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Miles-in-Trail Restrictions Relaxation: A Key Benefit Mechanism of Integrated Arrival Departure Surface Traffic Management

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Current-day metroplex traffic management practices lead to multiple operational shortfalls causing unnecessary surface and airspace delays, underutilization of available metroplex capacity and lack of predictability. Under the ATM Technology Demonstration-2 (ATD-2) subproject, NASA plans to address these shortfalls by demonstrating Integrated Arrival, Departure, Surface (IADS) scheduling technologies and transitioning them for field-implementation. These technologies aim to increase the predictability, efficiency, and throughput of metroplex operations while meeting future air traffic demands. This paper studies the impact of departure miles-in-trail (MIT) restrictions on ATD-2 operations using fast time simulations. The paper also discusses a metroplex departure metering simulation platform developed for supporting this study. Simulation-based analysis outlined in this paper demonstrates that maintaining MIT restrictions at current-day levels while ATD-2 is in operation, may impede the full realization of the benefits from ATD-2. We also demonstrate that relaxing MITs when ATD-2 scheduling is active would save around 1-3% total departure delay (gate + taxi + airborne delay) while retaining a high level of taxi and airborne delay savings over current-day operations, as well as maintaining a level of safety commensurate with current-day operations.

I.   Introduction

T HE combined transit of departure flights from the airport surface, through the terminal airspace and merging into overhead enroute air traffic streams is a major source of delay in the National Airspace System (NAS) [Z14]. This is especially true in metroplex regions where departures and arrivals from/to major and secondary airports compete for limited resources (e.g., mixed-use runways, shared departure-fixes, gaps in busy overhead traffic streams). Current-day metroplex traffic management practices lead to multiple operational shortfalls in this flight domain: (i) Identical ticketed departure times, a pushback-when-ready operational paradigm, and reactive first-come-first-served (FCFS) management of clearances at spots, lead to inefficient departure sequences causing takeoff delays, taxi inefficiency (stop-and-go traffic) and throughput loss; (ii) Lack of predictability in the departure process leads to large variances in TRACON departure loads and forces traffic management coordinators to impose buffers (e.g., runway separation buffers) to ensure safety; and forces Centers/TRACONs to impose inefficient departure restrictions (excess miles-in-trail (MIT), or approval requests, (APREQs)) on airports to make space for airborne merging; (iii) Lack of predictability in the gate pushback to runway takeoff process also causes airlines to set excess block times, which limits fleet utilization and increases personnel and fuel costs.

Under the ATM Technology Demonstration-2 (ATD-2) subproject, NASA plans to address these shortfalls by demonstrating Integrated Arrival, Departure, Surface (IADS) scheduling technologies and transitioning them for field-implementation. These technologies aim to increase the predictability, efficiency, and throughput of metroplex operations while meeting future air traffic demands [NA15]. The operational environment for the ATD-2 system consists of a local metroplex airspace overlying one or more well-equipped airports and multiple less-equipped airports. Departures from these airports may share departure fixes on the TRACON boundary and merge into busy

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enroute traffic streams in the Center airspace. Departures are subject to multiple restrictions including MITs at enroute merge points and departure fixes; Expected Departure Clearance Times (EDCTs) from Ground Delay Programs (GDPs); Weather-related departure fix/gate closures; and Takeoff time restrictions due to arrival metering constraints (i.e., Time Based Flow Management, TBFM, allocated landing time-slots) at a destination airport. The ATD-2 system will compute time-based departure schedules for all airports in the local metroplex while accounting for all departure restrictions.

The research work documented in this paper supports NASA's ATD-2 research. The overarching aim of our ongoing research is to examine different distributed scheduling schemes for improving the performance and robustness of IADS scheduling. Research presented in this paper supports the overarching aim by analyzing one key factor that may impede the full realization of benefits from ATD-2, and by suggesting procedural changes to mitigate the negative impacts of this key factor. The key factor we study here is the impact of miles-in-trail (MIT) restrictions imposed on departures in the metroplex, on the performance of the ATD-2 system. When MIT restrictions are imposed on departures, the impacted origin airport is required to depart the affected traffic with sufficient in-trail separation at runway takeoff, so that by the time the departures reach the impacted fix, they are in compliance with the MIT spacing requirement, without requiring significant delay maneuvering in the TRACON. Spacing increases away from the takeoff runway due to de-compression. So, in-trail spacing requirement at the runway is smaller than the MIT restriction size, however it is still more than the absolute minimum spacing requirement that the local controller would impose at runway takeoff if MITs were inactive.

In current day operations, Center TMU usually applies excess MIT restrictions on individual airport departure flows in order to provide the TRACON or Center controllers with some leeway for merging these flights when they get closer to the departure fix or to the enroute merge fix. However, in future operations with ATD-2 departure metering, departure flows will become more predictable, departure sequences will become more optimal (occurrences of consecutive departures going to the same departure fix will be reduced) and takeoff times will be better coordinated with departure-fix merge time-slots as well as overhead enroute traffic stream gaps. As a result, the requirement for additional MIT spacing at runway takeoff may be relaxed. This relaxation may provide additional efficiency, throughput, and workload benefits, while still enabling sufficient spacing at the constrained departure fix or enroute merge fix for easy merging.

This paper aims to evaluate whether MIT constraints can be relaxed when ATD-2 is in operation without impairing the safety of operations and to quantify the additional benefit that can be provided by relaxing MIT constraints in this situation. We use fast-time simulations for our evaluations. The paper is structured as follows: Section II provides the details of the fast-time simulation based evaluation method we used in our work. This includes (i) details of the track data analysis we conducted to obtain a backbone departure route scheduling structure for modeling key locations where departure flows from the Charlotte Douglas International Airport (CLT) and CLT's satellite airports merge at the departure fixes, and where they merge with Atlanta Hartsfield International Airport (ATL) departures and into overhead enroute traffic streams, (ii) historical departure restrictions analysis to support modeling of these restrictions in a fast-time simulation, and (iii) description of the metroplex departure metering simulation platform used for fast-time simulations. Section III presents the results obtained from our simulations. Finally, Section IV outlines the main conclusions drawn from our research work.

II.   Fast-time Simulation based Method for Analysis of MIT Impact on Departure Metering Performance

OUR research approach for assessing the impact of MIT restrictions on the performance of departure metering was to simulate operations in a busy metroplex environment under current-day operational procedures and separately under ATD-2 operational procedures, with varying levels of modeled MIT restrictions. Then, compare key operational performance metrics from the simulations to find out benefits and other impacts caused by relaxation of MIT restrictions. Departure restrictions models used in the simulations, including MIT restrictions and APREQs, were derived from data analysis of historical traffic flow restrictions.

Our research work addresses a known problematic departure management problem in the NAS: CLT airport departures, particularly CLT departures headed for destination airports in the Northeast U.S. (especially New York area airports and Washington D.C. area airports) face multiple capacity constraints in their transit. First, as shown in Figure 1, CLT airport surface consists of a large-size ramp area with constraining features such as a single-lane taxi-path near terminals D and E that handles bi-directional arrival and departure traffic. Second, CLT's most commonly-used runway configuration (South-flow, with departures on 18C and 18L, arrivals on 18R, 23, and 18C) involves a capacity-constrained, mixed-use runway 18C where departures have to be fit into gaps between arrivals landing on the same runway as well as arrivals crossing runway 18C after landing on runway 18R. Furthermore, takeoff

clearances for 18C departures have to be coordinated with gaps in arrival traffic landing on a virtually intersecting runway (runway 23). After taking off, the CLT departures merge with satellite airport departures before exiting the CLT TRACON via specific departure fixes on the TRACON boundary. Finally, these departures merge into busy enroute traffic streams going to the New York area and Washington D.C. area airports, including departure streams originating from ATL airport.

Our first step, before developing a CLT and ATL-focused departure metering simulation, was to analyze historical CLT, CLT-satellite and ATL departure tracks to determine the major departure flows and the major constraint points where the CLT departures merge with other traffic during their transit from runway takeoff to enroute stream merge. Section II-A discusses the technical approach we used for this departure track analysis and outlines the major findings. Following the departure track analysis, we analyzed historical traffic flow restrictions imposed on CLT and ATL departures. The purpose of this analysis was two-fold: (i) to develop a model of departure restrictions to feed the CLT-ALT departure metering simulation model and (ii) to support selection of an appropriate historical day for generating simulation scenarios. Section II-B describes this historical analysis of traffic flow restrictions. Following the departure tracks and departure restrictions analysis we developed an air traffic simulation model for simulating departure metering operations at the CLT airport. The simulation included modeling of (i) departure and arrival operations on the CLT airport surface, (ii) departure operations in the CLT TRACON (including departures taking off from smaller

Figure 1. Main surface constraints at the CLT airport

satellite airports within the TRACON), and (iii) CLT/CLT satellite departures merging into overhead enroute traffic streams in the Atlanta Center (ZTL) airspace. Our simulation also included a model of ATL airport departures taking off from ATL and merging with CLT/CLT satellite airport departures in Center airspace. The simulation focused primarily on departure traffic headed to destination airports in the Northeast U.S. Section II-C describes the simulation model in detail. Sections II-A, II-B, and II-C together describe our simulation-based method for evaluating MIT impact on departure metering performance.
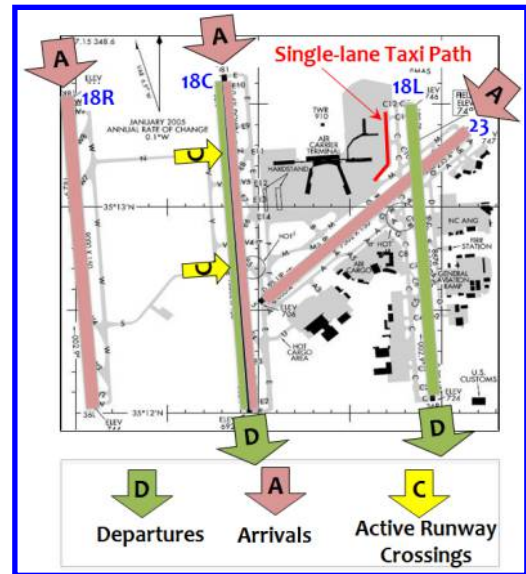
A. Identifying Major Departure Flows and Merge Locations

As mentioned above, our first step was to analyze historical departure track data from CLT, CLT-satellite airports and ATL—especially departures going to destination airports in the Northeast U.S. The purpose of this step was to identify the major departure flows and major merge/constraint points. The identified departure flows and merge-points would inform the simulation model development by providing a backbone scheduling network to base the departure restrictions and departure metering models on. For example, the identified merge-locations where CLT departures merge with ATL departures and overhead enroute traffic streams are used as key scheduling points when allocating overhead traffic stream time-slots to APREQ-impacted CLT and ATL departures, as we describe in Section II-C.

We used surveillance track data from the Performance Data Analysis and Reporting System (PDARS) for three days in the summer of 2015 for the departure flow analysis task. (Summer is the time when departure restrictions are most prevalent.) PDARS is a fully integrated performance measurement tool
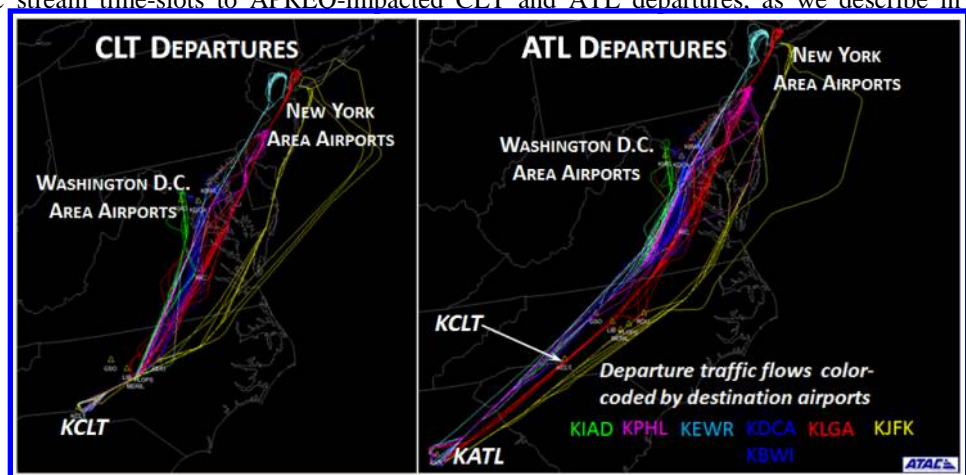

Figure 2. PDARS tracks for CLT and ATL departures to Northeast airports.

designed to help the FAA improve NAS safety and efficiency. PDARS fuses air traffic control automation and radar data from nation-wide Centers and regional TRACONs with other flight and environmental data into multi-dimensional flight tracks that cover NAS-wide IFR traffic in the U.S. from end-to-end. The task started with merging of track data from multiple FAA facilities involved. These included the CLT and ATL airports (ASDE-X surface surveillance track data), the A80 and CLT TRACONs, the ZTL Center, as well as neighboring Centers including ZDC, ZID, ZNY and ZOB.

As mentioned above, we focused on departure flows going to destination airports in the Northeast U.S. Figure 2 shows departure tracks from CLT and ATL going to major airports in the Northeast U.S. (New York area airports: JFK, LGA, and EWR; and Washington D.C. area airports: DCA, IAD and BWI). As seen from Figure 2, the departure flows are more or less separated-out based on the destination airport. In fact, when we looked at the altutide profiles in conjunction with lateral paths, the departure tracks going to the Washington D.C area destination airports were found to be completely laterally and/or vertically separated from departure tracks going to the New

York area destination airports. As a result, we analyzed these two sets of tracks separately to examine in more detail the exact location where CLT departures going to each of these two regions merge with ATL departures going to the respective regions.

Figure 3. Merge locations for CLT and ATL departures going to New York area airports.

Figure 3 shows CLT and ATL departure tracks going only to the New York area airports JFK, LGA and EWR. It can be seen from this Figure that the tracks going to the three airports are fairly separated from each other laterally. LGA bound departure flows from CLT and ATL appear to merge near the region surrounding the ZITTO waypoint; EWR bound departure flows merge in the vicinity of FAK VORTAC, and JFK bound departure flows merge near TYI. We further zoomed onto the identified region of potential merge location to assess the exact location of the merge. As shown in Figure 4 for EWR bound departures, we saw that the departures indeed merged exactly at the FAK VORTAC. We also looked at the altitude profiles of the departues to confirm that the merge indeed occurred at the identified waypoint.
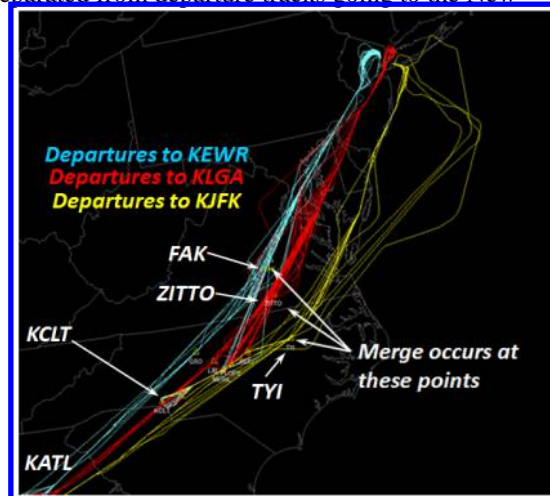
For departures going to Washington D.C. area destination airports, a clear merge in both lateral and vertical directions was not identied to occur until the flights are in the process of descending to their respective destination airports near their entry to the Potomac TRACON.

Table 1 shows the summary of findings from this track data analysis task and also outlines the implications of the identified merge-locations for departure restrictions (i.e., APREQ) modeling in our simulation model. In the case of LGA, EWR, and JFK-bound departure flows where we were able to identify a specific enroute waypoint as the location of merge, we apply APREQ modeling by reserving time-slots at the respective merge-locations. For example, (as we will explain in more detail in Section II-C) LGA-bound departures from CLT and ATL, when impacted by APREQ restrictions, will receive runway takeoff time constraints based on
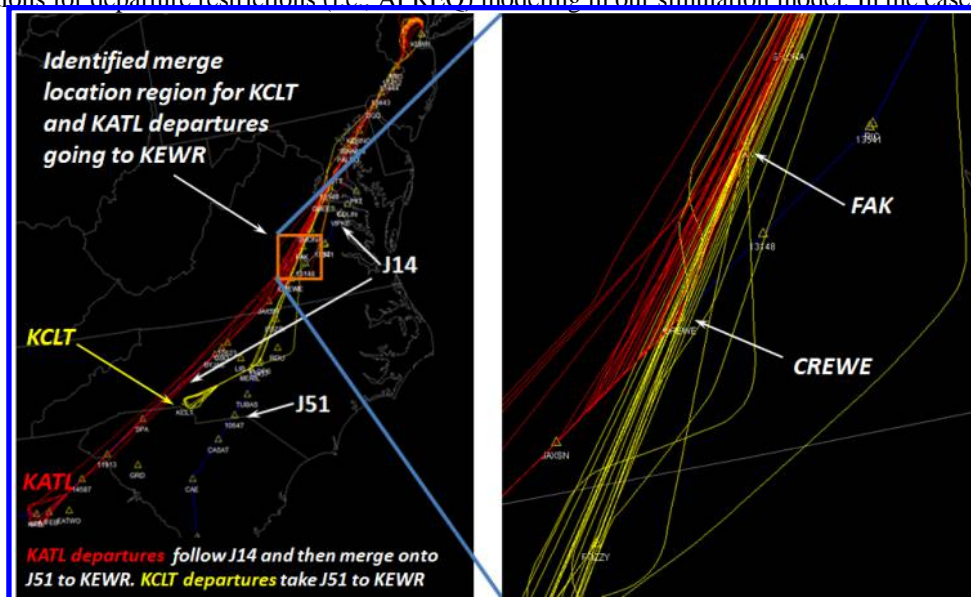

Figure 4. Identifying exact merge-locations for CLT and ATL departures

their allocation to time-slots at the ZITTO VORTAC. In the case of DCA, IAD, and BWI-bound departure flows we identified a merge occurring in the descent phase of the flight. So, DCA, IAD, and BWI-bound departures when impacted by APREQs will receive runway takeoff time restrictions based on allocation of time-slots at the respective destination airport landing runway.

Next, we describe our historical departure flow restrictions analysis.

Destination Airport	Merge-point for KATL and KCLT departure traffic streams	Implication for APREQ Modeling
KLGA	ZITTO	Reserve enroute traffic stream time-slots at ZITTO
KJFK	TYI	Reserve enroute traffic stream time-slots at TYI
KEWR, (also KPHL and KBOS)	FAK	Reserve enroute traffic stream time-slots at FAK
KIAD, KDCA, KBWI	Merge in descent phase of the flight	Reserve time-slots at the destination landing runway

Table 1. Identified merge-points for CLT and ATL departure streams

B. Historical Departure Restrictions Analysis

We conducted an analysis of historical departure restrictions, with two purposes in mind. One, was to support accurate and realistic modeling of these restrictions in the departure metering simulation platform. The second was to select a historical day with significant occurrence of departure restrictions, for generating simulation scenarios.

Our analysis looked at two types of departure restrictions—MITs and APREQs—imposed on CLT and ATL departures. We analysed one year worth of National Traffic Management Log (NTML) data for the year 2015 to support this analysis. The NTML data provides a single system for automated coordination, logging, and communication of traffic management initiatives (TMIs) throughout the NAS. NTML is a part of the Traffic Flow Management System (TFMS). Center Traffic Management Units (TMUs) as well as ATC System Command Center (ATCSCC) traffic managers enter new TMIs and update existing TMIs via a graphical TFMS tool [R10]. These entries are converted into database entries which are stored to aid TFM decision making and post operations analysis. More pertinent to the topic at hand, the NTML data contains a record of historically implemented MIT and APREQ departure restrictions (along with many other types of TMIs) including the times during which the restriction was active, the requesting and providing FAA facility, size of the restriction, and other relevant information such as which departure flows are impacted by the restriction. The data is stored as a series of TMI restriction records. Each record includes information about a new restriction imposed by a FAA facility or it could be an update to an existing restriction. Since one of our aims was to select a day with extended occurrence (e.g., number, duration and size of restrictions) and severe impact (e.g., departure delay impact) of MIT and APREQ restrictions on CLT and ATL departure flows going to the Northeast destination airports, we developed two normalized measures to help us with our analysis—a Normalized Departure Restriction Severity Score and a Normalized Departure Delay Score. Both these scores are computed for CLT and ATL per day.

Daily Normalized Departure Restriction Severity Score. This is measure of how severely an airport was impacted by MIT and APREQ departure restrictions on a particular day. The computation of this score starts by accessing NTML data records for one day at a time. The per day records are first filtered using multiple criteria to a smaller set of records containing features more relevant to the problem at hand. For our purpose the filtering criteria consisted of the following: (i) restriction is provided by the airport under consideration (CLT or ATL), (ii) the constrained NAS element causing the restriction is relevant to the problem we are focusing on, e.g., in this case, NAS elements of interest are constrained Northeast destination airports or enroute waypoints/sectors through which departure flows from ATL/CLT to the Northeast airports travel, and (iii) the restriction type is MIT or APREQ.

After the relevant NTML records are filtered, we next apply complex processing to assess whether each subsequent record represents a new restriction or if it represents an extension or update to an existing (already active) restriction. Identification of new or existing restriction is not straightforward because the restriction records originate from human controllers' input into a graphical tool and this human input process creates multiple discrepancies and peculiar features within the data records.

After this processing, records belonging to each individual restriction are merged and the real start and end times for each restriction are computed. For APREQ records the severity score is formed by simply summing the active durations of all APREQ records during the day. For MIT records the severity score is formed by multiplying the restriction duration with the respective MIT size, and summing this product over all the MIT restrictions active during the day. The departure restriction severity score for a particular day is computed by taking a weighted sum of the respective APREQ and MIT severity scores. After computing individual day scores for the entire year, all the scores are divided by the maximum score to obtain a normalized score (varying between 0 and 1).

Daily Normalized Departure Delay Score. This is a measure of the magnitude of departure delays experienced by an airport on a particular day. We used the FAA's Aviation System Performance Metrics (ASPM) database for computing this metric. In particular, we used the 'all flights' report provided by the ASPM access website. This report contains data-fields including the average gate delay, average taxi-out delay, number of scheduled departures, percent on-time gate departures and percent on-time takeoffs, for each 15-minute time-bin during a day. We combine all these metrics to compute the average departure delay (gate delay plus taxi out delay) over the entire day. The average departure delay is used as the departure delay score for each day. We compute the score for all days in the year and then divide all scores by the maximum departure delay to obtain a normalized departure delay score. One purpose of this data analysis was to select a day with both, extensive presence of departure restrictions and occurrence of severe departure delays as a result of those restrictions. To aid with this selection, we plotted all the days in 2015 on a scatter plot with the X-axis depicting the daily Normalized Departure Restrictions Severity Score and the Y-axis depicting the daily Normalized Departure Delay Score. Figure 5 shows this scatter plot.
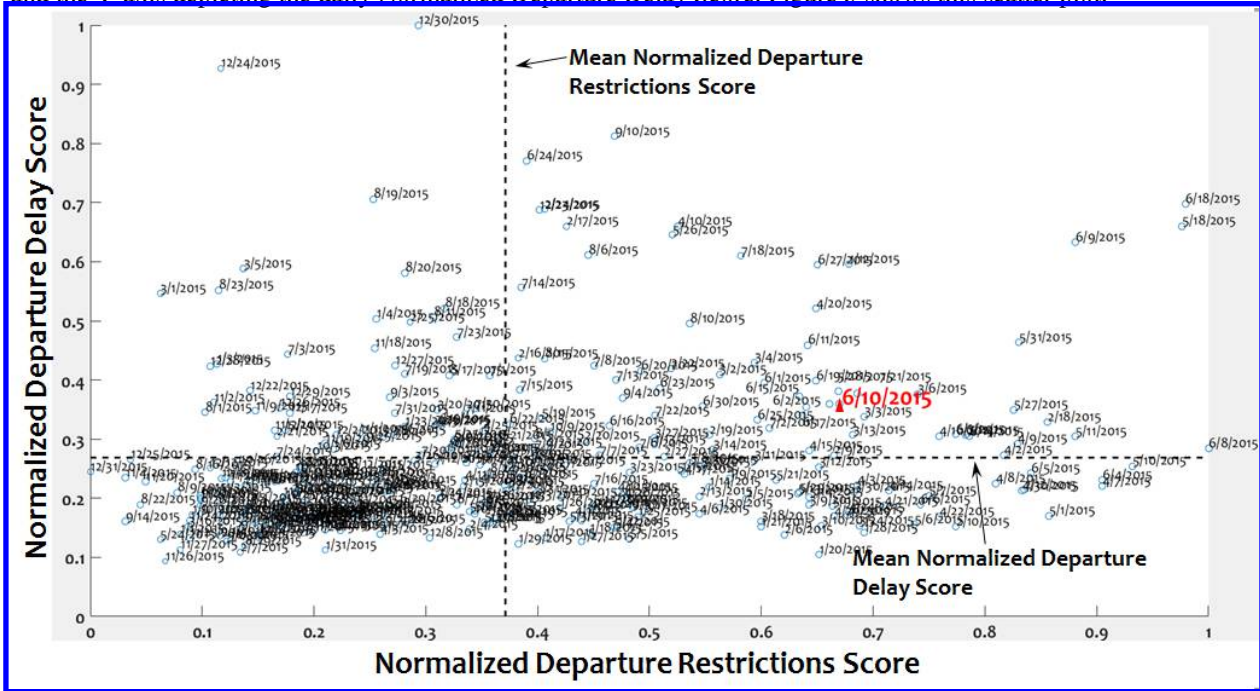

Figure 5. Categorization of days by severity of departure restrictions and departure delays

As expected, we see a roughly linear relationship between the daily departure restrictions score and the daily departure delay scores. But, we also see a lot of variance in the departure delay scores at similar levels of departure restriction scores. One reason for this could be delays caused by other factors besides departure restrictions. Moreover, we are only computing the departure restrictions score based on restrictions for departures going to Northeast airports, but the delay scores are computed by aggregating over ALL departures.

In Figure 5, days falling in the top right quadrant experienced higher than average severity of both, departure restrictions and departure delays. We further analyzed various features of departure restrictions (especially, what caused them) for the days that fell in the top right quadrant. Many of these days experienced departure restrictions caused by convective weather. In our research, we wanted to focus on days where all or a large majority of the departure restrictions were caused by volume related constraints rather than convective weather related constraints. This is because convective weather, we observed, tends to cause other types of TMIs such as Ground Delay Programs (GDPs) or Ground Stops (GSs) to occur in addition to MIT and APREQ departure restrictions. Delay-inducing effects of GDPs/GSs contaminate the analysis of the impact of MIT/APREQ departure restrictions. As a result, with a view to keep simulation results "clean", we avoided days with convective weather constraints. By this criterion, 06/10/2015 was observed to be an ideal candidate for the target simulation day (shown in red in Figure 5). Table 2 shows the departure restrictions that were active at ATL and CLT on 06/10/2015. All these restrictions were volume related. Separately, this restrictions data analysis helped us discover a major difference in the implementation of departure restrictions for ATL versus CLT. As seen from Table 2, ATL mostly received APREQ departure restrictions for specific destination airport-bound traffic, while CLT received MIT restrictions for departures headed to the same destination airports (with the exception of LGA). This trend was found to occur

across multiple days and seems to be a standard procedure for handling enroute merge constraint involving departures from these two airports.

Time Duration for Restriction	Departure Restrictions Imposed On	
	KATL Departures	KCLT Departures
10:00 to 13:30	APREQ for impacted NAS element 'GSO/PHL'	20 MIT restriction for NAS element 'GSO/PHL'
12:45 to 18:30	APREQ for LGA departures	APREQ for LGA departures
13:00 to 17:45	APREQ for DCA departures	30 MIT for DCA departures
18:15 to 20:15	APREQ for IAD departures	30 MIT for IAD departures
21:45 to 23:00	APREQ for TEB departures	30 MIT for TEB departures
22:45 to 23:30	APREQ for LGA departures	APREQ for LGA departures

Table 2. CLT and ATL departure restrictions active on 6/10/2015

As we discuss in the next section, we modeled the departure restrictions outlined in Table 2 in the simulation platform. We describe the simulation model in the next section.

C. Metroplex Departure Metering Simulation Platform

The fast-time simulation platform we developed to support our research work, provides a capability for simulating airport surface, terminal airspace, and enroute air traffic over a prescribed time-horizon, for a metroplex-wide scope. Simulated traffic includes departures originating at the selected major airport or airports and departures from neighboring satellite airports that may interact with the major airport departures, as well as overhead enroute traffic that merges with the major metroplex departure flows in the Center airspace. Simulation for departures starts at the terminal gates and ends at the enroute traffic stream merge point. Overhead enroute traffic is simulated by modeling reserved time-slots at the enroute merge-fix where metroplex airport departures merge with the overhead traffic stream. The simulation components are designed to evaluate the operational impacts and benefit mechanisms of ATD-2 decision support tools in comparison with current-day departure operations under varying levels of departure restrictions. Key components of the fast-time simulation were described in detail in our previous publication [ST15]. We have made some enhancements to the models described in that publication. Here, we discuss the important features, including new enhancements, for these fast-time simulation components in brief. The key simulation components are (i) link-node models that represent airport surface and airspace routes, (ii) transit time models for the links within the link-node network, and (iii) queue control methodology used for simulating the motion of aircraft over the link-node network.

1. Link-Node Models for Airport and Airspace Routes

We used links and nodes to model departure flows and key merge-locations obtained from the historical departure track data analysis described in Section II-A. Nodes are located at the terminal gate areas (groups of gates in the same geographical region of the airport), departure runways, departure fixes (metering fixes at the TRACON boundary), and Center airspace merge fixes (merge-points for the overhead en route traffic streams). The link-node models allow us to simulate traffic behavior accurately by allocating the correct ramp-area, taxi-path, runway-use, departure-fix use, en route stream merge-point use, and accurate inter-node transit times to the simulated flights.

2. Transit Time Models

Links connecting the nodes are associated with characteristic unimpeded transit times. These transit times are derived from analysis of historical operational data. The typical link-node model for a departure flight's route consists of one complex node representing a group of gates (where the flight originates), connected to a simple node representing the departure runway; then on to the departure-fix node; and finally from the departure-fix node to the enroute traffic stream merge node. So, the model contains three links—one link connecting the gate-group to the departure runway node, the second link connecting the departure runway node to the departure-fix, and the third connecting the departure fix node to the en route stream merge node.

The link joining each gate-group node to the departure runway node is characterized by a taxi-out time model in our simulation platform. We have developed two taxi-out transit time models of different fidelities. The simpler or lower fidelity model is primarily used for satellite airports that (i) do not have surface surveillance, and (ii) do not report taxi times to the Bureau of Transportation Statistics (BTS) for inclusion in the Airline Service Quality Performance System (ASQP) database. This simple model is a "Fixed" taxi-out time model. In this model, each departure flight from an airport is assigned the same fixed taxi-out time, assumed to be 10 minutes. The higher fidelity taxi-out transit time model is a "10-th Percentile" model. In this model, we first derive a distribution of taxi-out times for that airport, restricting to time-periods when the particular runway configuration that we are modeling was active. We use historical recorded taxi-out time data from the ASQP database to compute distributions of taxi-out times. Along with taxi-out time data, we also collect information on the airline to which each departure aircraft belongs—so that taxi-out distribution can be calculated for each airline separately. The underlying assumption is that since different airlines use gates/terminals in different geographical parts of the airport, their departures will

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accordingly take longer or shorter times to taxi to the departure runway. In other words, airline is used as a proxy for a specific gate-group. Once an airline-specific distribution is calculated, we pick the 10th percentile taxi-out time from the distribution for the respective gate-group and departure runway pair.

The second link connecting the departure runway to the departure-fix and the third link connecting the departure-fix to the enroute stream merge-point—are characterized by airborne transit time models. The airborne transit times are derived by analyzing PDARS track data, filtered by the appropriate runway, departure-fix and enroute-fix usage. An airborne transit time distribution for each combination of runway to departure-fix to enroute-fix is obtained by analyzing the PDARS data. The mean of this distribution is used to model the typical transit times for the two airborne links.

3. Queue Control at the Nodes

The algorithm for queue control at key nodes is the heart of the fast-time departure metering simulation platform. Figure 6 shows the main steps involved in the departure metering simulation. Each of the major control points in the link-node network (the gate-group, the departure runway, the departure-fix, and the en route stream merge-fix) is associated with a queue. The rest of this section describes how the simulation manages the entry and exit times for individual flights to/ from these queues. The fast-time simulation works in discrete time-steps of one minute. At each time-step, the simulation processes through the seven steps shown in Figure 6.

Figure 6. Departure Metering Simulation Steps

Step 1: Departure Pushback Management. In this step, the simulation first determines how many departure flights will be ready for pushing back at this time-step. When simulating current-day departure operations, the *Pushback Readiness Time* for a flight is computed by adding a random perturbation to the flight's *Scheduled Gate Departure Time*. This models pre-pushback delays. In current-day operations simulation, flights push back when they are ready (i.e., at their *Pushback Readiness Time*) with the execption of flights impacted by APREQ restrictions. Flights impacted by APREQ restrictions may receive gate delays. The simulation platform mimics the current-day APREQ implementation process where departure flights at CLT airport call the tower prior to pushback and wait until the tower obtains clearance from the Center. In the simulation, when the CLT departure flight is ready to push back we predict its estimated enroute merge-fix crossing time using unimpeded transit time estimates for taxi and airborne links in its route. Merge-fix crossing is modeled as fitting flights into 8 nmi-wide merge-slots (see [ST15] for more detail), some of which are already occupied by overflights or departures from ATL. We allocate the CLT departure flight to the next available enroute stream gap nearest to its estimated enroute stream merge-fix crossing time, i.e., we assume that the flight will eventually enter the enroute stream at this gap. Then, we back-compute the required gate pushback time for "hitting" this enroute stream gap. Any delay that this may cause is absorbed at the gate.

While simulating ATD-2 operations, the flight is assumed to be ready for pushback at its *Pushback Readiness Time,* but holds at the gate until the *Target Off Block Time* (*TOBT*). *TOBT* is the required gate pushback time computed by ATD-2 scheduling algorithm. Our prior publication [ST15] describes our model of the ATD-2
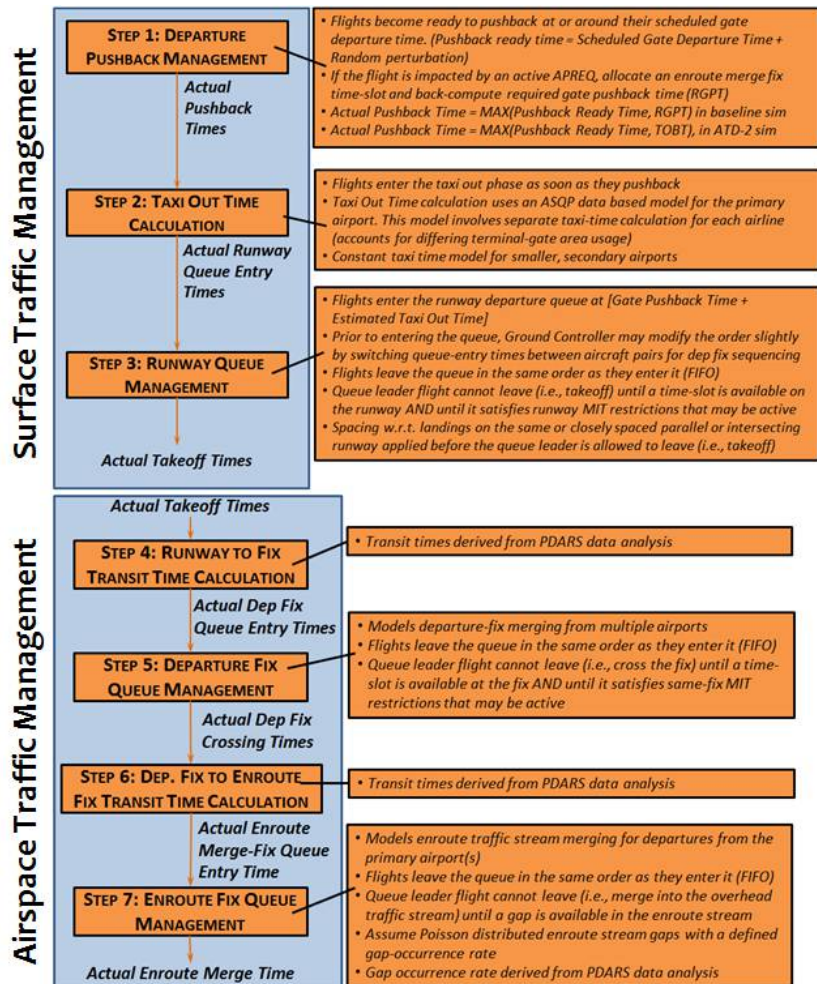
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departure scheduling algorithm, which we use to compute **TOBTs**. Note that the scheduling algorithm performs all computations based on the knowledge of **Scheduled Gate Departure Times**, it does not know the exact time when the flight would be ready to push back (i.e., **Pushback Readiness Times**). The next section briefly describes the main features of this scheduling algorithm.

After identifying the flights that are ready for pushback at this time-step, the simulation pushes them back by updating their **actual gate pushback time**.

Step 2: Taxi-out Time Calculation. In this step, the simulation identifies aircraft that have pushed back at the current time-step and updates the **actual runway queue entry times** for these flights using a taxi-out time model. Different taxi-out time (transit time) models used by the simulation platform were discussed in the previous section. It is assumed that the flights will enter the runway departure queue in the first-come first-served (FCFS) order. The FCFS runway queue entry order may be modified if there is an instance of two successive new runway queue entrants with the same allocated departure fix. In such cases, we simulate the sequencing decisions made by Ground Controllers by allowing sequence switches to avoid two successive flights going to the same departure-fix. A sequence switch is allowed only if the runway queue entry times of the flights switching sequence with each other fall within an allowed range of time (we used a 2 minute allowed time range for our simulation platform).

Step 3: Runway Queue Management. In this step, the simulation determines whether the leader of each runway queue can leave the queue (i.e., takeoff from the runway) at this time-step. Two criteria are used to determine if the flight can takeoff or not—(i) Runway minimum separation requirement for safety is satisfied: This constraint is not applied by enforcing an exact required time-separation. Instead, we divide the runway time-line into time-slots, each time-slot being of sufficient length based on a called runway departure rate (obtained from ASPM data). Then, we allow only one departure to takeoff per runway time-slot; (ii) MIT separation requirement for consecutive flights going to the same departure fix is satisfied: To enforce this separation requirement (if a MIT restriction is active for the runway under consideration), the simulation keeps track of the last flight to depart from each runway to each departure-fix. The current leader of the runway queue is not allowed to depart until it satisfies the prescribed MIT separation with the last departure flight to the same fix to takeoff from that runway. MIT restrictions may be specific to certain departure flows, e.g., some restrictions are only applicable to departures going to certain destination airport(s). Our simulation platform enforces such special MIT restrictions also.

If the current leader of the runway queue is eligible for taking off during this time-step (i.e., if it satisfies the above two conditions), then the simulation updates its **actual runway takeoff time**. Then, the simulation evaluates whether the next flight in the runway queue (the new leader of the queue) is eligible for takeoff during this time-step. This process continues until a leader is found that cannot takeoff during this time-step.

Step 4: Runway to Departure Fix Transit Time Computation. At each time-step, the simulation identifies the flights that have taken off during this time-step. For these flights, Step 4 computes and updates their **actual departure-fix queue entry time** by adding the estimated runway-to-fix transit time to the flight's runway takeoff time.

Step 5: Departure Fix Queue Management. In this step, the simulation evaluates whether the leader of the departure-fix queue can leave the queue (i.e., cross the departure-fix) during this time-step. The criterion used to determine if the flight can cross the departure-fix is the minimum separation requirement with respect to the previous flight crossing the departure-fix. Rather than implementing this as a straight time-difference computation, the simulation (similar to its handling of runway minimum separations), we divide the departure-fix timeline into time-slots. The length of each time-slot is computed by assuming that the controllers will try to maintain on an average seven miles in-trail between consecutive departure-fix crossings (this is a number we found out from discussions with ex-controllers) and the flights will cross the departure-fix at 250 knots. If a MIT restriction is active at that departure-fix, then time-slots are calculated assuming the bigger MIT restriction. The flight can cross the departure-fix if the departure-fix time-slot associated with the current time-step is available. In this case, the simulation updates the flight's **actual departure fix crossing time**.

Step 6: Departure Fix to Enroute Merge Point Transit Time Calculation. In this step, the simulation computes and updates the **actual enroute merge-point queue entry time** for each new departure-fix crossing, by adding the estimated departure-fix to merge-fix transit time to the flight's departure-fix crossing time.

Step 7: Enroute Stream Merge Point Queue Management. In this step, the simulation determines whether the leader of the merge-fix queue can leave the queue (i.e., merge with the enroute traffic stream). The leader can merge into the enroute traffic stream only if a traffic gap concurrent with the current time-step is available. As discussed above, merge-fix crossing is modeled as fitting flights into 8 nmi-wide merge-slots (see [ST15] for more detail), some of which are already occupied by overflights or departures from ATL. Enroute stream gaps available to CLT and ATL departures are modeled as Poisson random events with a known occurrence rate. To compute the rate parameter for this Poisson process, we compute the actual rate at which CLT and ATL flights utilize enroute traffic

stream time-slots for the day of simulation. We compute this rate by analyzing PDARS track data for ATL/CLT departures and overflight traffic merging with these departures before heading to destination airports in the Washington D.C. and New York areas. Once the rate is obtained, we apply Poisson random process with the defined rate to obtain a sequence of enroute merge-fix slots with slot-availability determined by the Poisson random process.

In Step 7, if an enroute traffic gap is available at the current time-step and a flight is waiting in the enroute merge-fix queue, then the simulation updates the flight's *actual enroute stream merge time*. The flight leaves the simulation at this time.

4. Models of Current-day and ATD-2 Departure Scheduling Algorithms

Since our aim is to assess how different levels of departure restrictions will impact ATD-2 operations as compared to current day operations, we developed scheduling algorithms that simulate sequencing and scheduling processes for departures under both, current-day operations as well as ATD-2 operations.

The following list summarizes the key events in a departure flight's transit in the current-day departure operations model:

- Departures pushback when ready. If the departure is impacted by an active APREQ restriction, then it may be required to absorb some delay at the gate (as explained above)
- Departures taxi according to taxi transit time models,
- Next, the departures enter the departure runway queue in a FCFS order. In some cases, the runway queue entry order may be slightly modified for departure-fix balancing (as explained above),
- Departures wait in runway queue until a time-slot becomes available and MIT restriction is satisfied if active,
- Departures takeoff and transit to the departure-fix queue according to the airborne transit time model,
- They wait in departure-fix queue until a departure-fix time-slot is available,
- Departures travel from the departure-fix to the enroute merge-fix queue according to the airborne transit time model,
- Departures wait in en route merge-fix queue until the next en route stream gap is available

For ATD-2 operations, it is assumed that a combination of airspace terminal departure scheduler and surface departure scheduler will generate *TOBTs* for each departure flight. These *TOBTs* take into consideration all the departure constraints in the model and will assign delays at the gate to optimize departure runway, departure-fix, and enroute stream gap utilization. The key events in a departure flight's transit under ATD-2 simulation are the same as current-day simulation events, except the departures push back at or near their *TOBTs* (they push back at the later of the following two times: *TOBT* and *Pushback Readiness Time*). *Pushback Readiness Time* for departures in both the current-day and ATD-2 simulations are exactly the same, i.e., we apply the same random perturbations to the respective *Scheduled Gate Departure Times* in both the cases. Note that the ATD-2 scheduling algorithm performs all its computations based on the knowledge of *Scheduled Gate Departure Times*, it does not know the exact time when the flight would be ready to push back (i.e., *Pushback Readiness Times*).

Furthermore, there is no gate holding for satisfying an APREQ constraint in ATD-2 operations. It is assumed that the ATD-2 scheduler will recommend a gate pushback time that maximizes the chances of hitting the allocated available enroute merge gap, and the current-day procedure of the tower holding the flight at the gate until a clearance from the Center is obtained, will not be required.

An important parameter used by the ATD-2 scheduler is worth mentioning here. The parameter is the Target Departure Queue Length (TDQL). The ATD-2 scheduler holds flights at their gates in order to reduce airport surface congestion. If flights are released from their gates exactly at the *TOBTs* computed by ATD-2 scheduler, we would be releasing them just-in-time to make their assigned runway departure time-slot, departure-fix crossing time-slot and enroute merge-fix gap. If the flight experiences any delay in its transit then there is a risk of missing the assigned time-slot at one or more of these constrained NAS resources. Furthermore, there is a risk of creating additional delay for the flight (i.e., double penalty delay—delay at the gate plus delay on the airport surface or in the air to fit into a later available time-slot, not originally assigned to it). In order to minimize the risk of missing allocated time-slots, ATD-2 scheduling algorithms make provision for defining the TDQL, which represents a number of departure flights that are always desired to be waiting in the runway departure queue in order to maintain pressure on the runway and the downstream constrained NAS resources. As we will explain in the next section, we utilized this TDQL parameter as a control-knob for adjusting the departure metering strategy in order to obtain the maximum delay benefit for each MIT setting used in the simulations.

This section described the simulation platform used in our research. The next section describes the results obtained by conducting fast-time simulation experiments to assess the impact of MIT restriction relaxation on ATD-2 operations.

III. Results

A preliminary fast-time simulation-based analysis was conducted to evaluate the impact of relaxing MIT restrictions on metroplex departure operations managed by ATD-2 scheduling algorithms. Here, we present results from this preliminary analysis. We simulated one full day of operations under three levels of MIT restrictions: (i) current-day MIT levels, (ii) current-day MITs reduced by 5 nmi each, and (iii) current-day MITs reduced by 10 nmi each. The day we simulated was June 10, 2015 (chosen for reasons explained in Section II-B). This was a busy traffic day which featured a total of 792 departures from CLT and 1373 departures from ATL. Of these, 101 and 148 departures from the respective airports were impacted by the merge into the modeled

Departure Fix	CLT	EQY	HKY	JQF	SPA	SVH
MERIL	162	11	1	11		
NALEY	155	1	1	1	1	7
ZAVER	138	1	1	9		
BUCKL	92					
DEBIE	73					
ANDYS	31		1	2	1	
GANTS	29					
LILLS	26			1		
GIPPR	16					
Other	70					

Table 3. Departure fix usage by airport.

overhead enroute traffic streams going to destination airports in the Northeast U.S. Table 3 summarizes the departure fix usage by CLT and CLT-satellite airport departures. Table 4 summarizes enroute merge-fix usage by CLT, CLT-satellite and ATL airports. Traffic demand sets for simulating departures at these airports (and arrivals for CLT) were derived from recorded PDARS data.

Our simulation also involved realistic models of departure restrictions. Table 2 in Section II-B showed the progression of departure restrictions impacting CLT and ATL on the simulated day. We simulated these MIT and APREQ departure restrictions using the approach described in Section II-C. For MIT restrictions, in addition to applying the requisite spacing at the departure runway, we modeled a corresponding drop in departure-fix capacity and enroute traffic stream gap availability to coincide with the restriction active times. We utilized the respective MIT size to compute the magnitude of the departure-fix capacity drop. The nominal 15-minute capacity for a departure-fix was assumed to be 9 fix-crossings (roughly corresponding to a 7 nmi in-trail separation and 250 knot fix-crossing speed). By the same distance-time calculations, a 30 nmi MIT restriction, for example, meant that departure-fix capacity drops to roughly 3 crossings per 15 minutes during the MIT active time.

Enroute Merge Fix	CLT	ATL	JQF
ZITTO	21	28	
FAK	39	59	2
TYI	8	8	
Potomac TRACON entry fix	33	53	

Table 4. Enroute fix usage

For computing a drop in enroute traffic stream gap availability during restriction active times, we conducted an analysis of CLT and ATL departure flows along with overhead enroute traffic flows that merge with them in ZDC airspace, before heading to the Northeast destination airports. In order to find out how many enroute traffic stream gaps were available to CLT and ATL departures to fit into, per 15 minute bin, we obtained the fix-crossing schedule (at the respective merge-fix) for all departures heading to major Northeast destination airports serviced by each enroute stream. Using this fix-crossing schedule (which was computed using PDARS data analysis) we calculated what percentage of the schedule slots were taken by CLT and ATL departures. As described in Section II-A, we identified four separate enroute streams, each associated with one of the identified merge-locations: FAK for EWR, TEB, HPN, PHL, and BOS-bound departures, ZITTO for LGA-bound departures, TYI for JFK-bound departures, and Potomac TRACON entry-point for DCA, IAD, BWI, RIC-bound departures. The percentage of schedule slots used by ATL and CLT departures was used to derive a rate parameter for a Poisson process model. This Poisson process model simulated randomly occurring enroute stream gaps available to CLT and ATL departures. ATL and CLT flights were fitted into the available enroute stream gaps in Step 7 of the simulation process described in Section II-C. For these enroute stream gap availability computations, we assumed that each enroute stream slot is 8 miles in length (as per observations from NASA for another enroute stream merge scenario [EC13]).

Using the traffic demand sets and realistic departure restrictions models described above, we performed multiple simulation-runs with models of current-day and ATD-2 departure scheduling processes. Size of MIT restrictions was varied between different simulation runs to assess the impact of relaxing MIT restrictions on the operations. For each current-day – ATD-2 pair of simulation runs with same MIT settings, we performed the following steps: (i) conduct current-day simulation (flights pushing back when ready), (ii) apply ATD-2 scheduling to compute *TOBTs*,

and (iii) conduct ATD-2 simulation (flights pushing back at or near their ***TOBTs***). The major simulation-runs performed for our preliminary evaluation are summarized below.

1. Run the current-day departure operations simulation model with the actual MIT settings that were active on the historical simulation day (6/10/2015). Compute metrics for current-day operations.

2. Apply the ATD-2 scheduling algorithm to compute ***TOBTs*** for traffic demand set from 6/10/2015.

3. Run the ATD-2 departure operations simulation model (i.e., flights push back at or near their respective ***TOBTs***) with the actual MIT settings that were active on the historical simulation day (6/10/2015). Compute metrics for ATD-2 operations. Try steps 2 and 3 with different values of the TDQL parameter. Select the ATD-2 simulation run with TDQL parameter that provides the lowest overall total delay for the respective MIT setting.

4. Run the current-day departure operations simulation model with the MIT restrictions relaxed by 5 MIT each as compared to the active MIT restrictions on 6/10/2015. Compute metrics for current-day operations, with relaxed MITs.

5. Run the ATD-2 departure operations simulation model with the MIT restrictions relaxed by 5 MIT each as compared to the active MIT restrictions on 6/10/2015. Compute metrics for ATD-2 operations, with relaxed MITs.

6. Repeat current-day and ATD-2 simulations with more and further relaxed MITs, e.g., MITs relaxed by 10 nmi each, 15 nmi each, … as compared to the active MIT restrictions on 6/10/2015). When MITs were relaxed by more than 10 nmi, we observed that the airborne delays became untenably large. Hence, we stopped our analysis at the 10 nmi MIT relaxation stage.

The primary delay metrics of interest included (total and average) gate delay, taxi delay, TRACON delay, and en route delay for CLT departures. Gate delay is defined as the difference between the ***actual pushback time*** and the ***pushback readiness time***. Taxi delay is defined as the ***actual taxi out time*** (pushback to takeoff) minus the unimpeded taxi time. TRACON delay is defined as the ***actual TRACON transit time*** (takeoff to departure-fix crossing) minus unimpeded TRACON transit time. Finally, enroute delay is defined as the a***ctual enroute transit time*** (departure-fix to enroute stream merge) minus unimpeded transit time over the same enroute segment.

Figure 7 shows the total delays for CLT departures over the entire day of simulation (computed over 792 CLT departures) for four simulation scenarios: (i) current-day operations, (ii) ATD-2 operations with current levels of MIT restrictions, (iii) ATD-2 operations with all MITs relaxed by 5 nmi each, (iv) ATD-2 operations with all MITs relaxed by 10 nmi each. In Figure 7, delays are separated out by their location: gate, taxi, TRACON, and enroute. As seen from the Figure, very little delay was absorbed at the gate in the current-day simulation. This small gate delay was a result of the APREQ restriction impacting CLT departures going to LGA (see Table 2), which caused some departures to hold at their gates in order to absorb delay for hitting their APREQ runway takeoff time-slots. Besides the flights impacted by APREQs, all other flights left their gates when they were ready to pushback (i.e., at their ***pushback readiness times***). As seen from the Figure, CLT departures
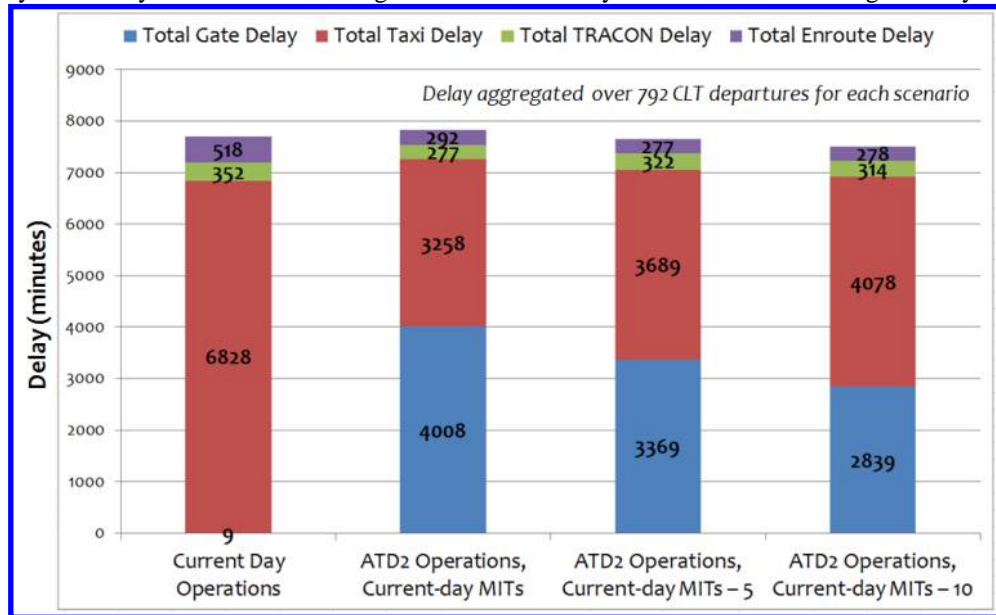

Figure 7. Delay distribution for different simulation settings

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experienced large taxi-out delays under simulated current-day operations. Airborne delays in the TRACON and enroute phases of flight were also extensive.

ATD-2 operations with current-day levels of MIT restrictions (second bar in the Figure) saw CLT departures experiencing 52% lesser taxi-delay, 21% lesser TRACON delay and 44% lesser enroute delay, as compared to current-day operations. Savings in taxi and airborne delays were more than compensated by an increase in gate delay. Thus, we see that the ATD-2 scheduler was successful in transferring the required delay from the inefficient delay absorption phases of taxi and airborne flight to the more efficient gate-hold delay absorption location. However, total delay aggregated over gate, taxi and airborne phases was bigger (by ~2%) in the ATD-2 operations as compared to current-day operations. Our hypothesis is that the main reason for this undesirable increase in overall delay was the following: application of restrictive MIT constraints at the runway had an adverse effect on the runway takeoff time coordination orchestrated by the ATD-2 scheduler via its recommendation of target gate pushback times. In other words, flights experienced double penalty delays as a result of MIT restrictions being implemented at runway takeoff on top of ATD-2 gate delays—many flights experienced gate delay as recommended by ATD-2 schedules and additional delay for applying runway MIT spacing constraints when they reached the runway departure queue.

Figure 8 shows the simulated delays experienced by CLT departures going to Washington D.C. area destination airports, in the CLT departure runway queue, for every 15-minute time-bin (red and green bars). The Figure also shows gate delays experienced by the same flights. Red bars show the runway queue delays in the current-day operations simulation. Green bars show runway queue delays in the ATD-2 simulation with the current-day MIT restrictions. Each bar shows the runway queue delays summed over all
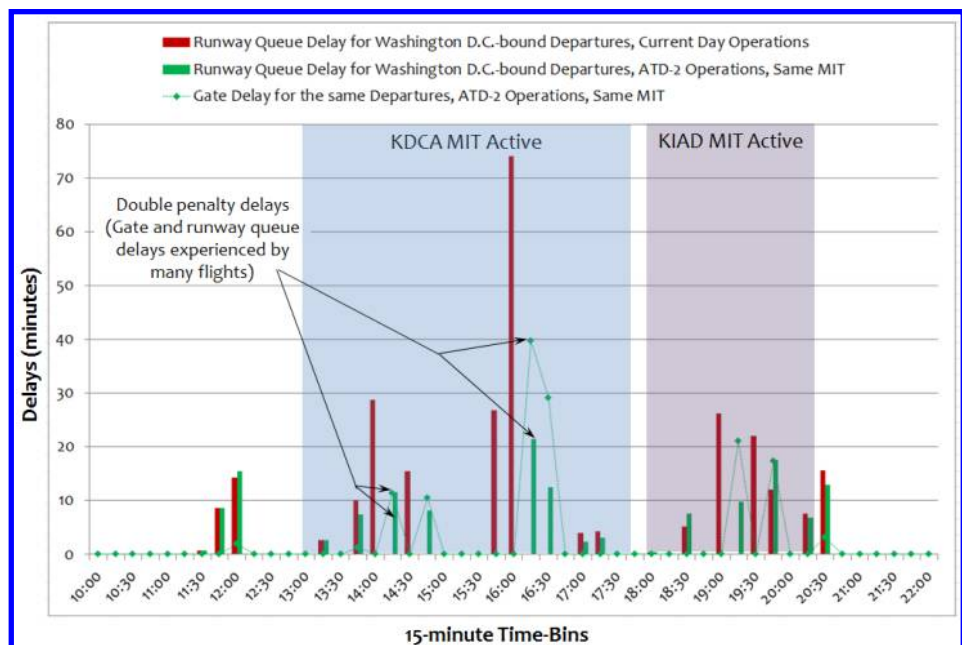

Figure 8. Runway queue and gate delays experienced by CLT departures to Washington D.C. area destination airports under different simulation scenarios

the flights that entered the runway queue during the respective time-bin. The green dotted line with diamond-shaped markers shows gate delays experienced by the same flights in the ATD-2 operations. (Note, in current-day operations Washington D.C. bound CLT departures did not experience any gate delays, because there was no corresponding APREQ active that day). It can be clearly seen from the Figure that especially during the time when KDCA and KIAD MIT restrictions were active (the blue and red shaded time-ranges), many flights experienced both, runway queue delays for MIT restriction implementation and gate delays imposed by the ATD-2 scheduler.

This double penalty delay effect can be avoided by relaxing the MIT restrictions when ATD-2 scheduler is in operation. Going back to Figure 7, we see that when MIT restrictions were relaxed by 5 and 10 nmi respectively, there was a drop in gate delays and a rise in taxi and airborne delays as compared to the ATD-2 operations with current-day MIT levels. More importantly, there was a drop in the total delay (gate + taxi + airborne).

Flight Domain Specific Delay Savings	ATD2 Operations		
	Current-day MITs	Current-day MITs - 5	Current-day MITs - 10
Taxi Out Delay Saving (%)	52	46	40
TRACON Delay Saving (%)	21	8	11
Enroute Delay Saving (%)	44	46	46
Total Delay Saving (%) (Including Gate Delay)	-2	+1	+3

Table 5. Percent Delay Saving over Current-day Operations

Furthermore, there were still significant savings in taxi and airborne delays as compared to current-day operations—specifically, 46% taxi delay saving, 8% TRACON delay saving, and 46% enroute delay saving over current-day operations for the ATD-2 operations with MITs reduced by 5 nmi; and 40% taxi delay saving, 11% TRACON delay saving, and 46% enroute delay saving over current-day operations for ATD-2 operations with MITs reduced by 10 nmi. Table 5 summarizes the percentage delay savings in different domains and also savings in the total delay (gate + taxi + airborne).

Thus, our simulations show clear benefit of relaxing the MIT spacing requirements imposed at runway takeoff under ATD-2 operations. However, whether relaxed MITs will lead to unsafe operations is still an open question. The main concern here is that with relaxation of runway MIT spacing requirements, the TRACON may experience a faster inflow of departures headed for constrained departure-fixes such as MERIL,with lesser in trail separations between them. This may cause excess workload for the departure TRACON controllers because they may have to delay more departures in the TRACON for safe merging prior to exiting the TRACON via departure-fixes. Moreover, after crossing the departure-fix, the Center controllers may also need to apply further delays to slow down departures for safe merging with overhead streams. We assessed the safety of operations under relaxed MIT restrictions by looking at airborne delay and TRACON departure demand metrics from our simulations. As seen from Figure 7, airborne delays for ATD-2 operations with relaxed MITs are well below the airborne delays with current-day MITs. So, this is a good initial indicator that relaxing the MITs when ATD-2 is in operation does not degrade the safety of operations. In contrast, when we conducted current-day operations simulation with relaxed MITs we saw that the airborne delays increased beyond the current-day operations with current-day levels of MITs, which is an indicator of worsening safety.

Further, we looked at TRACON departure demand for the constrained MERIL departure-fix, aggregated over departures from all airports within the CLT TRACON. The metric we focused on is the inter operation times between successive runway takeoffs from CLT TRACON airports for departures going to the MERIL fix. Figure 9 shows histograms of inter operation times for
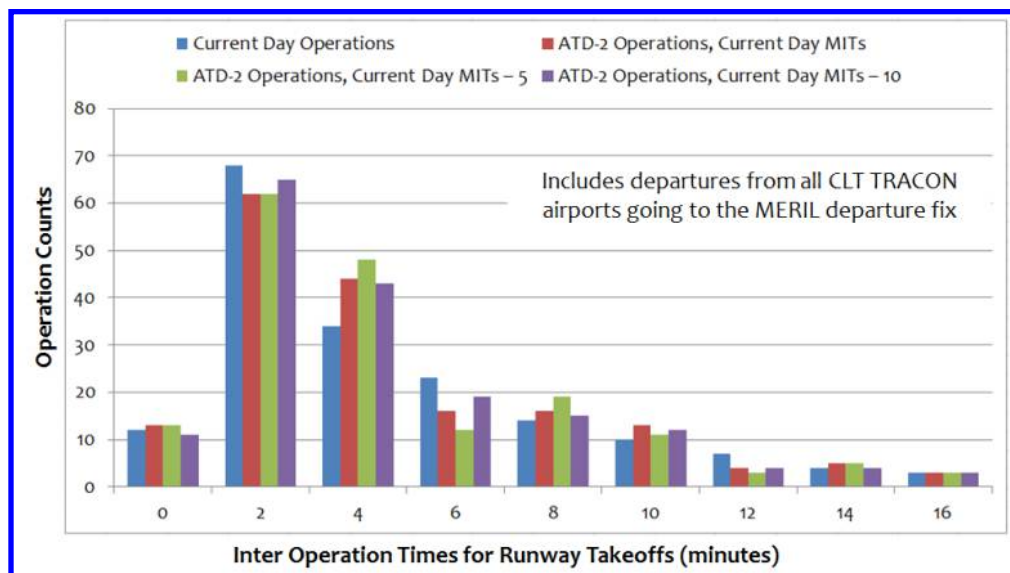

Figure 9. Inter operation times for runway takeoffs in CLT TRACON show that safety of operations does not degrade with relaxation of MITs under ATD-2 operations

CLT TRACON departure takeoffs to MERIL fix. We have truncated the histograms at the ~15 minute level because inter operation times greater than this limit will have no implication for the safety of operations. As seen from the Figure, there is not much difference between the inter operation times for the ATD-2 operations with relaxed MITs as compared to the current-day operations or to the ATD-2 operations with current-day level of MITs. This is another indicator that relaxing MITs during active ATD-2 departure metering operations would not degrade the safety of operations and would not cause additional workload for TRACON departure controllers.

IV. Conclusions

We presented a simulation-based method for evaluating the impact of relaxing MIT restrictions imposed on departures from a metroplex airport, when under the control of ATD-2 departure metering. We developed a metroplex departure metering simulation platform for supporting this analysis. This simulation platform included a realistic link-node model for airport surface and airspace routes, developed based on a PDARS track data analysis based identification of major departure flows and key enroute merge-locations, ASPM operations data and PDARS

track data analysis based quantification of taxi and airborne link transit times, as well as NTML departure restrictions data analysis based modeling of MIT and APREQ restrictions.

The objective of this analysis was two-fold: (i) to quantify how much efficiency benefit (i.e., delay reduction) can be gained by relaxing MIT restrictions when under ATD-2 scheduling and (ii) to evaluate whether relaxing MIT restrictions may lead to unsafe departure merging operations. We demonstrated that application of MIT restrictions along with ATD-2 gate holding causes double penalty delay effect, with flights receiving gate delays and then being delayed again in the departure runway queue. In our simulations, ATD-2 operations with current-day level of MIT restrictions demonstrated significant taxi and airborne delay savings over current-day operations, but the total delay (gate + taxi + airborne) was ~2% bigger in the ATD-2 operations owing to the double penalty delay effect. When MIT restrictions were relaxed by 5 and 10 nmi in our simulations, we saw that significant taxi and airborne delay savings with respect to current-day operations persisted. Furthermore, gate delays were reduced and overall, the total delay reduced below the total delay in current-day operations (with total delay savings of 1 and 3 % respectively).

We also evaluated the safety of operations under ATD-2 scheduling with relaxed MITs by comparing airborne delays and TRACON departure demand with the respective metrics from current-day operations. We found that the total airborne delays were lower in the ATD-2 operations and TRACON departure demands (inter operation times for runway takeoffs) were almost identical to current-day operations, despite the relaxed MIT restrictions. Thus, our preliminary conclusions are that relaxing MITs when ATD-2 scheduling is active would save around 1-3% total delays while retaining high level of taxi and airborne delay savings with respect to current-day operations, as well as maintaining a level of safety commensurate with current-day operations.

It is important to highlight that these are preliminary findings. The analyses documented in this paper can be further enhanced in multiple ways to provide a higher fidelity evaluation of the delay-reducing and safety-retaining effects of MIT relaxation. Some ways in which the analyses can be further enhanced are: (i) validating the departure flows, enroute merge locations, and enroute merge modeling approach adopted in the simulation platform via interviews with airport tower, TRACON and Center controllers, (ii) conducting simulations over multiple days with different levels of historical MIT restrictions modeling, (iii) improving the accuracy of airport surface modeling by integrating NASA's high-fidelity surface simulator, the Surface Operations Simulator and Scheduler (SOSS) into the current metroplex departure metering simulation platform, and (iv) enhancing the current emulation model of ATD-2 scheduling algorithm via knowledge transfer between NASA developers of the actual ATD-2 scheduling algorithm and our research team.

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