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MULTI-CENTER TRAFFIC MANAGEMENT ADVISOR INITIAL FIELD TEST RESULTS

Todd Farley*, Ty Hoang†, Steven Landry†
NASA Ames Research Center
Moffett Field, California

Monicarol Nickelson‡
Federal Aviation Administration
Moffett Field, California

Kerry Levin§, Dennis Rowe§
MITRE Center for Advanced Aviation System Development
McLean, Virginia

ABSTRACT

The Multi-Center Traffic Management Advisor (multi-center TMA) is a decision-support tool designed to help traffic management personnel in adjacent facilities develop and implement a coordinated, multi-facility time-based metering program to manage arrival demand for a terminal area. Real-time, controller-in-the-loop simulation studies suggest that multi-center TMA has the potential to improve arrival planning and coordination, reduce flow restrictions, and stabilize controller workload. This paper discusses a series of field test activities conducted between January and May 2003 to verify and validate the system architecture and to refine the operational concept, user interfaces, and system design. Field test methods, data, observations and conclusions are presented. The results of this initial set of field test activities confirm that the multi-center TMA architecture equitably distributes traffic management data among several facilities in a timely manner. The results further suggest that, using this shared information with the applications made available by multi-center TMA, traffic management coordinators at multiple facilities will be able to effectively implement time-based metering in the heavily congested arrival airspace to Philadelphia. A concept of use for multi-center TMA is also discussed.

INTRODUCTION

When near-term (1- to 2-hour) traffic forecasts indicate that arrival demand is expected to exceed capacity, traffic management coordinators (TMCs) have a number of traffic flow management techniques at their disposal to curtail and/or redistribute the demand:

- Miles-in-trail restrictions
- Approval request program (APREQ)
- Time-based metering
- Ground stops

Theory suggests that time-based metering is a more efficient operation than miles-in-trail spacing.[1] Metering trials at Atlanta Center, Los Angeles Center, and Miami Center are confirming the theory. Air Route Traffic Control Centers (ARTCCs or "Centers") that have transitioned from miles-in-trail restrictions to metering with single-center TMA (the predecessor to multi-center TMA) have realized increased arrival rates, reduced restrictions, and decreased airborne holding.[2] These findings suggest that time-based metering could benefit operations in the northeast corridor, where arrival delays, in-trail restrictions and airborne holding are commonplace. However, the centralized architecture of the single-center TMA system is inadequate to support the coordination and execution of time-based metering among the several facilities that manage the tightly constrained airspace surrounding the New York-Washington-Philadelphia metro areas.[3]

Researchers at the NASA Ames Research Center and MITRE's Center for Advanced Aviation System Development (CAASD) have teamed with the Federal Aviation Administration (FAA) and Computer Sciences Corporation (CSC) to develop a multi-center TMA system. The multi-center TMA design applies a new, distributed systems approach to time-based metering automation.[4] The result is a modular, scalable metering architecture that is expected to enable traffic managers in multiple facilities to formulate and coordinate an efficient, workable multi-facility metering operation.[5]

Philadelphia International Airport (PHL), a busy northeast corridor hub airport, has been chosen for initial development of multi-center TMA. Accordingly, the primary facilities involved in the PHL arrival process—Boston Center (ZBW), Cleveland Center (ZOB), New York Center (ZNY), Washington Center (ZDC) and the Philadelphia Terminal Radar Approach Control (PHL TRACON)—have been selected as multi-center TMA development sites. However, the multi-center TMA architecture is general enough to be

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* Aerospace Engineer, Senior Member AIAA.
† Aerospace Engineer, Member AIAA.
‡ Human Factors Engineer, Member AIAA.
§ Principal Engineer.

installed at any ARTCC(s) for any major TRACON or airport.

Two focuses of multi-center TMA

The multi-center TMA research has two focuses. One focus is to facilitate collaboration among the traffic management units (TMUs) at the target facilities. The second focus is to enable those facilities to transition from miles-in-trail spacing to time-based metering for their PHL arrival traffic. The multi-center TMA research supports each focus with new technology and procedures.

The multi-center TMA research plan places the initial emphasis on the “collaboration” focus, referring to it as “Increment 1.” Once the technology and operational procedures are in place to support multi-facility collaboration, then the research emphasis will expand to include the “transition to time-based metering” focus, or “Increment 2.” The initial field test activities reported on in this paper were conducted as part of “Increment 1,” assessing the ability of the multi-center TMA tools and procedures to support multi-facility collaboration.

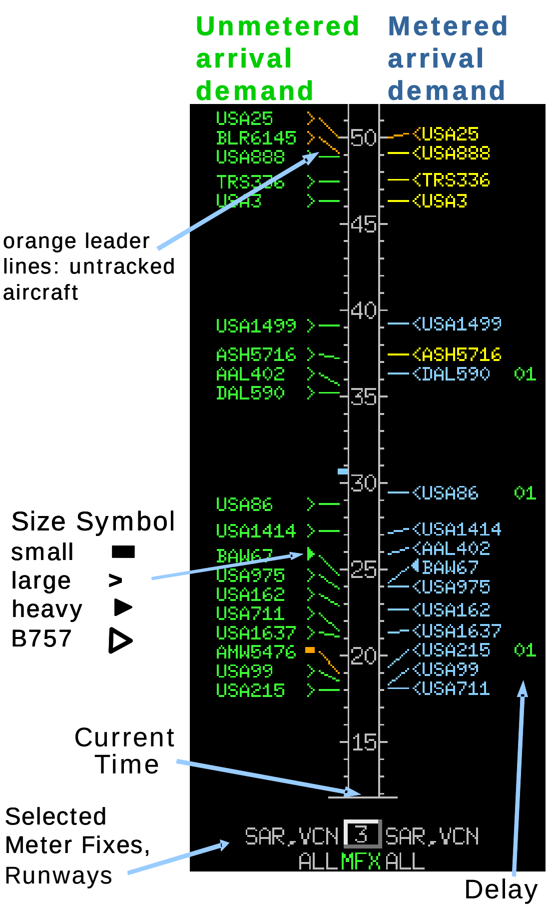

Figure 1. Multi-center TMA timeline display

Multi-center TMA collaborative tools and procedures

To support the Increment 1 focus on multi-facility collaboration, multi-center TMA is designed to deliver a number of products to each connected TMU. First, it must provide continuously updated, highly accurate 90-minute forecasts of future arrival demand and capacity. This information is presented in the TMU on multi-center TMA timelines and load graphs as illustrated in Figures 1 and 2. These same displays provide feedback to help TMCs assess the adequacy of the current metering plan. Communication and coordination between the local facility and its metering collaborators will occur both actively (for example, by telephone) and passively (by sharing information through the common multi-center TMA displays). The multi-center TMA shared displays provide the context for those interactions.

The multi-center TMA research seeks to complement the Increment 1 technology with practical procedures and a clear delineation of roles and responsibilities to ensure inter-facility coordination. For time-based arrival metering to succeed in the northeast corridor, managers and controllers at all facilities having a role in arrival operations to the destination airport will need to develop common situation awareness in order to implement a coordinated metering plan.

This paper discusses the field activities conducted in evaluating the multi-center TMA technology and procedures to support multi-facility collaboration. Field test methods, data, observations and conclusions are presented.

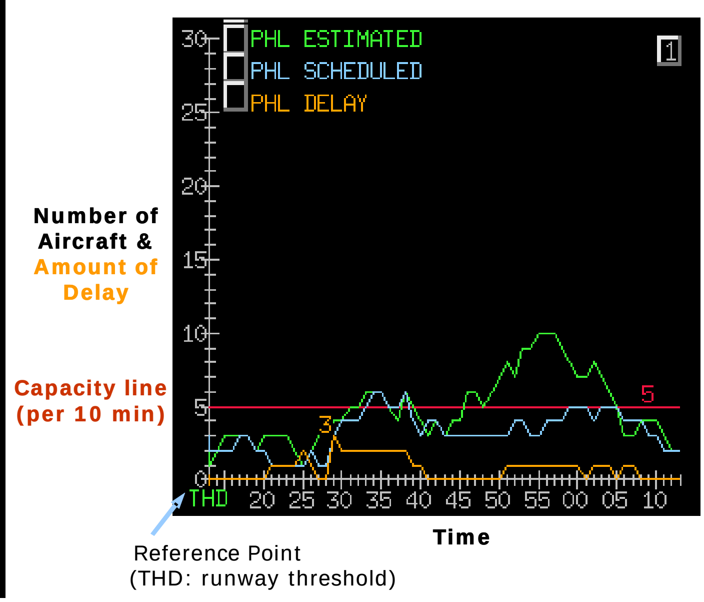

Figure 2. Multi-center TMA load graph display

OBJECTIVES

The objectives of the first increment of the field test were as follows:

- install the multi-center TMA system architecture and connectivity at the four ARTCC facilities and one TRACON facility: Boston Center (ZBW), Cleveland Center (ZOB), New York Center (ZNY), Washington Center (ZDC), and Philadelphia TRACON;
- evaluate the CTAS multi-facility trajectory predictions, which form the basis of the multi-center TMA demand forecasts and drive its distributed scheduling functions;
- propose and evaluate operational concepts for inter-facility collaboration, including the roles, responsibilities, and procedures for each traffic management unit (TMU);
- build familiarity and understanding of TMA displays and algorithms among the users' system development team.

APPROACH

NASA's prior experience developing single-center TMA for Dallas–Ft. Worth International Airport demonstrated the value of making the air traffic community—the eventual system operators—an integral part of the design and development team.[6] A similar approach has been adopted for the multi-center TMA research program, whereby researchers are teamed with a "cadre" of traffic management coordinators and sector controllers from each multi-center TMA facility: ZBW, ZOB, ZNY, ZDC, PHL TRACON, and the Air Traffic Control System Command Center ("Command Center"). The approach also stresses the importance of operational exposure in the field in order to ensure the relevance of the results. In this initial set of system evaluations, researchers and cadre members worked side-by-side at the facilities evaluating system operation in real-time with live data.

INCREMENT 1 FIELD TEST ACTIVITIES

To facilitate a smooth transition from system installation to full-up, multi-facility collaborative exercises, the Increment 1 field test plan comprised a series of short-term (two-week) activities of gradually increasing functionality and complexity. Each activity encompassed engineering, operations, and human factors assessments.

Personnel

A research engineering team of one or two people was deployed to each Center. The engineering team was assisted on an as-needed basis by on-site support from an FAA airway facilities (AF) representative and the local cadre members. A key asset at each site was the "facility liaison" for multi-center TMA, a project contractor who was also a former FAA employee at his assigned facility. The facility liaisons were instrumental in maintaining a productive relationship between the research project and the facility.

Facilities

Most of the Increment 1 field test activities took place at the ARTCC facilities with the multi-center TMA system operating with a one-way (receive-only) interface from the local Host Computer System. The one-way Host interface ensured that TMA advisories could not be sent to the Host and therefore could not be displayed at the sectors. Several additional measures were taken to ensure that essential air traffic control functions would not be disturbed during these initial evaluations. The TMA equipment was installed in a "back room" at each facility, an area away from the operational floor (Figure 3). No equipment was located in any operations area. Non-interference testing was performed in advance at each facility (and at the William J. Hughes FAA Technical Center) to ensure that multi-center TMA would not adversely affect operation of any element of the national airspace system (NAS). Finally, evaluations by multi-center TMA cadre members were conducted when they were off-schedule, so as not to conflict with their regular duties and to enable their focused attention.

Figure 3. "Back room" installation of multi-center TMA at New York Center

Protocol

The Increment 1 field test plan called for a step-wise approach to system evaluation, building from stand-alone operation at each facility and ultimately concluding with inter-center collaborative traffic management shadowing exercises using the fully networked, multi-center TMA system. No time-based metering trials were conducted for the Increment 1 field test.[**]

Stand-alone evaluations

The first four multi-center TMA field trials were evaluations of the newly installed local TMA system at each participating ARTCC. The Cleveland Center and New York Center field trials took place in parallel January 6-17, 2003. The Boston Center and Washington Center field trials took place in parallel January 27-February 7, 2003. Each of these four field trials was conducted independent of the others. The primary technical objective of each trial was to verify that the TMA equipment installation at the ARTCC was complete and functioning correctly as a stand-alone system. The primary operations objective of each trial was to introduce this new system to the air traffic (AT) personnel and airway facilities personnel at each facility who would support the Increment 1 evaluations.

Multi-center evaluations

Once all of the objectives of the stand-alone evaluations had been met, the field test program proceeded with multi-center evaluations. For the two-week period beginning March 3, 2003, the research team deployed to the "back room" at each multi-center TMA facility. The primary technical objectives of the multi-center evaluations were to connect, for the first time, the fully-networked, multi-center TMA system, and to analyze the quality of its input data, the accuracy of its output data, and the stability of the overall system. The primary operations objective was for air traffic personnel to shadow the system and assess its operation and performance from a user's perspective.

Multi-center TMA summit

With the benefit of multi-center TMA training, simulations, and now shadowing experience, the multi-center TMA cadre was invited to NASA Ames Research Center April 29-May 1, 2003 for a "Multi-Center TMA Summit." The purpose of the summit was to provide an impartial forum in which the multi-center TMA traffic management cadre members could discuss the operational issues associated with inter-center collaboration, address their provincial interests, and ultimately draft an initial concept of use for multi-center TMA. The cadre was able to evaluate alternative procedures "on the fly" in human-in-the-loop simulations in the Ames multi-center TMA laboratory.

Final Increment 1 field trial

With a candidate set of procedures identified for inter-facility collaboration using multi-center TMA, the cadre and research team returned to the facilities May 12-22, 2003 for the final Increment 1 field trial to assess the proposed procedures. Researchers and cadre members at each facility—along with subject matter experts from single-center TMA sites—shadowed ten PHL arrival rush periods from the "back room." Shadowing was coordinated across all facilities, including PHL TRACON and the Command Center, so that all sites were using multi-center TMA to collaborate on traffic management decisions for the Philadelphia arrival flows. The objective was to validate and refine the multi-center TMA concept of use, including the roles, responsibilities, and procedures for each TMU. Systems engineers recorded system performance data. Human factors specialists observed operations and queried the users to assess system usability, suitability and acceptability, and to determine the need for new or revised requirements.

RESULTS

All of the stated objectives of the multi-center TMA Increment 1 field test were accomplished. This section documents the findings.

Installation and networked operation

Multi-center TMA hardware, software and network connections were installed at all four ARTCCs. Due to facility restrictions at the PHL TRACON (unrelated to multi-center TMA), multi-center TMA equipment was not installed at that location. Instead, the equipment was installed at the FAA Technical Center, and the PHL cadre members were able to participate in the field activities from that location as though it were the "back room" at the PHL TRACON.[††]

The multi-center TMA hardware suite and data communications infrastructure demonstrated excellent performance. Hardware availability was 100% over the course of the field activities. Network communications functioned per design. Using a publish-subscribe paradigm, each TMA system was able to request and receive the information it required to compute and distribute its multi-center trajectory predictions. Each system also was able to connect repeater displays from

[**] The Increment 2 field test will incorporate operational tests, wherein arrival traffic will be actively controlled by appropriately-trained sector controllers (members of the multi-center TMA cadre) to conform with multi-center TMA advisories. The Increment 2 field test is scheduled to occur in May 2004.

[††] The TMA equipment for PHL TRACON is a remote display of the ZNY system. It does not interface to the PHL Standard Terminal Automation Replacement System (Stars).

neighboring facilities, thereby providing an immediate, common picture of the local traffic situation.

<u>Multi-facility trajectory prediction accuracy</u>

Accurate trajectory modeling is fundamental to the multi-center TMA algorithms for arrival demand forecasting and scheduling. On every radar update (12 seconds), multi-center TMA recomputes a four-dimensional arrival trajectory for every aircraft bound for the adapted TRACON (PHL in this case). Based on these trajectory predictions, multi-center TMA determines the overall arrival demand profile, and it allocates arrival slots on a first-come, first-served basis.[7] Error in the trajectory predictions directly contributes to error in the arrival demand forecasts and degrades the reliability and usefulness of its advisories.

One metric for assessing the accuracy of the multi-center TMA trajectory predictions is the 19-minute estimated time of arrival (ETA) error profile. 19 minutes is a general approximation of the lead time at which an aircraft's slot at the meter fix is assigned and frozen. Without a dependably accurate ETA at this point, the slot assignments and overall schedule computed by multi-center TMA will be at risk. Figures 4 and 5 are examples of 19-minute ETA error profiles from ZNY and ZDC. Each figure is a 25-minute composition of all arrivals to PHL over a period of approximately one hour. Each trace is normalized such that zero seconds on the x-axis corresponds to the aircraft's actual time of arrival (ATA) at the arrival fix. Each figure shows a plot of ETA error. The x-axis units are seconds before the actual time of arrival.

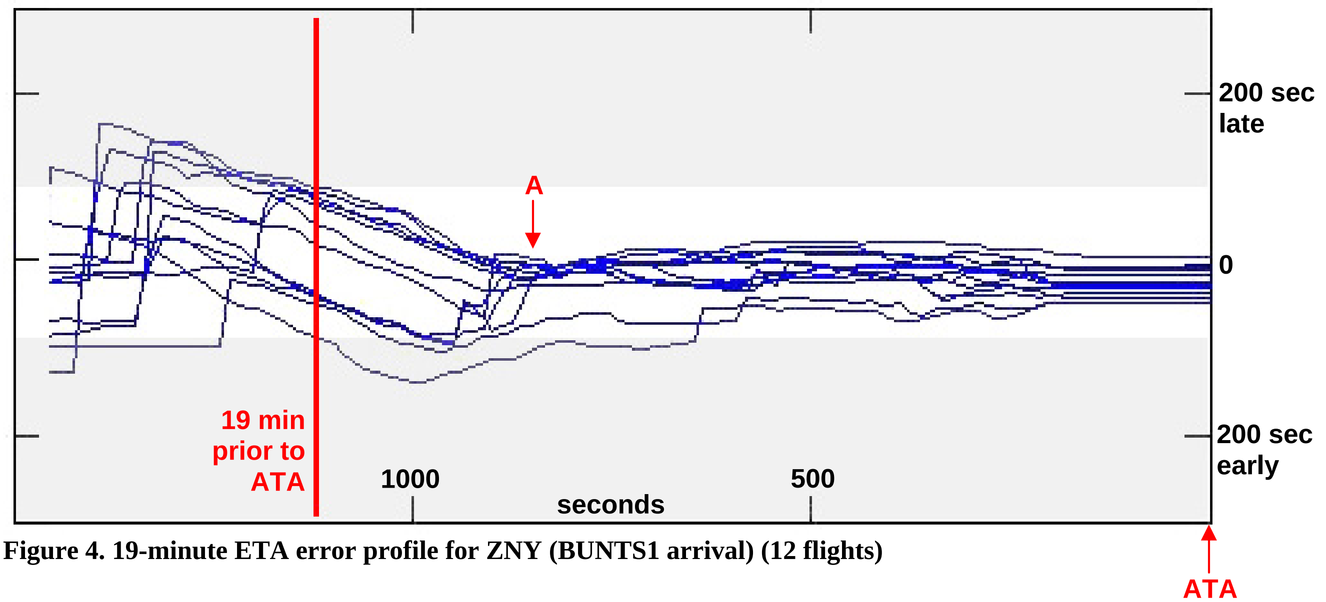

Figure 4. 19-minute ETA error profile for ZNY (BUNTS1 arrival) (12 flights)

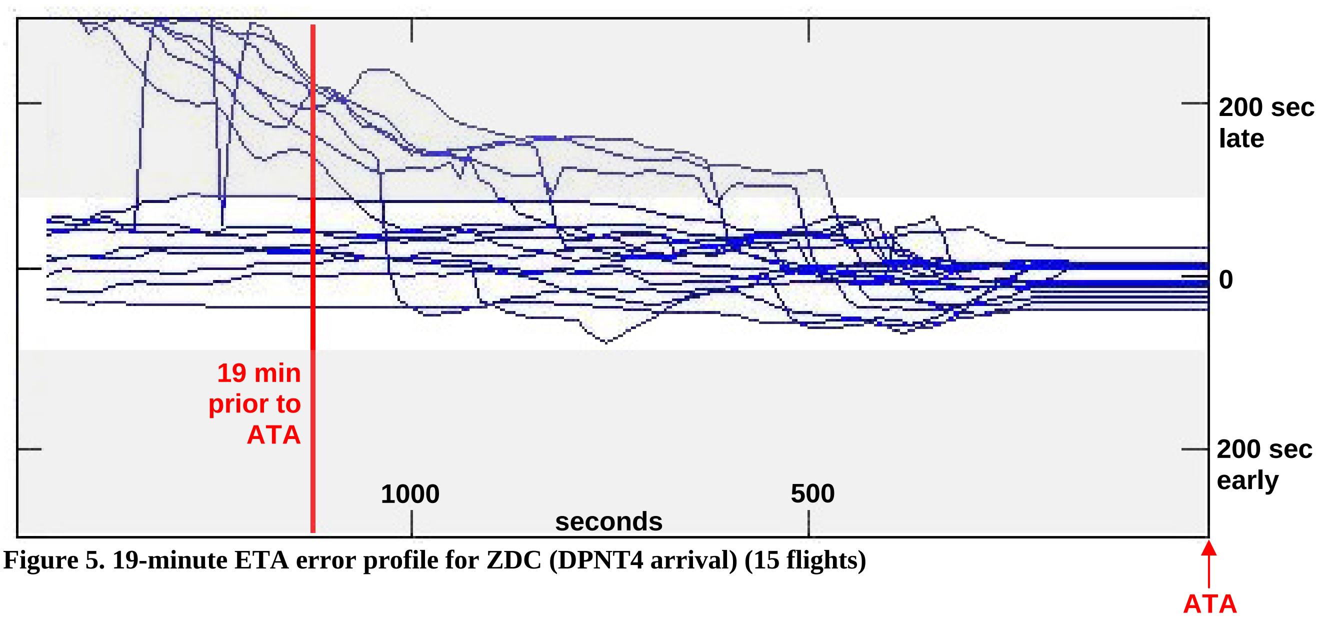

Figure 5. 19-minute ETA error profile for ZDC (DPNT4 arrival) (15 flights)

Figure 4 (ZNY) shows a 19-minute ETA mean error of 22 seconds, with a standard deviation of 63 seconds. This ZNY data exhibits marginal accuracy performance. However, note that there is a clear break point (marked “A”) approximately 15 minutes prior to the meter fix. ETA estimates prior to this time exhibit an increasing bias toward late estimates across all flights as the forecast time increases. This trend is an indication that the trajectory models could be improved for the initial segment of the trajectory. It is hypothesized that the error is due to the fact that arrival descents along this route are typically stepped descents, whereas the trajectory models assume a constant rate of descent to the meter fix. Work is ongoing to test the hypothesis and, if confirmed, make the necessary corrections to the trajectory models.

Figure 5 (ZDC) shows a 19-minute ETA mean error of 106 seconds, with a standard deviation of 95 seconds. This is not acceptable accuracy performance. The data exhibits two behaviors, however. A core set of eight flights demonstrate the desired characteristic of a stable, nearly-flat line throughout time. These eight flights have a 19-minute ETA mean error of 25 seconds, with a standard deviation of 42 seconds. These aircraft trajectories are being accurately modeled. The remaining set of seven flights, however, quickly diverge from the norm, demonstrating a large bias toward late ETA estimates. These seven flights have a 19-minute ETA mean error of 198 seconds, with a standard deviation of 25 seconds. Analysis has shown that these two sets of flights represent two different arrival routes to the meter fix, one of which is modeled accurately, and one of which is not. Data such as this is being used to identify and correct flaws in the trajectory models for error-prone routes.

Operational concept and supporting procedures

With support from the research team, the multi-center TMA cadre was successful in drafting an initial concept of use and procedures to support multi-center collaboration and metering. A few of the most significant findings are discussed in the paragraphs below.

Removal of historical restrictions

Historically, PHL TRACON has operated with a maximum airport acceptance rate (AAR) of 60 aircraft per hour under VFR operations in a west flow configuration. In addition, the TRACON issues restrictions of at least 10 miles in trail over each of the four arrival fixes (usually more). The AAR and in-trail restrictions are conservative (that is, restrictive) by design, in order to allow the TRACON to accommodate the uncertainty in arrival demand. Multi-center TMA is designed to reduce uncertainty in arrival demand, and operational experience at several single-center TMA facilities suggests that TMA is effective in doing so.[2]

Based on the testimonials of subject matter experts from Los Angeles Center, Fort Worth Center, and Minneapolis Center, the multi-center TMA cadre was comfortable adopting a concept of use that would reduce the in-trail restrictions over the arrival fixes to 7 miles and relax the AAR constraint to “unrestricted” (assuming favorable meteorological conditions). Each of these changes represents a relaxation of a key constraint. The reduction in these constraints is possible because Centers that use TMA typically find that metered traffic flows are more organized and have less variation in inter-arrival times. With an unrestricted AAR, multi-center TMA is given the latitude to use wake-vortex spacing standards and defined runway occupancy times to determine the spacing of arrival slots. These constraint reductions still require validation in simulation and during the Increment 2 field trials. Similarly, the appropriate AAR and in-trail restrictions for sub-optimal meteorological conditions will be investigated during the Increment 2 field trials. However, reaching an agreement in principle with the cadre that restrictions may be reduced as a direct result of moving to time-based metering operations with multi-center TMA is a significant result.

Implementation of a metering playbook

Multi-center metering is, by definition, more complex than single-center metering. Each TMU is responsible for setting roughly a dozen local TMA metering parameters such that they are compatible with the agreed-upon multi-center metering plan. The cadre recognized that coordinating all these settings among four different ARTCCs, the TRACON, and the Command Center would be a logistical challenge with a significant potential for error.

To help manage the complexity and to provide a context for multi-center planning, the concept of a “metering playbook” was introduced. Analogous to the reroute playbook instituted by the Command Center as part of the FAA effort to mitigate certain ATC “choke points,” the metering playbook would contain a set of standard metering “plays,” each of which contains a set of predetermined TMA settings. For example, the “west flow VFR noon balloon” play would define each center’s multi-center TMA parameters for the typical noon arrival rush into PHL when the runway configuration is for a west flow and visual flight rules are in effect. By using a playbook, the inter-facility discussion can occur at the more intuitive level of “what play should we run,” as opposed to negotiating dozens of individual metering settings for each facility's multi-center TMA system. The playbook and its plays become the context of the discussion, instead of TMA parameters. The proposed metering playbook will be developed during the Increment 2 field test.

Metered departure release of PHL arrivals

Unlike traditional time-based metering facilities such as Fort Worth Center or Denver Center, a large percentage of arrival traffic to Philadelphia departs from airports within 90 minutes' flying time. These "close-in" departures merge with an enroute stream that is being metered by multi-center TMA. In order to maintain the integrity of the metered schedule, it will be necessary to meter the departure times of those aircraft which are expected to compete for landing slots at the constrained runway(s).

For Washington Center, this would represent a change in procedures, as ZDC does not normally conduct a departure release program for its Philadelphia-bound internal departures. In discussion with the rest of the multi-center TMA cadre, however, it became clear that ZDC will need to institute a departure release program for internal departures to PHL when PHL arrival metering is active. This has been written into the operational concept with ZDC's concurrence, pending further simulations and field evaluations.

Free flow of tower-enroute PHL arrivals

Tower enroute control (TEC) flights present an operational challenge for metering operations. TEC flights are those which depart, cruise, and descend without ever entering Center airspace. These flights are never under ARTCC control. For example, flights from Dulles International Airport to PHL typically file as TEC. They depart Potomac TRACON and are handed off directly to PHL Tracon. They do not enter ZDC or ZNY airspace.

The NAS infrastructure, however, only supports the display of metering advisories to Center controllers; TRACON controllers do not have access to metering advisories. Therefore, TEC flights cannot be metered once they become airborne.

TEC flights represent a small but significant proportion (roughly 10%) of all PHL arrivals. The cadre considered incorporating these flights into a departure release program orchestrated by multi-center TMA. This would enable TMA to reserve an arrival slot for each TEC flight, reducing the volume of unplanned arrivals in the PHL TRACON. However, the cadre determined that the logistics and workload associated with conducting a departure release program for TEC flights would be unworkable.

An alternate solution was unanimously preferred by the cadre. TEC traffic will be allowed to depart and proceed to the PHL TRACON undelayed, as is the case today. To accommodate this unplanned arrival demand at the TRACON, multi-center TMA will be configured to limit the amount of metering workload that can be assigned to the TRACON to a level that is less than the TRACON's known workload capacity. This limit will be chosen to accommodate the expected workload increase associated with sequencing and spacing the unplanned TEC arrival demand. The initial value of this limit, which can be adjusted in real time, will be chosen based on simulation and experimentation.

Training and familiarization of the multi-center TMA cadre

Considerable effort was invested familiarizing the multi-center TMA cadre members with the system. A majority of the cadre did not have experience with time-based metering, so the curriculum included the basic theory of, and motivation for, metering. Back room shadowing exercises included many hours of hands-on use of the TMA system to learn how to access and interpret the shared multi-center data. Additional training focused on how multi-center TMA can help them coordinate traffic management decisions.

DISCUSSION

Much of the success of the Increment 1 field test can be attributed to three key factors: having a motivated cadre, maintaining facility relations, and providing testimony and guidance from operational experts.

Having a motivated cadre

Initial reaction from rank-and-file controllers to the notion of introducing time-based metering to these facilities elicited responses varying from keen interest to curt dismissal. ("Metering? We tried that already. You can leave now.") Considerable effort was invested early in the project to build the case for how this new automation could benefit each user in each facility. Selected at the outset of the program, the cadre members were involved in early simulations which were effective in demonstrating to them the utility of the system and in making them collaborators in system design. Testimonials from their ATC peers at other facilities already using TMA were also constructive in motivating the cadre. Once a cadre member was able to clearly identify the immediate personal benefit, s/he became a diligent advocate.

Maintaining facility relations

The multi-center TMA project enjoyed productive relations with the management and support personnel at all of the involved facilities. This was essential, given the need to coordinate and synchronize installation and operation of multi-center TMA across so many facilities. The mission demanded a degree of flexibility and responsiveness that is not always possible in a large, critical-systems organization.

Key in maintaining the working relationships at each facility were the multi-center TMA facility liaisons. In most cases, the facility liaisons were retired FAA employees of their assigned facility, now acting as the on-site face of the multi-center TMA project and the lightning rod for problems or questions when the research team was not on hand. The facility liaisons' personal rapport with facility personnel and personal knowledge of institutional idiosyncrasies were instrumental to getting things done in a timely and efficient manner.

<u>Providing operational experts</u>

The FAA made available at each field site a subject matter expert (an FAA air traffic representative from a single-center TMA facility). These experts were invaluable in helping the multi-center TMA cadre understand and appreciate the utility of TMA for their unique operational environment. Their first-hand experience and wealth of instructive TMA "war stories" covering nominal and off-nominal situations were effective in bridging the gap between what can be learned in a shadowing exercise versus operational use.

FUTURE WORK

Increment 2 of the multi-center TMA program is underway. Initial software development is complete, and the Increment 2 field test is scheduled to take place January through June, 2004. The goals of the Increment 2 field test are to continue to advance the Increment 1 objectives, but additionally focus on:

- refining the arrival scheduling algorithm and delay allocation scheme;
- assessing workload in each metering sector;
- refining the multi-center ETAs;
- validating the benefit mechanisms;
- validating system usability, suitability, and acceptability.

The Increment 2 field test is expected to begin with "back room" shadowing, then move to operational shadowing in the TMUs, and ultimately conclude with operational metering trials in each facility. Multi-center TMA cadre personnel will be involved throughout the field test activities, along with the research team.

In concert with NASA's Regional Metering program[8], research will also focus on expanding the application of multi-center TMA beyond the Philadelphia arrival problem. Multi-center TMA's innovative modular architecture is expected to enable an ARTCC to use its existing multi-center TMA system to meter air traffic flows to other terminal areas, other ARTCCs, and/or other congested airspace (such as an overloaded sector).

CONCLUSIONS

In this initial set of field test activities, the multi-center TMA research demonstrated several new capabilities for the NAS. First, it demonstrated the ability to collect and distribute local Host data to and from TMA systems at other multi-center TMA facilities according to a simple publish-subscribe model. The system demonstrated its ability to present traffic managers in multiple TMUs with a continuously updated, highly accurate, common picture of arrival traffic demand for Philadelphia. The TMCs found this common picture useful.

While hardware reliability and network performance was excellent, some of the trajectory models produced excessive error. Refinement of these models is in progress.

Based on the field test activities, the system development team of air traffic personnel concluded that multi-center TMA could foster certain procedural changes. Some common arrival restrictions could be reduced or removed. The concept of a metering playbook was introduced. The cadre agreed to institute departure release programs for PHL-bound flights during metering periods, even in Centers where that is not the current practice. TEC flights, they decided, should be accommodated outside of TMA on an exception basis, although this requires further evaluation in Increment 2.

Anecdotally, even though most of the ARTCCs involved in this research program are not time-based metering facilities, there appears to be strong support from the cadre members to move forward and begin evaluating time-based metering of Philadelphia arrivals using multi-center TMA. Those evaluations, part of Increment 2, are due to occur in the first half of 2004.

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