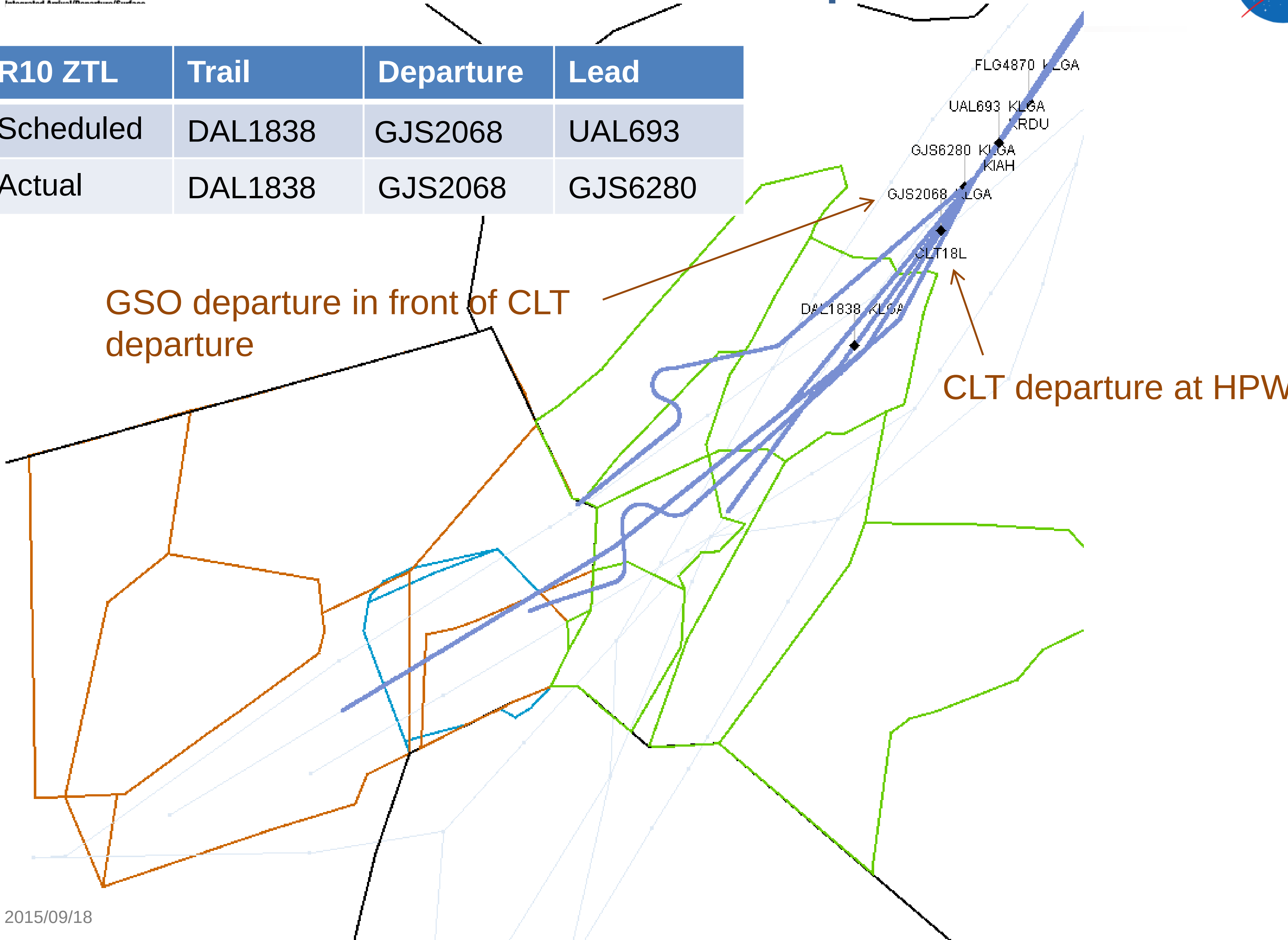
Example of GSO Departure Being Inserted in in Front of the CLT Departure

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



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



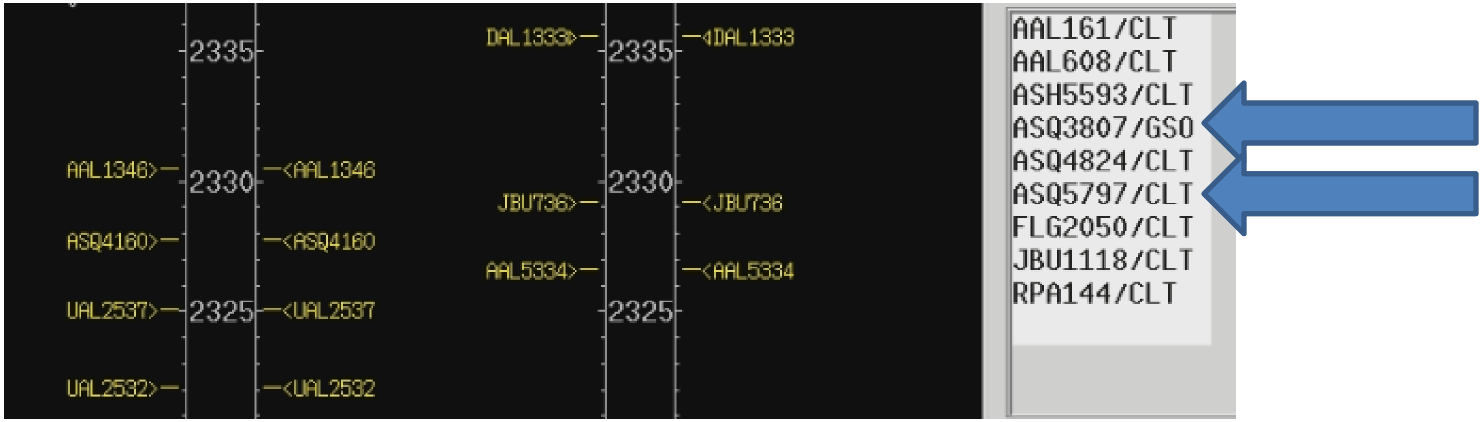
Example of Competitive demand South of Hopewell and how Unreliable the Schedule is

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

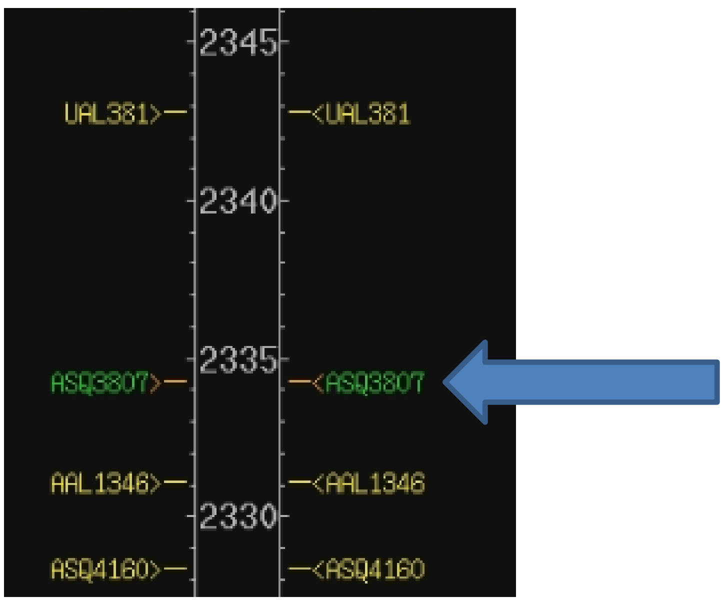
Example of conflicting demand between CLT and GSO across Centers

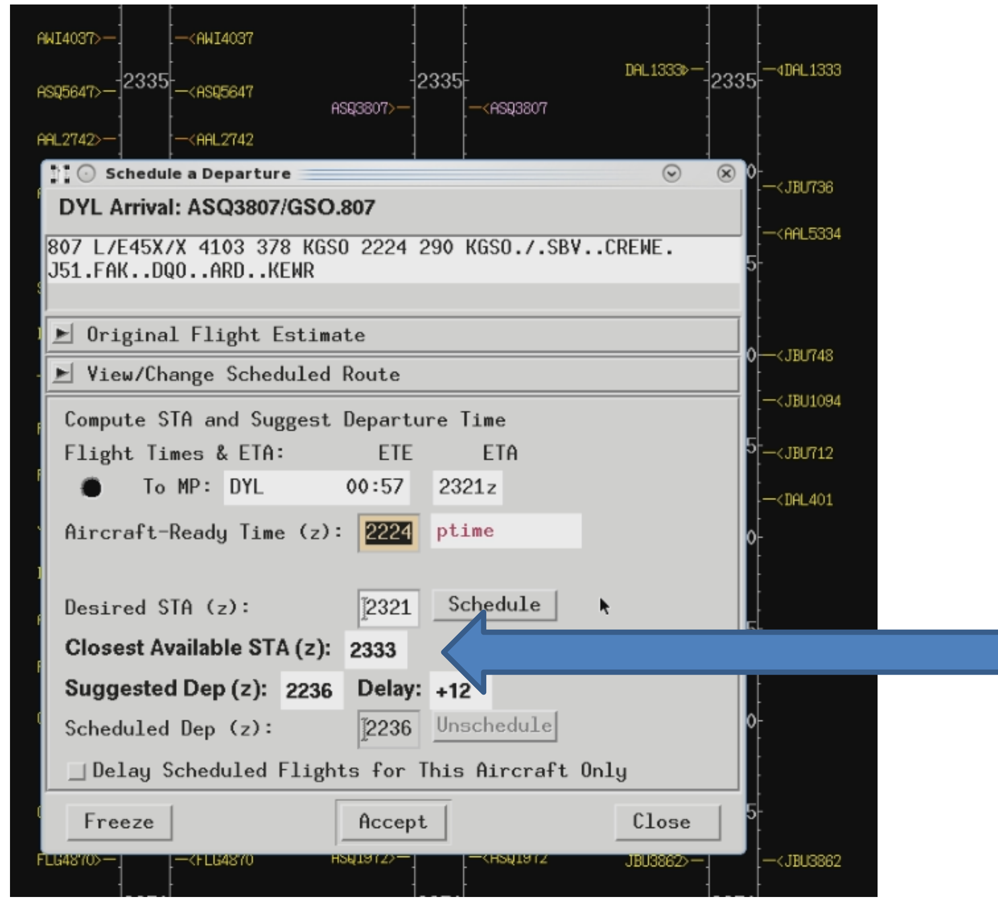
ASQ3807 from GSO & ASQ5797 from CLT

- 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



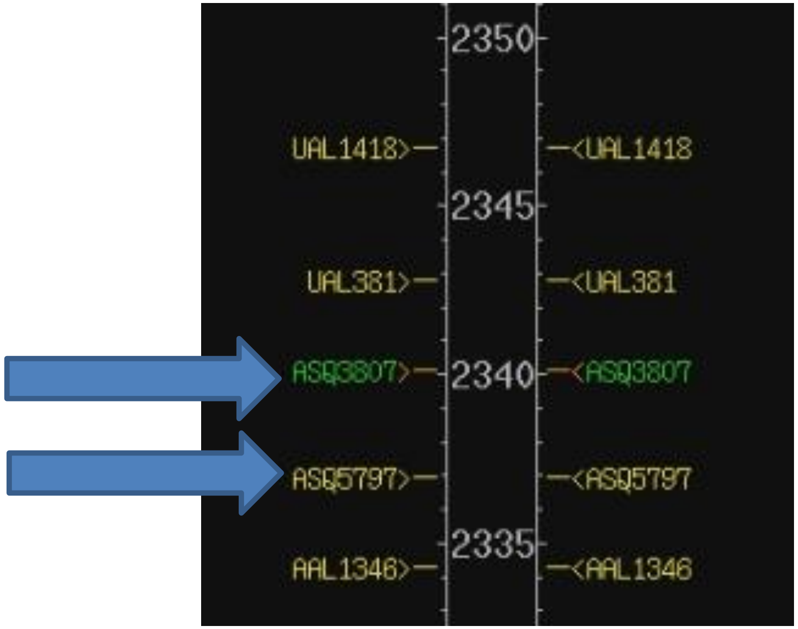
ZDC Schedules GSO Departure to the First Available Slot





ZTL Scheduled CLT Departure and Conflicts with the GSO Departure

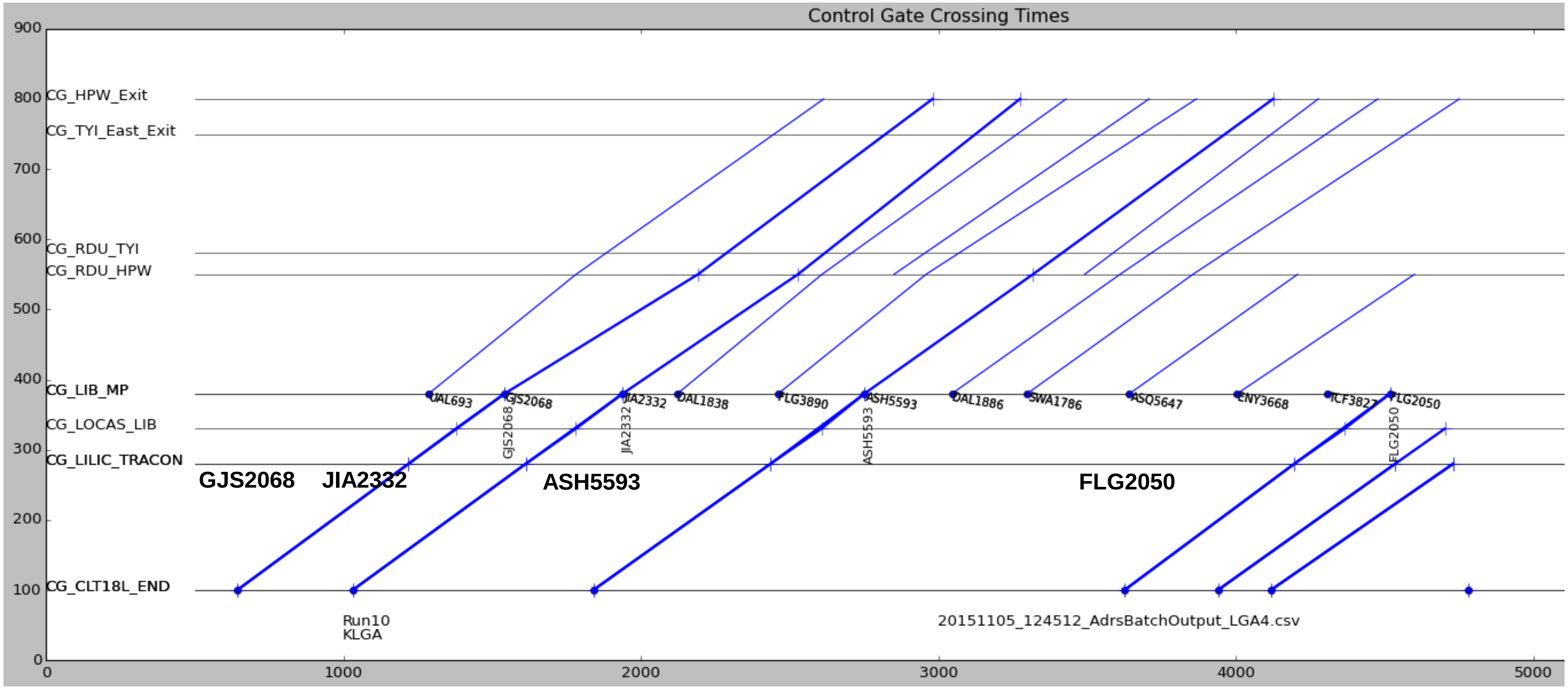
- Later on, CLT Departures ASQ5797 is scheduled by ZTL.
- Once ASQ5797 takes off and becomes active (yellow) it bumps the GSO departure STA, which is not active yet, to the next slot.
- Additionally, notice that AAL1346 is delayed by 4minutes. This further push ASQ5797 and ASQ3807 to a later slot.



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).

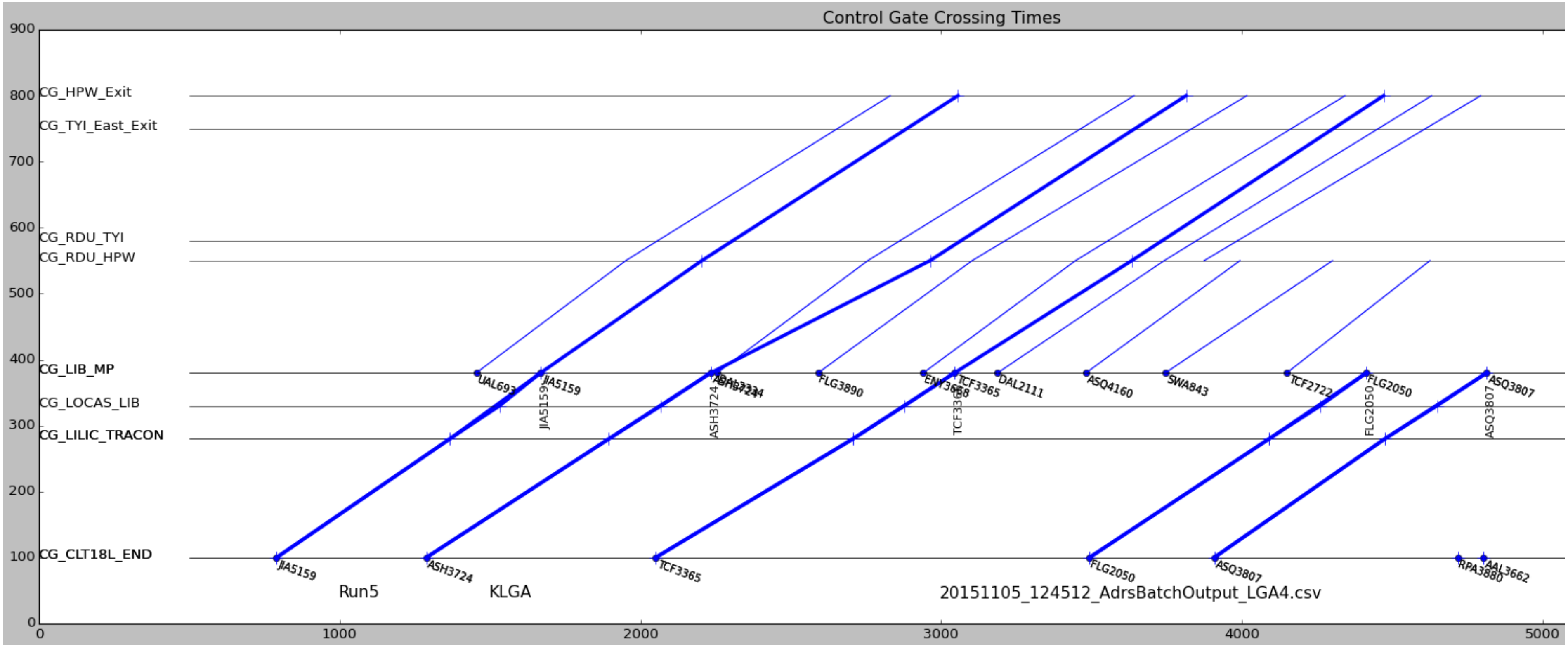
Run 10 – ZTL Full (30MP)



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 with 20MIT.
- Once the sequence of traffic is sorted in ZDC, the sequence remains fairly stable (see example of Run 4 below).

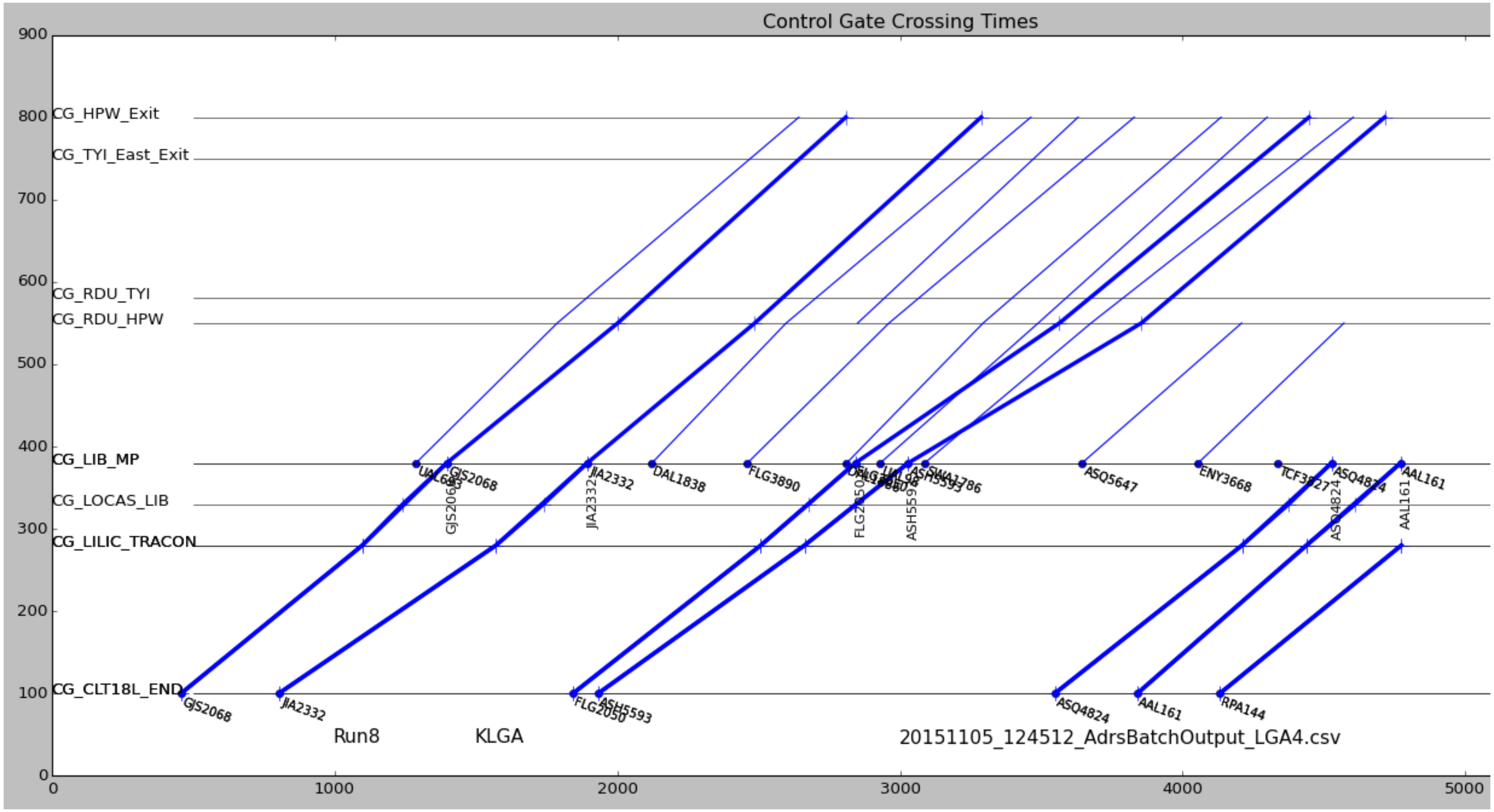
Run 5 – Full ZDC (20MP)



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).

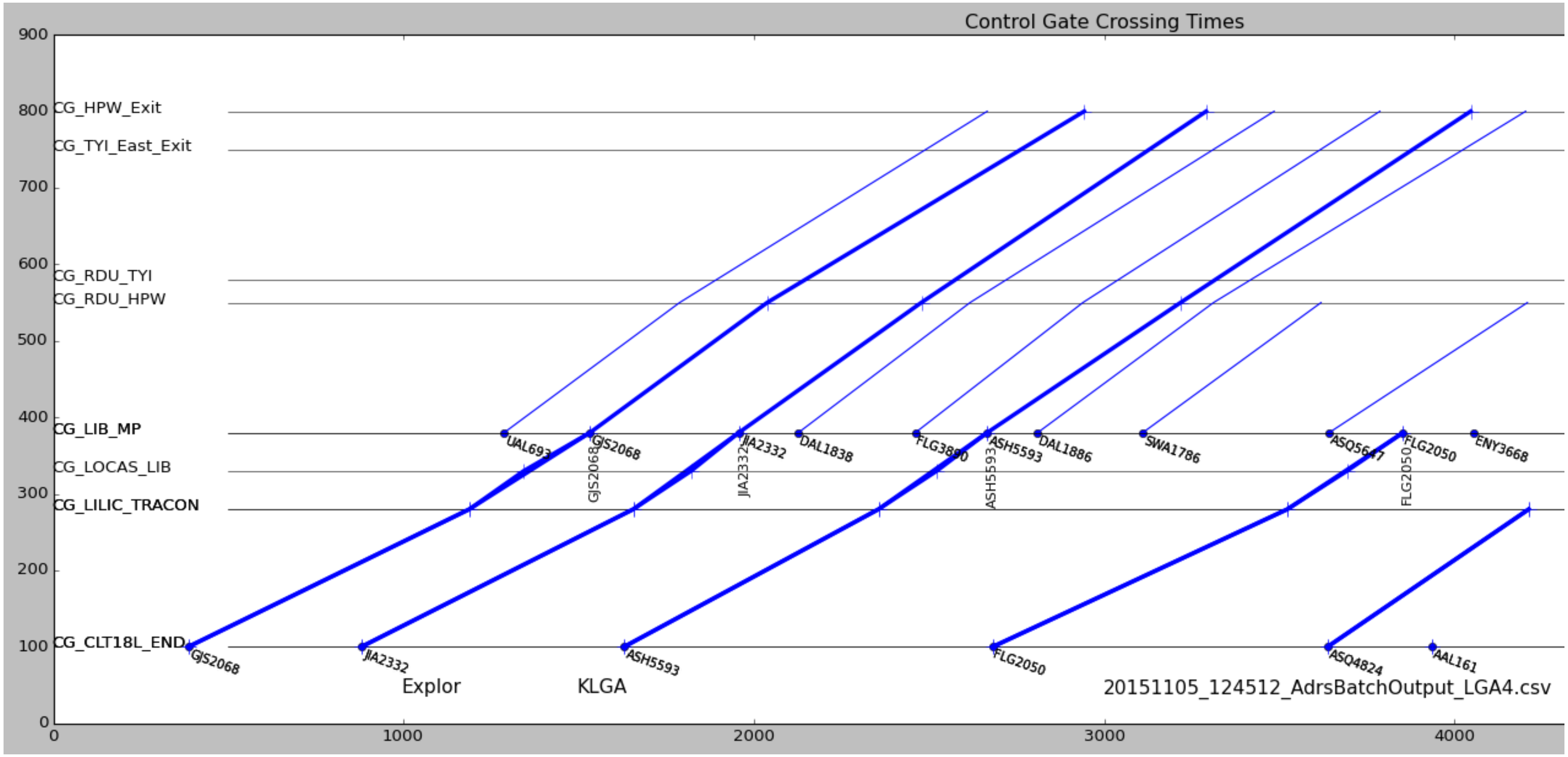
Run 8 – Partial MIT



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.

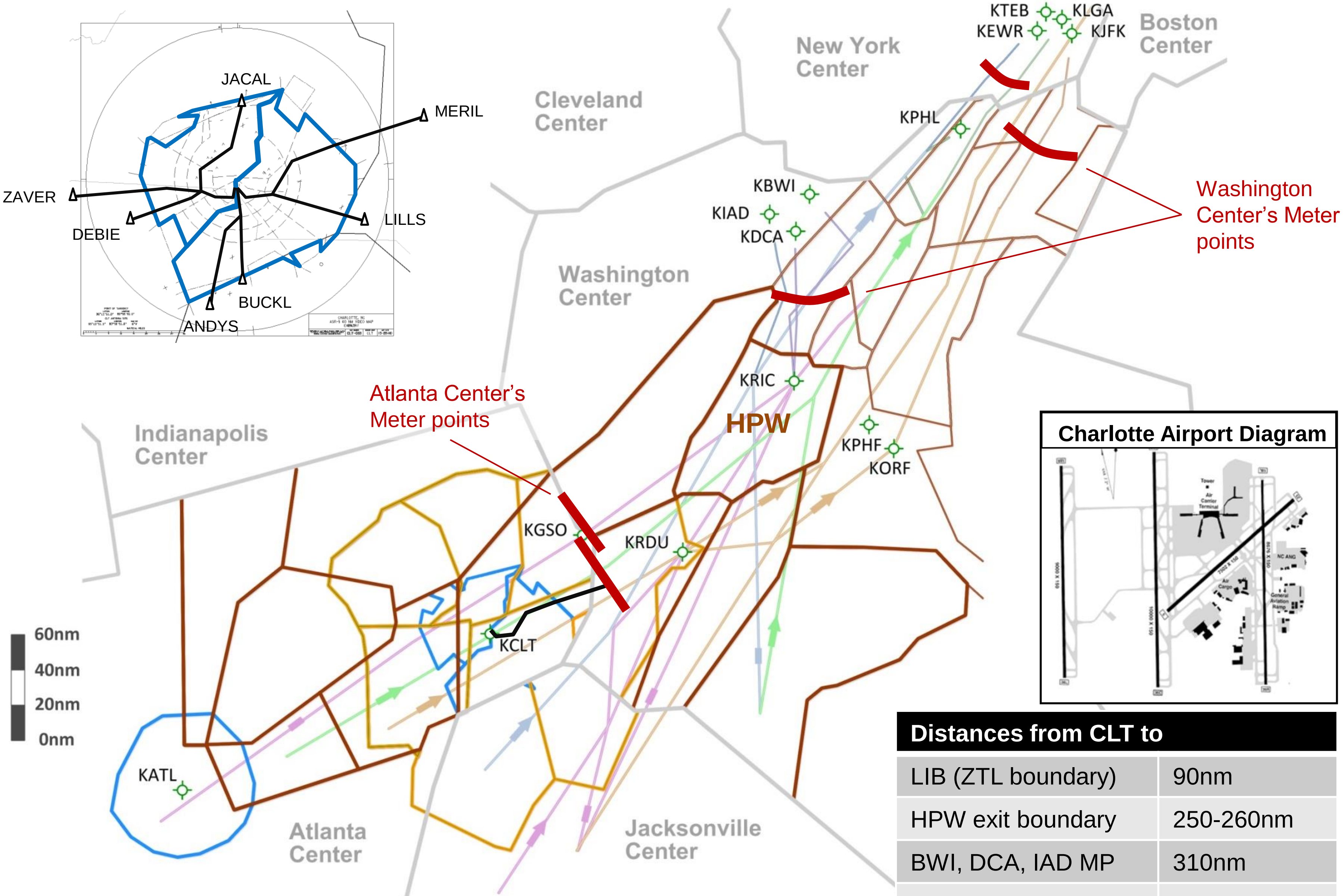
Run Explor – Full ZDC (15MP)



Problems to Address

- Stream insertions when the MP is located far away
  - ZDC schedules CLT departures to meter points that are located 300nm (DC metro) and 450 nm (NY metro) away.
  - At this distance, stream insertion can be impacted by inefficiencies from passback restrictions, excess volume, delays, multiple stream in the same sector capacity, and multiple departures
- Provide better control of the schedule, of the delays and the uncertainties in ZDC to improve predictability and reduce inefficiencies

Test Airspace



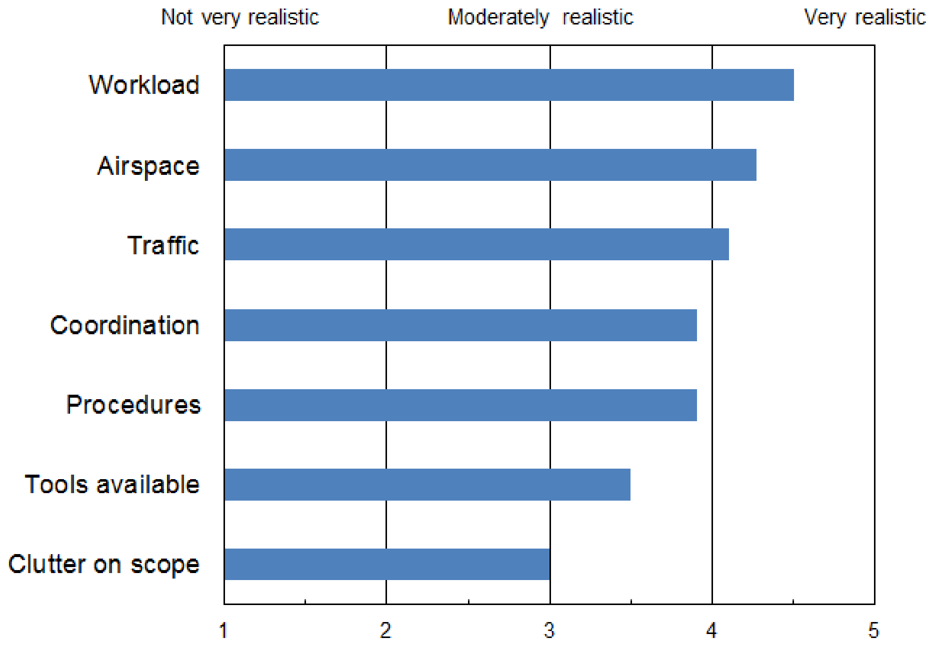
Distances from CLT to	
LIB (ZTL boundary)	90nm
HPW exit boundary	250-260nm
BWI, DCA, IAD MP	310nm
EWR & LGA MP	440-450nm

Criteria for Successful Stream Insertion

- Need to revisit what benefit the timely entrance of an departures in ZDC airspace provide?
- Is it correct to assume that departures will end up with the planned sequence of aircraft?
- It could be that the control of the timing of the departure in ZDC is more important than the actual strict sequence of aircraft.

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 in ZDC. 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."

Objectives for CEED HITL

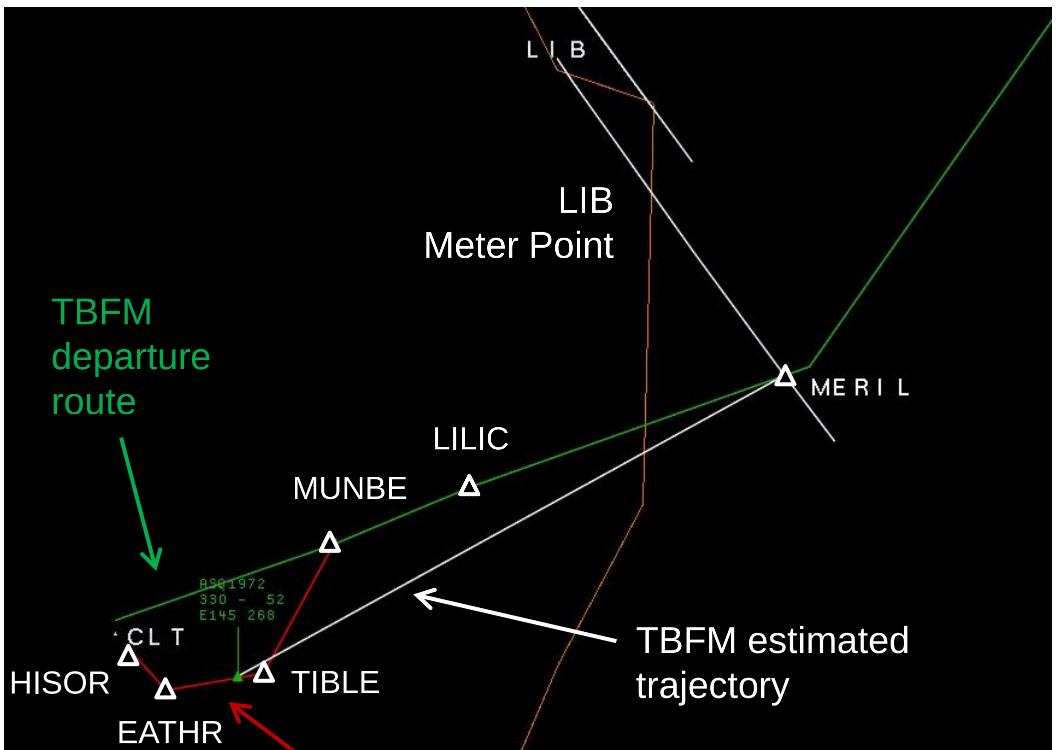
Objectives	Met ?
Establish simulation environment for airspace operation	✓
Simulate current-day departure and arrival operations with current technology	✓
Assess current Traffic Management Initiatives on departure flows and control operations	✓
Assess impact of compliance of departure release times	✓

Problems to Address

- Inefficient ETA predictions and flow management across adaptations
  - ZDC and ZTL adaptations do not have a good ETA predictions of flights at LIB
  - Include LIB as part of a T2T scheduling

MERIL departure routes in ZDC and ZTL TBFM adaptations

- MERIL departure route adapted in ZTL and ZDC TBFM are the same
- In ZTL's adaptation, MERIL is situated on the LIB Meter Point
- TBFM departure route is 10nm shorter than the actual filed route
- 10nm equals 1min 42sec of flight time for a CLT departure
- TBFM computes departures ETAs at MERIL/LIB too early



Filed SID route

CLT.MUNBE = 23.7nm
CLT.HISOR.EATHR.TIBLE.MUNBE = 33.7nm

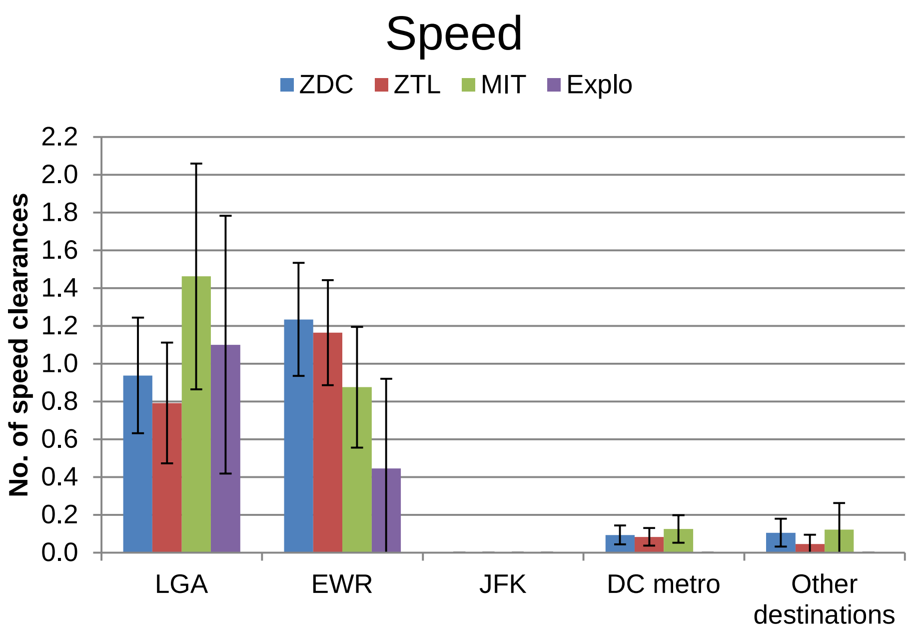
Average CLT departures' unimpeded fly time to:
23.7nm = 340sec
33.7nm = 442sec (102sec longer)

Additional results

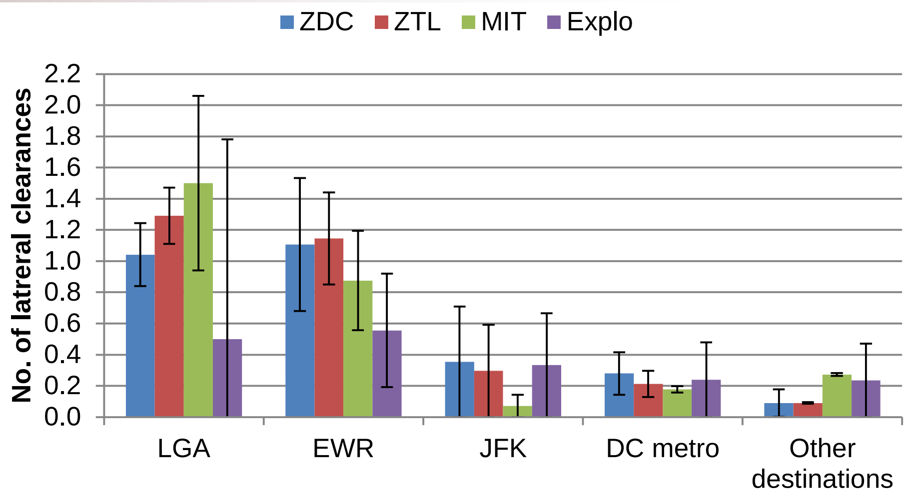
Back-up

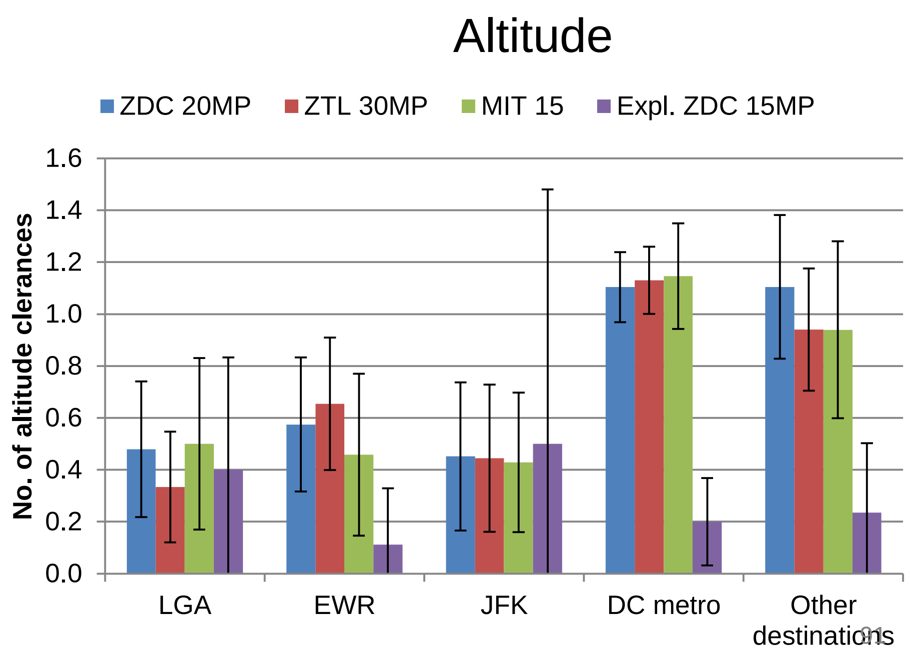
ATD2 Types of Clearances

Integrated Arrival/Departure/Surface

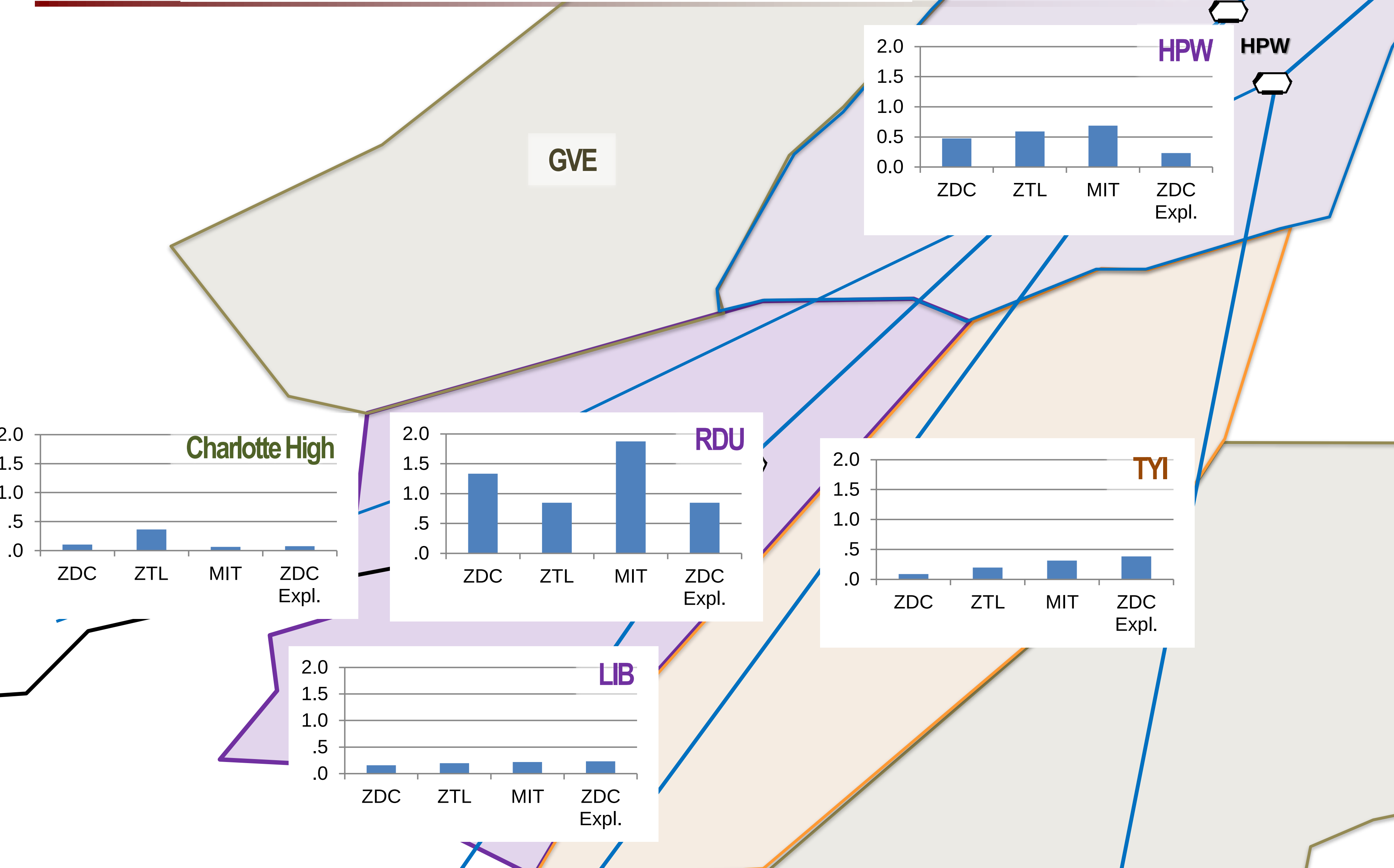


Lateral (route or heading)

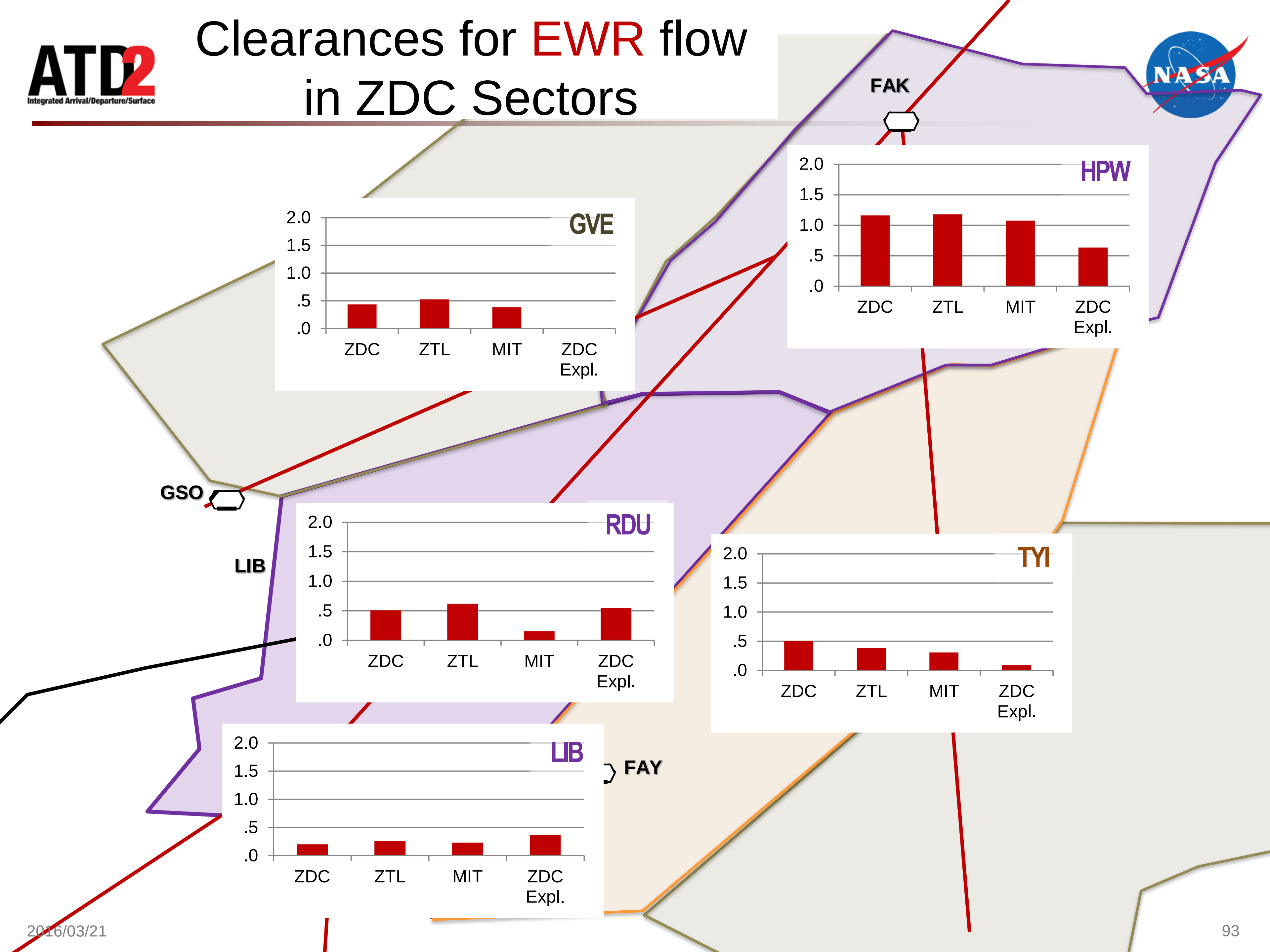




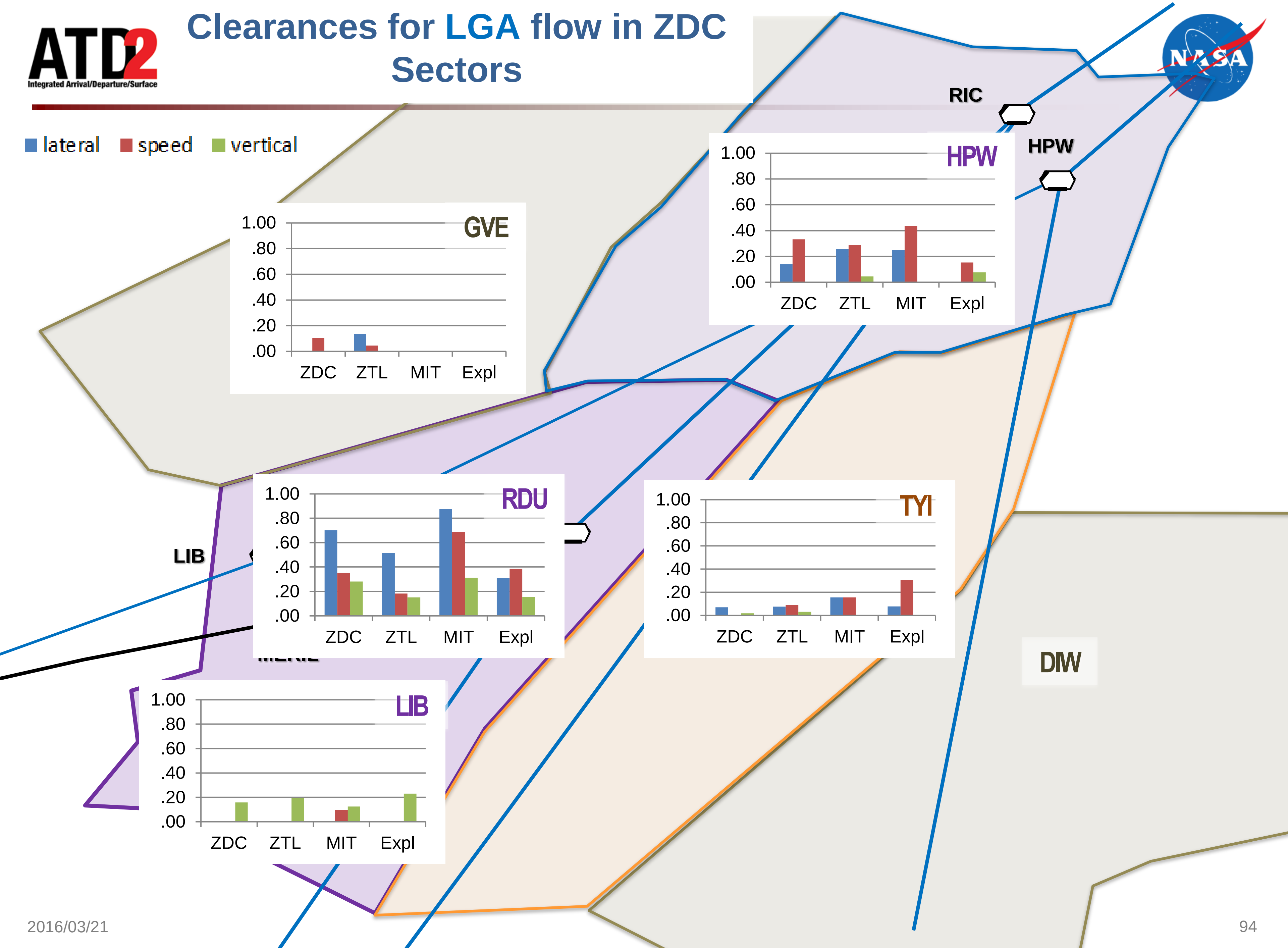
Clearances for LGA flow in ZDC Sectors



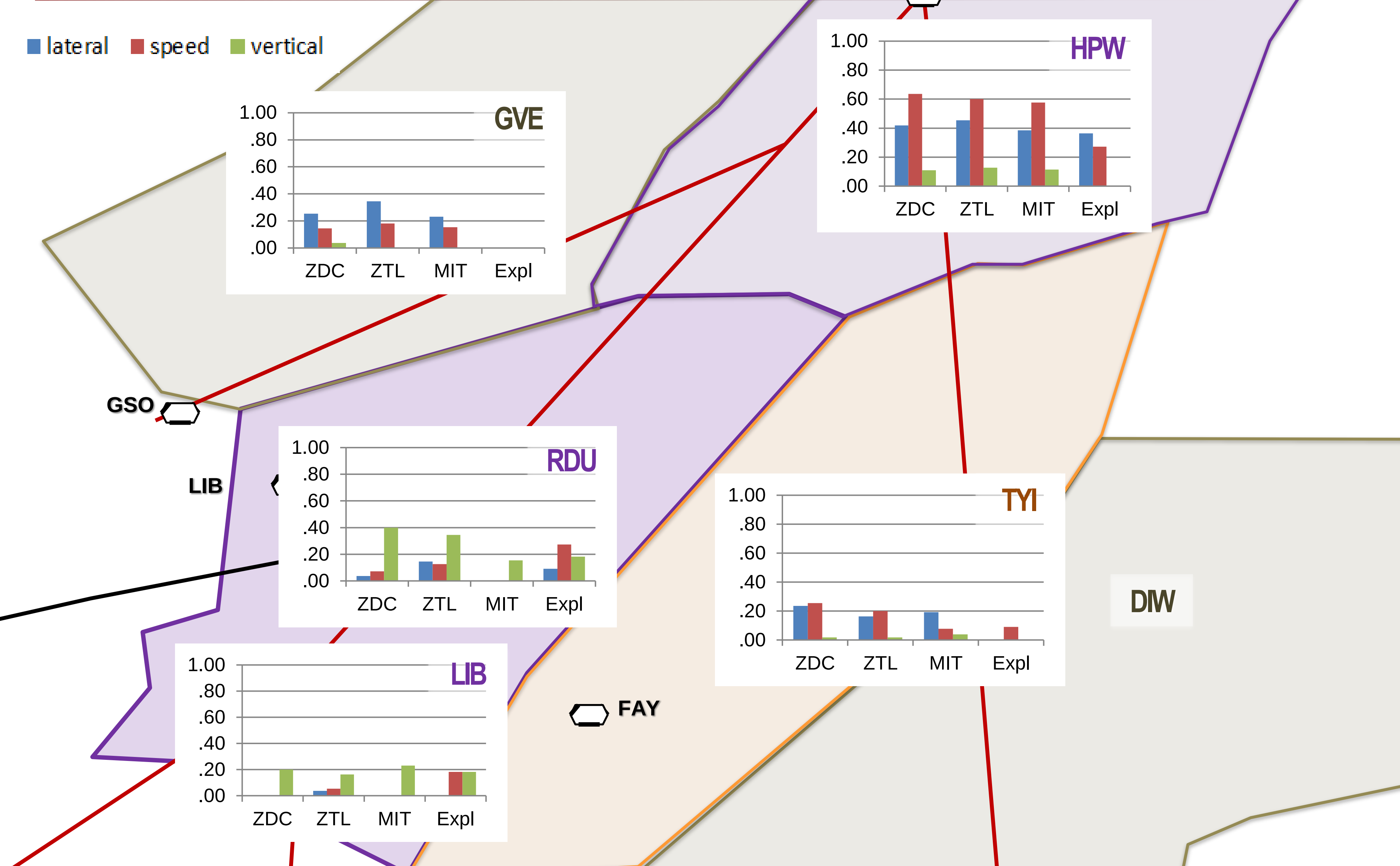
Clearances for EWR flow in ZDC Sectors



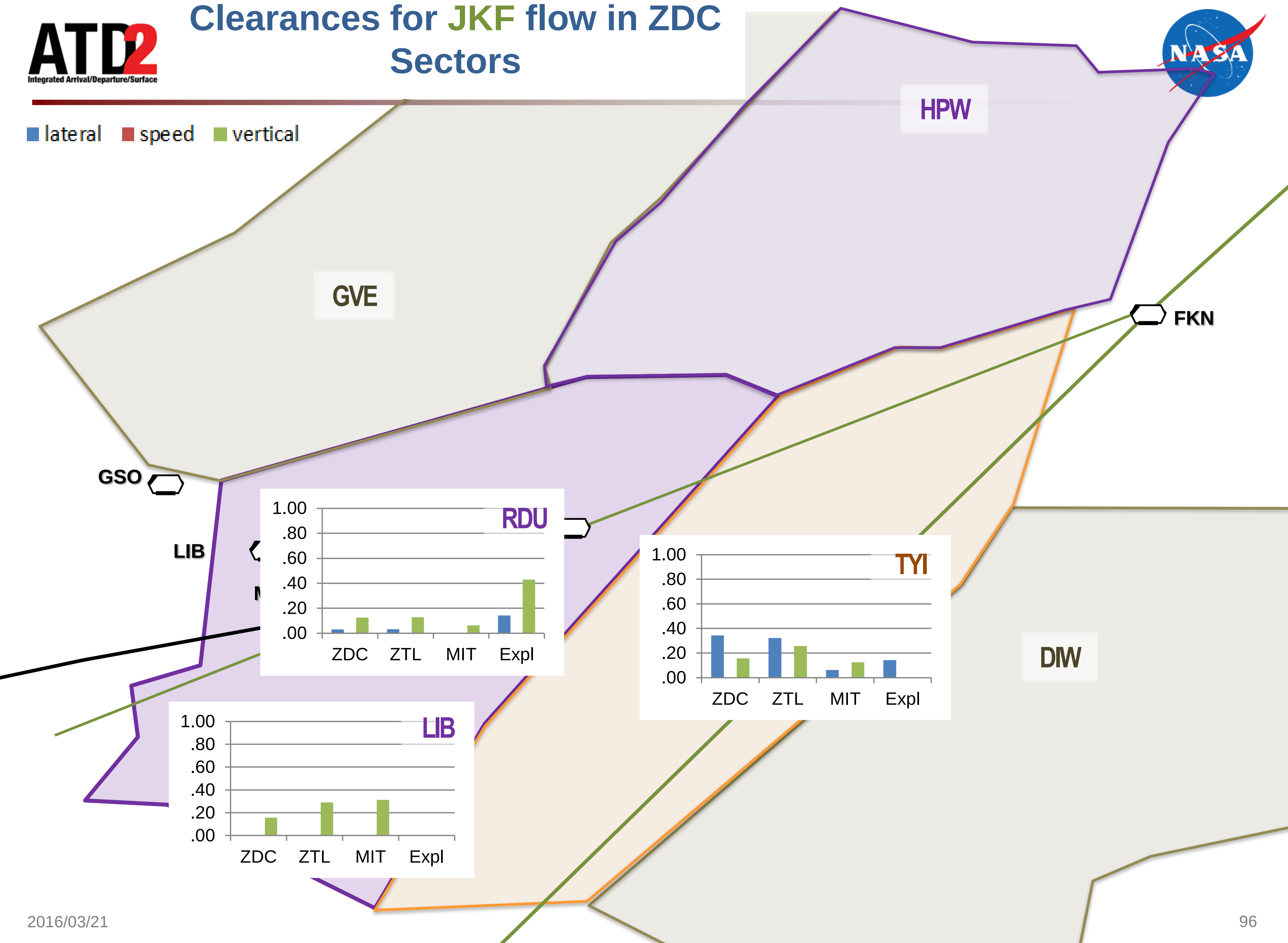
Clearances for LGA flow in ZDC Sectors



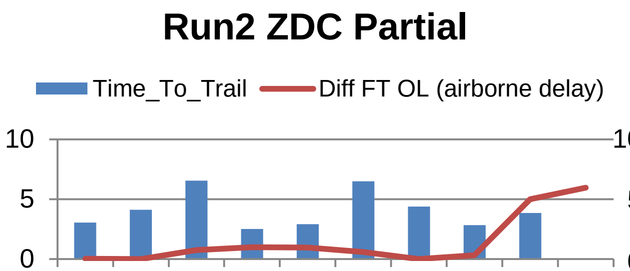
Clearances for EWR flow in ZDC Sectors

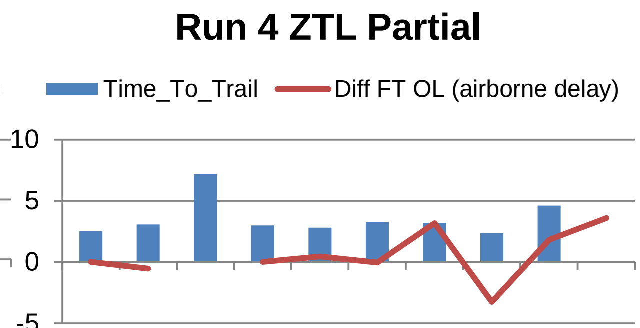


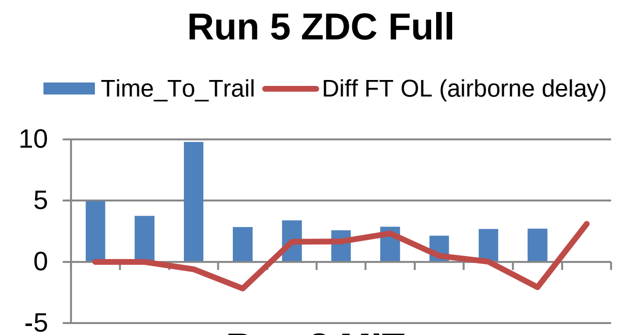
Clearances for JKF flow in ZDC Sectors

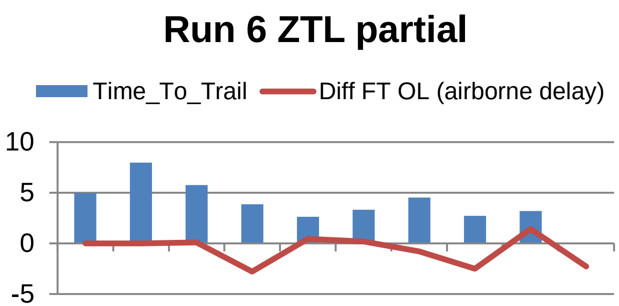


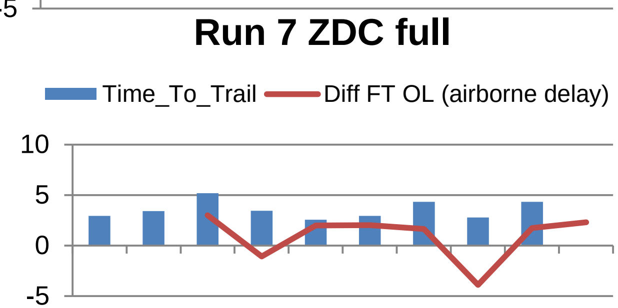
Delay and Trail Spacing for LGA at exit of HPW

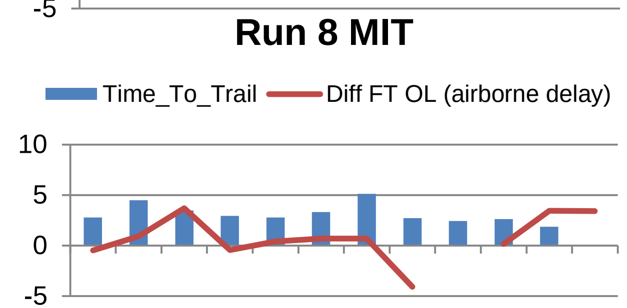


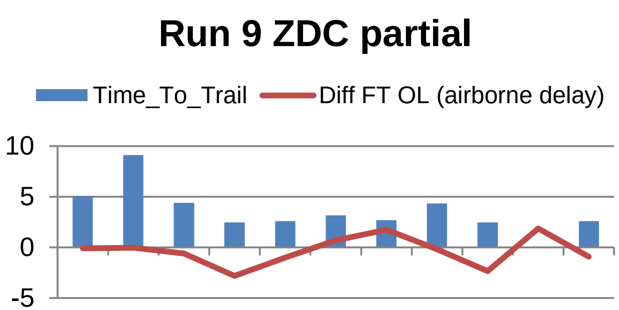


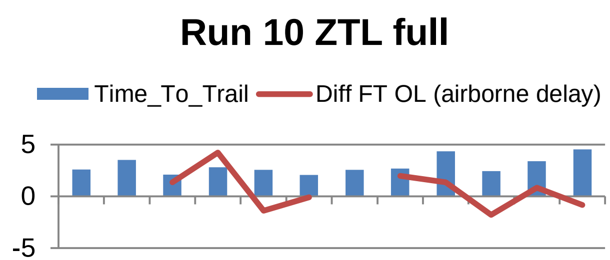


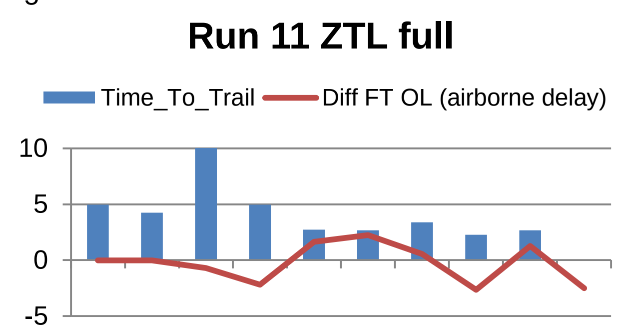


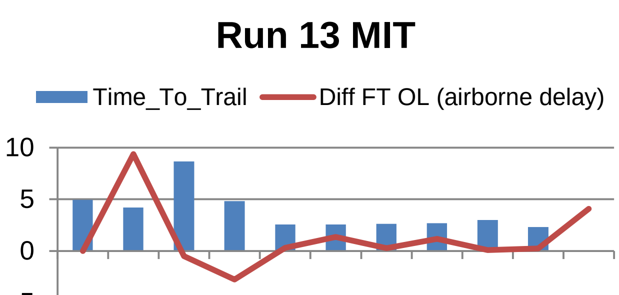


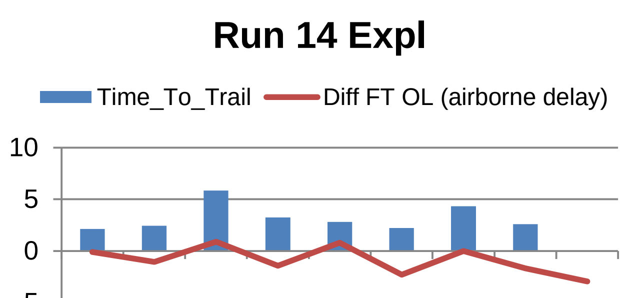








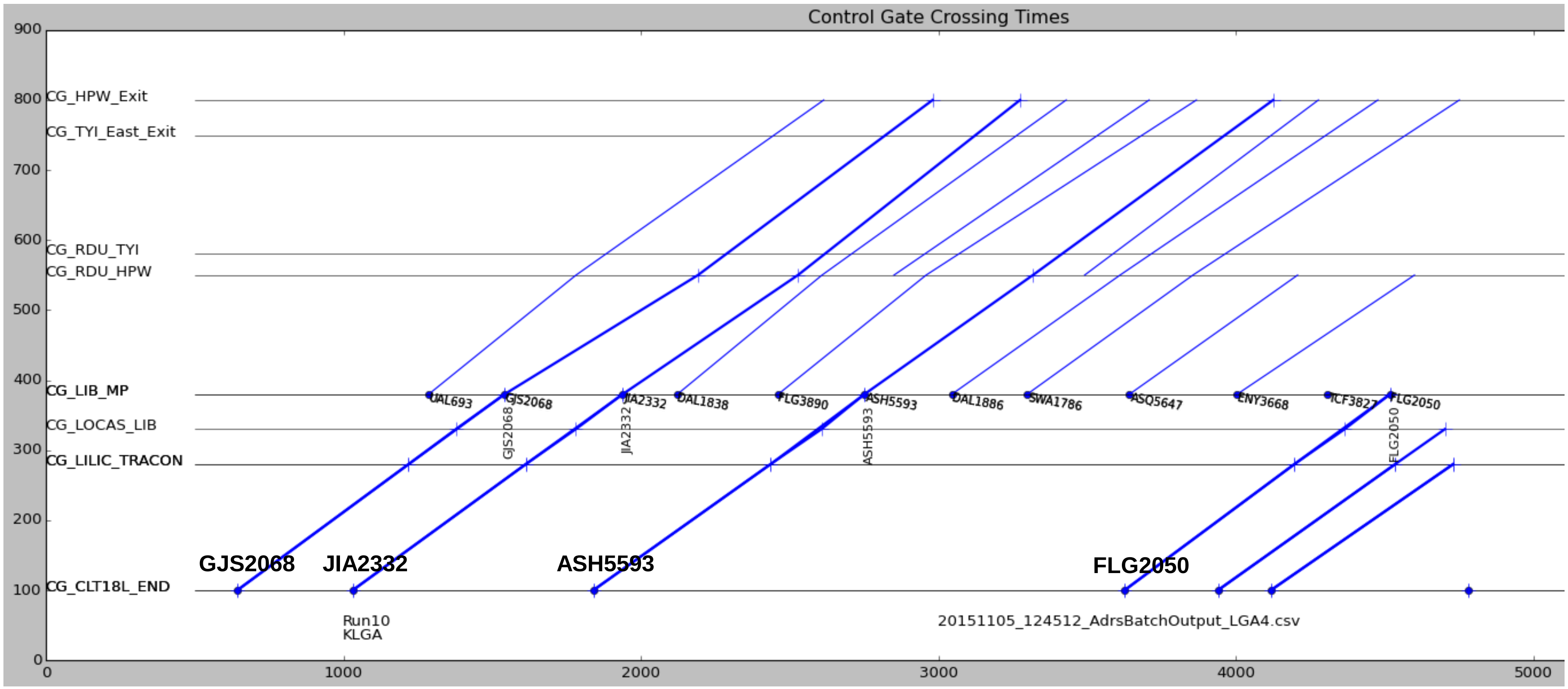




Time and Spacing Plots at Key Waypoints

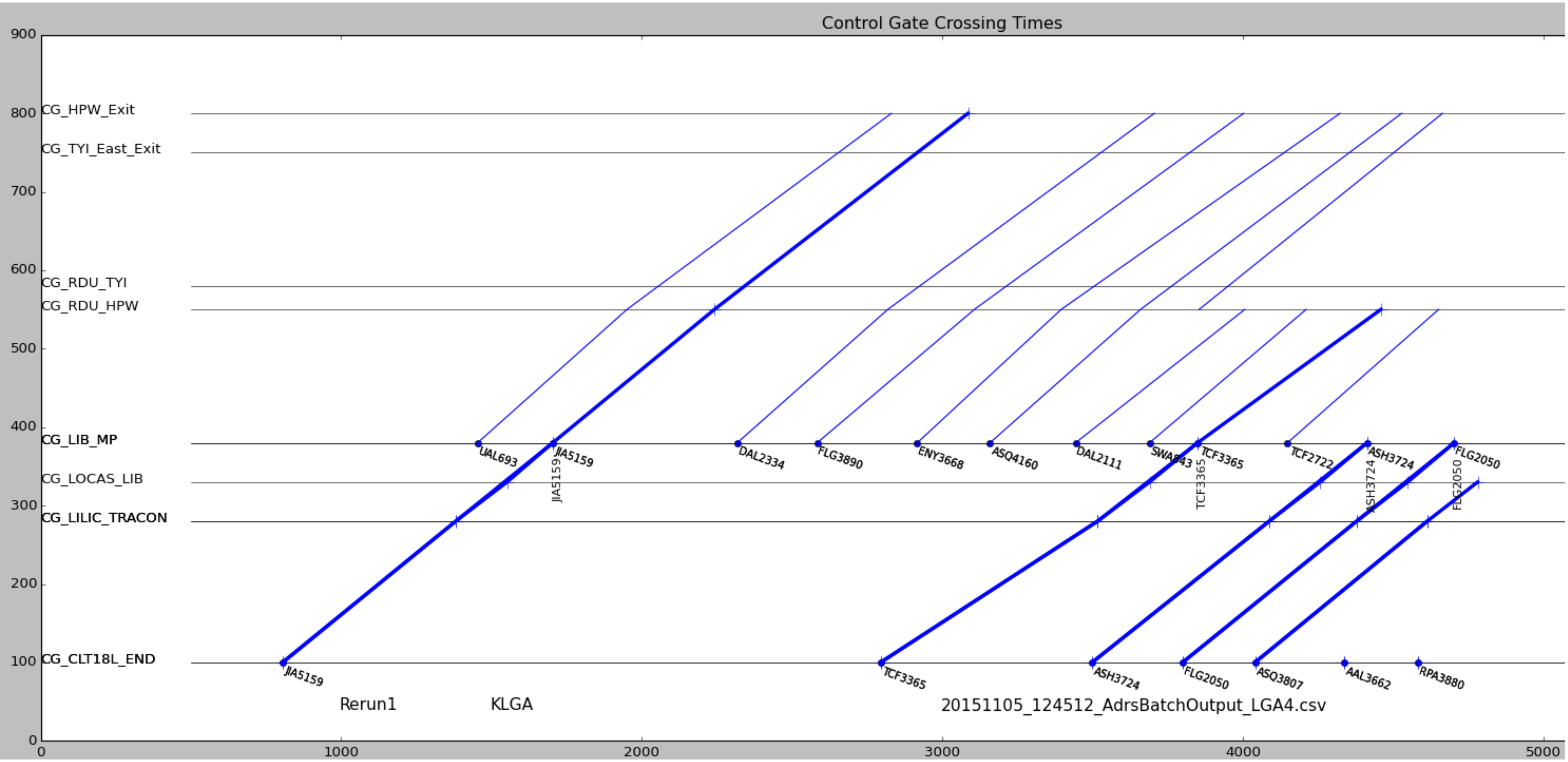
Examples

Run 10: CLT Departures bound for LGA Scheduled at LIB by ZTL



Run 10 – Full ZTL – Scenario 1

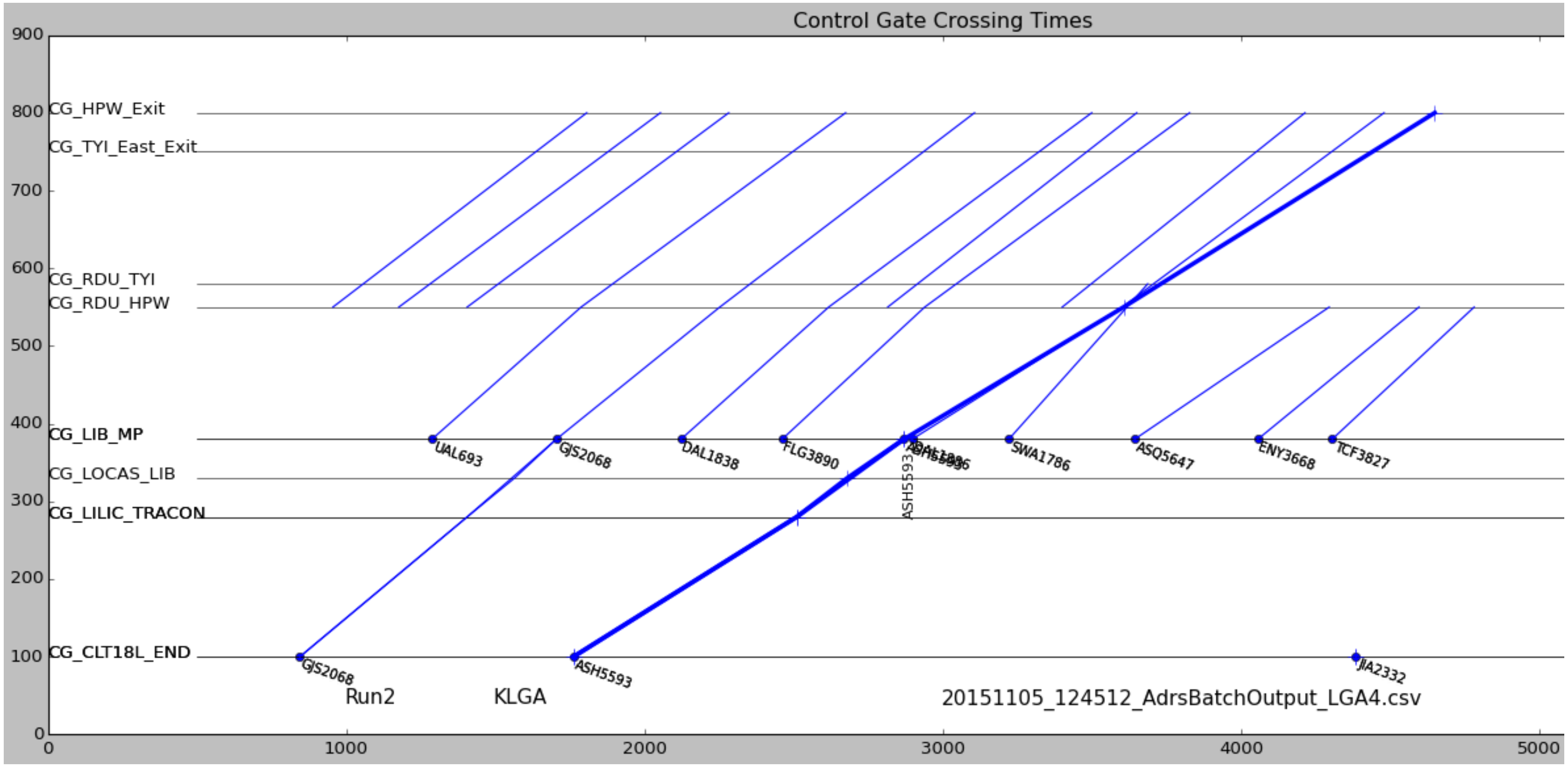
Run Rerun1: CLT Departures bound for LGA Scheduled at LIB by ZTL



Run Rerun1 – Full ZTL CFR - Scenario 2

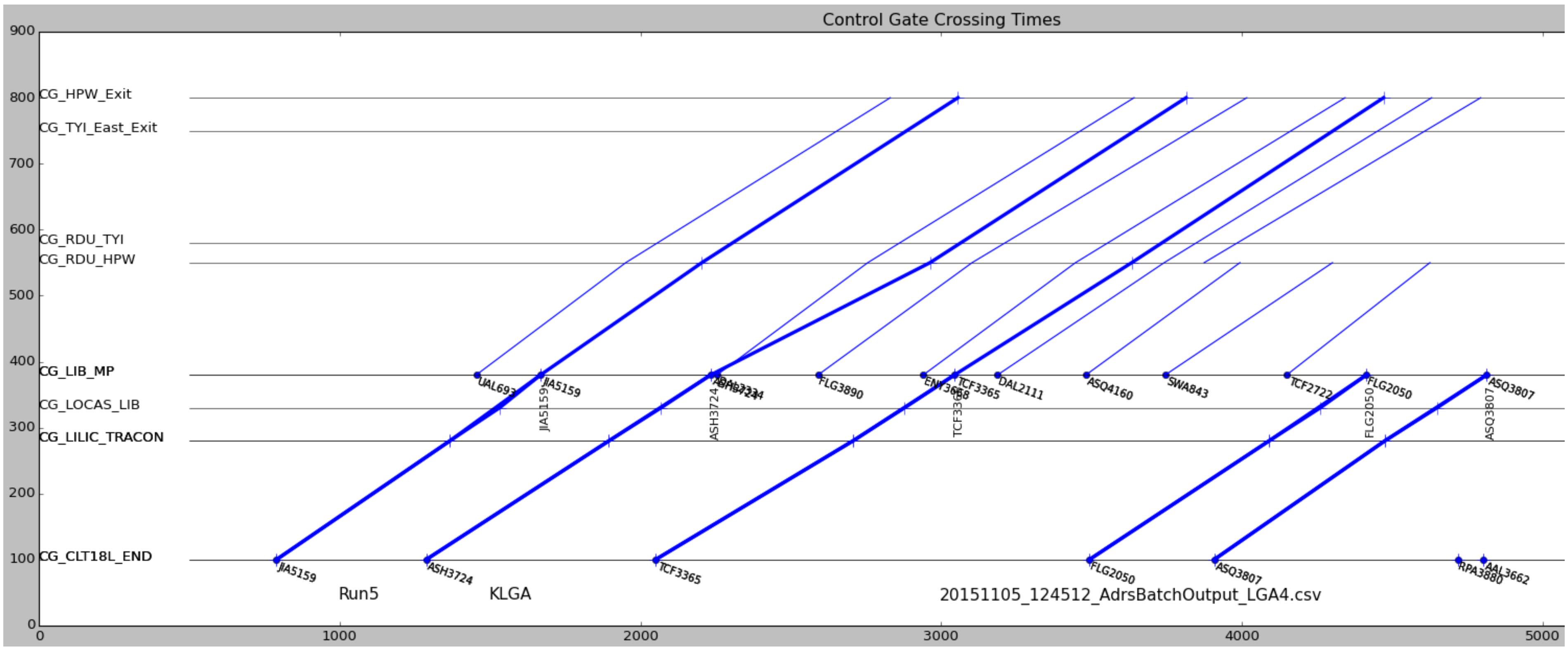
2016.02.05

Run 2: CLT Departures bound for LGA Scheduled by ZDC



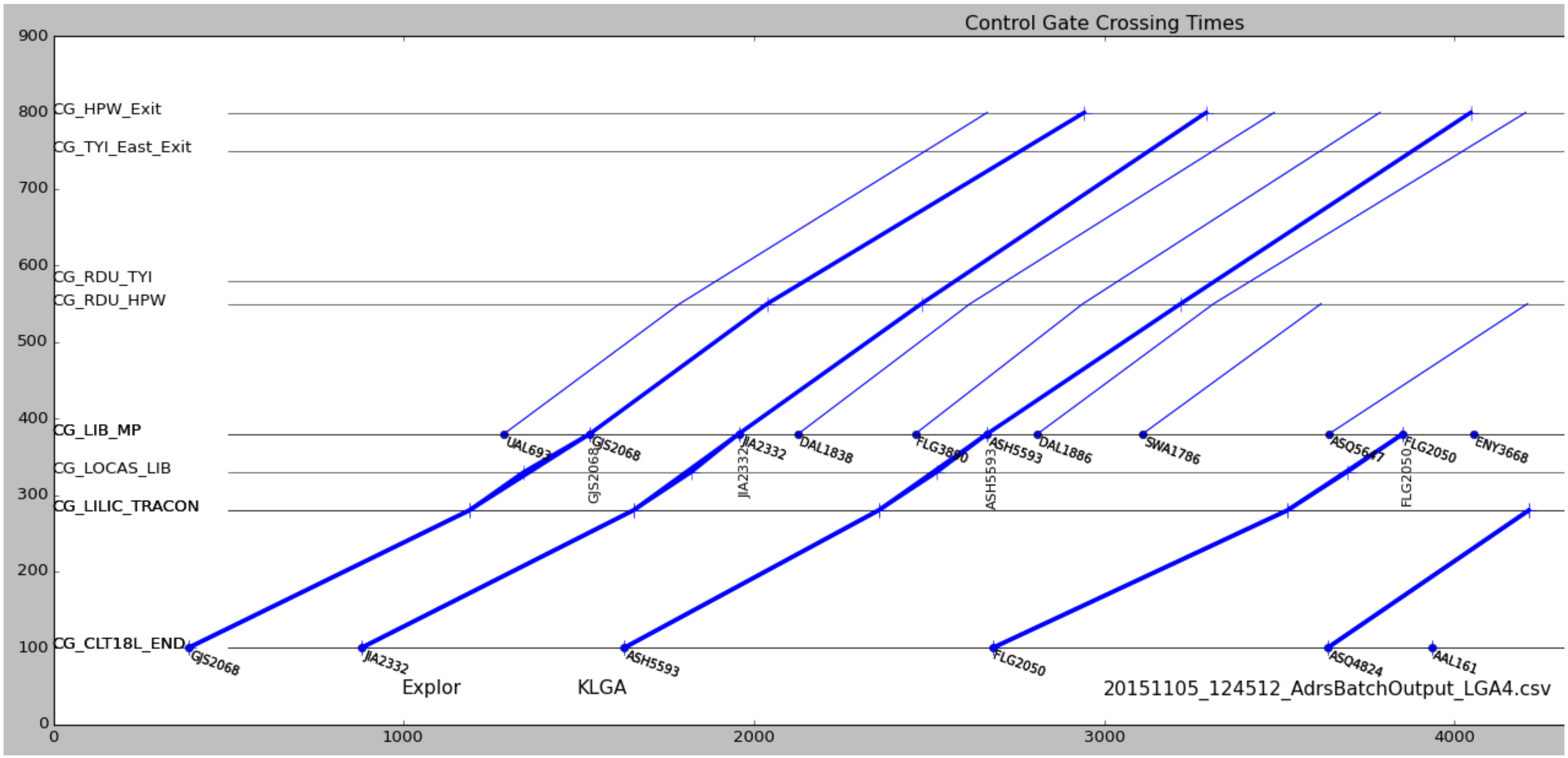
Run 2 – Partial ZDC CFR - Scenario 1

Run 5: CLT Departures bound for LGA Scheduled by ZDC



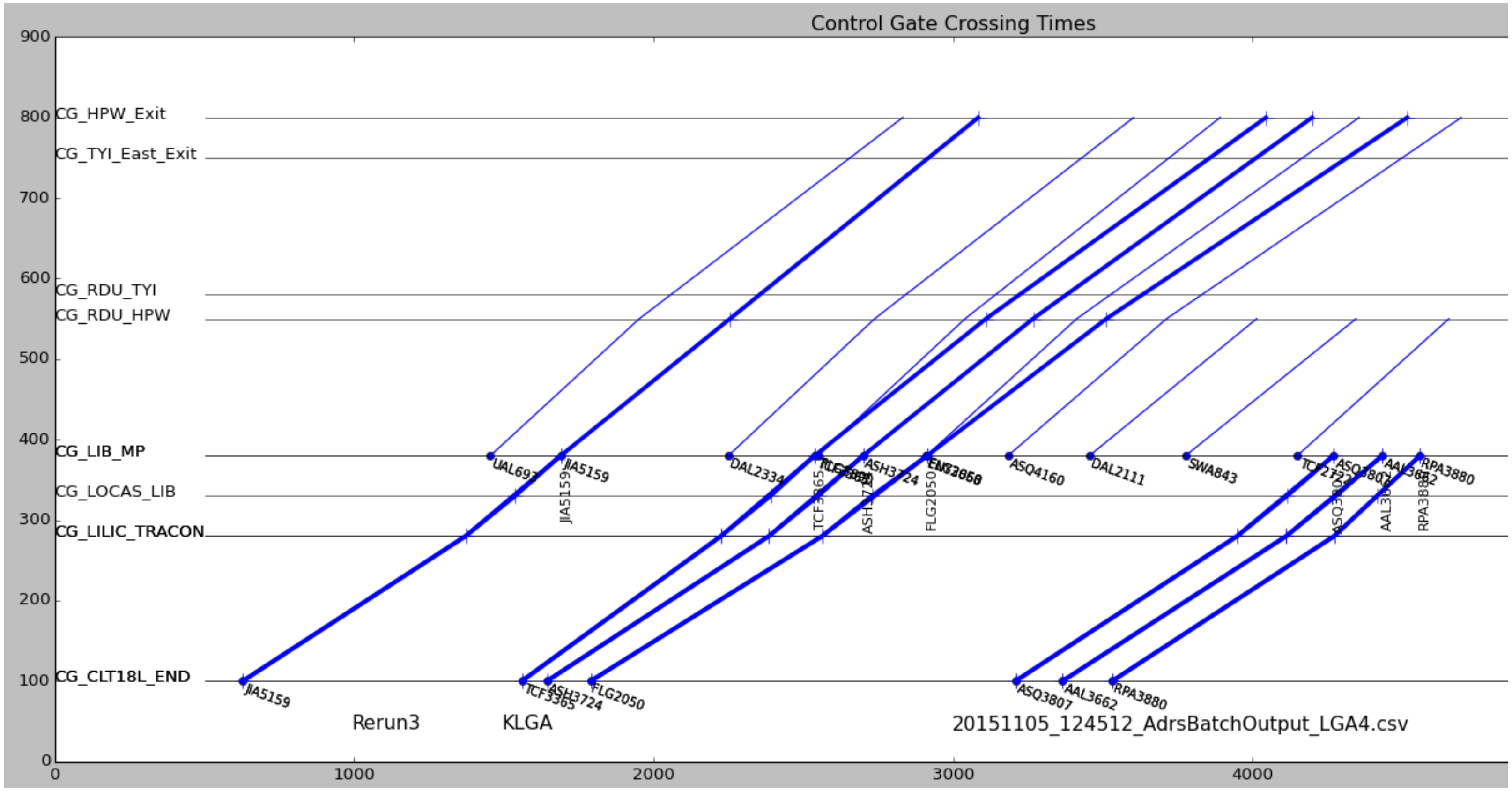
Run 5 – Full ZDC CFR - Scenario 2

Run Explor : CLT Departures bound for LGA Scheduled by ZDC



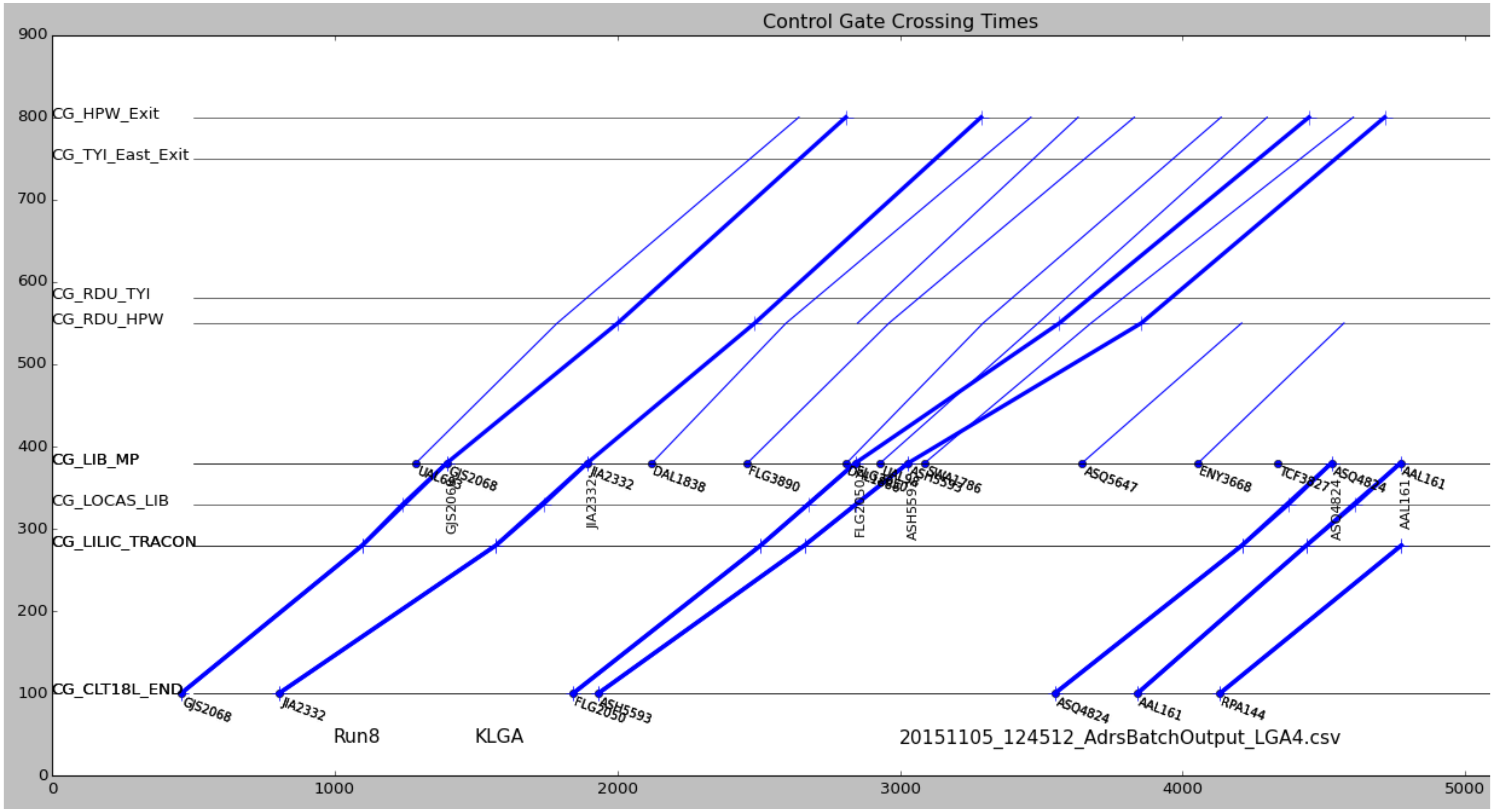
Run Explor – Full ZDC CFR – 15 MIT - Scenario 1

Run Rerun3 : CLT Departures bound for LGA



Run Rerun3 – Partial MIT - Scenario 2

Run 8 : CLT Departures bound for LGA



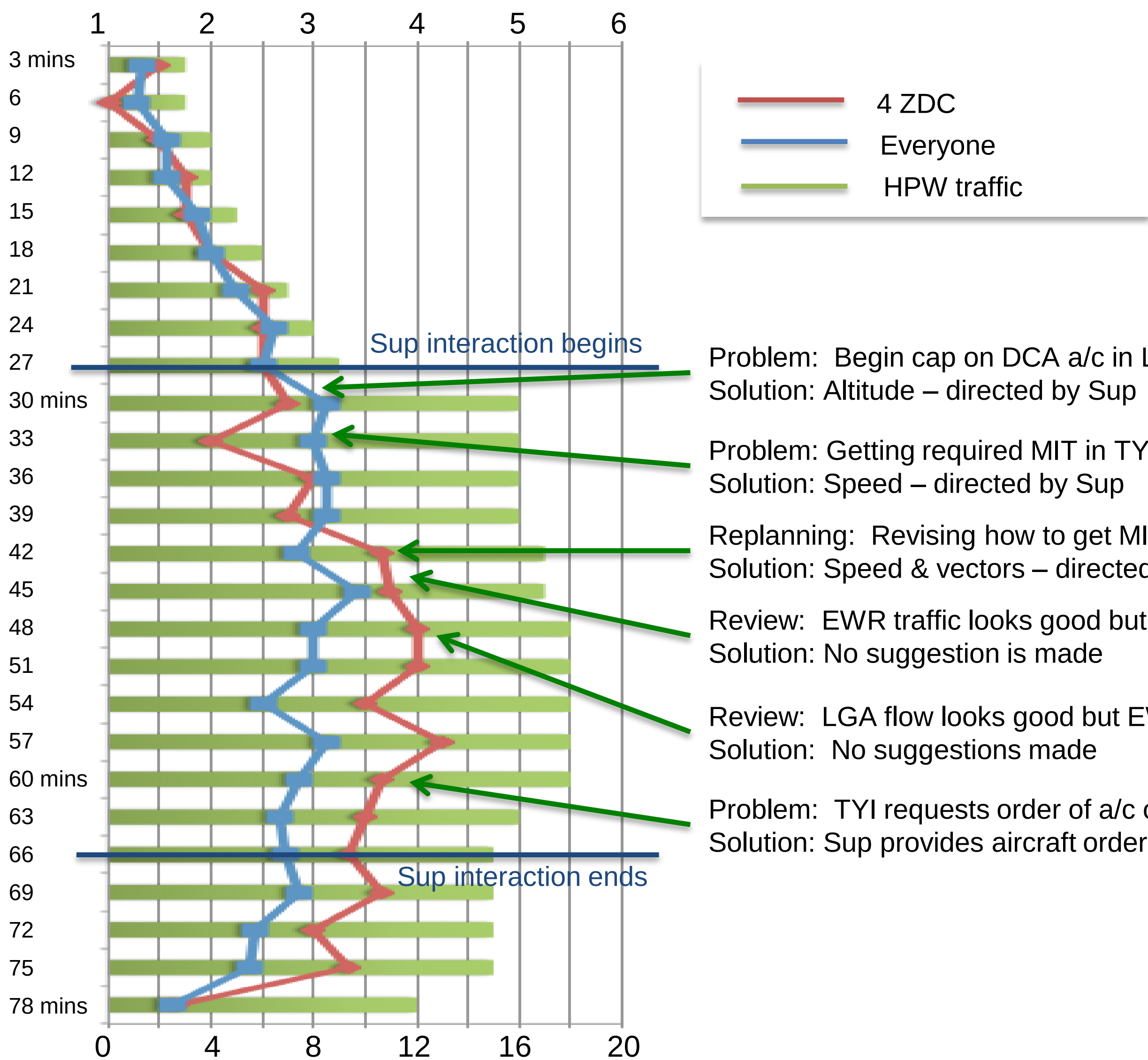
Run 8 – Partial MIT - Scenario 1

Analyses of problems in ZDC and Sup interventions

Lynne Martin

Kim Jobe

Map of supervisor problems to workload



2 Run 2
ZDC, Part
Scenario 1

Problem: Begin cap on DCA a/c in LIB
Solution: Altitude – directed by Sup

Problem: Getting required MIT in TYI on EWR flow
Solution: Speed – directed by Sup

Replanning: Revising how to get MIT on the EWR flow (TYI)
Solution: Speed & vectors – directed by Sup

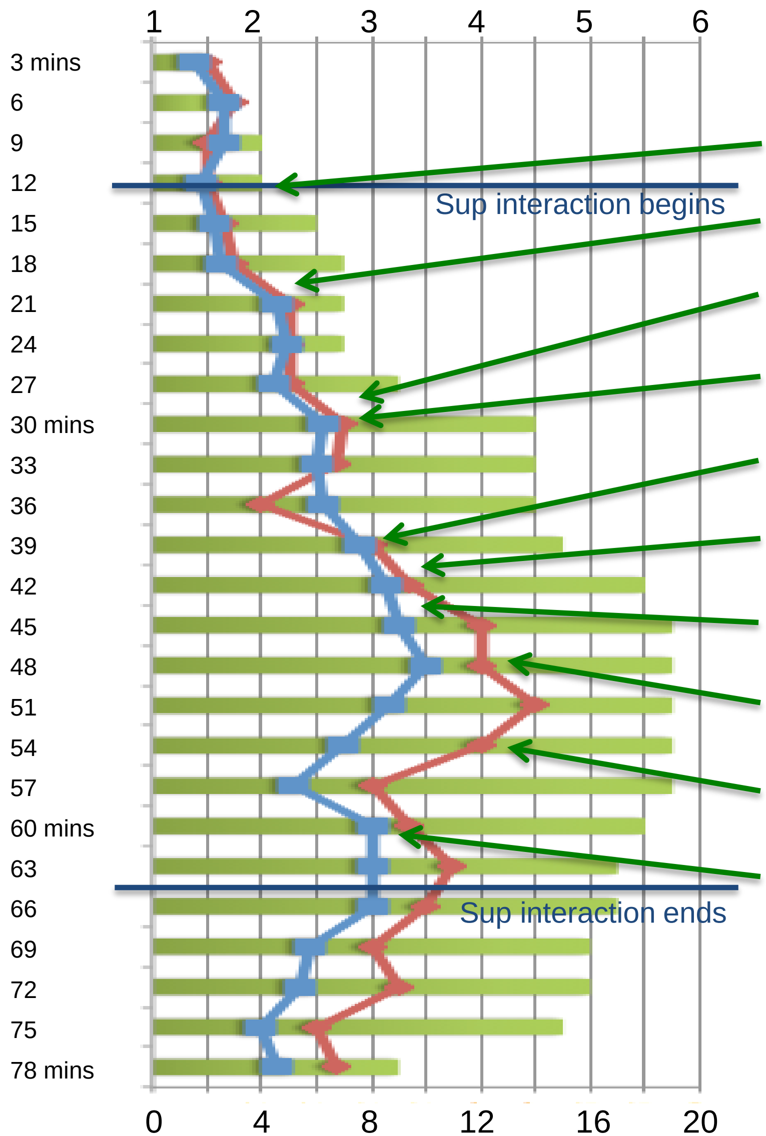
Review: EWR traffic looks good but LGA are high
Solution: No suggestion is made

Review: LGA flow looks good but EWR flow does not
Solution: No suggestions made

Problem: TYI requests order of a/c on LGA flow, RDU requests MIT on LGA flow
Solution: Sup provides aircraft order and MIT

Map of supervisor problems to workload

4 Run 4
ZTL, Part
Scenario 1



Problem: two aircraft are tied on EWR flow in HPE
Solution: No specific action, warns HPE

Problem: Too much traffic
Solution: Sup directs LIB to cap DCA a/c at FL230

Problem: spacing of a/c on EWR flow in LIB
Solution: speed directed by Sup

Problem: order of a/c on EWR flow in TYI & RDU
Solution: speed to put 1 a/c ahead of another

Problem: spacing on on EWR flow in TYI & GVE
Solution: Sup directs speed "slow these way back"

Problem: need more space on EWR flow in GVE
Solution: Sup directs vectors "spin this one"

Problem: need to fit another a/c on EWR flow in GVE
Solution: Sup directs speed "slow it way back"

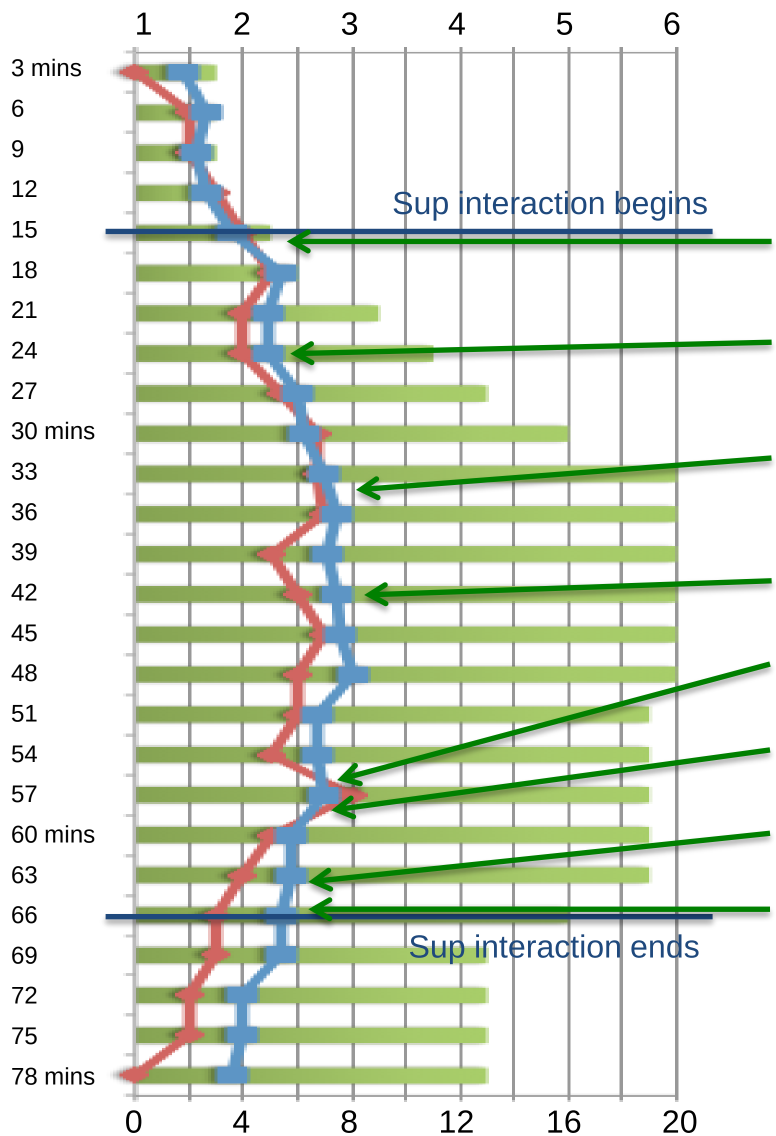
Problem: 4 aircraft now tied EWR flow/confusion re: order, which a/c to spin
Solution: Sup directs vectors; GVE spins 2 more a/c

Review: spacing of EWR a/c in HPW is OK; order changed
Solution: Sup directs speed "pick him up", then 2 min later "pick him up as well"

Review: spacing of EWR aircraft – OK
Sup to HPW: only need 15 MIT on "those 4"

4 ZDC
Everyone
HPW traffic

Chart of supervisor and ATC interactions



4 ZDC
everyone
HPW traffic

5 Run 5, ZDC, Full, Scenario 2

Problem: Sup directs LIB to keep DCA aircraft at FL230.
Base problem too much traffic.
Solution: Altitude decided by Sup

Problem: Need one aircraft GJS6280 (LGA) to outrun another
Solution: Speed - Sup says 'go fast' GVE issues 'max forward speed'

Problem: 3 EWR aircraft are in line & need to be spaced. Instruction to GVE: 'lose 10 or 15'
Solution: Vectors & speed: ATC uses vectors & speed, later Sup advises to 'turn more'

Problem: Two EWR aircraft are too close in line, need RDU to space
Solution: Speed – Sup determined

Review: spacing of LGA aircraft in HPW - need more
Solution: Speed and HPW plans to use vectors if speed is not enough

Review: spacing of EWR aircraft in HPW
Solution: OK- No action

Review: Fitting an EWR aircraft into the flow in GVE
Solution: OK – No action

Review: spacing of aircraft in Hopewell - OK
Solution: No action

Chart of supervisor and ATC interactions

6 Run 6
ZTL, Part
Scenario 2

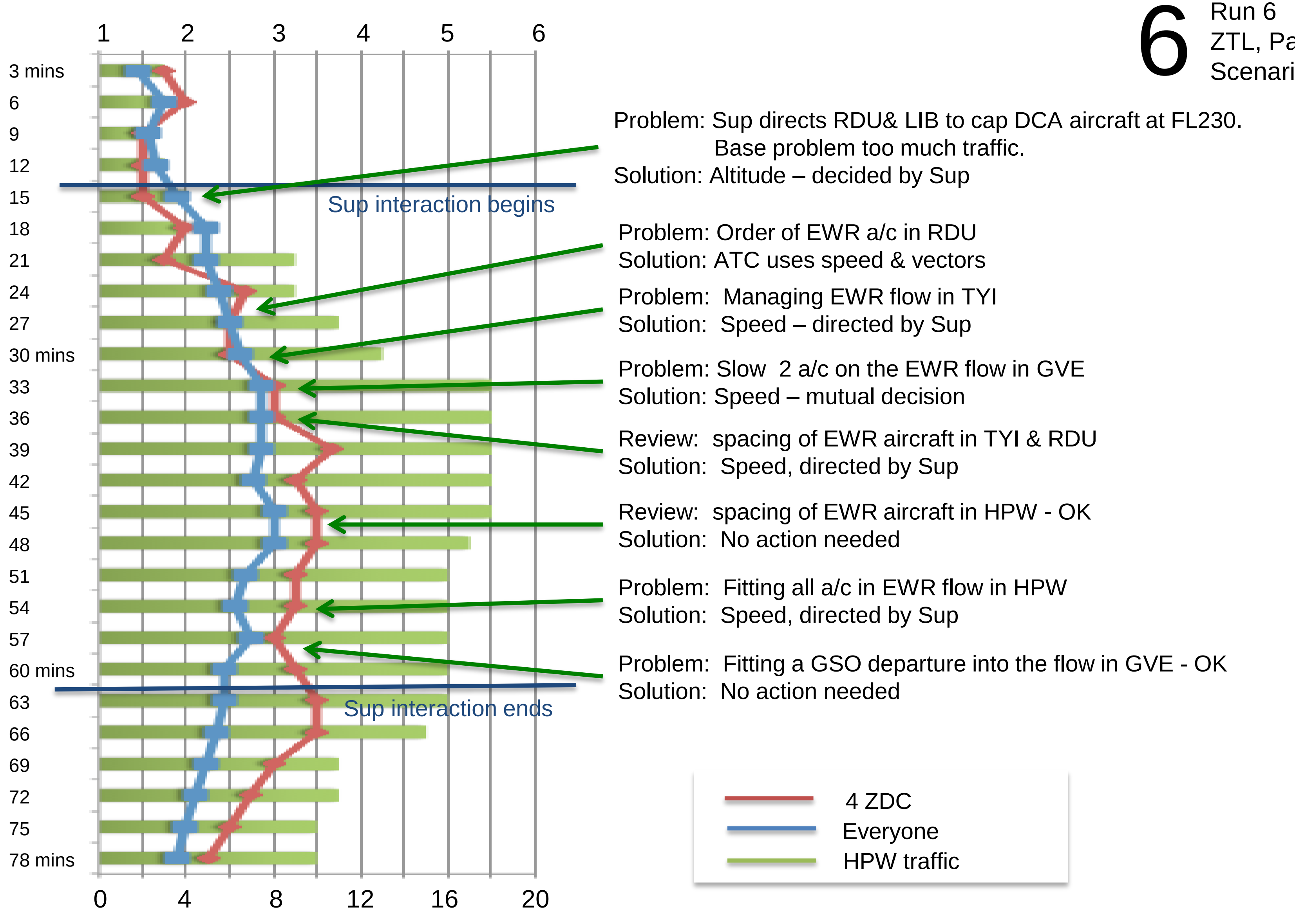
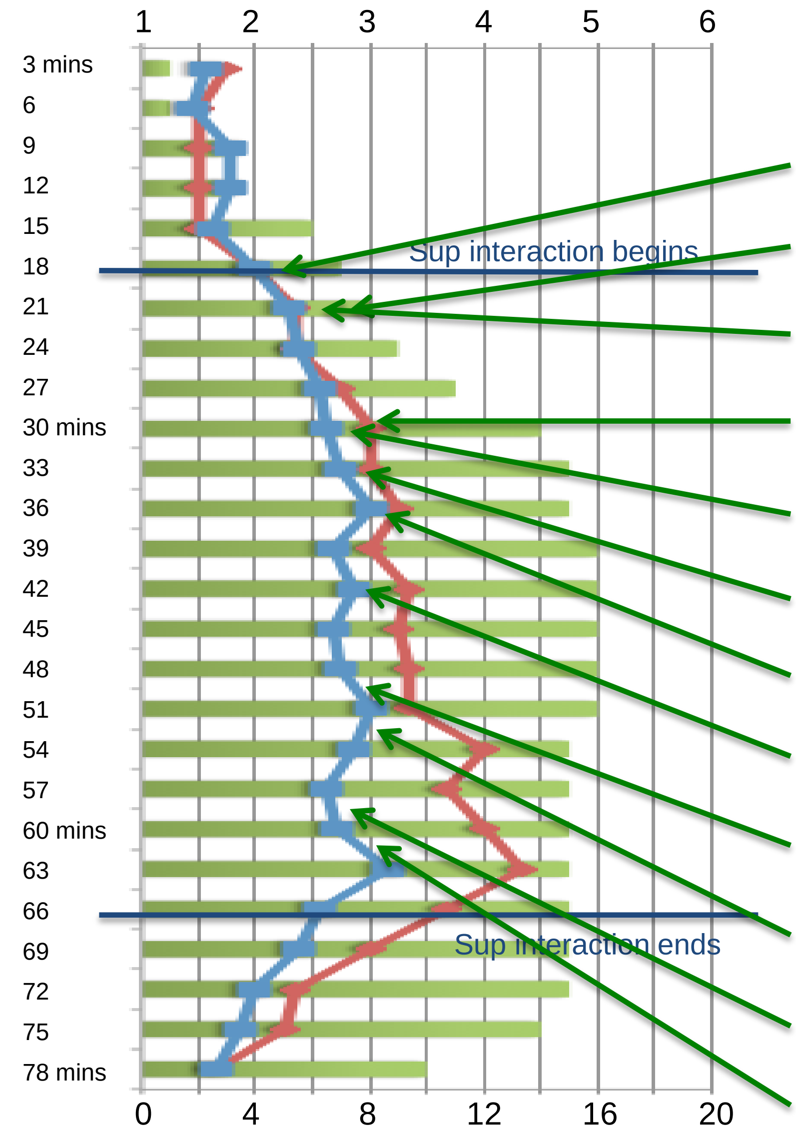


Chart of supervisor and ATC interactions



7 Run 7, ZDC, Full, Scenario 1

4 ZDC
Everyone
HPW traffic

Problem: spacing of a/c in LGA flow in RDU
Solution: Speed – Sup says “go fast”

Problem: order of a/c on LGA flow in GVE
Solution: Speed – Sup says “go fast”

Problem: Spacing on EWR flow in HPW
Solution: Speed – Sup says “go fast”

Review: spacing of first EWR aircraft in TYI – OK
Solution – no action

Problem: Order of a/c on EWR flow on TYI
Solution: Speed – Sup determined

Problem: Change / revision to EWR plan in GVE
Solution: Speed – Sup determined

Strategy: Delays giving a plan to TYI for aircraft in the EWR flow
Solution: No action

Problem: 2 a/c are tied on the EWR flow at GVE
Solution: Speed – Sup determined

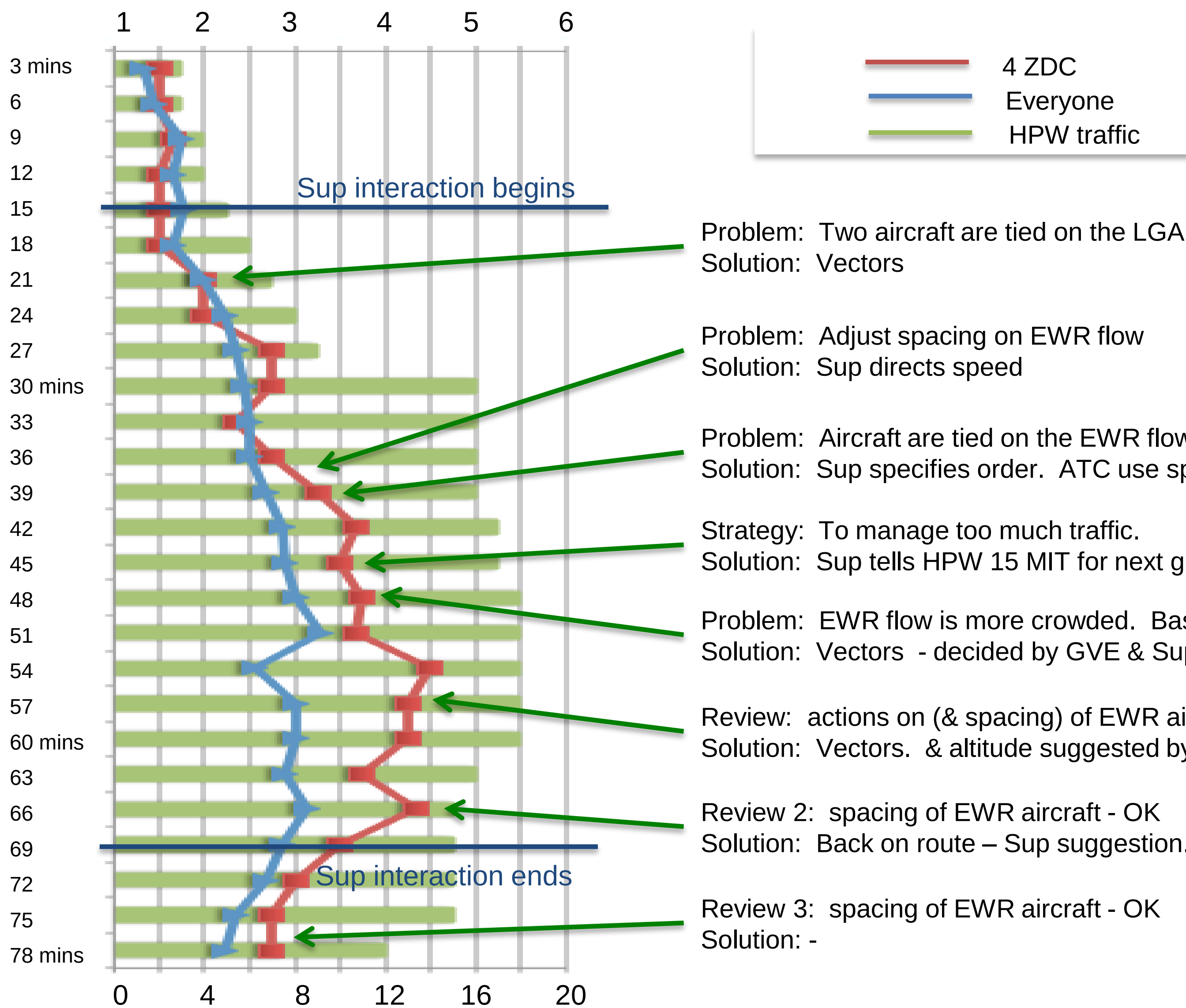
Problem: 3 a/c are tied on the EWR flow in TYI
Solution: Speed & vectors– Sup determined

Review: GSO departure complicates the EWR problem in GVE
Solution: Speed and ATC plans to use vectors if speed is not enough

Review: spacing of EWR aircraft with GVE is OK
Solution: New MIT for TYI

Review: spacing of second wave of EWR a/c with GVE & HPW – OK
Solution: Speed – Sup determined

Map of supervisor problems to workload



8 Run 8, MIT, Scenario 1

Problem: Two aircraft are tied on the LGA flow – need 20nm spacing
Solution: Vectors

Problem: Adjust spacing on EWR flow
Solution: Sup directs speed

Problem: Aircraft are tied on the EWR flow – need 40 nm spacing in GVE
Solution: Sup specifies order. ATC use speed & vectors

Strategy: To manage too much traffic.
Solution: Sup tells HPW 15 MIT for next group

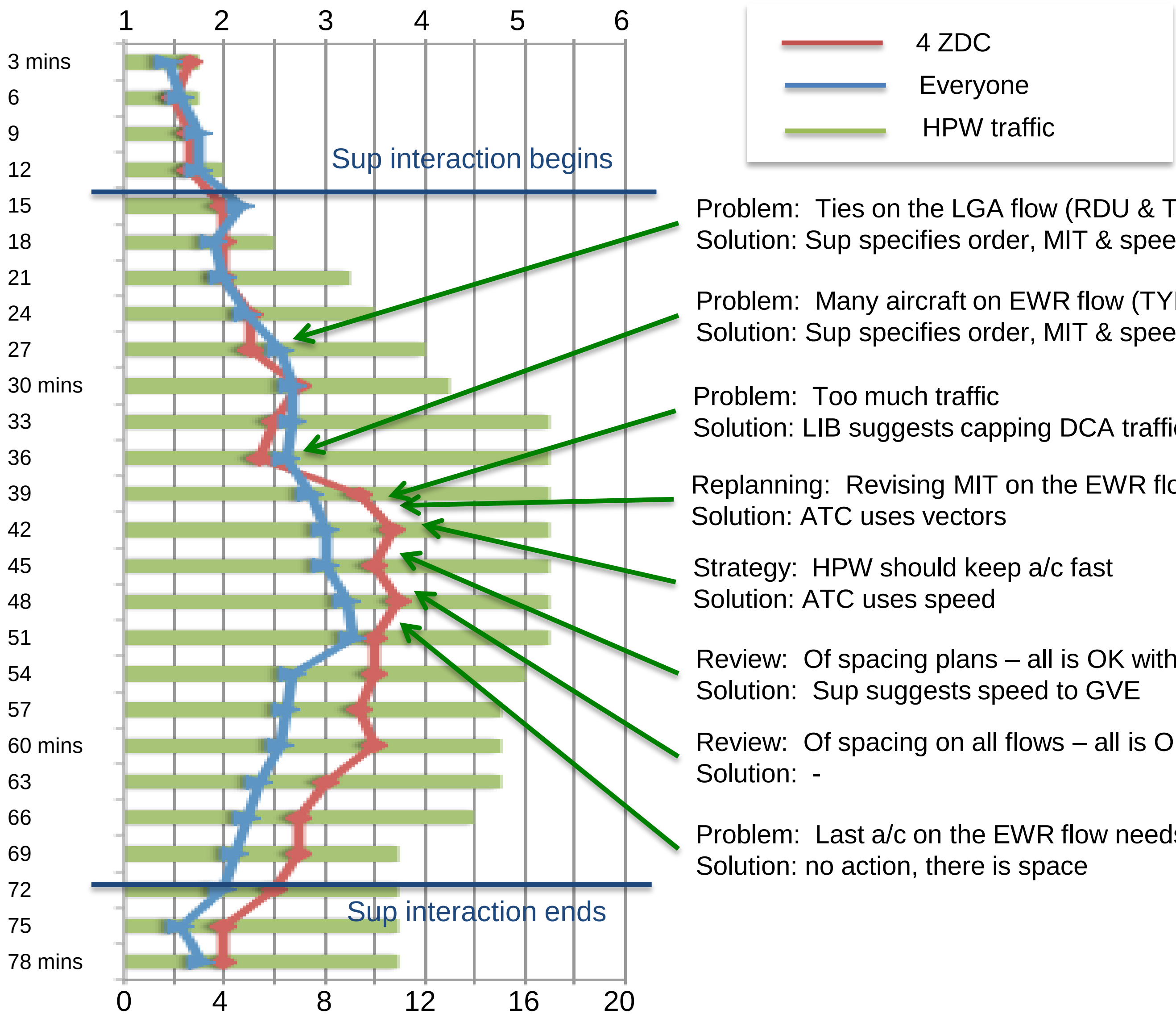
Problem: EWR flow is more crowded. Base problem too much traffic.
Solution: Vectors - decided by GVE & Sup

Review: actions on (& spacing) of EWR aircraft - need more.
Solution: Vectors. & altitude suggested by Sup

Review 2: spacing of EWR aircraft - OK
Solution: Back on route – Sup suggestion. Sup to HPW: 15MIT is OK

Review 3: spacing of EWR aircraft - OK
Solution: -

Map of supervisor problems to workload



9 Run 9
ZDC, Part
Scenario 2

Problem: Ties on the LGA flow (RDU & TYI)
Solution: Sup specifies order, MIT & speed

Problem: Many aircraft on EWR flow (TYI & GVE)
Solution: Sup specifies order, MIT & speed

Problem: Too much traffic
Solution: LIB suggests capping DCA traffic, Sup agrees

Replanning: Revising MIT on the EWR flow (RDU & GVE)
Solution: ATC uses vectors

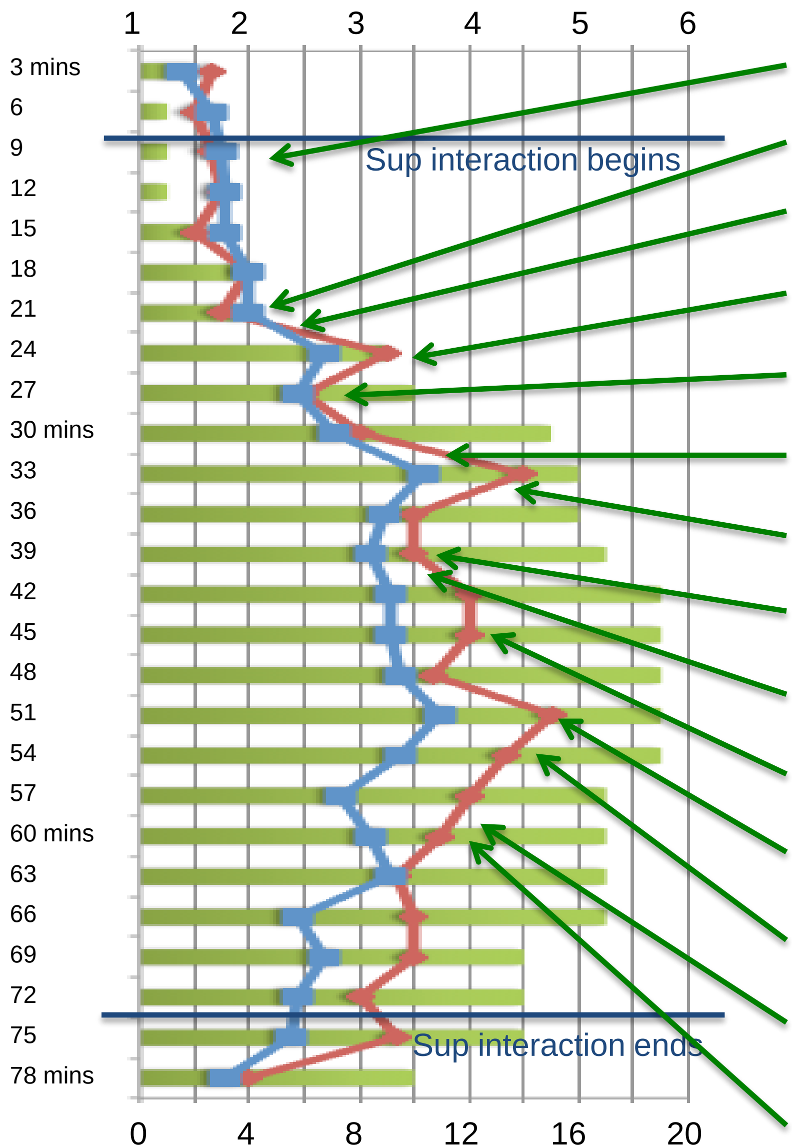
Strategy: HPW should keep a/c fast
Solution: ATC uses speed

Review: Of spacing plans – all is OK with some tweaks
Solution: Sup suggests speed to GVE

Review: Of spacing on all flows – all is OK
Solution: -

Problem: Last a/c on the EWR flow needs to be fitted in by GVE
Solution: no action, there is space

Map of supervisor problems to workload



10 Run 10 ZTL, Full Scenario 1

Problem: two aircraft are tied on EWR flow
Solution: HPE suggests vectors and "fly fast"

Problem: a/c on LGA flow need 40 MIT in RDU
Solution: RDU climbs/vectors for spacing

Problem: spacing of a/c on LGA flow in TIR
Solution: speed directed by Sup

Problem: spacing of a/c on LGA flow in RDU
Solution: Sup directs 60 MIT in RDU, sequence of a/c, speed (drop another 20), "spin that one"

Problem: Too much traffic
Solution: Sup directs LIB to cap DCA a/c at FL230

Problem: spacing of a/c on EWR flow in TIR
Solution: Sup directs speed "Go fast"

Problem: another a/c to fit into LGA flow in GVE
Solution: GVE: direct HPE? Sup: OK but "go slow"

Problem: need to "lose 10" on EWR flow in GVE
Solution: Sup directs speed "pull them back to M70"

Problem: Need more space on EWR flow
Solution: Get 40 MIT between last 2 a/c, Sup determines sequence

Problem: HPE not able to get 20 MIT either flow
Solution: Sup: if >20 MIT, let me know which flow

Problem: another a/c needs to fit into the EWR flow. Solution: Sup: spin that one, needs to follow 4 others in order to fit in.

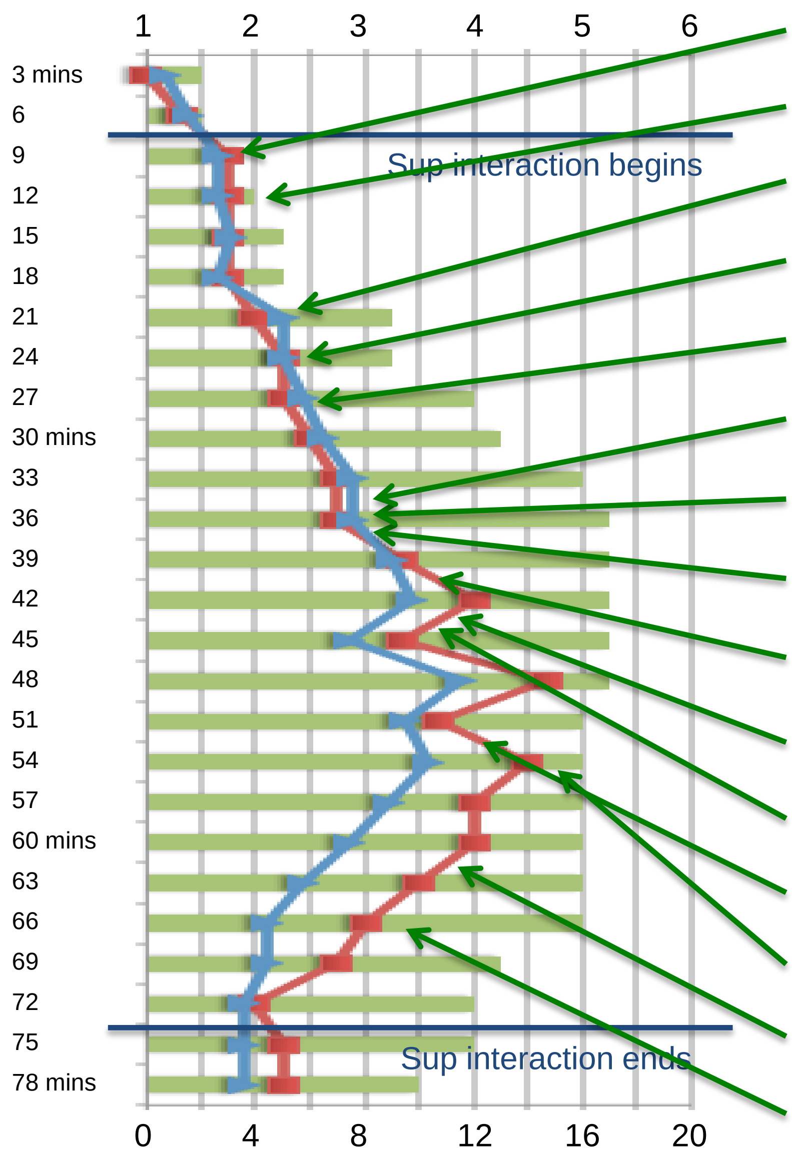
Problem: Sup observes HPE "running out of room" on EWR flow
Solution: Sup changes MIT requirement to 15 MIT

Problem: Not getting 15 MIT on the EWR flow.
Solution: Sup: directs speed in GVE "pick him up a little"

Problem: Need more space in HPE on the EWR flow. Sup: "more a/c coming up on EWR flow"
Solution: Sup directs speed: "bust this guy up"

4 ZDC
Everyone
HPW traffic

Map of supervisor problems to workload



Strategy: Don't cap Boston traffic until have to
Solution: RDU to work for now

Review: all LGA aircraft "fit right in"
Solution: no action for GVE & LIB

Strategy: RDU to move White Plains a/c out of problem. Later move JBU118 also
Solution: Vectors

Problem: EWR aircraft has to catch up to its overhead slot
Solution: Sup specifies speed to LIB

Problem: Needs to fit more EWR a/c into flow
Solution: Sup specifies vectors to TYI

Replanning: Needs greater space on EWR flow (40nm)
Solution: Vectors & speed (TYI & RDU)

Review: all EWR aircraft will make spacing
Solution: -

Problem: Tie on LGA flow (TYI & RDU)
Solution: Implied for one to follow the other.

Replanning: Extra aircraft to fit in EWR (GVE)
Solution: Sup specifies vectors & speed.

Review: Of EWR flow plan through TYI
Solution: Need more space (40nm)

Problem: Fitting one a/c into the EWR flow
Solution: GVE issues vectors. Sup focuses on MIT

Replanning: Fitting two more a/c into the EWR flow (RDU & GVE)
Solution: ATC issues & sup suggests speed.

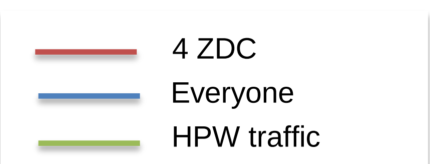
Review: of the incoming flows with HPW
Solution: -

Problem: Maintaining MIT in HPW
Solution: Sup suggests speed.

Review: of the MIT in HPW – all OK
Solution: -

11

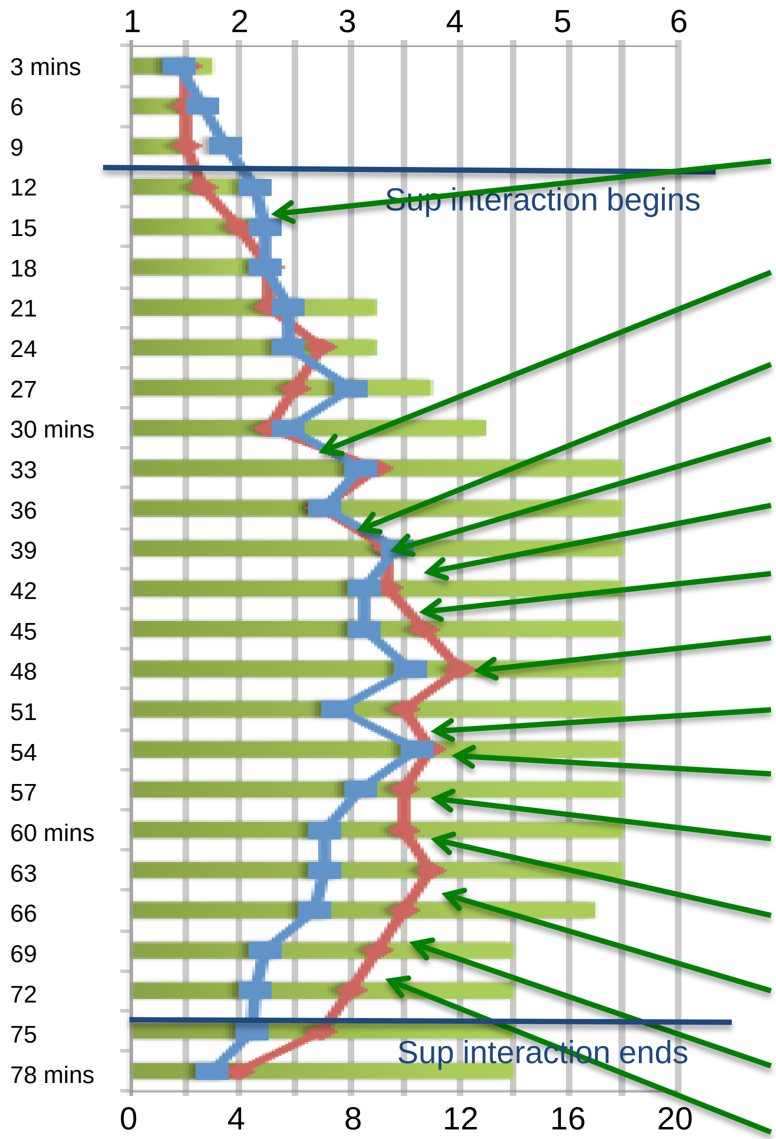
Run 11,
ZTL, Full,
Scenario 2



Map of supervisor problems to workload

ATD2 Integrated Arrival/Departure/Surface

13 Run 13
MIT
Scenario 2



Problem: 2 a/c in line on EWR flow need to be spaced
Solution: Sup directs GVE “go direct Flat Rock” with a/c 10 miles in front of a CLT departure

Problem: 3 a/c in line on LGA flow need to be spaced
Solutions: RDU suggests move White Plains/Boston a/c out of problem, Sup agrees. Sup directs vectors for spacing in TIR, then spins again later

Problem: Spacing on EWR flow
Solution: Sup directs speed in GVE

Problem: Spacing on LGA flow in RDU
Solution: Sup: will be ~ 8 a/c to space, “do best you can”

Review: Sup advises EWR flow in HPE not perfect, 2 a/c tie, but HPE has room to work with

Problem: spacing on LGA flow in RDU too tight
Solution: Sup directs “just go to 15 MIT with them”

Review: spacing on EWR flow in GVE – lost 40 MIT but ok for now

Review: spacing on LGA flow ok now; Sup directs TYI can put an a/c back on course now from 2nd problem above

Review: EWR flow in HPE close, but HPE has “big speeds working right now”, should be ok

Problem: need to fit another a/c in LGA flow
Solution: speed directed by Sup “build 30 between 2”

Problem: an a/c on EWR flow too slow, out of seq.
Solution: Sup directs speed and re-sequence

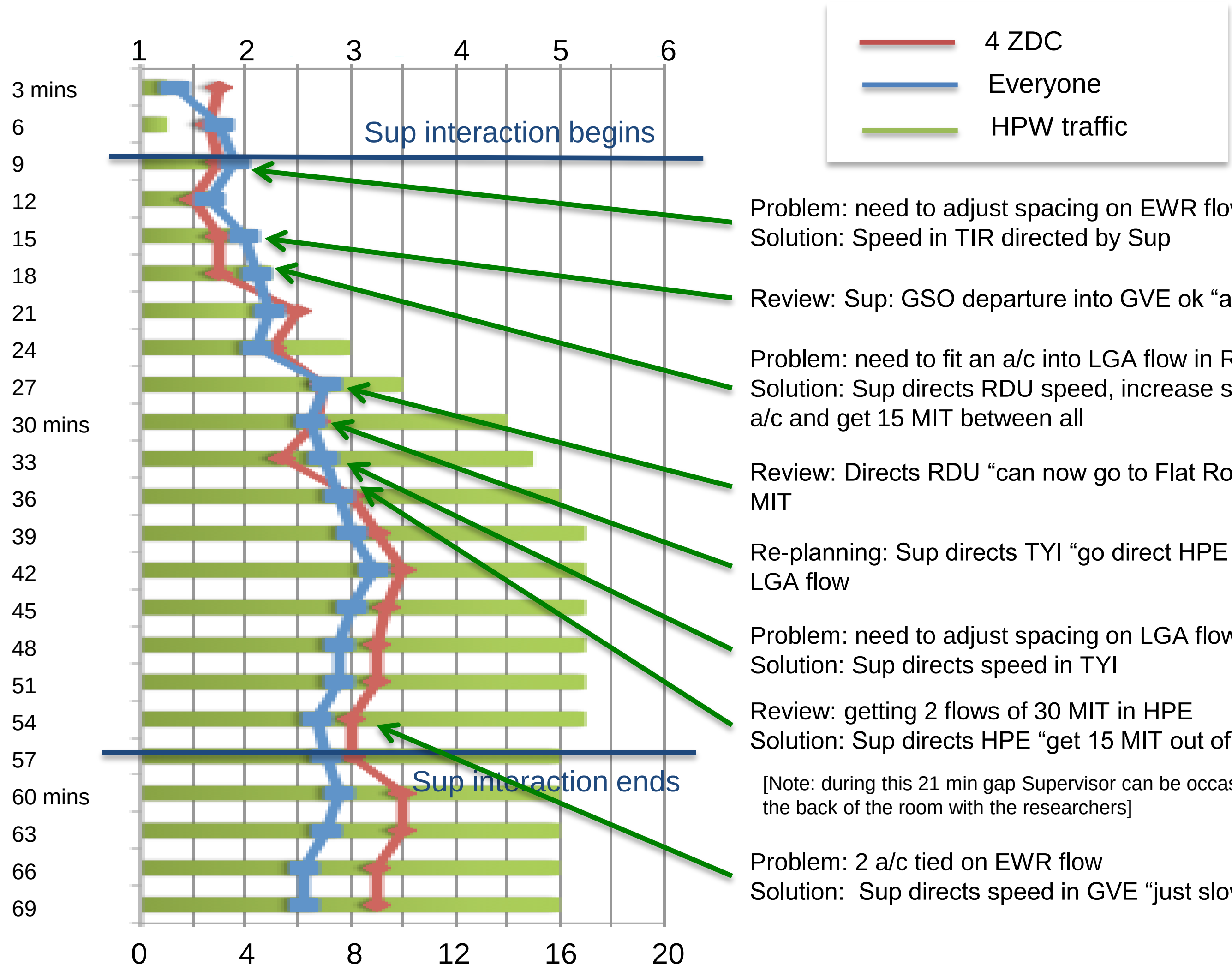
Problem: Need more space on LGA flow
Solution: Sup directs vectors in TYI

Review: a/c spun twice in TYI needs to fit into LGA flow in HPE; ATC “Think he’ll be alright, maybe a little left”

Review: Sup cautions re: spacing on LGA flow in HPE

4 ZDC
Everyone
HPW traffic

Map of supervisor problems to workload



14 Run 14 Exploratory Scenario 1

Problem: need to adjust spacing on EWR flow
Solution: Speed in TIR directed by Sup

Review: Sup: GSO departure into GVE ok "as long as you keep him at 15 MIT"

Problem: need to fit an a/c into LGA flow in RDU
Solution: Sup directs RDU speed, increase space between 2 a/c to 30 MIT to fit the a/c and get 15 MIT between all

Review: Directs RDU "can now go to Flat Rock with them" now that RDU has that 30 MIT

Re-planning: Sup directs TYI "go direct HPE now to stay ahead of next a/c in line" on LGA flow

Problem: need to adjust spacing on LGA flow
Solution: Sup directs speed in TYI

Review: getting 2 flows of 30 MIT in HPE
Solution: Sup directs HPE "get 15 MIT out of this"

[Note: during this 21 min gap Supervisor can be occasionally heard in discussion in the back of the room with the researchers]

Problem: 2 a/c tied on EWR flow
Solution: Sup directs speed in GVE "just slow him up"

Aircraft manipulation comparison

Run	Condition	Aircraft requiring actions	LGA flow	EWR flow	CLT dep	GSO/ RDU dep
Run 2	ZDC/ part (1)	13	5	6	1	1
Run 5	ZDC/ full (2)	15	8	5	1	3
Run 7	ZDC/ full (1)	17	4	13	2	0
Run 8	MIT (1)	14	5	9	3	1
Run 13	MIT (2)	15	9	4	4	2
Run 9	ZDC/ part (2)	7	1	6	0	0
Run 4	ZTL/ part (1)	10	0	10	3	1
Run 6	ZTL/ part (2)	11	0	8	3	0
Run 10	ZTL/ full (1)	16	5	11	2	3
Run 11	ZTL/ full (2)	12	1	10	3	1
Run 14	Explore	9	6	3	2	1

Conversation comparison

Run	Condition	Problems	Sup interaction time	Sup interactions	ATC interactions
Run 2	ZDC/ part (1)	6	39mins	13	9
Run 5	ZDC/ full (2)	6	52 mins	22	8
Run 7	ZDC/ full (1)	11	48 mins	43	10
Run 8	MIT (1)	7	47 mins	31	6
Run 13	MIT (2)	12	61 mins	20	21
Run 9	ZDC/ part (2)	6	54 mins	23	5
Run 4	ZTL/ part (1)	11	60 mins	15	14
Run 6	ZTL/ part (2)	6	44 mins	17	10
Run 10	ZTL/ full (1)	14	67 mins	23	24
Run 11	ZTL/ full (2)	11	67 mins	52	19
Run 14	explore	9	57 mins	11	11

Incl replanning but not reviews unless they incurred action

Runs are all approx 90 mins

CEED Post-Sim Data from September 25, 2015

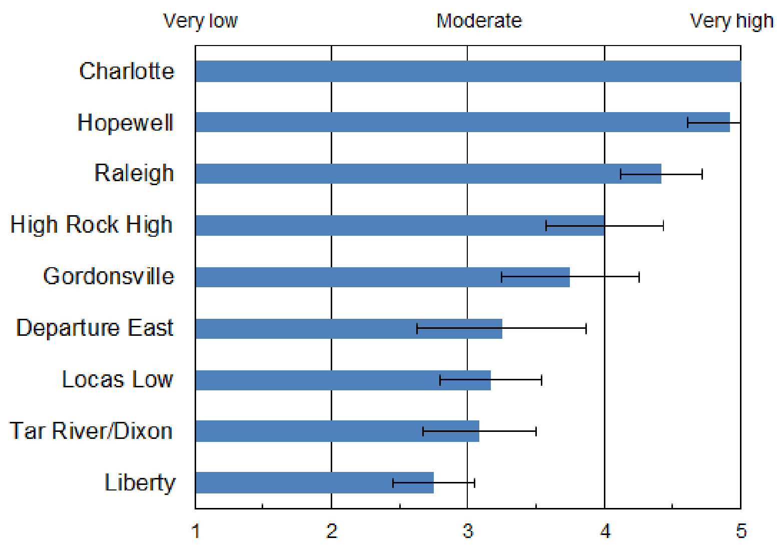
Bonny Parke

Main Points from Post-run Subjective Data

- Some controllers worked very hard at certain times in the simulation
  - High workload, and only "somewhat" acceptable
  - There was somewhat less workload in the ZDC scheduling condition for most overworked controllers
  - Why?
- Entering flows somewhat better in ZDC condition
- Most important: EWR & LGA flows were both rated as significantly less *difficult to provide* in the ZDC CFR condition
- Spacing of aircraft required: also less in <u>ZDC CFR</u> than in ZTL CFR and in full compliance compared to partial

Mental Activity During Busiest Time: Charlotte, Hopewell, & Raleigh Had the Highest Ratings

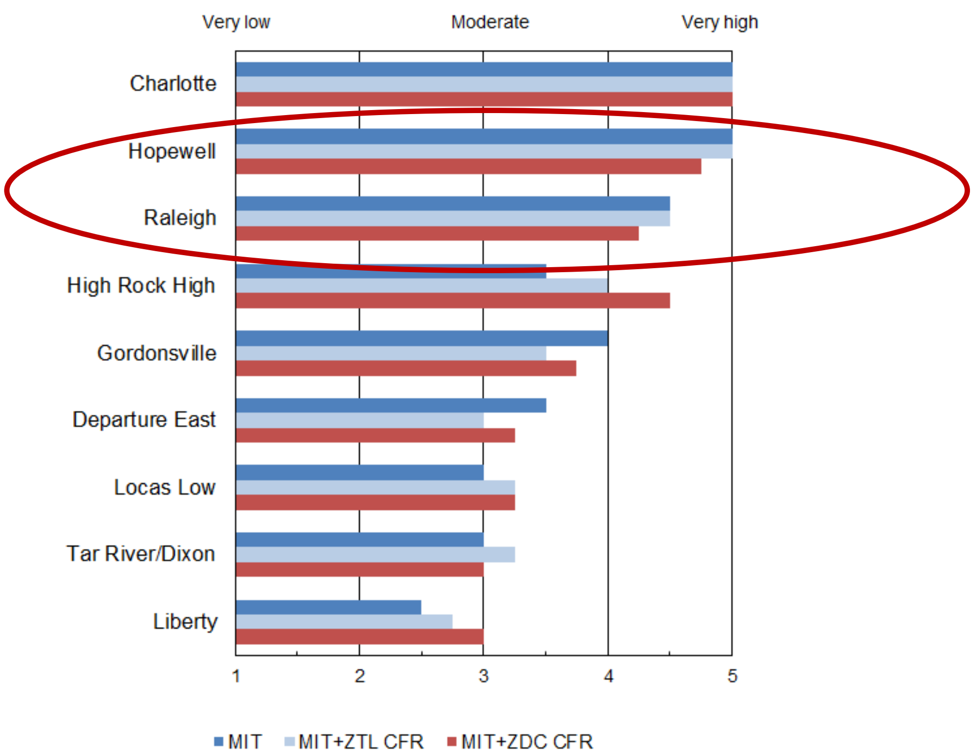
In this run, how much mental activity was required during the busiest time? (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)



MS 6.1, F(8,56) = 20.6, p <.000, error bars = 95% CIs adjusted for repeated measures.

Mental Activity During Busiest Time: Hopewell & Raleigh's Average Ratings Slightly Lower in ZDC Condition

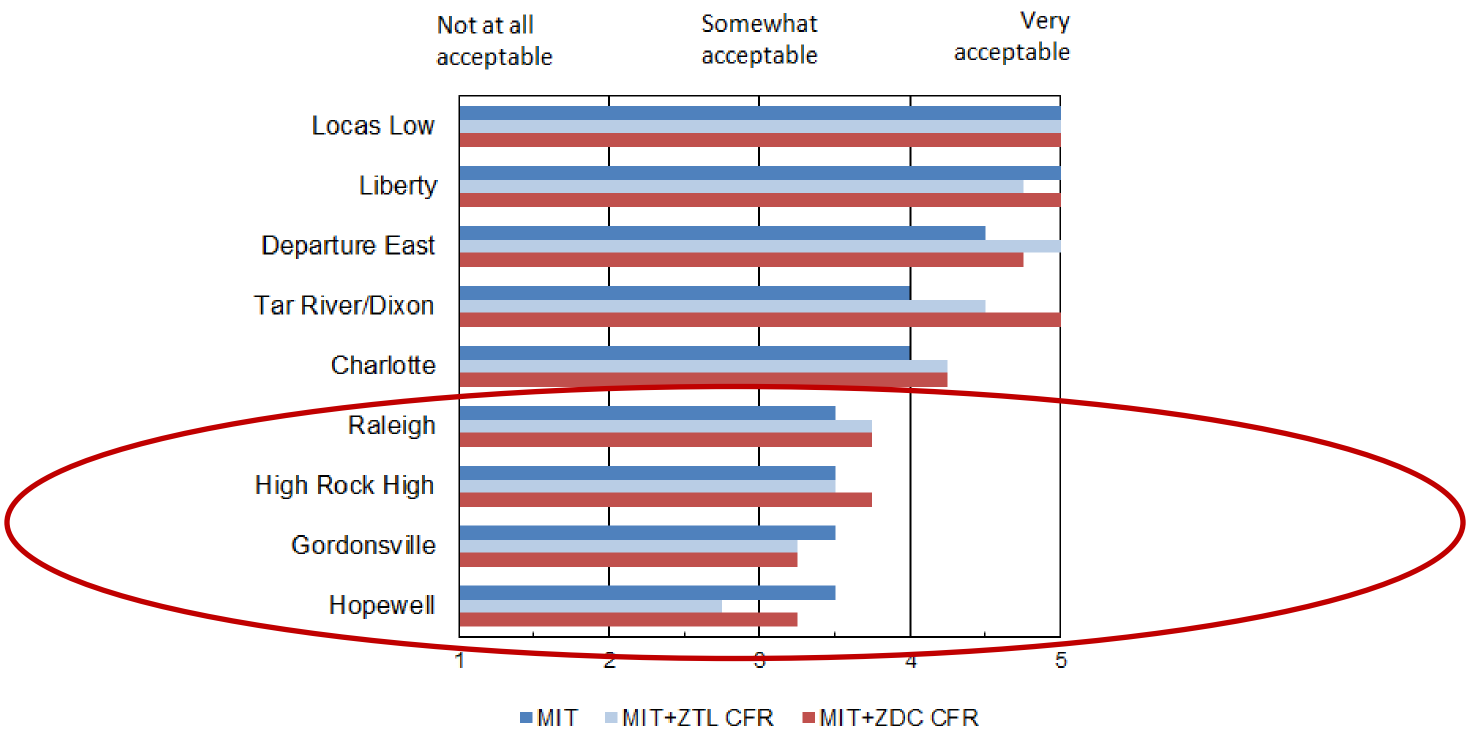
In this run, how much mental activity was required during the busiest time? (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)



ZTL controllers are Charlotte, High Rock High, and Locus Low

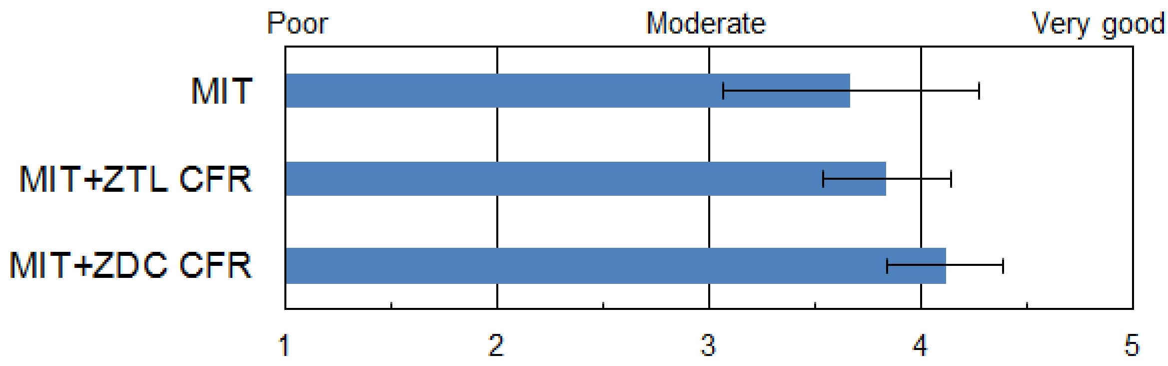
Acceptability of Workload: Workload Least Acceptable for Hopewell, Gordonsville, High Rock High and Raleigh

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



LGA Flows Received: ZDC CFR Slightly Better but Not Significantly So

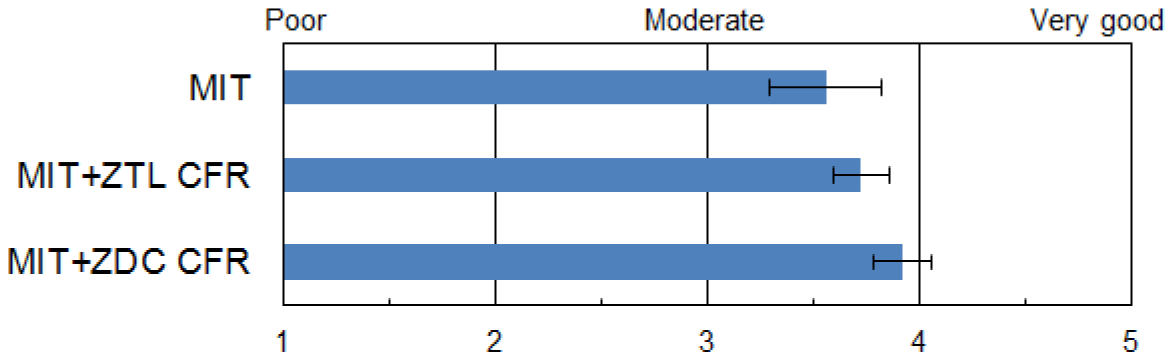
In this run, how would you rate the LGA flows you received?



Means 3.7, 3.8, 4.1

EWR Flows Received: ZDC CFR Slightly Better and Significantly So

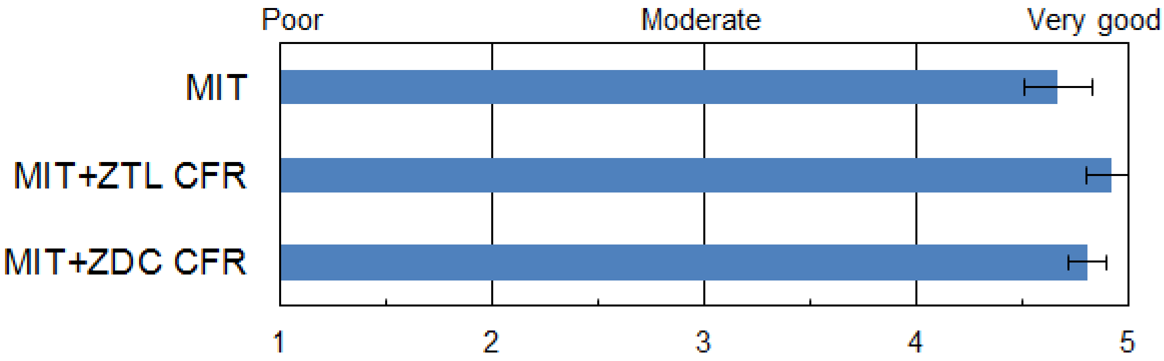
In this run, how would you rate the EWR flows you received?



Means = 3.6, 3.7, & 3.9, *MS* .10, $F(2,6) = 5.8$, $p = .04$.

LGA Flows Provided: High Overall but Less Good in the MIT Condition; Similar Results with EWR Flows

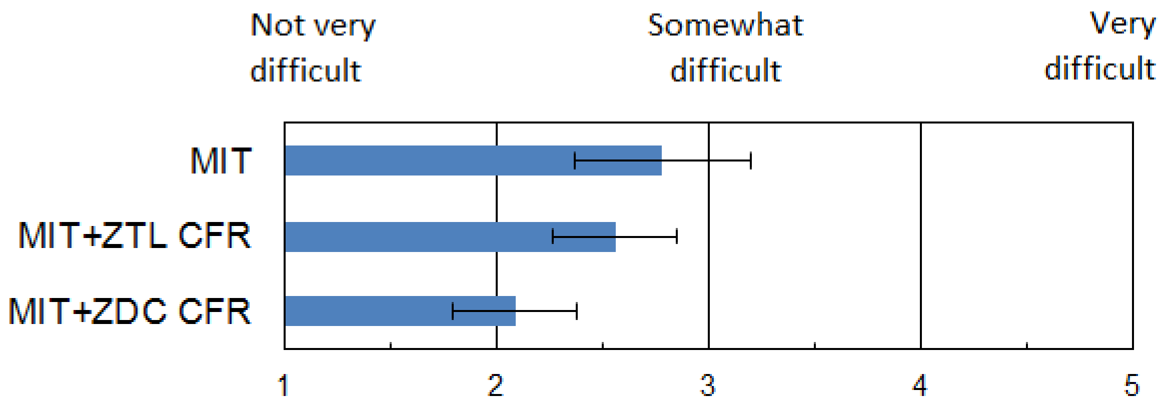
In this run, how would you rate the LGA flows you were able to provide?



All controllers rated this item, means were 4.7, 4.9, 4.8. *MS* .14, $F(2,16) = 3.34$, $p = .06$.

What was Different was the <u>Difficulty</u> Providing LGA Flows: ZDC CFR Least Difficult

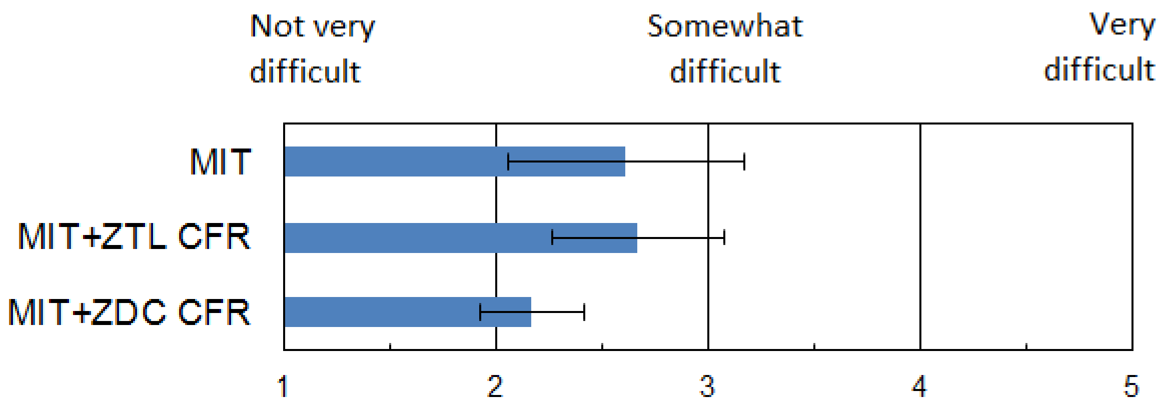
In this run, how difficult was it to provide the LGA flows?



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

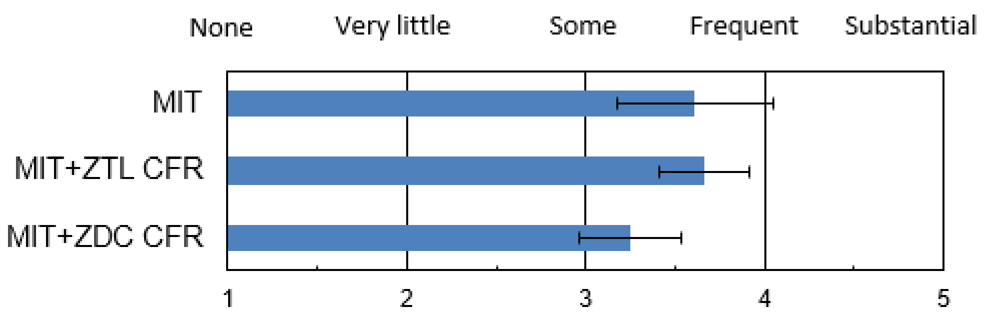
In this run, how difficult was it to provide the EWR flows?



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, $F(1,8) = 9.6$.

Spacing Required: Less Reported Total Spacing of Aircraft Required in ZDC CFR Condition than ZTL CFR

In this run, how much spacing/manipulation (e.g., with speed, vectoring, attitude changes, etc.) did the aircraft in your sector require?



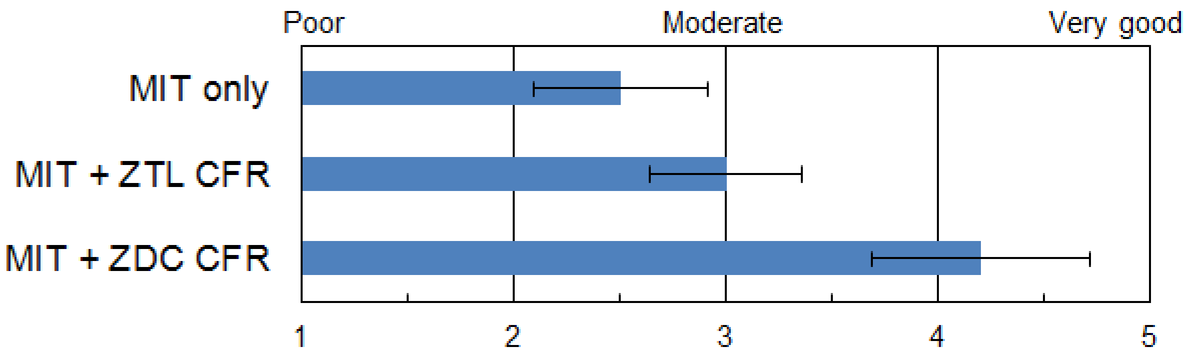
Means 3.6, 3.7, & 3.3. Difference between two scheduling conditions only significant at p = .02 in 2 X 2 repeated measures with MS = 1.6, $F(1,8)$, p = .02. Compliance also significant at p = .053 in this analysis with MS .56, F(1,8) = 5.1, means = 3.7 (partial) and 3.3 (full).

These Findings are Echoed in the Post-simulation Survey

- Quality of flows
  - ZDC controllers rated the LGA & EWR flows entering their airspace as best in the MIT + ZDC CFR condition.
  - They rated the LGA & EWR flows leaving their airspace as equally good in the three conditions
  - The required flows in the MIT + ZDC CFR conditions were rated as least difficult to provide.
- Realism (side note)
  - Workload, airspace, & traffic rated as most realistic—tools & clutter on scope least realistic

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

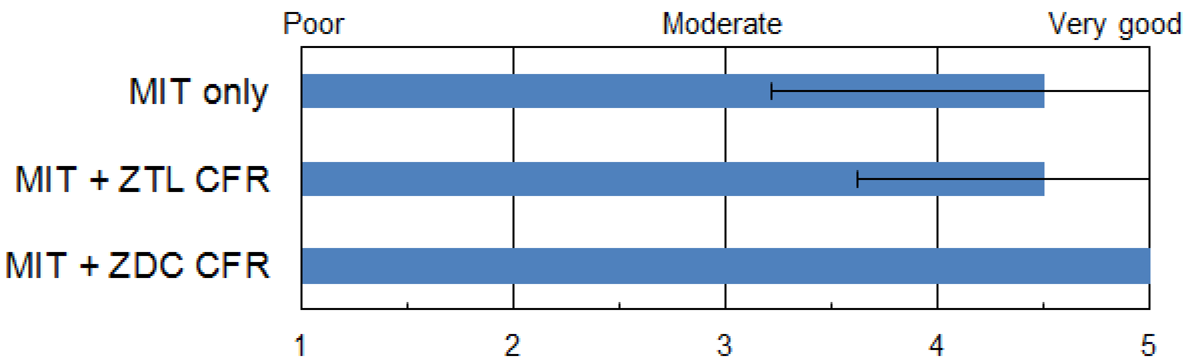
Question: "If you noticed a difference in the quality of the LGA flows <u>entering</u> your sector, please rate the flows in the different conditions."



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 $p = .08$.

LGA Flow: Those Who Noticed a Difference in the LGA Flow Leaving their Sector or Center Rated Those Flows as About Equally Good

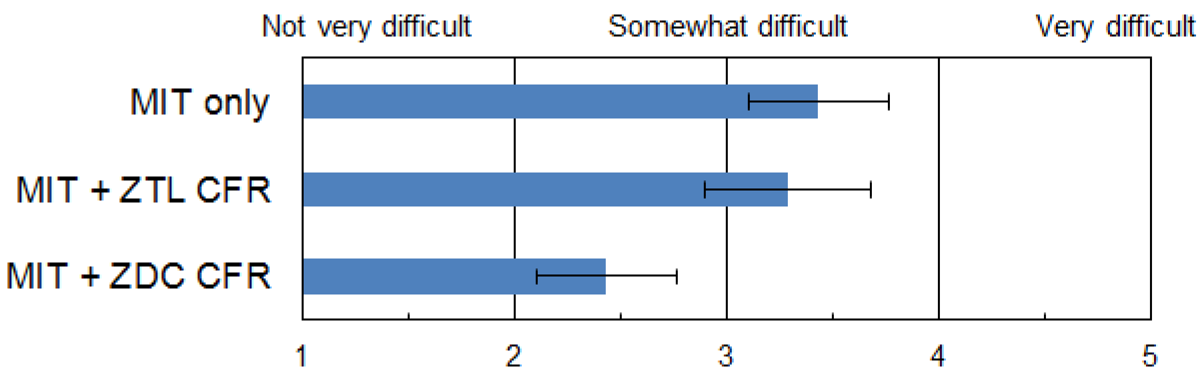
Question: "If you noticed a difference in the quality of the LGA flows leaving your sector, please rate the flows in the different conditions."



Raters were Dep. East, 4 ZDC controllers (excluding Tar River) and the ZDC TMC. Means were 4.5, 4.5, 5.0, *SDs* = 1.2, .8, .0, not significantly different.

LGA Flow: Those Who Noticed a Difference in the Difficulty Providing the Required LGA Flow Rated the MIT + ZDC CFR Flow as Least Difficult

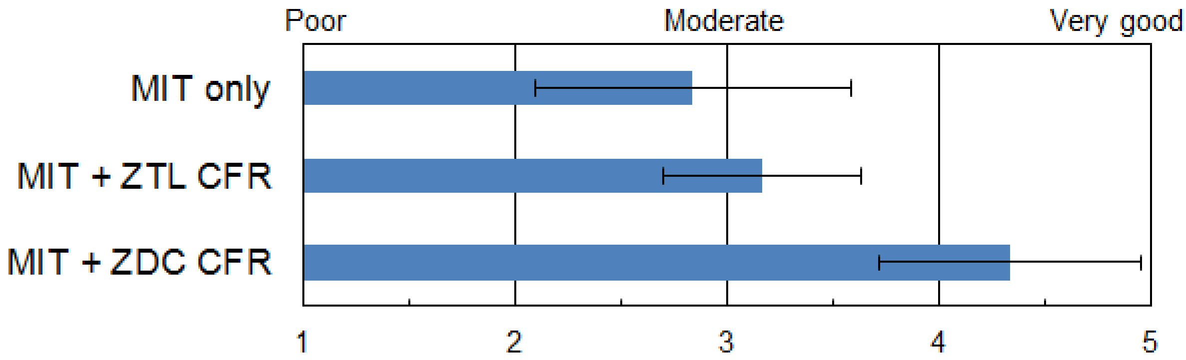
Question: "If you noticed a difference in how difficult it was to provide the required LGA flows, please rate the difficulty in each of the conditions."



Raters were Dep. East, 4 ZDC controllers (excluding Tar River) and the ZDC TMC and FLM. Means were 3.4, 3.3, 2.4, *SDs* = 1.3, 1.3, .8, *MS* 2.05, $F(2,12) = 9.6$, $p = .003$. Error bars = 95% *CIs* adjusted for repeated measures. First 2 conditions not significantly different.

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

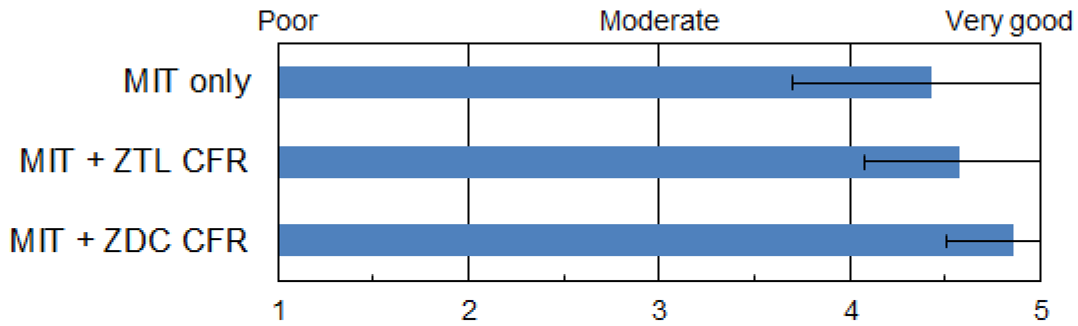
Question: "If you noticed a difference in the quality of the EWR flows entering your sector, please rate the flows in the different conditions."



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.

EWR Flow: Those Who Noticed a Difference in the EWR Flow Leaving their Sector or Center Rated Those Flows as About Equally Good

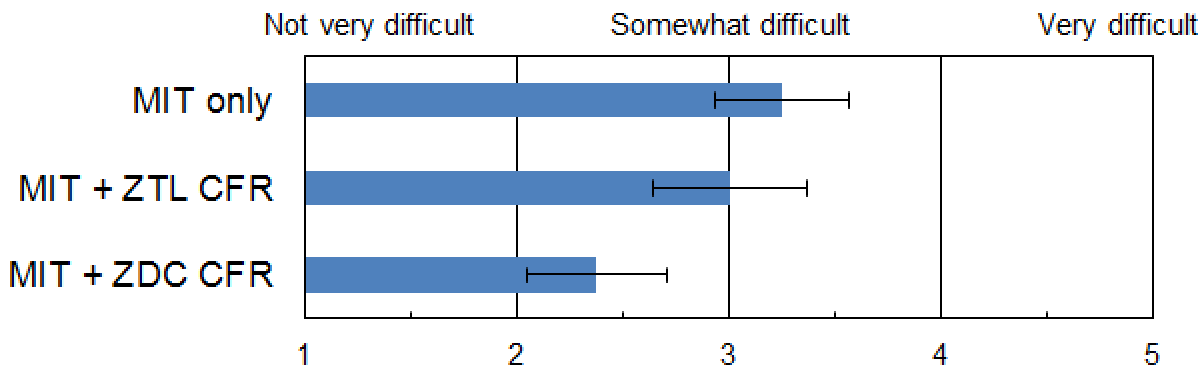
Question: "If you noticed a difference in the quality of the EWR flows leaving your sector, please rate the flows in the different conditions."



Raters were Dep. East, the 5 ZDC controllers, and the ZDC TMC. Means were 4.4, 4.6, 4.9, *SDs* = .79, .54, .38, not significantly different.

EWR Flow: Those Who Noticed a Difference in the Difficulty Providing the Required EWR Flow Rated the MIT + ZDC Flow as Least Difficult

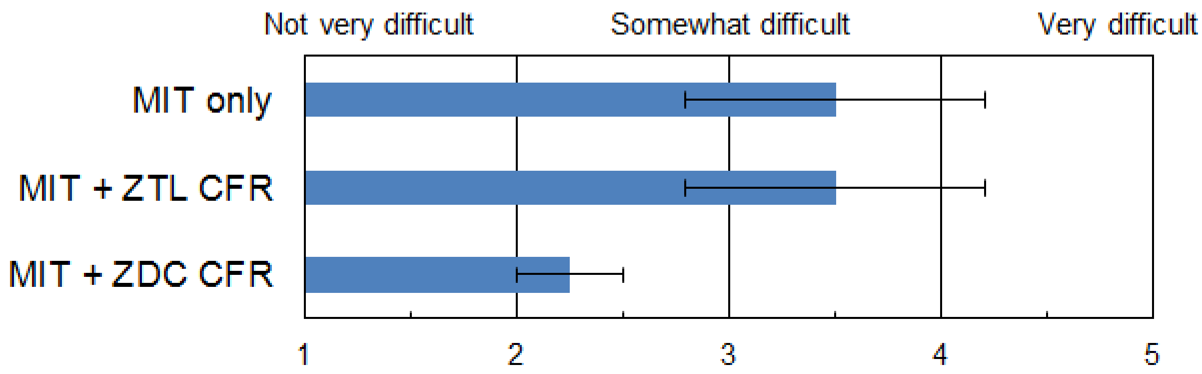
Question: "If you noticed a difference in how difficult it was to provide the required EWR flows, please rate the difficulty in each of the conditions."



Raters were Dep. East, the 5 ZDC controllers, and the ZDC TMC and FLM. Means were 3.3, 3.0, 2.4, *SDs* = 1.2, 1.3, .8, *MS* 1.6, $F(2,14) = 6.6$, $p = .009$. Error bars are 95% *CIs* adjusted for repeated measures. First 2 conditions not significantly different.

Inserting Departures into Overhead Stream: Also Easiest in the ZDC CFR Condition

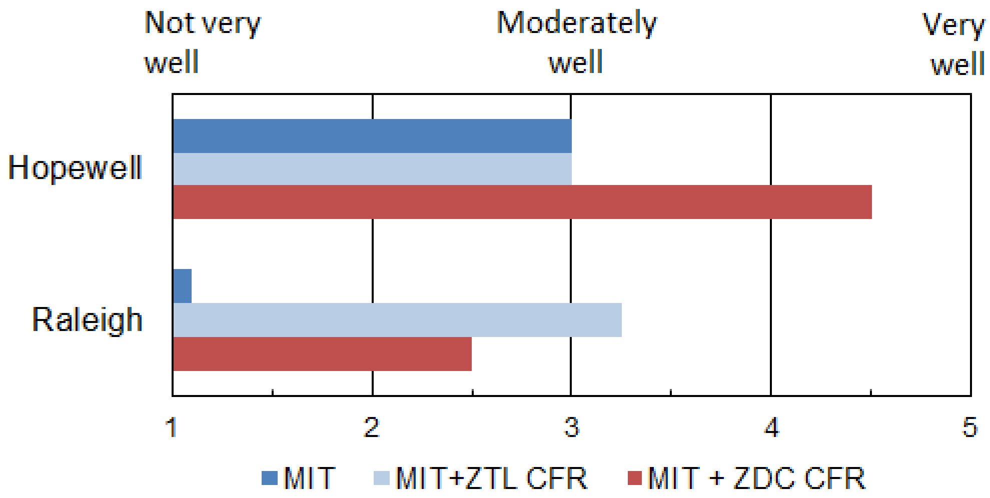
Question: "If you noticed a difference in inserting departures into the overhead stream, please rate the difficulty of doing so in the different conditions."



Raters were the ZDC TMC & FLM, ZTL TMC, Raleigh and Liberty. Means were 3.5, 3.5, and 2.3; *SD*s .6, .6., .5; *MS* 2.1, $F(2,6) = 10.7$, $p = .01$. Error bars are 95% *CI*s adjusted for repeated measures.

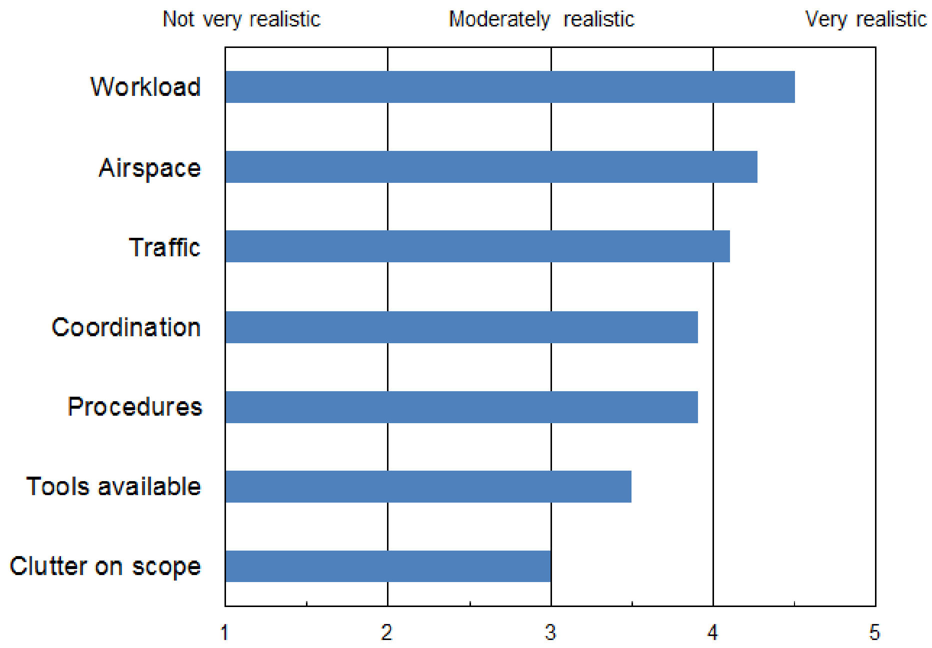
Hopewell Found that Departure Releases Fit Better in Overhead Stream in ZDC CFR

In this run, how well did departure releases fit into the overhead stream?



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.

References

- Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, 1, 476-490.
  - Basic reasoning: Since the between-subjects variance typically plays no role in statistical analyses of within-subjects designs, it can legitimately be ignored; an appropriate CI can be based on the standard within-subject error term. To arrive at this, one can normalize the data, i.e., subtract the mean (of each case) and add the grand mean to each data point. Hence the data within each case is normalized and one can from thence derive the appropriate CI.

See also

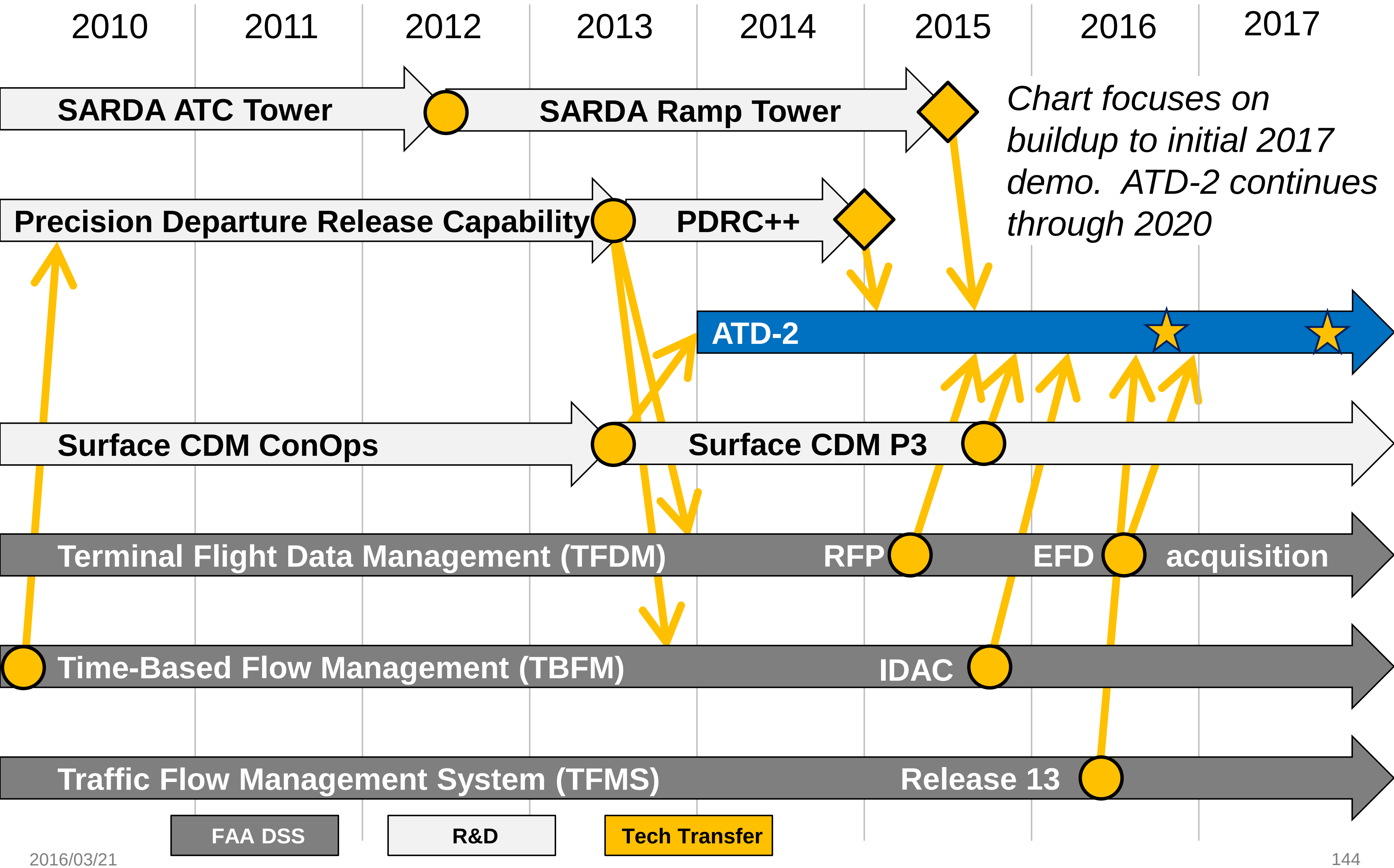
- Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology*, *1*(1), 42-45.
- Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorial in Quantitative Methods for Psychology* 4(2), p. 61-64.
- Baguley, T. (2012). Calculating and graphing within-subject confidence intervals for ANOVA. *Behavior Research Methods*, *44*(1), 158-175.

Altitude and Ground Speed Differences Between Flows at Key Locations

	LGA at LIB	LGA at HPW	EWR at HPW
CLT dep	Alt 29,800 GS 438	Alt 33,900 GS 455	Alt 33,600 GS 453
Overhead	Alt 34,400 GS 445	Alt 34,400 GS 452	Alt 36,200 GS 454

ATD-2 Introduction Back-up

Contributing Technologies



ATD-2 System Technologies

The ATD-2 system architecture is currently being defined. This slide lists some of the technology dependencies that have been identified during ATD-2 concept development. Section 5 of the ConOps companion paper has more details.

FAA technologies

- Time Based Flow Management (TBFM)
  - IDAC display (IDST), web routing infrastructure (WSRT), extended metering (XM)
- Traffic Flow Management System (TFMS)
  - IDRP and CTOP interaction with TBFM
- Terminal Flight Data Manager (TFDM)
  - Surface CDM (S-CDM) and other system level requirements

NASA technologies

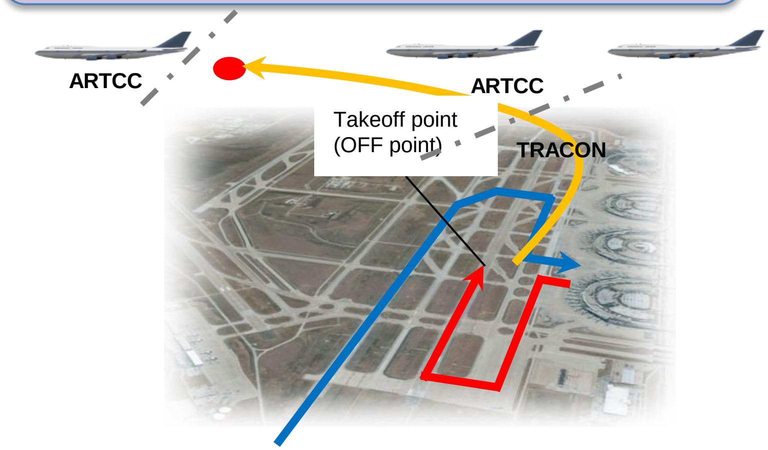
- ATD-1 Terminal Sequencing and Spacing (TSS)
  - Leverage TSS for the “A” in IADS traffic management for the metroplex
- Precision Departure Release Capability (PDRC)
  - Integration of surface predictions with TBFM tactical departure scheduling for highly-equipped airports
- Spot and Runway Departure Advisor (SARDA)
  - Optimal surface scheduling with gate and spot metering advisories for Ramp and ATCT controllers
- Surface Decision Support System (SDSS)
  - Surrogate for TFDM surface trajectory-based decision support capabilities

Industry technologies

- ATD-2 architecture enables effective use of collaborative decision making through enhanced two-way sharing of prediction and scheduling information.
- Specific technologies TBD as architecture is defined and partnerships are established.

Previous Research - PDRC

- **Enables OFF Time Coordination**
- **Builds a tactical departure airspace schedule**



PDRC

Approach

- Surface system predicts OFF times and runway assignments.
- En route system uses surface information for more precise tactical departure scheduling.
- PDRC technology enables communication between systems and coordination of assigned OFF times.

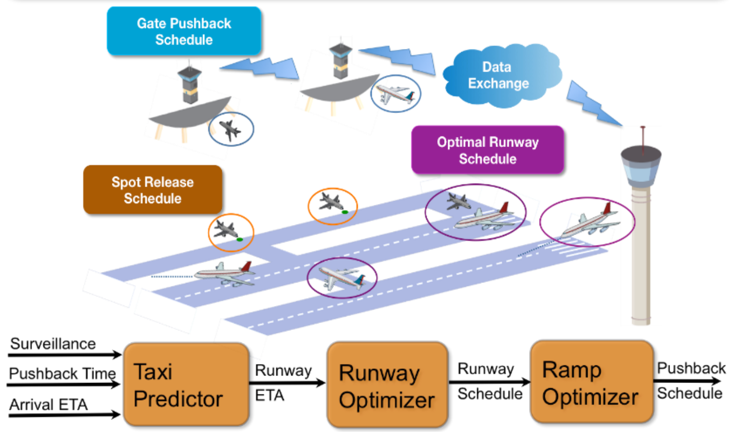
Highlights

- Conducted two-phase evaluation at NTX in Dallas/Fort Worth
- FAA TMC's used PDRC in field evaluation to schedule actual operational departure subject to traffic management restrictions
- Core elements of PDRC tech transferred to FAA in 2013

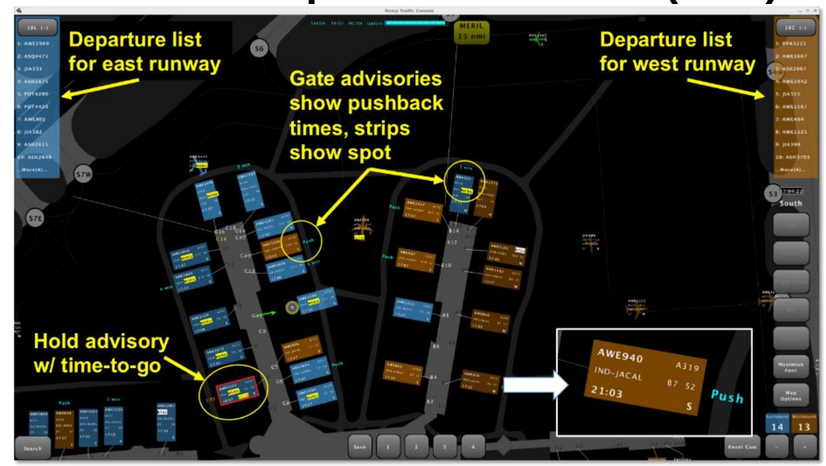
ATD2 Integrated Arrival/Departure/Surface

Previous Research - SARDA

- Builds an optimal runway schedule
- Generates spot release sequence and timing
- Determines when to push back from gates



SARDA Ramp Traffic Console (RTC)

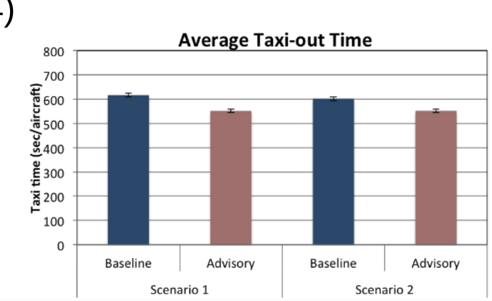


Approach

- Replace paper strips currently used by CLT AA ramp controllers with RTC
- Provide dynamic pushback advisory updates
- Display on a touch screen monitor:
  - Movable, zoomable map
  - Virtual strips
  - Radar position readings
  - Display TMI constraints
  - SARDA-CLT pushback advisories

Highlights

- Conducted HITLs to test spot release & runway sequence advisories for GC & LC (2010 &2012)
- Conducted HITLs to test ramp controller pushback advisory tool in collaboration with AA (2014)



1.1 min reduction in Scenario 1 (10.5%)
0.8 min reduction in Scenario 2 (8.3%)