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Characterization of Nationwide TRACON Departure Operations

Matthew S. Kistler*
Mosaic ATM, Leesburg, VA, 20175

Alan Capps†
Mosaic ATM, Fort Worth, TX, 76155

Shawn A. Engelland‡
NASA Ames Research Center, Fort Worth, TX, 76155

This paper presents a characterization study focused on nationwide TRACON departure operations. It assesses shortfalls of present-day operations and identifies the potential benefits of improving TRACON departure scheduling. To characterize present-day TRACON operations across the National Airspace System, an analysis of National Traffic Management Logs is performed along with interviews of operational subject matter experts and firsthand observations at a TRACON facility. The focus of the study is on miles in trail restrictions applied at the departure fix, as well as the process of compressing and swapping departure fixes and gates. The study shows that departure fix restrictions are frequently used and that implementation of these restrictions can be complex and workload-intensive. Also, significant facility-to-facility variation in the implementation of departure restrictions makes this problem even more challenging. The nationwide analysis shows that the top thirteen TRACONs issued more than 2,700 departure fix restrictions during the month of July 2013, affecting more than 28,000 flights. A substantial amount of delay was incurred by flights subject to these departure fix restrictions, totaling more than 4,700 hours for the month studied.

Nomenclature

Center	= Air Route Traffic Control Center
Command Center	= Air Traffic Control System Command Center
D10	= Dallas/Fort Worth TRACON
MINIT	= Minutes In Trail
MIT	= Miles In Trail
N90	= New York TRACON
NAS	= National Airspace System
NTML	= National Traffic Management Log
NTX	= NASA/FAA North Texas Research Station
TFMS	= Traffic Flow Management System
Tower	= Airport Traffic Control Tower
TRACON	= Terminal Radar Approach Control

* Analyst, Mosaic ATM, Inc., 540 Fort Evans Rd NE, Leesburg, VA, AIAA Member.
† National Airspace System Engineer, NASA/FAA North Texas Research Station, AIAA Senior Member.
‡ Aerospace Engineer, NASA/FAA North Texas Research Station, AIAA Senior Member.

I. Introduction

Recent NASA research[1-3] has focused on improving tactical departure scheduling in scenarios where well-equipped airport Towers interact directly with Center Traffic Management Units (TMUs) to implement departure management initiatives such as Call For Release (CFR). The research presented in this paper lays the foundation for extending tactical departure scheduling improvements to lesser-equipped airports and to address constraints that exist in the terminal environment, specifically at Terminal Radar Approach Control (TRACON) facilities. The FAA's Next Generation Air Transportation System (NextGen) plans,[4,5] call for the ability to accurately schedule a flight from its departing gate to its arrival gate in advance of its actual departure (i.e. gate-to-gate scheduling). Specifically, gate-to-gate scheduling presumes the planning and control of a flight from its departure gate to the runway, to the terminal departure fix, Center departure metering fix, through En-route airspace to the arrival metering fix, runway and finally to the arrival gate. For gate-to-gate scheduling to be effective in the NextGen environment, surface, terminal, Center, and national constraints must all be simultaneously satisfied by the departure scheduling tool. NextGen gate-to-gate scheduling also requires accurate prediction and execution of trajectory-based operations in the terminal area. This work was motivated, in part, when preliminary observations of present-day TRACON departure operations revealed substantial delay and inefficiency attributable to the workload-intensive process of implementing and executing terminal departure restrictions. Therefore, development of improved terminal departure scheduling tools requires a thorough understanding of current-day operational procedures and constraints.

The objective of this nationwide TRACON departure operations characterization study is to better understand current-day TRACON departure operations, where TRACON departures represent a subset of departures from all radar approach control facilities across the National Airspace System (NAS). According to the FAA Administrator's Fact Book, eighty-two percent of operations in 2011 for the top twenty-five radar approach control facilities were from TRACONs.[6] This study aims to assess the potential benefit pool associated with improving the current-day TRACON departure process. This characterization will be accomplished via analyses of National Traffic Management Log (NTML)[7,8] archives for various facilities, interviews with Traffic Management Coordinators (TMCs)/Supervisory Traffic Management Coordinators (STMCs) familiar with different TRACON environments, and firsthand observations of TRACON departure operations. The results are expected to help identify the NAS-wide benefits of terminal departure improvements, to focus a solution on the core issues facing the NAS, and to guide the development of the terminal departure scheduling concept of operations. This study gives insight into the frequency and scope of unique TRACON departure challenges that exist across the NAS, including but not limited to miles in trail (MIT) restrictions imposed on TRACON departures. Included will be documentation of departure scheduling challenges such as demand/capacity imbalances caused by departure fix swaps and compressions that are common to TRACON environments.

This paper begins with an overview of the current-day TRACON departure scheduling challenge, including a general description of a representative TRACON area and the types of constraints that exist within it. Following is a nationwide survey of TRACON departure operations, consisting of an analysis of NTML data, interviews with TMCs/STMCs, and observations conducted at Dallas/Fort Worth TRACON (D10). An impact analysis is then presented, which illustrates the effect of TRACON departure constraints on the flights and resources being used. This includes investigation into the number of flights affected, as well as the delay associated with the departure constraints. It will conclude with an identification of the potential benefits that may be realized by improving the current operations.

II. Current Day TRACON Departure Scheduling Challenge

This section summarizes the departure scheduling challenges that exist today in the TRACON area. It starts with an overview of a typical TRACON departure layout, using D10 as an example. A description of the types of constraints that are imposed on the departure fixes during inclement weather and demand/capacity imbalances follows.

A. TRACON Area Overview

This work is being performed out of NASA's North Texas Research Station (NTX). NTX is located in the D10 TRACON environment and has substantial capabilities that support timely and cost-effective analysis of D10 TRACON departure operations. As shown later in the analysis, D10 TRACON is listed amongst the top facilities that exhibit the problem being studied. Consequently, D10 TRACON serves as the pathfinder facility for this study. Data collection and analysis methods will be developed and refined for the D10 environment and then applied to other TRACON environments to ensure that the results of this study reflect TRACON departure operations throughout the NAS. A diagram of D10 TRACON is shown in Fig. 1, including airports contained within the boundaries and the departure fixes located on the borders. The D10 TRACON is centered on Dallas/Fort Worth International airport (DFW) and extends outward approximately forty miles in all directions. It contains two major scheduled passenger service airports, DFW and Dallas Love Field (DAL), which are separated by approximately ten miles. Several busy general aviation airports, a regional cargo hub, and a Naval Air Station Joint Reserve Base contribute to the complexity of this TRACON environment. The sixteen departure fixes are arranged in groups of four called departure gates (not to be confused with airport parking gates), which depict their general location relative to the TRACON boundaries. For example, the north gate includes departure fixes LOWGN, BLECO, GRABE, and AKUNA. It is common for restrictions to be imposed on entire gates, without mention of the fixes, so it is important to understand which fixes belong to which gates.

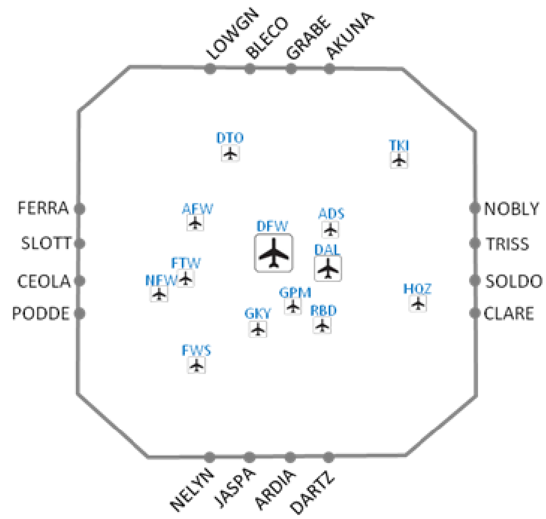

Figure 1. D10 TRACON airports and departure fixes.

B. Constraints in the TRACON Area

In the NAS today, MIT is used at the TRACON boundary to resolve local departure demand/capacity imbalances. These local demand/capacity imbalances may be triggered by weather events or downstream flow constraints that propagate back to the TRACON departure environment.

In the D10 TRACON, the most common occurrence of departure MIT is a result of weather events that partially or completely block a departure gate. If the weather event is entirely in TRACON airspace, the coordination requirements with Center TMCs may be different than when the weather events limit capacity in Center airspace. The weather event often leads to multiple, dynamic restrictions being issued. For instance, as a storm moves across the D10 TRACON from west to east, a variety of departure fix closures and swaps may take place until the weather has dissipated or moved out of the area. MIT restrictions are often imposed on the remaining departure fixes to account for uncertainty associated with the weather. For instance, airborne vectoring that is required near or immediately downstream of the departure fix requires the increased spacing that MIT provides.

Figure 2 illustrates the situation in which a weather cell to the east of the D10 TRACON boundary is closing off three of the four available departure fixes. In this scenario, the TRACON TMC decided to keep a single east departure fix open and route all traffic through this point. This means that all departure traffic from D10's airports whose routes include an east departure fix must compete for slots at the only open departure fix. In addition, MIT constraints are often added to the departure fix to provide margin for controllers to handle unexpected events that may occur due to weather. This type of departure fix constraint is often referred to by operational personnel as departure fix compression, departure radial compression, or combining departure fixes. For the remainder of the paper, this restriction will be referred to as departure fix compression, or simply fix compression.

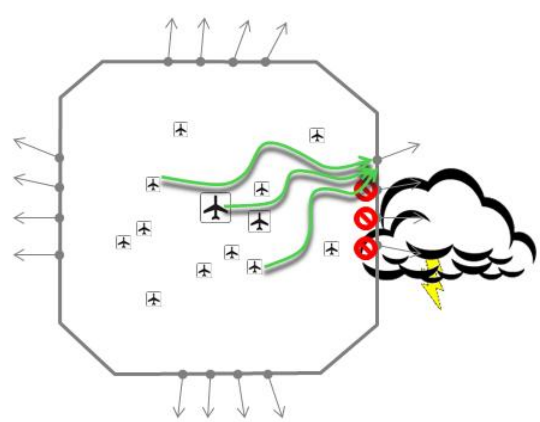

Figure 2. Departure fix compression may be caused by weather events in or near TRACON airspace.

Figure 3 illustrates a similar problem to that of Fig. 2; however, in this case no departure fixes on the south departure gate are open for use. In this scenario, the TRACON TMC decided to split the southbound traffic between the east and west gates. This type of departure fix constraint in often referred to as a departure fix swap, or in the case of an entire gate being unavailable, a gate swap. Often, a MIT constraint will be added to the swapped fix/gate. A procedural difference at D10 between departure fix compression and a swap is that airlines are required to file a new flight plan in the event of a swap, but they are not required to file a new flight plan for departure fix compression.

Weather is not the only reason for MIT usage at the TRACON boundary. For example local demand/capacity imbalance for D10 may be triggered when the Command Center implements a playbook. MIT restrictions often accompany playbook usage and can be expanded (e.g., often doubled) by adjacent facilities to accommodate departure uncertainty for the constrained flow. This can create high workload on Center controllers and TMCs, prompting them to implement a TRACON MIT constraint. This scenario is illustrated in Fig. 4.

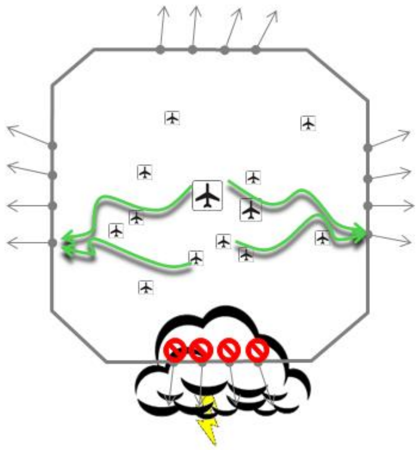

Figure 3. Complete blockage of departure fixes or gates may lead to fix/gate swaps.

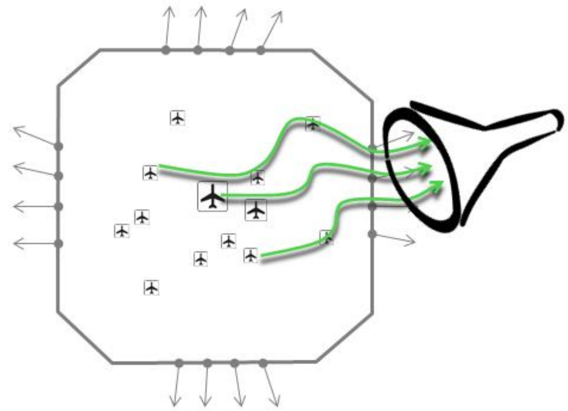

Figure 4. Downstream constraints may also lead to implementation of TRACON TMIs.

III. Nationwide Survey of TRACON Departure Operations

To provide a better understanding of current-day TRACON departure operations across the NAS, a nationwide survey was conducted which included various TRACON areas. This section describes the methodology and results of that nationwide survey, including an analysis of available NTML data, interviews with Subject Matter Experts (SMEs), and an account of firsthand observational data from April 2nd, 2013.

A. Analysis of National Traffic Management Logs (NTML)

The FAA's NTML system[7] is the only known archive for TRACON departure constraints. The NTML is utilized to record traffic management activities in air traffic control facilities. Facilities equipped with NTML are required to make the data entries, while at non-equipped facilities the first facility overlaying the non-NTML facility is responsible for making the NTML entries. Mandatory NTML entries facilitate inter-facility coordination and enhance situational awareness throughout the NAS. Some of the responsibilities of the entry facility include communication and coordination of events that may have an impact on the NAS, as well as using the NTML to document events and traffic management initiatives (TMIs).[9]

The data entered in the NTML can be obtained from three known sources: Command Center logs, the NTML database, and a Traffic Flow Management System (TFMS) Remote Site NTML query. The Command Center logs are obtained on the FAA intranet.[10] The types of logs available are NTML NAS summary reports, NTML shift summary reports, and executive summary reports. The NTML database includes all messages entered at a facility that have been forwarded to the Command Center. The third source of data, a TFMS Remote Site query, is obtained using the NTML application that is deployed as part of the TFMS Remote Site suite of tools. This function allows an authorized user to perform a variety of queries. This analysis used the *advanced query* which is similar but not identical to a local facility NTML report (e.g., does not contain log-in/log-out of users). In some cases, restrictions found using the TFMS Remote Site query are not found in the other two sources. Since TFMS Remote Site queries provide the most complete picture of departure restrictions they became the primary data source for the analysis presented in this paper. A corollary observation is that TRACON departure restrictions, from the perspective of the NTML database, are likely under-reported, and hence under-analyzed by researchers to date.

The objectives of the NTML analysis include identifying which TRACONs issue departure constraints while characterizing those constraints into frequency, duration, nature, and size.

1. Analysis of Departure Restrictions by TRACON

An initial list of TRACONs was obtained from the FAA website.[11] Using this list, with the exception of Anchorage TRACON (A11), NTML data from July 2013 is investigated for each TRACON area to determine whether that facility imposes any type of departure fix restriction. This particular month contains a high number of departure restrictions at D10 when compared to other months throughout the year, and was therefore chosen as the month to conduct this in-depth study. In the case of the facility not being equipped with NTML, the overlaying facility NTML logs were used. Operational counts were taken for each facility using TFMS flight plan data, resulting in a list of facilities ranked by traffic volume. This list of TRACON facilities is shown Table 1 below with the final column indicating whether or not there are a significant number of departure restrictions for that facility. In this case, significant restrictions are defined as more than fifty percent of the days contained at least one TRACON departure restriction. The top thirteen TRACONs, when ranked by operational counts, all exhibit a significant number of departure restrictions. From this, one can infer that facilities with a higher number of operations and enough weather events typically use departure fix constraints in some way to manage traffic. A TRACON with many weather events but little traffic volume would not result in a restriction unless an upstream facility issues it. The first thirteen TRACONs listed in Table 1 will be discussed in detail in the following sections of this paper.

Table 1. List of TRACONS.

TID	Facility Name	City	State	Avg Departures Per Day	Significant Restrictions
N90	New York TRACON	Westbury	NEW YORK	2988	TRUE
SCT	Southern California TRACON	San Diego	CALIFORNIA	2319	TRUE
C90	Chicago TRACON	Elgin	ILLINOIS	2224	TRUE
PCT	Potomac Consolidated TRACON	Warrenton	VIRGINIA	1848	TRUE
A80	Atlanta TRACON	Peachtree City	GEORGIA	1758	TRUE
D10	Dallas - Ft Worth TRACON	Dallas-Fort Worth	TEXAS	1661	TRUE
NCT	Northern California TRACON	Mather	CALIFORNIA	1648	TRUE
I90	Houston TRACON	Houston	TEXAS	1318	TRUE
D01	Denver TRACON	Denver	COLORADO	1234	TRUE
M98	Minneapolis TRACON	Minneapolis	MINNESOTA	852	TRUE
D21	Detroit TRACON	Detroit	MICHIGAN	850	TRUE
P50	Phoenix TRACON	Phoenix	ARIZONA	850	TRUE
A90	Boston TRACON	Merrimack	NEW HAMPSHIRE	825	TRUE
S46	Seattle TRACON	Burien	WASHINGTON	810	FALSE
L30	Las Vegas TRACON	Las Vegas	NEVADA	745	TRUE
F11	Central Florida TRACON	Orlando	FLORIDA	687	FALSE
S56	Salt Lake City TRACON	Salt Lake City	UTAH	555	TRUE
P80	Portland TRACON	Portland	OREGON	395	FALSE
T75	St Louis TRACON	St. Charles	MISSOURI	370	FALSE
M03	Memphis TRACON	Memphis	TENNESSEE	367	FALSE
K90	Cape TRACON	Falmouth	MASSACHUSETTS	246	FALSE
Y90	Yankee TRACON	Windsor Locks	CONNECTICUT	189	FALSE
R90	Omaha TRACON	Bellevue	NEBRASKA	171	FALSE
P31	Pensacola TRACON	Pensacola	FLORIDA	120	FALSE
U90	Tucson TRACON	Tucson	ARIZONA	93	FALSE
NMM	Meridian TRACON	Meridian	MISSISSIPPI	21	FALSE

2. Frequency and Characterization of TRACON Departure Restrictions

The second part of the NTML analysis characterizes the TRACON departure constraints, with a focus on the frequency, duration, nature, and size of the constraint. A comparison of restriction types and counts is performed, with any other unique restrictions to these areas also recorded.

In Fig. 5 below, a summary of MIT restrictions is shown during the month of July 2013 for each of the thirteen TRACONs. Each of the facilities issued a MIT constraint on greater than fifty percent of the days in July. Most MIT restrictions lasted between one and two hours, with some facility averages being slightly above or below this range. For example, MIT restrictions at Potomac Consolidated TRACON (PCT) lasted just over three hours on average, while restrictions at Minneapolis TRACON (M98) only lasted fifty-two minutes on average. Boston TRACON (A90) issued the fewest number of restrictions with twenty-one, while New York TRACON (N90) issued the most MIT restrictions at 357. The most common MIT value issued across the thirteen TRACONs is ten, appearing in eight of the thirteen facilities. A90 TRACON presents a case where MIT is rarely found in the NTML, minutes in trail (MINIT) are used instead. Typically, MINIT is used by the Towers to provide separation off the runway, which translates into MIT separation over the fix. This is common at some other facilities, like N90, but A90 is the only facility studied where MINIT was more commonly found in the NTML.

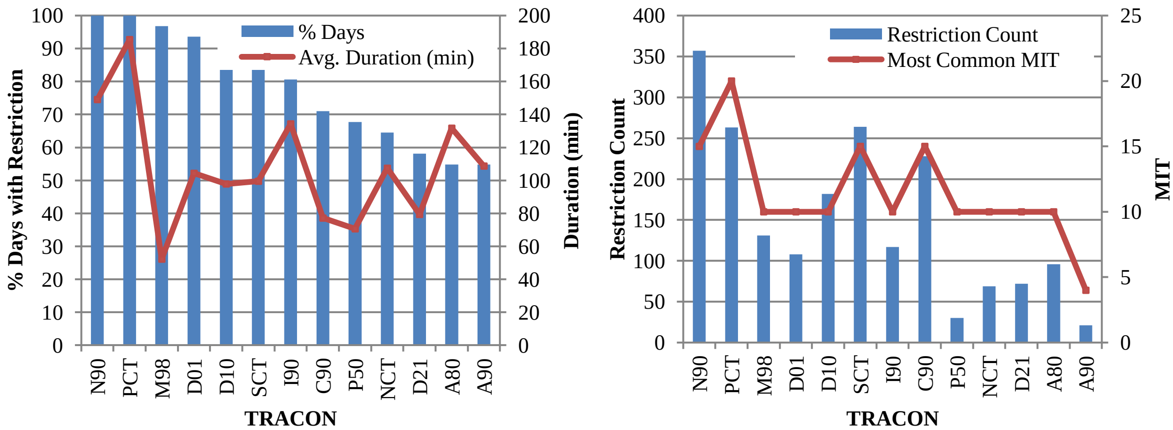

Figure 5. Summary of MIT restrictions by TRACON.

The majority of the thirteen TRACONs issued departure fix compression procedures during July 2013, with the exception of A90, Northern California TRACON (NCT), and Southern California TRACON (SCT). The following charts examine fix compressions with and without MIT restrictions. Denver TRACON (D01) and D10 issued the largest number of fix compression restrictions, at 198 and 234 respectively, as seen in Fig. 6 below. These constraints lasted 96 minutes on average for D10, and 121 minutes on average for D01. Phoenix TRACON (P50) presents the most unique case of the thirteen TRACONs, with an average restriction time of 474 minutes, much longer than the other facilities. As a result of this longer average restriction time, P50 issues fewer restrictions compared to D01 and D10, but still has a high percentage of days with a restriction in place.

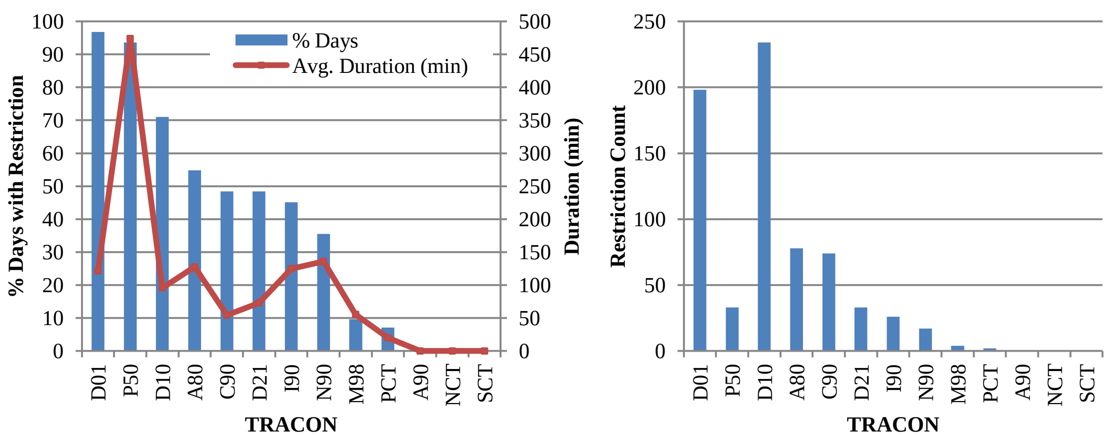

Figure 6. Summary of fix compression restrictions by TRACON.

In Fig. 7 below, only fix compression restrictions with MIT are shown. In some cases, all fix compressions issued by a facility included MIT, as is the case for A80, M98, and PCT. D10 issued the highest number of fix compressions with MIT during July, with slightly over 100 entries. This is roughly half of all fix compressions issued for D10 during the month. D01 exhibits similar behavior, with 88 of the total 198 fix compression restrictions containing MIT. D01 contains the highest percentage of days during the month in which a fix compression or fix compression with MIT is observed at ninety-seven and eighty-four percent respectively.

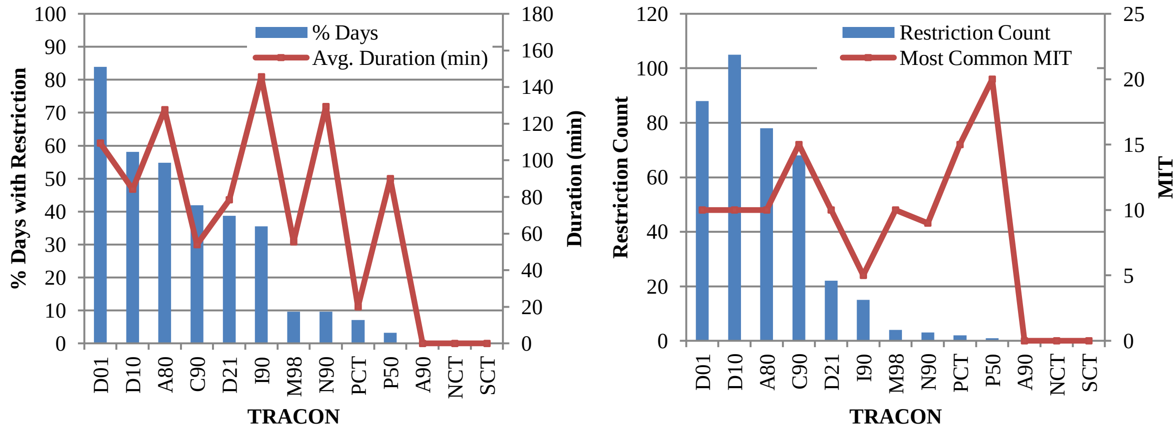

Figure 7. Summary of fix compression with MIT restrictions by TRACON.

A summary of fix swap restrictions is shown in Fig. 8 below. Slightly more than half of the thirteen TRACONs issued a departure fix swap constraint during July 2013. D01 is the only site where one of these constraints was in effect on more than half of the days in July. N90 issued almost the same number of constraints as D01, but they were issued on multiple occasions throughout the same day, resulting in only twelve of the thirty-one days containing a fix swap restriction. Similar to the fix compression procedures, P50 issues fix swap constraints at a time frame much larger than any of the other TRACONs. In this case, an average duration for a fix swap at P50 was slightly less than four hours. D10 published fifteen fix swap constraints during this month, which accounted for twenty-six percent of the days and lasted slightly under one hour on average.

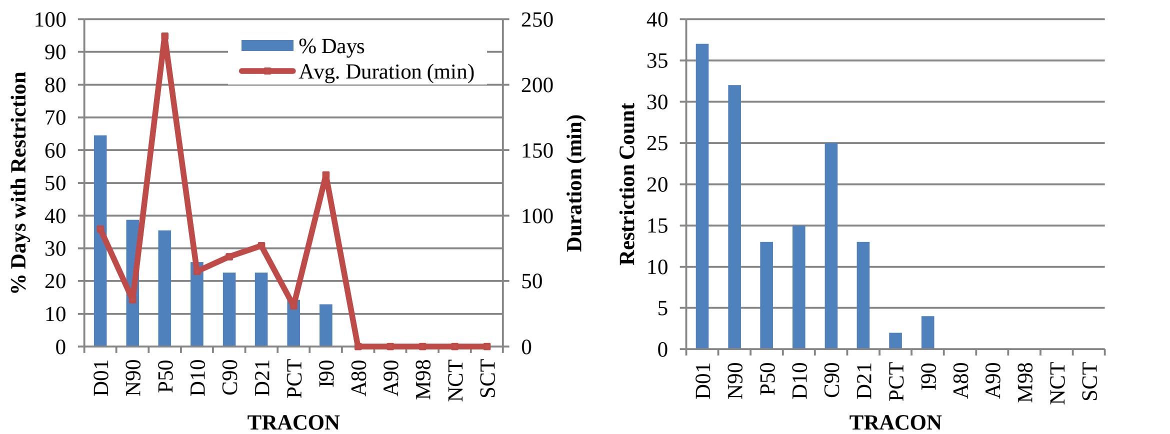

Figure 8. Summary of fix swap restrictions by TRACON.

The frequency of departure fix restrictions exhibits seasonal variation. A year's worth of D10 NTML data from 2011 was analyzed to count the number of TRACON departure restrictions for each month. According to the results shown in Fig. 9, the summer months exhibit the highest number of TRACON departure constraints, which is one of the reasons July was chosen as the particular month for this study. Based on this study, it seems likely that departure restrictions are imposed throughout the year at other TRACON facilities as well, although they may have varying types and durations.

Some TRACONs use different types of restrictions than those discussed above. The more common of these are speed restrictions and stacking at the departure fix. Speed restrictions are most commonly used for arrival flights, but can be used for departures. Stacking is the process by which flights are allowed to cross the TRACON boundary simultaneously at different altitudes. Some facilities, like N90, do this on a regular basis. Flights from John F. Kennedy International airport (JFK) headed to the north gates are crossed 1,000 feet above departures from the other airports inside N90. Other facilities require approval to stack at the departure fix, and may only use it on a case-by-case basis.

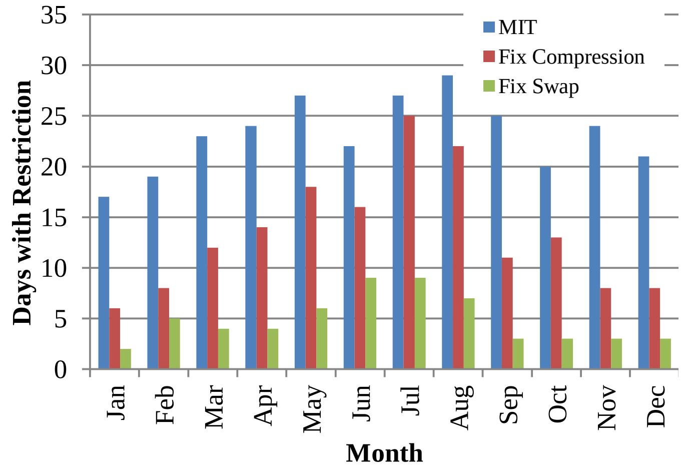

Figure 9. Frequency of D10 TRACON departure restrictions during 2011.

B. Interviews of TMCs/STMCs

Interviews were conducted with SMEs familiar with D10 TRACON and N90 TRACON. The objectives of these interviews were to verify the research team's understanding of TRACON departure processes and to obtain an assessment of the current system shortfalls from the perspective of operational personnel. This section describes the lessons learned from these interviews, and any unique characteristics that set these TRACONs apart from the others.

1. D10 TRACON Interview

Multiple interviews were conducted with an SME from D10 TRACON. The objective of these interviews was to expand operational knowledge of the D10 TRACON, and to explore specific questions regarding NTML constraints. The topics included each of the three TRACON departure constraints (e.g., MIT, fix compression, fix swap), with respect to their implementation from a facility perspective. This section will describe the lessons learned about each of the unique departure fix constraints, as well as any unique NTML knowledge that was obtained.

Regarding MIT constraints, the SME noted that the nature of these can be dependent on the airports that will be using the constrained resource. Inefficient communication between the TRACON and the Towers at each of the airports can cause a difference between the published and the actual fix crossing values. Consequently, buffers may be added to the published MIT to compensate for inconsistent adherence to the published constraint.

Numerous factors may contribute to observed fix crossing spacing that differs from the published MIT restriction. Towers may not always communicate engine shut downs by flights awaiting a Call For Release; therefore, the aircraft will not be ready to go when D10 transmits the release clearance to the Tower. Also, most of the satellite airports in the TRACON area have mixed-use runways meaning that departures may need to wait for arrivals to land. Due to this uncertainty regarding satellite airports meeting departure times, D10 will often use a "batching" procedure to increase the efficiency of the departure process. In this procedure, multiple departures are released from a single airport, decreasing the uncertainty in the departure times and thereby increasing the throughput over the fix by more accurately meeting the published MIT restriction.

Another challenge to meeting published MIT restrictions is related to the variation in flight times from the different satellite airports to the various departure fixes. Flight times depend on current flow direction, traffic, and weather conditions making it difficult for D10 departure controllers to know exactly when a flight should be released from different airports to meet the MIT. Rules of thumb are frequently used; however, there is a lack of consistency of use. The effects of this uncertainty are quantified in the departure fix efficiency section later in this paper.

Departure fix compression is a procedure commonly used at D10 TRACON. There are instances during these procedures when a predetermined crossing point is not specified (e.g., *1 route west out the gate*). In contrast, sometimes departure fix compressions clearly state the fix at which the affected flights will cross (e.g., *1 route west over FERRA*). If the fix is closed as a result of weather, which is most often the case at D10, the weather constraint could be constantly moving across the departure gate, making the available crossing point change over a short period of time. As a result, no crossing point is specified in the restriction and it is up to the controller to determine where each flight will cross the gate. Handoff procedures from the TRACON to the Center occur between 12,000 and 13,000 feet, with the aircraft intending to cross their filed fix around 17,000 feet. Once the flight is under Center control, the crossing point may be altered if the flight is already above TRACON airspace and it makes operational sense for the Center to do so. Therefore the actual fix crossed may be different from prescribed NTML entries, making post-flight analysis challenging when measuring adherence to the constraints, and illustrating the volatile nature of departure restrictions.

At D10 TRACON, departure fix swaps are often used as a result of weather. As mentioned previously, fix swaps result in flight plans having to be re-filed. Ideally, airlines would let controllers handle the re-file, because it is the easiest logistically. However, there are cases when this does not work, such as when MIT are applied to swapped aircraft because airlines want to avoid the delay. Also, some airline procedures do not allow them to file into known convective weather, so they will almost always re-file themselves. Extensions to fix swap procedures, such as MIT and flight exceptions tend to create a workload-intensive environment for controllers. Not only do they have to concentrate on which flights are subject to the swap, but also which flights are exempt that file over the same fix.

The SME noted that TRACON departure restrictions can be very volatile in nature, leading to multiple restrictions being published, modified, and cancelled as factors cause the demand/capacity imbalance to change. The process of sequencing and scheduling departures during these constraints is currently handled without support from automation, resulting in decreased efficiency. Throughput over a fix with applied MIT is often lower than what can be handled, resulting in an increase of departure delay.

2. N90 TRACON Interview

SMEs with recent experience at N90 TRACON and the Port Authority of New York and New Jersey (PANYNJ) were interviewed with the goal of gaining insight into basic departure operational procedures at N90, and how they might differ from other TRACON facilities in the NAS. In addition specific questions related to NTML entries were asked, focusing on interpretation of NTML syntax and how the restrictions might be implemented.

The discussion began with a verification of the departure fixes used at N90, and how they are grouped according to gates (e.g., EAST or NORTH gate). Accurately grouping of departure fixes by gate is important, since some restrictions entered in NTML apply to gates and not fixes. If a departure fix is incorrectly classified, then the detailed analysis will not be accurate. The N90 TRACON, with airports and departure fixes, is depicted in Fig. 10.

There are five airports within N90 that provide the majority of flights for the TRACON. These are Newark Liberty International airport (EWR), Westchester County airport (HPN), John F. Kennedy International airport (JFK), La Guardia airport (LGA), and Teterboro airport (TEB). EWR, JFK, and LGA are the top three contributors to the demand at N90, consisting mostly of scheduled passenger airlines. TEB is a general aviation airport that mostly supplies private or corporate jets to N90 TRACON. HPN is served by six scheduled passenger airlines, but the majority of flights from this airport are local or transient general aviation.

N90 handles JFK departures somewhat differently than the other four major airports. Departures from JFK are

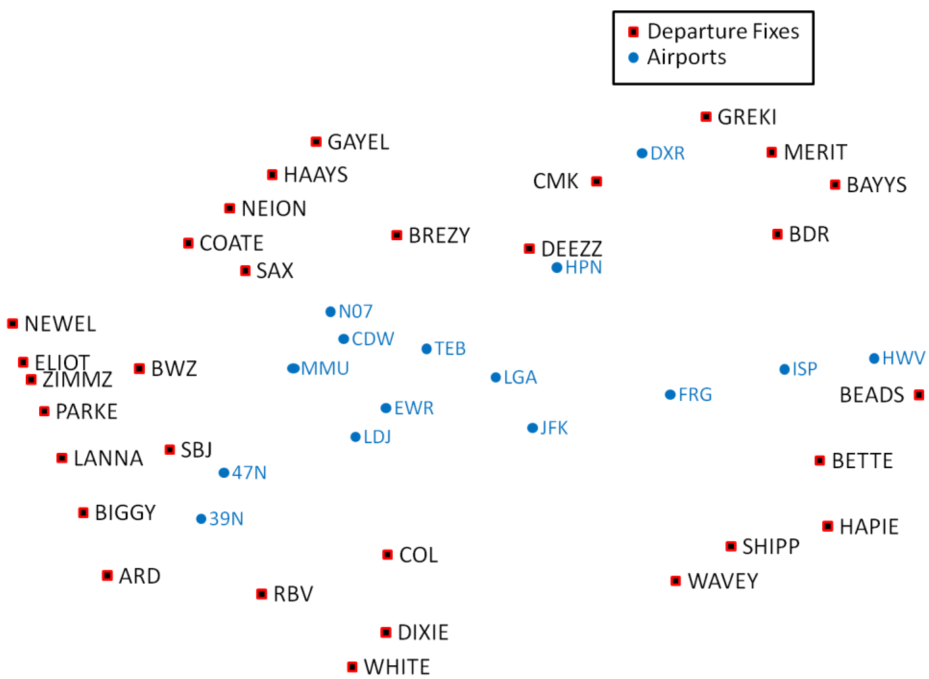

Figure 10. N90 TRACON airports and departure fixes.

stacked above departures from other airports at most fixes. This is clearly defined over the north gate (e.g., COATE, NEION, HAAYS, GAYEL), where JFK departures cross the N90 TRACON boundary at 17,000 feet, while other departures cross at 16,000 feet. West gate departures from JFK are also routed differently than departures from the other airports. The main departure fixes used by EWR, HPN, LGA, and TEB out the west gate are NEWEL, ELIOT, ZIMMZ, PARKE, LANNA, and BIGGY. JFK departures to the west use RBV. RBV is considered the west ***gate*** for JFK departures, with multiple jet route options available after crossing RBV (e.g., J75, J48, Q42).

It is very common for N90 to operate with a MIT restriction over a departure fix. The restriction can originate from a Center, or internally from the TRACON facility. Restrictions passed from the Center to N90 are typically passed down to the airport Towers, either in the form of MIT or MINIT. The restrictions passed to the Towers refer to MIT/MINIT off the runway, so that N90 can meet the required MIT spacing at the departure fix. JFK typically uses MIT off the runway, while the other major airports use MINIT. All restrictions, from Center to TRACON to Tower, are recorded in the NTML. This allows the researcher to follow the flow of the restriction from time and place of origin to final implementation.

Regarding MIT/MINIT restrictions, adherence is very important. If the restrictions are not met, the result will typically be a ground stop implemented for flights bound to the restricted fix. Sometimes this is avoided if airports like TEB and HPN do not have the demand to meet the MIT/MINIT restriction, but that is not always the case. One difference observed between D10 and N90 facilities is that D10 restrictions are sometimes implemented with buffer values built in. At N90, it was emphasized that buffers are not applied to restrictions. If ten MIT is needed, ten MIT is published.

At N90, it is common to close fixes, or even entire gates, due to weather or volume. If a fix is stopped for weather, flights will typically be re-routed to another fix. If the fix/gate stop is generated by N90, it will typically be a volume stop, and in this case the TMCs do not want a re-route issued. The problem is that the restriction may not indicate a volume stop, so Tower controllers may surmise that it is a weather stop and therefore re-route the aircraft. This communication breakdown can complicate the problem and just moves the volume related issue to another fix/gate. In the case of a re-route due to weather stops, the airlines are not responsible for re-routing. In the case of short-term stops between five and ten minutes, flights will typically be held on the surface and not re-routed. If the stop is longer than this, New York Air Route Traffic Control Center (ZNY), which is the Center airspace containing N90, would be responsible for specifying what fix/gate the flights should be swapped over to. N90 will take low altitude flights around the weather as much as possible, which may simply move the volume around to other fixes, solving one problem by creating another.

N90 uses the same general terminology as D10 for compressing departure fixes, which includes the use of the term ***as one***. For example, *'metering: n90 tmu: intrail update -zimmz, parke and newel 8 minit as one /1900z'*. In this case, the resulting fix that flights will go over is not specified, which means it can be any of the three. They do this because weather may dynamically change the location in which flights can cross, so they want to leave the final choice to the controller. There are cases where a crossing fix is specified. Fixes are combined with the controller in mind, and in this case, fixes ZIMMZ, PARKE, and NEWEL are handled by one controller, while LANNA and BIGGY are handled by another. As a result, fix compression over the west gate will typically merge ZIMMZ, PARKE, and NEWEL as one, and then LANNA and BIGGY as one.

Some of the NTML messages contain references to the Departure Spacing Program (DSP).[12] For example, *'dept via biggy, n90 passback ztl passback 2000-2200, wx:thunderstorms n90:ewr,lga,hpn, dsp: (ov: ewr/lga/hpn)'*. DSP is a tool intended to improve the efficiency of departure traffic scheduling and coordination. It evaluates the schedules and routes of flights from participating airports, calculates departure fix demand and loading, and assigns departure time windows based on projected fix crossing times. In this case, a rate was not specified for the restriction, because DSP is being used. DSP is primarily used for a destination restriction to airports since it uses different logic to sequence flights. To find the restriction value, one must look back at what ZNY requested.

The N90 TRACON uses many unique shorthand phrases that represent different restrictions. These are understood by N90 personnel but difficult for the uninitiated observer to follow. For example, two MIT values may be assigned to the north gates in a single restriction message, and since N90 operations dictate that JFK airport is operated with different procedures from the other large airports, that is how the values are applied. There are many other cases such as this, which highlights the fact that researchers must have in-depth knowledge of the particular TRACON being investigated.

C. Firsthand Observation of TRACON Departure Operations

D10 TRACON departure operations were observed during an inclement weather situation. A detailed account of this observation is recorded and described below to illustrate the types of constraints that can be imposed on the departure fixes. The reader is encouraged to refer to Fig. 1 for the airspace geometry associated with the following discussion.

On April 2nd, 2013, an extremely slow moving moderately convective storm with an unusual front line moved through the D10 TRACON. Initially, the front extended north-south just to the west of DFW airport, and then east-west between Fort Worth Alliance airport (AFW) and Fort Worth Meacham International airport (FTW). The convective weather was generally developing west to east along an arced path such that first the west gate, then the south, and finally the east were affected. There were also times throughout the day when several gates were impacted simultaneously. In addition, weather in Oklahoma was drifting towards the Red River such that the north gate was eventually impacted as well.

Throughout the day, multiple restrictions were placed on the departure fixes, including MIT, fix compression, and fix swaps. For example, the west gate was fully swapped at one point, with ten MIT imposed on swaps. This means that all flights originally filed over a west departure fix were required to file new flight plans, either to the north or to the south. These flights would be sequenced over their new departure fixes with ten MIT. As time progressed and the storm moved east, only two routes out the east gate were left open, an example of a fix compression, with the closed fixes now being routed over the two open departure fixes. Over a twenty-five minute span, the restrictions in place over the east gate were very volatile. Restrictions went from two routes out the gate to one, with ten MIT in place. Then the MIT was removed, followed by another fix opening up with ten MIT reinstated. Speed controls were also used by controllers at this time to meet the required constraints. To the north, another fix compression was in place. The north gate was restricted to only the inner departure fixes, meaning departure fix LOWGN was routed over BLECO, and AKUNA was routed over GRABE.

The observations from this day indicate that workload associated with departure sequencing is often shared between two or more positions. This includes the coordination with individual airports. The actual spacing achieved at the departure fix often differs significantly from the desired spacing, which results in a tendency to apply buffers to the published MIT restrictions. The ability to meet the required spacing may vary between different personnel. The required spacing between flights appears to be harder to achieve when switching between airports as opposed to the spacing achieved when multiple flights depart from the same airport (e.g., batching of flights). The spacing prescribed at the departure fix is often based upon rules of thumb involving initial radar contact. Air Traffic Control (ATC) personnel may be switched out during these periods in order to allow those with more experience meeting MIT restrictions to deliver aircraft to the departure fixes. One of the criteria TMCs and controllers use to determine departure priority is the number of flights which have reportable delay. The more flights with reportable delay, the higher the departure priority for a particular airport. Multiple parties may be involved in the determination of a departure fix constraint.

IV. Impact of Departure Fix Constraints

In this section the impact of TRACON departure restrictions are described in a number of different ways. First, a macro-level view of the number of TRACON facilities operating with a departure constraint at any one time is shown. This describes a top-level view of the NAS, looking at the significance of these restrictions on a facility aggregated basis. Second, the number of flights involved in a TRACON departure restriction during the month of July 2013 is shown. These results are displayed on a per facility basis, as well as an overall count for the entire month. Third, a departure fix efficiency analysis is presented, which shows the most commonly used departure fixes across the thirteen TRACONs investigated. It measures the efficiency of departure fix throughput during times of MIT usage. Finally, a departure delay analysis is presented, which measures the delay incurred by flights involved in any type of TRACON departure constraint.

As restrictions are imposed on departure fixes in the TRACON, both the flights using the resources and the controllers required to direct the operations are affected. The level of impact may be a function of severity of the weather or other cause of the restriction. Multiple restrictions can be in place at one time, as described above. This can result in high controller workload, and inefficiency in the utilization of the active departure fixes. Additional tools available for the controllers to use are speed controls and stacking, as explained in the previous section. These can help ensure proper spacing over the constrained resources, but come at the cost of higher workload and frequency congestion.

Data from the TFMS is used to identify which flights are involved in a TRACON departure constraint by correlating their actual departure fix, and departure fix crossing times with restrictions from NTML. TFMS receives data from NAS host computers, such as radar track data, flight plans, and aircraft departure and arrivals, and also receives data directly from NAS users, such as estimated flight operation times, intent of flight operations, and arrival slot assignments. TFMS processes these various data messages, matches each message to the appropriate flights, and calculates various value-added derived data elements, such as estimated entry time in each of the airspace sectors. This enables TFMS to project traffic demand NAS-wide for hours in the future. For this research, data from TFMS is used to measure the impact of the TRACON departure constraints found in NTML by matching flight plans and tracks with any restriction currently in place.[13]

1. Macro-level Analysis of TRACONs Operating with a Restriction

A high-level impact study of the breadth of TRACON departure constraints across the NAS involves investigation into TRACON facilities that are issuing departure restrictions at any one time. In this analysis, hourly time bins are used to count the number of facilities that are currently operating with a TRACON departure restriction in place. For the entire month of July 2013, the thirteen TRACONs identified in previous sections are used to classify the range of constraints issued. In Fig. 11, a box and whisker plot for each hour, in UTC time, is displayed. The box represents the upper and lower quartiles of the data, with the median value displayed as a red line inside the box. The maximum and minimum values, excluding outliers are depicted as the whiskers, with any outliers displayed as a red cross. The general trend of this figure follows closely with operations in the NAS. Fewer flights operate at night between the hours of 0400 and 1000 UTC (12 am and 6 am EDT), in which there is typically only a single facility that has issued a TRACON departure constraint. The highest levels of demand are between 1900 and 2400 UTC (3 pm and 8 pm EDT), where as many as ten facilities have been recorded as issuing a TRACON departure constraint for similar hours. The most common occurrence would be between four and seven facilities operating with TRACON departure constraints during peak traffic hours.

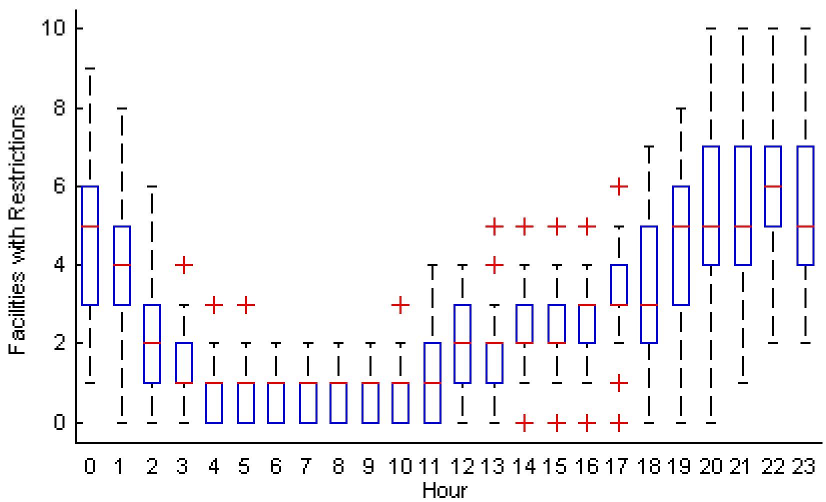

Figure 11. Hourly count of TRACONs with departure restrictions during July 2013.

The significance of this study is that during the time periods between 1900 and 2400 UTC, it is common for up to seven facilities to be operating with a TRACON departure constraint during the month of July 2013. These seven facilities could be any of the top thirteen facilities with regards to traffic volume in the NAS. In order for the overall concept of gate-to-gate scheduling to be successful, these TRACON level departure restrictions need to be addressed and resolved.

2. Flights Affected By TRACON Departure Restrictions

As discussed previously, the scope and duration of TRACON departure restrictions varies by facility. These traits, when combined with traffic counts for each TRACON, determine the number of flights that are directly impacted by the issued departure constraint. For example, the highest volume TRACON, N90, may impose a constraint for a short duration of time, but this may impact more flights than a facility like M98 with a constraint in place for multiple hours. The analysis described in this section cross references the time frame of each TRACON departure constraint with the number of flights operating under the scope of the restriction. This means a flight must be using the affected resource during the time it is under a TRACON departure constraint. TFMS route and track data is used for this analysis to determine values such as destination, actual departure fix crossed, and departure fix crossing time, which are then correlated with the restriction characteristics found in NTML.

First, flights affected by each type of restriction are analyzed, followed by an aggregate count of flights affected by any kind of TRACON departure restriction. It is possible for a flight to be affected by multiple constraints at any one time, and therefore the aggregate count of all restrictions shown later takes this into account and only records each flight affected once.

In Fig. 12, the average and total number of flights involved in a MIT constraint is shown for each TRACON facility, in descending order of the most flights affected. There are two average count metrics depicted, indicated by the suffix *single* or *daily*. The average number of flights affected by each individual MIT restriction is shown in Fig. 12 as a red line, representing the prior mentioned wording of *single*. The average daily count of flights affected is in reference to all MIT restrictions that occurred over the course of a day. There are times when constraints are issued and very few flights are affected and other times where a constraint can affect a large number of flights. In the case of N90, which has the highest volume of flights, a single MIT constraint involves twenty-two flights on average. In a single day, about 175 flights departing N90 airspace are involved in a MIT constraint over one of the departure fixes. This equates to 5,440 flights affected by MIT departure constraints at N90 alone. At D10, which issued 182 MIT restrictions during July 2013 (see Fig. 5), about six flights are affected by each individual MIT restriction. This number appears low, and is a result of the constraints changing frequently, which accounts for a higher number of constraints issued. As noted in the observations at D10, restrictions themselves can be volatile, changing frequently to handle the transforming weather conditions. The duration of each constraint and the number of flights affected can vary significantly as a result.

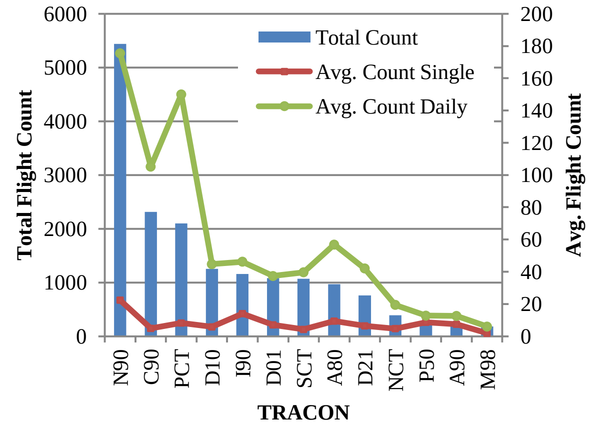

Figure 12. Flights affected by MIT restrictions.

A summary of flights affected by fix compression restrictions in shown in Fig. 13. D10 and D01 are the facilities with the highest number of flights affected by this type of constraint. On average, about 193 flights are involved in a fix compression per day at D10, with about 121 flights affected at D01 per day. At P50 TRACON, the largest number of flights is affected on average for each of these constraints issued, which can be explained by their durations. In reference to Fig. 6, fix compression restrictions at P50 last just under eight hours, which is significantly longer than any of the other TRACON facilities.

There are three TRACON facilities that exhibit similar results for the average number of flights affected during a single fix compression and MIT constraint, as seen in Fig. 14. These are Houston TRACON (I90), N90, and P50, which on average about twenty-three flights are involved in one of these constraints. On average, D10 issues fix compression and MIT constraints that affect the highest number of flights on a daily basis, with about 104 flights affected per day.

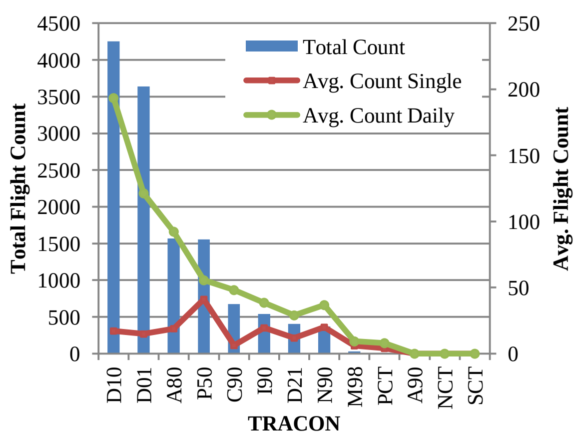

Figure 13. Flights affected by fix compression.

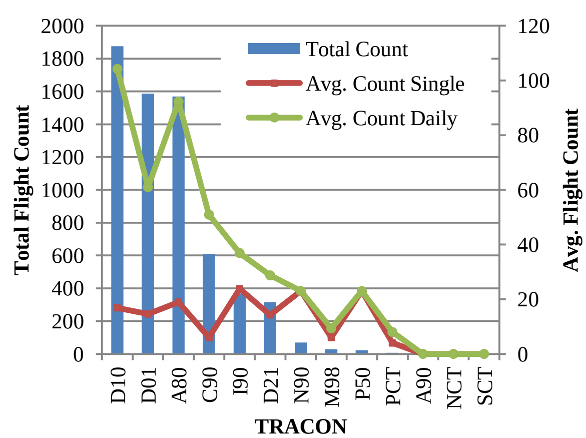

Figure 14. Flights affected by both fix compression and MIT restrictions.

Figure 15 displays a summary of flights affected by fix swap restrictions at each of the thirteen TRACONs. The most flights affected by this type of restriction depart from N90, followed by D01. The number of flights affected by this type of restriction at D10 appears to be small, and may be a result of flights re-filing their flight plans as a result of the restriction. Interviews at D10 specified that flights were required to re-file in the event of a fix swap. This is procedurally different at N90, where flights were not required to do so. PCT only issued two of these swap events, with no flights restricted as noted in the table below. This may indicate that PCT procedures are similar to D10, in that flights are required to re-file when a fix swap is implemented.

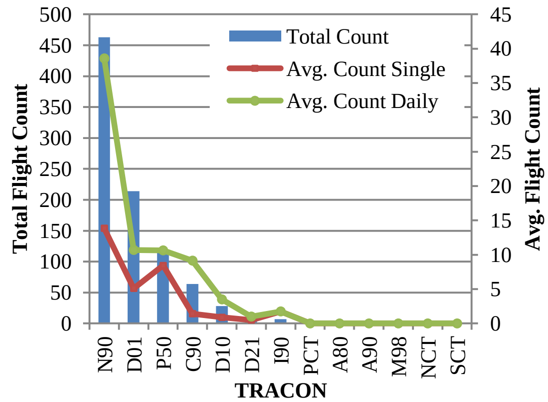

Figure 15. Flights affected by fix swap restrictions.

In Fig. 16 below, the aggregate number of flights affected from this study is displayed. N90 tops the list with the most flights affected during the month of July 2013, but it is not the facility with the highest percentage of flights affected. This honor goes to D01, where greater than eleven percent of all departure operations during July 2013 were impacted by a TRACON departure restriction.

At D10, where this study originated, just over 4,600 flights were impacted by a TRACON departure constraint, translating to just over nine percent of total operations in July 2013. Depending on the size and scope of the constraint in effect, controllers handling the flights may have additional workload associated with the constraint. As observed at D10, ATC personnel may be switched out during a TRACON departure constraint to allow controllers with more experience to provide the required spacing. If these constraints are issued in a tactical fashion as a result of dynamic weather, and there is no opportunity to swap personnel, the result may be inefficient handling of departure flights involved in the constraint.

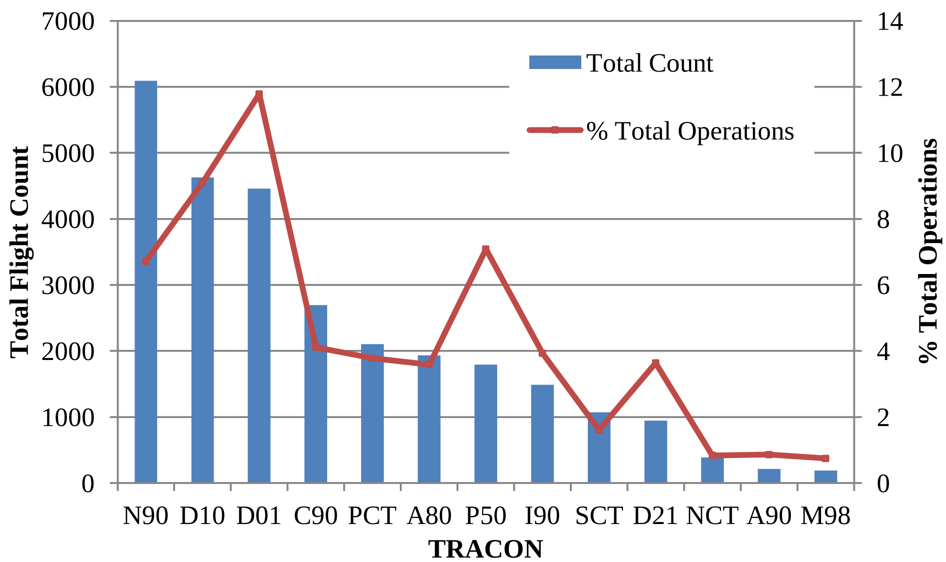

Figure 16. Flights impacted by TRACON departure restrictions (July 2013).

3. *Departure Fix Efficiency Analysis*

The departure fix efficiency analysis investigates the top ten utilized departure fixes in terms of volume across the thirteen TRACONs used in this study. The number of flights involved in a TRACON departure restriction that cross these fixes is recorded and compared to the total number of flights that use that particular fix during July 2013. A measure of efficiency is calculated over that departure fix, which compares the maximum available throughput and the actual throughput during times of no constraints and times when a MIT constraint is in effect. MIT is used for this study as opposed to the other TRACON departure restrictions since the flow to that particular fix is specifically being reduced in terms of throughput.

The top ten departure fixes in terms of volume are shown in Fig 17. Departure fix HOLTZ, located in the SCT TRACON, is the most used fix across the thirteen TRACONs. However, it is not restricted very often, with only one percent of flights crossing HOLTZ restricted in July 2013. The second highest utilized fix, LDN, experienced over 5,000 flight crossings, with approximately 700 of those restricted by a TRACON MIT departure constraint. Departure fix MOBLE, ranked third in terms of volume, experienced 468 restricted flights, which is about nine percent of all MOBLE flights.

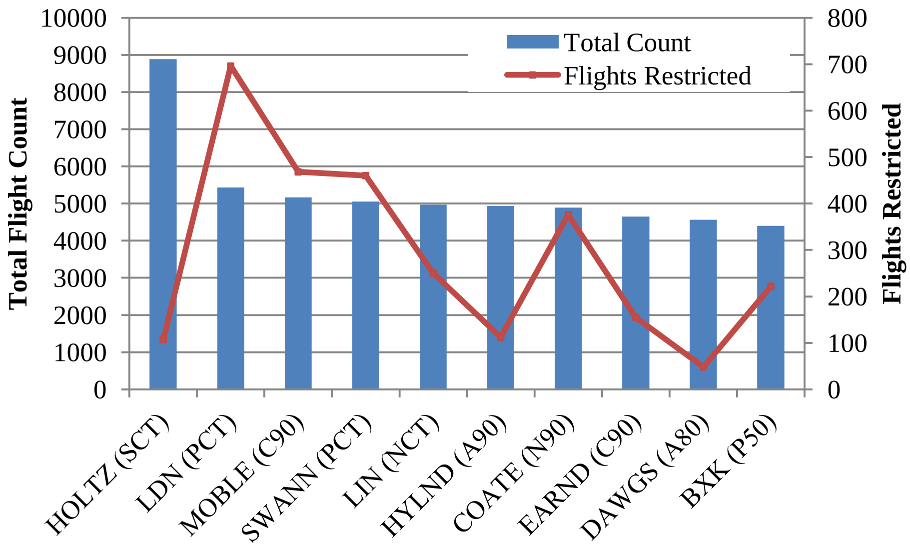

Figure 17. Departure fix usage and number of restricted flights.

To determine the efficiency for each departure fix, the throughput is calculated in one hour increments. Throughput is determined using the time frames in which no TRACON departure restrictions are in effect, as well as times when MIT restrictions are present. Throughput values are then divided by the maximum throughput for that departure fix. In times of no TRACON departure constraints, it is assumed a single altitude is used for crossing the fix (no stacking), with a default miles in trail of five miles. This results in a maximum throughput of seventy flights per hour. During a TRACON restriction, the maximum throughput is the maximum number of flights that can cross with the published MIT imposed. The analysis assumes an average departure fix crossing ground speed of 350 knots, which was determined from actual fix crossing ground speeds.

$$Throughput_{max} = \frac{average\ speed\ over\ fix}{miles\ in\ trail} \tag{1}$$

$$Efficiency = \frac{Throughput_{actual}}{Throughput_{max}} \tag{2}$$

The analysis assumes that during times of no constraints the demand is less than the capacity. It is expected that the efficiency level during these times will be less than 100 percent. When a MIT constraint is issued, the demand is most likely at or above the new throughput value. If it is below that level, flights could be released without any control and would have no trouble meeting the spacing value imposed on that fix. As a result, the efficiency level during times of MIT would be expected to approach 100 percent. Any value below 100 percent translates into wasted capacity for that fix. Wasted capacity means that the published MIT restriction is not being met. This may be caused by flights not being ready to depart, controllers waiting too long to release a flight, or difficulty estimating the time to fly from satellite airports to departure fixes under various weather and traffic conditions.

The following figures represent the efficiency for departure fixes LDN and MOBLE, the second and third highest utilized resources. The time frame is reduced to the hours between 1800 and 2300 UTC, when most of the traffic crosses the fixes. Efficiency levels without MIT are low, typically between fifteen and twenty-five percent. As mentioned previously, it is expected that these values are less than 100 percent, since unconstrained capacity over the fix is high. During times in which a TRACON MIT is in effect, the efficiency levels vary depending on the size of the constraint. Note that increased MIT results in higher efficiency on average. This may be a result of the smaller capacity values for the fix at this time, with demand levels remaining the same. The efficiency levels for

LDN appear to be higher than MOBLE on average. Departure fix MOBLE tends to have levels of efficiency below forty percent, LDN is well above that. An important thing to note is that 100 percent efficiency is not commonly achieved, and therefore there is room for improvement during times of MIT constraints. It is believed that improved awareness and scheduling during times of MIT can increase the throughput to the assigned departure fix, thereby filling the gap of the observed efficiency and maximum attainable efficiency. This process is currently implemented when more experienced controllers are re-assigned positions with MIT in effect, as observed in the D10 TRACON, but is reliant upon those experienced controllers being available.

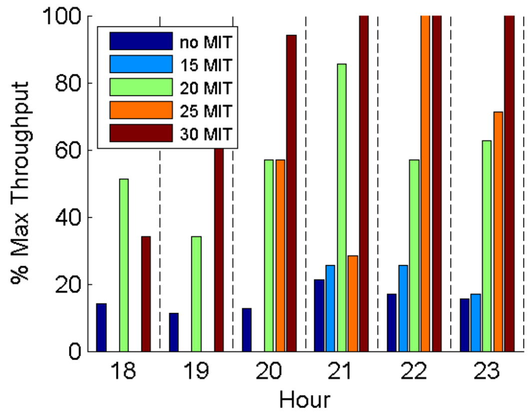

Figure 18. Fix efficiency for LDN.

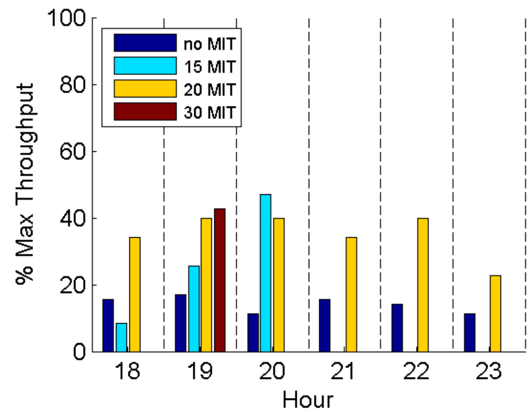

Figure 19. Fix efficiency for MOBLE.

The average efficiency across all times periods when a MIT constraint is in effect is calculated for each of the top ten departure fixes. In Fig. 20, the average efficiency is shown for fifteen MIT at eight of the top ten departure fixes. The other two fixes, HYLND, and DAWGS did not experience fifteen MIT restrictions, and are therefore not

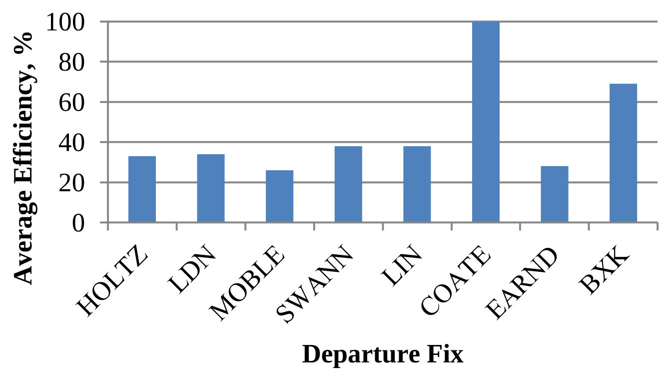

Figure 20. Departure fix efficiency for 15 MIT.

depicted on the figure. Only two of the departure fixes operated at levels of efficiency greater than fifty percent, with COATE depicted at 100 percent efficiency. This departure fix is located in the busiest TRACON, N90, and therefore the significant amount of demand is able to feed the departure fix without wasting space. There is room for improvement over the other departure fixes, especially MOBLE and EARND, where efficiency values are less than thirty percent on average.

4. Departure Delay Analysis

This analysis leverages the results of the impact analysis described in a previous section by calculating departure delay values for each of the flights involved in a TRACON departure constraint. Departure delay values are extracted from the Surface Decision Support System (SDSS),[14] where the estimated departure time when a flight crosses the spot is compared to the actual departure time. Data from SDSS is only available for a limited number of airports, referenced in Table 2, so the total reported delay values will be lower than if departures from all

Table 2. List of Airports with SDSS Data.

Airport	TRACON
ATL	A80
BOS	A90
DFW	D10
EWR	N90
IAD	PCT
JFK	N90
LGA	N90
ORD	C90

airports in the TRACON were included. The equation for calculating delay of flights departing DFW is shown below:

$$Delay = OffTime_{actual} - OffUndelayed_{spot} \quad (3)$$

where:

- $OffTime_{actual}$ *is the start of roll time on the runway as determined by SDSS.*
- $OffUndelayed_{spot}$ *is the earliest possible Off Time for the flight, as determined by SDSS when the flight is at the spot.*

This equation is used to calculate departure delay for each of the flights in the SDSS datasets, which are then correlated to the TFMS route data using flight matching logic. This logic uses a combination of callsign, origin, destination, and Estimated Time of Departure (ETD) to match the correct flight. In the case of a flight from the TFMS dataset not producing a match to the SDSS data, departure delay is recorded as an empty value and will not be counted towards the total.

The calculation of departure delay on a flight by flight basis is identical across all flights involved in a TRACON departure restriction. Once this first step is complete, average values of departure delay for each of the TRACONs listed in Table 2 for the entire month of July 2013 are calculated. The absence of certain restrictions at each TRACON (e.g., only MIT at PCT) results in no colored bar corresponding to that restriction type in Fig. 21 below. The average departure delay for all restrictions combined, as indicated by the red line, is highest at A90 and N90 TRACONs, with values greater than twenty minutes. At N90, fix swap restrictions result in the highest average delay at just less than forty minutes.

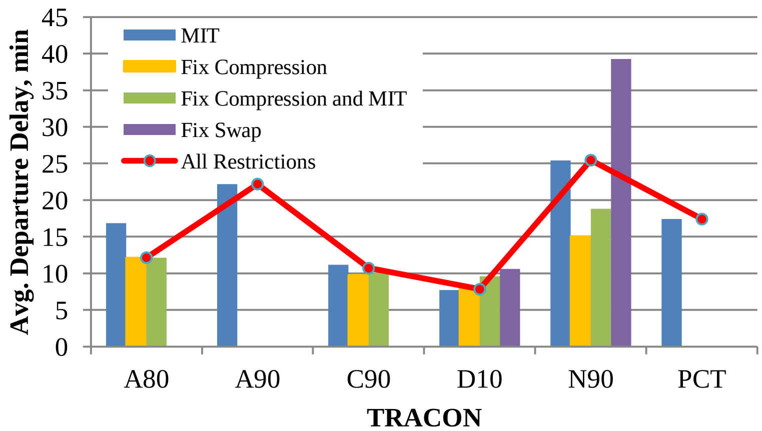

Figure 21. Departure delay for six TRACONS with SDSS data.

V. Summary

This paper studied TRACON departure constraints in the NAS, to better understand departure scheduling challenges of current-day operations, and to characterize the frequency and scope of the different departure constraints employed at various TRACONs.

Analysis showed substantial use of departure constraints by the top thirteen TRACONs as ranked by volume. The most common of these restrictions was MIT, occurring in more than half of the days in July 2013 for all thirteen TRACONs. Approximately 1,900 MIT constraints were issued, impacting flights with average delays up to twenty-five minutes. There were slightly fewer than 700 fix compression constraints issued by ten of the thirteen TRACONs, with half of these restrictions including MIT. At D10 TRACON, 193 flights were affected per day on average by fix compression restrictions in July 2013. Delays associated with these restrictions were eight minutes on average with no MIT, and ten minutes on average when MIT was included with fix compression. Fix swaps occurred less frequently than the other restrictions, with 141 fix swaps occurring at eight of the thirteen facilities. However, this particular constraint has the largest impact in terms of departure delay, with average delays up to forty minutes observed. TRACON departure restrictions at the thirteen facilities affected more than 28,000 flights total in July 2013.

It is common for more than half of the thirteen TRACONs studied to have departure constraints in place at the same time. Also, researcher observations and interviews with SMEs representing two TRACONs gave insight into the significant variation in current-day strategies and tactics used to handle flights during these restrictions. These concurrent restrictions combined with facility-to-facility variations in departure traffic management practices suggest potential challenges for strategic traffic management initiatives implemented by the Command Center and for future NextGen concepts like gate-to-gate scheduling. These insights suggest future research to better understand the rationale for various departure traffic management practices and to assess impact on NAS-wide traffic management initiatives and future NextGen concepts.

Analytical results, researcher observations, and SME comments all indicate opportunities to increase throughput during times of TRACON departure constraints. The potential throughput improvements would primarily be achieved by increasing the efficiency of departure fix/gate utilization. Analysis presented in this paper shows six of the top eight departure fixes operating at less than fifty percent efficiency under commonly-occurring departure restrictions. These findings motivate NASA research that is focused on extending tactical departure scheduling improvements to lesser-equipped airports and to address TRACON boundary departure constraints.[15] As detailed in Ref. 14, development of a terminal departure scheduler reveals observed delay and loss of throughput can be partially reclaimed. Simulation results of this terminal departure scheduler show potential delay savings of up to thirty-five percent, with an increase in throughput of up to seventeen percent. In addition to identifying the potential benefits of increased automation in the terminal area, the findings presented in this paper were used to validate fast-time simulation models and develop the Concept of Operations for the terminal tactical departure scheduling system described in Ref. 14. This research illustrates the significance of the problem that terminal departure constraints introduce, as well as the potential benefits to be obtained from improving the current departure scheduling process.

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