Free Flight Program

Performance Metrics Results to Date

June 2003 Report

INTRODUCTION

This is the seventh semi-annual report on Free Flight Program (FFP) performance metrics. This report focuses on performance enhancements associated with the deployment of the User Request Evaluation Tool (URET) and Traffic Management Advisor (TMA). We have also included a summary of a recent study of a new tool in the Collaborative Decision Making (CDM) program.

The primary FFP performance goals are to increase capacity (airport and airspace) and improve efficiency (reduce flight times and fuel consumption), while maintaining the current high level of safety. Many of the metrics used in this report can be normalized and translated into delay savings, which is a commonly used measure of the value of improvements in National Airspace System (NAS) operations. The intent is for these metrics analyses to quantify user benefits of early system deployments, and to be used in the development of benefit/cost estimates for future deployments.

An integral part of the metrics analysis involves in-depth discussions with air traffic controllers who use the FFP tools. These discussions often focus the analyses on specific conditions where improvements are expected. For example, after mandatory use of TMA for planning purposes was instituted at ATL in January 2003, ZTL/ATL personnel stated that they were able to begin calling higher airport acceptance rates (AAR). A detailed statistical study supporting this assertion is included in this report.

The FFP metrics team was established at the beginning of Free Flight Phase 1 with the goal of evaluating the user benefits of Free Flight deployments. The approach used to measure operational impact was developed in collaboration with the RTCA Free Flight Steering Committee. The metrics team now includes research analysts, database specialists, and air traffic controllers from the following organizations: FAA, MITRE Center for Advanced Aviation System Development (CAASD), CNA Corporation (CNAC), Jerry Thompson and Associates (JTA), and Crown Consulting.

If you have questions or comments on this document or the FFP metrics program please contact Dave Knorr at 202-220-3357 or Ed Meyer at 202-220-3407.

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TABLE OF CONTENTS

FIGURES

TABLES

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1.0 SAFETY

Free Flight Tools were developed to increase system capacity and efficiency for airspace users while maintaining the highest standards of safety. While we have not measured a safety improvement associated with the Free Flight tools, the underlying functionality in the User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC) each support a safer airspace system. For example, URET may prevent some operational errors by identifying potential conflicts sooner. URET identifies conflict-free direct routes, addressing both safety and efficiency. TMA supports a safer NAS environment by smoothing flows and reducing congestion in and around the terminal environment.

URET and TMA both improve situational awareness. Loss of situational awareness is often a major factor in operational errors. Early awareness by the controller of a potential conflict with another aircraft supports reduced operational errors.

1.1 Independent System Safety Assessment

The safety program during Free Flight Phase 1 was tailored to limited deployment and spiral development of the Free Flight tools. Free Flight system safety engineers developed and authored an Independent System Safety Assessment. This assessment was the first product of its type in the FAA and received praise from both the FAA System Safety Work Group (SSWG) and the FAA System Engineering Council. This workgroup and council are the final authority on all safety issues associated with new systems deployed in the National Airspace System. Additionally, Free Flight has been tracking and reviewing all Problem Trouble Reports (PTR) for Free Flight systems, and none have revealed any unresolved safety issues.

For Free Flight Phase II a Free Flight System Safety Workgroup worked closely with the FAA SSWG to adopt the System Safety Assessment concept as the most prudent, safe, and cost effective method for both URET and TMA to proceed to JRC-2B. The Free Flight procedures for conducting the safety assessment for URET and TMA were implemented by the Director of the Free Flight Program Office and Program Directors for URET and TMA on October 31, 2002. The independent system safety assessment requires the following:

1. Review PTRs identifying those with safety implications. Track these safety-related PTRs to closure and elevate the issue to the appropriate program manager if closure is not timely.

2. During URET implementation, identify any safety-related issues and validate. Elevate validated issues to the URET Program Manager and track to closure.

3. Review any operational error, operational deviation, accident, or incident where URET or TMA was a contributing factor. Elevate the issue to the Director of the Free Flight Program Office for immediate resolution and track it to closure.

4. Submit special emphasis items on URET and TMA safety to the Air Traffic and Airway Facilities Evaluation Staffs. The special emphasis items will be evaluated during Air Route Traffic Control Center (ARTCC) facility evaluations. Review the results of the special emphasis items and elevate any validated issue to the appropriate program manager for resolution. Track the issue to closure.

5. Conduct site visits to evaluate high severity safety risks. Brief the Director of the Free Flight Program Office on the findings and recommended resolution, and track the hazards to closure.

6. Brief the Free Flight System Safety Workgroup at each meeting on safety issues identified during the assessment.

7. The Independent System Safety Assessment is an on-going process and continues throughout the life cycle of the Free Flight Program.

1.2 Free Flight System Safety Workgroup Activities

The Free Flight SSWG is tasked with the safety oversight of the various Free Flight tools. Initially, the Free Flight SSWG met on a monthly basis to ensure that all safety prerequisites were being met with CPDLC, TMA, and URET. Members of the work group include a chairperson from the Free Flight integration team and members from the TMA, URET, and CPDLC Program Offices. Also serving on the Free Flight SSWG are System Safety Engineers from the Office of System Safety (ASY), the Chief Engineer from the Office of System Architecture and Investment Analysis (ASD), and two consultants from Operational Support (AOS) considered to be experts in the areas of system safety and engineering.

The Free Flight SSWG has been meeting quarterly for the last two years to ensure that any safety issues with Free Flight Program tools are immediately resolved.

In concert with the Air Traffic Investigations and Evaluations Staff (AAT-20), all operational errors occurring in the en route environment are evaluated to ensure that Free Flight tools did not contribute. To date, no Operational Errors or Operational Deviations have been attributed to any of the Free Flight tools. Additionally, PTRs continue to be reviewed to ensure that the Free Flight tools are not creating any disruptions to the NAS. Any identified discrepancies are immediately elevated to the appropriate program for immediate resolution.

2.0 USER REQUEST EVALUATION TOOL (URET)

URET is a decision support tool designed to aid ARTCC controllers in the en route environment. URET's primary function is to alert controllers to conflicts between aircraft (up to 20 minutes in advance of the conflict) and to conflicts between aircraft and airspace (up to 40 minutes in advance). URET provides controllers with a trial planning capability to create a conflict-free amendment that can be sent directly to the Host Computer. URET also manages flight data electronically, reducing the need for paper strips. URET has been shown to increase the number of direct routings given to aircraft, and to reduce the number of static altitude restrictions in place at the Centers.

The production version of URET, known as the Core Capability Limited Deployment (CCLD), was deployed to six ARTCCs between December 2001 and April 2002. The Initial Daily Use (IDU) dates (when controllers began routinely using URET) are shown in Table 1. Prototype URET systems were in use at ZID and ZME for several years before CCLD; versions of the prototype with two-way Host communication enabled, which provided capabilities comparable to those of CCLD, were put in service at ZID and ZME in July 1999.

Table 1. Dates for CCLD Initial Daily Use (IDU)

ARTCC	IDU Date
ZKC	December 3, 2001
ZID	January 26, 2002
ZME	January 27, 2002
ZOB	January 28, 2002
ZAU	February 25, 2002
ZDC	April 12, 2002

2.1 Description

The key URET capabilities include:

- Trajectory modeling
- Aircraft and airspace conflict detection
- Trial Planning to support conflict resolution of user or controller requests
- Electronic flight data management.

URET processes real-time flight plan and track data from the Host computer system. These data are combined with local airspace definitions, aircraft performance characteristics, and winds and temperatures from the National Weather Service to build four-dimensional flight trajectories for all flights within or inbound to the facility. URET also provides a "reconformance" function that continuously adapts each trajectory to the observed position, speed, climb rate, and descent rate of the modeled flight. Neighboring URET systems can exchange flight data, position, 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 in advance for aircraft-to-aircraft conflicts and up to 40 minutes in advance for aircraft-to-airspace conflicts. Trial planning allows a controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then send the trial plan to the Host as a flight plan amendment.

These capabilities are packaged behind a Computer Human Interface (CHI) that includes both textual and graphical information. The text-based Aircraft List helps the controller manage flight data electronically, reducing the dependence on paper flight strips. The Plans Display manages the presentation of current plans, trial plans, 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 trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan routes, altitudes, or speed changes, and enables the controller to send flight plan amendments to the Host. For more details about URET capabilities, benefits, and the operational concept, please see Reference [1].

2.2 Operational Use

The operational use of URET is gauged by measuring the number of trial plans created and the number of amendments sent to the Host through URET. Data obtained directly from the Host and URET allowed measurement of the number of direct amendments and the distance saved because of URET-initiated amendments. Direct routes are those that decrease distance, measured from the point of the amendment to the destination airport.

Figures 1 through 6 show the average number of direct amendments per day initiated by HOST and URET, and the number of URET-initiated direct amendments for August 2002 through April 2003 at ZID, ZME, ZKC, ZOB, ZAU, and ZDC, respectively. Between 15 and 30 percent of the amendments at ZID, ZME, ZKC, ZOB, and ZAU were entered using URET, and over half were generated by URET at ZDC.

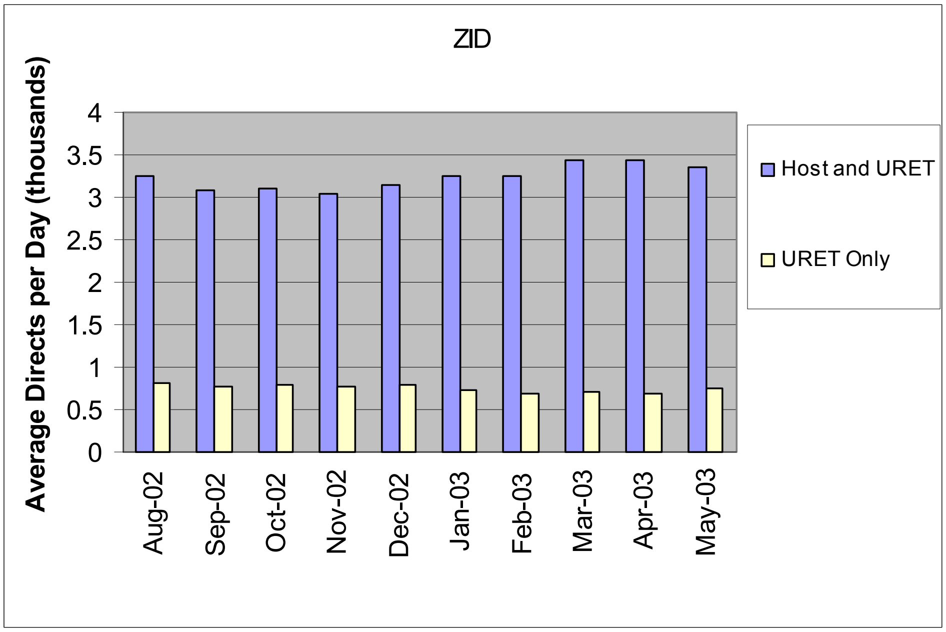

Figure 1. URET directs as a subset of total directs at ZID

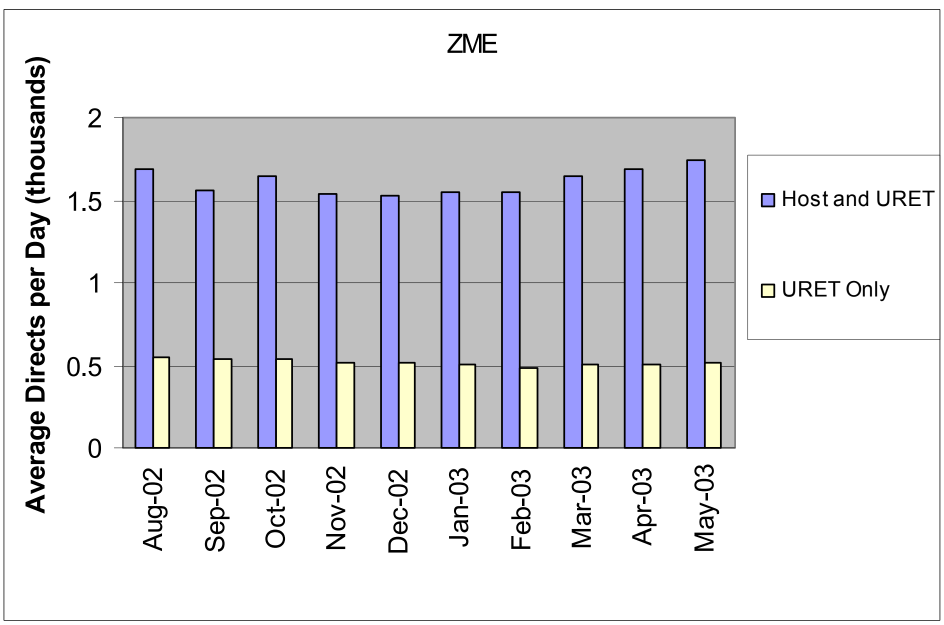

Figure 2. URET directs as a subset of total directs at ZME

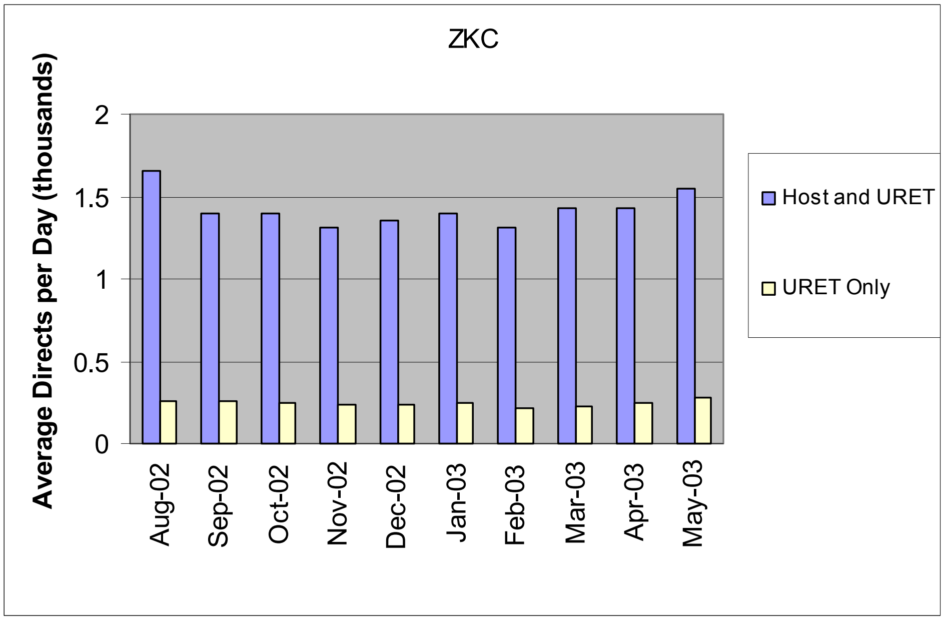

Figure 3. URET directs as a subset of total directs for ZKC

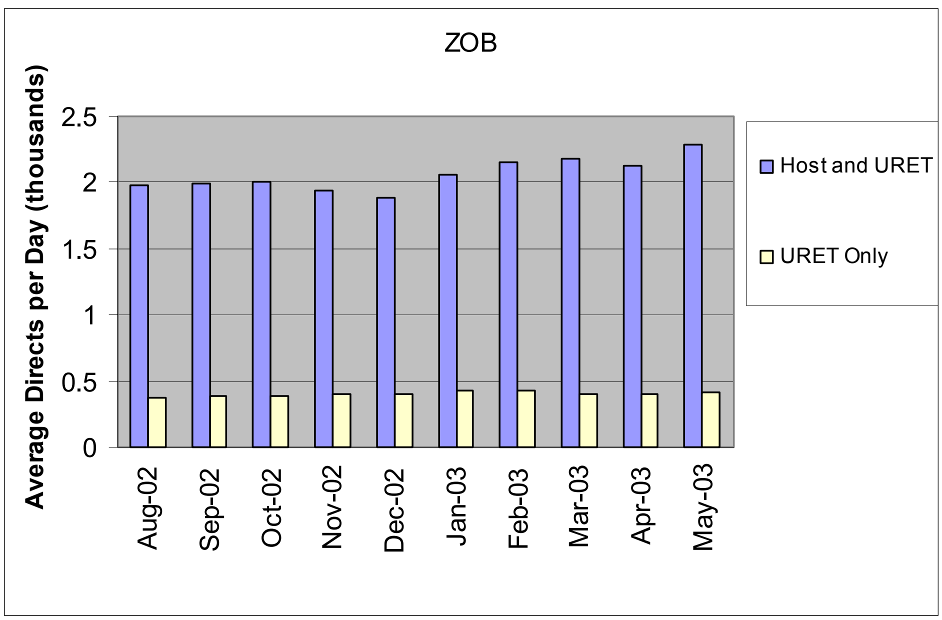

Figure 4. URET directs as a subset of total directs for ZOB

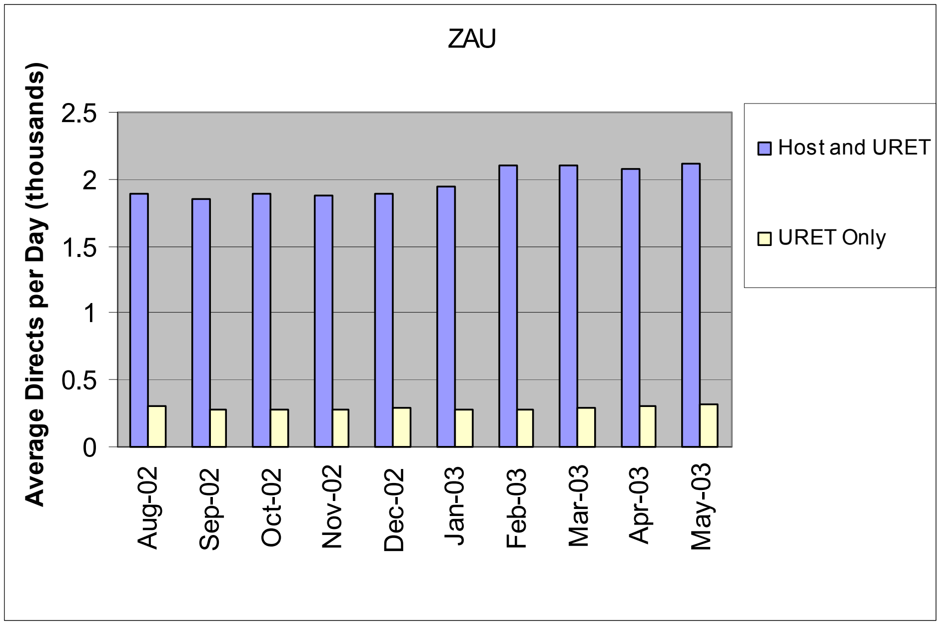

Figure 5. URET directs as a subset of total directs for ZAU

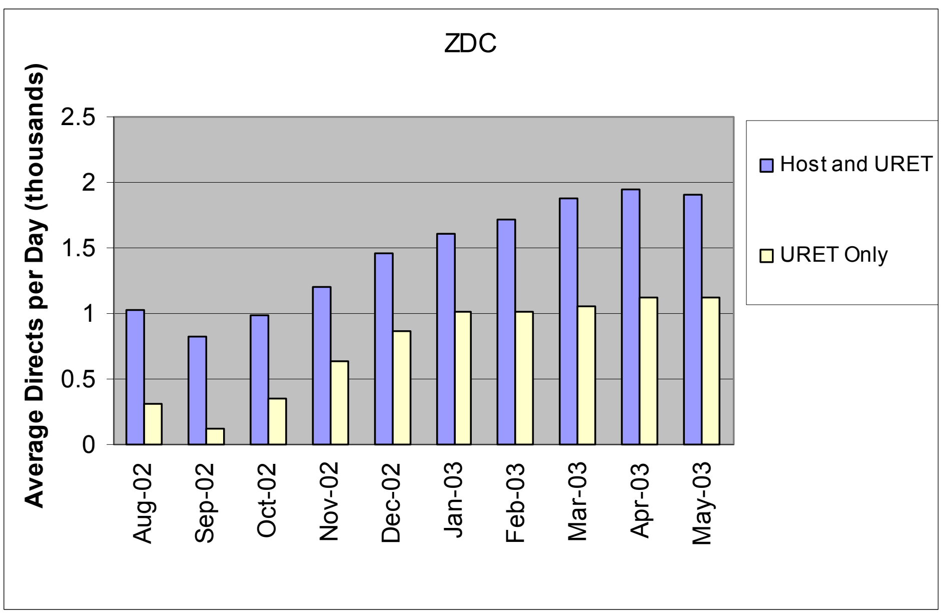

Figure 6. URET directs as a subset of total directs for ZDC

2.3 URET User Benefits

2.3.1 Metrics Used

The primary metrics that address URET benefits to NAS users are distance and time saved, static altitude restrictions lifted, and increased airspace capacity. A more complete description of the distance and altitude restriction metrics may be found in the FFP1 June 2001 report (Reference [4]).

Several measures were employed to estimate the distance savings facilitated by URET. These measures include:

- Change in distance flown because of lateral amendments
- Change in average distance flown through each Center's airspace
- Change in distance flown for specific city pairs
- Change in time of flight for specific city pairs.

In addition to distance and time savings, there have been improvements in fuel efficiency resulting from the removal of altitude restrictions. The ZID and ZME Procedure and Benefits team was established to evaluate and, if appropriate, modify or remove altitude restrictions. As URET is deployed to bordering Centers, there is increased opportunity to eliminate inter-facility restrictions.

This report will focus on lateral amendment savings. Please refer to earlier reports (References [1-7]) for information on other metrics.

2.3.2 Lateral Amendments

Lateral flight plan amendments are defined as those that change the direction of an aircraft but not necessarily its altitude. They include increases (e.g., turns to avoid congestion or heavy weather areas) as well as decreases in distance. The distance saved metric[1] captures the average of the daily sum of distance changes resulting from lateral amendments. The data include *all* lateral amendments entered into the Host for the specified time, not just URET amendments. Figure 7 shows the average distance savings per day from lateral amendments at ZID, ZME, ZKC, ZOB, ZAU, and ZDC between August 2002 and April 2003 as provided by Lockheed-Martin using the CCLD version of URET.

Note that the values for ZID are substantially higher than those for the other Centers. However, this difference does not result from more traffic, as ZOB, ZAU, and ZDC all have more flights per day than ZID.

[1] Distance saved for a given flight is the difference between the flight distance for the existing flight plan at the time of the amendment and the amended flight plan, where flight distance for each flight plan is calculated from the point of the amendment to the destination airport.

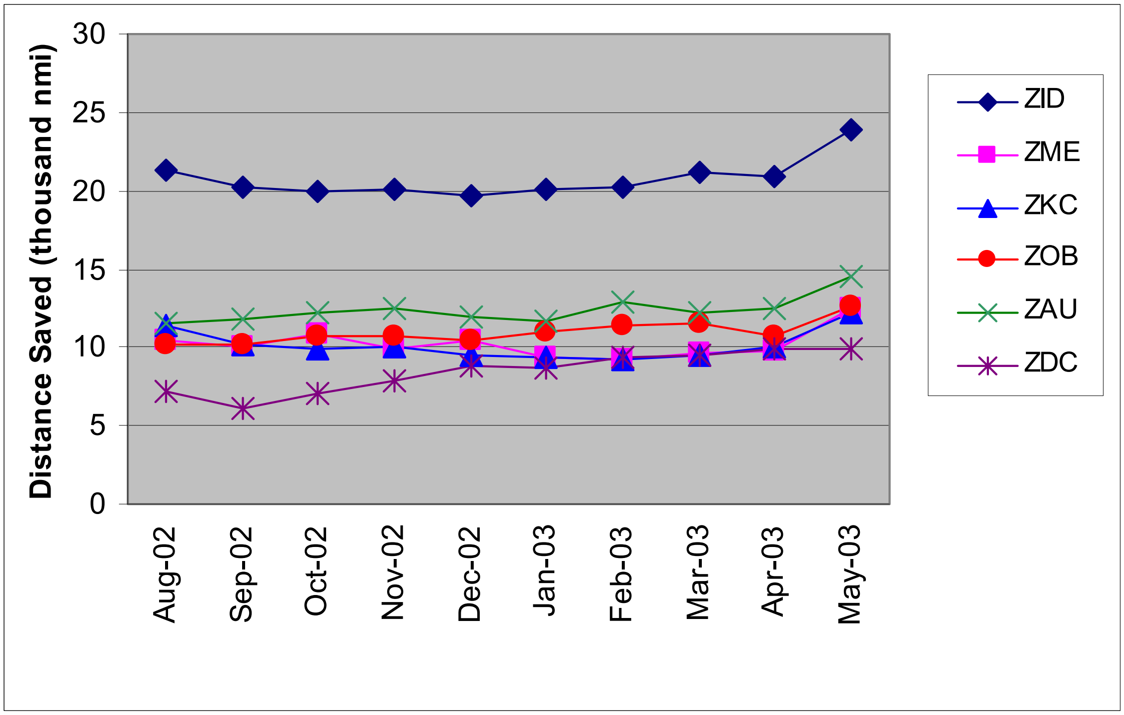

Figure 7. Average distance saved per day by lateral amendments at URET sites

The distance saved metric does not indicate the net benefit of URET to NAS users. To calculate this net URET benefit, one would need to compare the URET distance savings with the baseline case (i.e., what the distance saved would be without URET). Often the lateral savings before URET deployment is used as a proxy for this non-URET value. However, CCLD did not begin collecting this data until August 2002, which is after IDU at all current URET sites. In the absence of a means to directly calculate the distance saved from archived data sources, such as the ATA Laboratory's Enhanced Traffic Management System (ETMS) database, one must use indirect methods to infer the savings.

One means to estimate the distance savings is to use data from the prototypes at ZID and ZME. The MITRE prototypes captured lateral savings data before and after two-way Host communication was implemented, which is roughly equivalent to having data before and after CCLD IDU. Figure 8 presents the average daily distance savings from lateral amendments for ZID, as monitored by the URET prototype, through October 2002. Distance savings from lateral amendments increased from approximately 500 nmi daily (May and June 1999, before URET could send amendments to the Host) to more than 7,000 nmi through Fall 2002[2]. The ZID and ZME benefits could then be extrapolated to the other URET centers.

[2] The prototype values for August – October 2002 are different from those for the CCLD system for reasons that are understood, as explained in the December 2002 metrics report. See Reference [7].

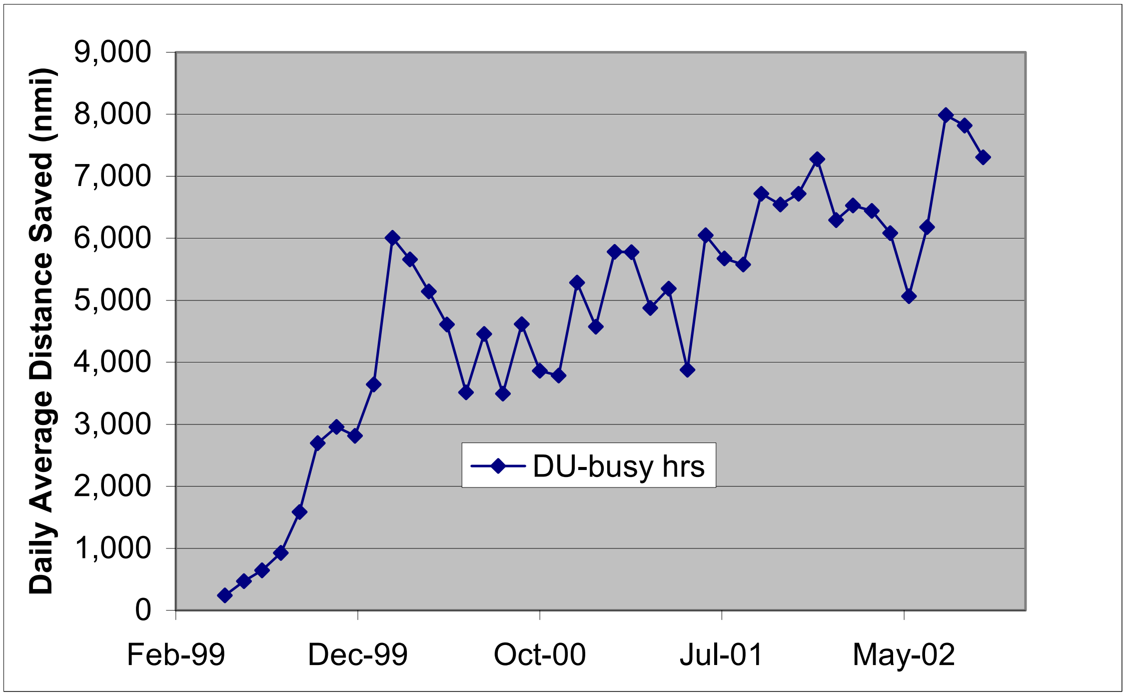

Figure 8. Distance saved at ZID, as monitored by URET prototype

Another way to approach the problem is to find a different measure that increases along with lateral savings. The increase in distance saved combines contributions from two possible sources: a change in the number of amendments and a change in the distance saved per amendment. Figures 9 and 10 show the number of amendments per flight at ZID as determined from the ETMS database for January 1998 through May 2003. The vertical lines in this figure indicate the approximate date when two-way communication was added to the URET prototype at ZID.

Figure 9 shows the count of amendments recorded in the ETMS database. However, this count includes amendments that do not change the route of flight, such as amendments for changes of altitude. Figure 10 shows the remaining amendments after removing those amendments not changing the 'Field10' of a flight. Field10 is that part of the flight record that contains the route of flight. However, the Field10 may change even when the route of flight does not, and so the data plotted in Figure 10 are an upper bound on the number of route-changing amendments per flight.[3] For both corrected and uncorrected data, it is apparent that the number of amendments began to increase after the deployment of URET. In the future we will show only the corrected data.

[3] Note that pre-URET uncorrected amendments per flight varied more between Centers than did the corrected data.

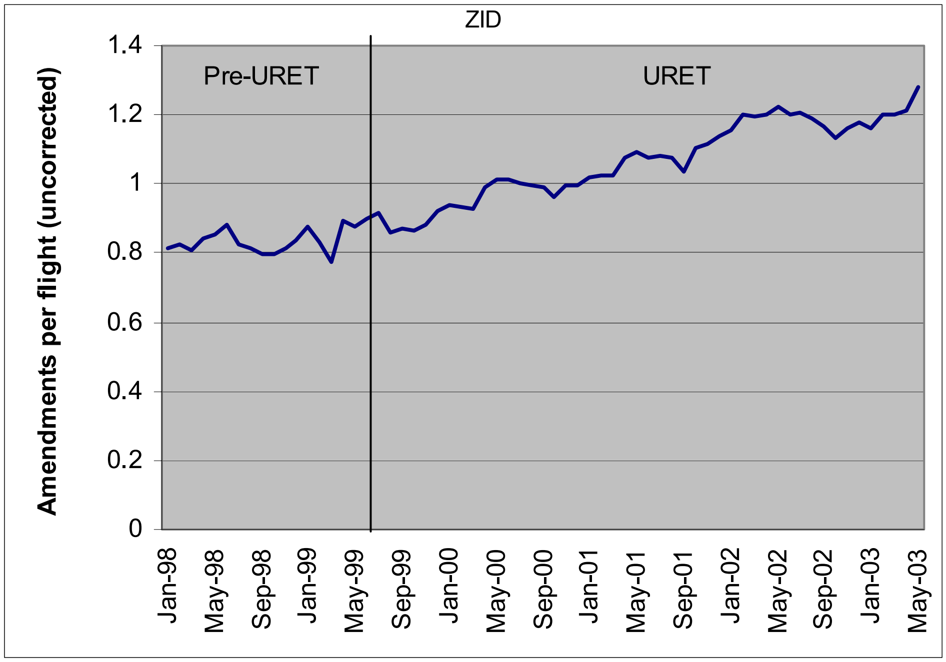

Figure 9. Number of amendments per flight (uncorrected) at ZID

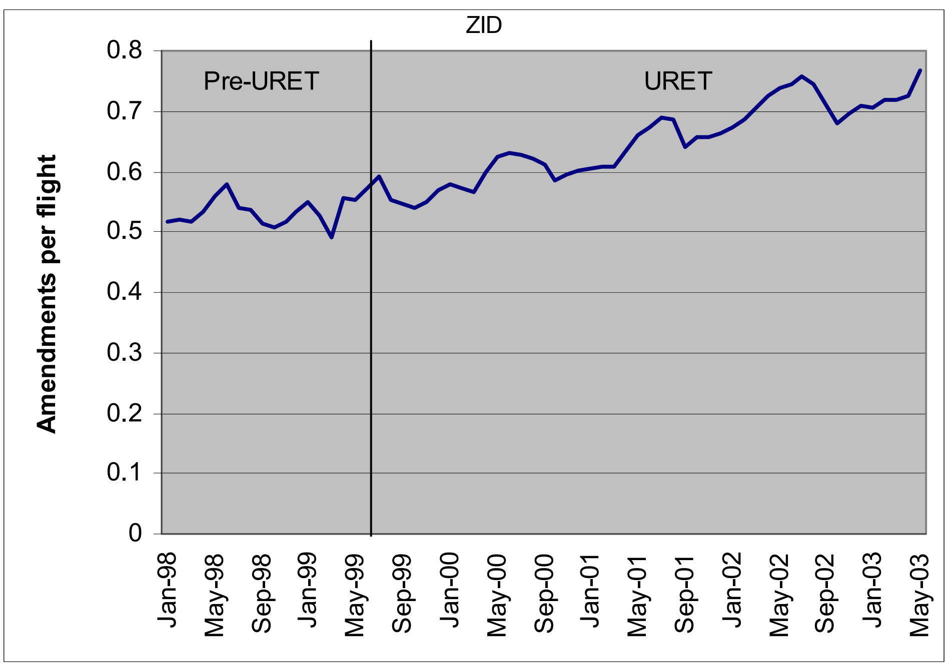

Figure 10. Number of amendments per flight (corrected) at ZID

We therefore assume that an increase in amendments per flight at a Center implies that the distance saved from lateral amendments in that Center also increased. If URET were to increase the number of direct amendments (as it did at ZID), this change should be reflected in the number of amendments per flight within a Center. Figures 11 through 15 show the monthly average of the number of amendments per flight at ZME, ZKC, ZOB, ZAU, and ZDC between January 1998 and May 2003. In these figures, the vertical lines indicate the approximate CCLD IDU dates for ZKC, ZOB, ZAU, and ZDC, and the two-way Host communication IDU date for ZME. To the left of the lines, aside from a seasonal effect, there is no obvious trend in the data. To the right of the line, we see an increase in the number of amendments per flight after the introduction of URET.

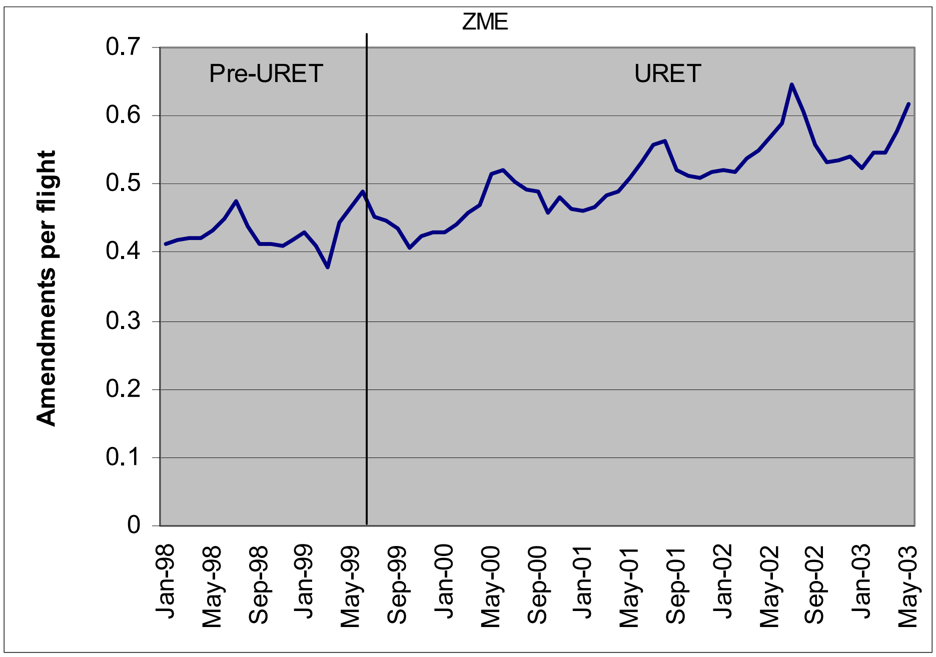

Figure 11. Flight plan amendments per flight at ZME

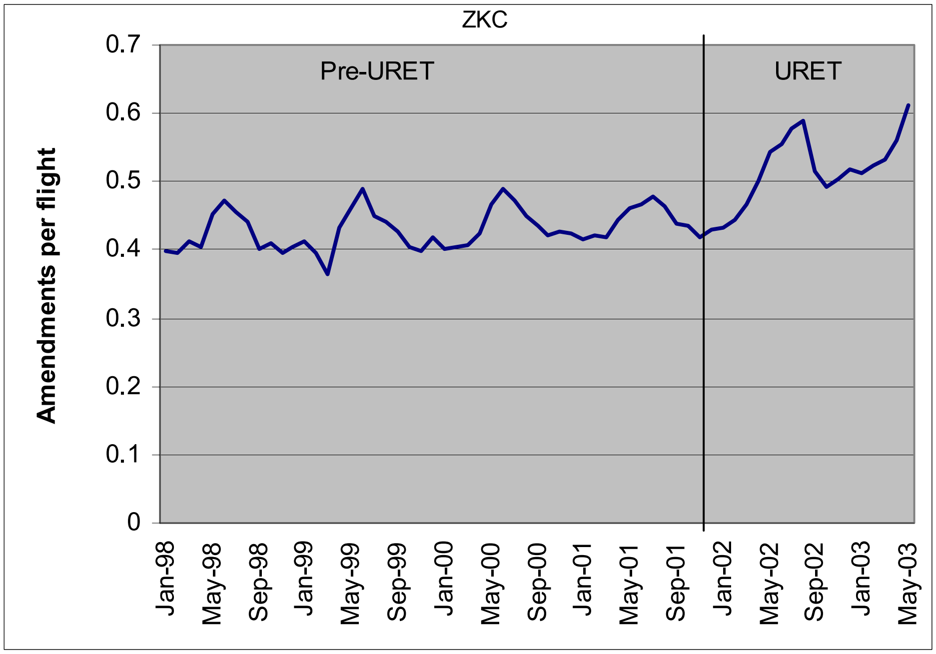

Figure 12. Flight plan amendments per flight at ZKC

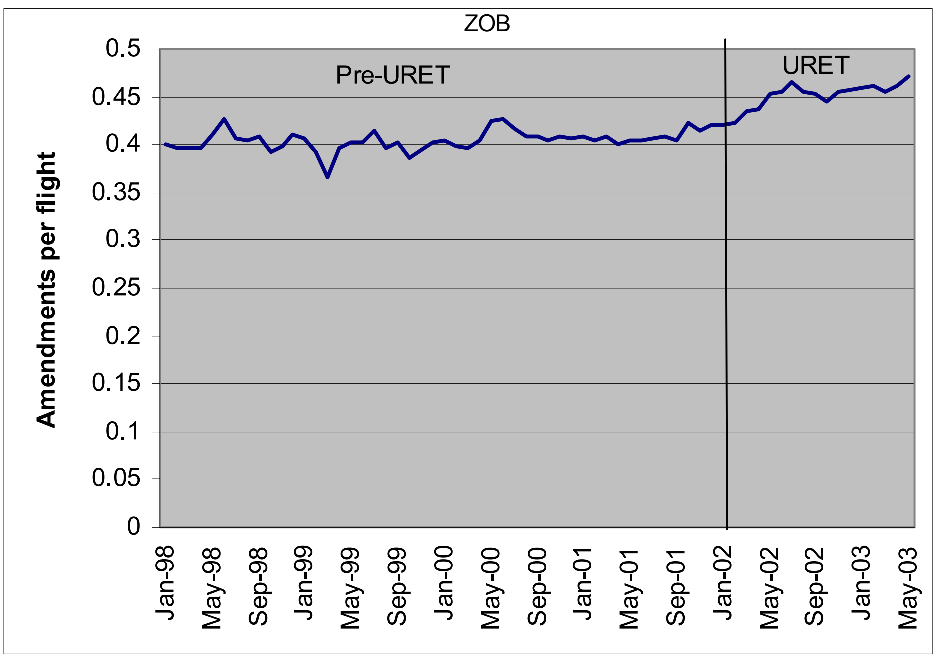

Figure 13. Flight plan amendments per flight at ZOB

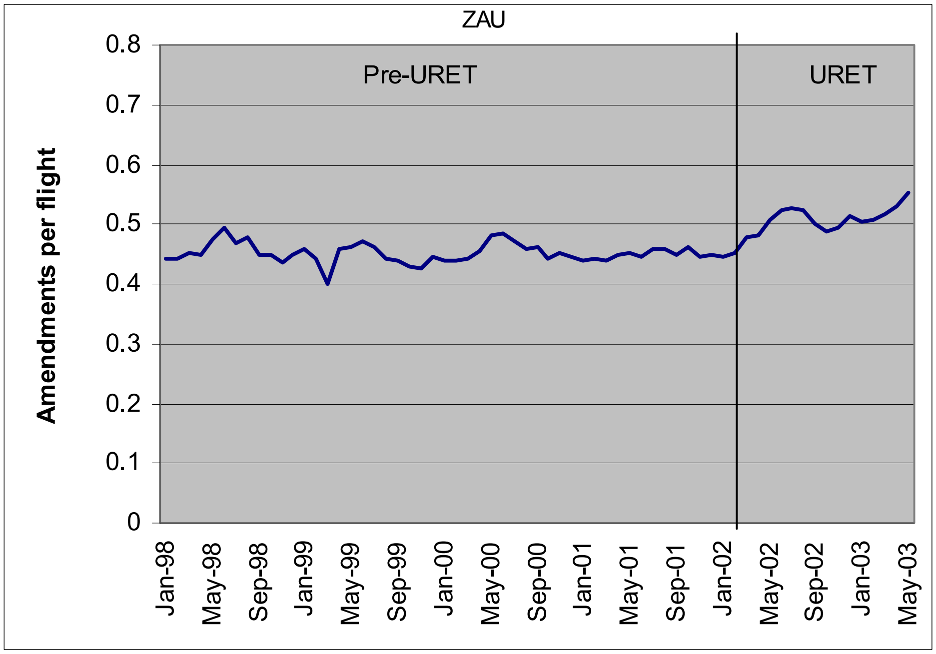

Figure 14. Flight plan amendments per flight at ZAU

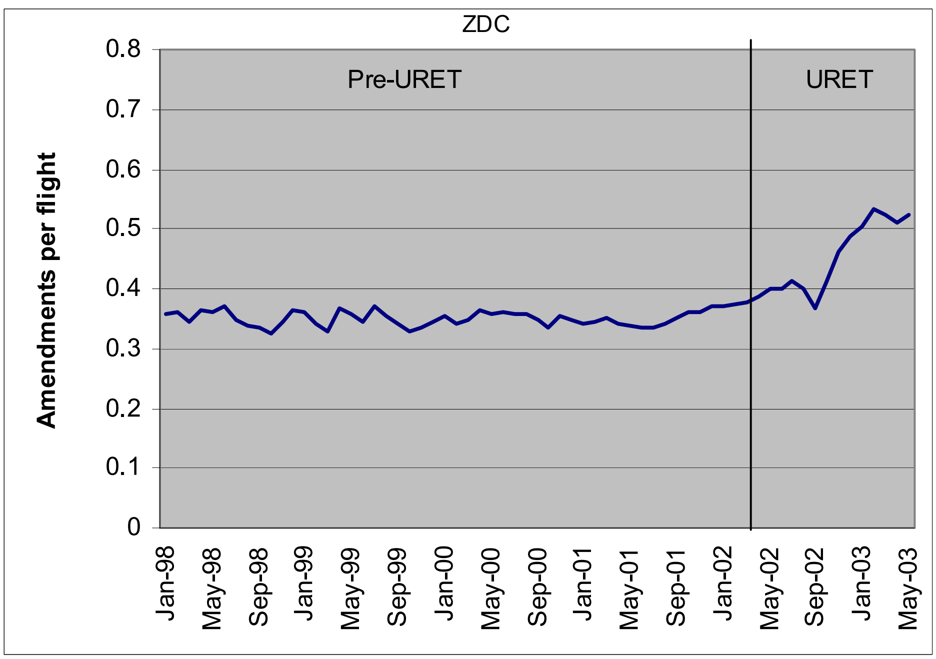

Figure 15. Flight plan amendments per flight at ZDC

Figure 16 displays the number of amendments per flight for the non-URET Centers, and there is no appreciable change in the number of amendments per flight over this time period. We note that prior to the introduction of URET, most URET Centers were issuing approximately 0.4 amendments per flight, which is roughly the same as the constant value for the non-URET Centers.

We cannot, however, directly determine the user benefit (i.e., distance saved) from the number of amendments per flight, or from total amendment counts, without an appropriate conversion factor. We can estimate this conversion factor from the CCLD metrics data provided by Lockheed-Martin, and the results for all URET centers are shown in Figure 17. With the exception of ZDC, the distance saved per amendment is constant over the data collection period, and for most centers is between four and five nautical miles per amendment. For conversion to distance saved, we will use an average value of 4.5 miles per amendment.

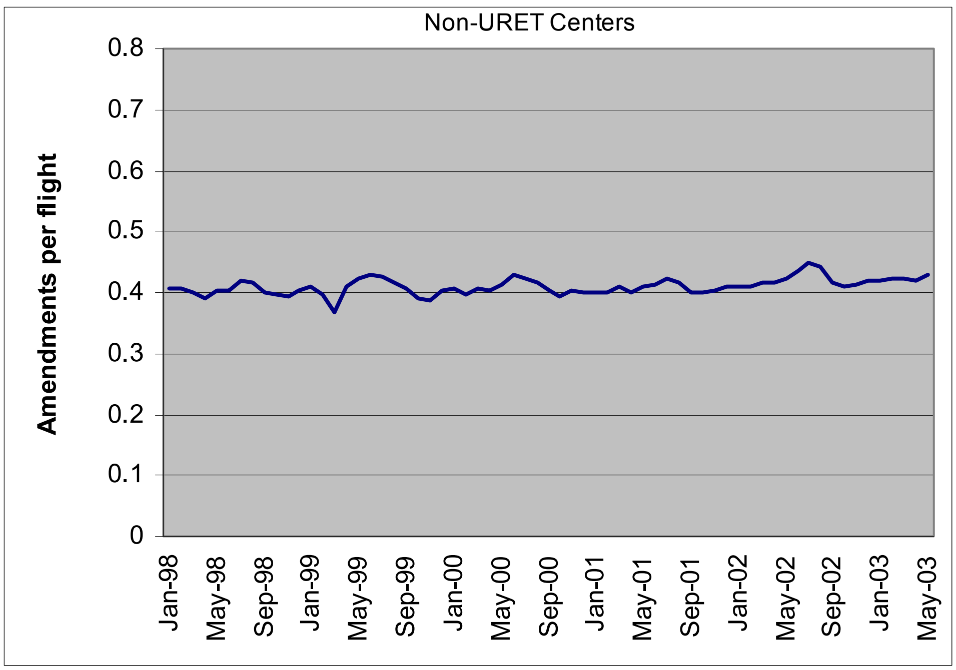

Figure 16. Flight plan amendments per flight at non-URET centers

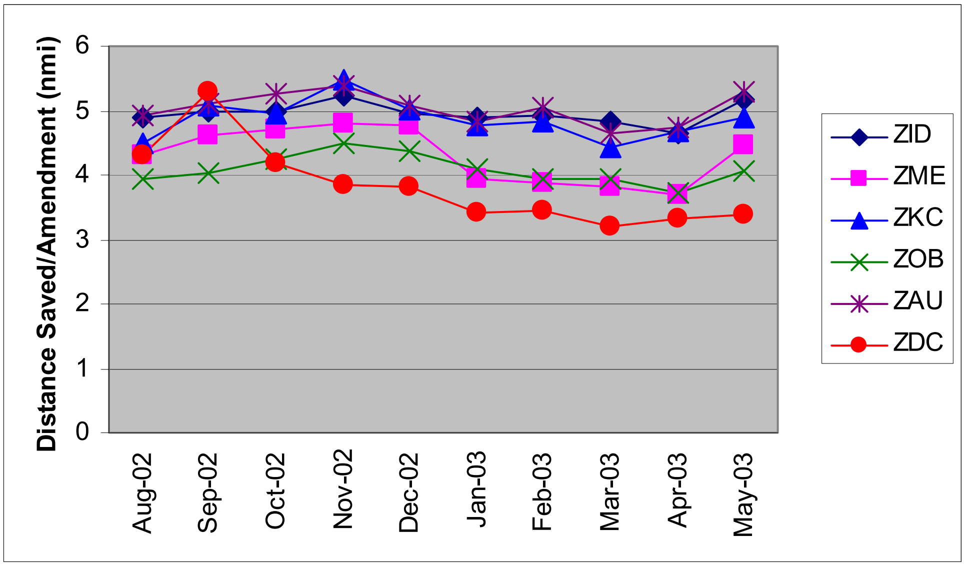

Figure 17. Distance saved per amendment at URET CCLD centers

Figures 18 to 23 show the average number of amendments per day for the six URET Centers, based on ETMS data. We can estimate the increase in the number of amendments after deployment for each Center by comparing the average of the most recent (post-URET) months to the average level prior to URET deployment. The distance saved was determined from the number of amendments using a conversion factor of 4.5 nautical miles per amendment, and the results are shown in Table 2. The total estimated distance saved for all URET Centers combined is 27,000 nautical miles per day.

Table 2. Amendment increase after URET deployment

ARTCC	Amendment Increase	Distance Saved (nmi)
ZID	1750	7875
ZME	1000	4500
ZKC	750	3375
ZOB	500	2250
ZAU	500	2250
ZDC	1500	6750

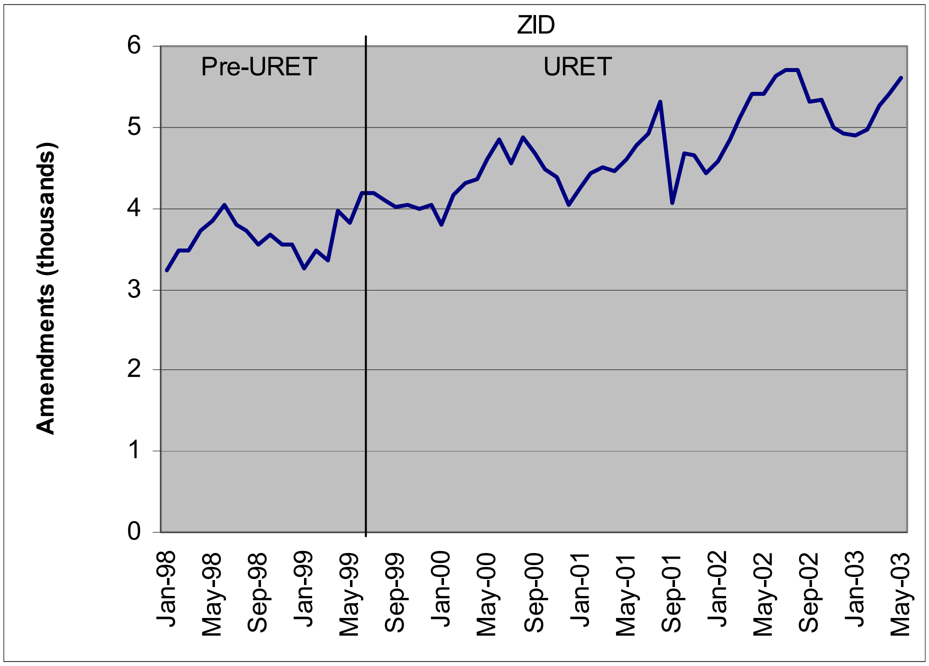

Figure 18. Average number of amendments per day at ZID

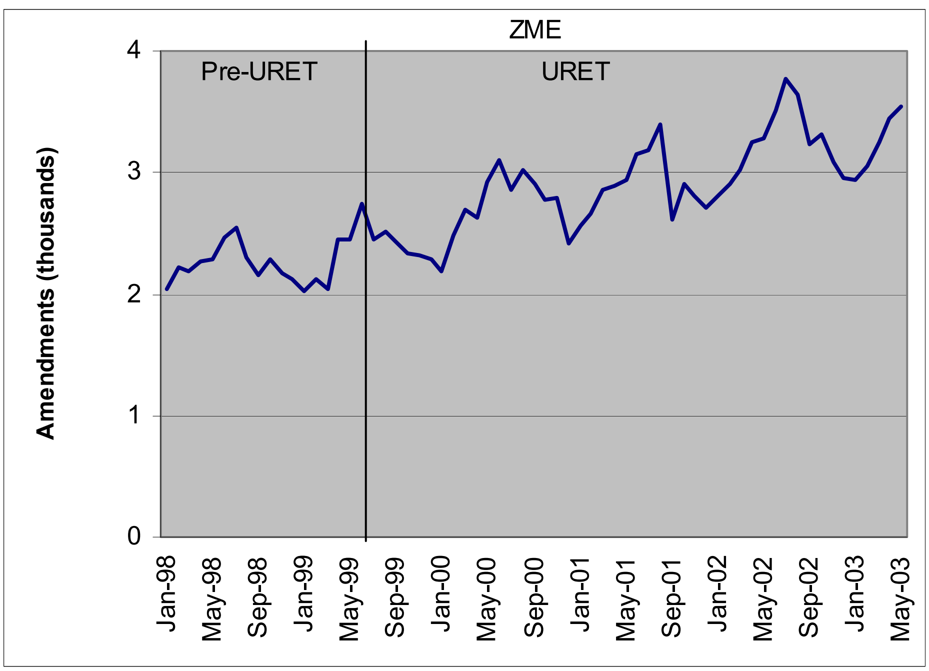

Figure 19. Average number of amendments per day at ZME

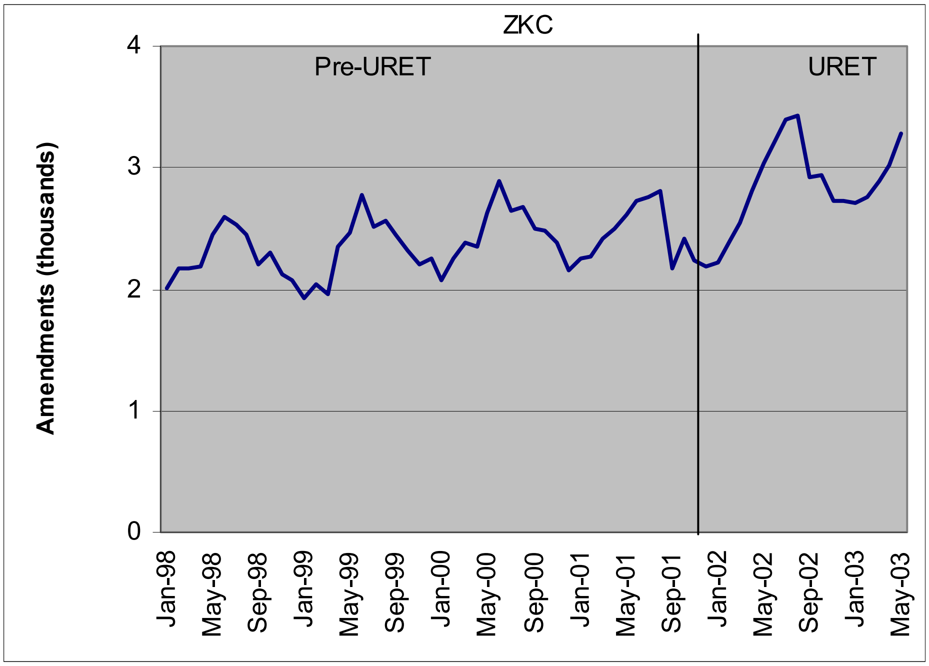

Figure 20. Average number of amendments per day at ZKC

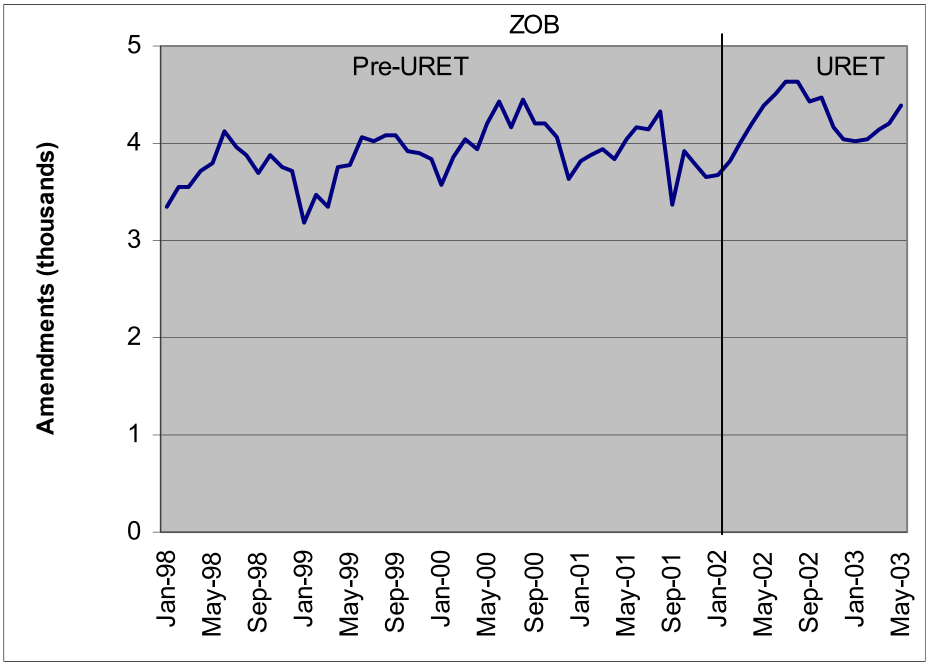

Figure 21. Average number of amendments per day at ZOB

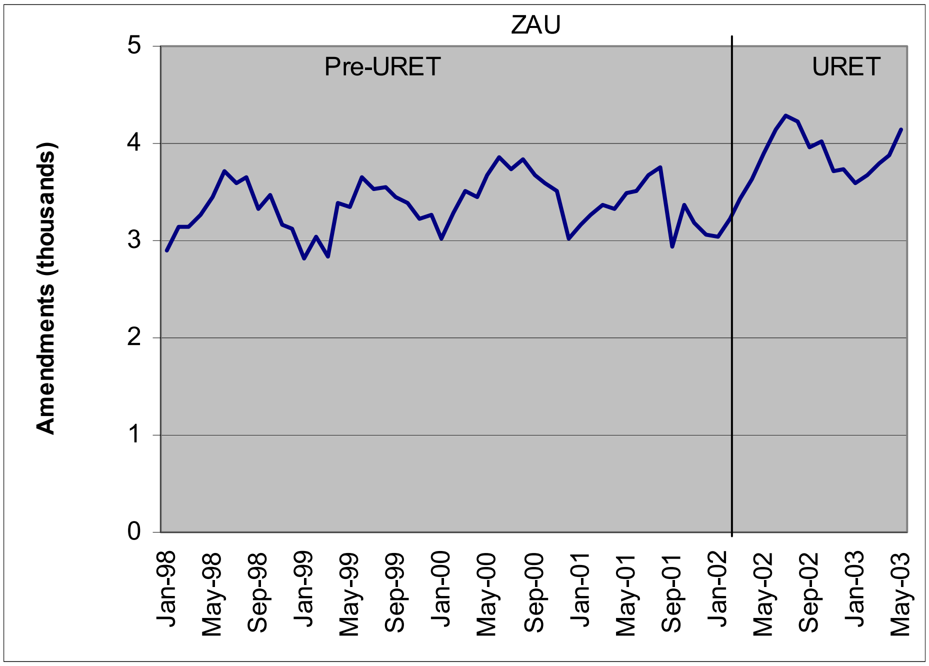

Figure 22. Average number of amendments per day at ZAU

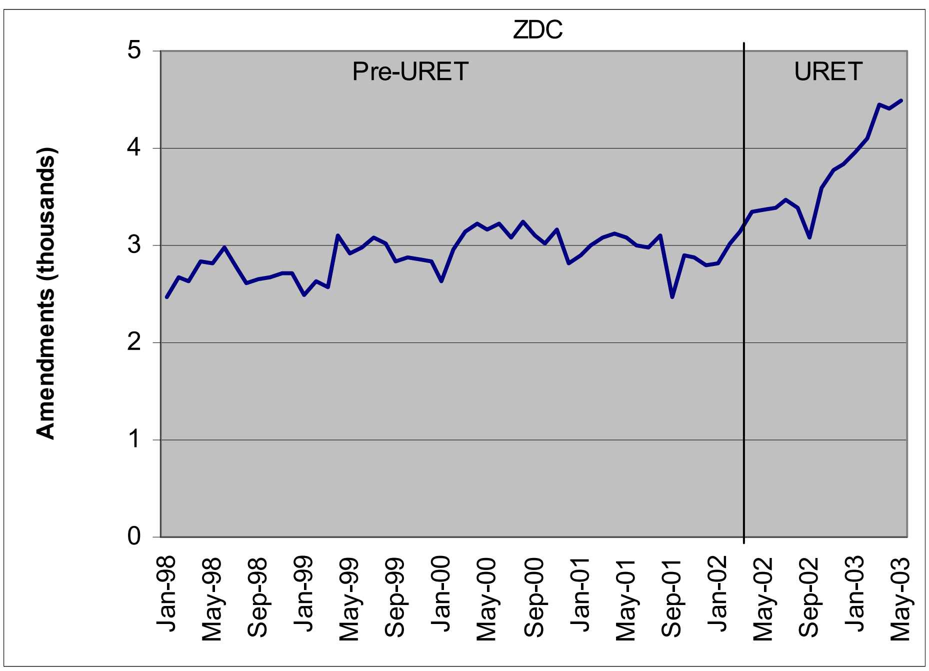

Figure 23. Average number of amendments per day at ZDC

This estimate of the distance saved can be compared with measured data for ZDC. To address a technical issue, ZDC reverted to the use of strips on August 8, 2002, and began using URET again on September 25, 2002. Lockheed-Martin used the CCLD metrics data from the period when strips were being used at ZDC to establish a baseline for comparison. Figure 24 shows the distance saved resulting from lateral amendments for ZDC as computed by URET between August 2002 and April 2003. The distance savings from lateral amendments increased by 4,000 miles during this time, in contrast to the 6,750 miles estimated using the conversion factor as described above. If we use this example to estimate the systematic uncertainty in our earlier calculation of distance saved, we can place a lower bound on total distance saved at all URET centers combined at 19,000 nautical miles per day.

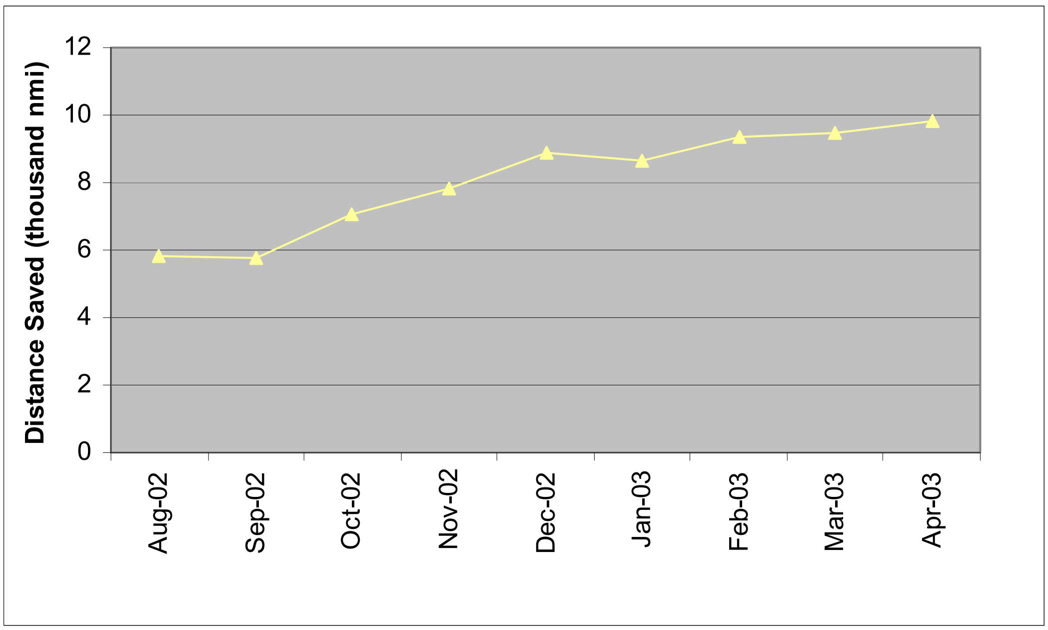

Figure 24. Distance saved from lateral amendments at ZDC, using the period 8/25/2002 to 9/23/2002 as a baseline

3.0 TRAFFIC MANAGEMENT ADVISOR (TMA)

TMA is currently operational at seven ARTCCs. At each ARTCC, TMA computes arrival schedules for a specific airport. The deployed sites are shown in Table 3. This section describes the operational use of TMA, summarizes the benefits to date at all ARTCCs, outlines the methodologies used in recent measurements of benefits, and presents results of the benefits analyses. More specifically, the results include studies of the effects of TMA on the following: acceptance rates, departure delay for internal departures, and restrictions for ZLA/LAX; holding and acceptance rates at ZTL/ATL; and arrival rates at ZMA/MIA.

Table 3. Deployed TMA Sites

ARTCC		Airport	
Name	**Identifier**	**Name**	**Identifier**
Fort Worth	ZFW	Dallas/Fort Worth International	DFW
Minneapolis	ZMP	Minneapolis-St. Paul International	MSP
Denver	ZDV	Denver International	DEN
Los Angeles	ZLA	Los Angeles International	LAX
Atlanta	ZTL	Wm. B. Hartsfield Atlanta International	ATL
Miami	ZMA	Miami International	MIA
Oakland	ZOA	San Francisco International	SFO

3.1 Description

TMA assists controllers with arrival aircraft in the en route cruise and transition airspace managed by ARTCCs. TMA provides ARTCC personnel with a means of optimizing the arrival throughput of capacity-constrained airports, thereby reducing delay. The resulting uniformity of arrival flows can also lead to an increase in departure rates and a decrease in 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 trajectory models use this information, updated every 12 seconds, to optimize schedules to the meter fixes for all arriving aircraft which have filed Instrument Flight Rules (IFR) flight plans, with consideration given to separation, airspace, and airport constraints. These optimized schedules may then be displayed on controller radar displays, and used to ensure a smooth, efficient, and safe flow of aircraft to the terminal area.

3.2 Summary of Previous TMA Results

Various studies have examined the operational benefits of TMA metering and traffic management capabilities. TMA metering has been found to increase arrival throughput and thereby reduce arrival delays. At some airports with shared runways, overall operations rates have increased (arrivals plus departures) during arrival peaks. When used by traffic managers as a planning tool, TMA has been found to reduce holding, reduce flight times, and reduce departure delay for airports controlled by the TMA ARTCC (so-called "internal departures"). Benefits assessment results for TMA Free Flight Phase I (FFPI) sites are summarized in Table 4, and a more detailed description of benefits seen at each TMA site is also given in this section.

Table 4. Changes in metrics following TMA introduction at FFP1 sites

	Center/Airport						
Metric	**ZFW/DFW**	**ZMP/MSP**	**ZDV/DEN**	**ZLA/LAX**	**ZTL/ATL[1]**	**ZMA/MIA[1]**	**ZOA/SFO[1]**
AAR	+5%	+0.7/hr vis, +1.4/hr inst		~ +1/hr			
Arrival Rate			+1/hr vis, +2/hr inst	~ +5% inst			
Ops. Rate		+4/hr vis, +5/hr inst					
Delay, all arrivals	-70 sec						
Delay, internal departures				-23% small airports, -10% LAS		-56%	-35%
Flight Distance		-5 nmi vis, -9 nmi inst				-6 nmi	-2.5 nmi
Flight time						-1.1 min East config, +.25 min West config	-.2 to -.3 min
Delay Distribution[2]		-2%					
Holding				-12%[3]	-24%[4]		

[1]Not currently using time-based metering capability
[2]Percentage of flight distance from 160 nmi to runway that is within the TRACON
[3]Total holding pattern circuits
[4]Total holding time

TMA was initially implemented at ZFW before the establishment of the FFP1 program, concurrent with the redesign of DFW terminal airspace. The impact of TMA at ZFW was analyzed by the NASA Ames Research Center [9]; delays were reduced by 70 seconds per arriving aircraft during periods when demand exceeded capacity. Additionally, the Terminal Radar Approach Control (TRACON) was able to increase the Airport Acceptance Rate (AAR) by 5 percent.

At ZMP, TMA is used both as a strategic planning tool by the Traffic Management Unit (TMU) and tactically by controllers who are actively controlling aircraft using time-based metering (TBM). Initial Daily Use (IDU) of TMA at ZMP for MSP arrivals began in June 2000. Operational analyses have reported an increase in rates at MSP of 4 and 5 operations per hour under visual and instrument conditions, respectively [5]. Initially there was no discernible change in AAR at MSP. Once TMA displays were given to TRACON traffic managers, however, the AAR was found to increase by 0.7 and 1.4 arrivals per hour during visual and instrument conditions, respectively [6]. Finally, an examination of flight distances for arriving flights showed a decrease of from 5 nmi (visual) to 9 nmi (instrument), and a redistribution of delay to higher, more fuel-efficient altitudes [5].

TMA was next installed at ZDV for arrivals at DEN, with IDU in September 2000. While DEN has excess capacity at most times, there are times during poor weather where demand exceeds capacity and delays accrue. An assessment of TMA during these times found that the tool increased arrival rates by 1 (visual) to 2 (instrument) aircraft per hour [5]. Most of the time, air traffic managers use TMA to make strategic decisions about miles-in-trail (MIT) restrictions. We expect that benefits from TMA will increase at ZDV/DEN as demand increases.

Active use of TMA started at ZLA for arrivals at LAX in June 2001. Until mid-May 2002 TMA was used primarily as a strategic tool by ZLA traffic managers to determine the necessity of location-based MIT restrictions. Controllers at ZLA have only recently begun using TMA for metering arrivals. Initial studies focused on the use of the tool by traffic managers for planning and management. Reference [6] reported an increase in actual arrival rates of about 1.7 aircraft per hour, and an increase in AAR of about 1 aircraft per hour during instrument conditions. Reference [5] also reported a decrease in holding for arrivals, and a decrease in departure delay for internal departures. A more recent analysis [7] has shown a further increase in arrival rates of five percent, as well as a small increase in AAR, when time-based metering is employed.

The last three sites to receive TMA in the FFP1 program are ZMA, ZTL, and ZOA, none of which is currently using time-based metering. Nevertheless, some operational improvements have been observed as a result of improved situational awareness in the TMUs. Traffic managers can use the tool to model MIT restrictions before applying them, and to release internal departures. Reference [7] reports that MIA and SFO terminals have seen a reduction in average flight times and distances during peak periods, and also a reduction in the variability of flight distances. ZMA and ZOA have also seen a reduction in departure delay for internal departures. ZTL has seen a reduction in holding for arrivals at ATL.

3.3 TMA at ZLA/LAX

ZLA began IDU of TMA in June of 2001. The overlay list that allows tactical use of the tool by individual controllers was not in use at ZLA because the ARTCC was not using time-based metering. Personnel at ZLA conducted an operational suitability assessment of TBM with TMA between May and July 2002. Additional operational testing was performed in August and September 2002, and on November 14, 2002, mandatory TBM usage began in the time periods 9:00 AM to 12:00 PM, Monday through Friday.

This report compares equivalent time periods before and after mandatory time-based metering to assess its effects on airport acceptance rate, internal departure delay, and restrictions issued by ZLA.

3.3.1 Airport Acceptance Rate

According to controllers in the traffic management unit at ZLA, higher acceptance rates are now being used by the TRACON during instument conditions. To study any changes in airport acceptance rate, we considered two time periods for comparison: a five-month period after mandatory TBM began (December 2002 – April 2003) and the same five-month period the previous year (December 2001 – April 2002). For each period, we considered only Mondays through Fridays from 9:00 AM to 12:00 PM local time, the hours TBM was used. The data source used for analysis was the FFP internal metrics database, comprising both ETMS and ARTS track data.

A preliminary linear regression analysis was performed to investigate the relationships between AAR and several variables. Only flights landing under IFR were included since the focus at LAX was the effect of TBM under IFR conditions. The effect of runway configuration was considered, but for the pre-TBM time period the East airport configuration was only used on one occasion. Therefore, this variable was excluded from the analysis. Variables that were included were the implementation of TBM as well as relevant meteorological conditions such as visibility, ceiling, and precipitation. The initial regression results showed that the effects of ceiling and precipitation were not statistically significant, so these factors were excluded from the final regression analysis.

Figure 25 displays the results of the final regression of the AAR at LAX. The regression results show that the effect of visibility is statistically significant (at the 5 percent level) but very small. The impact of TBM implementation is to increase the AAR slightly. ZLA reports that under IFR conditions they are able to keep the AAR higher for longer periods of time. However, according to the regression results, we cannot conclude that the increase in AAR is statistically significant. Therefore, at this time we can neither refute nor validate the ZLA claims about increased AAR.

Dependent variable: AAR, weighted by minutes in configuration

R Square	Adjusted R Square	F	Sig.
.101	.082	5.250	.007

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	67.042	.233		287.390	.000
TBM	.381	.207	.182	1.836	.070
Visibility	.082	.034	.239	2.413	.018

	Explanation of Variables
TBM	0 = Pre-TBM, 1 = During-TBM
Visibility	Reported in statute miles

Figure 25. Results of LAX AAR regression analysis

3.3.2 Internal Departures

We examined the en route, gate, and taxi out delays for aircraft arriving at LAX that departed from airports within the ZLA airspace (i.e., “internal departures”). We used the Aviation System Performance Metrics database (ASPM) as our source to obtain delay data for the following airports: BFL, BUR, CRQ, FAT, IPL, LAS, MRY, ONT, OXR, PMD, PSP, SAN, SBA, SBP, SMX, SNA, VNY, and YUM.

As in the previous section, the post-TBM period we considered was December 2002 through April 2003. The pre-TBM baseline period was December 2001 through April 2002, a comparable period one year prior to the use of time-based metering at ZLA.

The results of the analysis are shown in Figure 26. Average airborne, gate, and taxi out delays have all decreased for internal departures since the introduction of TBM at ZLA.

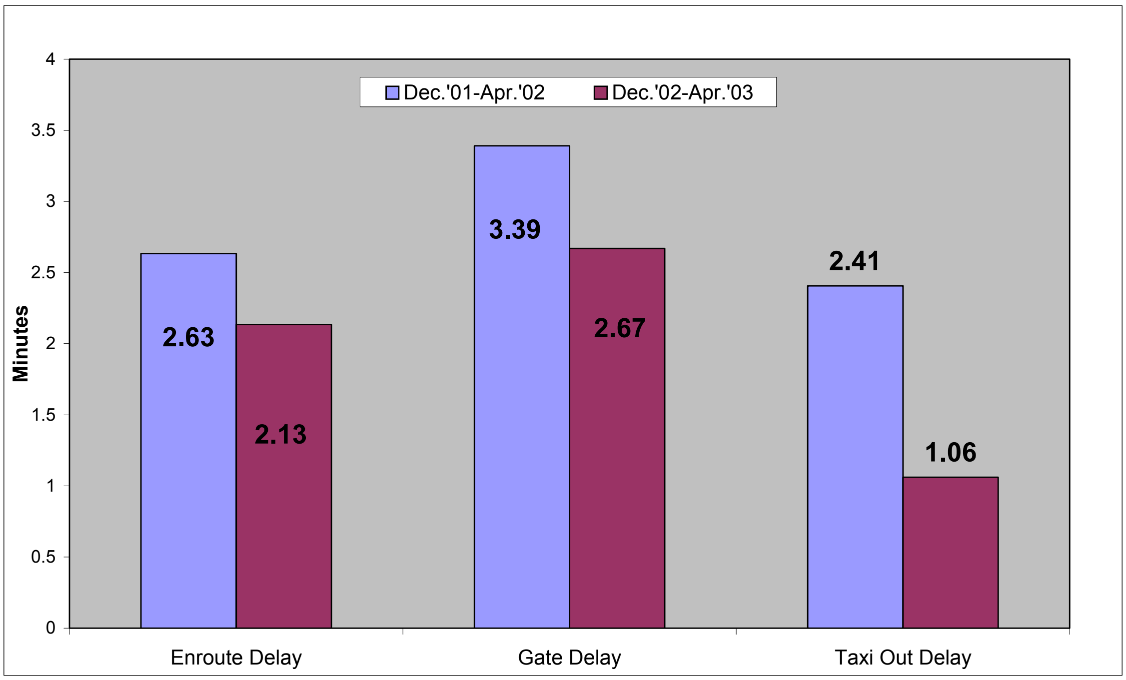

Figure 26. Delays for ZLA internal departures to LAX

3.3.3 Restrictions Issued by ZLA

Another positive impact reported following the implementation of TMA and TBM at ZLA has been a reduction in the number of restrictions passed back to Oakland ARTCC (ZOA). ZOA TMCs and other TMA personnel claimed that there had been a reduction in miles-in-trail restrictions over the DERBB intersection. We used data collected from ZOA logs to verify and quantify this observation.

Based on ZOA input, the primary benefit we expected to see was a reduction in restrictions of 15 miles or greater. Our analysis showed an 11 percent reduction in the fraction of restrictions that were 15 miles or greater, as indicated in Figure 27.

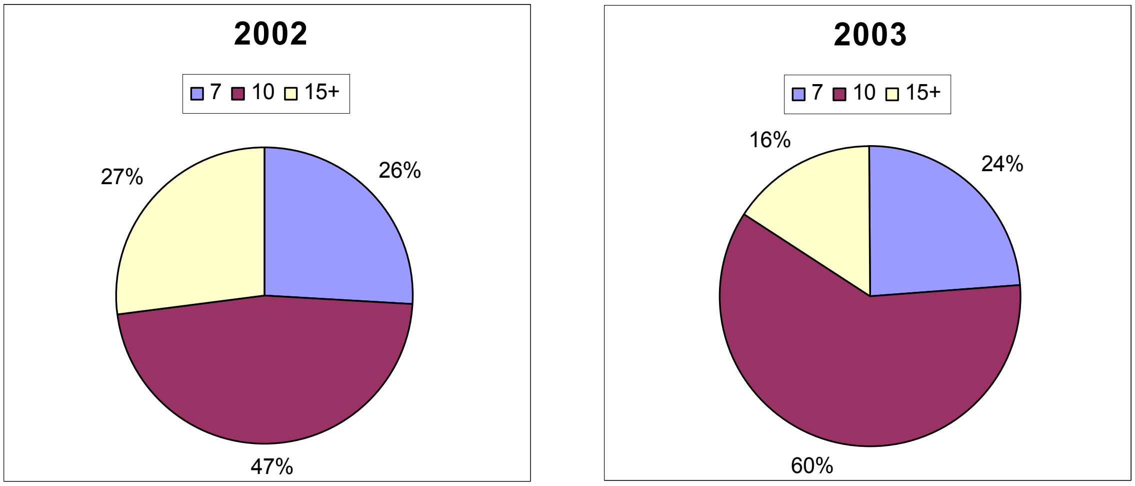

Figure 27. Miles-in-trail restrictions given to ZOA from ZLA, Feb-May 2002 compared to 2003

Next, we factored in the duration of the restriction time for the same periods used above. We computed a restriction "value" by multiplying the duration of the restriction by the number of miles-in-trail. We then compared the total value for each time period. As can be seen in Figure 28, there was a 24 percent reduction in this restriction parameter. Note that the average AAR for February through May of 2002 was 74, while for the same period in 2003 the average AAR was 73. There was similar demand during each period. This gives us confidence we are looking at the system under comparable conditions.

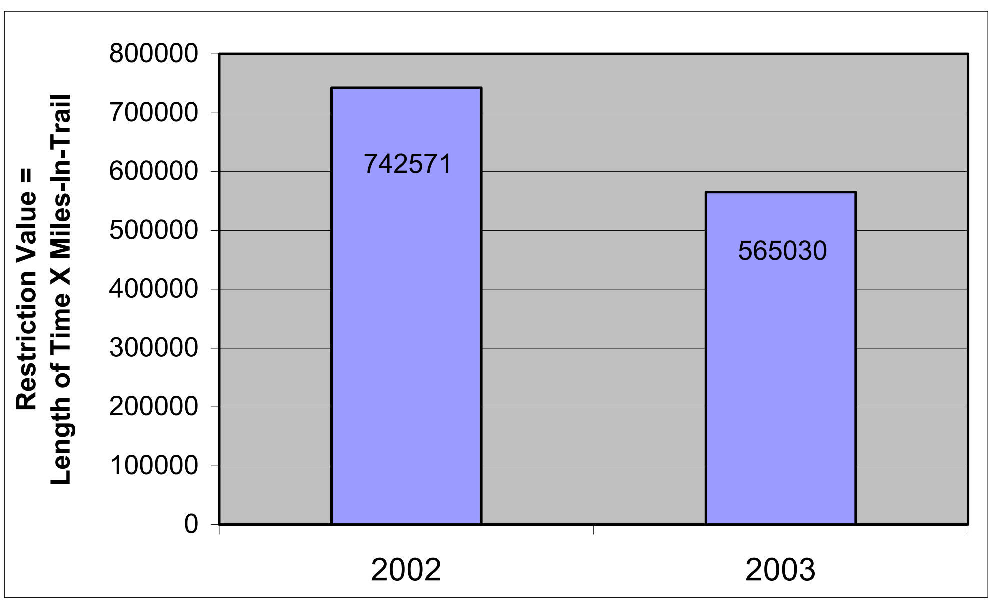

Figure 28. Restriction values for ZOA departures to LAX

In addition to the reduction in miles-in-trail restrictions to LAX, there has also been a significant reduction in OPSNET reportable departure delays to LAX from the internal ZOA airports. This reduction is based on data from the ZOA TMU logs. According to this data, there were 126 instances in the time period February through May 2002 when there were reportable delays of 15 minutes or greater. In contrast, there was only one occurrence for the same months in 2003. Although there has also been a reduction in demand of approximately 7 percent for internal ZOA traffic to LAX, the virtual elimination of reportable departure delays would seem to exceed the improvement expected from reduced demand alone. We believe that TMA at ZLA, particularly the implementation of TBM, is responsible for a significant portion of this reduction in delays.

Further improvements may be achieved with adjacent center metering implemented in May 2002. We will analyze this improvement in the upcoming December 2003 report.

3.4 TMA at ZTL/ATL

Initial Daily Use of TMA at Atlanta Center began in February 2001. At the outset, traffic managers used the tool to increase their situational awareness. By June 2001 all traffic managers had been trained in the use of the tool and were using it for various management functions. ZTL has not yet implemented time-based metering. However, as of January 15, 2003, ZTL requires mandatory usage of TMA by TMCs as the primary data source for the strategic planning of restrictions.

TMCs use the TMA load graph, which displays a projected delay timeline for each fix and the airport as a whole, to determine when traffic is exceeding capacity and action is needed. Managers have reported to us that the use of TMA to establish miles-in-trail restrictions in this way has led to fewer instances of restrictions and/or less severe restrictions. As a consequence, they have observed less holding of aircraft arriving at ATL. To attempt to quantify this, we studied holding at ATL before and after implementation of mandatory usage of TMA for restrictions planning.

Additionally, discussion with the TMU indicated that Atlanta TRACON, in conjunction with ZTL, has been increasing the AAR because of information coming from TMA. To assess terminal capacity effects of ATL after the TMU implemented mandatory usage of TMA for planning purposes, we analyzed both the called rate (normalized for weather conditions) and the actual peak arrival throughput.

3.4.1 Holding at ATL

We obtained holding logs from the ZTL TMU, and the periods selected for analysis were January through April, 2002 and 2003. For January – April 2002, the average length of holding for a held aircraft at ATL was 17 minutes. An illustration of a typical flight track for a flight held at ATL for 17 minutes is shown in Figure 29.

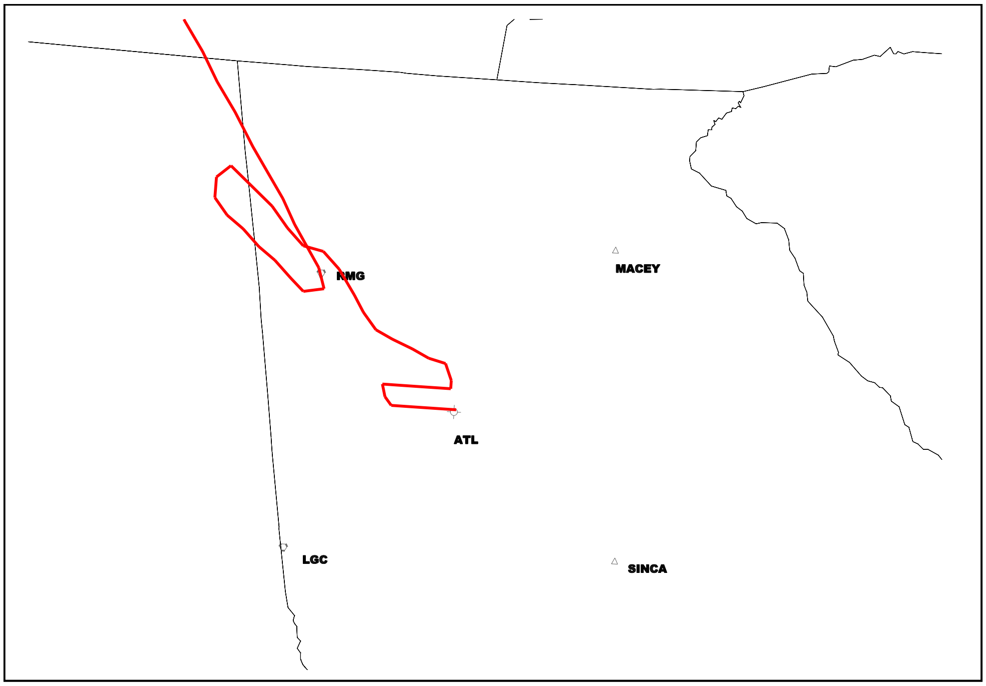

Figure 29. Example of ATL arrival held in ZTL airspace

Before proceeding with the holding analysis, we compared scheduled traffic during the time periods of interest (Figure 30). Data is taken from ASPM and is based on airline scheduling. The graph shows that demand during these two periods was roughly equivalent. Therefore, we assume that any change in holding is not likely to be due to changes in demand.

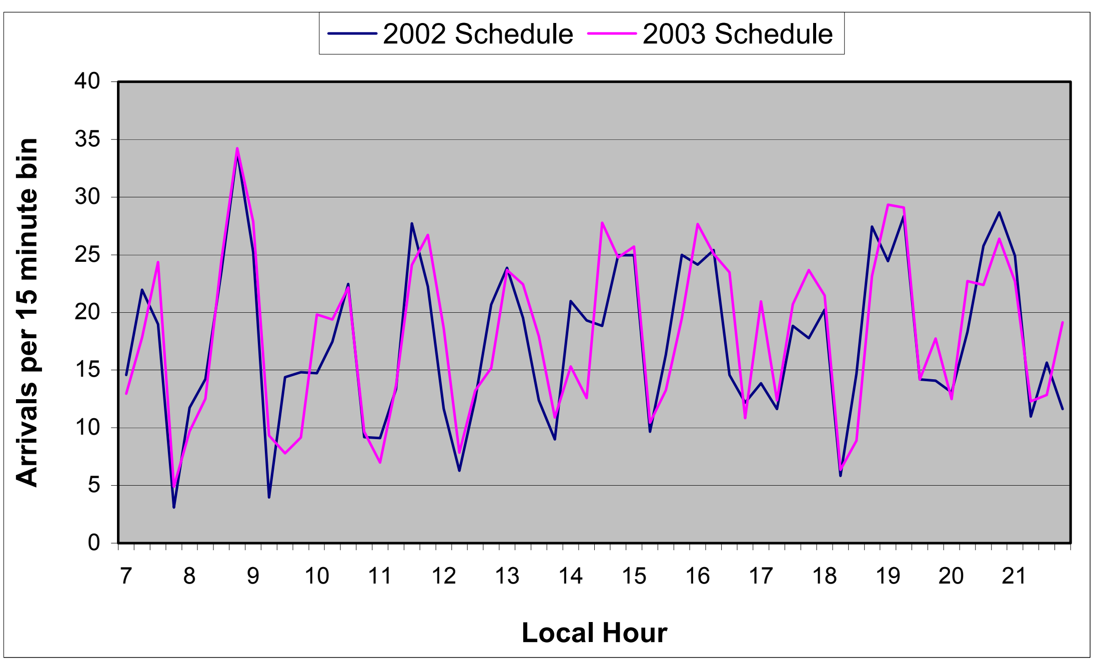

Figure 30. Comparison of scheduled arrivals at ATL, January - April

The comparison of holding at ATL for January – April 2002 versus 2003 is shown in Table 5. Since last year, the total amount of holding has dropped, and the average hold time per held flight has decreased by 0.8 minutes, a drop of 4.8 percent.

Table 5. ATL Holding Comparison

	Jan - Apr 2002	Jan - Apr 2003
Aircraft Held	5,683	5,433
Mean Holding Time per A/C Held	17.0 min	16.2 min
Total Holding Time	1,613 hr	1,468 hr

Figure 31 is a graph of the means of the 2002 and 2003 holding data, and the ranges show the 95 percent confidence intervals for each data set. The difference in means portrayed in the figure is statistically significant at the 5 percent level.

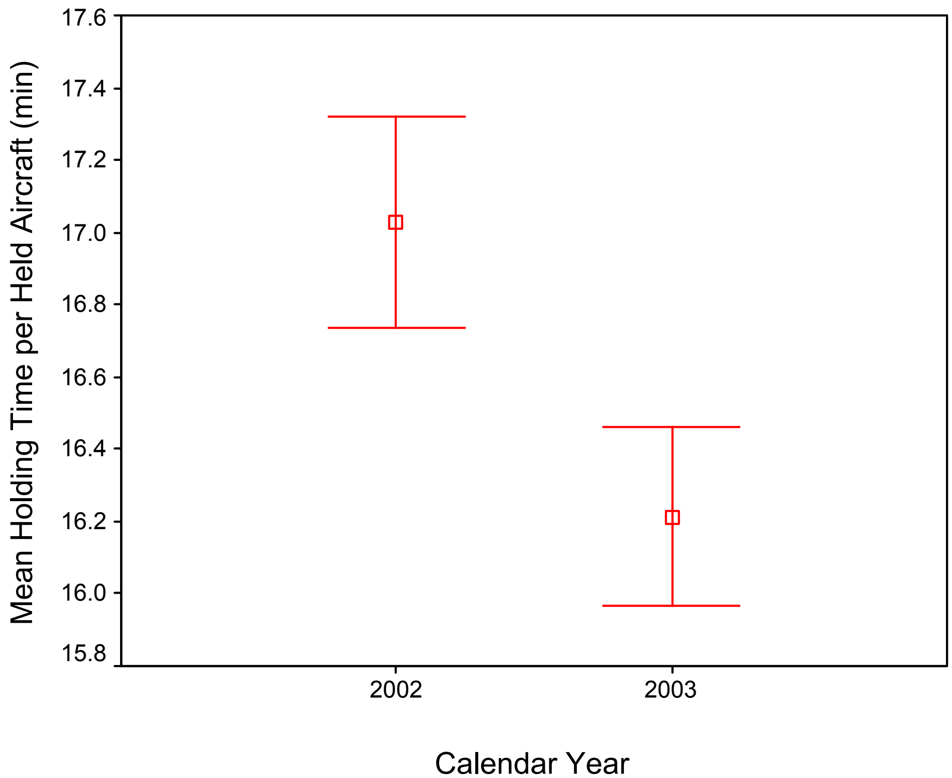

Figure 31. Plot of ATL holding data averages with 95% confidence intervals

3.4.2 Airport Acceptance Rate and Throughput Analysis

We considered two time periods for comparison: a four-month period before mandatory usage (September-January 14, 2003), and a mandatory TMA operational period of similar duration (January 15-May 2003). Data sources available were the FFP internal metrics database and the ASPM database; both produce similar results.

First we consider the impact of certain variables on the AAR. These variables included the type of approach used (instrument or visual), implementation of mandatory usage of TMA, and some relevant meteorological conditions (precipitation, ceiling, etc.). Thunderstorms were excluded from the final AAR regression because of low statistical significance.

Figure 32 displays the results of the final regression of the AAR. The goal is to study the impact of TMA independent from the changes in AAR associated with ceiling and visibility. The modeling of ceiling and visibility indicates an expected relationship with the AAR; as visibility and ceiling increased, so did the AAR. We found an improved relationship using logarithmic transformations for both the ceiling and visibility variables to account for the decreasing effect on the AAR as both these factors are increased. The regression results suggest that when TMA is used for planning purposes, and all other factors are held constant, the overall AAR increases by two aircraft per hour.

Dependent Variable: AAR

R Square	Adjusted R Square	F	Sig.
.748	.746	635.739	.00000

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	60.225	.996		60.490	.000
FORAPPRO	10.379	.366	.558	28.394	.000
RAIN	-1.068	.573	-.030	-1.863	.063
LOGCEIL	4.578	.335	.342	13.676	.000
LOGVISIB	2.177	.807	.057	2.698	.007
TMA	2.001	.286	.108	6.999	.000

	Explanation of Variables
FORAPPRO	0 = Instrument Approaches, 1 = Visual Approaches
RAIN	0 = All other weather conditions, 1 = rain
LOGCEIL	Log of ceiling with unlimited ceiling replaced with 33,000 feet
LOGVISIB	Log of visibility
TMA	0 = Pre-mandatory usage, 1 = During mandatory usage

Figure 32. Results of ATL Acceptance Rate regression analysis

Once we had concluded that TMA caused an increase in the AAR, we then investigated whether the increase in AAR caused an increase in the actual peak rate. In this analysis, peak periods are defined as those non-overlapping 15 minute time intervals where actual arrival rates are greater than or equal to the AAR. Figure 33 depicts the mean peak arrival rate before and after mandatory usage of TMA for planning purposes for both approach types. Additionally, this figure depicts the 95 percent confidence intervals for our dataset. For visual conditions (which have mean values of 22.6 and 23.5 for "Before" and "After" periods, respectively) the difference in means is statistically significant. For instrument conditions (which have mean values of 19.6 and 20.1 for "Before" and "After" periods, respectively) the difference in means is also statistically significant. This analysis indicates that peak arrival rates under visual approaches have increased 3.9 percent, and 2.5 percent under instrument conditions as a result of mandatory usage of TMA for planning purposes.

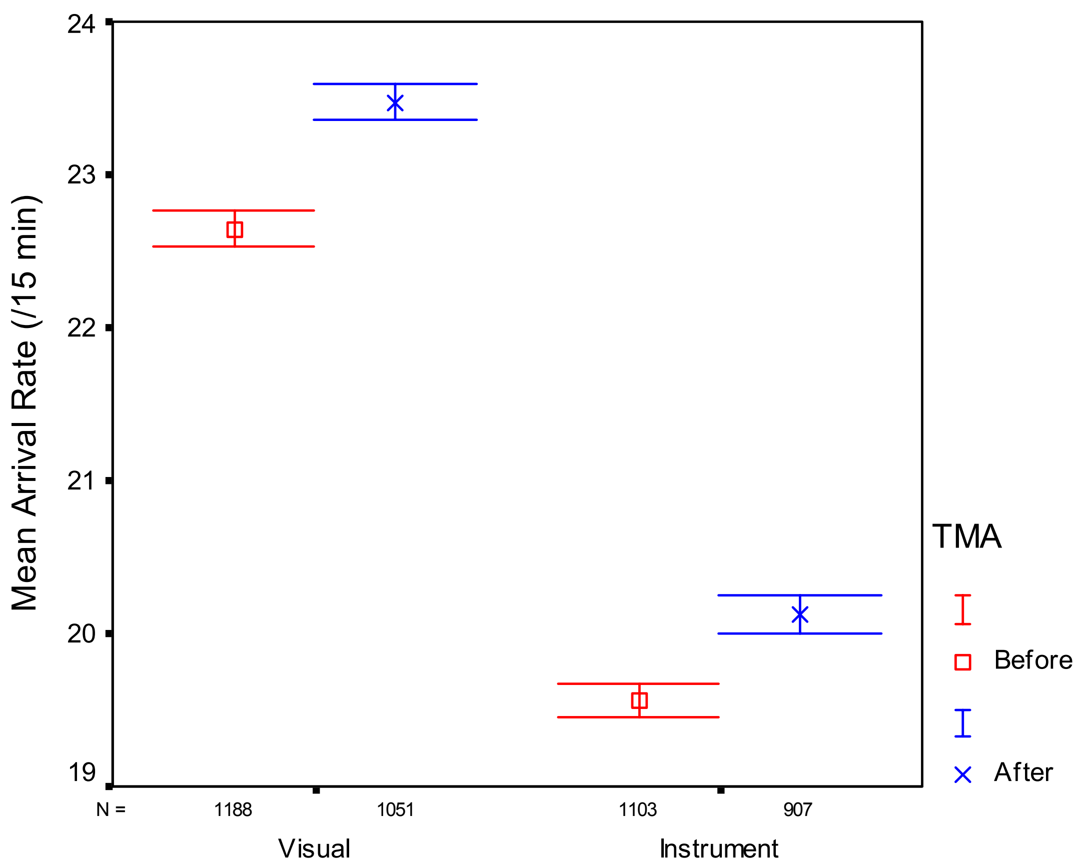

Figure 33. Mean AAR at ATL with 95% confidence intervals

3.5 TMA at ZMA/MIA

TMA became operational at ZMA for MIA arrivals in May 2001. The TMU is using TMA as an aid in decision-making and strategic planning, and the tool is currently used daily between 6:00 and 22:00 local time. Meanwhile, controllers have completed dynamic simulation (DYSIM) training in time-based metering. TMA displays are also operational at the MIA TRACON, where the TMU uses the system load graph to help make decisions about airport configuration, restrictions, and staffing.

ZMA has not yet fully implemented time-based metering although they ran an initial test of TBM at the end of January 2003. In this section of the report we present the results of an analysis of arrival rates during the TBM test.

3.5.1 Arrival Rate Analysis

The purpose of the arrival rate analysis is to determine if TBM has had an impact on the arrival rate at MIA. The TBM test was held between 14:00 and 16:00 local time at MIA on Thursdays and Fridays, January 23-31, 2003. Flights arriving at these times were all landing under VFR.

The data source used for the arrival rate analysis was the FFP internal metrics database. Arrival rates were determined for a rolling 15-minute bin for the hours and dates of the TBM test. For comparison, arrival rates were also calculated for a rolling 15-minute bin between 14:00 and 16:00 on Thursdays and Fridays from June 2002 through January 2003, when VFR conditions applied for the entire period each day.

For each day in the test and pre-test time periods a maximum arrival rate was selected from the rolling 15-minute arrival rates. To qualify as a peak, the AAR had to be greater than or equal to 64, and demand had to be greater than the AAR. Any aircraft that was in the TRACON airspace within the 15 minute period counted towards demand.

Figure 34 presents a histogram of all the calculated peak arrival rates in the pre-test time frame and during the TBM test. The arrival rates have been weighted for aircraft type to normalize for flight separation[4]. Observations from the pre-test time frame are shown in dark gray, and observations from the TBM test period are shown in light gray. Of the four days included in the TBM test period, two did not meet the requirements for analysis because demand in the TRACON was not high enough. The other two days did meet the criteria for AAR and demand, and these two data points are labeled on the figure. On January 31, MIA had a 15-minute arrival peak higher than any time in the pre-test time period, and on January 30, they tied the highest 15-minute arrival peak prior to testing.

[4] Since heavy aircraft require more separation because of wake turbulence effects, we have weighted these aircraft by a factor of 1.4 when calculating the peak arrival rate.

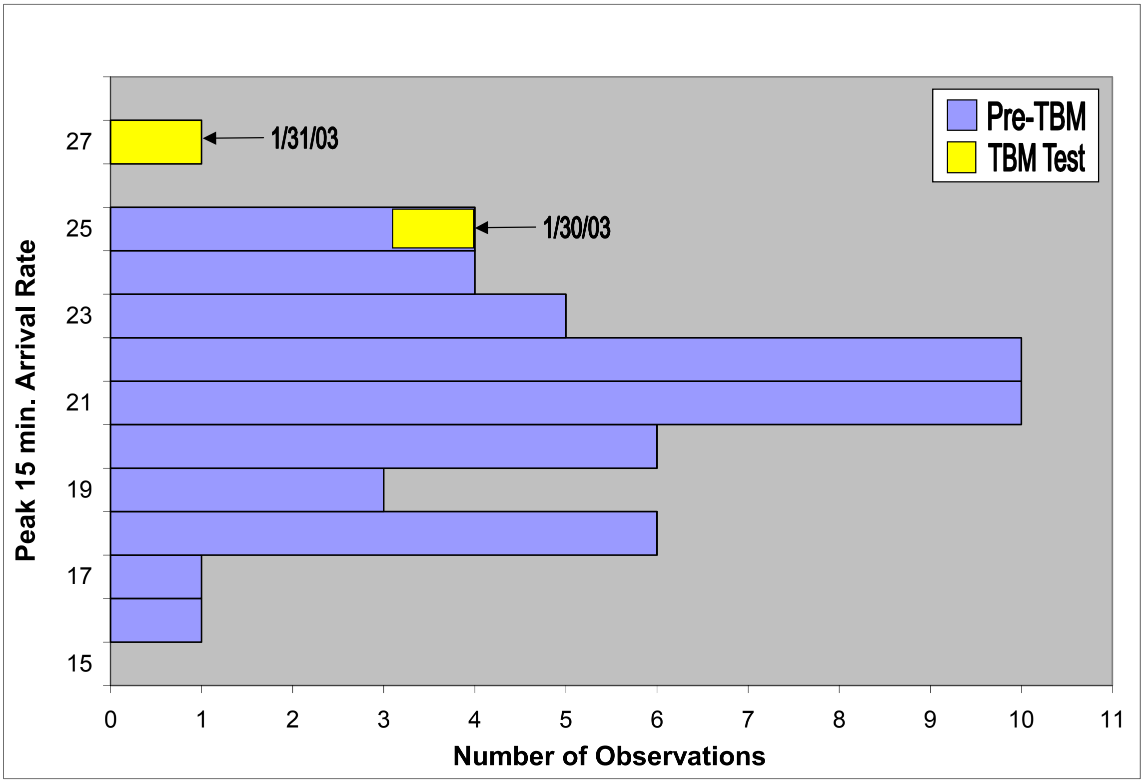

Figure 34. Peak adjusted arrival rates at MIA, historical and during TBM test

4.0 COLLABORATIVE DECISION MAKING (CDM)

CDM is a joint government/industry initiative aimed at improving air traffic management through increased information exchange, procedural changes, tool development, and common situational awareness among the various parties in the aviation community. The program is one of the core technologies in the FAA's Free Flight program and includes participants from the FAA, aviation industry, and academia.

Evaluations of CDM conducted prior to this report [10] focused on the benefits of Ground Delay Program Enhancements (GDPE). A Ground Delay Program (GDP) is an air traffic management initiative used to control traffic flow into an airport by delaying flights on the ground at their departure airports. The following quantifiable results were attributed to GDPE:

- increased departure compliance (for flights in a GDP)
- improved flight departure predictions (for flights in a GDP) as a result of airline input to ETMS modeling
- better GDP performance, measured by how well the actual arrival flow matched the predicted arrival flow
- increased user equity, based on how arrival slots are allocated during GDP
- delay savings by *compression*, a GDP revision feature in which flights are moved into earlier arrival slots vacated by cancelled or delayed flights.

Each year the CDM scope is expanded as new tools or enhancements are developed and employed. The latest Free Flight Program Office review of CDM initiatives [7] reported the following:

- A change in the compliance window for Estimated Departure Clearance Times (EDCTs) from –5/+15 minutes to –5/+5 minutes resulted in improved EDCT compliance and actual arrival times closer to scheduled arrival times.
- The Post Operations Evaluation Tool (POET) is used by over 100 analysts in the FAA, at the airlines, and in academia and industry for a variety of analyses, including studying arrival/departure traffic at various airports (including delays, rates, and fix loading), estimation of sector loading, and identification of fixes where holding occurred.
- While a quantitative assessment of Collaborative Convective Forecast Product (CCFP) use on days of convective weather did not clearly demonstrate a benefit, both airlines and FAA personnel perceived an improvement in CCFP production efficiency and accuracy, compared to the previous year.

The most recent CDM tool that has been implemented is Slot Credit Substitution (SCS). SCS was first used on May 12, 2003, and the Air Traffic Control System Command Center (ATCSCC) Quality Assurance department assessed its usage through June 9, 2003. The results of this review are presented in this section.

4.1 Description and Operational Use of Slot Credit Substitution

SCS is a procedure designed to allow slot-by-slot substitution during a GDP that was not available previously. The current rules of airline substitution during a GDP, referred to as "simplified subs," only allow intra-airline substitution. If, for example, an airline cancelled a flight, the airline still "held" that slot, and only that airline could substitute into that slot. If the airline did not have another flight that could arrive during that GDP slot, the slot may have gone unused, wasting airport capacity. With SCS, an airline can relinquish that earlier arrival slot to other users in exchange for a slot at a later time. Flights from other participating airlines are used to bridge the gap between the slot given up and the later slot.

Benefits from SCS should include:

- Smoother arrival flows during a GDP
- Improved EDCT compliance
- Arrival rates closer to AAR.

To better illustrate when SCS is needed, the simple method of substituting and the SCS procedure are shown in Figures 35 and 36, respectively. The left hand side of Figure 35 shows successful "simplified subs," and the right hand side shows unsuccessful "simplified subs." Figure 35 shows flights in a GDP for one airline only. Flights in arrival slots designated by the original airline schedule are shown in white. During a GDP, each flight is given a set amount of delay, and the new "GDP schedule" is shown by the flights in gray. If a flight on the GDP schedule is cancelled, as designated by the flight with the "X" through it, the airline can move the next flight to that slot and do the same for subsequent flights, resulting in a delay savings for each of these flights. In the second scenario, illustrated in the right side of Figure 35, a flight has been cancelled, but because of scheduling or other operational considerations, the flight in the next arrival slot cannot be moved up (also indicated by an "X"). In this case, a slot will remain empty and go unused. SCS makes it possible for this empty slot to be used by another airline, so that airport capacity is not wasted.

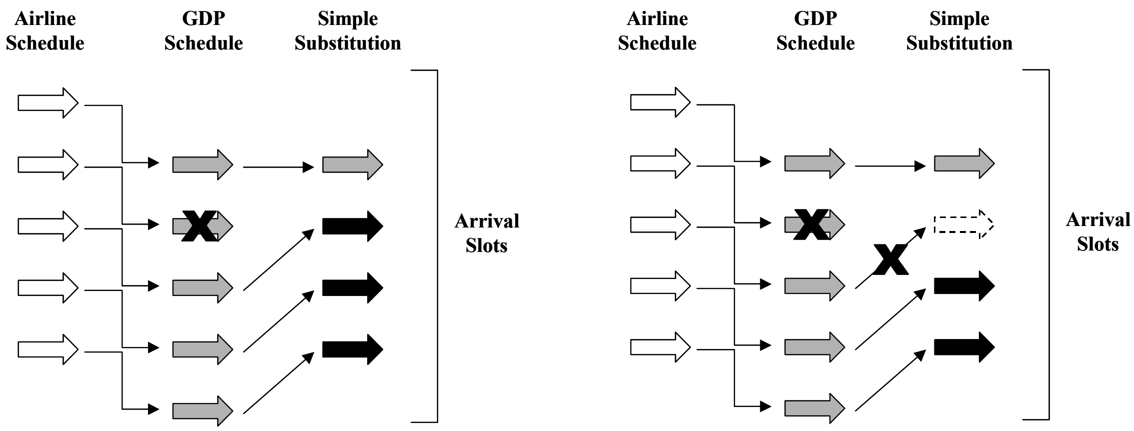

Figure 35. Successful (left) and unsuccessful (right) simple substitution within a GDP.

Figure 36 is a schematic of the mechanism of Slot Credit Substitution. The left-hand column shows the arrival slots for flights before an SCS request is made. Each block represents an arrival slot, and the label designates the flight slated to arrive in that slot. Flights for Airline 1 have "A" in the "flight number"; all other airline flight numbers begin with a "B".

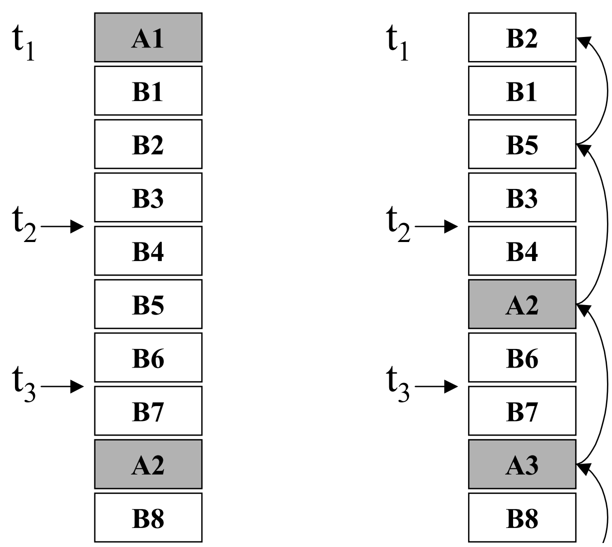

Figure 36. Arrival slot swapping using Slot Credit Substitution (SCS).

Say that Airline 1 cancels flight A1, scheduled to arrive at time t_1, and that it cannot substitute another of its own flights at that time. The earliest time another flight from Airline 1 could arrive is t_2, although Airline 1 would accept a time as late as t_3. Airline 1 submits an SCS request offering the slot at t_1 in exchange for a slot between t_2 and t_3. This request is processed by Volpe within ETMS to try to identify a "bridge" among other airline flights that can accommodate the request. If a suitable bridge does not exist, the request is rejected. If the request is successful, the new arrival slot allotment could look like the right-hand column of Figure 2. When flight A1 is cancelled, B1 cannot make the vacated slot, due to schedule constraints, but B2 can and is therefore moved into this earlier slot. This sets off a chain of substitutions involving flights from several airlines that are able to move into earlier arrival slots. When flight B5 moves into the slot vacated by flight B2, Airline 1 is able to move flight A2 into the time frame in which they requested an arrival slot. Because the successful SCS request frees up the slot previously held by flight A2, Airline 1 can now move one of its own flights, A3, into this slot.

SCS can be used not only for cancelled flights but also when a user has a flight that cannot meet its Estimated Departure Control Time (EDCT) and therefore will miss its arrival slot.

4.2 SCS Implementation and Initial Results

SCS went on-line on May 12, 2003, and the ATCSCC Quality Assurance Department studied SCS usage through June 9, 2003. On the first day, three airlines were using SCS; by the fourth week, eleven airlines were sending SCS transaction requests. During that time, 156 SCS requests were made, and 50 of these were successful. The successful requests indicate that SCS offers the airlines greater flexibility and allows the use of arrival slots that may have otherwise gone unused, increasing airport capacity.

Failed SCS requests were attributed to insufficient lead time, the airline not "owning" the slot they were trying to relinquish, and airlines submitting multiple SCS requests with the same information. It is expected that all of these factors can and will improve as airlines become more experienced with using the SCS request.

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ACRONYMS

AAR	Airport Acceptance Rates
AOZ	Free Flight Program Office
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASPM	Aviation System Performance Metrics
ATCSCC	Air Traffic Control System Command Center
ATL	William B. Hartsfield Atlanta International Airport
BFL	Meadows Field, Bakersfield
BUR	Burbank-Glendale-Pasadena Airport
CAASD	Center for Advanced Aviation System Development
CCFP	Collaborative Convective Forecast Product
CCLD	Core Capability Limited Deployment
CDM	Collaborative Decision Making
CHI	Computer Human Interface
CPDLC	Controller-Pilot Data Link Communications
CRQ	McClellan-Palomar Airport
CTAS	Center TRACON Automation System
DEN	Denver International Airport
DFW	Dallas/Ft. Worth International Airport
EDCT	Estimated Departure Clearance Times
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FAT	Fresno Airport
FFP	Free Flight Program
GDP	Ground Delay Program
GDPE	Ground Delay Program Enhancements
GPD	Graphic Plan Display
IDU	Initial Daily Use
IFR	Instrument Flight Rules
ISSA	Independent System Safety Assessment
JRC	Joint Resources Council
LAS	Las Vegas-McCarran International Airport
LAX	Los Angeles International Airport
MIA	Miami International Airport
MIT	Miles-In-Trail
MRY	Monterey Airport
MSP	Minneapolis/St. Paul Airport
NAS	National Air Space
NASA	National Aeronautics and Space Administration
ONT	Ontario International Airport
OXR	Oxnard Airport
PMD	Palmdale Regional Airport

POET	Post Operations Evaluation Tool
PSP	Palm Springs International Airport
PTR	Problem Trouble Reports
SAN	San Diego International Airport – Lindbergh Field
SBA	Santa Barbara Municipal Airport
SBP	San Luis County Regional Airport
SCS	Slot Credit Substitution
SCT	Southern California TRACON
SEC	System Engineering Council
SFO	San Francisco International Airport
SMX	Santa Maria Public Airport
SNA	John Wayne Airport – Orange County
SSWG	System Safety Work Group
TBM	Time-Based Metering
TMA	Traffic Management Advisor
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control Facility
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
VNY	Van Nuys Airport
YUM	Yuma International Airport
ZAU	Chicago ARTCC
ZDC	Washington ARTCC
ZDV	Denver ARTCC
ZFW	Ft. Worth ARTCC
ZID	Indianapolis ARTCC
ZKC	Kansas City ARTCC
ZLA	Los Angeles ARTCC
ZMA	Miami ARTCC
ZME	Memphis ARTCC
ZMP	Minneapolis ARTCC
ZOA	Oakland ARTCC
ZOB	Cleveland ARTCC
ZTL	Atlanta ARTCC