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An Operational Assessment of Terminal and En Route Free Flight Capabilities

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Abstract

The Federal Aviation Administration's Free Flight Program is delivering controller tools aimed at improving service to National Airspace System users through more efficient routings and increased terminal capacity. The User Request Evaluation Tool (URET) and the Traffic Management Advisor (TMA) are two of the technologies deployed in the initial phase of Free Flight. URET, originally developed by the MITRE Corporation's Center for Advanced Aviation System Development, is a decision support tool that assists air traffic controllers with the detection and resolution of aircraft-to-aircraft and aircraft-to-airspace separation problems. TMA, a component of the Center-TRACON Automation System originally developed by the National Aeronautics and Space Administration, uses real-time radar data and near-real-time wind data to create schedules for arriving traffic so that TRACON-specified arrival rates are met but not exceeded. The Free Flight Program Office is conducting an operational evaluation of the impact of URET and TMA implementations at selected sites. These evaluations seek to determine if additional deployments are warranted or if modifications to the system may be required. The metrics and methods used to characterize the impact of these tools differ significantly. Results for both capabilities suggest operational improvements have been achieved. This paper uses TMA and URET case studies to describe results as well as the differences in metrics and methodologies.

Introduction

The Federal Aviation Administration's (FAA's) Free Flight Program is deploying five Air Traffic Management (ATM) tools at a limited number of sites through 2002, and collecting detailed performance data in order to assess their operational effectiveness. These assessments will allow the FAA to make informed decisions concerning additional deployments and/or further development of the systems. The Traffic Management Advisor (TMA) and User Request Evaluation Tool (URET) are primary capabilities in the initial phase of Free Flight. TMA is a component of the Center-TRACON Automation System (CTAS) pioneered by the National Aeronautics and Space Administration (NASA). TMA is a metering tool which uses aircraft trajectory models, detailed wind data, and optimization algorithms to generate a schedule for arriving aircraft, and then displays delay times to controllers for those aircraft so that TRACON acceptance rates are met but not exceeded. This in turn can lead to increased airport arrival and departure rates and decreased delay. URET, originally developed by the MITRE Corporation's Center for Advanced Aviation System Development (CAASD), is a decision support tool that assists air traffic controllers with the detection and resolution of aircraft-to-aircraft and aircraft-to-airspace separation problems.

TMA and URET Operational Assessments

The Free Flight Program has conducted an operational assessment of both TMA and URET at selected sites. The metrics and methods used to assess TMA and URET operational improvements have differed significantly. TMA delivers aircraft to a common endpoint – the runway. Measuring improvement in delivering aircraft to a common endpoint provides structure and focus to the operational assessment. "Peak" periods can be studied to estimate changes in throughput under varying conditions. URET detects potential conflicts between aircraft in en route airspace and gives the controller tools to test possible resolutions before sending a flight plan amendment. Aircraft in airspace serviced by URET are destined for many different endpoints, hence throughput is not clearly characterized. Increased direct routings and allowing aircraft to fly at higher, more efficient altitudes have been used as alternative goals for URET.

The measurement of changes in National Airspace System (NAS) performance must also consider changes in demand. With TMA, as long as there is a sufficient base level of demand across all sample peak period observations, throughput measures should not be affected by varying demand levels. Both tools are beneficial when demand is constrained by capacity. When analyzing operational data, in the terminal environment (or in the final phase of en route flight) one can readily identify when demand exceeds capacity. In the en route environment, on the other hand, bottlenecks are usually resolved through ground holds or miles-in-trail restrictions, often leaving no evidence in historical flight tracks of a binding capacity constraint.

The case studies below detail TMA and URET operational analyses. They highlight various metrics, methodologies, and results intended to produce valid and meaningful operation assessments.

TMA System Description

CTAS is a set of decision support tools that generate aircraft schedules and advisories in order to regulate arrivals to a runway complex, thereby assisting air traffic managers and controllers. CTAS was originally developed at the NASA Ames Research Center, and additional advanced research is ongoing there. Two components of CTAS are being fielded by the Free Flight Program at a limited number of sites: passive Final Approach Spacing Tool (pFAST) and Traffic Management Advisor.

TMA assists controllers in the en route cruise and transition airspace managed by Air Route Traffic Control Centers (ARTCCs). TMA provides ARTCC personnel with a means of optimizing the arrival throughput of capacity-constrained airports. Inputs to the system include real-time radar track data, flight plan data, and an extensive wind grid. TMA's trajectory models use this information, updated every 12 seconds, to compute routes and optimal 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.

At the time of writing TMA was operational at Ft. Worth, Minneapolis, Denver, Los Angeles, and Atlanta Centers for Dallas/Ft. Worth, Minneapolis/St. Paul, Denver International, Los Angeles, and Atlanta arrivals, respectively. TMA will become operational at Miami, and Oakland Centers in calendar year 2001.

TMA Metrics

The TMA evaluation focuses on safety, capacity improvement, and efficiency of user operations. TMA is not intended to increase the safety of operations in the NAS, but since safety is paramount in all modernization efforts the potential safety impacts must be carefully considered. This paper will not address the safety analyses being performed as part of the Free Flight Program. To date there have not been any Operational Error or Operational Deviation reports that identify TMA as a contributing factor (or any other Free Flight automation tool, for that matter). For a description of the Free Flight operational safety evaluation methodology, see Reference 1.

Capacity metrics for TMA seek to address the following issue: *Does TMA increase peak-period throughput at airports where it is implemented?* We anticipate that by smoothing the flow of arriving traffic during arrival peaks, and by more predictably matching the arrival rate specified by the TRACON, TMA metering will help TRACON controllers to land more airplanes in a given period of time. It is also possible that by making arrival flows more predictable, TMA will help TRACON and tower controllers to depart more aircraft during arrival peaks. Thus our primary TMA capacity metrics are:

- Airport Acceptance Rate (AAR)
- Actual peak-period arrival rate
- Actual peak period operations rate (arrivals + departures)
- Difference between AAR and actual arrival rate
- Meter fix interarrival time
- Threshold interarrival time.

Only the first three of these metrics will be discussed further in this paper.

Efficiency metrics for TMA seek to address the following issues:

- *Does TMA impact flight times for traffic arriving at airports where it is implemented?*
- *Does TMA redistribute delay from lower to higher, more fuel efficient altitudes for arriving aircraft at airports where it is implemented?*

By helping ARTCC controllers to meter arriving traffic, TMA may reduce the flight time for those flights by reducing holding or vectoring outside of TRACON airspace. On the other hand, it is possible that arrival rates to the TRACON are increased, but that landing rates cannot be increased, so that final approach segments need to be increased and additional delays are obtained within the TRACON. The TMA efficiency metrics attempt to determine whether overall flight times from the point where TMA first detects an arriving aircraft to the runway have changed. Since flight time is significantly impacted by wind speed and direction, we also look at distance flown from the TMA detection boundary to the airport.

Use of TMA might also redistribute delay from the lower altitudes of the TRACON to the higher altitudes of Center airspace. This would be advantageous to aircraft operators, since aircraft typically burn less fuel per unit of time when flying fast at high altitudes than when "low and slow." Thus even with no change in total delay, any redistribution of delay between the TRACON and Center should be measured.

For this preliminary analysis the TMA efficiency metrics are:

- Flight time from the 160 nmi range ring to the runway threshold
- Flight distance from the 160 nmi range ring to the runway threshold.

A 160 nmi range ring was used for this study since this is the largest ring centered on the airport that will fit entirely within Minneapolis Center airspace.

Preliminary TMA Results

Capacity

When examining the impact of a change in automation or procedures at an ATC facility, we typically begin by examining the rates that the facility is specifying; for TMA at MSP, this means the Airport Acceptance Rate (AAR). We examined AARs at MSP from 1 October 1999 through 31 May 2001 to see if they have increased since TMA was implemented.[1] TMA became operational at ZMP/MSP in late June 2000; we have elected to exclude data from 15 June 2000 to 15 July 2000 from this (and all subsequent) analyses because of uncertainties concerning the status of the system during that time period.

Table 1 presents a two-way analysis of variance (ANOVA) of AAR, with a TMA indicator variable and an instrument approaches indicator variable as the independent factors. The data for this analysis were obtained from MSP logs, which were reviewed each day. Each observation of the dependent variable (AAR) was weighted by the length of time (in minutes) that a particular log entry was in effect. This analysis suggests that TMA has had a small but statistically significant *negative* impact on AAR during instrument operations. While the TMA variable is not significant by itself, the interaction term between TMA and IFR is significant and negative.[2] The negative coefficient on this interaction term indicates that AAR is reduced by about 0.9 operations per hour, on average, following TMA implementation when instrument approaches are in use. The instrument approaches variable was also significant, decreasing the AAR on average by 4.8 arrivals per hour. These results were confirmed by a more detailed regression analysis that is not included here.

Table 1. Airport Acceptance Rate ANOVA

Tests of Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2300714222	1	2300714222	323374	.000
TMA	2703.9	1	2703.9	.380	.538
IFR	4998004	1	4998004	702.5	.000
Interaction	38772	1	38772	5.450	.020
Error	19914048	2799	7114.7		
Total	2739743610	2803			

Parameter Estimates

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	58.976	.165	357.5	.000	58.653	59.299
TMA	.341	.230	1.484	.138	-.110	.793
IFR	-4.804	.305	-15.750	.000	-5.402	-4.206
TMA * IFR	-.928	.398	-2.334	.020	-1.707	-.149

Next, we examined the actual arrival rate during arrival peaks at MSP. Figure 1 illustrates one month's worth of arrival rates at MSP. The dark areas in the figure indicate periods of few arrivals, while the bright areas indicate periods of intense activity. There are six distinct arrival peaks during the day resulting from Northwest Airlines hub scheduling practices, and one or two somewhat less distinct peaks between 19:30 and 20:30 local time. It is apparent from this figure that the first five peaks of the day are fairly consistent, but that after this the operation is less predictable, perhaps because delays early in the day eventually take their toll on the hub operation.

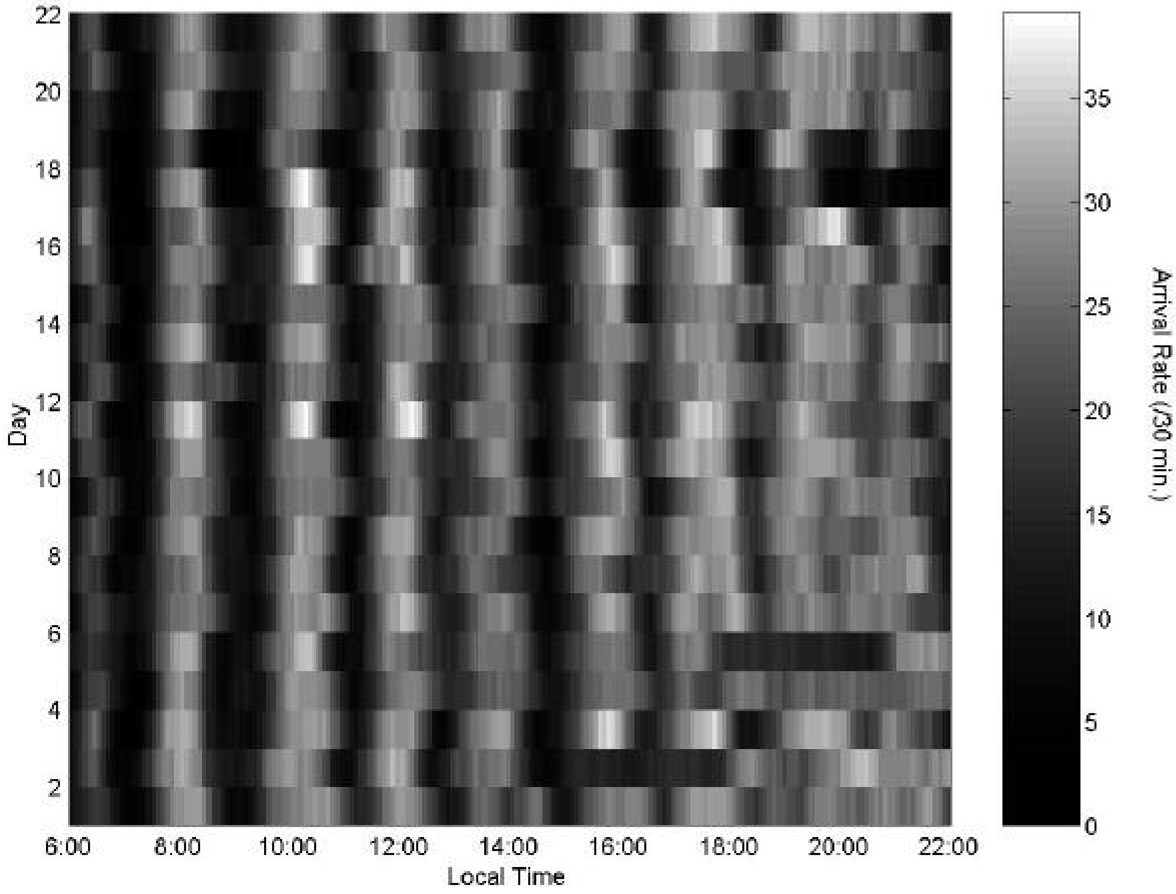

Figure 1. MSP Weekday Arrival Rates, November 2000

We use an algorithm to isolate peaks from arrival data of the type illustrated in Figure 1. This algorithm identifies the closest-spaced 30 aircraft during periods of at least 30 minutes when the arrival rate is greater than the day's average arrival rate. These 30 aircraft typically land within a 28 minute period. We compute an equivalent hourly arrival rate for this period of time. The hourly arrival rate, or "Peak 30 Rate," then becomes one observation for subsequent statistical analyses.

We performed a regression analysis of the peak arrival rate, in which we were able to include several variables relating to airport conditions, weather, and airline schedule in addition to TMA usage and the type of approaches in use. For this analysis we included data back to 23 July 1999, the beginning of our data set, since we could explicitly account for the completion of construction at the airport at the end of September 1999 with a dummy variable.

The independent variables included in the regression analysis are as follows:

TMA	TMA usage dummy variable 0 = pre-TMA deployment 1 = post-TMA deployment
postSept99	Taxiway construction dummy variable 0 = July – Sept. 1999 1 = Oct. 1999 – Dec. 2000
P30DEPS	number of departures during arrival peak
IFR	instrument approaches dummy variable 0 = visual approaches 1 = instrument approaches
CROSSING	crossing runway dummy variable 0 = runway 12/30 not in use 1 = runway 12/30 in use
Two_Parallels	two parallels in use dummy variable 0 = no or one parallel in use 1 = two parallels in use
log(Vis)	$\log_{10}$ of surface visibility in statute miles
log(ModCeiling)	$\log_{10}$ of reported ceiling in feet (zero ceiling replaced with 10 ft., unlimited replaced with 30,000 ft.)

SN	snow dummy variable 0 = SN not in surface weather report 1 = SN in surface weather report
FZ	freeze dummy variable 0 = FZ not in surface weather report 1 = FZ in surface weather report
RA	rain dummy variable 0 = RA not in surface weather report 1 = RA in surface weather report
TS	thunderstorm dummy variable 0 = TS not in surface weather report 1 = TS in surface weather report
VWIND	surface wind velocity in knots
SPRING	season dummy variables
SUMMER	
FALL	
WEEKDAY	day of week dummy variables
SAT	
BANKn	daily arrival bank dummy variables (n = 2 thru 8)

The season and bank variables are included here to try to account for airline schedule (different aircraft arrive in each bank, and the schedule changes with the seasons). All of the independent variables were found to be significant at the five percent level. Various other variables were tried, but were not found to be significant.

The results of this regression are presented in Table 2. The coefficients of the model all have the expected signs. For example, the snow, rain, and thunderstorm variables all have negative signs, as we would expect. The visibility and ceiling variables both have positive signs, since increases in these variables could be expected to lead to increased arrival rates. The TMA variable was found to be statistically significant, with a positive coefficient of 0.4. Thus when weather, airport conditions, and demand (albeit crudely) are taken into account, TMA appears to increase actual arrival rates by about 0.4 aircraft per hour.

We also examined the potential impact of TMA on total operations at MSP during arrival peaks. It has been suggested that the use of TMA smoothes the arrival flow to such an extent that the tower is able to increase the number of departures during arrival rushes (arrivals and departures share the same runways at MSP). In order to test this, we summed the arrival rate examined above with the departure rate achieved at the same time to obtain an operations rate.

We conducted a regression analysis on the operations rate, as we did for the arrival rate. A slightly different set of variables was found to be significant in this regression analysis (Table 3), but the form is very similar to that of the previous regression. In this regression analysis the coefficient on the TMA dummy variable is 2.459 and is statistically significant. Thus TMA was found to increase operations by about 2.5 operations per hour.

Efficiency

Finally, in order to see if aircraft arriving at MSP are being forced to fly longer flight paths since TMA adoption, we examined flight times and distances. The first metric examined is mean flight time from the 160 nmi range ring (a circle centered on the airport with a radius of 160 nmi) to the airport. The 160 nmi radius was chosen because this is the largest circle that lies within Minneapolis Center airspace (TMA does not receive data from beyond the Center boundary).

Table 4 presents an ANOVA for flight time from the 160 nmi range ring to the runway for all arriving flights. Independent variables here are TMA usage and the type of approaches in use (e.g., visual or instrument). This analysis suggests that TMA usage has resulted in a small but statistically significant time savings of approximately 0.2 minutes, on average, during visual operations. This time savings is lost during instrument operations.

Distance flown is probably a more robust measure of flight efficiency than flight time, as the former metric is less sensitive to potential wind changes during the period of evaluation. Table 5 presents an ANOVA for flight distance from the 160 nmi range ring to the runway for all MSP arrivals, using the same data set as used for the flight time analysis. This ANOVA suggests that TMA usage has reduced flight distances by approximately 4.8 nmi, on average, during arrival peaks and visual operations. Again the interaction term is significant, with TMA decreasing flight distance an additional 3.4 nmi during instrument operations.

URET System Description

URET assists air traffic controllers with the detection and resolution of aircraft-to-aircraft and aircraft-to-airspace separation problems. In this way it helps the NAS support a greater number of user-preferred flight paths, and allows increased system capacity while maintaining the current level of safety. The key currently fielded URET capabilities include:

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

Table 2. Actual Arrival Rate Regression Results

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.727	.529	.526	5.353

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	141660	25	5666.4	197.76	.000
Residual	126299	4408	28.652		
Total	267960	4433			

Coefficients

Term	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	57.109	1.283		44.509	.000
TMA	.417	.178	.027	2.350	.019
postSept99	1.077	.400	.043	2.693	.007
P30DEPS	-.392	.012	-.450	-33.338	.000
IFR	-2.409	.231	-.148	-10.445	.000
CROSSING	-3.750	.461	-.122	-8.136	.000
Two_Parallels	1.683	.674	.026	2.496	.013
log(Vis)	3.869	.559	.100	6.924	.000
Log(ModCeiling)	1.478	.220	.106	6.724	.000
SN	-2.384	.457	-.064	-5.219	.000
FZ	-3.086	1.547	-.021	-1.994	.046
RA	-1.282	.493	-.028	-2.598	.009
TS	-7.176	2.417	-.031	-2.969	.003
VWIND	-.190	.019	-.109	-9.964	.000
SPRING	2.915	.223	.171	13.091	.000
SUMMER	3.603	.292	.169	12.353	.000
FALL	3.389	.230	.197	14.713	.000
WEEKDAY	2.121	.234	.123	9.070	.000
SAT	-1.281	.307	-.057	-4.178	.000
BANK2	1.833	.329	.080	5.568	.000
BANK3	1.705	.316	.075	5.398	.000
BANK4	1.234	.334	.054	3.693	.000
BANK5	-3.760	.325	-.164	-11.559	.000
BANK6	3.437	.314	.152	10.931	.000
BANK7	2.081	.321	.088	6.489	.000
BANK8	-1.279	.387	-.042	-3.309	.001

URET processes real-time flight plan and track data from the Host Computer System (HCS). 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 Center. 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 URET CCLD is completed, the seven 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 (AM) for potential conflicts before a clearance is issued. The controller can then send the Trial Plan (TP) to the HCS as a flight plan AM. Coordination of TPs between sectors, which might include those of neighboring centers, may be achieved using automated capabilities.

URET incorporates both textual and graphical computer interfaces. For more details about URET capabilities, benefits, and operational concepts, refer to Reference 2.

Table 3. Operations Rate Regression Results

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.619	.383	.381	13.137

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	473531	20	23676.5	137.2	.000
Residual	761636	4413	172.6		
Total	1235167	4433			

Coefficients

Term	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	85.035	2.765		30.759	.000
TMA	2.459	.416	.074	5.909	.000
IFR	-1.767	.561	-.051	-3.147	.002
CROSSING	-4.967	.888	-.076	-5.594	.000
Two_Parallels	4.850	1.653	.035	2.934	.003
log(Vis)	4.992	1.259	.060	3.964	.000
Log(ModCeiling)	1.404	.532	.047	2.639	.008
TS	-13.929	5.896	-.028	-2.362	.018
VWIND	-.278	.046	-.074	-5.995	.000
SPRING	4.526	.538	.123	8.412	.000
SUMMER	8.258	.690	.180	11.961	.000
FALL	4.641	.544	.126	8.529	.000
WEEKDAY	2.871	.573	.077	5.010	.000
SAT	-1.844	.751	-.038	-2.454	.014
BANK2	-11.002	.768	-.224	-14.333	.000
BANK3	7.082	.770	.145	9.198	.000
BANK4	14.544	.775	.296	18.763	.000
BANK5	-13.970	.781	-.284	-17.883	.000
BANK6	5.861	.771	.121	7.599	.000
BANK7	1.951	.787	.039	2.479	.013
BANK8	6.989	.930	.107	7.512	.000

Table 4. Flight Time ANOVA

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	156442008	1	156442004	3488212	.000
TMA	429.4	1	429.4	9.575	.002
IFR	68226	1	68226	1521	.000
Interaction	291.4	1	291.4	6.498	.011
Error	6500784	144949	44.85		
Total	196262945	144953			

Parameter Estimates

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	35.752	.033	1092.7	.000	35.688	35.816
TMA	-.220	.044	-4.991	.000	-.306	-.134
IFR	1.421	.063	22.57	.000	1.298	1.544
TMA * IFR	.199	.078	2.549	.011	4.593E-02	.352

Table 5. Flight Distance ANOVA

Tests of Between-Subject Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	4064791707	1	4064791707	10185843	.000
TMA	1233037	1	1233037	3089.8	.000
IFR	806050	1	806050	2019.9	.000
Interaction	84380	1	84380	211.4	.000
Error	57556037	144228	399.1		
Total	4980801733	144232			

Parameter Estimates

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	185.997	.098	1898.530	.000	185.805	186.189
TMA	-4.790	.132	-36.334	.000	-5.048	-4.532
IFR	6.942	.189	36.781	.000	6.572	7.312
TMA * IFR	-3.394	.233	-14.541	.000	-3.851	-2.936

URET Metrics and Data Considerations

The FAA's Free Flight Metrics Team has developed a set of metrics related to flight quality and is evaluating these metrics using empirical data. The goal is to determine how URET supports operational personnel in providing benefits to users of the NAS. These metrics may be classified as either full-flight metrics, those that measure attributes of flights roughly from origin to destination, or Center-wide metrics, those that measure attributes of flights within a Center. For Indianapolis (ZID) and Memphis (ZME) Centers the metrics have been computed over a time span that begins before the two-way HCS deployment (July 1999), when there was only very limited use of URET, and continues to the widespread use experienced today. Thus the time frame examined covers the period during which controllers accustomed themselves to URET and became progressively more proficient at using it.

For future URET sites, some metrics will be computed over a time span that begins before implementation to approximately one year after the capability is in full use. These metrics will provide a before and after URET comparison.

There are two primary sources of data for these metrics: HCS Interface Device (HID) files and Enhanced Traffic Management System (ETMS) files, both of which contain flight plan and flight track data. Data are collected at 12-second intervals in the HID files and at 1-minute intervals in the ETMS files. Also, URET produces a data log (DLOG) file based on the input from the HID data. These intermediate data files contain center traversal information (time, actual distance, and great circle distance from actual entry point to actual exit point) for each flight.

Data from the ETMS files are used to extract the en route distance metrics, as well as the Center-wide metric of excess distance flown (the excess of actual distance over great circle distance flown in a Center).

There are many factors that can affect the performance of individual flights and of the system as a whole. A major factor that has a significant impact on air traffic and which can be controlled for in identifying traffic patterns is weather, and in particular precipitation. For comparability, therefore, many of the metrics are calculated only on what have been called "good weather days," i.e., days that experience little or no precipitation throughout the day at or near the Center of interest. Nationwide NEXRAD weather is used to identify good weather days. The data are collected in five minute increments in three different altitude layers: 0-FL240, FL240-FL330, and FL330-FL600. Days were selected with minimum precipitation in the subject ARTCC or in first-tier ARTCCs (those bordering the subject ARTCC).

Traffic patterns vary by day of the week, the heaviest traffic days being Wednesdays and Thursdays. To adjust for this variable, some metrics were collected for the same weekdays over time. While it is not possible to control directly for wind, differing wind patterns can be partially accommodated by including comparison of metrics by season (since prevailing wind patterns tend to be seasonal). For certain metrics, differences were lessened by using only flights that traveled between certain origin and destination cities.

Table 6 sets forth the time frame, days of the week, and weather factors for the metrics described in this paper.

Table 6. URET Metrics

Metric	Airspace	Time Frame	Data Selection Criterion
URET Utilization	ZID/ZME	Jan. '98 – Apr. '01	All days URET available
Number of Directs	ZID/ZME URET initiated as part of Total Number	May '99 – May '01	2 days/week; good Wx days
Distance Saved from Lateral Amendments	ZID/ZME: All HCS initiated from point of amendment through remaining airspace	May '99 – May '01	2 days/week; good Wx days
Excess Distance over Great Circle Route	ZID/ZME – ZDC comparison	Sept. '98 – Apr. '01	All days
En Route Distance	Through ZID/ZME airspace Between specified city pairs	May '99 – May '01	Small number of good Wx days each month

URET Results

ZID and ZME have different airspace and operational characteristics. ZID has more complex airspace, about 35 percent less airspace, and 5 to 10 percent more traffic during peak hours. ZID frequently staffs its sectors with two controllers; ZME more typically has one controller staff each sector. The airspace, traffic, and operational differences between the sites are reflected in the metrics described below.

Metrics on Distance Saved

Metrics were calculated to estimate the total distance saved for flights through ZID and ZME airspace. These metrics are:

- Distance saved by lateral amendments
- Excess distance
- En route distance.

Distance Saved by Lateral Amendments

Lateral amendments consist of turns with no altitude changes. The metric determines the average of the daily sum of distance changed for all lateral amendments from the point of the change in flight plan to the destination airport. The before- and after-amendment trajectories for the remainder of the en route portion of the flight, into TRACON airspace, are compared. The data source is all lateral flight plan amendments sent to URET by the ZID and ZME Host Computer Systems. Note that only two days per week of data were examined.

URET lateral amendments comprise approximately 44 percent of total lateral amendments entered. Most of the other lateral amendments are entered by the R-side controller without using URET. Thus there could theoretically be an increase in flying distance, especially when aircraft are vectored off course to avoid severe weather.

As is apparent from Figure 2, the distance saved from May 1999 (before the two-way HCS interface was effected) through May 2001 has increased substantially at both Centers. Some of the increase is attributable to the fact that Radar Associate Controllers (RACs) in the past would frequently not enter lateral amendments. URET makes it easier for a controller to enter a lateral amendment on the D-console, resulting in increased accuracy of the trajectory.

Figure 2 shows an increase in distance saved from approximately 500 nmi per day in May 1999 to approximately 4000 nmi per day in May 2001 for both Centers. The data includes all HCS lateral amendments during the ten busiest hours at ZID and the eight busiest hours at ZME on the two most heavily trafficked days of the week (Wednesday and Thursday).

To estimate the economic benefit to NAS users of this observed operational benefit, we relied on data provided by the Air Transport Association (ATA). The assumed ground speed for all flights was 7 miles/minute. The ATA preliminary delay cost estimate for 2000 is $62.50 per airborne minute. When ZID and ZME are averaged together, distance saved is 3500 nmi per day per Center over the baseline (before the controller could send amendments directly to the HCS via URET), which equates to 500 minutes per Center. At $62.50 per minute, the savings per month is $937,500 per Center, or $1,875,000 total. This savings estimate is very conservative, as distance saved is calculated for only the ten busiest hours, and the extrapolation does not include the other hours of the day.

ZID consistently exhibits more distance savings than ZME. The different airspace characteristics and operational practices at the two sites affect this metric. As mentioned previously, ZID has more traffic than ZME. With less airspace, ZID controllers vector aircraft more and give more direct routings than ZME controllers (see Figure 3). Operationally, ZID uses 2-person sectors more frequently than ZME, which may give RACs at ZID more

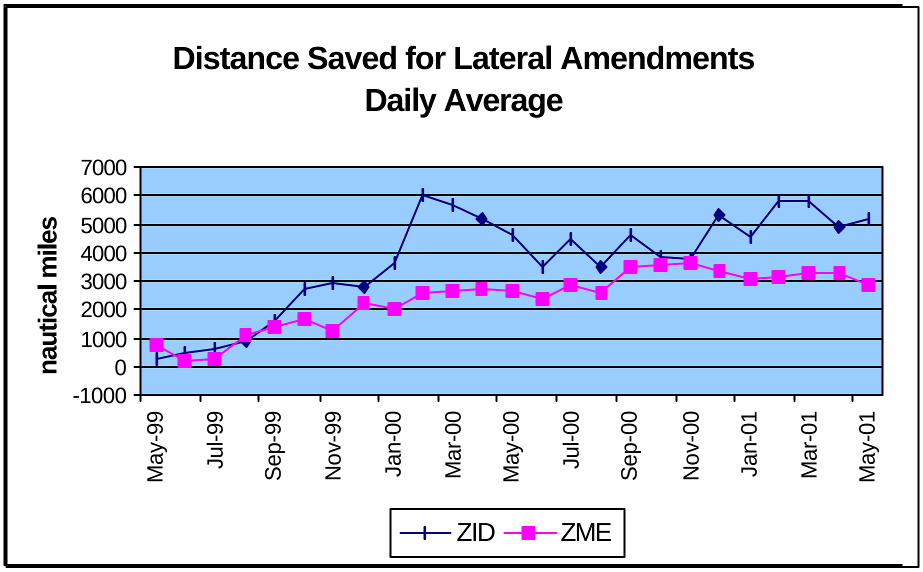

Figure 2. Daily Average Distance Saved – Lateral Amendments

opportunity for strategic planning. Generally, traffic through ZME airspace is on more direct routes than in ZID. ZME controllers, therefore, have less need to reroute aircraft to reduce distance.

Excess Distance

The excess distance flown metric measures how close aircraft come to flying great circle routes within a center. Excess distance flown is calculated on a per flight basis by taking the difference between the actual distance flown and the great circle distance between Center entry and exit points. The data are derived from ETMS track data. Excess distance was calculated for the two URET centers, ZID and ZME, and for a single non-URET Center, Washington Center (ZDC), used for comparison. The metric is the monthly average of excess distance for all flights through a center.

Each flight was examined to ensure that it was reasonable and a possible candidate for URET benefits. Only civilian flights that were in the Center for a minimum of 15 minutes and for more than 50 nmi were included. The metric was computed for all days in the sample period.

Figure 3 shows the excess distance flown from September 1998 through April 2001. There is a substantial difference between the URET Centers and ZDC. The trend line also is significant. There is a slight positive slope over the period for ZME (approximately 0.5 nmi), a slightly shallower slope for ZID, and a substantially greater increase in excess distance over the period for ZDC (about 1.8 nmi). Table 7 displays the seasonal variability of excess distance among the Centers.

As expected, the excess distance is greatest in the summer months, and the summer of 2000 shows an increase in excess distance at both ZID and ZDC. This was surprisingly not true at ZME. These results are consistent with the differences noted in some of the earlier charts between the two sites, and may be accounted for by the different airspace and operational characteristics of the sites. Aircraft are consistently on more direct flight paths in ZME airspace than in ZID; ZME vectors aircraft less than ZID; and aircraft flying through ZME airspace save less distance from lateral amendments. More data and further analysis are required to characterize the differences between ZDC and the URET Centers.

En Route Distance

En route distance is calculated for a small number of good weather days each month. The savings are calculated for the entire "en route" portion of a flight, not just ZID and ZME. Time and distance spent in the terminal area are deliberately omitted by including only that portion of a flight that is more than 40 nmi from the origin and destination airports. For each flight of interest, these metrics are calculated from the flight's ETMS position reports. In order to have results that are comparable from one data set to another, these two metrics are tabulated for a limited number of city pairs for flights that cross the subject en route Center. Table 8 lists the city pairs used for this analysis. These city pairs were selected primarily because a substantial number of flights between them pass through ZID and ZME.

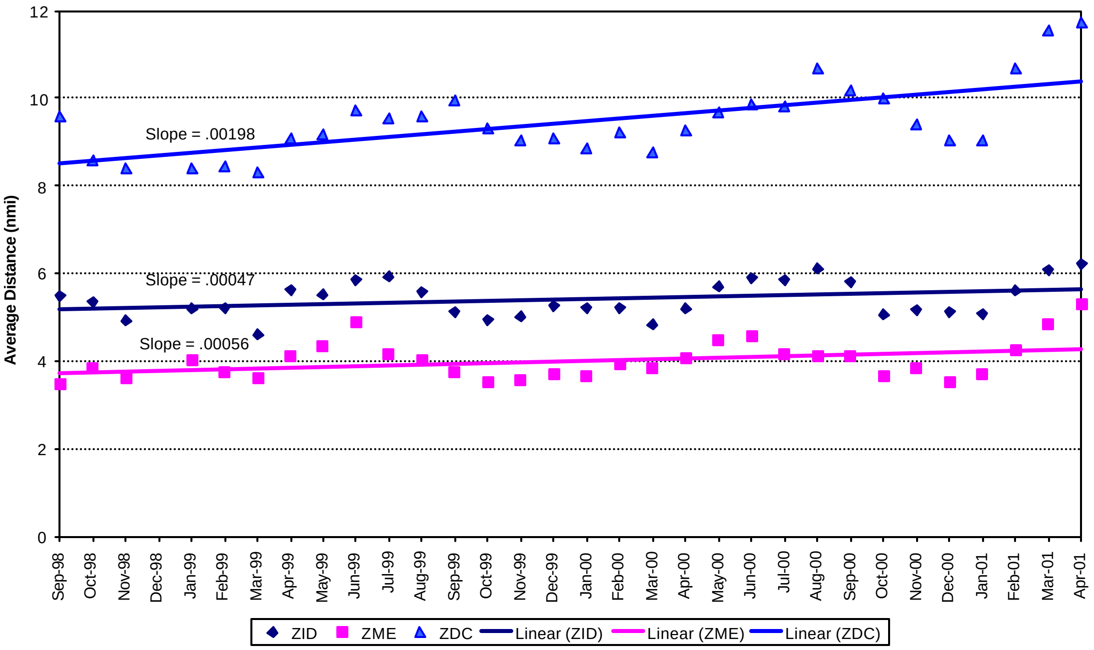

Figure 3. Excess Distance Over Great Circle Route

Table 7. Excess Distance by Season and Center

Season	Average Excess Distance (nmi)		
	ZID	ZME	ZDC
Winter ‘98-‘99	5.03	3.83	8.32
Winter ‘99-‘00	5.23	3.82	9.05
Spring ‘99	5.23	4.02	8.87
Spring ‘00	5.23	4.15	9.25
Summer ‘99	5.78	4.34	9.63
Summer ‘00	5.96	4.27	10.11

Table 8. City Pairs for En Route Distance Metric

ZID	ZME
Detroit-Cincinnati	Little Rock – St. Louis
Cincinnati – St. Louis	Memphis - Dallas
Nashville – Detroit	Chicago - Atlanta
Detroit – Atlanta*	Atlanta – Dallas*
Atlanta – Chicago*	Chicago - Houston
	Atlanta - Denver

*Bi-directional data used

Filters are applied to ensure that URET has had ample opportunity to influence a flight. A flight is not used if it spends less than 15 minutes within the Center of interest. In addition, only flights departing after 0500 GMT for ZID and 1100 GMT for ZME are considered for analysis. This is to ensure that URET is operational for all flights over the entire time span for which data will be collected.[3]

To date, en route distances have been examined in ZID and ZME over a two-year period – from May 1999 through May 2001. For each selected analysis day, the average for each of the metrics was calculated for each of the designated city pairs.

The results obtained so far differ for the two Centers (see Figure 4). For ZME, the average en route distance over the two-year period appears to have slightly decreased. A regression analysis indicates that the trend line has a negative slope of roughly 2.1 nmi over the two-year period for ZME. The decrease is statistically significant only at the 10 percent level (the p-value is .093). For ZID the average en route distance decreased by .65 nmi over the period. However, the slope is not statistically significant at this time.

Tests were made to determine whether en route distance is measurably affected by traffic volume in each Center. So far, no significant correlation has been found.

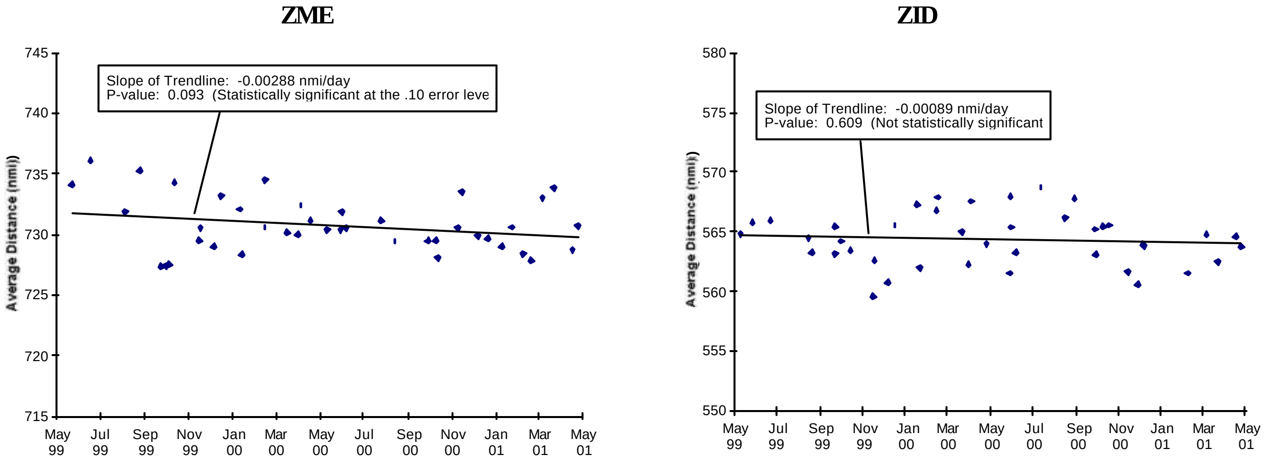

Figure 4. En Route Distance, ZME and ZID

Altitude Restriction Removal

URET provides support to controllers to better manage traffic without the imposition of altitude restrictions. In the fall of 1999, ZID and ZME established Procedure and Benefits Teams to review static altitude restrictions and modify them as appropriate for user benefit. The goal was to provide fuel savings to aircraft by allowing aircraft to stay at their preferred altitudes longer. This initial effort is documented in Reference 3. This section provides a brief update of the ongoing work.

ZME has removed the restrictions that were within its control. ZME has fewer altitude restrictions than ZID; ZME has 35 percent more airspace and slightly less traffic than ZID, so operational personnel do not require as many static altitude restrictions to manage traffic. Most of ZME's restrictions are of the inter-facility variety, and neither center is willing to lift arrival restrictions with a non-URET Center, as controllers would not have enough advance warning of possible conflicts. Also, a significant number of the inter-facility restrictions are imposed by other centers for traffic departing ZID or ZME.

In the fall of 1999, when ZID and ZME personnel began reviewing altitude restrictions, ZME had only 10 intra-facility arrival restrictions that did not involve an approach control. Of these, ZME removed the five going into Nashville (BNA). The other five restrictions are required to get aircraft to the proper altitude to enter ZID airspace for arrivals at Louisville and Cincinnati. ZME can not unilaterally remove these restrictions.

ZID has continued to evaluate intra-facility static altitude restrictions for possible removal. The Procedures and Benefits Team meets regularly in-house and quarterly with airline representatives, the Free Flight Program Office, and CAASD. This team identifies candidate restrictions based on the potential savings to users as well as feasibility; they evaluate the restrictions by temporarily removing them (usually for about a two week period) to determine if permanent removal or modification is feasible, and then decide how to proceed (i.e., remove, modify, re-evaluate, leave in place). Twenty-five restrictions have been lifted so far, the ten most significant of which are listed in Table 9. The removal of these restrictions has resulted in an annual savings of approximately $950,000.

Conclusions

An analysis of the impact of TMA on NAS operations at MSP suggests that the system has led to increases in the actual arrival rate and operations rate during arrival peaks of about 0.4 arrivals per hour and 2.5 operations per hour, respectively. TMA usage appears to have led to a decrease in flight distances in the extended terminal area around ZMP for peak arrivals of 4.8 nmi during visual operations and 8.2 nmi during instrument operations.

The ongoing work at ZID and ZME has demonstrated that URET is an enabler of increased user benefits – both in the reduction in distance from the increased number of directs and in the reduction of fuel burn from the removal of static altitude restrictions. Since URET utilization has stabilized at ZID and ZME (it is used all the time that it is available at all sectors), the distance saved from lateral amendments has increased by about 3500 nmi per day. Experience at ZID also shows that the URET capabilities enable controllers to lift static altitude restrictions, which is currently saving airlines approximately $950,000 annually. We expect there to be substantially more savings to NAS users once URET is deployed to all the Free Flight Phase 1 Centers.

Table 9. Specific Restrictions and Savings, ZID 2000-2001

Restriction (Description, To-From Sectors, Altitude)	No. of A/C Daily	Average Distance at Restricted Altitude (nmi)	Annual Projected Dollar Savings @ $1.00/gal
PIT arrivals, 83/85 FL290	9	88.5	$168,840.00
CLE arrivals, 83/87 FL290	2	82.0	16,725.06
BNA arrivals from DET DTW and CLE, 88/82, FL310	5	99.6	33,747.17
SDF arrivals, 35/17, 150	11	19.2	15,037.81
SDF arrivals via Darby, 85/83, FL280	16	40.7	23,716.00
CMH, 86/85, FL290	23	35.9	84,206.00
PIT Arrivals, 86/85, FL290	8	90.1	73,508.00
CVG arrivals, 80/35, FL240	62	46.3	424,893.00
IND arrivals, 88/33, FL240	34	20.9	105,179.00
SDF arrivals, 83/26, FL240	15	5.9	13,099.00
Estimated Annual Dollar Savings			**$958,951.05**

References

[1] *FFP1 Performance Metrics Results to Date: December 2000 Report*, FAA Free Flight Phase 1 Program Office, December 2000.

[2] Celio, Joseph C., et al., *User Request Evaluation Tool (URET) Benefits During Free Flight Phase 1*, MP99W0000183, The MITRE Corporation, McLean, Virginia, July 2000.

[3] Burski, Michael J., and Joseph Celio, *Restriction Relaxation Experiments Enabled by URET, a Strategic Planning Tool*, 3rd USA/Europe Air Traffic Management R&D Seminar, Naples, Italy, June 2000.

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Daniel Howell is a Research Analyst at The CNA Corp. Dr. Howell has a B.S. in Physics from Southwest Missouri State University and a Ph.D. in Physics from Duke University.

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[1] While we have data prior to 1 October 1999, there was taxiway construction activity at the airport prior to this date. Consequently AARs were lower at that time.

[2] The relatively high *F* value in the *Tests of Between-Subject Effects* table, and the related low significance value, indicate that the interaction factor is significant.

[3] In the earliest days of implementation, URET hours of operation were somewhat limited.