AIAA 5th Aviation, Technology, Integration, and Operations Conference (ATIO) <br>
26 - 28 September 2005, Arlington, Virginia

AIAA 2005-7301

# The Effects of the Uncertainty of Departures on Multi-Center Traffic Management Advisor Scheduling

Jane Thipphavong* and Steven J. Landry*
*NASA Ames Research Center, Moffett Field, CA, 94035*

**The Multi-Center Traffic Management Advisor (McTMA) provides a platform for regional or national traffic flow management. It allows long-range, cooperative, time-based metering to constrained resources, such as airports or air route traffic control center boundaries. Part of the demand for resources is composed of proposed departures, whose actual departure time is difficult to predict. For this reason, McTMA does not schedule the departures in advance, but rather relies on traffic managers to input their requested departure time. Because this action occurs only a short time before the aircraft's actual departure, McTMA may be unable to accurately predict the amount of delay airborne aircraft need to accommodate the departures. This study provides a preliminary analysis on the effects proposed departures have on airborne delay for a 400 nautical mile metering horizon. Results indicate that within this range, delays needed by airborne aircraft to accommodate these proposed departures are feasible for controllers to handle. However, McTMA needs to be extended beyond its current metering limits to support traffic flow management nationwide. As the metering horizon increases, the proportion of demand that is comprised of such proposed departures increases. Supporting data shows that a rise in the number of proposed departures worsens the effect on airborne delays.**

## I. Introduction

THE Multi-Center Traffic Management Advisor (McTMA) is an Air Route Traffic Control Center (or simply Center) decision support tool that provides scheduling advisories for arrival, en route, and departure aircraft. Researchers at the NASA Ames Research Center in cooperation with the Federal Aviation Administration (FAA) and MITRE's Center for Advanced Aviation System Development developed McTMA as an enhancement to the Single-Center TMA. Key innovative features include a new architecture to support a network of McTMA systems that can exchange data across many Centers. This architecture allows personnel at all Centers to collaboratively plan, negotiate, and implement efficient long-range scheduling plans for capacity-constrained airports. To accommodate the scheduling of aircraft spanning multiple Centers, a new scheduling system called the distributed scheduler was developed. The approach makes use of a distributed network of loosely-coupled schedulers to distribute delay over a large area while mitigating errors in predicting trajectories over such distances.[1]

McTMA uses flight plan, track, weather, and controller input data to create time-based metering schedules. Time-based metering is a traffic management technique that assigns crossing times for aircraft at points along its route of flight to manage the flow of traffic into a constrained resource, such as an airport.[1] McTMA assists in determining crossing times to create an efficient and orderly traffic flow and maximize the utilization of the constrained resource. Schedule information is displayed in the Traffic Management Unit (TMU), and advisories are displayed at the appropriate sectors to inform the controllers of how much delay each aircraft needs to take (or "absorb") in order to conform to the scheduled times.[2] If the delay required to meet a scheduled time exceeds what the sector can handle, the excess delay is allocated to upstream sectors in the same Center and, if necessary, adjacent Centers. By absorbing delay at upstream facilities, workload at the Terminal Radar Approach Control (TRACON) is reduced. As a result, McTMA reduces miles-in-trail restrictions, increases airport utilization, and reduces airborne holding without compromising safety.[2]

The delay times McTMA assigns to an aircraft to meet its scheduled time of arrival (STA) are based on the perceived future demand. Some of the demand may include aircraft that have not yet departed. Such aircraft are temporarily scheduled to depart at their proposed departure times (P-time) given by their flight plans. However, P-times are often erroneous,[3] resulting in inaccurate demand predictions and, consequently, inaccurate delays assigned

---

* Aerospace Engineer, Terminal Area Air Traffic Management Research Branch, Mail Stop 210-6, AIAA Member.

to airborne aircraft. When an airborne aircraft are assigned more delay than necessary, the airport may be underutilized. In contrast, if too little delay is assigned, then the airspace near the airport may be overloaded. This could lead to longer final approaches or airborne holding. If the actual wheels-up times of departures were known beforehand, the delay needed by each aircraft can be predicted more accurately, allowing for a smoother flow into the airport.

This paper explores the severity of the uncertainty in departure times on the McTMA scheduler over a 400 nautical mile metering horizon. The next section illustrates various dimensions of the problem in greater detail. Section III outlines the methodology used to evaluate the situation. Lastly, sections IV and V discuss results obtained from the study and potential solutions to accommodate the findings from this analysis.

## II. Motivation

McTMA's architecture facilitates communication across multiple Centers, providing relevant data for scheduling aircraft between Centers. Taking advantage of this capability, McTMA may eliminate ground stops, where flights destined to an affected airport are held at their departure point because of congestion at the arrival TRACON. Ground stops are inefficient because when lifted, the previously held aircraft will add to the airborne traffic, which will again increase TRACON congestion, often leading to another ground stop. As an alternative to ground stops, the McTMA scheduling capabilities across Centers can assist in smoothly incorporating departures into the airspace, allowing for an orderly flow into the airport. As flights are integrated into the airspace, airborne aircraft often take on additional delay to accommodate the departures. The additional delay needed to accommodate the departures should not create excessive sector controller workload. Consequently, departures need to be scheduled early enough so that the appropriate delay can be distributed and absorbed over a longer range.

Ideally, automatically scheduling the departures in advance at their exact wheels-up time would yield the most accurate schedule, and the corresponding delay amounts could be suitably allocated. One problem is determining which departure time to use. A flight's proposed departure time (P-time) is given hours in advance by its flight plan. However, P-times are notoriously unreliable. Figure 1[3] shows the frequency of delays taken by proposed departures leaving Cleveland Center. The delay was measured by subtracting the departure's P-time from its wheels-up time. From Fig. 1, departures from Cleveland Center departed on average 21 minutes after their recorded P-time. Some flights have P-time deviations on the order of hours. Regardless, even a 5 minute deviation from the P-time could cause departures to either miss their slots, resulting in underutilized airports, or cause undue workload to the sector controller.[2]

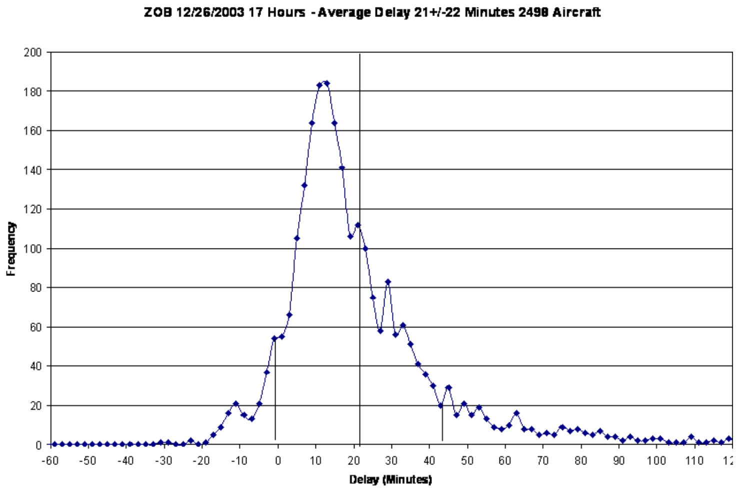

**Figure 1. Frequency of delays (in minutes) taken by proposed departures at Cleveland Center.[3]**

To further illustrate how these departures impact airborne traffic delays, a simplified example is provided in Figure 2. Figure 2 shows timelines typically used by Traffic Management Coordinators (TMCs) to determine aircraft estimated times of arrival (ETAs) and McTMA-produced scheduled times of arrival (STAs) to a particular location.[4] The current time begins at the bottom, and aircraft are situated along the timeline according to their calculated ETAs and STAs. For illustrative purposes, suppose airplanes require 3 minutes worth of separation between them. The airborne delays needed to heed this restriction are computed by subtracting the ETAs from the STAs and indicated in parentheses next to the aircraft identification (ACID) in the STA column.

In Fig. 2, suppose AC 1, 2, and 3 are airborne and AC 4 is a proposed departure with a P-time at 10:04. Consider Fig. 2a, where the proposed departure, AC 4, is scheduled at 9:00 using its P-time, 10:04. When AC 4 is scheduled, the appropriate delays (in minutes) needed by the airborne aircraft, AC 1, 2, and 3, are computed. An hour later, when the actual departure time is known with reasonable certainty, AC 4 is then rescheduled to reflect the updated situation in three possible scenarios as shown in Fig. 2b, 2c, and 2d.

Consider the three scenarios that could occur when a departure is initially scheduled at its stated P-time. The best situation occurs when the actual departure is its stated P-time as shown in Fig. 2b. Then, the airspace is efficiently utilized, and the delays originally assigned to AC 1, 2, and 3 are correct and fairly distributed across upstream sectors. However, as Fig. 1 indicates, it is often the case that an aircraft has a wheels-up time later than its P-time. Figure 2c depicts the situation where AC 4 has an actual departure time of 10:11, resulting in it being behind AC 3 in the schedule. Suppose that AC 3 has already taken the 4 minutes of delay to account for the anticipated delay needed when AC 4 was initially scheduled at its P-time, 10:04. The effect of the new departure time results in a missed slot and the airspace not being used as efficiently. In contrast, Fig. 2d illustrates the situation where AC 4 has a departure time earlier than its P-time. This bumped AC 2's STA so that an additional 3 minutes of delay had to be absorbed to accommodate AC 4. If AC 2 is close to the airport, the additional delay would need to be absorbed entirely within the terminal area sector immediately preceding the airport, without the help of upstream sector controllers. This likely would cause additional workload to the terminal sector controller, since the extra delay may not be easily absorbed. More drastic methods to slow the aircraft, such as airborne holding, may be needed.

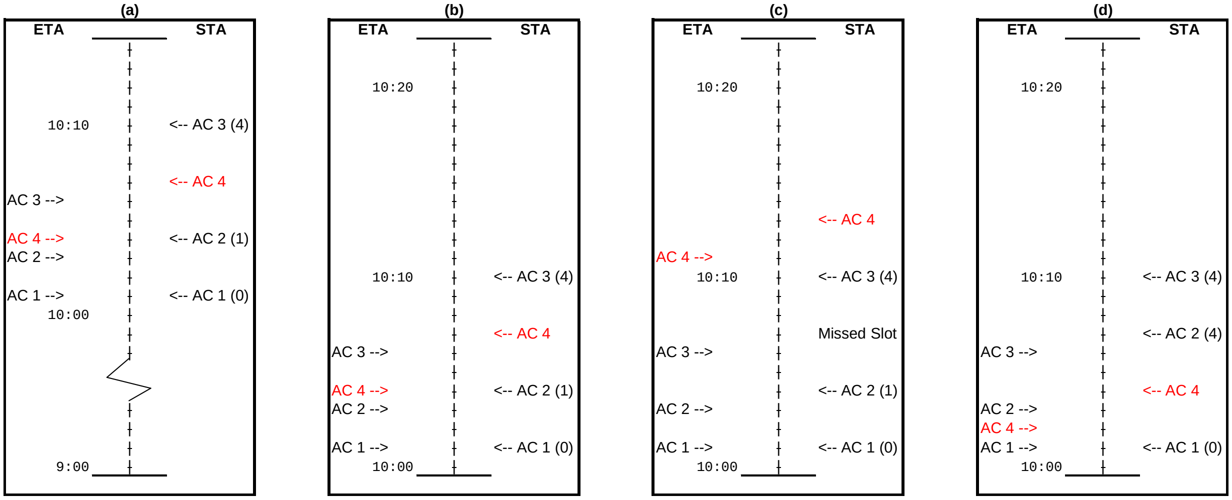

**Figure 2. (a) The departure, AC 4, is initially scheduled at its P-time, 10:04. (b) AC 4's actual departure time is at its P-time. (c) AC 4 is departing later than its P-time. (d) AC 4 is departing earlier than its P-time.**

In practice, P-times are not used by the TMCs since the uncertainty of the departure times create schedules that are unreliable. Instead, TMCs have opted to not schedule the proposed departures in advance, and then manually schedule the aircraft in McTMA when they are near their ready times. This process is part of the operational Approval Request (APREQ) procedure, which is used during busy periods to incorporate departures into the overhead stream. The procedure involves air traffic controllers at the Air Traffic Control Tower (ATCT) calling the Center TMC with a requested time of departure. The TMC manually schedules the departure in McTMA at its requested time to determine the soonest acceptable departure time for the aircraft that meets all restrictions on the stream of aircraft into which the departure will merge. This time is passed to the ATCT, which can accept the time or decline it (in which case some negotiation would take place). When the flight departs at the given time, airborne aircraft may need to be delayed to accommodate it. Since the requested time of departure is usually close to the actual wheels-up time, the delay needed by airborne aircraft often cannot be anticipated beforehand. For example, referring back to Fig. 2c, if the departure had not been scheduled beforehand, the delay assigned to AC 1, 2, and 3 would be 0, 1, and 1 minute respectively. That is, AC 3 would have been scheduled in the Missed Slot at 10:07. Then when the departing flight is assigned an APREQ time of 10:11, the delays assigned to AC 1, 2, and 3 would remain the same. However in Fig. 2d, when the flight is assigned an APREQ time at 10:02, the succeeding airborne aircraft ETAs are shifted later in time, resulting in increased delays that may significantly be more difficult for sector controllers to handle.

As the metering horizon increases, more departures make up the arrival demand, exacerbating the issue. This study investigated the severity of the effects on the airborne aircraft delays by departures. The goal was to quantify the accuracy of the delay assigned to airborne aircraft when: (1) scheduling the proposed departures in advance at their P-time, and (2) not scheduling the proposed departures in advance. The delays incurred by these two methods were then compared to the delays that the airborne aircraft actually needed. When too little delay is initially allocated to airborne aircraft, this may cause additional workload for sector controllers. In contrast, if excessive airborne delay is assigned, this could lead to inefficient use of the airspace as well as lower throughput to the airport.

## III. Method

McTMA was initially developed for Philadelphia International Airport (PHL), a busy northeast corridor hub airport. Facilities involved in the PHL arrival process include Boston Center (ZBW), Cleveland Center (ZOB), New York Center (ZNY), Washington Center (ZDC) and the Philadelphia TRACON as shown in Fig. 3. Together, the facilities cover a radius of approximately 400 nautical miles of metering distance into PHL. ETAs and groundspeeds of live data were collected from these facilities on June 30, 2004 starting at 11:00 (Live1), 15:00 (Live2), 17:00 (Live3), and 18:00 (Live4) Eastern Time, each dataset comprising approximately 1.5 hours. The start times were chosen to be at the beginning of a period when traffic into PHL becomes highly congested. Departures originated mainly from airports in ZBW and ZOB headed to PHL. In addition, two models of simulated traffic were developed with the same demand, but differing percentages of proposed departures. The datasets were labeled Model10 and Model20, having 10 and 20 departures respectively and spanning approximately 1.5 hours each. The P-times of the departures were randomly picked to be within the first hour, where most of the demand occurred. STAs were then calculated from the ETAs and groundspeeds for all 6 datasets so that aircraft were sequenced in a first-come-first-serve manner and separated by a 5 miles-in-trail restriction. Airborne aircraft and departures for each dataset are summarized in Table 1.

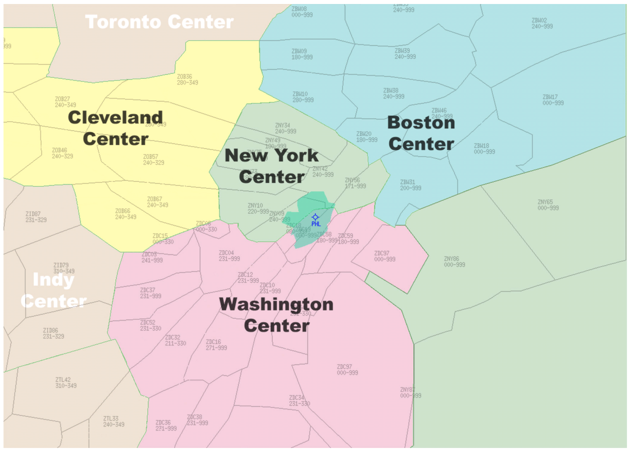

**Figure 3. Map of McTMA test sites.**

**Table 1. Mix of traffic for the datasets.**

| | Airborne Aircraft | Proposed Departures | Total Aircraft |
|---|---|---|---|
| **Model10** | 54 | 10 | 64 |
| **Model20** | 44 | 20 | 64 |
| **Live1** | 45 | 6 | 51 |
| **Live2** | 46 | 20 | 66 |
| **Live3** | 47 | 22 | 69 |
| **Live4** | 62 | 9 | 71 |

Two ways of accommodating the departures were evaluated: (1) scheduling the departures at their P-time, and (2) the current operational procedure, where aircraft are not scheduled in advance. In the first instance, Fig. 4a shows that at 9:00, the proposed departure, AC4, is scheduled at its P-time, 10:04. This causes the airborne aircraft, AC 1, 2, 3, 5, and 6, to incur some amount of delay to accommodate AC4. In the second instance, Fig. 4b shows that if AC4 is not scheduled in advance, the other aircraft incur delays that meet the miles-in-trail restriction without taking into account AC4.

The delays calculated for AC 1, 2, 3, 5, and 6 in Fig. 4a and 4b were then compared to the actual delays that these aircraft *should* have incurred. To calculate the actual departure times, a random amount of minutes normally distributed with mean and standard deviation of 20 minutes were added to the P-times. These parameters were taken from the study of departure uncertainty as shown in Fig. 1.

The timeline in Fig. 4c shows the timeline situation when AC 4 actually departs. In this example, AC 4's actual departure time is at 10:07, 3 minutes later than its P-time. When comparing the delays needed by airborne aircraft between Fig. 4c with 4a, AC 3 only needed 1 minute of delay rather than the 4 minutes of delay initially allocated to it. The rest of the aircraft have the same assigned delay. In contrast, when comparing Fig. 4c to Fig. 4b, AC 5 needed 3 additional minutes of delay to accommodate AC 4. As a result of AC 5's STA being delayed, AC 6 needed another minute of delay to adhere to the airspace restriction.

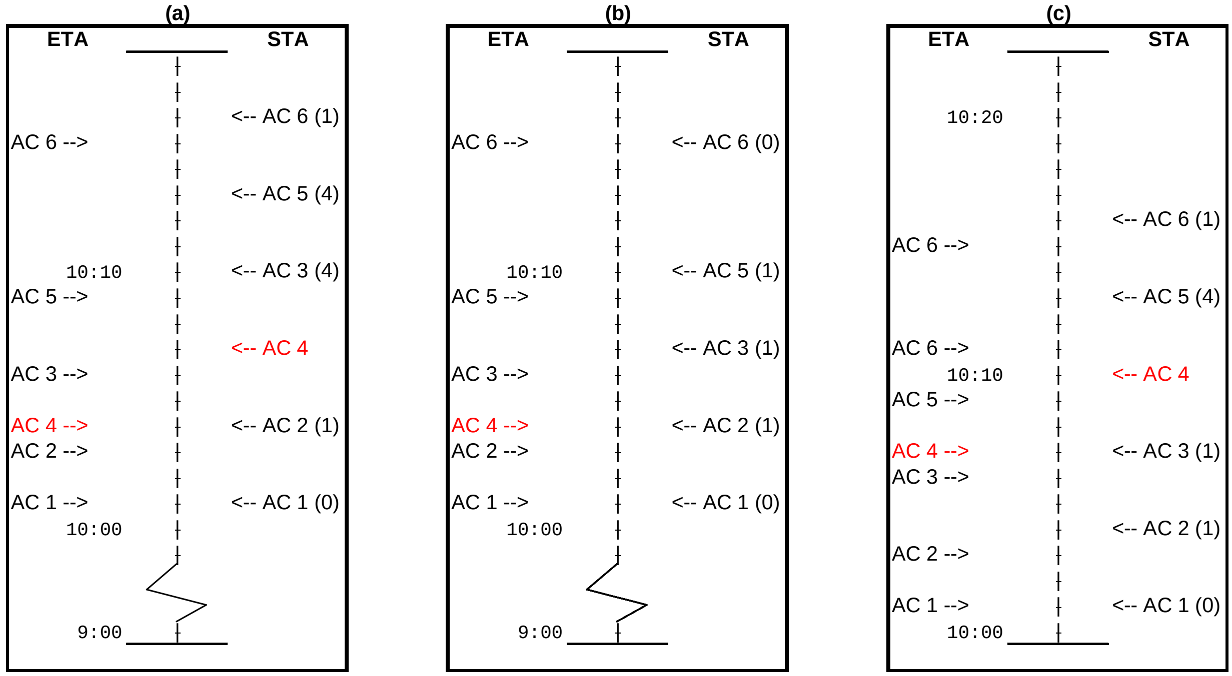

**Figure 4. (a) The departure, AC 4, is initially scheduled at its P-time, 10:04. (b) AC 4 is not scheduled in advance. (c) AC 4's actual departure time is at 10:09.**

To provide a metric of how well these two methods yield airborne delays (Fig. 4a and 4b) that are the same as the delays actually needed (Fig. 4c), the *delay difference* is computed for each airborne aircraft. The delay difference is calculated by subtracting the delays allocated by the two methods from the delays airborne aircraft should have taken. For example in Fig. 4a and 4c, the delay difference for AC 1 when AC 4 is scheduled at its P-time, is 0 (0-0) and likewise for AC 2, 5, and 6. A delay difference of 0 indicates that the delays that were initially allocated to airborne aircraft were correct when the time came to accommodate departures. AC 3 has a delay difference of -3 (1-4) minutes. A negative delay difference indicates that the airborne aircraft needed less delay to handle departures. Aircraft that take on unnecessary delay cause an inefficient use of the airspace and could also cause unnecessary delay for trailing aircraft. On the other hand, when comparing the delays assigned to airborne aircraft in Fig. 4b and 4c, AC 1, 2, and 3 have delay differences of 0 and AC 5 and 6 have delay differences of +3 (4-1) and +1 (1-0) minutes respectively. A positive delay difference indicates an aircraft needed more delay to handle the departures. Excess delay may cause excessive controller workload, especially in small or narrow sectors, where absorbing all the delay within the sector may not be feasible.

For each dataset in Table 1, the delay differences were calculated from a series of Monte Carlo simulations as described above. Then the delay differences for each airborne aircraft were averaged. Results from the study are discussed below.

# IV. Results

## A. Scheduling Departures at their P-times

Departures were initially scheduled at their P-times, and the delays needed by airborne aircraft for Model20 are graphed in Fig. 5. In addition, the demand profile is superimposed on the graph with its y-axis on the right. To calculate the demand for an aircraft, the number of airplanes within 5 minutes of its ETA was tabulated. The demand includes both airborne and proposed departures scheduled at their P-times. As Fig. 5 shows, the delays resulting from scheduling at P-times increases after the demand peak, since later airborne aircraft need to absorb a compounded amount of delay needed by all the planes before them. At a certain point, delays begin to decrease as later aircraft are spaced farther apart, absorbing some of the accumulated delay.

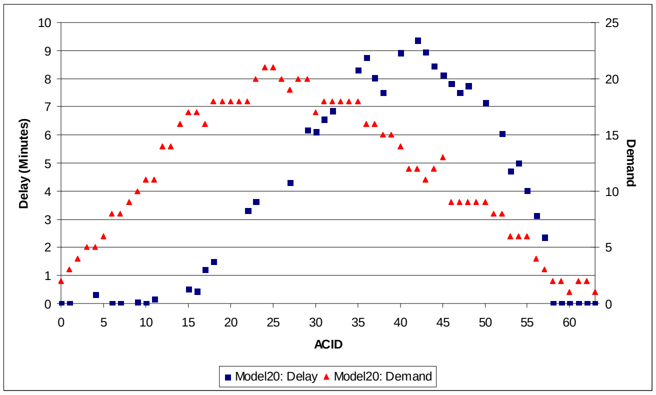

**Figure 5. Model20 demand and airborne aircraft delays incurred when proposed departures are scheduled at their P-times.**

Figure 6 shows the delay differences for the Model10 and Model20 datasets. The delay differences are the averages from the Monte Carlo simulations for each airborne aircraft. The associated ACIDs for the airborne aircraft are ordered from earliest to latest ETAs. Note that the time difference between tick marks may be uneven depending on the demand of the traffic.

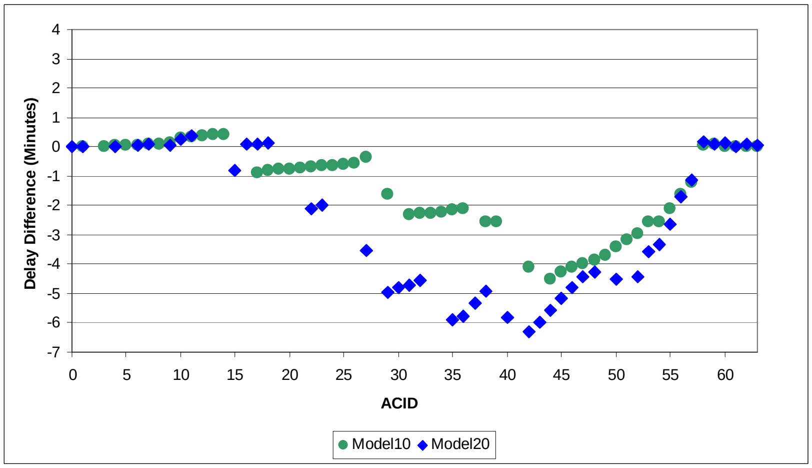

**Figure 6. Delay differences for Model10 and Model20 when scheduling proposed departures at their P-times.**

The trend from Fig. 6 indicates that the majority of airborne aircraft actually needed less delay than assigned when departures were scheduled at their P-time. This occurs because the proposed departures in Model10 and Model20 have actual wheels-up times that are often later than their P-times. Consequently, the airborne delays that were initially required to accommodate these departures at their P-times are no longer needed.

The largest delay differences occur around the same time as the largest airborne delay, since these airborne aircraft that initially had the largest amount of delay will have significantly less delay as the peak of the demand becomes less congested. These aircraft no longer need to absorb all the accumulated delay that was initially allocated. The airborne aircraft are now utilizing slots that have become vacant as a result of these departures not leaving at their P-times. Further in time, when the departures actually occur, the delay differences become less negative since airborne aircraft now need to accommodate the unexpected departures. In this case, the delay differences remain negative, since the negative airborne delay differences that occurred when departures did not leave at their P-times are greater than the positive delay differences needed to accommodate the actual departure times. At the beginning and end of the traffic period when demand is low, airborne aircraft are separated far enough to easily accommodate the proposed departures. Hence, the departure delays are only slightly positive.

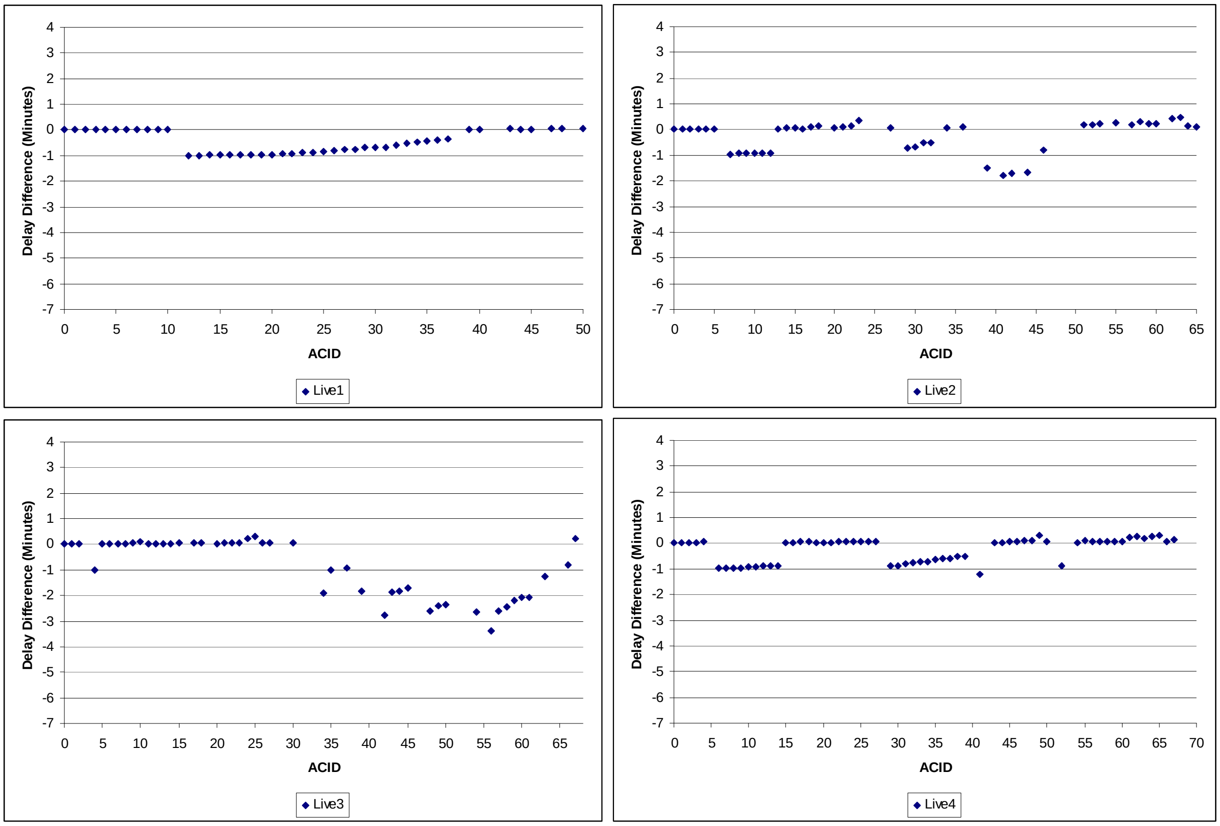

**Figure 7. Delay differences for Live1, Live2, Live3, and Live4 when scheduling proposed departures at their P-times.**

Figure 7 shows the delay differences for each live data set. Absolute delay differences were generally lower than Model10 and Model20. Among all the live datasets, Live3 had the highest delay differences. Some delay differences are over three minutes, indicating that some inefficiency of the airspace may occur. This is less than what Fig. 6 shows, where delays could be as high as six minutes. Airborne aircraft having significant negative delay differences is a concern since slots to the runway are unused, resulting in lower airport throughput.

### B. Not Scheduling the Departures in Advance

Instead of scheduling proposed departures at their P-times, the current practice is to not schedule them in advance. Later, when their APREQ times are known, the proposed departures are then scheduled in McTMA. APREQ times are not given until departures are near their wheels-up times, so airborne aircraft delay cannot be anticipated in advance. Consequently, this is equivalent to studying the difference in delays assigned to airborne aircraft when the departures are not scheduled beforehand versus the delays incurred when the departures actually depart.

Figure 8 shows the delay differences and the demand for Model10 and Model20. Here, the delay differences are all non-negative, since airborne aircraft can only be subject to additional (not lesser) amounts of delay to accommodate the departures. Since departures usually have wheels-up times that are later than P-times, many departures having P-times in the demand peak now have actual departure times that lie where the delay difference peaks. The delay difference peak is approximately 20 minutes away from the demand peak since the actual departure time was computed by adding to the P-time a random number of minutes normally distributed with mean of 20 minutes. The delay difference declines since the number of departures have decreased and airborne aircraft are separated sufficiently to incorporate departures more easily. Analysis of the live data sets in Fig. 9 show most delay differences within one minute.

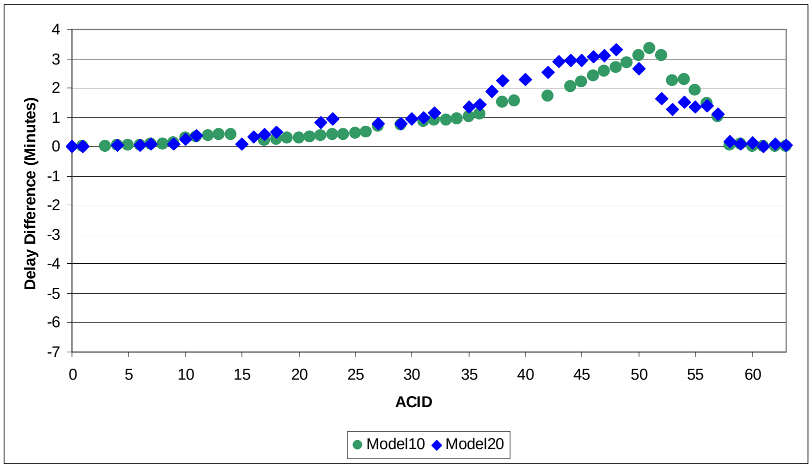

**Figure 8. Delay differences for Model10 and Model20 when not scheduling proposed departures in advance.**

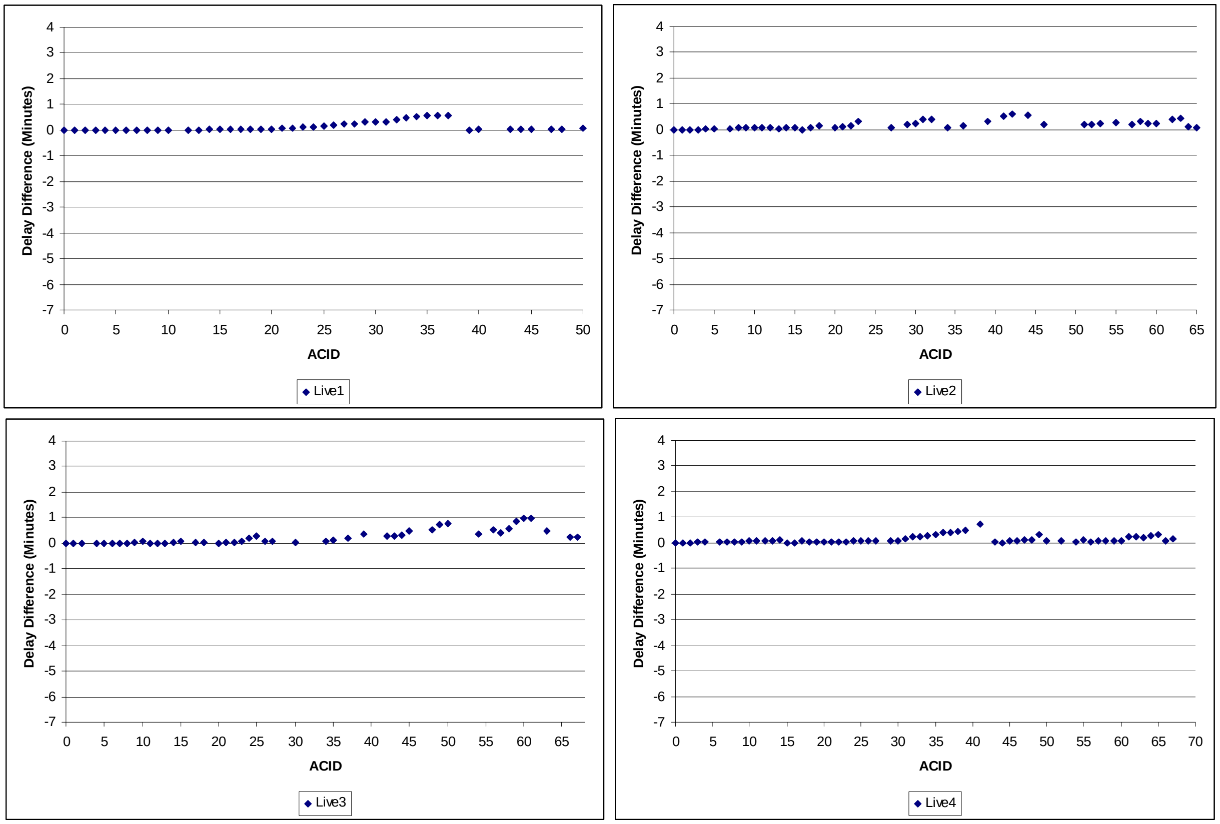

**Figure 9. Delay differences for Live1, Live2, Live3, and Live4 when not scheduling proposed departures in advance.**

## V. Discussion

For each dataset, Table 2 lists the maximum absolute delay differences, as well as the percentage of delay differences that fall within one minute from both methods that were used to handle proposed departures. Generally, the live data sets had lower delay differences than Model10 and Model20. The absolute maximum delay differences were less for the live data sets and the percentage of delay differences that were within one minute is much higher than what was computed for Model10 and Model20.

Note, however, that Live2 and Live3 dataset have a similar amount of airborne and departure traffic as Model20 (see Table 1). Figure 10 compares the delays needed by airborne aircraft to accommodate departures scheduled at their P-times for Live3 and Model20. Lower delay amounts in the Live3 dataset can be attributed to the fact that the airborne traffic is less congested than Model20. With less congestion in the Live3 dataset, airborne aircraft can accommodate proposed departures easier, resulting in lower delay differences than Model20.

**Table 2. Summary of delay difference results.**

| | Absolute Maximum | | Percentage within 1 minute | |
|---|---|---|---|---|
| **Dataset** | **Not Scheduling in Advance** | **Scheduling at P-time** | **Not Scheduling in Advance** | **Scheduling at P-time** |
| Model10 | 3.35 | 4.50 | 73% | 55% |
| Model20 | 3.30 | 6.30 | 69% | 41% |
| Live1 | 0.56 | 0.99 | 99% | 99% |
| Live2 | 0.61 | 1.77 | 98% | 89% |
| Live3 | 0.98 | 3.24 | 96% | 63% |
| Live4 | 0.73 | 1.23 | 99% | 96% |

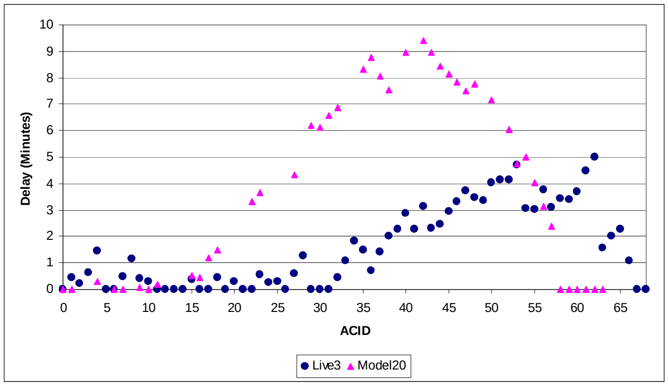

**Figure 10. Live3 and Model20 airborne delays when scheduling proposed departures at their P-times.**

One objective of the study was to quantify how the current practice of not scheduling the proposed departures in advance affected airborne delay. From Table 2, results for the live data indicate that the percentages of airborne aircraft having delay differences within one minute are over 96%. Since the McTMA scheduler has tolerances of 1 minute, having delay differences within one minute is acceptable. Furthermore, the controllers can easily accommodate the additional minute.

When comparing the two methods used to handle proposed departures, the current practice yields lower maximum absolute delay differences than initially scheduling proposed departures at their P-times. Moreover, the percentages of delay differences that are within one minute are consistently higher than scheduling the departures at their P-time. This may explain why, although the impact has not been quantified until now, the current practice is used instead of scheduling proposed departures at their P-times.

To support traffic flow management from a nationwide perspective, the metering horizon will need to be extended. This extension of the scheduling process will result in a greater number of proposed departures, which may have a more significant effect on airborne delay. Consider Model20 and Model10, where the total demand is exactly the same, but the amount of proposed departures has doubled. From Table 2, the percentage of aircraft that are within one minute of their actual airborne delay for Model20 is less than Model10. These trends are also seen when comparing Live2 and Live3 versus Live1 and Live4, confirming the finding of greater errors in airborne delays as the number of departures increases. Further research will explore how much the metering horizon can be expanded using this current practice before having a major effect on traffic delays.

In the future, as overall demand and the number of proposed departures increases, alternative means of handling proposed departures may be needed. One solution is to integrate McTMA with airport surface decision support tools such as the Surface Management System which would provide better predictions of the departures' wheels-up times in advance.[5] Another possible solution is to predict the graphical patterns of the delay differences and add (or subtract) the delays for airborne aircraft accordingly. For example in Fig. 6, the delay differences have peaks similar to the peak delays required when the departures are scheduled at their P-time. In Fig. 8, the delay differences appear to peak after the demand peak. If the delay differences could be predicted beforehand, then additional delay could be assigned to airborne aircraft if the delay difference is positive or vice versa. If no pattern exists, historical data could be used calculate the delay differences, and the amount of airborne delay would be adjusted accordingly.

## VI. Conclusion

This study quantified the effects of the uncertainty in departure times on the McTMA scheduler. Two methods of handling proposed departures were investigated: (1) scheduling the proposed departures at their P-times in advance, and (2) the current method of not scheduling the proposed departures beforehand. Results indicate that the current method of not scheduling the departures in advance is acceptable for a 400 nautical mile metering horizon. The errors in the delays assigned to airborne aircraft are mostly within one minute for the live data, which is feasible for controllers to handle. In contrast, automatically scheduling departures at their P-times would impart excessive delay on airborne aircraft. When the metering horizon expands, the number of proposed departures will also increase. Further research will determine the limits of the metering horizon before alternative methods for handling proposed departures need to be explored.

## References

[1] Landry, S., Farley, T., Foster, J., Green, S., Hoang, T., and Wong, G.L., “Distributed Scheduling Architecture for Multi-Center Time-Based Metering,” *AIAA Aircraft Technology, Integration and Operations Forum*, Denver, CO, November 2003.

[2] Farley, T., Foster J., Hoang, T., and Lee, K., “A time-based approach to metering arrival traffic to Philadelphia,” *AIAA Aircraft Technology, Integration, and Operations Forum*, Los Angeles, California, October 2001.

[3] Kille, R., “Summary of the July 1999 Internal Departure Delay Investigation for ZDV Along with New Departure Delay Data From ZOB, ZID, ZFW and ZDV”. Computer Sciences Corporation, May 2004.

[4] Wong, G. L., “The Dynamic Planner: The Sequencer, Scheduler, and Runway Allocator for Air Traffic Control Automation,” NASA Technical Memorandum TM-2000-209586, April 2000.

[5] Jung, Y., Monroe, G., “Development of Surface Management System Integrated with CTAS Arrival Tool,” *AIAA Aircraft Technology, Integration and Operations Forum*, Arlington, VA, September 2005.