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Analysis and Modeling of Miles-in-Trail Restrictions in the National Airspace System

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This paper presents an analysis of values and locations of Miles-in-Trail restrictions used within the National Airspace System over the last three years. Using specific severe weather avoidance routes, various locations are selected to implement the Miles-in-Trail restrictions to study their individual impact on the delay of flights and sector congestion in the airspace. The current traffic management operational infrastructure lacks the modeling of multiple restrictions with passback Miles-in-Trail values to upstream facilities. The model developed here allows implementation of multiple restriction locations for multiple merging streams of traffic. The model also permits speed control, vectoring or airborne holding, and passback of restrictions to upstream facilities. The simulation environment allows implementation of these restrictions, enabling a what-if capability in a rapid evaluation mode for Miles-in-Trail impact. Preliminary results are presented for delay of impacted flights due to implementation of three different playbook routes and Miles-in-Trail values at various locations with passbacks to upstream facilities. Results of sector congestion in the airspace for those cases are discussed as well. It was observed that for a particular playbook route implementation with Miles-in-Trail between 25 and 30 nmi applied at a reference fix resulted in low total delay and sector congestion. Overall, the model appears to be a good starting point for evaluation of passback restriction impact and, with operational feedback, could be used for advising passback values to upstream facilities.

I. Introduction

THE air traffic managers of the National Airspace System (NAS) in the United States regularly implement various traffic management initiatives to handle traffic in a safe and efficient manner. One such initiative is the Miles-in-Trail (MIT) restriction. Imposed MIT is the value of spacing required between aircraft flying along a certain path. They help air traffic managers control the flow of aircraft into and out of an air traffic control facility. MITs could be implemented independently or in conjunction with other Traffic Management Initiatives (TMIs), e.g., a severe weather avoidance plan route or a Playbook route. If a certain facility is unable to manage traffic with the imposed MIT value, it passes back the restriction to an upstream facility. In order to predict the impact of imposing a certain value of Mile-in-Trail value along a particular path, and perhaps additional passback values, on flight delays and congestion of airspace, it is important to model these restrictions in a NAS-based simulation environment.

Several research articles are available which document the modeling of the Miles-in-Trail restrictions. Sridhar[1] presented an integrated set of traffic management initiatives implemented within the Future ATM (Air Traffic Management) Concepts Evaluation Tool (FACET)[2]. Wanke[3] also presented an integrated impact assessment capability. Both of these works were more than a decade ago. Since then, the traffic patterns have changed and other new traffic management initiatives have been developed. At the end of a decade, some of the Miles-in-Trail modeling and impact analysis issues still persist. Grabbe[4] presented modeling and evaluation of MIT restrictions in the NAS. A linear programming model was developed for implementing MITs for departure flows out of New York area airports. Kopardekar[5] presented a perspective on the MIT operations. The strengths and weaknesses associated

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with the MIT modeling were presented in that paper. A refined modeling of the initial work presented in Wanke, et al. was presented in two subsequent works. They are by Ostwald[6] on the MIT impact assessment capability and by DeArmon[7] on the validation of the MIT model. The reported MIT modeling appears to be a robust capability but some of the implementation parameters (e.g., the range limit, multiple stream analysis, passback of restrictions, etc.) are not directly applicable or missing for current operations and traffic. Not many simulation environments are available which model these Miles-in-Trail initiatives across the country in the en route environment. The fidelity for a few available MIT models is limited and not all aspects of a Miles-in-Trail restriction are available, especially operationally viable recommendation of passback values to upstream traffic management facilities.

Rios[8] provided a comprehensive description of the various TMIs used in the US airspace. In order to model the impact of MITs, it is important to understand where and how they were implemented. For this paper, MIT restriction data (subset of the TMI list) were obtained for 2010, 2011, and 2012. The top-ten number of en route MIT restrictions are presented from each year. A comparison between the three years in terms of value and frequency is presented. However, the focus of the paper is in applying the extended MIT modeling capabilities to a particular case of playbook routes and associated fixes with MIT restrictions and the corresponding passback to upstream facilities. After presenting the top-three playbook routes used during the three years, a description of how the modification of these MIT values affect flight delays and sector counts is presented.

The rest of the paper is structured as follows. Section II describes the 2010, 2011, and 2012 Miles-in-Trail and Playbook route implementation values and frequency distribution data. Section III describes the FACET simulation environment used for MIT modeling. Section IV presents the MIT model. Section V shows results for three specific cases of multiple MIT implementations in conjunction with applied playbook routes. The paper ends with some concluding remarks in the last section.

II. Analysis of Past Data

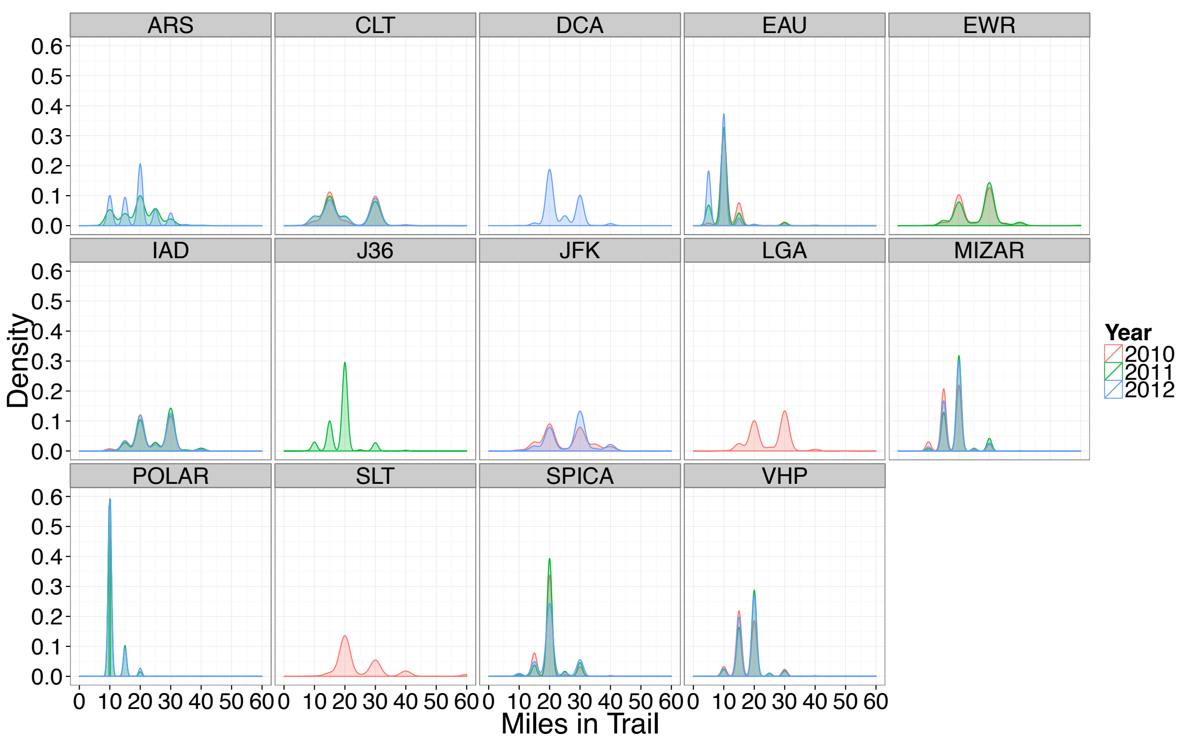

Figure 1. A comparison of 2010 (red), 2011 (green), and 2012 (blue) MIT restriction values at top ten locations in the US.

In this section the MIT restriction data from 2010, 2011, and 2012 years are presented. For each year, the top ten MIT providing locations are shown. For each of those locations, the frequency distribution plots are shown in Fig. 1. There are 14 locations shown, accounting for total count of each location for each year. The values shown in red are for 2010, in green for 2011, and those in blue are for 2012. Due to space limitations, some of the colors are highlighted in the next figure. In these figures, the area under the curve for each plot is one, so they can be compared across various locations. Also, they are shown ranked based on the maximum occurrences. The ARS or the Atlantic Routes were the most used group. Additionally, aggregate number of Charlotte, NC (CLT) restrictions appeared more times in the data than those requested for Washington Reagan National Airport, DC (DCA), and so on. The data indicate that there are several locations in the NAS where high MIT values (e.g., at Newark, NJ (EWR) and LaGuardia, NY (LGA) with up to 30 MIT) were used often in 2010. On the other hand, up to 30 MITs were used in 2012 but not in the top 10 for 2010 at locations like DCA. EWR and LGA did not show up in the top-ten list for 2012, while LGA appeared in 2010 (red) only. This indicates several attributes. First, the traffic patterns are changing. Second, the FAA is imposing restrictions at different locations to manage traffic based on need. Third, at some locations (e.g., Brickyard, IN (VHP)), smaller restriction values were used in 2010 while larger values were used in 2011 and 2012. All of these locations are displayed in Fig. 3 below.

The values shown in Fig. 1 are for all locations in the NAS. The data could be further partitioned into restrictions for arrival flows and en route fixes, specifically for Departure/Arrival Spacing Programs (DASP). In particular, Cleveland Air Route Traffic Control Center (ARTCC or Center) DASP, Detroit TRACON (D21) and Chicago Center Restriction Coordinator (RC) requested the most number of restrictions for arrivals.

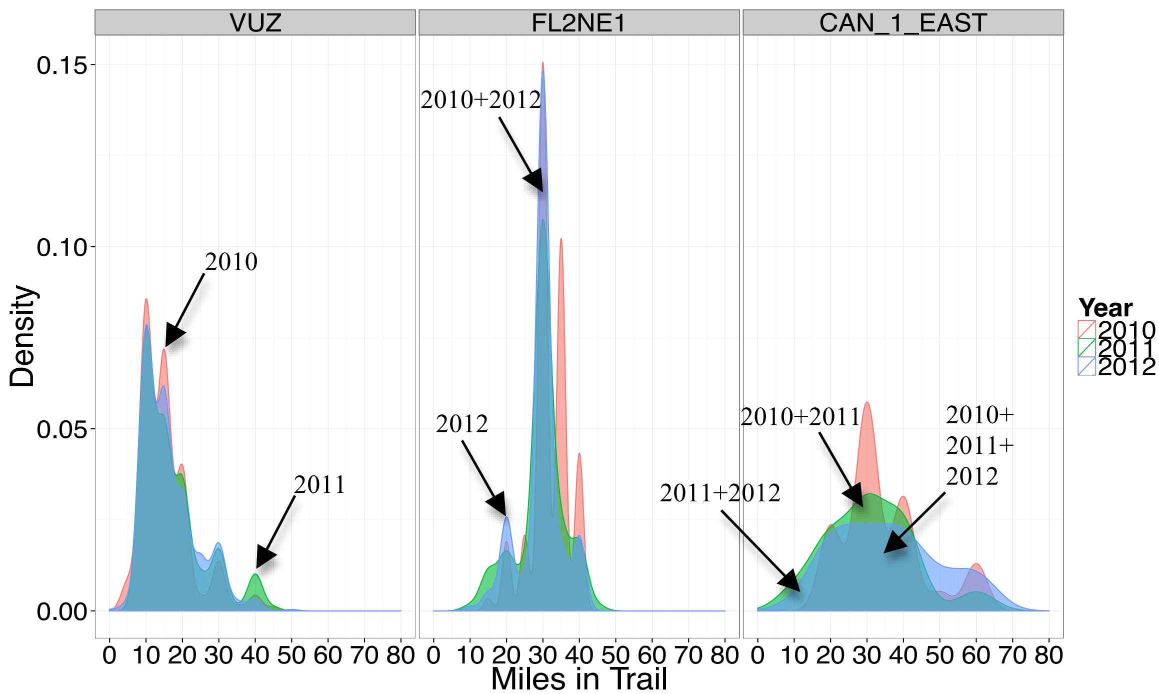

Figure 2. A comparison of top three restrictions applied to Playbook routes.

Often, the MITs are implemented in conjunction with severe weather avoidance plans or Playbook routes. When Playbook routes are implemented, traffic generally funnels through a catch and pitch point sequence of fixes. Within that segment, there is a high likelihood of sector congestion. Therefore, MITs are put in place to throttle traffic and avoid high sector congestion levels. Figure 2 shows a similar plot as Fig. 1 but for the most used Playbook routes. These are the Vulcan, AL (VUZ), Florida to North East (FL2NE1), and the CAN_1_East Playbook routes. These three routes are displayed in green in Fig. 3 below. Each of these routes is designed to take traffic from various parts of the country to the northeastern US airports. The colors are same as in Fig. 2, with 2010, 2011, and 2012 in red, green, and blue, respectively. As before, the overlaps of all three year values appear in gray, while overlaps of 2010(red)/2011(green) appear in yellowish color, 2011(green)/2012(blue) in cyan, and 2010(red)/2012(blue) in magenta. These colors are pointed out with arrows in Fig. 2 above. The VUZ route generally uses lower (10-15) MIT values while the FL2NE1 and CAN_1_East routes use higher (30 or more) MIT values. It appears that CAN_1_East continues to be used with larger MIT values across the years. Based on this, the CAN_1_East Playbook route and associated MIT restrictions are used as the primary example for this study, while the VUZ and FL2NE1 cases are presented with lesser detail. The results for the analysis are presented in Section V, after the modeling approach is described.

III. Simulation Environment

The FACET software developed at NASA Ames Research Center was used for this study. FACET is a modeling and analysis system developed to explore advanced ATM concepts. It handles traffic information at various spatial levels in the National Airspace System (NAS), from the Center and Sectors to individual aircraft trajectories. The simulation mode within FACET allows the user to take traffic initial conditions from a certain time. It evolves the air traffic based on the FAA's Enhanced Traffic Management System[9] (ETMS) provided air traffic data, consisting of flight plans that provide origin, destination, route of flight, aircraft type, cruise speed, cruise altitude and take-off time. The flight plan intent is used for assessing which flights would be impacted by the Playbook routes and associated MIT restrictions.

Figure 3 shows a snapshot of FACET graphical user interface. The 14 locations shown in Fig. 1 and 3 Playbook routes named in Fig. 2 are shown here. The Jet route J36 is shown in yellow. The Detroit airport arrival fixes POLAR, SPICA, and MIZAR are seen closely overlapped. Similarly, LGA, EWR, and JFK in the New York area are seen overlapped, along with the fix CAMRN. The VUZ, FL2NE1, and CAN_1_East playbook routes are shown in green, along with the combined Atlantic Routes (ARS) along the eastern seaboard. Some of the fixes associated with the CAN_1_East route, e.g., Aberdeen, SD (ABR) in Minneapolis Center (ZMP) and Rapid City, SD (RAP), Meeker, CO (EKR), Crazy Woman, WY (CZI) all three in Denver Center (ZDV), and Helena, MT (HLN) in Salt Lake Center (ZLC), are shown. Similarly, Vulcan, AL (VUZ), Little Rock, AK (LIT) and Sidon, MS (SQS) are shown along the VUZ green route, while Raleigh Durham, NC (RDU) and Flat Rock, VA (FAK) are seen along the Florida to Northeast (FL2NE1) green route. The 20 Center boundaries are shown in gray and the state boundaries are shown in red. Using the simulation capabilities of FACET, aircraft were flown along the specified route along with the imposed MIT values. These are described in Section V below.

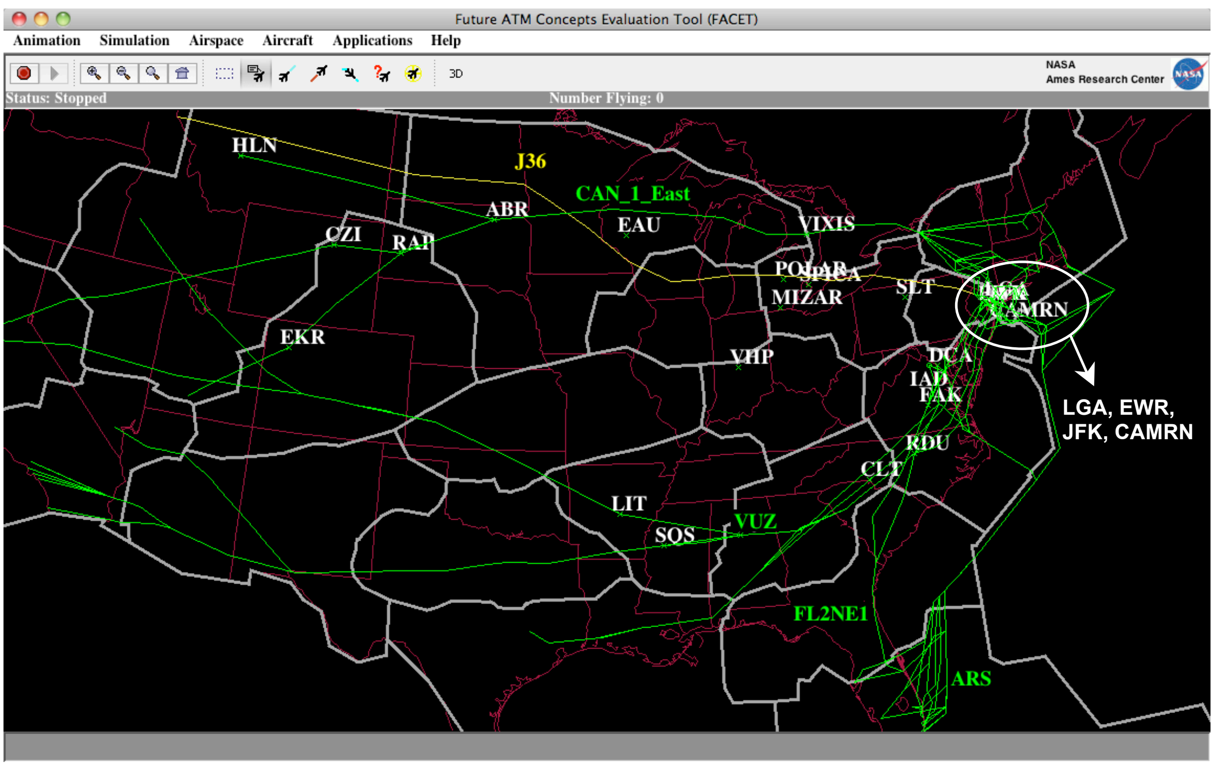

Figure 3. A snapshot of FACET graphical user interface showing the 14 locations from Fig. 1 and the 3 Playbook routes from Fig. 2.

IV. Modeling Approach

Previous MIT models in FACET[1,4] were enhanced with speed and vector control, and airborne hold modules. The new model can handle multiple merging streams, MIT values at multiple locations across those traffic streams, and optional passback to upstream Center. In today's operations, passbacks are restrictions that are requested by the current facility from upstream facilities. This request is made because the available controls are unable to absorb the delay required within the current Center boundary to meet the constraint. This feature allows the user to understand the impact of implemented MITs, in terms of the amount of delay and sector congestion along the way. In order for the simulation platform to be useful for what-if analyses, a rapid evaluation mode is employed in FACET. This allows a quick assessment of various scenarios of MIT constraints and locations. The approach is described next.

A metering constraint is modeled as an ordered list. It contains the name of the restriction, metered location, metered direction, aircraft spacing value, start time, end time, and an optional list of crossing boundary locations, which are used by the rapid evaluation mode (REM, described in IV.D below). The REM is employed to recommend passback values for upstream Centers. The metering constraint is said to be active during the time interval determined by the start and end times. Since the recorded data used for this study does not provide information if the aircraft were jets or propeller-driven, this model does not distinguish them. This may be a significant limitation and will be addressed in future work.

An FAA published restriction from July 3, 2012 for CAN_1_East Playbook route contained the following: "CAN1, 15:45-03:00 UTC, ABR, 40MIT, ZMP, ZDV, JETS, Reason: Vol Enrt Sctr". This indicates that Minneapolis Center (ZMP) requested Denver Center (ZDV) for 40 MIT for ABR fix for jets from 15:45 to 03:00 (next day) UTC. Figure 4 shows the schematic of the metering constraint model for such a constraint along the CAN_1_East Playbook route. There is a 40 MIT restriction at Aberdeen (ABR) located in ZMP for aircraft flying east. There are two streams merging at Aberdeen, one from Helena, MT (HLN) located in Salt Lake City Center (ZLC) and the other from Rapid City, IA (RAP) located in ZDV. Normally, the stream coming from ZDV has a higher stream rate than the one coming from ZLC into ZMP. The streams are represented by dashed lines and their typical traffic flow or stream rate by unfilled triangles. In order to prevent sector congestion (as per the posted restriction, Vol Enrt Sctr, meaning Volume Enroute Sector) and other traffic flow management issues near ABR, boundary crossing locations, represented by brown lines orthogonal to the dashed lines, are used to measure and control stream rates. These boundary crossings allow instantiation of passback restrictions per stream.

An aircraft is considered to be subject to metering, if it is predicted to pass through the metered location in the specified metered direction when the metering constraint is active. For example, aircraft f1, f2, and f3, depicted by blue filled triangles will be metered by the metered aircraft scheduler (see IV.A below) on a first-come, first-served basis. Aircraft f1will be scheduled as is, since there are no other aircraft ahead of it, while f2 and f3 will be required to slow down. Further, f3 may be held (by vectoring or in a holding pattern), depending on its performance capability for speed reduction. Currently, each of the (brown) boundaries are considered independent. However, it is plausible for multiple streams routing aircraft from several boundaries (belonging to same Center or different Centers) to the same metering constraint (e.g., ABR), to be combined into one boundary for flow rate calculations. This is being considered as an enhancement to this model for future work. Also, increasing speed of aircraft is not permitted in the current model and will be addressed in the future.

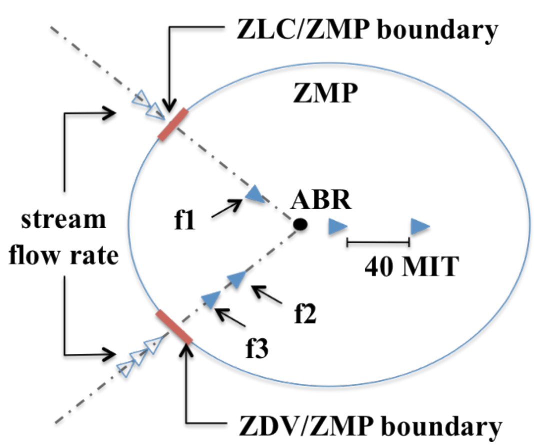

Figure 4. Schematic for the metering constraint model as applied to the CAN_1_East Playbook route. The merging of streams is shown from two upstream Centers (ZLC and ZDV) at ABR fix.

Figure 5 shows the display within FACET for a simulation run with the implemented constraints. The metering constraint model used to simulate air traffic along the CAN_1_East Playbook route in FACET. Four boundaries (similar to brown bars in Fig. 4) are used to meter traffic across Center boundaries, two from ZLC to ZDV, one from ZLC to ZMP, and one from ZDV to ZMP. These are shown with four thick light green bars in the figure. The aircraft affected by the constraints of the playbook route and metering are seen as yellow triangles close to the green playbook route lines.

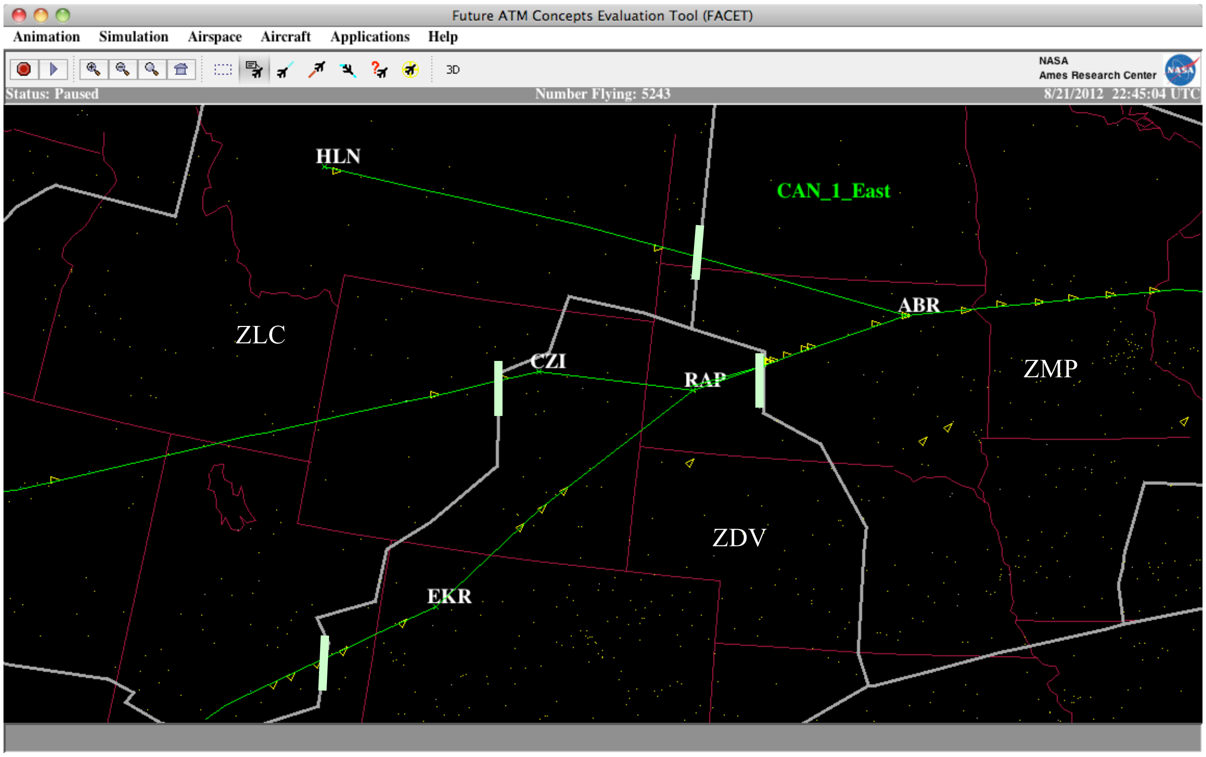

Figure 5. The metering constraint model as applied to the CAN_1_East Playbook route. Four boundary-crossing lines are shown as green bars for traffic. Two boundaries for traffic from ZLC to ZDV, one from ZDV to ZMP, and one from ZLC to ZMP.

A. Metered Aircraft Scheduler

The metered aircraft scheduler is responsible to ensure all metered aircraft comply with the inter-aircraft spacing at the metered location, e.g., ABR. The required distance is achieved through speed adjustment, distance adjustment (e.g., vectoring), holding, or a combination of all. If system operations require, ground delay can additionally be imposed on a metered aircraft that has not yet departed. In this study, metered aircraft are classified into three types: IC, for In-Center flying metered aircraft, within the Center containing the metering constraint; OC, for Out-of-Center flying metered aircraft, outside the Center containing the metering constraint; and NB, for Not-through-Boundary metered aircraft, not passing through any specified boundary.

At each minute from start time of the constraint, the metered aircraft scheduler first attempts to meter type IC aircraft by adjusting the aircraft's speed up to a fraction of the nominal cruise speed. For this study, the minimum fraction used was 0.86. If this is not sufficient, then a holding pattern is also imposed. Once all type IC aircraft have been scheduled, the scheduling of type OC aircraft starts around them. For type OC aircraft, metering can start in any of the Centers along the aircraft's flight plan, from the aircraft's current location up to the metering constraint, depending on passback values. Similar to scheduling of type IC aircraft, the scheduling algorithm starts with the Center that contains the metering constraint. When it is determined that an aircraft cannot be scheduled from a Center through speed adjustments, a passback to the upstream Center along the aircraft's flight plan is used to lengthen the distance within which the aircraft is constrained. If the aircraft cannot be scheduled through speed adjustments and passbacks, a holding pattern is imposed until the aircraft can comply with the inter-aircraft spacing. Finally, type NB aircraft are scheduled in a similar manner as type OC aircraft. Airborne holding is used for in-flight aircraft and ground delay is used for aircraft that have not yet departed. This process is repeated next minute until all aircraft are scheduled or the end time is reached.

B. Speed Adjustment

In this study, speed adjustment is used to slow down an aircraft up to 86 percent of the aircraft's nominal cruise speed. The required average speed for the i^{th} aircraft is calculated as follows:

$$Speed(i) = D_{mc} / ((eta(i) + dt(i)) - tstart)$$

where,

D_{mc} is the distance to the metering constraint (from current location of the aircraft),

eta(i) is the estimated time of arrival at the metering constraint of the scheduled aircraft that is ahead of this i^{th} aircraft,

dt(i) is the time interval for the i^{th} aircraft being scheduled to travel the mile-in-trail distance at the average speed required to trail the scheduled aircraft ahead of this aircraft, and

tstart is the time this aircraft enters the Center containing the metering constraint.

C. Aircraft Holding

An aircraft enters in a holding pattern when an extra distance is required to comply with the metering constraint. This holding can be achieved by vectoring in the available airspace or racetrack like holding patterns. In this particular case, the i^{th} aircraft holding time is calculated as follows:

$$Holding(i) = eta(i) + dt - orig_{eta}$$

where,

eta(i) is the estimated time of arrival at the metering constraint of the scheduled aircraft that is ahead of this i^{th} aircraft,

dt is the time interval for the i^{th} aircraft being scheduled to travel the mile-in-trail distance at the previously predicted speed, and

$orig_{eta}$ is the original estimated time of arrival to the metering constraint.

D. The Rapid Evaluation Mode (REM)

In order to prevent excessive aircraft holding and sector overloading near a metering constraint, passbacks are usually requested to upstream Centers. However, passback values are highly sensitive to traffic patterns, and demand-capacity imbalances. That is, historical passback values might not work the way they did in the past and shifting traffic patterns create the need to revise those values. The REM is an iterative process capable of determining a passback value per traffic stream at the Center boundary, while enforcing the metering constraint. In addition, the REM can be used to evaluate the efficiency and validity of historical passback values for specific scenarios. The method for simulation of assignment of schedules described in this section, is completed in less than ten seconds for a seven-hour period.

The REM takes as inputs a metering constraint containing a list of boundary crossing locations, as well as current and predicted traffic for a specific period of time. The boundary locations are meant to intersect a traffic stream at the Center boundary, since they are used by the REM to define the passback values. The REM outputs a list of time-ordered passback values in the form of MIT value, start-time, and end-time for each boundary crossing location. These recommended passback values provide stream predictability and reduce aircraft holding at the Center, potentially reducing the need for additional constraints in the system.

The REM consists of two phases. First, in the initialization phase, all metered aircraft are flown unconstrained in simulation mode and they are tagged with the time and boundary they traversed. With this information, the crossing rate for each boundary location is calculated in 15-minute intervals. Finally, all boundary crossings initialize their MIT value to zero. The start and end times are set to the metering constraint start and end times. Second, in the scheduling phase, the REM uses the metered aircraft scheduler (described in IV.A above) to iteratively schedule metered aircraft in a time ordered fashion as follows: after type IC aircraft are scheduled and when a type OC or type NB aircraft that received a holding or ground delay traverses a boundary crossing at time t, the boundary crossing with the highest crossing stream rate in the last 15 minutes within the Center is selected. For the selected boundary crossing associated with the current MIT, set the end time to t. A new entry with the MIT value incremented by 5 nmi is added to the list. For this entry, the start time is t and the end time is the metering constraint end time. All type OC and type NB aircraft with boundary crossing times t and later are reset to original schedule, and the scheduling process for these aircraft is restarted. If no type OC or NB aircraft received holding or ground delay, the MIT value is decremented by 5 nmi to assess if the aircraft can be scheduled with a lower MIT value. The scheduling phase terminates once all metered aircraft are scheduled. Since time advances after every iteration, termination is guaranteed.

Fig. 6 shows one solution of this iterative nature of REM. The specific case illustrated is for the MIT value at Rapid City streaming aircraft to Aberdeen. The imposed constraint at ABR is 35 MIT for aircraft heading to downstream fixes along the CAN_1_East route. It can be seen that the passback value starts at zero initially. As more aircraft are scheduled, at about 17:20 UTC, the inter-aircraft spacing required is about 280 nmi for one minute, after which, the MIT value drops down to 35 nmi. (The 280 nmi value is prescribed to give only the current aircraft distance behind its predecessor aircraft downstream.) The reduction is imposed since there are no aircraft that experience holding or ground delay. At the end of REM process, all the values in this graph are sorted. The top 25% of the values are stripped and the median of the remaining values is selected as the passback MIT value for that boundary. For the case illustrated in Fig. 6, that value is 35 MIT. This process is followed for each stream and their passback values are computed.

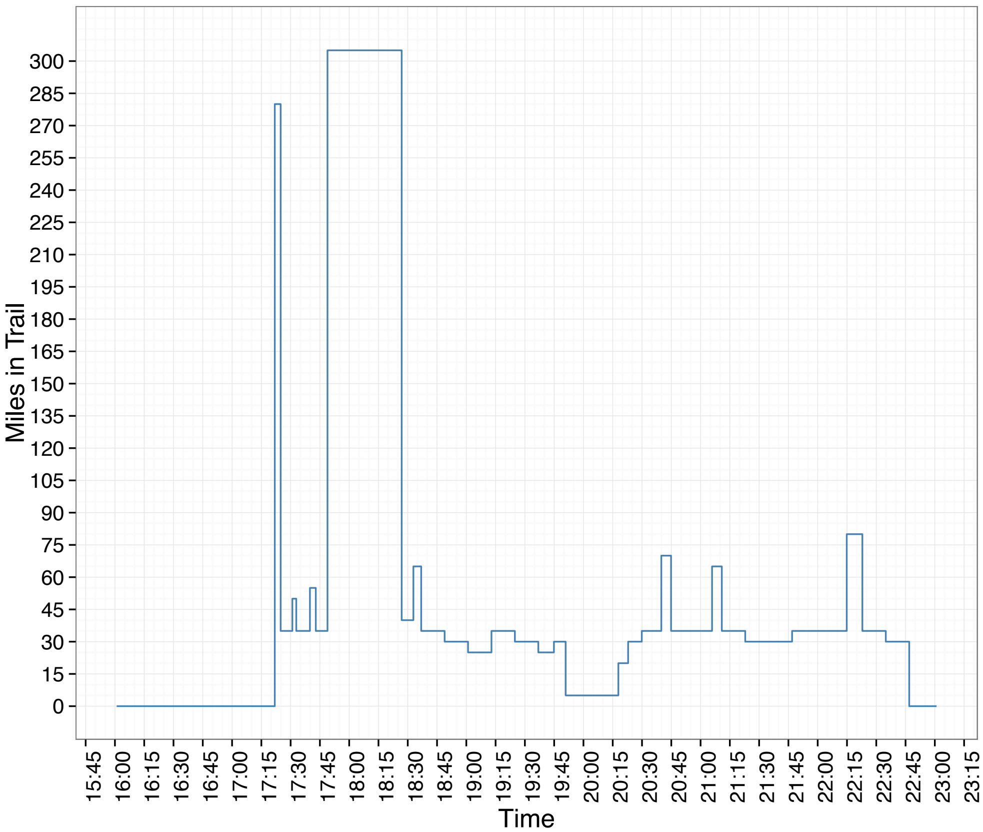

Figure 6. One solution of the iterative second phase of REM for MIT passback values at RAP for a 35 MIT restriction implemented at ABR in conjunction with CAN_1_East Playbook route.

V. Modeling Results

In order to study the robustness of the new multiple merging streams model with passback values, three of the most-used Playbook routes described in Fig. 2, were applied to traffic. Then, MIT restrictions were implemented at various locations on the routes. The flight delay values and sector congestion were monitored for each of the cases. A description of the specific case and corresponding results are presented in the rest of this section.

A. The CAN_1_East Playbook Scenario

The CAN_1_East Playbook route was operationally implemented on August 9, 2012, among many other days. In conjunction with the playbook route, 30 MIT were implemented for all flights going from Aberdeen, SD (ABR) to VIXIS on their way to the east coast destinations from 18:30 UTC until 02:30 UTC the following day. It was not obvious from the implemented restrictions data if passback values were used that day. Since Thursday, August 9, 2012 recorded data had the restrictions already embedded, unperturbed data from the previous and next week were searched to see if CAN_1_East was employed. It was found that CAN_1_East was used on July 31 (previous week), and August 14 (following week). Subsequently, CAN_1_East was not used Tuesday through Thursday, August 21 through 23, 2012. Therefore, those days' data were selected for analyses presented here.

1. Passback Restriction Values

Table 1 presents the results of the analyses. The time of implementation of the initiatives in FACET was between the hours of 16:00 and 23:00 UTC. The start time is different from the times on August 9 because some amount of startup traffic was needed to implement the restrictions. The end time is shorter because the simulation data ended at 23:59 UTC. The model was used to implement MIT restrictions at ABR from 10 to 50 in increments of 5, as presented in column 1. In order to manage this restriction, additional passback values were obtained using the metered aircraft scheduler and the Rapid Evaluation Mode presented earlier. As mentioned previously, the values for passback restrictions depend heavily on the traffic patterns. Columns 2 through 4 (in blue) represent the data for August 21. Similarly, columns 5-7 (in brown) and columns 8-10 (in purple) represent the data for August 22 and August 23, respectively. Each day's data presents passback restriction values for the Rapid City (RAP), Crazy Woman (CZI), and Meeker (EKR) fixes (see Fig. 3). Aircraft from Oakland Center (the Northern California flights) arrive at RAP through CZI. Aircraft from Los Angeles Center (the Southern California flights) arrive at RAP through EKR. As is seen from Fig. 5 and is expected, the EKR stream has a higher flow rate than the CZI stream. Both these streams merge at RAP and then move on to ABR, where another stream from Seattle Center (the Northwest US flights) through Helena, MT (HLN) merges. The stream from HLN has much lower flow rate compared to the stream from RAP to ABR. For this study, initially HLN was included but later dropped due to this low stream rate.

Table 1: Computation of passback restrictions at three locations on three days.

Date	Aug. 21, 2012			Aug. 22, 2012			Aug. 23, 2012		
ABR MIT	RAP	CZI	EKR	RAP	CZI	EKR	RAP	CZI	EKR
10	10	10	0	0	0	0	5	0	0
15	15	15	15	10	0	0	10	10	0
20	20	20	20	20	20	20	20	25	5
25	25	55	75	20	20	20	25	30	20
30	25	55	75	25	25	20	25	30	20
35	35	80	90	30	35	70	30	55	65
40	40	250	100	40	70	75	35	70	70
45	45	250	100	50	90	100	45	45	110
50	50	225	110	50	55	110	50	50	110

As can be seen from Table 1, the MIT passback values vary significantly as the traffic patterns change from day to day, Tuesday through Thursday in this case. It is observed that for MIT of 40 nmi at ABR (column 1), the passback values turn out to be very large (225 to 250) for CZI on Aug. 21 but are about a third or less on the other two days. In general, the values of 40 to 50 MITs at ABR are used infrequently but are presented here to report results of the modeling process. Currently, it is difficult to judge if the model, as implemented, is working well and therefore to ascertain goodness, operational feedback is being sought. However, as mentioned earlier, the results are sensitive to traffic patterns so there is no 'best' set of passback values. Since it was not known what other traffic management initiatives were used or whether there were passbacks used on August 9, current results were not compared with August 9 data. In all, between 50 to 100 flights were involved from 10 to 20 different flight operators on those 3 days.

2. Flight Delays and Sector Congestion

The results presented in Table 1 are for the implemented MIT restriction at ABR and the corresponding computed passback restriction values for the three corresponding fixes feeding traffic to ABR. It is possible to compute the delay values for the case where the restriction is completely absorbed by ground delay, rather than a combination of speed/vector control, airborne holding, and ground delay. Figure 7 (green curve, ABR_P) presents results for this limiting simulated case of highest delays. The delay values shown here are the total delay values and no distinction between ground delay and airborne delay is attempted. In the top half of Fig. 7, the flight delay values are shown as a function of increasing MIT values at ABR for August 21, 2012. The bottom half represents the number of one-minute instances when any high altitude Sector went over capacity along the CAN_1_East route from the west until ABR. Over the capacity is defined as the number of aircraft in excess of the nominal monitor alert parameter for that Sector. There are four curves shown. The limiting case is shown in green (ABR_P) for passback of restriction all the way to the departure airport. The cases where no further restrictions are passed back from a certain fix are represented by the other three curves. The orange, blue and purple curves represent the cases for no-further-passback restrictions implemented for ABR (ABR_NP), CZI and EKR (CZIEKR_NP), and RAP (RAP_BDRY) only. The delay for the green curve is the highest, as expected because no airborne holding and no speed reduction are implemented. The rest of the curves represent the delay based on the distances available for absorption of the MIT restriction. The most important feature to notice is that the sector congestion and delay values are simultaneously low between 25 and 35 MITs at ABR. After a value of 35 MIT restriction, the delay values and the sector congestion, both significantly increase. The main reason for these high values is that the spacing required by the imposed constraint starts interspersing with the schedule of traffic along several controlled streams and traffic going to ABR outside of the controlled stream boundaries. The right side of Fig. 7 is explained next.

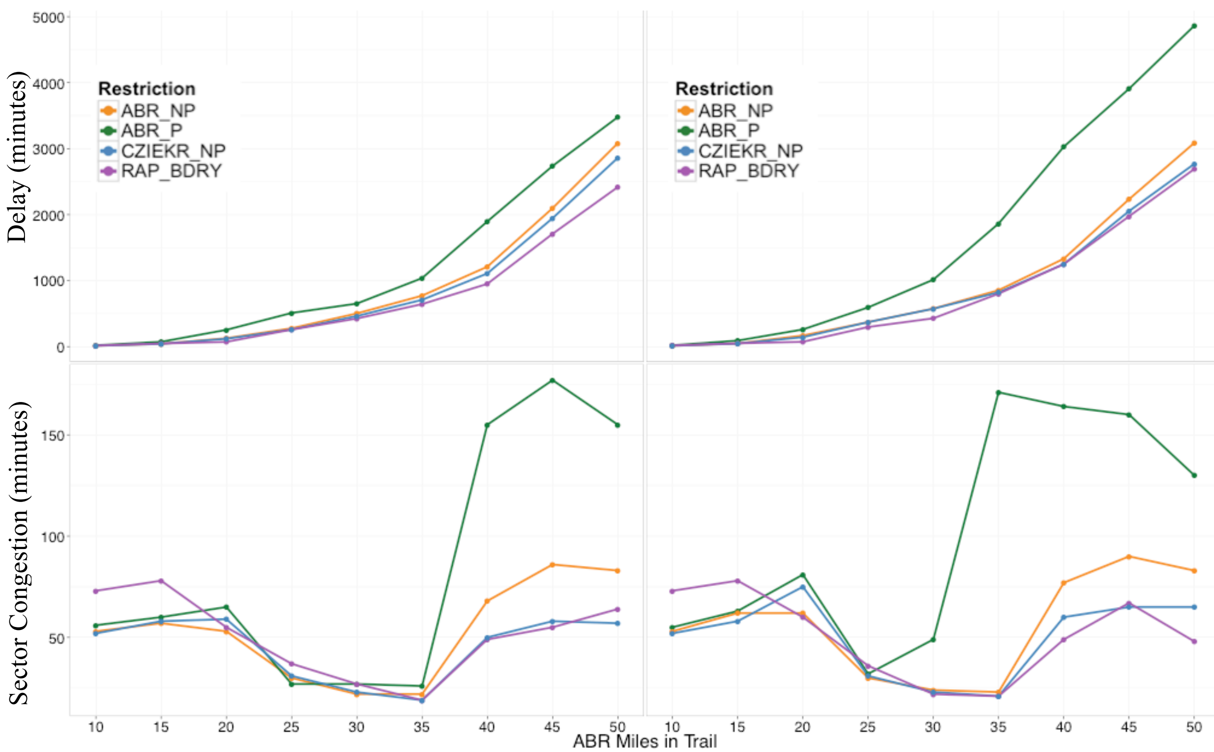

Figure 7: Delay and Sector congestion results for CAN_1_East scenario.

3. Speed Control

Table 1 above represents the values where the speed reduction, as mentioned earlier, was a maximum of 86% of the nominal cruise speed. Results shown in left half of Fig. 7 are for this speed reduction case. In order to understand the behavior of the modeling process, the speed was allowed to be reduced to an arbitrarily chosen value of 75% of the nominal cruise speed. This may not be possible for all aircraft, however, the model behavior would be similar if traffic managers are able to absorb the delay by more airborne holding for type OC and NB aircraft. The right half of Fig. 7 represents the results for this additionally reduced speed case. As expected, the green, ideal case curve has much larger delay, since the speed is allowed to further reduce by 11% compared to the Fig. 7 left case. It should be noted that all of Fig. 7 results are for multiple merging streams and therefore the complex traffic pattern plays an important role. The orange curve does not change by definition, since all of the metering happens upstream of ABR in both cases. The blue and purple curves have small changes since the only change is the 11% speed reduction between Fig. 7 left and right.

B. The FL2NE1 and VUZ Playbook Scenarios

The Playbook route Florida to North East (FL2NE1) delay results are shown on the left of Fig. 8. In Fig. 8 right, the Vulcan, AL, (VUZ) Playbook route delay results are displayed. These results are for all the traffic on August 21, 2012 with the FACET simulation running from 16:00 through 23:00 UTC. It was observed in both of these playbook routes that no sector congestion was observed upstream of the considered fix due to the amount of space available for absorbing the delays with 14% speed reduction. The FL2NE1 route has the entire east coast for delay absorption while the VUZ route has most of the west to east southern US airspace available for absorbing delay. Thus, the observed delay values are high but there is not a significant impact on sector congestion. This could be improved by computing an appropriate trade-off between total delay and sector congestion at appropriate fixes in a future version of this model.

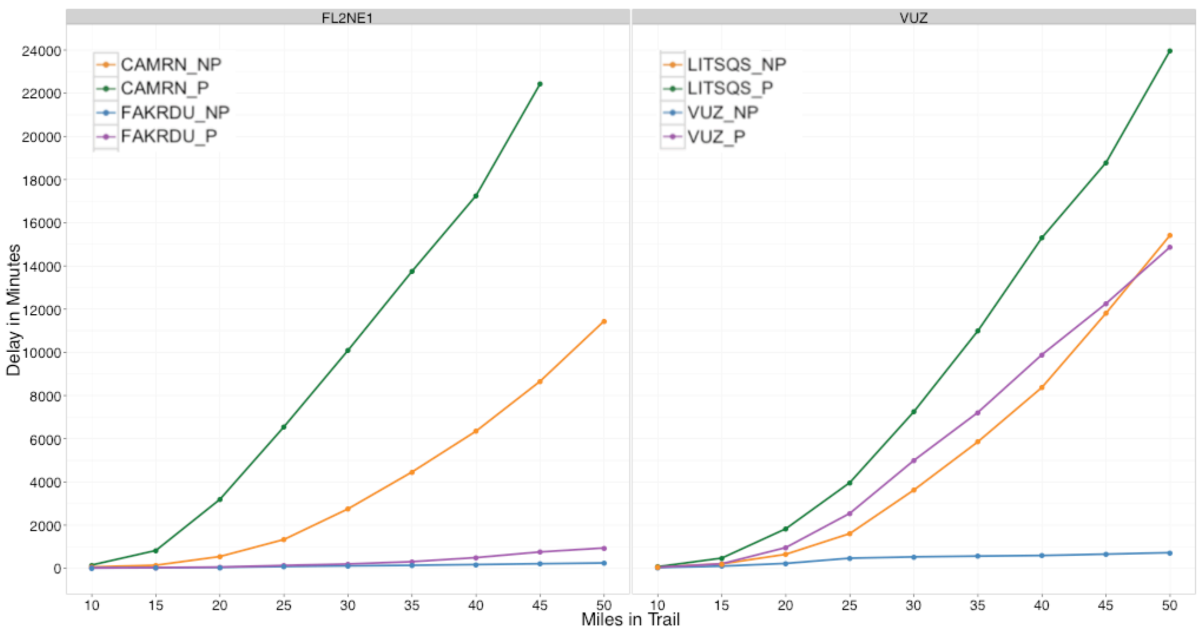

Figure 8: Delay results for Vulcan (VUZ) and Florida to North East (FL2NE1) scenarios.

The Florida to North East (FL2NE1) Playbook is a Regional route, which carries traffic from every Center along the east coast of United States. It traverses all southeastern traffic from Miami and Jacksonville Centers along a single route until Florence, SC (FLO). It funnels all of this traffic to Raleigh Durham, NC (RDU) and Flat Rock, VA (FAK) then directs the traffic to destinations in the northeastern United States. In order to implement the MIT restrictions for FL2NE1, RDU and FAK were chosen for implementing passbacks. This route is often used for John F. Kennedy International Airport, NY (JFK) and other New York area airports, with CAMRN as the transition fix. The left part of Fig. 8 shows the delay curves for both CAMRN and FAK/RDU passbacks to the origin airports using green (CAMRN_P) and purple (FAKRDU_P) curves. The FAK/RDU curves have minimal delay because there is not much traffic until those fixes, and most of the other traffic joins after those two fixes. Consequently, the CAMRN curves have high delay because most of the traffic funnels through there. Experimenting with other fix locations along the route and operational feedback may shed more light on the passback and delay values.

The VUZ Playbook is a West to East Transcontinental route, which carries traffic from every Center west of Chicago except Minneapolis, and merges various streams at various locations. It funnels all of this traffic through Vulcan and then carries the traffic to destinations in the northeastern United States. In order to implement the MIT restrictions, VUZ, Little Rock, AK (LIT) and Sidon, MS (SQS) fixes were chosen for passback computation. The right part of Fig. 8 shows the delay curves for both VUZ and LIT/SQS passbacks to the origin airports using green (LITSQS_P) and purple (VUZ_P) curves. The VUZ no-further-passback blue curve has minimal delay because of the delay is being absorbed by LIT and SQS streams, and there is not much other traffic joining after those two fixes. Consequently, the LITSQS no-further-passback orange curve has high delay. In hindsight, maybe further-west fix locations along those streams and operational feedback may have shed more light on selection of fixes, and the passback and delay values.

VI. Concluding Remarks

In this paper, analysis and modeling of Miles-in-Trail (MIT) restrictions is presented. Statistics for the Miles-in-Trail restrictions and Playbook routes use for 2010, 2011, and 2012 years is described. The top ten fix MIT values were examined from each year to see how the location and frequency changed over the three years. From the data, it was observed that the locations and values of MITs vary as a response to changing traffic and airspace constraints. Along with the MIT values, statistics for three most used severe weather avoidance plans or Playbook routes across those years were described as well.

An enhanced MIT model with speed/vector control along with airborne holding and ground delay is presented. The main contribution of this paper is in the implementation of this model with MIT passbacks to the upstream facilities (Centers). In particular, the CAN_1_East Playbook route with MIT values at Aberdeen (ABR) and associated fixes was simulated within the FACET simulation environment. Additionally, two other Playbook routes, namely, the Vulcan transcontinental west to east route and Florida to North East regional east coast route, were simulated with associated fixes along the way for varying MIT values.

The implementation of these restrictions in FACET testbed allows a user to study the delay and sector congestion values with varying MIT restrictions and passback values. At the current time, a modeling capability that suggests passbacks to upstream facility does not exist for operational use and the FAA is looking for such modeling solutions. The current implementation provides a what-if analysis capability where multiple options can be quickly evaluated for impact of implementing reroutes and MITs at various locations with merging streams of traffic. The Rapid Evaluation Mode employed for this method allows the computations of results in under ten seconds. Preliminary results suggest that implementing passbacks in a simulation environment is complicated, and counter intuitive sometimes. The need for operational feedback for implementation of these cases becomes essential for real cases.

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