Performance Metrics
Results to Date

December 2000
Report

INTRODUCTION

This *December 2000 Report* is the second semiannual report on the methodology and results to date of the Free Flight Phase 1 (FFP1) Operational Performance Evaluation. The first report was released in June 2000 (Reference 1). The FFP1 Metrics Team is led by Dave Knorr (AOZ-40) and includes Federal Aviation Administration analysts and controllers as well as support from MITRE's Center for Advanced Aviation System Development (CAASD), The CNA Corp. (CNAC), G.E.M.S. Inc., Analytics Associates, and TASC Inc.

The following highlights the status of the five FFP1 capabilities as of December 2000:

> **CDM**: The completed system is now part of every-day National Airspace System (NAS) operations.
>
> **SMA**: The planned implementation of SMA was completed on schedule. The acceptability of (and demand for) the system by airlines is expanding beyond original expectations.
>
> **pFAST**: While the implementation schedule is on track, the next Initial Daily Use (IDU) is scheduled for February 2001. Therefore, we have no new analyses to report. Data collection has begun to "baseline" performance for comparison once implementations are complete.
>
> **TMA**: FFP1 has achieved Core Capability Limited implementation (CCLD) IDU systems at three new locations (ZMP, ZDV, and ZLA) since the June report. Preliminary data analysis indicates performance improvements in airport arrival rates at MSP.
>
> **URET**: The trend of increased direct routings and reduced altitude restrictions continues at ZID and ZME. Again, the implementation schedule is on track, but no new locations have been completed since our last report.

This report will focus on new data and analyses compiled since June 2000. The report will also discuss the continued refinement of the metrics contained in our August 1999 Evaluation Plan (Reference 2). With more than a year's experience evaluating operational data and discussing results with stakeholders, we have a much better understanding of which metrics are measurable and have clear meaning to stakeholders.

This report is divided into sections consistent with the June 2000 Report. CDM, which has proven benefits and has already become a day-to-day operational system, will not be examined in this or future reports. For more information on CDM please see the metrics section of the Free Flight web site at http://ffp1.faa.gov/.

Safety: In addition to monitoring operational errors and deviations at FFP1 sites, we are working with the FAA Evaluations and Investigations Office (AAT-20) to identify potential safety concerns associated with FFP1 capabilities. To date there have been no known safety-related incidents associated with these capabilities.

User Request Evaluation Tool (URET): This section includes updated results on prototype URET installations at Indianapolis (ZID) and Memphis (ZME) Centers.

Passive Final Approach Spacing Tool (pFAST): A short progress report on pFAST installations is included. With no new installations completed, there is no new data for analysis.

Traffic Management Advisor (TMA): We have collected data and done some preliminary analyses for one of the new TMA sites (ZMP), and have included some preliminary results. The two other new implementations have occurred too recently for us to include preliminary results.

Surface Movement Advisor (SMA): An update on SMA activity is included.

Refinement of Metrics: As anticipated, the measurement process has evolved. This section discusses metrics that have been found to be measurable and also effectively demonstrate system activity and capacity improvements. Reference 2 described several planned metrics for evaluating operational impact. Some of these metrics have proven to be virtually impossible to measure, while others are measurable and effective.

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1.0 SAFETY

1.1 Description

The FFP1 capabilities are intended to provide benefits to users while maintaining the current high level of system safety. Safety has been a fundamental FAA objective since the agency was established, and it continues to underlie the development and implementation of every FFP1 tool. Safety objectives are reflected throughout the *Free Flight Phase 1 Program Master Plan,* the document that describes the implementation process for FFP1 capabilities.

To help meet these objectives, FFP1 management has established a risk management process that will track the performance of each FFP1 tool throughout the implementation phase. The FFP1 risk management team has identified safety as one of the critical risk areas. To mitigate safety risks, service providers have been and will be involved in both the design and validation processes for all FFP1 capabilities.

FFP1 safety metrics are being used to support the FFP1 safety evaluation, thereby helping to ensure that no fielded tool will inadvertently cause a reduction in system safety. As with all FFP1 metrics, the FFP1 safety metrics reflect collaboration with Stakeholders, and a consensus among airspace users, the FAA, industry, and unions.

In the FFP1 Metrics Plan, the principal safety metrics were defined to be the change in operational errors (OEs) and operational deviations (ODs) associated with the use of the FFP1 capabilities. The plan further stated that, where possible, baseline data would be segregated by conditions or factors that influence the number of OEs and ODs (e.g., weather, traffic density, communications congestion).

1.2 Methodology

The methodology being used by the FFP1 Metrics Team for the analysis of safety impact can be summarized as follows:

- Track facility ODs and OEs during a baseline period and after implementation of FFP1 capabilities, focusing on the total number of errors/deviations per facility and the number of errors/deviations attributed to one or more FFP1 capabilities.
- Analyze OE data in detail during the baseline and post-implementation periods to identify and track underlying factors. Examples of such factors include
    - Traffic density
    - Controller readback errors
    - Communication workload
    - Inappropriate controller use of displayed data
    - FFP1 capabilities in use
- In coordination with FAA headquarters, regions and facilities, establish a process to collect pertinent information relating to OEs and ODs before and after FFP1

implementation. In particular, the Metrics Team will keep appraised of the FAA Evaluations and Investigations Staff (AAT-20) program to evaluate OEs and ODs as they occur. AAT-20 will advise the Metrics Team any time an FFP1 tool is identified as a factor in any OE or OD.

- Track relevant data maintained by various FAA offices and other government agencies (e.g., NASA, NTSB), including:
  - Aviation Safety Reporting System (ASRS) data
  - NTSB Accident/Incident Reports
  - FAA Incident Data System
  - FAA Near Mid-Air Collision (NMAC) Database

1.3 Analysis Results to Date

Analysts have long recognized that aviation safety is difficult to measure. Operational errors and deviations are commonly used as metrics, even though they are often the product of a complex series of events that make tracking causes and trends difficult.

In this analysis the first step has been to track the number of OEs and ODs at each of the Free Flight Phase 1 sites. This data has been taken from the FAA's Air Traffic Service Evaluations and Investigations Staff's compilation of NAS-wide OEs and ODs. No significant change in monthly OE or OD rates beyond that experienced NAS-wide can be identified from these data.

Each OE and OD at an FFP1 site has also been evaluated to see if any FFP1 tool was identified as a factor. As of 7 December 2000, no FFP1 capabilities have been identified as a factor in any OE or OD. In addition, no reports of FFP1 capability involvement in any accidents or incidents have been reported in the NASA ASRS, NTSB Accident/Incident Reports, the FAA Incident Data System or the FAA NMAC Database as of 7 December 2000. The response times for these databases vary, so that their individual currency will be somewhat earlier than December 2000. Most of the databases have been updated through November 2000.

1.4 Next Steps

As the fielding of FFP1 capabilities proceeds, the FAA will take the following steps to continue the evaluation of FFP1's safety impact:

- Continue analyzing the relationship between OE and OD trends and the fielding of FFP1 tools.

- Compare OE and OD rates at FFP1 sites with those found at sites not hosting FFP1 capabilities.

- Continue analyzing factors identified in OE reports that may explain why OE counts are varying. Possible factors include:

- Communication workload (e.g., frequency congestion, incorrect readbacks, wrong call signs).
- Timely controller use of available information.

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2.0 USER REQUEST EVALUATION TOOL (URET)

2.1 Overview

The User Request Evaluation Tool (URET) will be implemented at seven Air Route Traffic Control Centers (ARTCCs) under the Free Flight Phase 1 initiative. These centers are identified in Figure 2-1. Currently, a URET "daily-use" (DU) system is operational at the Indianapolis (ZID) and Memphis (ZME) ARTCCs. The URET DU system serves as a means of understanding procedural and training issues that need to be addressed for the success of URET in FFP1. It also provides an opportunity to evaluate prospective benefits to users and to achieve those benefits as early as possible.

URET has been used on a daily basis at ZID and ZME since 1997. Approximately 800 operational personnel have been trained on the use of the tool. Both facilities are operating URET 22 hours a day 7 days a week. Evidence indicates that controllers have come to accept the tool as a new way of doing business and have largely integrated it into their strategic planning.

In July 1999, URET's two-way interface began operation. This functionality allows the controller to enter a trial plan as a Host flight plan amendment with a click of a button. It is expected that this "what-if" checking will provide better capabilities for handling pilot requests.

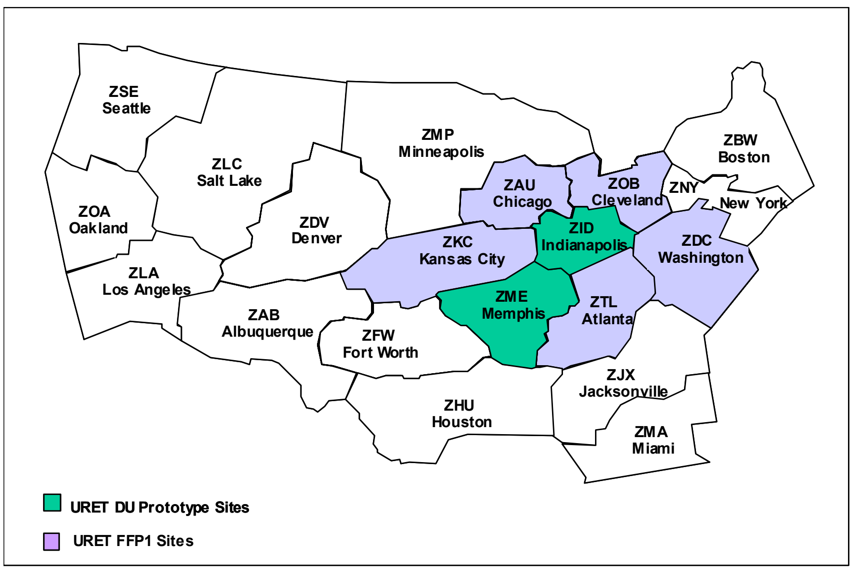

Figure 2-1. URET FFP1 Implementation Sites

2.1.1 Functionality

The key URET capabilities for FFP1 include:

- Trajectory modeling,
- Aircraft and airspace conflict detection,

- Trial Planning to support conflict resolution of user or controller requests, and
- Electronic flight data management.

URET processes real-time flight plan and track data from the Host computer system. These data are combined with site adaptation, aircraft performance characteristics, and winds and temperatures from the National Weather Service (NWS) in order to build four-dimensional flight profiles, or trajectories, for all flights within or inbound to the facility. URET also provides a "reconformance" function that adapts each trajectory to the observed speed, climb rate, and descent rate of the modeled flight. For each flight, incoming track data are continually monitored and compared to the trajectory in order to keep it within acceptable tolerances. Once implemented, neighboring URET systems will exchange flight data, position and reconformance data, and status information in order to model accurate trajectories for all flights up to 20 minutes into the future.

URET maintains "current plan" trajectories (i.e., those that represent the current set of flight plans in the system) and uses them to continuously check for aircraft and airspace conflicts. When a conflict is detected, URET determines which sector to notify and displays an alert to that sector up to 20 minutes prior to the start of that conflict. Trial planning allows a controller to check a desired flight plan amendment (AMs) for potential conflicts before a clearance is issued. The controller can then send the Trial Plan (TPs) to the Host as a flight plan AM. Coordination of TPs between sectors, which might include those of neighboring centers, may be achieved non-verbally using Automated Coordination capabilities.

These capabilities are packaged behind a Computer Human Interface (CHI) that includes text and graphic information. The text-based Aircraft List and Plans Display manage the presentation of current plans, TP, and conflict probe results for each sector. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and TP results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan routes, altitudes, or speed changes and the sending of flight plan AMs to the Host.

For more details about URET capabilities, benefits, and operational concept, please refer to the paper by Celio et al. (Reference 3) on the MITRE/CAASD URET web site, www.caasd.org/proj/uret.

Figure 2-2 presents a graphic representation of the functionality of the system. As shown in the graphic, URET detects a potential conflict between two aircraft (American Flt. 843 and United Flt. 1801) when the aircraft reach ZME airspace, if they maintain their present flight plan course. Both aircraft are hundreds of miles away from the point of conflict at this time. URET alerts the controller, who alters the flight plan for one aircraft (dashed line) via the URET system. This intervention resolves the potential conflict and provides a more direct, shorter route for the flight.

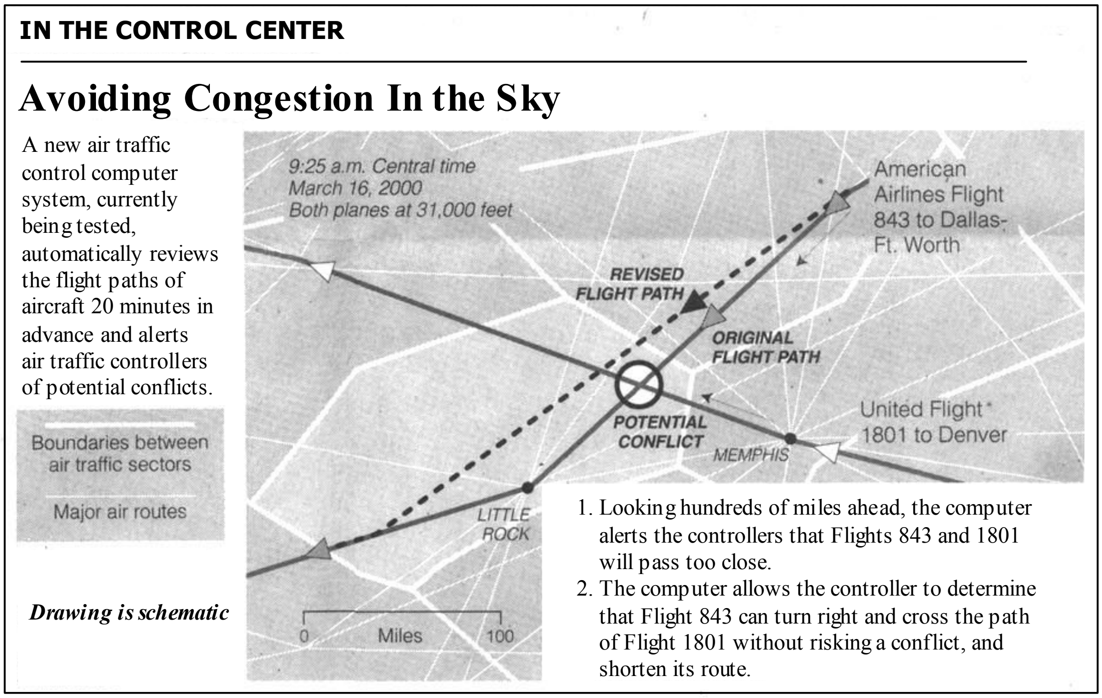

Figure 2-2. URETConflict Probe Functionality

Since February 1999, the Metrics Team of the Free Flight Program Office has been systematically examining the use of URET at ZID and ZME on a monthly basis. The metrics being analyzed focus on how the URET system is used and the benefits gained by the aviation community from URET. These benefits include:

- Savings from direct clearances issued by controllers;
- Overall shortening of distance and time flown; and
- Remaining longer at higher, more efficient altitudes during the flight.

In the process of identifying potential benefits, it is important to isolate the effect of URET on the system vs. other possible causes. Data has been collected over a period of a year and a half to get a baseline before and after extensive use of URET. A third center is used to show how flights are affected in facilities that do not have URET. Several different metrics are analyzed ensuring we do not focus on one positive effect while having one or more negative effects. It is also important to analyze consistent weather days as extreme weather may cause the routes and altitudes of flights to change dramatically.

The overall analysis leads to average savings of more than 0.5 mile per flight for every flight going through ZID and ZME airspace. This translates to a monthly economic benefit of approximately $1.5 million for both Centers combined. Additionally, the removal or relaxation of static altitude restrictions has allowed flights to remain at more efficient altitudes longer.

As previously referenced, ZID has already begun removed static altitude restrictions. Other restrictions are being dynamically relaxed allowing for more fuel-efficient trajectories. US Airways has reported a savings of more than $125K annually from the removal of one restriction.

The following sections provide the data to support these conclusions and describe the continued activities to enhance benefits and improve the measurement techniques.

2.2 System Utilization

In order to determine what benefits URET is providing, it is important to examine how URET is being used. Metrics on the use of various URET capabilities are collected and updated on a monthly basis. A set of metrics has been produced based on the daily files generated by URET at ZID and ZME. This set of metrics has grown since February 1999 when such data were first examined on a systematic basis.

Over time, URET has grown from a single workstation to full center operations at ZID and ZME. Both facilities are operating URET continuously throughout the day, especially during busy periods, 22 hours a day 7 days a week. Figure 2-3 illustrates the usage trend over the period January 1998 – November 2000, showing the total URET scheduled hours and the percentage of those hours that URET was actually in operation. As seen in the chart, the utilization has remained high since our last report in June 2000. The slight dip in August 2000 was due to extensive new controller training that required training time at the sector using flight progress strips.

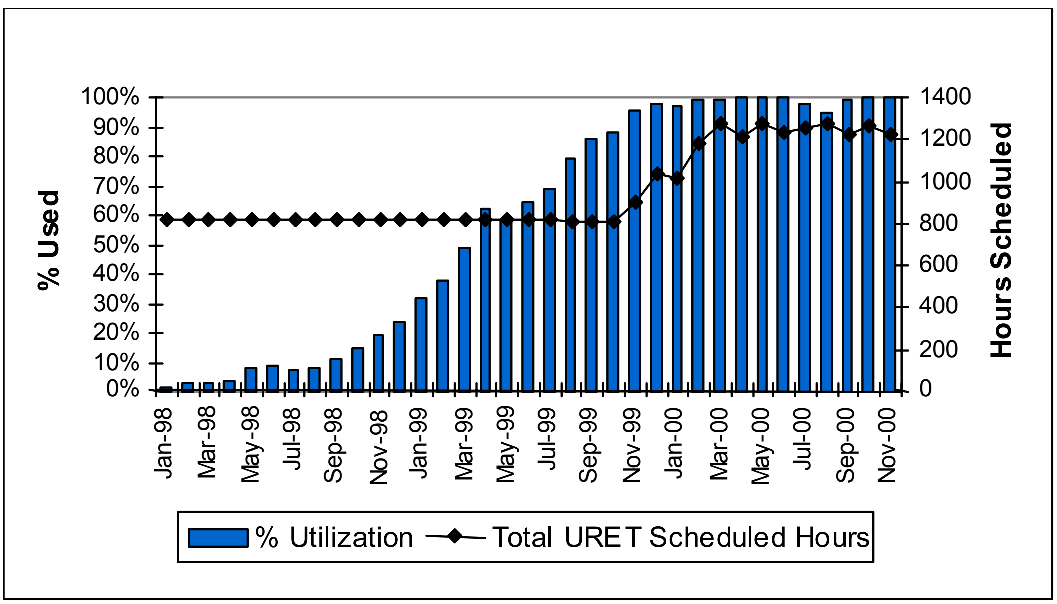

Figure 2-3. URET System Utilization (ZME and ZID)

2.2.1 Direct Routing Amendments

Since two-way communications between URET and Host started in July 1999, controllers have been granting an increasing number of direct clearances resulting in a shortening of aircraft routes. Using the data sent to URET from the Host, any flight plan amendment, which caused a shorter trajectory to be built, was counted as a "direct" clearance. The URET amendments that were created from TPs that saved distance were also counted. The counts for ZID and ZME are shown in Figure 2-4 and Figure 2-5 respectively. Note that the data were analyzed on a sampling rate of two days per week.

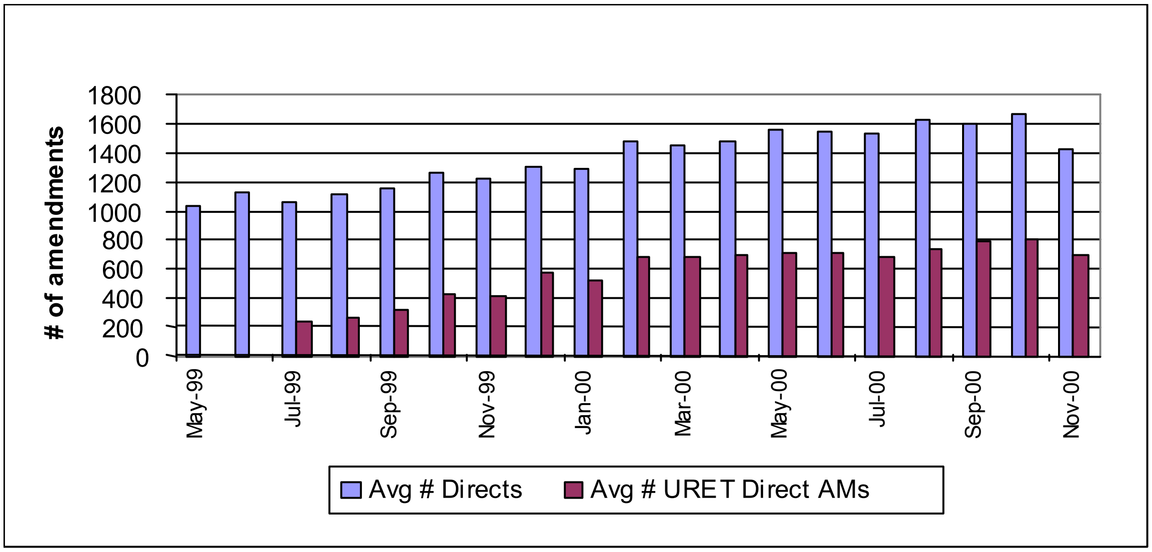

Figure 2-4. ZID: Total Directs and URET Directs

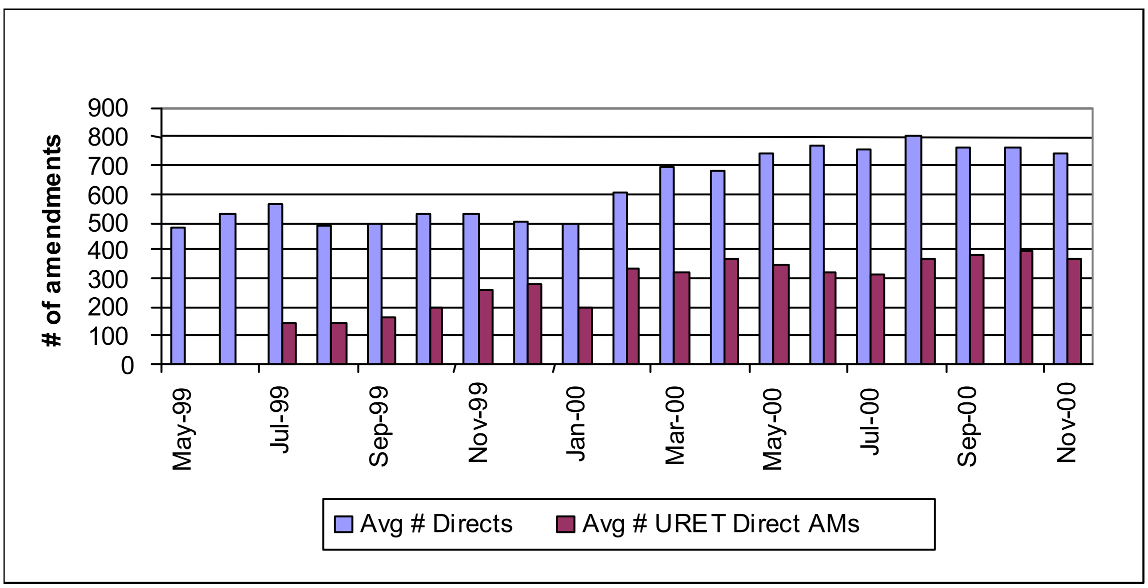

Figure 2-5. ZME: Total Directs and URET Directs

With over a year of data collected, results indicate that the number of directs given by the controllers has increased by about 50 percent over the pre- "two-way" Host levels. Some of this increase can be attributable to more flight plan amendments being entered by the controllers because URET allows more efficient entry of direct to fix amendments than the methods used prior to URET. It should also be noted that the increase in directs does not appear to be seasonal. Although, the November 2000 decrease in the number of directs can be correlated to a decrease in air traffic that month. Close examination of the data and observations of the controllers using URET shows that events such as the one depicted in Section 2.1.1, issuing a direct clearance to solve a conflict, are a common practice that would have only come with the use of URET capabilities.

2.3 Observed Metrics

Three metrics are calculated that provide an estimate of the total distance saved for flights going through ZID and ZME airspace:

- Distance saved for lateral amendments,
- Excess distance, and
- En route distance.

Each metric is calculated using different algorithms and methodologies in order to normalize for weather and other factors. Using different methods helps to attribute the benefits to a specific enhancement such as URET.

2.3.1 Distance Saved for Lateral Amendments

Using the same raw data used for the Direct Routing Amendment analysis, this metric looks at all lateral amendments (turns but no altitude changes) not just those with a distance reduction. Figure 2-6 shows the trend for the average number of lateral amendments per day. Figure 2-7 shows the trend for miles saved per amendment. Note that in both cases the trend is upward and both facilities are averaging more than 1000 amendments per day with approximately 3 miles saved per amendment.

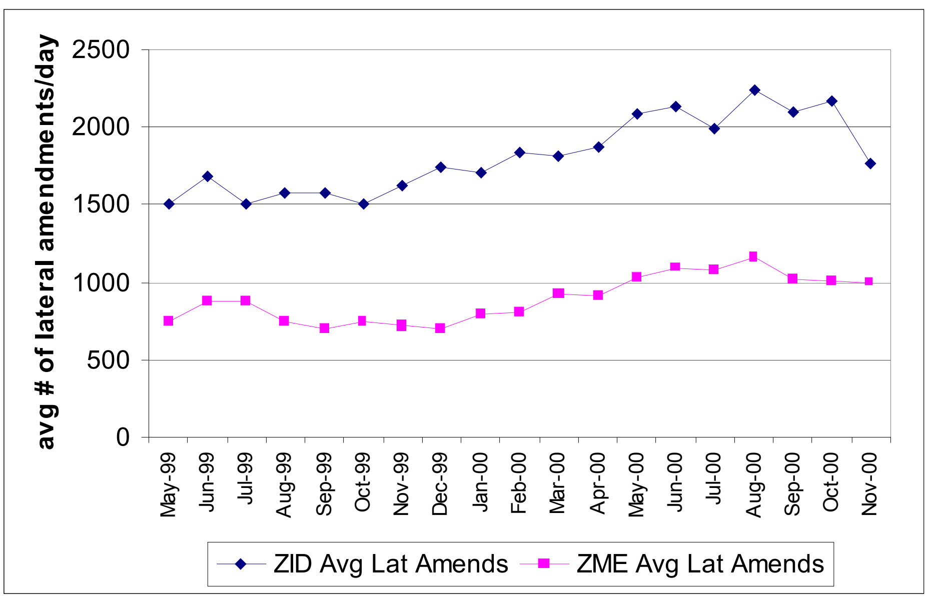

Figure 2-6. Avg. Number of Lateral Amendments per Day

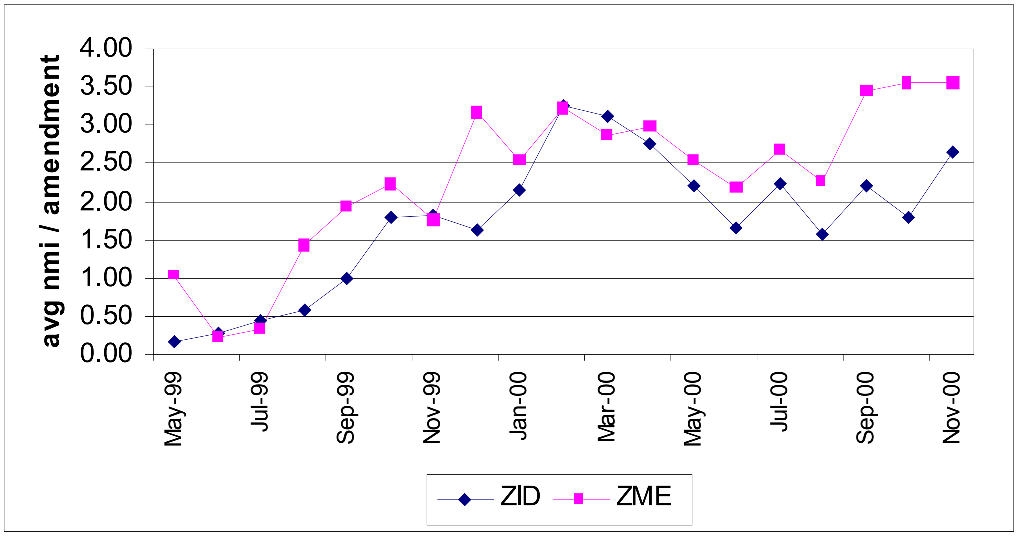

Figure 2-7. Avg. Distance Saved per Amendment

From the underlying data in Figures 2-6 and 2-7 we were able to calculate the daily savings of distance flown from lateral amendments. Figure 2-8 shows these daily savings averaged over each month.

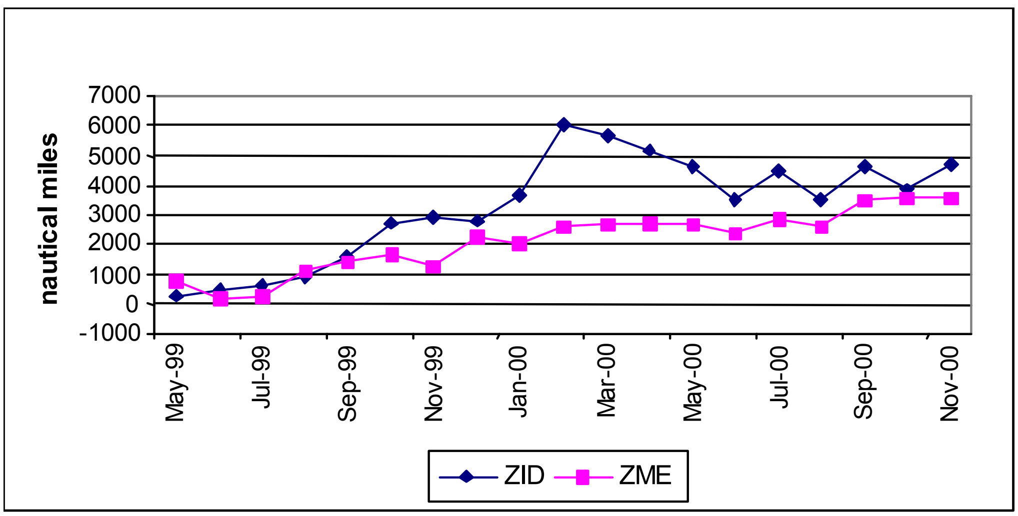

Figure 2-8. Distance Saved for Lateral Amendments

The time periods used for these analyses incorporated the busiest hours of the day for each facility. For ZID and ZME these periods were between 1300Z and 2300Z (10-hours) and 1400Z and 2200Z (eight-hours), respectively. These Figures show savings since two-way communication started in June 1999 to be approximately 3,500 miles per day for each facility. The 3,500 mile total savings are drawn from about one-half of the daily traffic, so this is considered a conservative estimate. Dividing the average number of flights per day at each Facility (approximately 7,000 flights per day)[1] by 3,500 miles saved gives an average saving per flight of 0.5 miles.

2.3.2 Excess Distance

Excess distance is the difference between the actual distance flown and the great circle distance from center entry and exit points. Excess distance was calculated for the two URET centers, ZID and ZME, and a single non-URET Center, Washington Center (ZDC), used as a "control." The time period for this analysis was from October 1998 through October 1999. This metric is the monthly average of excess distance for all flights through a center.

Figure 2-9 illustrates the results. In summary, the monthly average excess distance decreased in ZID and ZME from October 1998 to October 1999, during which time traffic counts increased. The monthly average excess distance increased at ZDC, the non-URET center, during the same time period.

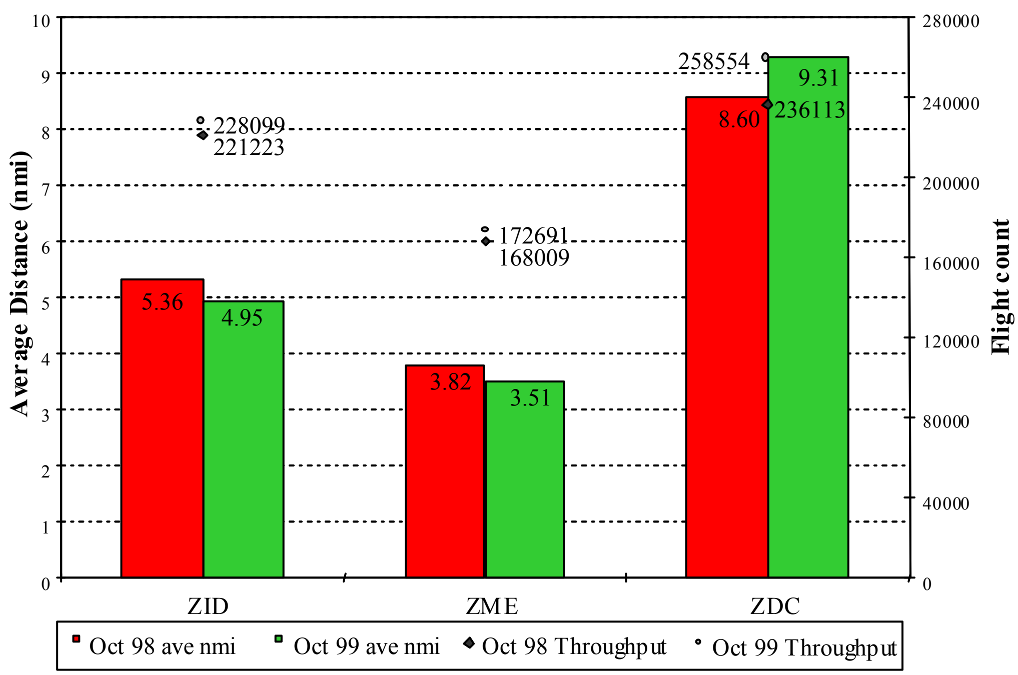

Figure 2-9. Excess Distance in Three Centers for October 1998 and 1999

It must be cautioned that there are a number of factors, which might have contributed to the change in the value of the metric from 1998 to 1999. Since this metric is calculated for all days of the month, weather patterns play a large role in how closely a flight can remain on course and how many weather-related deviations are necessary. Also, airline flight scheduling can affect traffic densities independently of the actual daily throughput. As flight densities decrease, fewer deviations are required to maintain safe separation. Analysis comparing other months of the year and aggregated into seasons of the year

[1] FAA Administrator's Fact Book, July 2000.

show a consistent trend for ZID and ZME of smaller or nearly the same excess distance while the ZDC control center has consistently larger excess distance.

2.3.3 En route Distance

This section takes a broader look at the impact of URET on flights that *traverse* ZID or ZME airspace. One question of interest was whether or not a flight distance savings realized in ZID or ZME would be offset or reduced by an increase in flight distances in other ARTCC facilities. Unlike the previous two sections that analyze the impact of URET within ZID or ZME, this analysis explores this distance savings question by looking at the entire "en route" portion of a flight, not just that within ZID or ZME.

To answer this question, the en route distance was calculated for flights traversing ZID or ZME airspace over a 14-month period (May 1999 to June 2000). En route distance is calculated by summing the straight-line distance between reported aircraft positions, beginning with the entry point of a flight into en route airspace (approximately 40 nautical miles [nmi] from the departure airport) and ending with the exit point of a flight (approximately 40 nmi from the destination airport). For each of the selected analysis days, the average en route distance was calculated for each of ten designated city pairs. In addition, a weighted average was used so that the overall average would not be distorted from one data set to another by variations in the number of flights between particular city pairs. The results are illustrated in Figure 2-10.

In summary, visually inspecting the plot of average daily distance versus date indicated a slight decrease in distance flown for ZME. However, using regression analysis to confirm the visual inspection is inconclusive as the results are not statistically significant. Additional data and further analysis is necessary to draw any stronger conclusions.

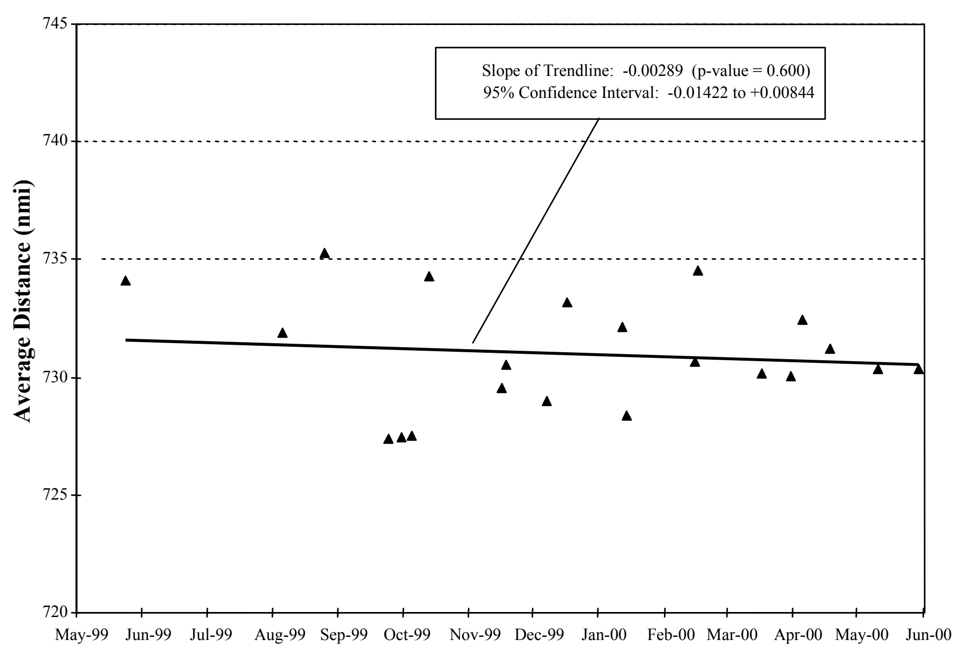

Figure 2-10. En route Distance for ZME, with Trend Line

2.4 Restriction Removal

The Procedures and Benefits Team is currently evaluating all applicable altitude restrictions at ZID and ZME to determine the potential for additional restriction removals. At present, ZID has been successful in permanently removing the restrictions presented in Table 2-1. To a limited extent, other restrictions not removed permanently, are being dynamically relaxed as traffic complexity allows.

Table 2-1. Restrictions Removed by ZID

Airports	Flow	From Sector	To Sector
Cleveland (CLE)	Arrivals	83	87
Toledo (TOL)	Arrivals	83	87
Akron-Canton (CAK)	Arrivals	83	87
Pittsburgh (PIT)	Arrivals	83	85
Detroit City (DET), Wayne Cnty. (DTW), Hopkins Intl (CLE)	Departures destined for Nashville (BNA)	88	82

On January 15, 2001 the Procedures and Benefits Team will begin tests on two additional restrictions. These include the Standiford (SDF) to Midway (MDW) restriction and Indianapolis (IND) arrivals from Area 6 to Area 5. Furthermore, these two facilities will continue their efforts to remove altitude restrictions as existing procedures and traffic permits.

The following sections describe the work of the Procedures and Benefits Teams at ZID and ZME in the lifting of restrictions, specifically in identifying candidates for removal.

2.4.1 Activities of the Procedures and Benefits Teams

Procedures and Benefits Teams were formed at ZME and ZID in the autumn and winter of 1999 to review operations and determine how URET can help in strategic planning. The teams consist of one controller from each area, a traffic management specialist, an airspace and procedures specialist, a training specialist and two supervisors. Airlines participate in the Procedures and Benefits Team at ZID on a quarterly basis and provide input to the process. ZME has merged their Procedures and Benefits team into the local Facility Implementation Team (FIT). This team is now called the ZME CCLD FIT.

The impetus for the establishment of the teams was an inter-facility evaluation of restriction relaxation between ZID and ZME that took place in May 1999. At that time, the teams began reviewing static altitude restrictions to identify candidate restrictions that could be relaxed. Based on this evaluation, there was a general agreement that URET capabilities do support restriction relaxation. Operational personnel acknowledged that URET worked well as an enabler in this short evaluation. They expressed a willingness to review other restrictions and lift them as appropriate.

Since the initial evaluations, the teams have identified restrictions that were candidates for removal. During the evaluation period, the restrictions were turned off in URET and the controllers did not issue the restrictions to the aircraft. The teams monitored the process to determine if the situation was acceptable, or if conditions required that the restrictions be reimposed early. At the conclusion of the test period, the effects were assessed to determine whether or not to permanently remove the restrictions.

2.5 Fuel Saving Extrapolation

Determining the economic impact of removing static altitude restrictions on the airlines requires the knowledge of the miles gained en route at more efficient altitudes, the type of aircraft affected, and the fuel burn differential for the altitudes involved. This data can then be combined and extrapolated to yield an estimate of the gallons per year of jet fuel saved, which can be converted to dollar savings with an estimate of the average dollar per gallon fuel cost.

For a given sample set, the Analysis of Restriction Tool (ART) determines how many aircraft are eligible for a given set of restrictions, how long the aircraft stay at the restricted altitude, and other statistics. Using this information, the ART output can be used to determine which restrictions have the most impact on ATC and airline operations.

In examining the internal restrictions currently imposed in ZID between ZID sectors, there are approximately 70 that could be candidates for evaluation and possible relaxation. An order of magnitude analysis was conducted for these restrictions to estimate the possible fuel savings if they were all relaxed. This analysis yielded savings of 200 gallons of fuel per day average for each restriction lifted. Thus the fuel savings from relaxing all 70 restrictions could amount to 5 million gallons per year.

2.6 Additional Observed Benefits

Other benefits are being realized using URET that do not have a quantitative impact. These benefits include increasing controller efficiency during Radar and Host system outages, operational transition to DSR, and allowing additional procedural exceptions.

URET has increased the efficiency of the controller team in managing flight data at the sector. This efficiency includes:

- Less physical movement to manipulate and write on strips;
- Reduced mental projections of flight paths to determine possible conflicts; and
- Quicker entry of route amendments into the Host.

Since July 1999, the controllers have been able to send amendments built via URET's Trial Planning functionality back to the Host. The two-way functionality with the Host greatly increased the utility of URET as a tool for the controller. Reduced paper flights strip manipulation has also contributed to controller efficiency.

During a complete critical power failure on 31 October 2000, ZID controllers used URET to improve their situational awareness making it easier for them to control traffic. The URET interfacility capability allowed URET to maintain uninterrupted real-time communication with ZME, thus permitting the smooth handling of aircraft near the ZME boundary. Although URET does not provide controllers with radar updates, the GPD shows flight positions by extrapolating the latest flight plan information allowing controllers to get a graphic view of the traffic as time progressed.

The DSR transition at ZID and ZME was much improved by the URET system. The facilities imposed fewer restrictions to traffic than other facilities during the transition. ZME had the fewest number of delays attributed to the transition than any other facility.

A waiver was granted to make it easier for controllers to handle a Wrong Altitude for Direction clearance. When URET shows no conflicts in the next sector, coordination is not required prior to handoff.

2.7 URET Benefits During Adverse Weather Conditions

Measuring time or distance savings during adverse weather events can be extremely difficult. Variations in the location, severity, and type of weather can cause significant challenges in normalizing the data. As a result, it may be impossible to identify any trends associated with benefits of the tool in adverse weather conditions.

Regardless of the limitations of these metrics, anecdotal evidence suggests URET benefits do exist under adverse weather conditions. The graphic reroute function of URET is regularly used during these periods. This function facilitates the controller in honoring pilot requests for weather avoidance routing. The graphical user interface supports this functionality by displaying:

- A graphic presentation of the requested flight path,
- Traffic conflicts from newly created routes, and
- A text line with the new route displayed.

If the route does not interfere with normal traffic flows, the controller accepts the amendment and the aircraft's flight plan is changed. This process has shown to be a quick and easy method of finding alternative routes around adverse weather. It allows controllers to maintain a steady traffic volume through sectors without overloading normal traffic flows. Furthermore, this function can save unnecessary vectoring or excess mileage due to overloaded sectors.

In addition to traffic flow problems, adverse weather conditions can also create a high stress environment for both controllers and pilots. URET's fast and simple updating functions lower the workload for controllers by reducing the need for manual updating of current flight plans thus providing controllers with more time to make critical decisions. The result is improved decision making providing more efficient services to system users.

Measuring potential benefits of this function is difficult since this capability was not available prior to URET implementation. Consequently, data is not available indicating what would have transpired without the use of URET. Nevertheless, controllers are using the graphic reroute function extensively during these weather conditions. Overall, there are strong indications that the use of URET during periods of adverse weather is providing increasing benefits to both controllers and system users.

2.8 Next Steps

This section describes some future work that the FF Program Office plans to undertake to enhance user benefits and improve our ability to measure these benefits at the seven FFP1 sites. The areas of focus are:

1. Transferring the benefits methodology developed at ZID and ZME to the other URET FFP1 sites.
2. Collecting data one year before IDU in order to have a baseline for comparison when URET is in use.

2.8.1 Transfer of Methodology for Benefits

During the 2001-2002 timeframe, URET will be deployed at the seven FFP1 sites. The FF Program Office is working with the first site, Kansas City Center (ZKC), to help site personnel prepare for implementation and operational transition of URET so that benefits could be achieved as early as possible. The new URET FFP1 sites have the advantage of being able to profit from the experience of operational personnel at ZID and ZME as they develop their site-specific ways of incorporating the new technology.

Site personnel have established FITs to facilitate the transition to and operational acceptance of URET. The FITs will work with the Free Flight Program Office, Lockheed Martin, and CAASD to define and resolve transition issues. Specific activities include:

- Establishing site specific adaptation;
- Identifying operational conditions requiring procedural modification; and
- Transitioning the electronic management of flight data.

2.8.2 Baseline Data

Prior to IDU, the Free Flight Program Office will have a methodology in place to collect baseline data from each site. This data will allow a comparison of metrics before and after URET implementation. This effort is currently on schedule. In addition to the metrics being collected today at the prototype sites, other efforts are underway to investigate additional parameters of data collection for quantifying benefits. These will include how to normalize for weather (use of lightning strikes database), great circle routes versus wind-optimal routes, etc.

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3.0 PASSIVE FINAL APPROACH SPACING TOOL (pFAST)

3.1 Description

The Passive Final Approach Spacing Tool (pFAST) is used by controllers and air traffic managers to manage the flow of arrivals in terminal airspace. pFAST computes a runway assignment and a relative sequence for all arriving aircraft at an airport in such a way as to maximize airport throughput, with consideration given to aircraft type, speed, and trajectory. These advisories are displayed to the controller on the ARTS display. The controller may manually override both the relative sequence number and the runway advisory displayed by pFAST, and the system will automatically adjust.

3.2 Implementation Status

pFAST became operational at the Dallas/Ft. Worth International (DFW) TRACON in early 1999. For a detailed analysis of the impact of pFAST on airspace system users there, please refer to our previous semi-annual FFP1 performance metrics report (Reference 1). Additional information is presented in Reference 4.

The implementation schedule for pFAST is presented in Table 3-1.

Table 3-1. pFAST Implementation Schedule

Airport	Initial Daily Use	Planned Capability Available
Los Angeles (LAX)	February 2001	August 2001
Atlanta Hartsfield (ATL)	March 2001	September 2001
Minneapolis (MSP)	June 2001	December 2001
St. Louis (STL)	October 2001	April 2002
Chicago O'Hare (ORD)	To Be Determined	To Be Determined

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4.0 TRAFFIC MANAGEMENT ADVISOR (TMA)

4.1 Description

The Traffic Management Advisor (TMA) component of the Center TRACON Automation System (CTAS) assists controllers in the enroute cruise and transition airspace around major airports by providing them with a means of optimizing arrival throughput. By optimizing throughput TMA helps to reduce arrival delays, and the resulting uniformity of arrival flows can also lead to an increase in departure rates and decreased departure delays. Inputs to the TMA system include real-time radar track data, flight plan data, and a three-dimensional grid of wind speeds and directions. TMA's trajectory models use this information, updated every 12 seconds, to compute routes and optimal schedules to the TRACON meter fixes for all arriving IFR aircraft, with consideration given to separation, airspace, and airport constraints.

TMA is used both as a strategic planning tool by managers in the ARTCC Traffic Management Unit (TMU) and tactically by controllers who are actively controlling aircraft. The TMA computer interface incorporates two primary strategic displays. The Timeline Graphical User Interface (T-GUI) displays estimated time of arrival, CTAS-computed per aircraft delay, scheduled time of arrival, and runway assignment for each track in the TMA area of regard. The Planview Graphical User Interface (P-GUI) displays a planview depiction of arriving aircraft. TMU managers use these and other displays to determine if and when metering will need to be imposed in the Center's airspace so that the arrival rate specified by the TRACON is not exceeded. When metering is imposed, floor controllers see a sequence list on their radar displays that indicates which aircraft need to be delayed and by how much.

4.2 Implementation Status

TMA has been operational at Ft. Worth Center (ZFW) since June 1996, where it is used to meter arrivals into Dallas/Ft. Worth International Airport (DFW). Additionally, since our last semi-annual report TMA has become operational at the following three facilities:

- Minneapolis Center (ZMP) for Minneapolis/St. Paul (MSP) arrivals: IDU[2] 21 June 2000, Planned Capability Available (PCA) 20 December 2000.
- Denver Center (ZDV) for Denver International (DEN) arrivals: IDU 6 September 2000.
- Los Angeles Center (ZLA) for Los Angeles International (LAX) arrivals: IDU 21 November 2000.

TMA has not yet achieved PCA status at Denver or Los Angeles Centers.

The future implementation schedule for TMA is presented in Table 4-1.

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[2] IDU signifies that hardware and software are installed and the initial cadre of operators is using the system to provide air traffic services. PCA signifies that all planned operators are using the system on a regular basis to provide air traffic services.

Table 4-1. TMA Implementation Schedule

Center	Airport	Initial Daily Use
Atlanta (ZTL)	Atlanta Hartsfield (ATL)	22 February 2001
Miami (ZMA)	Miami International (MIA)	23 May 2001
Oakland (ZOA)	San Francisco International (SFO)	3 September 2001
Chicago (ZAU)	Chicago O'Hare (ORD)	31 December 2002

This semi-annual report will focus on results of preliminary analyses at ZMP/MSP. As we reported in our June 2000 report, TMA performance at ZFW/DFW is not being analyzed, since the automation tool has been in virtually uninterrupted use there since the redesign of the DFW Metroplex airspace, and adequate baseline data is not available. Analyses for ZDV/DEN and ZLA/LAX will be included in our next semi-annual report in June 2001.

4.3 ZMP/MSP Preliminary Analysis

Unlike URET, where we have more than a year's worth of experience in analyzing data from two Centers, our analysis of TMA at ZMP/MSP is in its early stages. TMA just achieved PCA status in December 2000. A complete data set including weather, tracks, and logs was only available through October 2000. We therefore have only three and one-half months worth of initial in-use IDU data with which to draw any conclusions. We are monitoring numerous metrics which may be indicators of TMA's operational impact without establishing a specific benefit. The results that follow should therefore be considered preliminary, and will likely change as controllers and managers become more familiar with the tool and we obtain more data.

4.3.1 Summary of Results to Date

The results of some of our preliminary analyses of the impact of TMA on airspace system users at ZMP/MSP are summarized below. More details regarding each of these preliminary results follow.

- As yet there has been no measurable change in Airport Acceptance Rates (AARs) at MSP.
- There has been a small increase in actual arrival rates when visual approaches are in use, and a slightly larger increase when instrument approaches are in use. We continue to develop a more sophisticated statistical model in order to isolate the impact of TMA from other factors and thereby refine our estimates.
- There has similarly been a small increase in operations rates (arrivals plus departures) during arrival peaks under both visual and instrument approaches.
- There has been an increase in the difference between actual arrival rates and AARs, and the standard deviation of this difference has decreased.
- Flight times from the 200 nmi range ring to the runway threshold have slightly decreased.

- There has been no operationally significant change in flight distances from the 200 nmi range ring to the runway threshold.
- Both taxi-in and taxi-out times have slightly increased.

4.3.2 Airport Acceptance Rate

Since TMA allows Center controllers to more smoothly feed arriving traffic into TRACON airspace, we might expect TRACON traffic managers to increase Airport Acceptance Rates (AARs) following TMA implementation, as smoother flows are easier to accommodate. This was found to be the case at Dallas/Ft. Worth International (DFW), where acceptance rates increased by approximately six aircraft per arrival rush following TMA implementation at Ft. Worth ARTCC. In order to see if TMA has had a similar impact on acceptance rates at MSP, we first compared mean AARs for the periods prior and subsequent to TMA implementation. The source of this data was MSP TRACON daily traffic management logs, which we have collected from the facility since the summer of 1999. When computing the mean AARs, the individual log entries were weighted by the length of time for which the entry applied. Table 4-2 presents the weighted mean AARs for MSP, pre- and post-TMA implementation, segregated into visual and instrument approach conditions. While these differences are small, they are statistically significant at the 5 percent level.

Table 4-2. Weighted Average Airport Acceptance Rates

Approaches In Use	pre-TMA Implementation[1]	post-TMA Implementation[2]
Visual	59.2	59.3
Instrument	54.1	54.6

[1] 1 October 1999 – 13 June 2000

[2] 15 July 2000 – 31 October 2000

In order to determine if these observed differences could be accounted for by other factors (such as differing weather conditions during the periods under examination), a regression analysis was performed on the logged values. Independent variables accounting for surface weather conditions, runway configuration, taxi-way construction, arrival bank, and TMA usage were included in the model. A weighted least squares technique was used, with each observation weighted by the time spent in that particular configuration and AAR. The results of this more detailed analysis suggest that TMA has *not* had a significant impact on AAR.

4.3.3 Actual Arrival Rates

Next the actual arrival rate into MSP during busy periods was examined. Generally, there are eight arrival pushes a day at MSP; these are the times at which TMA is expected to yield the most benefit. The day was divided into eight distinct time spans, and the peak number of arrivals in any 30 minute time period was determined for each time span (this was also done for 20 and 40 minute periods, however these have not yet been subject to analysis). Single factor regressions were done to get a preliminary indication of the effects of TMA.

Overall, prior to TMA implementation, the mean number of arrivals in a peak 30 minute period is 31.6. The effect of TMA is to increase the number of arrivals by 0.9 to 32.5, as illustrated in Figure 4-1.

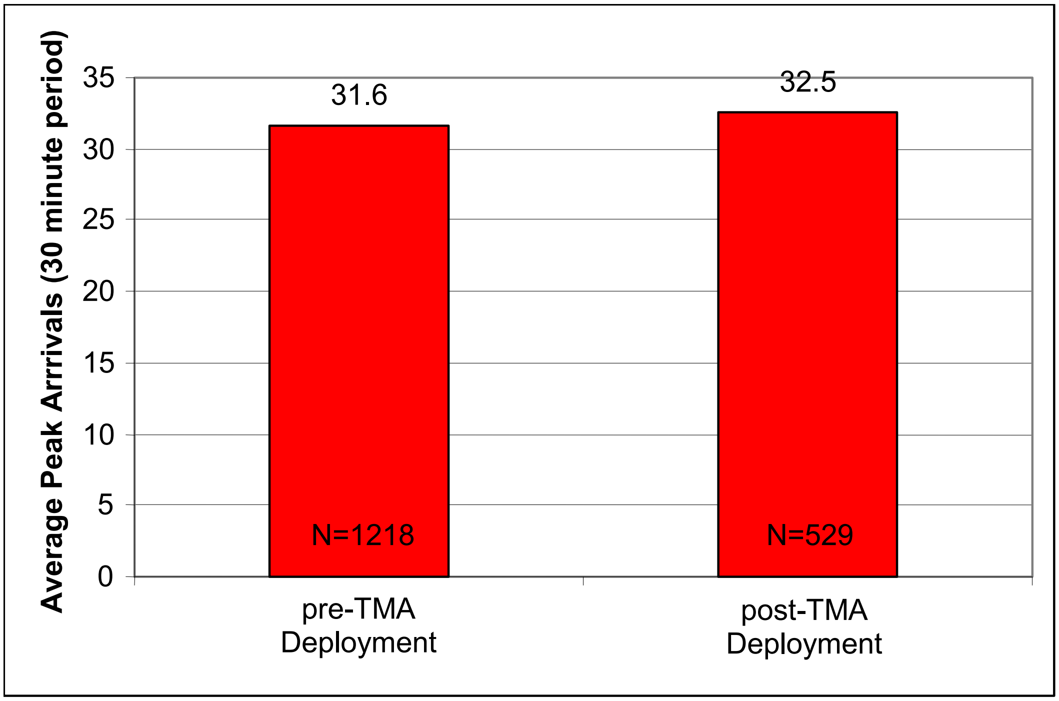

Figure 4-1. Increased Arrivals During Peak Periods

A refinement of this analysis is to examine instrument and visual approach periods separately. Under visual approach conditions, the mean number of arrivals in a peak 30 minute period was 32.4 prior to implementation. With TMA, this number rises to 33.1. Under instrument approach conditions, the mean number of arrivals in a peak 30 minutes period prior to implementation is 29.8. After implementation, the new number of arrivals with TMA rises 1.3 to 31.1. These findings are illustrated in Figure 4-2. A t-test of means indicates that the differences are statistically significant at the 5 percent level.

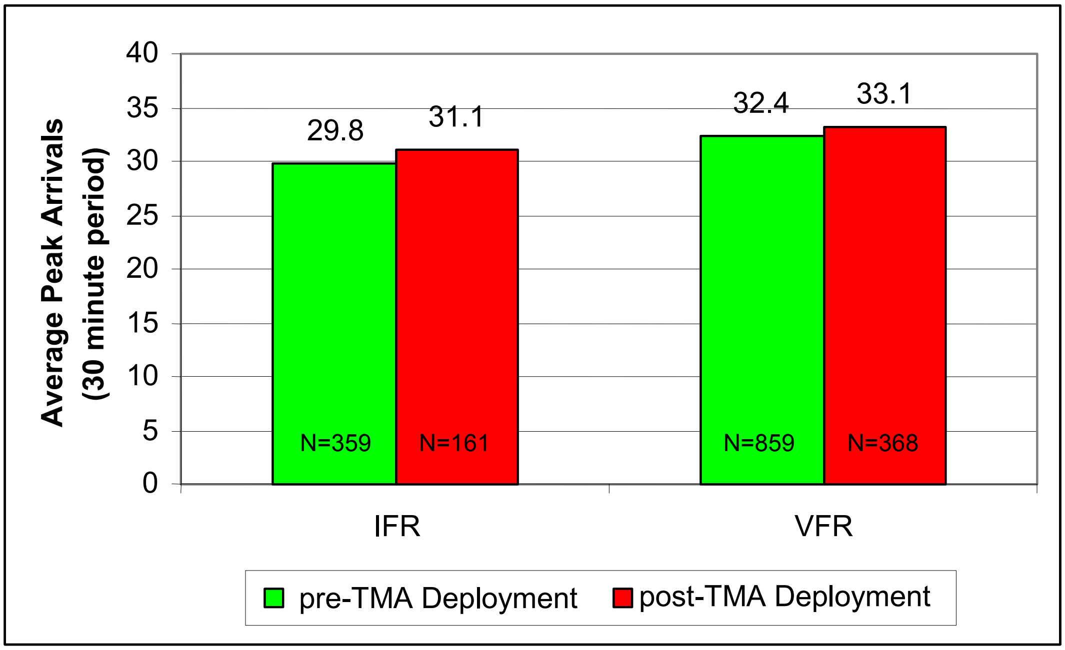

Figure 4-2. Increased Arrivals During Peak Periods, Visual and Instrument Conditions

Further analysis in this area will focus on developing a regression model, the goal of which is to discern the effect of TMA while excluding the possibility that the apparent TMA effect is the result of other factors that changed at the same time TMA was implemented. Preliminary investigation of the data has highlighted a number of factors that should be considered.

Visual/Instrument Approaches. Single regression results for this factor were provided above. This variable is determined using the TMU logs. The airport acceptance rate under visual approach conditions is about four aircraft per hour higher than under instrument approach conditions, assuming all runways are in use. Controlling for this variable is important because the AAR set by the TRACON, and therefore the rate that TMA is metering to, is contingent upon the approach conditions.

Visibility. Surface visibility is generally correlated with arrival rates. Sometimes a logarithmic transformation of visibility is used so that small changes at lower levels of visibility have more impact on modeled arrival rates than small changes at higher levels (in other words, a change from one to two miles visibility is likely to have a larger impact than a change from nine to ten miles).

Ceiling. Likewise, cloud ceiling is generally correlated with arrival rates, with rates increasing as ceilings increase. Again, a logarithmic transformation will be considered so that small changes with low ceilings have more effect than small changes with high ceilings.

Surface Wind. Increased wind speed tends to decrease arrival rates. Various transformations of wind can be used, such as cross-wind component, head-wind component, and gust component. The square of the wind velocity is also sometimes used. This transformation has the opposite effect of the logarithm discussed above, producing a larger impact for changes at large values than at small values.

Runway 22 in Use. This crossing runway is used for purposes of noise abatement, or when a pilot requires it due to its greater length, or because of wind conditions. Its use is generally correlated with lower arrival rates.

Runways 30/12 in Use. The number of arrivals in a peak 30 minute period does not seem to be affected by this airport configuration variable, however this factor has not been eliminated from consideration.

Season. The arrival rate during peak 30 minute periods appears to vary by season of the year. There are two approaches to defining the seasons. The first is to adopt the calendar definition, where for example spring starts on March 20th. The second is to align more closely with the meteorological seasons, where spring starts on March 1st. Airline scheduling patterns tend to change by meteorological season, so the second approach is likely to be adopted.

Weekend. The number of arrivals in a peak 30 minute period tends to be lower on the weekends than on weekdays. Further investigation will determine whether this is true of Saturdays only, or both Saturdays and Sundays. This effect may be due to lower demand on weekends, so a demand variable may be substituted as an explanatory variable in the regression model. Arrival rates during peak 30 minute periods have not been shown to vary by day of the week, other than weekend.

Bank ID. As mentioned earlier, the day was divided into eight time spans in order to isolate the pronounced eight arrival banks at MSP. The pushes have been found to differ in a number of respects, including fleet mix, whether the traffic is coming from the west or the east, arrival traffic flow over the meter fixes, and possibly the level of demand. Further exploration is needed to determine whether the "bank id" is an adequate explanatory variable that includes the effects of these other variables, or whether a combination of these variables can be used instead.

Percentage of Heavy Jets. This is a variable that is used to represent the fleet mix, specifically the percentage of heavy jets within a given time period.

Percentage of 757's. This is another indicator of the fleet mix. 757's are classified as large jets, but require special handling.

Percentage of East Arrivals. This is a measure of the direction from which the traffic is arriving at MSP. This variable varies between zero and one, increasing as the percentage of traffic from the east increases. The east/west boundary is simply the line of longitude passing through MSP.

Dispersion. This variable indicates to what extent meter fix use is balanced. The variable varies between zero and one, equaling one if all four fixes have the same amount of traffic, and zero if only one fix is used.

Demand. TMA is expected to have its greatest effect when the system is stressed. Therefore, an indicator is needed of how much demand was available to be met, and whether the demand was close to the AAR. There are a number of ways in which an explanatory variable for demand can be defined. The scheduled demand during peak 30 minute periods has been explored as a possibility; the question is whether scheduled demand on any given day actually arrives. It has also been suggested that actual traffic flow over the outer arcs could be used, although this may be so highly correlated with actual arrival rates that the effect of TMA cannot be discerned.

4.3.4 Operations Rates

The number of operations (the number of arrivals plus the number of departures) during busy periods was analyzed in a manner similar to the analysis of peak arrival rates. The dependent variable is the number of operations in the time period in which the peak 30 minute arrival rate was observed. Single factor regressions were performed to see if TMA may have affected operations rates.

Prior to TMA implementation, the mean number of operations per 30 minute arrival peak was 51.8, while after implementation the mean rose by 2.9 to 54.7. This is illustrated in Figure 4-3.

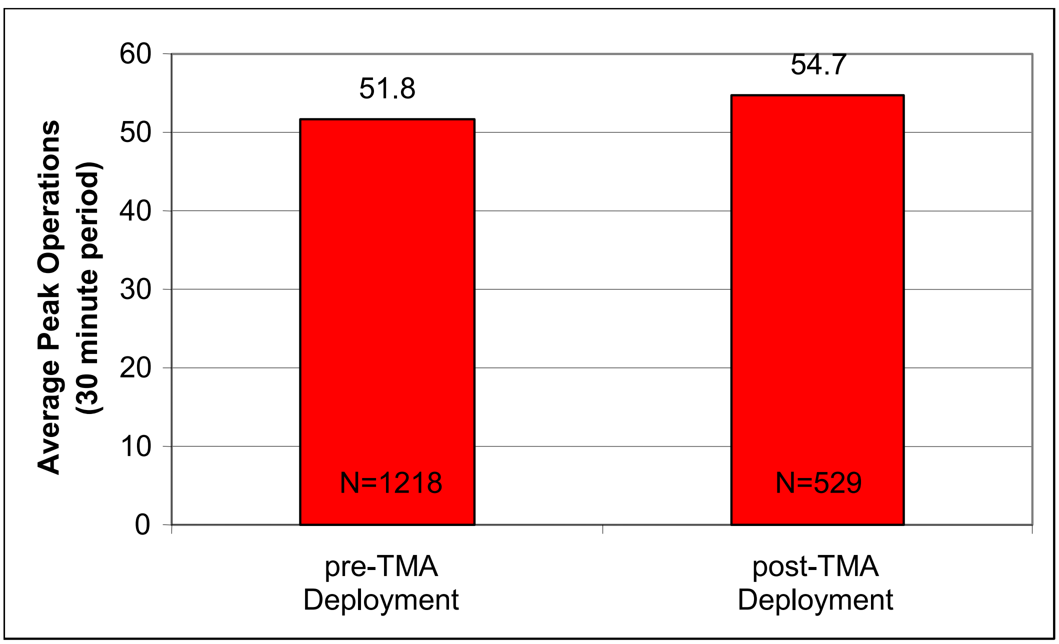

Figure 4-3. Increased Operations During Peak Periods, Visual and Instrument Conditions

Under instrument approach conditions, the mean peak 30 operations rate was 50.5 prior to implementation, and 53.4 following implementation as shown in Figure 4-4. For comparison, under visual approach conditions the mean operations rate was 52.4, rising to 55.3 after implementation. TMA apparently has the same effect on operations rates under both visual and instrument approach conditions, whereas TMA had more effect on the arrival rates in instrument approach conditions. In all cases, a t-test of means indicates that the differences are statistically significant at the 5 percent level.

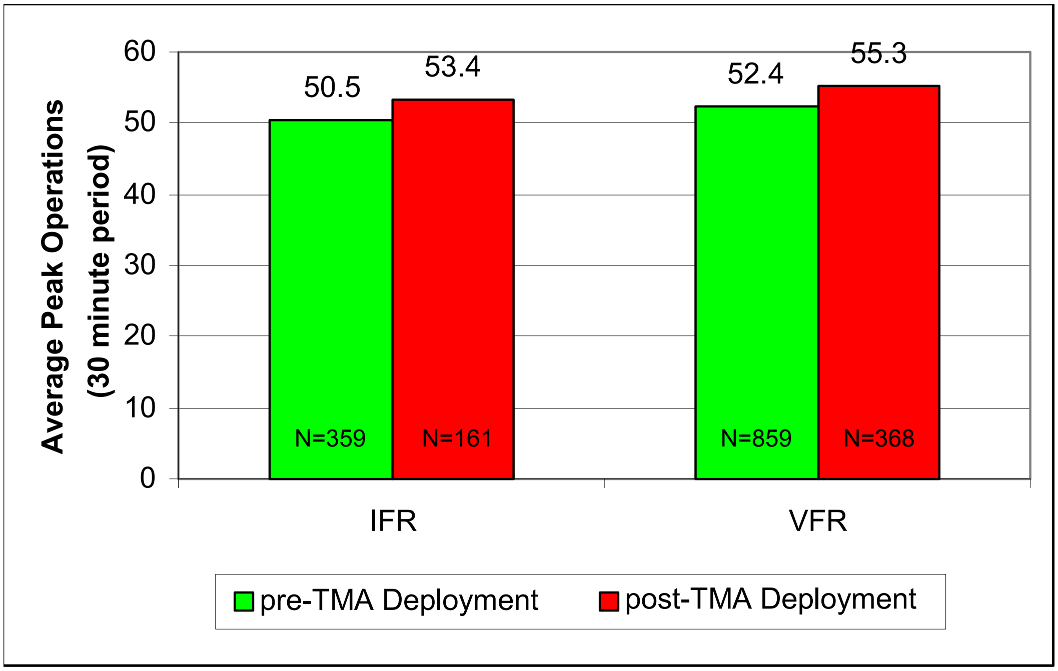

Figure 4-4. Increased Operations During Peak Periods, Visual and Instrument Conditions

Further analysis of operations rate will focus on developing a regression model, similar to what is being done for peak arrival rates. The same explanatory variables as described above will be employed in developing the model.

4.3.5 Comparison of AAR and Actual Arrival Rates

TMA is used by Center controllers to help meter arrival flows into TRACON airspace. All else being equal, we would expect to see a "smoother" flow of traffic into the TRACON when TMA is used to meter than when it's predecessor ASP was used, or when no tool was used. In addition, we would expect to see the actual arrival rate more closely match the rate specified by the TRACON (i.e., the AAR).

In order to see if this is the case, we examined the difference between actual arrival rates and AARs during arrival peaks. While the previous analyses of arrival and operations rates used the 30-minute peak arrival intervals as the sample set, for this analysis we used the 30-aircraft peak arrival periods (we find the closest-spaced 30 aircraft during an arrival push, and use this time interval).[3] Each observation consists of the actual arrival rate less the AAR for a 30-aircraft peak. We used ZMP logs to determine when the Center was using TMA to display delay times on controllers' radar displays. The times logged were manually matched with the 30-aircraft peak periods, and those which closely corresponded were judged to have been metered. Currently, the Center does not log every occurrence of metering, so while we are able to identify peaks when metering is performed, we cannot tell with any certainty when metering is *not* being performed

[3] The 30-aircraft peak periods tend to last approximately 30 minutes, but each sample is different. The median 30-aircraft duration is 28.3 minutes, the 5th percentile is 23.3 minutes, and the 95th percentile 34.9 minutes.

following TMA introduction. Therefore we have only used peaks from prior to TMA IDU for the non-metering sample, and a subset of peaks subsequent to IDU for the metering sample.

The results of the initial comparison of the difference between actual and specified arrival rates is presented in box plot form in Figure 4-5 (for a description of the box plot, see Appendix A). Two points should be obvious from this figure: first, that the median of the difference between actual arrival rate and AAR is higher when TMA is used to meter traffic; and second, that the variance of this difference is smaller when TMA metering is used. A statistical test on the difference between these two medians confirms that the difference is statistically significant at the 5 percent level (Reference 5). Additionally, a squared-ranks test on the difference between the observed variances of the two samples similarly confirms that the difference is statistically significant at the 5 percent level (Reference 5). The finding that the difference between actual and specified rates is higher with TMA metering than without is consistent with the results reported above, namely that AARs have not appreciably changed but that actual arrival rates have increased. For this to be true the difference between actual rates and AAR must have increased.

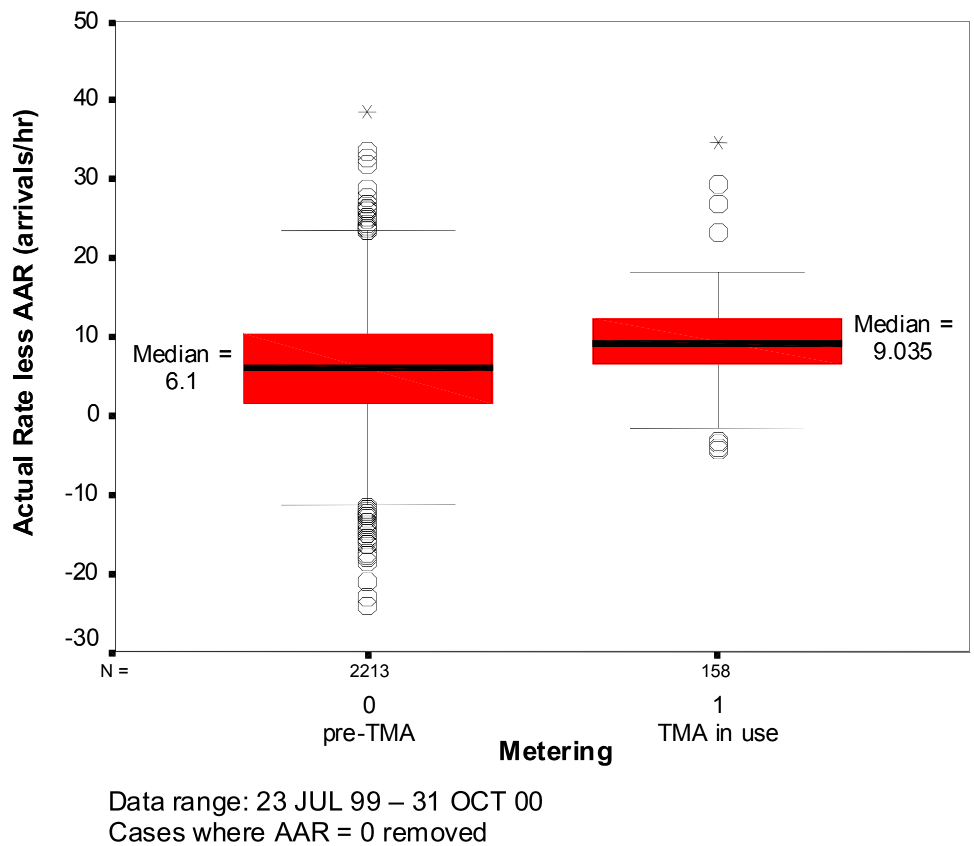

Figure 4-5. Comparison of Actual Arrival Rate and AAR

Although the above results seem conclusive, we were concerned that there might be some statistical bias inherent in the manner with which the samples were selected. While the baseline sample includes an equal weighting of data from each of the eight daily peaks at MSP, the metering sample could be skewed towards a subset of peaks, if metering is not equally likely throughout the day. A histogram of the banks for which metering was recorded and which make up our subsample, shown in Figure 4-6, does indeed suggest that metering is not uniformly used throughout the day. For example, metering appears to be much more frequently used during Bank 6 (16:23 – 18:45 CT) than during Bank 8 (20:15 – 22:00 CT).

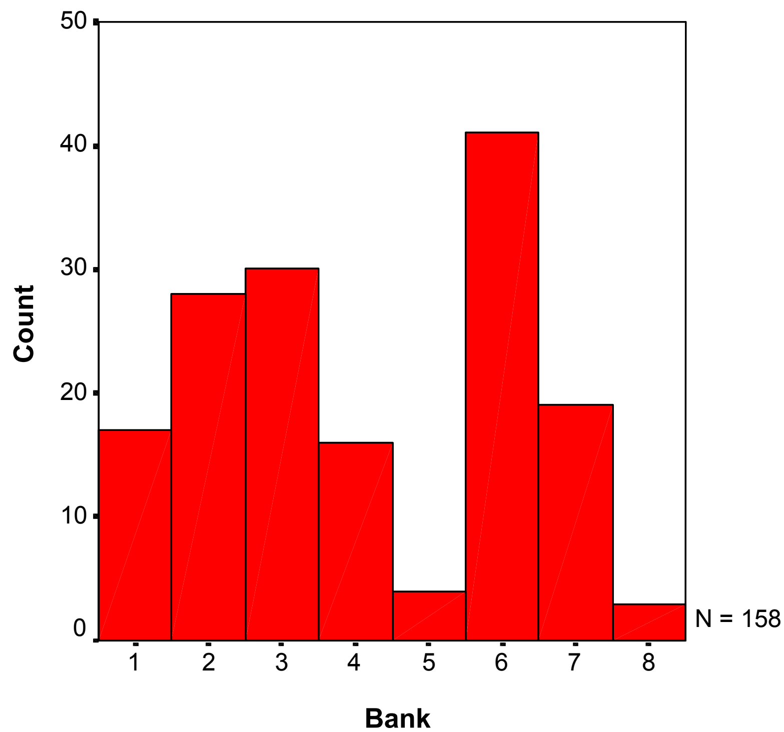

Figure 4-6. Distribution of Observed Metering Periods

In order to see if this sampling bias had any impact on our conclusion regarding the difference between actual arrival rate and AAR, we re-examined this metric, this time segregating the data by bank. Figure 4-7 presents histograms of the difference between actual arrival rate and AAR by arrival bank, both with and without TMA metering. Many of the banks exhibit small sample sizes for the metering case. However, Banks 3 and 6 have adequate sample sizes, and for both of these banks the previously noted trends continue, namely, that the mean difference between the actual and specified rates is greater when metering, and that the variance of this difference is smaller.

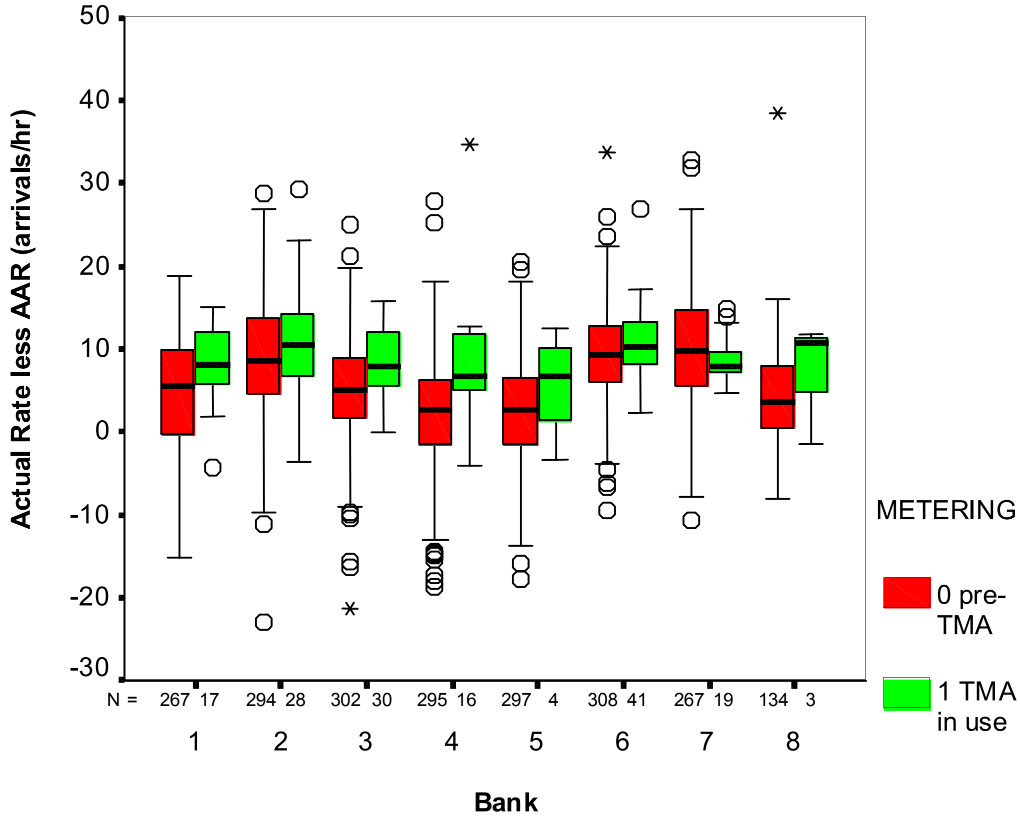

Figure 4-7. Comparison of Actual Arrival Rate and AAR by Bank

4.3.6 Flight Times

As part of the analysis of the effects of TMA at MSP, we analyzed arrival aircraft flight times in Minneapolis Center (ZMP) airspace. TMA seeks to meter aircraft according to the Airport Acceptance Rate (AAR) being called by the TRACON. If issuing delay to the arriving aircraft is necessary, it is most economical to incur this delay (i.e., speed control and/or vectoring) at higher altitudes where aircraft are more fuel efficient. Therefore, to conduct our analyses the flight path of the arriving aircraft is divided into events associated with arcs centered at MSP (see Figure 4-8). The predefined arcs are as follows: Extreme Arc (EA) at 200 nmi, Outer Arc (OA) at 160 nmi, Inner Arc (IA) at 100 nmi, and Meter Arc (MA) at 40 nmi. Host data was used to calculate the average flying time between each successive pair of these arcs for those flights that arrived during the approximate eight peak 30-minute periods each day from 1 October 1999 through 31 October 2000.

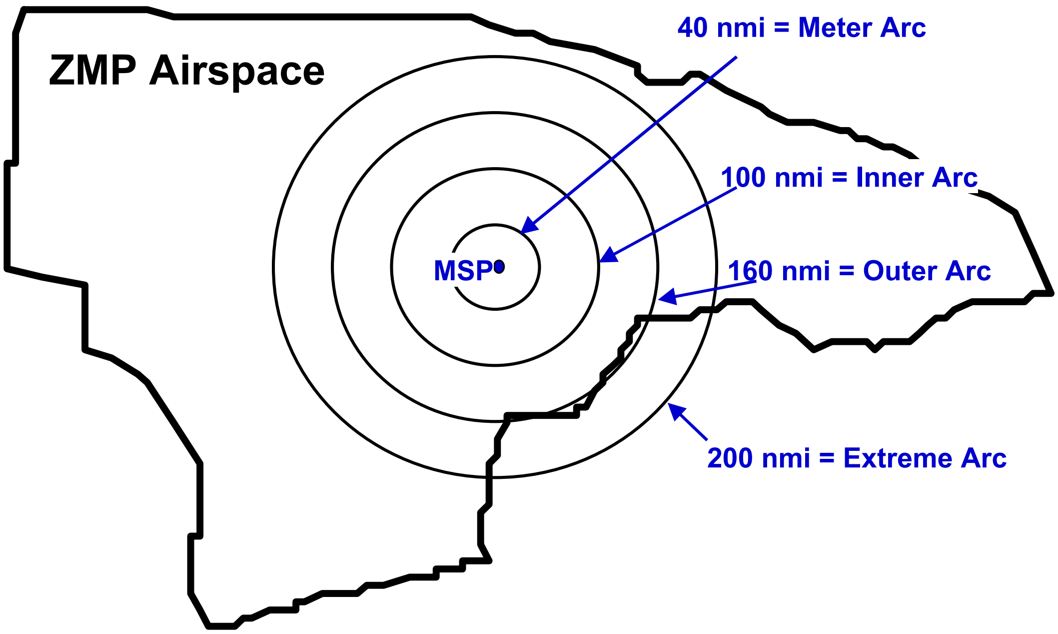

Figure 4-8. MSP Arc Events for Analysis of Flight Time and Distance

The average flying time *savings* following TMA implementation are presented in Figure 4-9. Only small differences in flight times were reported across each of the arc events; however, in the aggregate, the effect of TMA on flight time from 200nmi to runway threshold is a reduction of 69 seconds under instrument approach conditions and a reduction of 45 seconds under visual approach conditions.

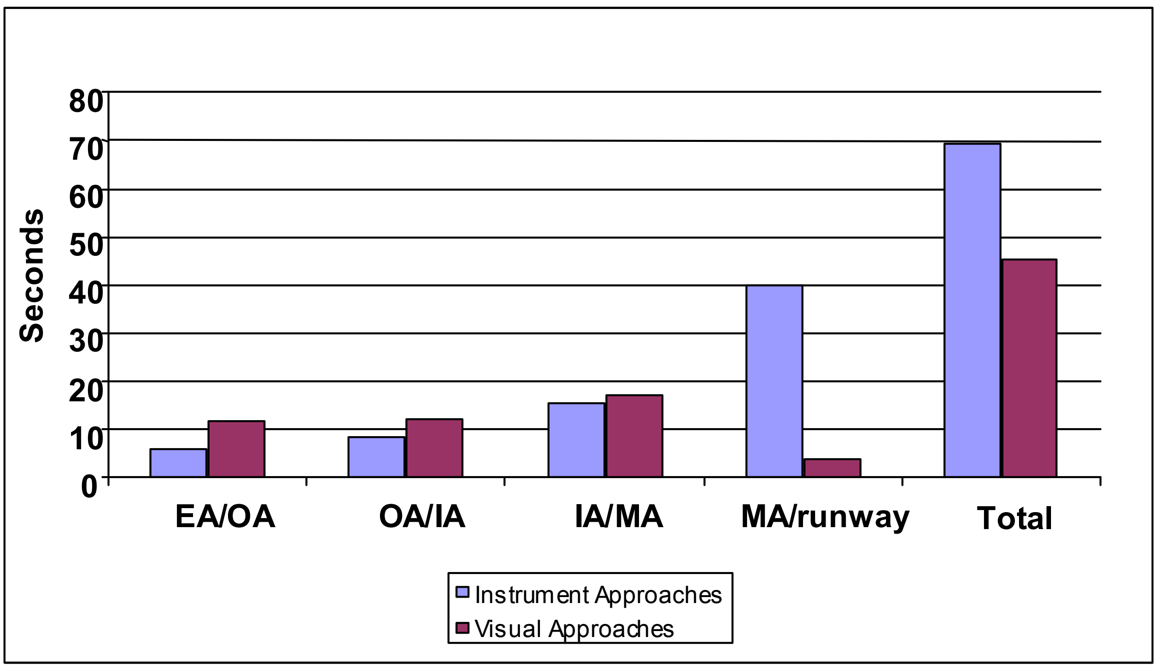

Figure 4-9. ZMP Flight Time Savings (Following TMA Implementation)

4.3.7 Flight Distances

In conjunction with flight times we also analyzed flight distances across each of the above mentioned predefined arcs. The same flights that were analyzed in the above flight time analysis were analyzed to determine if their flight distance changed with the implementation of TMA. Preliminary results suggest that there has been an operationally insignificant increase in flying distance from the 200 nmi range ring to the runway threshold since TMA implementation. The results, broken out for instrument and visual approach conditions, are presented in Figure 4-10.

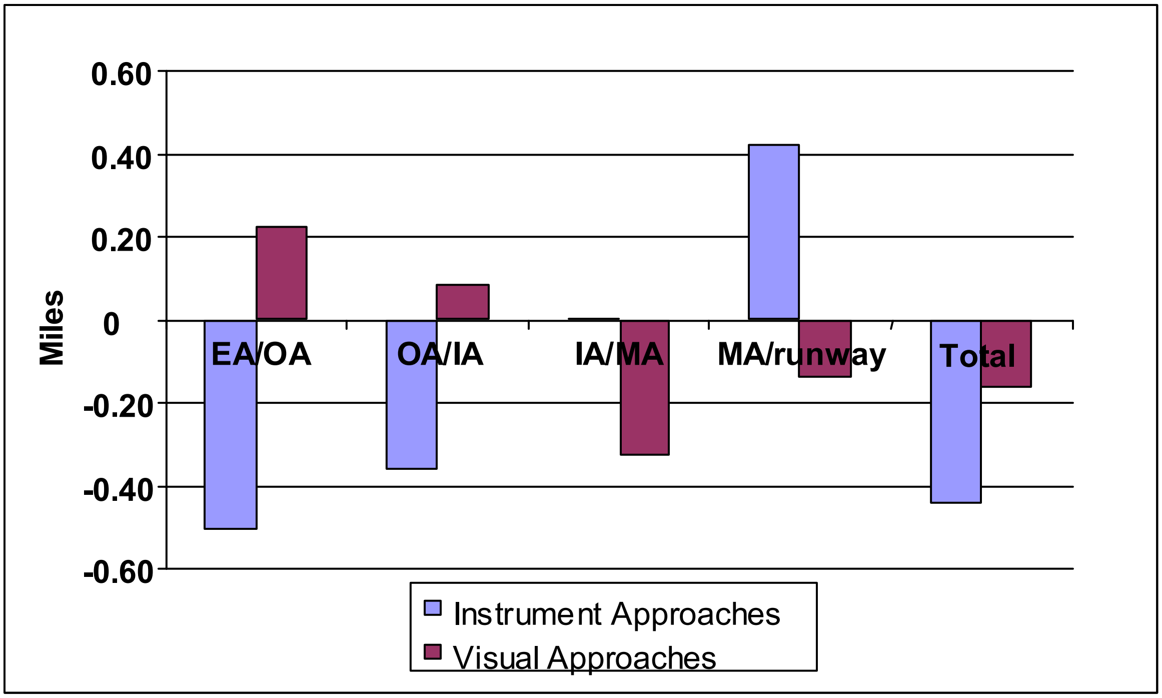

Figure 4-10. ZMP Flight Distance Savings (Following TMA Implementation)

4.3.8 Taxi Times

Part of the analysis of TMA includes a study of potential "downstream" impacts. Although TMA is an automation tool intended to assist controllers with arriving aircraft, it is important to understand whether TMA might indirectly affect ground movement (taxi) times.

Airline Service Quality Performance (ASQP) data, which includes taxi times, was collected for both arriving and departing flights during the 30-minute peak arrival periods. The data for the study spans the period from 1 October 1999 to 30 September 2000 (excluding the same periods as the other analyses). ASQP data encompasses approximately 60 percent of the total flights at MSP. The resultant data set contained approximately 54,000 flights. For this analysis TMA was considered to be in use during July, August, and September 2000.

The preliminary analysis shows a slight increase in the mean taxi-out and taxi-in times following TMA implementation (Figure 4-11). Without correcting for other factors, the mean taxi-in time increased by 0.55 minutes and the mean taxi-out time increased by 0.29 minutes following implementation. These differences are small, but statistically significant at the 5 percent level. The median times for both taxi-in and taxi-out are essentially unchanged.

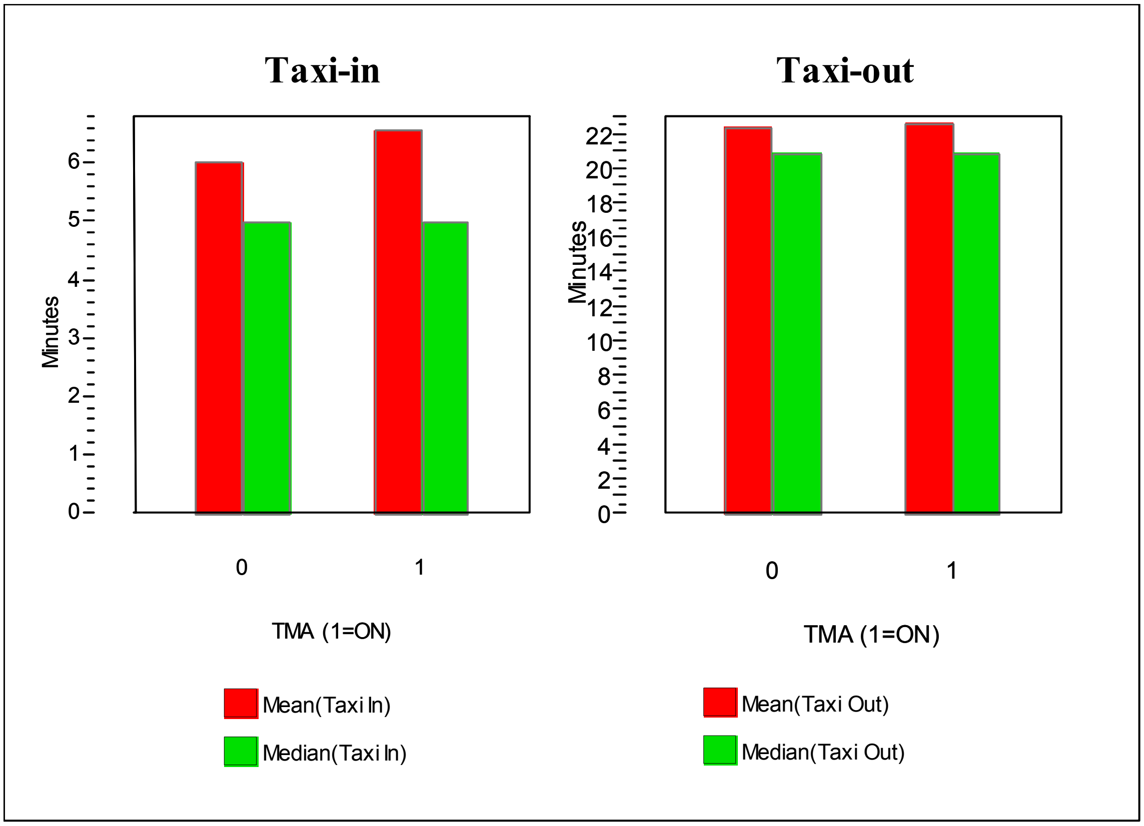

Figure 4-11. Taxi Time Analysis at MSP, October 1999 – September 2000

The small increases in mean taxi times are a possible result of increased arrival rates. We will require additional data to effectively capture the impact of other factors such as demand, weather, and airport configuration. Notably, with the median times remaining unchanged, the differences in means are being affected by changes in the extremes (upper and lower values) – possibly due to factors other than TMA. In order to isolate the impact of TMA on taxi times, we intend to conduct a regression analysis on these metrics as well.

5.0 SURFACE MOVEMENT ADVISOR (SMA)

5.1 Description

Surface Movement Advisor (SMA) provides aircraft arrival information to Airline Operations Centers (AOCs) and/or to airline ramp towers. At those airports where SMA is implemented, ARTS III data is available. This data provides airline operations managers with the necessary information to remain informed of the status of arriving aircraft. Similarly, ramp controllers are able to use SMA to enhance user's gate and ramp operations. In short, the availability of this system facilitates greater collaboration between tower controllers and ramp personnel and provides real-time information for decision making.

ARTS III provides real-time data on arriving aircraft that may be used to facilitate accurate prediction of future traffic flows. ARTS III data includes information on aircraft identification and position in TRACON airspace, providing the necessary information to compute estimated touchdown times. Additionally, this data can allow users to better coordinate ground support operations, allocating resources such as ramp and airport services more efficiently. SMA includes a display which visually provides information on arriving aircraft and calculates arrival statistics including estimated time to touchdown (ETT).

5.2 Reported Anecdotal Benefits

Based on the ability of the AOC and ramp tower personnel to observe near real time location of aircraft in the terminal domain, operational improvements have been demonstrated at SMA locations. In the past, when AOCs were interested in knowing the exact location of aircraft in the terminal domain of an airport, they were forced to make a call to an FAA facility. Enhanced Traffic Management System (ETMS) is also available, but because this data is limited to 4-minute updates it does not provide the precision necessary for evaluating terminal area traffic flows.

With the implementation of the ARTS III data feed and proof of concept display, AOC managers can now receive aircraft location and estimated touchdown times in near real-time. This improvement in situational awareness in the AOC can be relayed to the pilot enabling improved decisions when a diversion is being considered. The ARTS data feed is also valuable to airline ramp tower operators in efficient management of gates.

These benefits, although primarily qualitative are being reported by participating airlines. Many of these reported benefits have been translated into actual dollar savings by the airlines. The June 2000 Report also provides an estimation of dollar benefits based on reported diversions saved. The following provides a list of additional SMA benefits followed by a brief update to the SMA system.

- Improved Situational Awareness to AOCs,
- Reduced Aircraft Diversions,
- Reduced Phone Coordination with FAA TMU,

- Improved Planning for Missed Approaches, and
- Improved Ground Operations.

In the June 2000 report, it was stated that US Airways (USA) has found many benefits from the SMA ARTS III flight display in observing terminal flight operations at PHL. Specifically, these benefits include a reduction in diversions due to better and timelier information contributing to better tactical decision making, especially under irregular operations. In fact, USA stated that the ability to quickly see the arrival flow, observe runway changes, use of the overflow runway, and observe departure flow and rates has also reduced diversions at PHL.

US Airways has recently stated that they have expanded the SMA data to the (USA) Express ramp tower in Philadelphia (PHL) and are currently putting SMA data in the LGA ramp tower, planned to be operational in late January 2001. The Free Flight Office has also developed and provided airlines with display software to facilitate airline operations.

US Airways has found the ARTS III data feed to be so beneficial that they are willing to invest their own money setting up additional ramp tower locations at existing SMA airports. Additionally, they have expressed interest in finding out what is necessary to have SMA installed in Charlotte and Pittsburgh.

6.0 REFINEMENT OF METRICS

The FFP1 Metrics Plan (Reference 2) was developed in collaboration with the RTCA FFP1 Steering Committee. The Plan recognized that measuring operational impact required developing methods to measure specific parts of the very complex National Airspace System. Since this was the first time that measuring operational impact of new capabilities had been undertaken, the plan was developed with expert judgment but without the benefit of first hand experience. Since the Plan was developed, much experience has been gained on the measurability and interpretability of the original metrics. The FFP1 Metrics Team has focused in on a primary set of metrics that we believe best capture the performance impact of each tool. We will continue to track other metrics as secondary measures to confirm results in the primary metrics. As more data is collected and our ability to process data improves we will continue to refine our measures.

6.1 Focus on Certain User Objectives

The Metrics Plan states “the underlying goal of FFP1 is to provide early benefits to NAS users using proven technologies.” This goal has not changed. The plan went on to say “these benefits will be measured based on each capability’s performance in achieving NAS user objectives.” These user objectives include:

- Safety
- User access
- Delay/efficiency
- Predictability
- Flexibility
- System productivity

The Metrics Team has found that some of the items on this list are not readily measurable and that some of the originally planned methodologies needed further refinement. From a practical standpoint the list has been further narrowed to three objectives:

- Safety
- Capacity Improvements
- Efficiency

6.2 Safety Metrics

Safety remains an objective that we need to measure, however, the original plan was to count the changes in OEs and ODs associated with each tool. To accomplish this goal it is necessary to understand the root causes of the historical set of OEs and ODs. On a facility level OEs and ODs are infrequent and have no clear historical trends. Where FFP1 tools have been deployed we have seen no change in error rates. However, to be assured no OEs or ODs had occurred as a result of the tools, we have begun to work closely with the FAA's Air Traffic Evaluations and Investigations Office.

For each OE, AAT-20 specifically determines whether it might be attributable to new procedures or equipment including FFP1 capabilities. If an OE or OD occurs in a facility where FFP1 capabilities exist, specific questions are asked to determine whether an FFP1 tool might have been a cause. In some cases, the initial indication was that an FFP1 tool did contribute to an OE, however, further investigation determined that not to be true. In some of these OEs, it was determined that if more attention had been given to the FFP1 tool the error might have been avoided. To date, AAT-20 has reported that no OEs have been attributable to FFP1 capabilities.

6.3 Capacity Metrics

Within the FAA, measuring and tracking delay statistics has been the traditional primary measure of system performance. The Metrics Plan also included "delay" metrics for measuring efficiency. The Metrics Team has since found that while there is meaningful information in this delay tracking, it does not adequately reflect gains in system performance when a new capability is added. The problem with tracking delays alone is that system demand is a factor in delays. That is, within a given amount of time, if more aircraft try to operate than the system has capacity for, then delays occur.

A better way to measure the impact of new capability is to measure capacity. If capacity increases the result is more throughput during peak traffic times. Increases in throughput would cause a decrease in delays with a given level of demand.

Early in the process of measuring system performance it became apparent that demand on the system must be considered. When attempts are made to measure capacity improvements measuring throughput alone does not tell the whole story. For example, during times when demand is low and few aircraft want to use the system, low throughput does not mean that the system capacity somehow became less.

The team recognized that system capacity improvements would only be measurable during times when the system is busy or stressed. Analysis of data showed that traffic periods tend to peak at about the same rate from peak to peak and day-to-day varying some with differing conditions. These peaks in traffic throughput are constrained by capacity limits at these points. Therefore, measuring changes in throughput during peak traffic periods is a way of measuring changes in capacity. For these reasons, when measuring capacity improvements, the metrics team has focused on measuring throughput only during peak traffic periods.

6.4 Efficiency Metrics

Efficiency improvements in aircraft operations can be expressed as savings in time, savings in distance, or savings in fuel. Each of these has some problems associated with it in any attempt to measure them and attribute the savings to the addition of a FFP1 capability.

Of these three ways to measure and express efficiency, the FFP1 Metrics Team has focused primarily on distance savings. In most cases, a reduction of distance flown will result in a reduction of time flown and a reduction in fuel burned. It is recognized that this will not always be true. For example, aircraft occasionally will not fly the shortest route in order to take advantage of favorable winds. This is especially true on very long flights. With the limited implementation of FFP1 capabilities, the benefits expected will occur in relatively short flights or measured segments of flights. With short segments of flights we would not expect to see significantly longer segments preferred for beneficial winds. We believe the opportunities for wind routes in the airspace where FFP1 will be deployed will be minimal and we will try to collect information from en route facilities when wind routes are in effect.

The team has attempted to measure time savings. When comparing times flown for segments of flight one must normalize for the wind effects. This is a nearly impossible task in that wind is nearly infinitely variable with changes of altitude and changes in location. Obtaining accurate data to properly account for wind is a cost prohibitive task given the minimal additional value. Of course, not using a time metric limits our ability to see the impacts of “speed” control as an ATC technique. Our experience with controllers indicates that speed control is used much less frequently than vectoring, especially in the en route environment. Lastly, we will continue to collect flight time data as a secondary metric. In the future we may be able to make better use of flight time data.

Any attempt to measure fuel efficiency requires detailed fuel consumption data. When trying to obtain this data, the Metrics Team found that it is not available in the detail that would be needed for effectively measuring specific flight segments. There is a inability of the air carriers related to pilot union agreements to share fuel usage data even on a per flight level. The only way the team has been able to quantify fuel savings at all is to use some approximate average fuel savings data for aircraft flying at other than optimum altitudes. These figures have then been used to extrapolate approximate fuel savings for the removal of static altitude restrictions.

6.5 Predictability and Flexibility

Our experience indicates that these two measures are often in conflict with one-another. With predictability we are assessing the consistency with which service to the users can be provided. We address predictability in the FFP1 metrics through the variance associated with data sets. For example, we estimate mean arrival rates and mean flight distances in TRACON airspace when a tool is both off and on. Increased predictability is associated with increased consistency in the data (less variance) indicating a more predictable level of service to users.

With the Flexibility metric we were attempting to capture how well the ATC system allows for an individual flight to meet its objectives. An example was the ability for late departing flights to recoup flight time in order to reduce delay. Flexible service to an individual flight may negatively impact the flight time of other flights and increase the overall variance of the data set. Although we plan to continue to address the difference in flight times for late departures with the flight times of on-time departures, we do not view this as a primary metric.

Flexibility was also envisioned to capture user objectives which might be to the contrary of the assumed preferred intent of each flight. For example some flights may desire a longer flying time to allow for time for a gate to open up or to give more time to the flight crew to finish food and drink service and to prepare for landing. Determining which flights may fall in this category would be costly and provide little additional information regarding the value of the FFP1 tool.

In total the Metric Team's focus on predictability has increased while the focus on flexibility (as defined in the Metrics Plan) has decreased. As we continue to collect and analyze data and determine additional or improved data sources our metrics and approaches will continue to evolve.

7.0 REFERENCES

1. Free Flight Program Office, "FFP1 Performance Metrics Results to Date: June 2000 Report," June 2000.

2. Free Flight Program Office, "Free Flight Phase 1 Performance Metrics: An Operational Impact Evaluation Plan," August 1999.

3. Celio, J. C., Bowen, K. A., Winokur, D. J., Lindsay, K. S., Newberger E. G., Sicenavage, D., January 2000, "Free Flight Phase 1 Conflict Probe Operational Description," MTR 00W0000010, The MITRE Corporation, McLean, VA.

4. Meyer, E., et al, "An Operational Assessment of the Passive Final Approach Spacing Tool at Dallas/Ft. Worth International Airport," 45th Annual Air Traffic Control Association Conference, October 2000.

5. Conover, W.J., *Practical Nonparametric Statistics*, New York: John Wiley, 1980.

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8.0 GLOSSARY

AAL	American Airlines
AAR	Airport Acceptance Rates
ALR	Airport Landing Rates
AM	Amendment
AOC	Airline Operations Center
ART	Analysis of Restrictions Tool
ARTS	Automated Radar Terminal System
ARTCC	Air Route Traffic Control Center
ASP	Arrival Sequencing Program
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATL	Atlanta Hartsfield airport
AWE	America West
BNA	Nashville International Airport
CAASD	Center for Advanced Aviation System Development
CARJ	Canadair Regional Jet
CCB	Configuration Control Board
CHI	Computer Human Interface
CODAS	Consolidated Operations and Delay Analysis System
CR	Collaborative Routing
CTAS	Center TRACON Automation System
CVG	Cincinnati International Airport
DLOG	URET DU recorded data
DR	Discrepancy Report
DSR	Display System Replacement
DSS	Decision Support System
DU	Daily Use
EDCT	Estimated Departure Clearance Time
ETMS	Enhanced Traffic Management System
ETT	Estimated Time to Touchdown
EWR	Newark
FAA	Federal Aviation Administration
FADE	FAA's Airline Data Exchange
FFP1	Free Flight Phase 1

FIT	Facility Implementation Team
FL	Flight Level
FSM	Flight Schedule Monitor
GAL	Gallon
GDP	Ground Delay Program
GDP-E	Ground Delay Program Enhancements
GPD	Graphic Plan Display
HID	Host Interface Device
IDU	Initial Daily Use
IFR	Instrument Flight Rules
IPE	Integrated Predictive Error
LB	Pound
MEP	Midwest Express
MIT	Miles-in-Trail
MSP	Minneapolis/St. Paul
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASSI	National Air Space Status Information
NATCA	National Air Traffic Controllers Association
NCDC	National Climactic Data Center
nmi	Nautical mile
NRP	North American Route Program
NWA	Northwest Airlines
OAG	Official Airline Guide
OD	Operational Deviation
OE	Operational Error
PCA	Planned Capability Available
pFAST	Passive Final Approach Spacing Tool
P-GUI	Planview Graphical User Interface
RBS	Ration-by-Schedule
RCI	Rate Control Index
RJ	Regional Jet
RUC	Rapid Update Cycle
SFO	San Francisco
SDF	Louisville International Airport

SMA	Surface Movement Advisor
SOC	Systems Operation Center
SUA	Special Use Airspace
T-GUI	Timeline Graphical User Interface
TMA	Traffic Management Advisor
TMU	Traffic Management Unit
TOC	Top of Climb
TOD	Top of Descent
TP	Trial Plan
TRACON	Terminal Radar Approach Control Facility
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
ZDC	Washington Center
ZID	Indianapolis Center
ZKC	Kansas City Center
ZME	Memphis Center

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APPENDIX A. Description of Box plot

Box plots are used to graphically depict the range and shape of the distribution of a data sample. The central box represents the interquartile range containing 50 percent of the values. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers. A line across the box indicates the median, which is the middle of a distribution (half the scores fall above the median and half fall below).

Figure A-1 presents an example of a box plot. The shaded box stretches from the lower hinge (defined as the 25th percentile) to the upper hinge (the 75th percentile). This box contains the middle half of the observations in the distribution. Therefore, one quarter of the distribution is between this line and the top of the box and one quarter of the distribution is between this line and the bottom of the box.

The "H-spread", or interquartile range, is defined as the difference between the hinges. A "step" is defined as 1.5 times the H-spread. Inner fences are 1 step beyond the hinges. Outer fences are 2 steps beyond the hinges. The whiskers extend from the ends of the box to the outermost data point that falls within the upper (+1.5 * interquartile range) or lower (-1.5 * interquartile range) fences. In the box plots presented here, outliers are defined as values between the inner and outer fences, and are plotted with open circles. Extreme values are those outside the outer fences, and are plotted with asterisks.

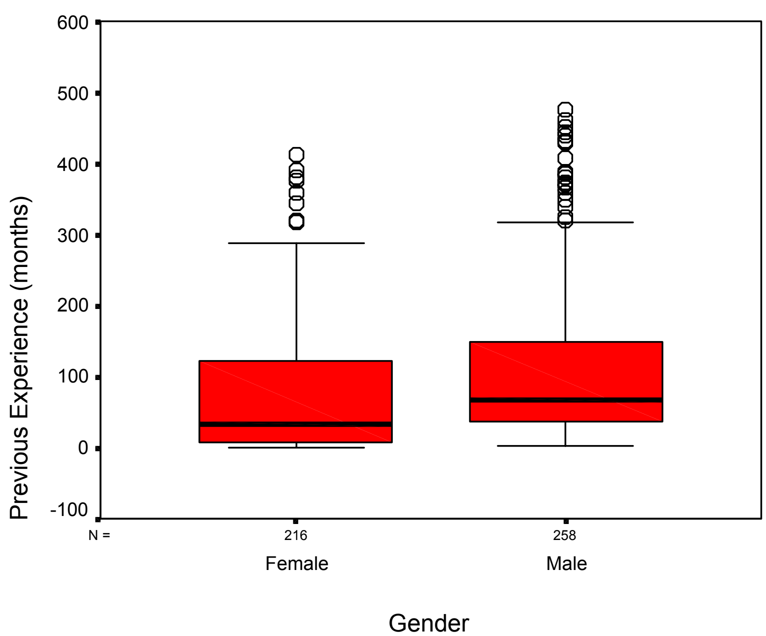

Figure A-1. Sample Box Plot

Within a display (such as that presented in Figure A-1), box plots are shown side by side for each of the groups defined by a factor (variable). The factors for Figure A-1 are "Female" and "Male." This display is particularly useful when the different variables represent a single characteristic measured at different times. Above the names of the factor labels ("Female" and "Male" in Figure A-1), the sample sizes (N) are presented, which indicate the number of data points included in the sample.

In examining Figure A-1, the sample on the right has a slightly higher median than the sample on the left. In addition, the whiskers extend further from the box showing that the data (excluding outliers) is more spread out than the sample on the left. Where one whisker and its outliers extend further than the other whisker and outliers in the same sample, the sample is skewed in the direction of the longer whisker. In Figure A-1, the whiskers for both boxes are positively skewed. Lastly, the sample on the right has many more outliers extending above the upper whisker. No outliers are found below the lower whisker since each lower whisker extends to zero, and months of experience must have a non-negative value.

It is often useful to compare data from two or more groups by viewing box plots from the groups side by side. Figure A-2 presents such an example. Plotted are the same data from Figure A-1 with an additional variable for comparison. Whereas Figure A-1 presents summary data on previous work experience (in months) by gender only, Figure A-2 provides the additional variable Minority Class. This offers a view that facilitates the comparison of data across multiple variables.

The data sample for Minority Class (Yes) yields longer boxes with whiskers that are more spread out and having a positive skew. A positive skew indicates that the mean (not shown) is higher than the median. This example also illustrates the outliers and extreme values for each grouping; the Minority Class groupings (Yes) display fewer outliers and extreme values.

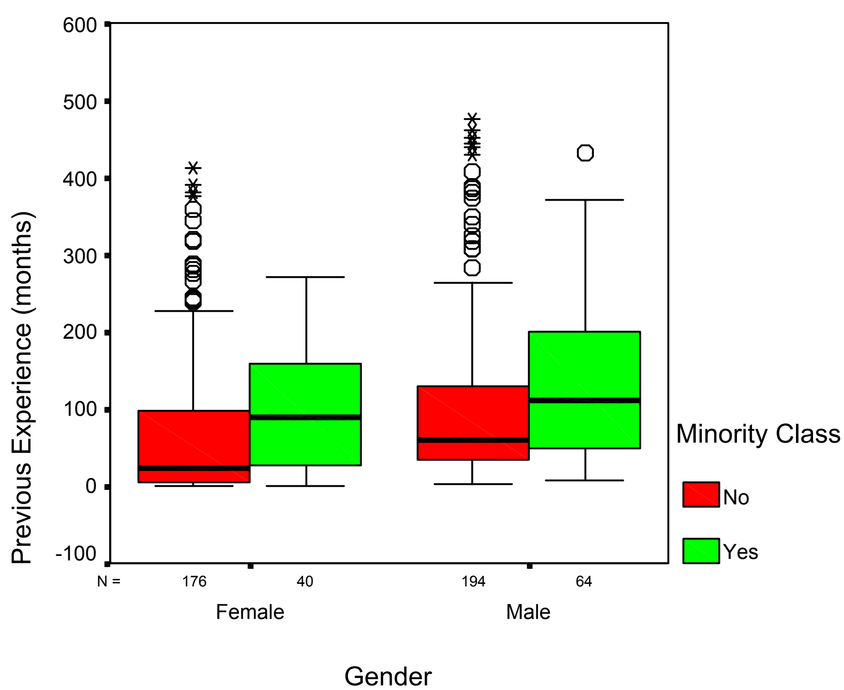

Figure A-2. Side-by-Side Box Plot Comparison