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Human Factors Report:
TMA Operational Evaluations 1996 & 1998

Katharine K. Lee, Cheryl M. Quinn, Ty Hoang, and Beverly D. Sanford

February 2000

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Katharine K. Lee, Cheryl M. Quinn, and Ty Hoang
Ames Research Center, Moffett Field, California

Beverly D. Sanford
Sterling Software, Mountain View, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

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Human Factors Report:
TMA Operational Evaluations 1996 & 1998

KATHARINE K. LEE, CHERYL M. QUINN, TY HOANG, BEVERLY D. SANFORD*

Ames Research Center

ABSTRACT

The Traffic Management Advisor (TMA) is a component of the Center-TRACON Automation System (CTAS), a suite of decision-support tools for the air traffic control (ATC) environment which is being developed at NASA Ames Research Center. TMA has been operational at the ATC facilities in Dallas/Ft. Worth, Texas, since an operational field evaluation in 1996. The Operational Evaluation demonstrated significant benefits, including an approximately 5% increase in airport capacity. This report describes the human factors results from the 1996 Operational Evaluation and an investigation of TMA usage performed two years later, during the 1998 TMA Daily Use Field Survey. The results described are instructive for CTAS-focused development, and provide valuable lessons for future research in ATC decision-support tools where it is critical to merge a well-defined, complex work environment with advanced automation.

1. ACRONYMS

AAR	Airport Acceptance Rate
ACID	Aircraft ID
ACT	Waco (Specialty): Southwest gate in the pre-Metroplex airspace
ARTCC	Air Route Traffic Control Center, also referred to as “Center”
ASD	Aircraft Situation Display
ASP	Arrival Sequencing Program
ATC	Air Traffic Control
BYP	Bonham (Specialty): Northeast gate in the Metroplex airspace
CM	Communications Manager (module of CTAS)
CQY	Cedar Creek (Specialty): Southeast gate in the Metroplex airspace
CTAS	Center-TRACON Automation System
D-side	Data Position Sector Controller
DFW	Dallas/Ft. Worth (typically refers to DFW TRACON)
DSR	Display System Replacement
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FZT	Frankston (Specialty): Southeast gate in the pre-Metroplex airspace
GUI	Graphical User Interface
JEN	Glen Rose (Specialty): Southwest gate in the Metroplex airspace
MF	Meter Fix
MiT	Miles-in-Trail
NOAA	National Oceanic and Atmospheric Administration
NTX	North Texas Field Site
OJT	On-the-Job (referring to training)
pFAST	The Passive Final Approach Spacing Tool
PGUI	Planview Graphical User Interface
PVD	Planview Display

* Sterling Software, Mountain View, California.

R-side	Radar Position Sector Controller
Red-X	Warning indicator that appears on the TGUI display when there is an update loss
SFH	Spatial Freeze Horizon
SGFF	Single Gate Free Flow
SPS	Wichita Falls (Specialty): Northwest gate in the pre-Metroplex airspace
STA	Scheduled Time of Arrival
TGUI	Timeline Graphical User Interface
THD	Threshold
TMA	Traffic Management Advisor
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control, also referred to as "Terminal Area"
TXK	Texarkana (Specialty): Northeast gate in the pre-Metroplex airspace
UKW	Bowie (Specialty): Northwest gate in the Metroplex airspace
ZFW	Ft. Worth ARTCC (Center)

2. INTRODUCTION

The Traffic Management Advisor (TMA) is a component of the Center-TRACON Automation System (CTAS), a suite of decision-support tools for the air traffic control (ATC) environment which is being developed at NASA Ames Research Center in cooperation with the U.S. Federal Aviation Administration (FAA). TMA has been used operationally on a daily basis at the Ft. Worth Air Route Traffic Control Center (ARTCC, or Center) and Dallas/Ft. Worth Terminal Radar Approach Control (TRACON) since an operational field evaluation of TMA in 1996. This report summarizes the human factors results from the 1996 Operational Evaluation of TMA as well as a follow-on investigation (conducted in 1998) as part of the TMA Daily Use Field Survey.

Ft. Worth Center and Dallas/Ft. Worth TRACON have served as the test sites for TMA research and development activities since 1994. Traffic management coordinators (TMCs) and controllers from Ft. Worth Center (ZFW) and Dallas/Ft. Worth TRACON (DFW) have been continually involved in the design and development of CTAS tools, providing their expertise in the creation and evaluation of new CTAS functionalities. CTAS development is human-centered (ref. 1), with human factors issues investigated and addressed throughout the development process. Iterative prototyping is emphasized in the CTAS development process, incorporating the feedback from the end-user as new concepts are tested. Human factors engineers, integrated into the tool development teams, help to ensure that end-user concerns are not overlooked. Human factors engineers also help to determine requirements and provide human factors-based assessments as the systems are developed. The reader is referred to the CTAS website: http://www.ctas.arc.nasa.gov for more detailed information on CTAS development and the other CTAS tools.

Both engineering and human factors data were collected during the Operational Evaluation of TMA, conducted in June-July 1996 at ZFW. As reported in reference 2, the Operational Evaluation determined that there was an increase in airport acceptance rate (AAR) of approximately 5% and a reduction in delays of 2-3 minutes under TMA operations. Some of the preliminary human factors findings were reported in reference 2; Section 3 of this report contains the complete human factors results and conclusions from the 1996 Operational Evaluation, which were based on observations of TMC interactions with TMA and questionnaires and interviews with TMCs and Center Sector controllers.

The 1996 results formed the basis for some of the operational questions that were posed in the TMA Daily Use Field Survey, conducted at ZFW/DFW in July 1998. It was expected that there would be changes in how TMA was used in an operational evaluation versus on a daily-use basis. The Daily Use Field Survey focused on both the Center and the TRACON; observations, questionnaire, and interview data were collected to examine TMA interactions in a daily-use environment as well as to understand the impact of some significant airspace and procedures modifications that were implemented in October 1996 (these changes are described in detail in Section 4.1.1). The TMA system was also made available to the DFW Tower just prior to the July 1998 evaluation, and some limited observations were conducted in the Tower. An internal trip report and training recommendations were produced from this field survey. Section 4 of this report fully summarizes the human factors results from the 1998 Survey and contrasts them with the 1996 Evaluation. The 1998 Daily Use Field Survey results can be used as a baseline against which pending and future changes to TMA functionality will be evaluated. Periodic follow-on studies are planned to examine how TMA usage continues to change over time, especially as significant functionality is introduced.

This report contains specific references to ATC operations at the Ft. Worth Center and DFW TRACON facilities as they relate to TMA functionality and features. It is assumed that the reader has a general knowledge of air traffic control operations as they pertain to traffic flow management, and also has some familiarity with TMA. Specifics regarding the functionality of the TMA software can be obtained from the TMA Reference Manual (ref. 3).

2.1 Background

2.1.1 TRAFFIC FLOW MANAGEMENT

Traffic flow management in the en route environment is required to regulate arrival traffic into a terminal area when the traffic demand exceeds capacity. The Center TMCs, as part of the traffic management unit (TMU), are responsible for the management of the traffic flow in the en route environment. TMCs evaluate the overall traffic demand and determine how the Center will deliver aircraft safely and efficiently to the TRACON. Because the TRACON is the receiving facility, the TRACON determines the overall AAR and conveys other restrictions, as needed, to the Center. If the amount of traffic that the TRACON receives from the Center exceeds the TRACON's capacity, the TRACON may elect to "shut the door" on the Center, meaning they may elect to stop accepting arrivals from the Center. Shutting off the Center has the operational effect of arrival aircraft being held in the Center's airspace until such time as the TRACON can once again accept the aircraft. How traffic is held varies from facility to facility; there are some TRACONs that can hold aircraft in their airspace, but in many facilities, TRACONs do not have enough airspace to safely hold aircraft, and holding is accomplished in the Center's airspace.

To prevent overloading the TRACON, the Center may use several procedures for managing the arrival flow of traffic into a terminal area from the en route airspace. Two of the primary means of achieving traffic flow management are Miles-in-Trail (MiT) or Time-based Metering; MiT is the most commonly-used method for traffic flow management (ref. 4). Under MiT operations, aircraft in the Center are delivered over a feeder fix with a particular in-trail spacing between aircraft. Under metering operations, aircraft are scheduled to cross a metering fix at a particular time.

Under either procedure for traffic flow management, the Center sector controllers typically vector or use some speed control within their sectors to achieve the required in-trail spacing or to cross the aircraft over the meter fixes at the assigned time, "absorbing" the delay that is assigned to the aircraft. It is possible that even with such methods in place, some holding may still be required; for example, at ZFW, when the delays exceed 6 minutes, the controllers often establish a holding pattern at a fix within their sector.

MiT operations are procedurally simpler than metering operations (ref. 4); metering operations require controllers to follow the schedule presented on a metering list, which shows each flight with its corresponding fix crossing time and an assigned amount of delay. In general, some form of automation is needed to generate the metering schedule. The Arrival Sequencing Program (ASP) was a metering scheduling system which was in operation at ZFW prior to the Operational Evaluation of TMA in 1996. Given the complexity of meeting the metering schedule, the controller workload associated with metering operations is generally higher for metering than for MiT operations (M. Foster, personal communication, 1999). However, research has shown that time-based metering is more efficient than MiT spacing of aircraft, and results in lower overall delays (ref. 4).

2.1.2 TMA DEVELOPMENT AND TESTING

TMA uses flight plans and radar tracks of arrival traffic to calculate Estimated Times of Arrival (ETAs) to various reference points (the meter fix, the final approach fix, and the runway threshold). TMA further calculates Scheduled Times of Arrival (STAs) to these locations based on legal separation requirements, the overall traffic conditions, the constraints imposed by the TRACON (such as AAR) and aircraft performance models. The STAs form the basis for the overall schedule and sequence of aircraft which are conveyed to the TMCs via two types of graphical user interfaces, the Timeline Graphical User Interface (TGUI) and the Planview Graphical User Interface (PGUI). Through these two interfaces, TMCs view the current traffic and scheduled delays projected over an amount of time into the future (depending upon the availability of radar data). TMA enables TMCs to plan changes to the traffic flow and to view the results of such changes. The TMA schedules and delays may also be provided to the Center Sector Controller. However, the TGUI and PGUI are not available for the sector controller to view at the radar position; the schedule information is presented to the controllers via metering lists on their radar displays. Consequently, the presentation of the scheduling information is determined by the capabilities of the existing radar displays and the associated software in the

Center facility. Figures depicting typical TGUI and PGUI displays can be found in Appendix A.

Although TMA is meant to be a tool used by Center TMCs, it is also used to convey traffic flow and traffic management information to the TRACON TMCs. TMA provides a comprehensive picture of the traffic flow into the terminal area, and as the Center conducts its flow management based on TMA information, the TRACON TMU can better understand the overall traffic picture and the Center's traffic decisions. The basic TGUI and PGUI features were, in large part, determined through previous TMA development activities and human factors assessments at Denver Center and Denver TRACON; these early recommendations for feature use and appearance are documented in reference 5.

Currently, the Denver ATC facilities, as well as ATC facilities in Atlanta, Miami, and Los Angeles, have operational TMA systems that have limited scheduling functionality (the schedules are not presented to the sector controllers, and TMA is not used for metering). At the time of this writing, ZFW and DFW are the first of many sites that have the TMA functionality planned for national deployment as part of Free Flight Phase I.[1] While the results described in this report are focused on the operations at only the ZFW/DFW field sites, it is possible to draw inferences that would benefit the understanding of how TMA might function in other facilities with different airspace and air traffic management requirements.

2.1.3 HUMAN FACTORS ASSESSMENTS

Human factors assessments are conducted throughout the development of the CTAS tools. These human factors assessments focus on the tool's usability, suitability, and acceptance (ref. 6). These categories form the basis for the data that are described in this report and are defined as follows:

> Usability: perceptually-based aspects of the human-computer interface, such as keystrokes, detectability of colors and text, and equipment manipulation.
>
> Suitability: information content and representation for the users' tasks, including questions of workload and the way in which the tool supports the desired work functions.
>
> Acceptance: reflecting usability and suitability of the system, as well as job satisfaction, demonstrable performance, and self-esteem (ref. 7).

TMA human factors issues were examined in 1993 at the Denver ATC facilities, and the findings were used to provide feedback on the look and feel of the user interface, as well as document how TMA was incorporated into daily operations. As detailed in reference 5, TMA was shown to be a significant aid in determining the traffic load, evaluating whether or not metering would be required, and how long a metering period should last. TMA enabled the Center and TRACON to work from a common picture of the traffic demand, and facilitated their coordination regarding the airport acceptance rate and configuration changes. The TRACON additionally used TMA information to help make staffing decisions. This assessment of TMA provided many insights into how TMA was likely to be received at other ATC facilities.

In contrast to the Denver assessment of TMA, which focused primarily on how TMA was used to enhance TMC situational awareness, the human factors assessment objectives described in this report describe how the TMA-generated schedules were utilized for metering operations at ZFW and DFW. In both the 1996 and 1998 evaluations, the TMCs and controllers were asked to make specific comparisons between TMA and ASP schedules. The human factors results described in this report are instructive for CTAS-focused development, and highlight issues for future research in ATC decision-support tools where it is critical to merge a well-defined, complex work environment and advanced automation.

3. 1996 HUMAN FACTORS TMA OPERATIONAL EVALUATION

3.1 Objectives and Methods

The goal of the 1996 operational evaluation, conducted over 4 weeks in June-July at ZFW, was to examine the usefulness of the TMA functionality and the acceptance of the user-interface according to the ZFW TMCs and sector controllers (ref. 8). The engineering results are described in references 2 and 8 and describe the accuracy

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[1] Free Flight Phase I is an FAA program under which several air traffic management decision-support tools will be deployed to ATC facilities nation-wide. Included in the capabilities are two of the CTAS tools, TMA and the Passive Final Approach Spacing Tool (pFAST). More information about Free Flight Phase I can be found on the website: http://ffp1.faa.gov.

of STAs[2] and delay values. Sequencing efficiency, the use of available landing slots, and runway balancing were also measured.

Human factors objectives concerned questions of how the scheduling information was displayed, and the workload associated with, and the usefulness of, the TMA-calculated schedules and sequences compared to ASP. Questionnaires were presented to TMCs and Center Sector Controllers to specifically collect ratings of workload and system acceptance, and suggestions for system improvement. Observations were also conducted at arrival sectors during test rushes, as staffing permitted. Although the TRACON and Tower were affected by ZFW decisions based on TMA, there was no formal assessment made of the impact of TMA on TRACON or Tower operations. Some anecdotal data from the TRACON TMU were collected.

The sector controller metering list displays were not affected by CTAS information beyond the addition of a single line to the list header to indicate that CTAS metering was in progress. However, changes were made to the nature of the information provided in the metering lists, and what the controller could do with this information. The three new features that were added with CTAS, the manual swap, delay countdown, and outer arc crossing times, are defined in table 1.

Table 1. Sector Controller Features.

Feature	Description
Manual swap	Allows the sector controller to swap the meter times between two aircraft in the metering list. A number of keyboard entry inputs are required to achieve the swap. Swapping the meter times between two aircraft effectively changes the sequence of the aircraft in the meter list.
Delay countdown	Delay values are provided on the metering list associated with each aircraft. The countdown provided the controller with information on the amount of delay remaining to be absorbed. (The ASP delay information remains static, and does not change to indicate how much delay is left.)
Single outer arc metering list (outer arc crossing times)	For sectors in which there are aircraft crossing more than one outer fix, the crossing times were incorporated into a single list referenced to an outer metering arc (an adaptable, fixed radial distance from the meter fix) (ref. 2).

One of two TMCs was dedicated to working with TMA during the Operational Evaluation. Observations and interviews were conducted in the Center TMU. The observations consisted of noting TMC interactions with TMA, the information gathered from other data sources within the TMU, TMC coordination with other TMCs and Area Supervisors, as well as coordination with other facilities. Following each test rush, the TMC working the test rush was interviewed regarding TMA's performance and the impact on workload.

In 1996, the arrival airspace at ZFW was divided up into 4 arrival area specialties responsible for the aircraft arriving from 4 geographical locations: Wichita Falls (SPS) in the Northwest, Texarkana (TXK) in the Northeast, Waco (ACT) in the Southwest and Frankston (FZT) in the Southeast. Observations were conducted at both the high and low arrival sectors in an area, and focused on manual swap entries, discussions about the TMA-generated sequences and crossing times, and any deviations from the TMA sequences at the boundary crossings. Questionnaires were distributed to sector controllers at the conclusion of each metering period, and when possible, individual controllers were interviewed.

[2] The accuracy of the STAs is a function of algorithms responsible for the ETA and STA calculations. ASP calculations are based on simplified models of the air traffic system. ASP schedules all aircraft to a single reference point that represents all of the runway thresholds and uses a general model of aircraft speeds (ref. 9); it creates schedules based on the AAR without considering separation requirements between aircraft types or specific runway constraints (refs. 2 and 9). CTAS, in contrast, uses much more accurate aircraft state models and precise routing to specific runway thresholds. As delays are derived from the difference between the ETA and STA values, a delay can be considered accurate based the accuracy of these ETA and STA calculations. In addition, as the aircraft state changes, the delay countdown information that was provided would increase or decrease to reflect the current aircraft conditions, thus providing a more dynamic measure of the delay to be absorbed.

A total of 154 sector controller questionnaires were collected. Due to limitations on available personnel for data collection, and the desire to concentrate the observations and questionnaire collection from the sectors most impacted by metering operations, most of the human factors data were gathered from the busier arrival sectors. Data from the TXK specialty were collected more frequently than from the other sectors.

3.2 Results and Discussion

3.2.1 CENTER TMC GENERAL IMPRESSIONS

The human factors data collected in the TMU indicated that TMA use contributed to delay reduction, smoother traffic flow and improved situational awareness. Specifically, the ZFW TMCs subjectively estimated a 2-3 minute delay reduction per aircraft, on average, across the various test periods. TMCs from both ZFW and DFW reported that the flow of traffic into the TRACON was smoother when TMA was in operation.

The Center TMCs also reported that their situational awareness was improved with the display of the single outer arc metering list and the delay countdown on the sector plan view displays (PVDs). The added information helped the TMCs to more quickly grasp the traffic conditions as they monitored the individual sectors. The TMCs did not report any significant impact upon their coordination as a result of using TMA for metering.

3.2.2 CENTER SECTOR CONTROLLER DATA

3.2.2.1 Data Collection

Questionnaires were distributed to controllers in the 4 arrival area specialties. Approximately 33% of the questionnaire data were collected from TXK and 31% were collected from FZT (the East-side specialties), and the remaining questionnaire data were collected from SPS and ACT. The questionnaire data were collected from both R-side and D-side controllers.[3] Approximately 78% of the questionnaire data were collected from the R-side controllers.

3.2.2.2 CTAS Features Ratings

After each metered test rush period, the Center Sector Controllers rated the workload associated with using the new features of CTAS (compared to ASP): the single outer arc metering list, scheduled times, sequences, keyboard inputs for the manual swap feature, delay information, metering list ripples,[4] and the overall workload associated with using CTAS. The controllers were also asked to rate the acceptability of these features. The sector controller workload results are plotted in figure 1, which depicts the mean ratings for the different elements, along with the standard deviations indicated by the vertical bars. As the workload ratings show, each of the TMA features provided some decrease in controller workload. Each of the scheduling, sequencing and delay features was rated as slightly reducing controller workload. While the amount of list ripples were rated between minimally increasing and not affecting workload, note that the overall workload associated with CTAS was rated as a minimal decrease in workload.

The sector controller mean acceptability ratings (with the standard deviations represented by the vertical bars) are plotted in figure 2. The acceptability results show that all of the CTAS features were rated as being somewhat acceptable, with the exception of the list ripples, and the overall acceptability of CTAS use was rated between somewhat and completely acceptable. The controllers rated the TMA scheduled times as more acceptable than the ASP scheduled times.

[3] Center sector controllers can be assigned to several positions, including R-side (the radar position) and D-side (the data position). The R-side controller is primarily responsible for issuing control instructions to the aircraft (ref. 10). The D-side controller is generally responsible for assisting the R-side controller; when the D-side position is active, this controller typically takes care of coordination and managing the flight progress strips.

[4] The controllers use the metering list to plan the control of their aircraft. During metering, there may be conditions (such as change in AAR, airport configuration, and weather deviations) which may require the TMU to change the sequence and delay times of the aircraft. This is known as a “ripple” of the schedule (and of the metering list) which may initially cause confusion and increase controller workload. Consequently, the TMU tries to avoid rippling the metering list once a metering period has begun (M. Foster, personal communication, 1999).

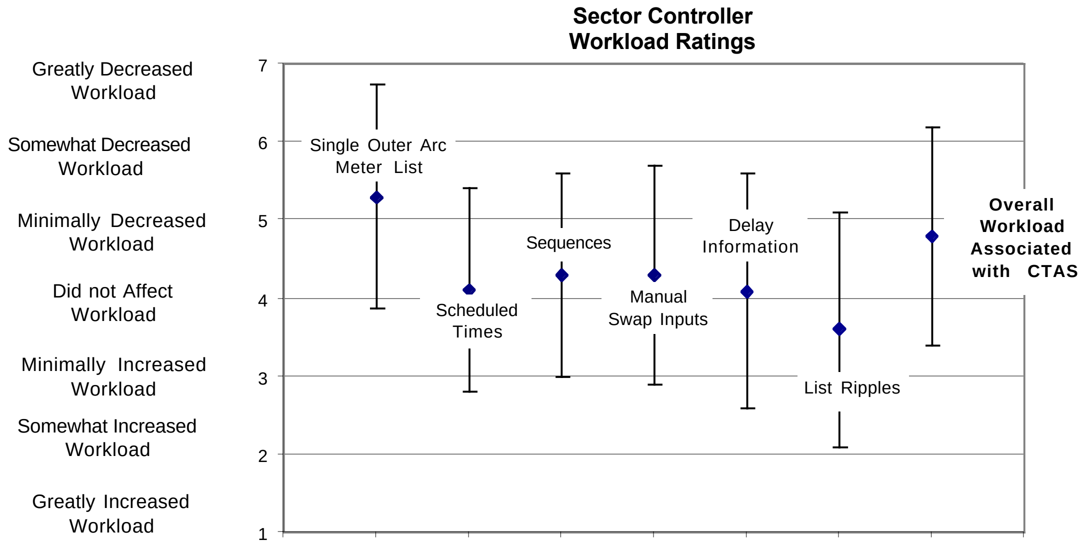

Figure 1. Center Sector Controller Mean Workload Ratings (standard deviations represented by vertical error bars)

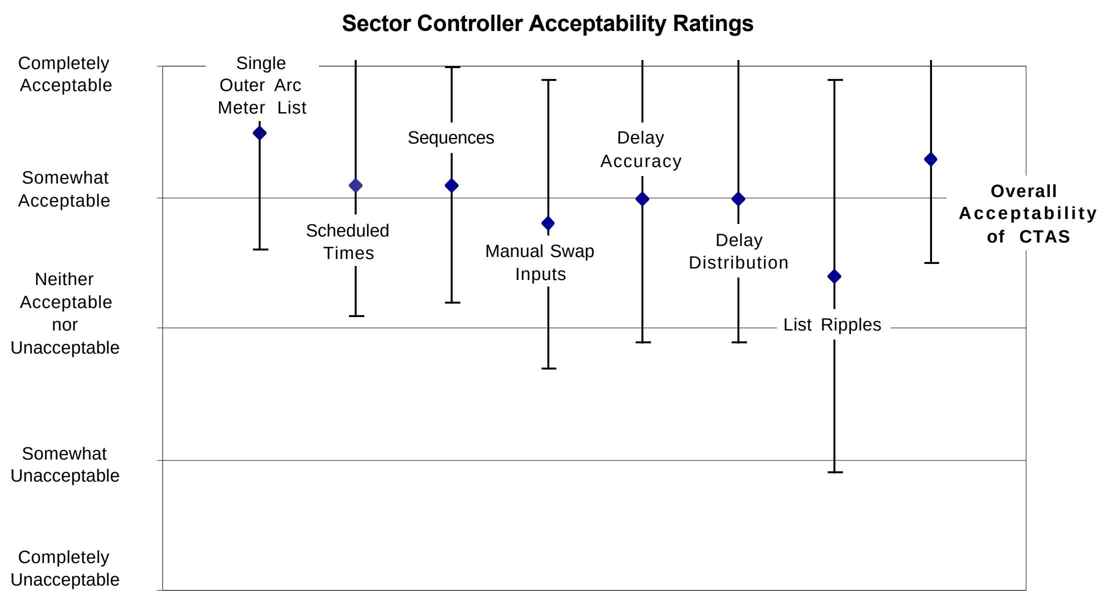

Figure 2. Center Sector Controller Mean Acceptability Ratings

Sector controllers also reported their satisfaction with CTAS. They indicated that they were slightly more satisfied with CTAS overall, compared to ASP. Several controllers said that they would prefer not to meter at all, but that the use of CTAS is preferable to the use of ASP. Additionally, many sector controllers commented positively on the reduced delays during TMA test periods.

3.2.3 CENTER GENERAL IMPRESSIONS

General Comments: Controllers indicated that CTAS metering operations produced more accurate measures of delay compared to ASP metering. As a result, metering appeared to begin later under CTAS operations, and holding would happen later as well. One controller noted that when ASP was in operation, its use led to second-guessing the system because sometimes ASP would assign clumps of times to controller positions or would leave huge gaps in times when a sector was very busy. As a result, metering was seen as increasing the overall traffic complexity, and controllers would tend to disregard the metering times and just work to separate the aircraft.

Single Outer Arc Metering List: The single outer arc metering list received the highest acceptability ratings, and of all the features that were individually assessed, it was rated as reducing workload the most. Controllers reported that the single outer arc list reduced the amount of information integration required to meter in the high sectors. As mentioned before, TMCs also found this feature useful. They reported that the single list reduced the amount of time needed to understand the sector controller's plan when they quick-look[5] the sector.

Aircraft Sequences: With regard to the sequence of aircraft displayed on their metering lists, the controllers frequently reported that they did not refer to the sequences in the metering list (regardless of whether CTAS or ASP was being used for metering) and it appeared that this was prompted by experience with ASP sequence inaccuracies. Some controllers who did refer to the sequences often reported that the lists seemed to be more accurate than those provided by ASP.

Manual Swap Feature: Use of the manual swap feature depended primarily on sector staffing and traffic levels. R-side controllers working without a D-side often did not use this feature, especially on busy sectors. However, this feature was used often by sectors with D-side controllers, and it was not clear whether the R-side or the D-side was chiefly using the swap feature. Traffic levels dictated whether or not the D-side controller position was staffed, and whether the R-side controller would be able to convey the intended sequence to the D-side controller. Depending upon the load on the R-side controller, the planned aircraft sequence did not always match the metering list, as the D-side did not necessarily know the sequence that was planned until an aircraft was turned in by the R-side controller.

When the swap feature was used, three main benefits of manually swapping aircraft were identified. First, it provided a more centralized source of information within the sector. Rather than having to reconcile the traffic flow on the radar scopes with the positioning of the flight progress strips (which generally reflect the sequence that the controller was planning), it was possible to just refer to the controller's radar scope in order to view all of this information. Second, entries made in the high sector were reflected at the lower sector, thus providing more accurate information for the next controller. Third, since the list better represented the radar controller's plan for the traffic flow, it reduced the time needed by TMCs to understand the traffic flow when quick-looking the sector.

One of the most frequent complaints about the manual swap feature was that only one pair of aircraft could be moved in the metering list per entry. The controllers often wanted to be able to swap (or resequence) several aircraft in the list. With the functionality available during the 1996 Operational Evaluation, that would require several entries to specify the order of aircraft.

Delay Countdown: Initially, controller opinion about the delay countdown feature seemed to be divided. However, through the course of the test, controller acceptance of this feature increased as the countdown information was shown to be reliable. Controllers reported that the countdown provided useful feedback about delay absorption.

Metering List Ripples: Although the TMCs typically try to avoid rippling the list once metering has begun, there are conditions that will require a change in the schedule and consequently a change in the controller's metering list. According to controller ratings, the list ripples during the TMA test did not meaningfully contribute to their workload. The acceptability rating for list ripples neared the "somewhat acceptable" anchor. Controllers

[5] Quick-look is defined as the ability to display the datablocks of the tracked aircraft from other controller positions (ref. 10). When a TMC quick-looks a controller's sector, s/he is able to see the traffic that the controller is working, and also view exactly what information is displayed on sector radar scope, including the sector's metering list.

commented that ripples seemed to occur less frequently with TMA than with ASP. They also commented that when the list did ripple, it seemed to result in a more accurate, usable list.

3.3 1996 Operational Evaluation Summary

The comparison of TMA and ASP in the human factors data is based on anecdotal evidence and specific questions aimed at this comparison; there was no opportunity to collect baseline human factors data (such as ratings or systematic observations during metering with ASP). However, the impressions of the TMCs and Sector Controllers echo the overall improvements that were found in the engineering analyses. The engineering data determined that under TMA metering, there were more accurate meter fix crossing times, per-aircraft delay reductions, and overall, better delay distribution (ref. 2). Additionally, DFW TMCs reported that the length of the finals was more consistent through the rush during TMA test periods. Samples from a particular rush during which TMA was used demonstrated a 70 second average delay reduction with TMA versus ASP schedules (ref. 2). TMCs subjectively reported that TMA usage resulted in some per-aircraft delay reductions of about 2 minutes, and the controllers reported a noticeable reduction in delays. Several controllers said that given the traffic conditions, they felt that the delays would have been higher with ASP. The manual swap, delay countdown, and the single outer arc metering list features contributed to the observed improvements in accuracy of meter fix crossing times (ref. 2). The Sector Controllers reported that the scheduled times were, in general, more accurate than the ASP scheduled times, even with list ripples. The controllers reported better spacing of aircraft arrival intervals. Both TMCs and Sector Controllers reported all of the TMA features to be acceptable and useful.

In terms of overall workload, the Sector Controllers reported that TMA provided a minimal decrease in their workload and there was no individual TMA feature that was reported to increase controller workload. In some cases, the controllers said that the use of TMA seems to have prevented the need for metering and that they felt this contributed significantly to reducing their workload. As expected, the list ripples were rated as minimally increasing their workload. While this might be seen as a negative finding, the controllers' comments suggested that with TMA, the overall disruption caused by list ripples was reported to be less than with ASP, and the TMA-based list ripples were not rated to be unacceptable. In addition, the increased workload from list ripples under TMA also underscored the basic problem that ASP list ripples often resulted in generally unusable lists; controllers had become accustomed to ignoring the ASP metering lists because they were often inaccurate. With TMA providing better, more usable metering lists, the controllers had to start paying attention to meeting the metering times, thus creating more workload.

The discussion of the workload results demonstrates the complexity of metering. While implementing metering does help to make the traffic more manageable from a system-wide perspective, metering creates extra workload for the individual controllers (ref. 4). Thus, controllers and TMCs will consider any metering operation, by default, an increase in their workload. How much more workload is incurred from TMA versus ASP must be considered, and whether this increase in workload is acceptable, given the more efficient traffic conditions that generally result from traffic management practices.

Traffic levels also interact with the interpretation of workload. The traffic levels change how the controller manages the traffic situation; as traffic levels increase, the controller may not have opportunities for as much strategic planning as there is less time to coordinate with the D-side controller or other controllers, and the controller may resort to reacting to the traffic. The manual swap feature, intended to improve overall system efficiency, may not have been utilized as much due to the extra effort required. The manual swap feature might have been used more frequently when the traffic was lighter; however, lighter traffic might also mean that controllers would be more likely to make mental swaps (as it would be easier to mentally keep track of fewer aircraft).

The evaluation of the manual swap feature also highlighted the difficulty in conveying its benefits to the controllers. While a metering list with an old schedule is not necessarily detrimental within an individual sector, the lack of updated information has implications for the controller in the next, receiving sector, who would not have the most accurate schedule on her/his metering list. As this inaccuracy propagated, controllers would continue to evaluate the slots rather than associating the specific aircraft assigned to each slot. It remained to be determined if the controllers would eventually begin to use the manual swap feature over time, with more training or practice, or if some change to the user interface might be required.

3.4 Recommended Issues for Future Evaluations

The human factors findings from the 1996 Operational Evaluation resulted in a number of issues that warranted follow-up once TMA was in daily operation at ZFW. These issues focused on both improving the data collected and examining how operations might have changed and affected the use of TMA:

- A manual sequence feature was requested so that more than one aircraft could be moved in the metering list at a time. This feature was implemented and later examined in the 1998 Daily Use Field Survey.
- Most of the data from the TMU reflected the opinions of TMCs who were familiar with CTAS and TMA development. Though these responses were thorough, a wider range of respondents and opinions was desired for future assessments.
- Human factors observations were limited, and primarily reflected observations at the heavy sectors/meter fixes. Data from lighter sectors could be less informative (as the controllers would be less likely to use the CTAS features or evaluate the times) but lighter sectors should be assessed in case other issues were overlooked.
- The times of day during which the testing took place meant that the same crews provided input to the questions. This created fatigue for the crews, and may have created some bias in the questionnaire responses.
- Some of the data collected might have been uneven because of the distribution of responsibilities by the R-side and the D-side controllers. The use of the swap feature in busy sectors depends upon how well the R-side and D-side controllers are able to communicate, and the workload level of the D-side.
- Due to limited research personnel, no data were gathered from the DFW TRACON or Tower; this resulted in a lack of information on how the downstream facilities were affected by TMA metering operations.
- To detect any benefits from TMA metering, the traffic levels must be adequate. Traffic levels influence noticeable delays, holding, and whether or not the controllers are able to pay attention to the metering list.

4. 1998 DAILY USE FIELD SURVEY

4.1 Background

Since the 1996 Operational Evaluation, ZFW has had a single TMA system that is used to make operational traffic management decisions. This operational system also feeds a “repeater” system at the DFW TRACON which allows the DFW TRACON TMU to view the same information that ZFW has. The repeater is automatically updated with the scheduling inputs from ZFW’s system. The DFW TMU also has two additional TMA systems, which do not interact with the Center. One is used for the TRACON to conduct its own scheduling evaluation; the TRACON TMU may update this system according to the changes on the Center system, but may additionally test out different configurations or schedule modifications without impacting the Center’s system. The other TRACON TMA system is used to view Passive FAST (pFAST) schedules. Beginning in April 1998, TMA displays (which are also repeaters of the Center’s data) were added to the three DFW Towers.

Currently at the DFW/ZFW facilities (also collectively known as the North Texas Field Site, or NTX), the FAA and its contractors provide daily use operational support through a team of engineers who work with the facilities to maintain and troubleshoot the CTAS tools. Also at NTX are a group of NASA scientists and contractors who conduct research at the field site. Both groups work closely together and with the users to provide feedback on tool development and daily use issues.

Modifications have been made to the CTAS functionality and user interface since 1996. Some of these changes have been the result of informal evaluations conducted at DFW/ZFW, in which the TMCs have identified changes to help improve the system’s usability. For example, the manual sequence feature was implemented as a direct result of the 1996 Operational Evaluation. The manual sequence feature allows the sector controller to change the existing sequence of aircraft to better match the time slots. The controller may specify a desired sequence in the metering list of up to 5 aircraft at a time. A number of keyboard inputs are required to enter the sequence in the metering list. To use this feature, the controller must have track control of the aircraft, and the sequencing can only be done for like aircraft types (all jets or all props).

A number of operational changes occurred following the 1996 Operational Field Evaluation. A significant airspace redesign was implemented, as well as the addition of a dual route operation. These two significant changes are described below, and provide a context for understanding the changes in TMA use.

4.1.1 AIRSPACE CHANGES

The Ft. Worth Center/DFW TRACON airspace was modified in October 1996 for the purposes of accommodating the projected increase in DFW Airport traffic (M. Foster, personal communication, 1999). The new airspace is commonly referred to as the Metroplex. The old navaids were decommissioned and new Metroplex cornerpost fixes were created. The new arrival gates and fixes are depicted in figure 3. The DFW TRACON was expanded by a radius of approximately 10 miles and new arrival routes into DFW were added. A new parallel runway was also opened at DFW Airport, enabling triple simultaneous approaches. As a result of the airspace change, CTAS software adaptation changes were required to incorporate the new arrival routes into the TRACON.

4.1.2 DUAL ROUTE OPERATIONS

Dual route operations were introduced into the ZFW/DFW traffic management procedures following the airspace change. A dual route allows arrival traffic to be routed over a secondary metering fix at a particular cornerpost. Because these aircraft assigned to the dual route are not counted toward the AAR, this enables the Center to feed more aircraft into the TRACON than designated by the AAR. By taking these aircraft out of the schedule, the Center can also remove 3-4 minutes of delay from the system. The Center will request the operation of a dual route from the TRACON, and if granted, the TRACON specifies the number of aircraft that can be accommodated on the dual route. Only one dual route is granted at a time; the dual route may be granted over one corner, and then switched to another corner later in the rush. Aircraft on a dual route are separated by in-trail restrictions (typically 10 miles-in-trail) and the TMU uses TMA to suspend the aircraft from further CTAS scheduling (so that they are not counted in the AAR).

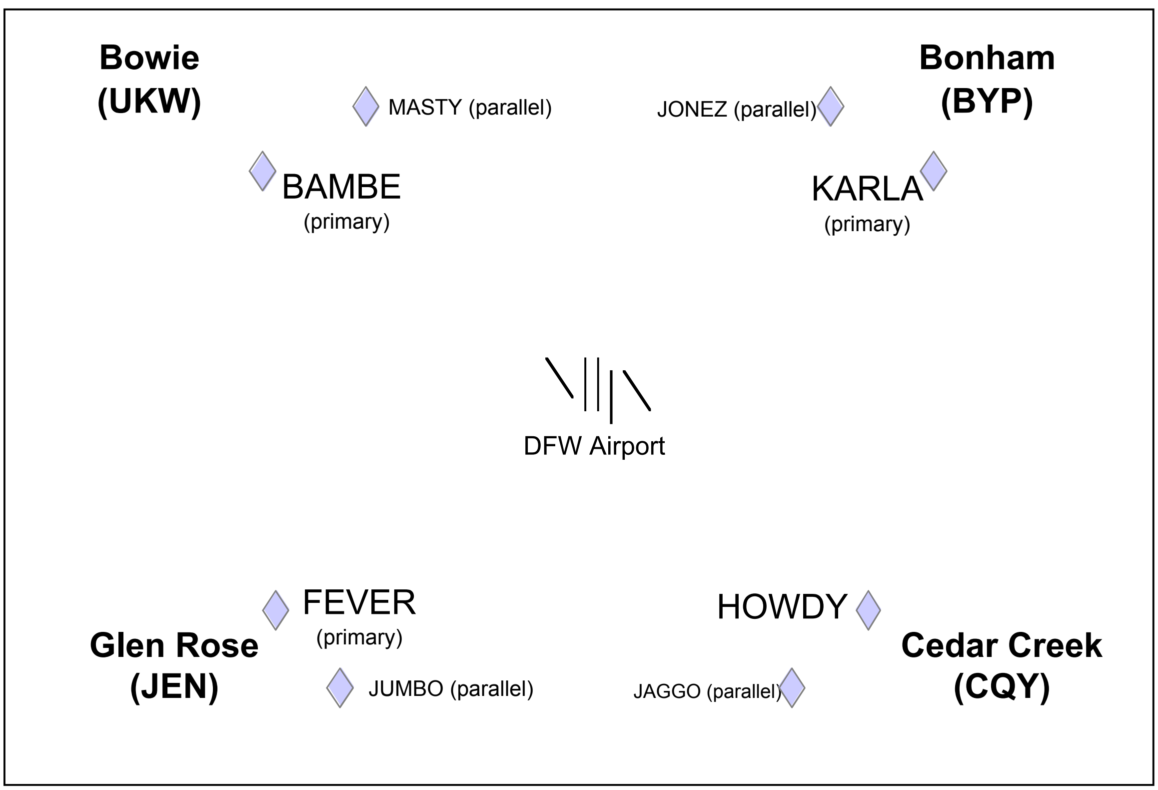

Figure 3. Metroplex Airspace Arrival Gates (in bold) and Primary and Parallel Arrival Fixes (figure not to scale). Satellite airport arrival fixes are not represented in this figure.

4.2 1998 Daily Use Field Survey Objectives

A number of issues motivated the 1998 Daily Use Field Survey effort. With the enlarged airspace and new dual route operation, it was naturally anticipated that the use of TMA might change and it was of interest to determine how flexible TMA would be to such operational changes. In addition to documenting these effects upon TMA usage, there were six other general areas objectives for investigation:

1. Follow-up to 1996 Operational Evaluation Issues.

The 1996 Operational Evaluation, and subsequent field reports, revealed some TMA use issues that warranted further investigation, including:

- The manual swap and manual sequence features were not reported to be widely used by the controllers, although the manual swap feature was favorably received during the 1996 Operational Evaluation.
- The impact of TMA operations on the TRACON was not documented in the 1996 Operational Evaluation.

2. Transition to Full-Time Usage.

Since 1996, ZFW and DFW transitioned from merely testing TMA functionality to using it full-time to manage traffic. The incorporation of TMA into daily operations meant that the system was used more frequently and more regularly by a larger pool of users than the small cadre of TMCs who had been actively involved in its development. A formal field survey under daily use operations was needed to create a baseline for comparison with future TMA/CTAS enhancements.

3. Anticipation of Evolving Traffic Flow Management Strategies.

Previous studies suggested that the increased exposure to TMA in the operational environment would lead to new strategies of traffic flow management (ref. 5).

4. Anticipation of New TMA Use Strategies.

The use of the TMA features themselves were expected to evolve; previous reports suggested that the TMC's strategy for using the timelines or the traffic load graphs to make metering decisions would be affected by training and increased exposure to TMA operations (refs. 5 and 11).

5. New Status and Scheduling Panel Information in the TGUI.

The CTAS software release just prior to the Field Survey included significant changes to the appearance of the TMA Scheduling and Sequencing panels, which would likely have long-term effects on use patterns, training, and understanding of TMA. These issues needed to be documented, and any problems with the new interface needed to be captured.

6. Continued Follow-Up as Part of the CTAS Development Process.

Despite the fact that TMA development was sufficiently mature to be included in plans for national deployment, continued follow-up and evaluation of TMA is a critical part of the CTAS software development process.

4.3 Methods

To meet the objectives outlined above, observations, interviews, and questionnaire data were collected from Ft. Worth Center, DFW TRACON, and the DFW Towers. The Daily Use Field Survey consisted of a pre-test phase and a test phase. During the pre-test phase, questionnaires were distributed to controllers and TMCs to get feedback to determine major areas of concern regarding TMA/CTAS use. Engineering data gathered during the pre-test phase, which included recordings of adherence to the TMA sequences at the meter fix, were analyzed to determine when sequence swapping occurred at each cornerpost. The test phase consisted of observations during metering operations and interviews with TMCs and controllers regarding TMA use. Specific areas that were explored in the questionnaires are described in table 2. (The questionnaires used in the pre-testing phase can be found in Appendix B.)

Table 2. Specific Issues for 1998 Daily Use Field Survey.

User Group	Issues
Center TMCs	• How TMA is used for metering, and how often certain features are used. • Conditions under which the TMCs revert to ASP for metering. • What they like/dislike about CTAS/ASP for metering. • How TMA is used under metering and dual route operations.
Center Sector Controllers	• How often manual swap or manual sequence entries are made, and difficulties encountered in using these features. • If the manual swap or manual sequence entries are not used, why not. • The acceptability of the sequences and schedules. • The effect of CTAS metering (compared to ASP) upon workload.
TRACON TMCs	• Comparison of the TRACON's own TMA system and a TMA system that served as a "repeater" of the Center's TMA system. • How TMA is used under metering and dual route operations. • How helpful the TMA features are in terms of workload and in making staffing decisions. • The acceptability of the TMA features.

4.4 Results and Discussion

The results of the Daily Use Field survey and the discussion of the findings are organized below according to the three main TMA user groups: Center TMC, Center Sector Controller, and TRACON TMC. The results are also organized into the following topic areas:

1. Equipment and CTAS displays
2. ATC and CTAS experience and training
3. Metering
4. Dual route operations
5. Use of CTAS
6. General impressions

4.4.1 CENTER TMC SUMMARY DATA

4.4.1.1 Equipment and CTAS Displays

The ZFW TMU has CTAS information displayed on several monitors. At the time of the Daily Use Field Survey, two monitors were devoted to TGUI information and two were devoted to PGUI information. One TGUI displayed timelines with all traffic to DFW Airport, except for the dual route. A second TGUI displayed timelines of traffic over the dual route and Dallas-Love Field arrivals. A load graph for the traffic to DFW Airport was also displayed on this monitor. The two PGUI monitors showed maps (which were configured differently at different times, according to TMC preferences) and sequence list information. The PGUI was also configured to show timelines depicting aircraft on the dual route.

4.4.1.2 ATC and CTAS Experience and Training

The ZFW TMU is staffed by approximately 20 TMCs. The questionnaire data from the TMU were obtained from seven TMCs. The TMCs who responded to the questionnaires were generally a less-experienced group of users; the seven TMCs had an average of 2.7 years of TMC experience, with a range of 4 months to 5 years. The amount of CTAS training time that these TMCs reported ranged from 0 to 24 hours, with a mean of 10.8 hours (note that the amount of training time is generally related to the amount of TMC experience; more experienced TMCs have potentially had more opportunities for training). Overall, the TMCs reported their comfort level with CTAS as 2.8 (on a 0 [very uncomfortable] to 4 [very comfortable] scale). The range of comfort levels reported was 2 to 4.

The interviews were conducted with 13 TMCs. These TMCs had from 6 months to several years of TMC experience. The interviews consisted of general questions regarding the usage of TMA, as well as specific questions that were raised from the questionnaire results.

4.4.1.3 Metering Operations

From the questionnaire data, the TMCs reported that on average, the facility meters 2.5 times a day; they use the dual route procedure in addition to metering 2.1 times per day. They reported that they revert to ASP for metering 2.3 times per month. When CTAS was used for metering, the TMCs reported rippling the list less frequently, on average, than when ASP was used: only 1.6 times per metering period under CTAS (with a range of 1 to 2.5 times), and 4 times per metering period for ASP (with a range of 2 to 9 times).

In general, metering now occurs for shorter periods of time (usually 20 minutes or less); it is stopped when delays go below 4 minutes or once the sequence of all the traffic is set. In the past, metering would last an entire rush (approximately 30 minutes). The reason for this change is partially due to the change in the airspace, as well as the implementation of the dual route procedure. The TMCs estimated that metering is unnecessary 95% of the time when the dual route procedure is used. Due to personal preferences, some TMCs may feel that they need to do all they can to avoid metering. Consequently, some may prefer to run dual route operations.

4.4.1.4 Dual Route Operations

As described in Section 4.1.2, use of the dual route procedure is negotiated between the Center and the TRACON. In general, the TRACON will grant up to 8 aircraft per rush to fly over the dual fix. Of the 8 slots, 6 slots are used on average. By moving aircraft over to the dual route, as the system delay is reduced, metering is sometimes eliminated for a particular rush.

The dual route procedures have evolved over time. According to the Center, the TRACON was initially reluctant to accept aircraft on the dual route and would limit the total number of aircraft allowed on a dual route to 2-3. Now, during some rushes, the TRACON will accept a higher number of aircraft on the dual routes in order to assist in the front-loading process.[6]

Initially, the Center only used the dual route if there wasn't an available slot in the primary stream. Now the Center tries to use all of the dual route slots granted from the TRACON, even if aircraft slots are available on the primary stream. Six to 8 aircraft placed on the dual route may reduce the need for metering; metering may still be required if only 3 to 4 aircraft are placed on the dual route.

There is generally a constant stream of traffic over the Bonham cornerpost (BYP), and the TMCs reported that 60% of the time that there is a rush over BYP the dual route procedure is used. Forty percent of the time that there is a rush over the Bowie cornerpost (UKW) the dual route procedure is used. The Center TMU will keep track of which aircraft were first and last on the dual route, and how many aircraft altogether used the dual route. Despite this record-keeping, the TMU didn't have a way to directly measure how much the dual route operations reduced their need for metering.

When metering and dual routes are being used together, TMCs will sometimes estimate which aircraft will be bound for the dual route and suspend those aircraft from scheduling. Although the TMCs can generally guess which aircraft will be on a dual by looking for ties (where two aircraft appear to be arriving at the same merge point at approximately the same time), if aircraft assumed to be bound for the dual routes end up taking the primary route, or if controllers pick the aircraft for dual route at the last minute, and the aircraft are inside the freeze horizon,[7] there is no efficient way to take the dual route aircraft out of the schedule without rippling the list. It should be noted that at the time of the Daily Use Field Survey, there were no firmly-established procedures for determining how to use metering and the dual route procedure together; this was still an evolving process.

4.4.1.5. Use of CTAS

The TMCs were asked to report how frequently they use the different CTAS features on a scale of 0 to 4, where "0" represented never and "4" represented often. The plots of the mean ratings are divided into three groups:

[6] "Front-load" is a term typically associated with metering facilities. During a rush period, there is a gradual buildup of the traffic level. At the beginning of the rush, there is insufficient pressure put on the airport by the number of arriving aircraft. As a result, it is possible to relax constraints into the TRACON so that the traffic is allowed to arrive without traffic management restrictions (no additional delays) until the airport capacity is reached. Metering would not be implemented until after front-loading had occurred.

[7] The freeze horizon (or "freeze"), as described in this paper, is also known as the STA Freeze, or the time after which TMA generally stops performing regular scheduling calculations for an aircraft. The freeze horizon differs between stream classes and is site-dependent (ref. 9).

figure 4 shows the main TGUI features (such as timelines, delay information, and the information contained on the function panels), figure 5 shows the Scheduling Options (which are more specific scheduling features that are also part of the TGUI interface), and figure 6 shows the PGUI and Single Outer Arc Metering List results. The plots depict the mean rating values, with the standard deviations indicated in parentheses along the y-axis with the feature's legend. The TMCs who responded to the questionnaires indicated that they never used the features which are found on the F4 panel: Proposed Flights, Not on Timeline Flights, and Departure Time. These features are typically used for scheduling internal departures (from airports within the Center's airspace to the primary airport), and have been found to be used more frequently at other sites.

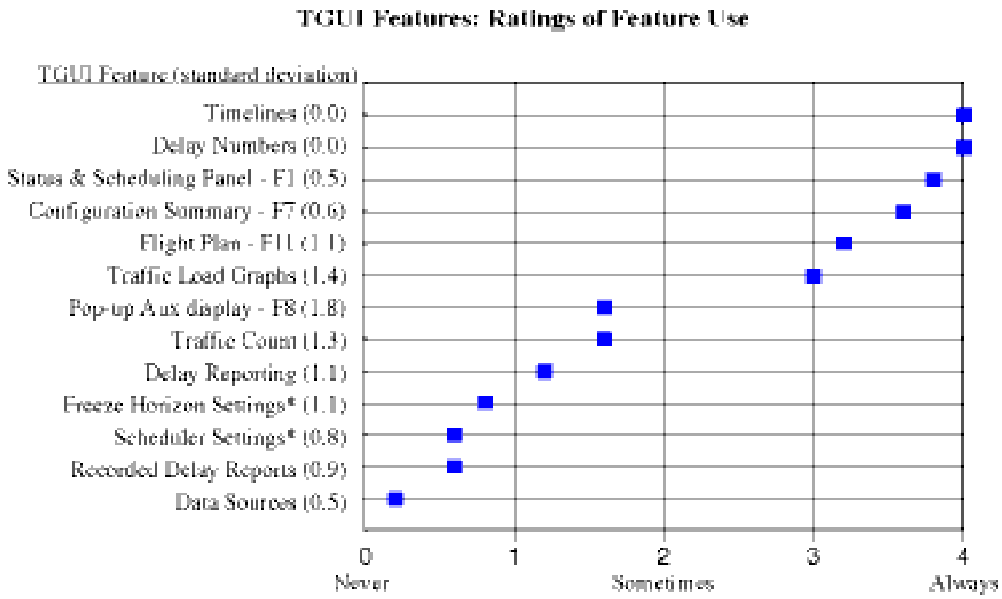

Figure 4. TGUI Features: Mean Ratings of Feature Use (standard deviations in parentheses with legend).

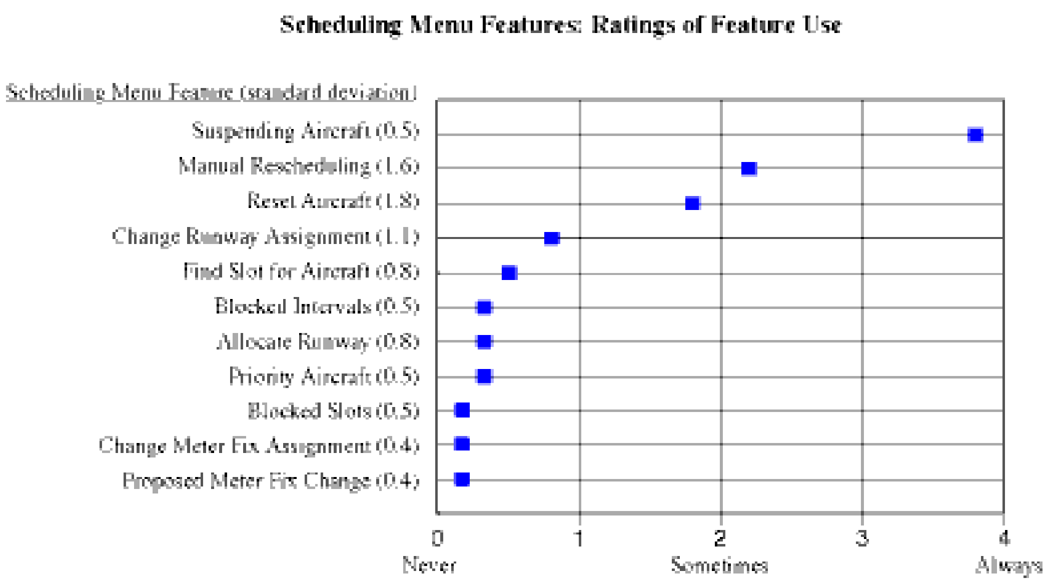

Figure 5. TGUI Scheduling Menu Features: Mean Ratings of Feature Use (standard deviations in parentheses with legend).

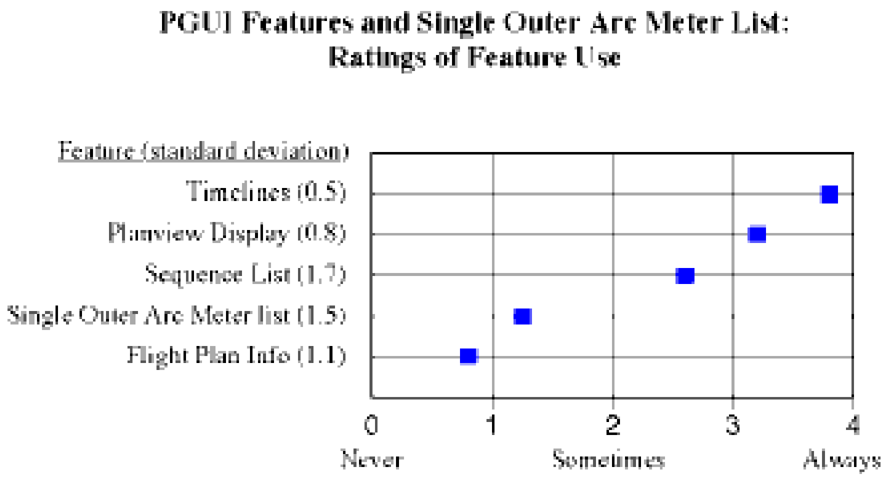

Figure 6. PGUI Features and Single Outer Arc Meter List: Mean Ratings of Feature Use (standard deviations in parentheses with legend).

As illustrated in figure 5, many of the scheduling features available to the TMC through the scheduling menu are not frequently utilized. The TMCs themselves observed that they lacked training on these features, and this lack of training contributed to their infrequent usage.

The TMCs reported (in the questionnaire and interview data) that they use the CTAS displays to give them traffic information, delay information, and to keep track of dual routes. They use a variety of strategies to determine whether or not to meter. The TMCs will check the delay information on a traffic load graph; one traffic load graph was frequently displayed (zoomed in), that showed all the expected and planned traffic, and the number of minutes of delay. A load limit line was set at 4 minutes and the TMCs noted when the delay plot exceeded this limit to indicate that metering could be needed. Several TMCs said that they use this information as the first cue, and then they consult other sources of traffic information (such as the Aircraft Situation Display [ASD]). It is possible to view front-loading with the traffic load graphs, and they are able to monitor the reduction in the traffic load due to metering.

The TGUI timelines are used to check the delays, and comparisons are made between delays shown on meter fix (MF) and runway threshold (THD) timelines to determine the actual delay that the Center has to absorb. Five to six minutes of Center delay as shown on the THD timelines typically indicates that metering is necessary. Some TMCs reported that prior to the freeze horizon, they sometimes see large delays for the unfrozen aircraft which prompt them to reschedule several times, rather than to wait and see what schedule results after the freeze.

As indicated in responses to the open-ended questions, the delay information represented on the MF versus THD timelines is sometimes confusing and leads to questions about whether or not metering is needed. The TMCs noted that there were specific prop flights each day that are assigned excessive delay (11-12 minutes) because of their position; their schedules are frozen later, and their slots are lost to jets. One or two of these flights are affected each day in the “noon balloon” (the rush that occurs around the noon hour).

The TMCs were asked to describe the conditions under which they do not use CTAS. While metering is often unnecessary when the weather is clear, CTAS may also not be used when the weather conditions result in the closure of one or more cornerposts. Usually, the TMU changes to a MiT operation if a corner is shut down. Some of the TMCs may not be aware that TMA can be used in such conditions, by utilizing the blocked interval feature to block the unavailable arrival fixes during the closure.

If CTAS is not working properly, and metering appears to be necessary, the TMU may elect to revert to ASP. The reasons they reported reverting to ASP included: the Red-X graphical warning message on the TGUI (or other indication of CTAS software failure), shuffling of delay times, or the appearance of unequal delay distribution.

The PGUI sequence list is not used extensively, and the newer TMCs, who have not had as much experience with ASP, generally do not consult the sequence list. The difference between the information provided on the sequence list versus the timelines is that on the sequence list (like the PVD linear list), the aircraft are displayed with their exact numerical ETAs and STAs. On the TGUI, however, the aircraft times are presented as an aircraft tag on a moving timeline, and the exact time must be estimated from the timeline position. The TMCs did not indicate that making such estimates was a problem.

The TGUI and the PGUI are both used to monitor aircraft on the dual route. The TMCs suspend the aircraft from scheduling via the PGUI's sequence list or timelines. The aircraft assigned to the dual route are displayed on a single PGUI timeline (referenced to the THD) on a monitor adjacent to the main TGUI display. The controllers decide which aircraft get assigned to the dual route; often aircraft naturally fit there based on their current routing. It should be noted that although there are timelines on the TGUI, there is still use for timelines as part of the PGUI. In fact, the PGUI timelines were rated as the most-frequently used of the PGUI features.

4.4.1.6 General Impressions

TMCs were asked what features they liked or disliked about using the ASP system versus the CTAS system for metering. In general, the TMCs responded that ASP was simpler to use. They found that it was easier to determine when metering should begin and with which aircraft. With ASP, there was little need to interpret the data. However, the TMCs also noted that ASP was less flexible, and that the metering times were less accurate and sometimes unrealistic (when two aircraft were assigned the same crossing time).

TMCs indicated that CTAS was more complex, requiring more training than ASP. Other TMCs indicated that the CTAS information was easy to read and apply, and that the presentation of the traffic load graphs was especially helpful. One TMC noted that with CTAS operations, metering occurred less frequently. The delay information that was provided by TMA required some interpretation in order to determine when to begin metering.

From the questionnaires, it was clear that not all of the TMA functionality was being exercised. Overall, only 7 of 20 TMCs responded to the questionnaire; those who did fill out the questionnaire were less-experienced with TMA/CTAS, reporting only about 10 hours of training on average; however, these TMCs reported feeling "very comfortable" using the CTAS system.

Interviews with TMCs revealed many problems that further underscored the need for additional training. One TMC said that CTAS does not efficiently assign runways to alleviate congestion on the East side. However, he was not aware of the TMA manual assign feature that could be used to schedule aircraft to the West side as needed. Another issue brought up was that some TMCs who are more familiar with the system may turn a feature like rush alert on and then new TMCs don't know how to turn it off. While there appears to be a fairly standard way in which TMA information is displayed in the TMU, this does not necessarily account for which details of the TGUI displays may be enabled. Another effect on the assessment of TMA usage was that at the time of our interviews, the weather had been unusually clear and dry for several months, with no thunderstorms or other weather phenomena. The weather was characterized as "severe clear." As a result, no one could recall recently exercising all of TMA's functionality.

Some TMCs reported that they will never use all of TMA's capabilities because they only use TMA for metering. This is another issue that could be a function of training. It is clear that any added training should include the opportunity to observe the system in use during actual traffic rushes, under varying traffic conditions. The TMCs should be given the chance to test the different features in a shadow-mode, or by shadowing TMCs who are very familiar with TMA operations.

4.4.2 CENTER SECTOR CONTROLLER SUMMARY DATA

4.4.2.1 ATC and CTAS Experience and Training

Questionnaire responses were received from 32 controllers in 4 specialties, with the following distribution: 22% from Bowie, 19% from Bonham, 28% from Glen Rose (JEN), and 31% from Cedar Creek (CQY). Some of the controller data below were supplemented with additional interviews with the controllers regarding the manual swap and manual sequence features and TMA/CTAS metering in general.

The respondents reported working approximately 8.2 metering periods per month. On average, the respondents had 12 years of ATC experience, and had worked 11.6 years at a level 3 facility, and 9.7 years at ZFW.

4.4.2.2 Metering and Dual Routes Operations

In addition to the effect of training, controller responses towards CTAS were also influenced by their opinions regarding metering. Some of the controllers clearly felt negatively about metering and indicated that metering increased their workload. As a result, their opinions of CTAS were negative because CTAS was used as a metering tool.

Dual route procedures are not clearly defined (as noted above). A general operating practice is that controllers will use dual routes instead of vectoring aircraft on the primary route, when possible. The sector controllers may not always use the dual routes, or they may not always use all the available dual route "slots." Alternatively, the controllers may sometimes leave an aircraft on the dual route if it works out better for the aircraft, even if there is a slot on the primary route.

4.4.2.3 Use of CTAS

Due to winds or aircraft performance, the controllers may need to change the sequence of the aircraft. The swap features that were implemented allowed either the R-side or D-side controller to manually swap a pair of aircraft (manual swap) or change the sequence of up to 5 aircraft (manual sequence). Seventy-two percent of the questionnaire respondents had used the manual swap feature, 47% had used the manual sequence feature, and 60% reported having used the delay countdown feature. The controller questionnaire posed some possible reasons for not using the manual swap or manual sequence features. From these choices, the controllers reported the following reasons for not using the features (in order of frequency):

- Too busy.
- Easier to make manual swaps using the strips.
- Too many keyboard entries required.
- Some controllers indicated that when they were working as R-side controllers, the D-side controller was responsible for making the swap entries.
- Prefer to use the strips to make the swaps (regardless of the ease of using the manual swap feature).

Although some controllers noted that having the sequence set up properly by the high sector would mean that swaps were not necessary for the low sector, many controllers reported that they were never trained on the use of the manual swap and manual sequence entries and they did not know where to access the instructions on how to use the features. In fact, there was no documentation at the positions indicating the commands necessary to use the manual swap and manual sequence features. Some controllers did use the swap feature for props in low altitude. Others mentioned that they did not care about matching the aircraft IDs (ACIDs) and the slots; they matched whatever aircraft was convenient with an available slot.

Controllers who were very familiar with the swap features felt that they were very helpful. It is likely that with practice, the keyboard inputs will not seem to add too much workload, and eventually the swap features will be generally regarded as helpful. Some controllers indicated in the questionnaire data that they were too busy to use the swap features, or that it was easier to have a list on paper (though they acknowledged that if the metering list rippled, that makes the paper list unusable).

The mean ratings of how difficult it was to use the manual swap, manual sequence, and delay countdown features are plotted in figure 7 (the vertical bars represent the standard deviations). The scale used was from 0 to 4, where "0" represented Very Difficult and "4" represented Very Easy.

The delay countdown feature was rated towards the easy end of the scale. The swap features were rated near the neither easy nor difficult anchor, but towards the difficult end of the scale.

The controllers were asked to rate the acceptability of the following CTAS features: scheduled times, sequences, delays at the sector, the delay countdown feature, the single outer arc metering list, and the overall acceptability of CTAS. The mean acceptability ratings are plotted in figure 8 (the vertical bars represent the standard deviations of the ratings). The scale used was from 0 to 4, where "0" represented Completely Unacceptable and "4" represented Completely Acceptable.

The acceptability of the CTAS features were nearly all rated between Neither Acceptable nor Unacceptable and Completely Acceptable. The acceptability of the single outer arc metering list was rated 3.1 on this scale; favorable comments were made indicating that the single outer arc list was helpful in figuring metering times. Overall CTAS acceptability was rated 2.6.

The controllers were also asked to rate the workload associated with using the following CTAS features as compared with ASP: the scheduled times at the sector, the aircraft sequences, the delays at the sector, and the delay countdown feature; these results are plotted in figure 9 (vertical bars representing standard deviations). (As this was a CTAS versus ASP comparison, the controllers were not asked for a workload rating associated with the single outer arc metering list, which is only available during CTAS metering.) The scale used was from 0 to 4, where "0" represented Better with ASP and "4" represented Better with CTAS.

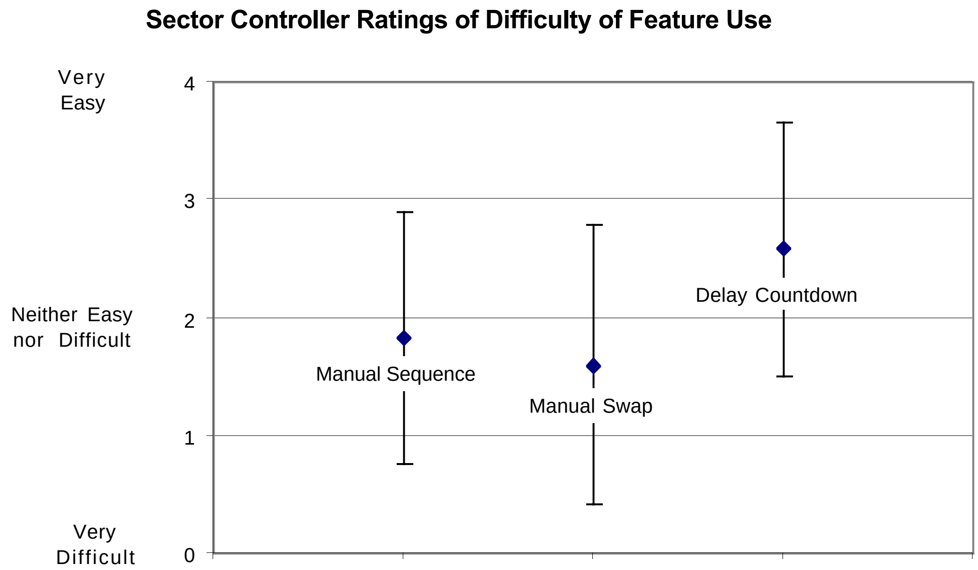

Figure 7. Center Sector Controller Mean Ratings of Difficulty of Feature Use (standard deviations represented by vertical bars).

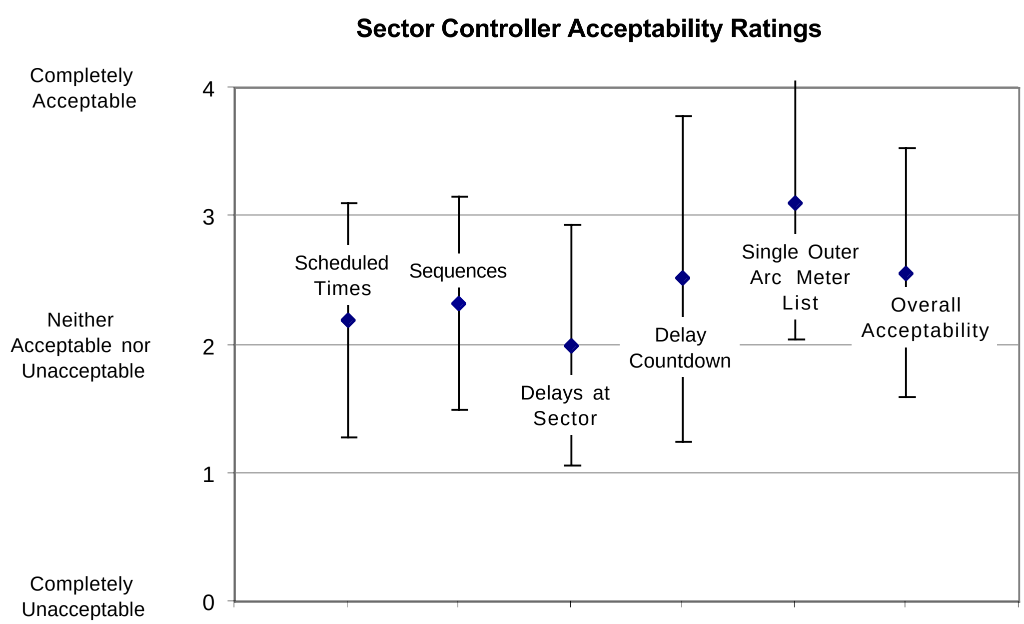

Figure 8. Center Sector Controller Mean Acceptability Ratings (standard deviations represented by vertical bars).

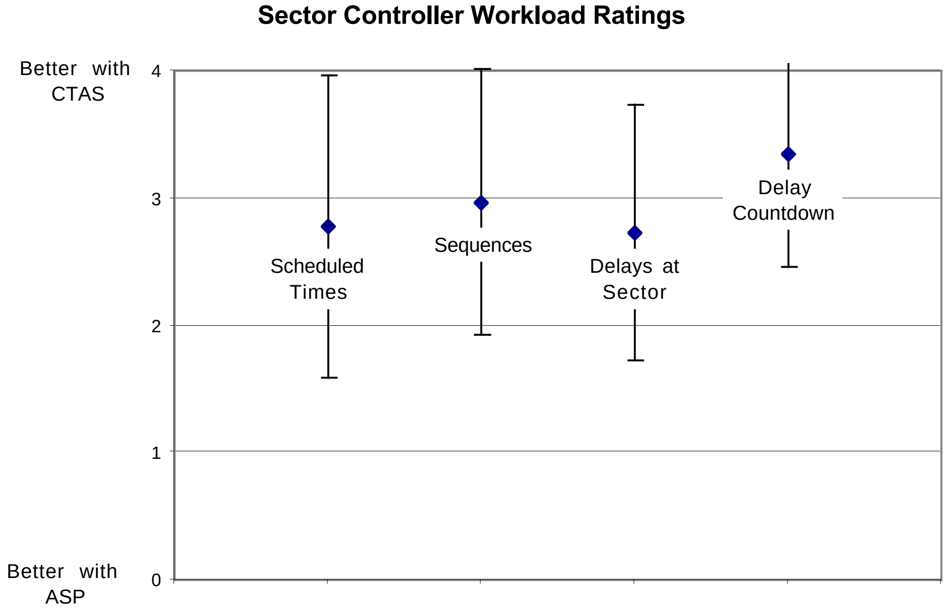

Figure 9. Center Sector Controller Mean Workload Ratings (standard deviations represented by vertical bars).

All of the CTAS features were rated toward the Better with CTAS end of the scale. Some controllers commented that the delay countdown did not seem to take into account the effect of wind variations between the sectors. It is possible that the CTAS wind input was sometimes old; at the time of the Field Survey, CTAS wind information was updated from National Oceanic and Atmospheric Administration (NOAA) every hour, with forecasts valid for up to three hours. There may have been situations in which the wind information was not current. However, it is more likely that the delay countdown problem was due to the freeze occurring too early at some sectors under certain weather conditions; this problem will be investigated with the new Spatial Freeze Horizon (SFH) feature.[8] Overall, the controller questionnaire data show that CTAS had less of an impact on controller workload than ASP.

4.4.2.4 General Impressions

Controller opinions of CTAS were generally favorable compared to their opinions of ASP, but some of the controllers' opinions were influenced by their negative opinion of metering in general. As was found in the 1996 Operational Evaluation results, the metering system used affects how the controllers run their traffic. Some controllers observed that they would have liked to know whether to expect CTAS or ASP metering as they perceived a difference in how reliable the metering list information was under the two systems. Other controllers also mentioned wanting more advance notice when metering is likely to be implemented. It is possible that the addition of the SFH will aid with earlier traffic planning in some sectors, including addressing the problem of the prop aircraft that are assigned excessive delay in the noon balloon. The SFH feature may help to address controller concerns that they should get information on some aircraft earlier, and SFH should also help in situations where controllers feel that they need to do several swaps due to winds or aircraft performance.

Metering operations have been reduced overall, which is attributed to the greater airport capacity at DFW. While some controllers seemed to feel that the reduced metering

[8] The Spatial Freeze Horizon (SFH) will be used to establish a freeze horizon that is defined by spatial location, rather than using an estimated time to the meter fix (which is how TMA currently operates). This is expected to be useful in conditions when large headwinds or tailwinds are encountered that create uncertainty in the determination of the aircraft sequence. For example, under the existing system, aircraft negotiating a headwind may have their schedules frozen deep in the sector airspace, effectively reducing the usable airspace and creating controller workload, as the controller has fewer options for vectoring or sequencing this aircraft. By using a SFH in this situation, the controller can establish a SFH at a spatial location relative to the meter fix, and can more easily predict aircraft freeze order and reduce workload.

frequency was a positive trend, they also noted that they were more proficient at metering operations when they metered all the time.

The controllers recognized that their opinions of CTAS were influenced by their level of CTAS training. One controller felt that CTAS didn't work as well as advertised, but was unsure if this was due to unrealistic expectations, or if the CTAS features were not being used correctly. Another example was the responses regarding the usefulness of the delay countdown feature; some controllers reported it was very helpful, and others did not understand how it worked.

There was at least one enthusiastic controller who thought the manual swap feature was easy to use. Many of the controllers did not use the swap features regularly or had not been aware of the features.

4.4.3 TRACON TMC DATA

4.4.3.1 Equipment and CTAS Displays

As discussed in Section 4.1, the DFW TRACON has 3 sets of CTAS displays: a Center TMA Repeater TGUI and PGUI, their own TMA PGUI and TGUI, and a pFAST PGUI and TGUI. The Center Repeater system provides added situational awareness for the TRACON, so that they can view how the Center is managing the arrival flow. The TRACON's own TMA system is used for creating what-if scenarios for traffic management. The TMU keeps the TRACON and Center systems synchronized; the TMCs look for changes on the Center repeater and enter these changes on their own system. The TRACON TMCs reported that they always compare the Center Repeater and TRACON systems.

4.4.3.2 ATC and CTAS Experience and Training

Questionnaire responses were obtained from 4 out of the 7 TMCs at DFW TRACON. These TMCs reported an average of 6.25 years of TMC experience, with a range of 2 to 9 years.

The TMCs that were surveyed reported an average of 30 hours of CTAS training, with a range of 4 to 80 hours. The comfort level they reported with TMA was 3.4, on a scale of 0 to 4, where "0" represented very uncomfortable and difficult to use, and "4" represented very comfortable and easy to use.

4.4.3.3 Metering Operations

When the TRACON TMU feels that the traffic levels exceed capacity, they may elect to "shut off" the Center, and not allow any more traffic into the TRACON. The TRACON reported that they rarely shut off the Center now, and do so only for weather reasons. The TMCs attribute the reduced metering frequency to their "good airport." One TMC said that the equipment that they have (including CTAS) helps them to achieve smoother operations than under ASP metering. Because of CTAS, the traffic information that they have is more accurate, and allows them to plan more effectively. The TMCs indicated that there was more uncertainty with ASP, but that when the delays did not appear correct in CTAS, the Center would revert to ASP.

4.4.3.4 Dual Route Operations

The TRACON reported allowing about 3-4 aircraft over one dual fix and then opening up a dual route over another fix. They only run one dual at a time but recognized that the Center may wish to increase the number of simultaneous dual routes. The TMCs noted that if one side of the airport was shut off due to weather that it would be helpful to run dual routes over the other fixes. The decision whether to use the dual route procedure depends on several considerations, including whether the aircraft have a place to go, and if there are departure conflicts (including Dallas-Love Field departure traffic).

4.4.3.5 Use of CTAS

The TMCs use the timelines a great deal. One TMC uses the F4 panel to verify flight proposals to Dallas-Love Field. They also display a load graph to show traffic on the dual route.

The TMCs were asked to rate how frequently they use the CTAS/TMA features. Overall, since TMA is not being used to the same extent (nor for the same purposes) as TMA is used in the Center, many of the scheduling features are not utilized. The TMCs reported that they most often reference the timelines and delay information (delay numbers appended to the aircraft tags). As in the Center, the TMCs reported using the PGUI timelines the most frequently of the PGUI features. The features they reported using least frequently were the TGUI traffic count, the TGUI F11 flight plan information and the TGUI F8 pop-up auxiliary information.

4.4.3.6 General Impressions

The TMCs reported a high level of comfort with TMA, and expressed confidence that with TMA, they can "count on what the system says it is going to deliver." One TMC suggested that under ASP operations, there was a "fudge factor" that affected their planning. The TRACON spends considerable time comparing the data from the Center and

TRACON TMA systems in order to understand the basis for Center metering decisions.

4.4.4 TOWER TMCS

The DFW airport has three air traffic control towers, the East Tower, the West Tower, and the center tower. The East and West Towers are staffed during the day and the center tower is staffed only at night during the 11:00 PM to 7:00 AM shift. If there is any problem with an outer tower, the staff moves to the center tower.

4.4.4.1 Equipment and CTAS Displays

TMA was installed in the East Tower in April 1998 and the West Tower in June 1998. There are 4 traffic managers who work in both of the Towers. The area supervisors use the TMA system more than the TMCs. TMA provides the first glimpse of arrival traffic that the Towers have ever had; their existing radar display system, the BRITEs, only provide traffic information 15-20 minutes into the future.

4.4.4.2 Use of CTAS

The West Tower is not as busy as the East Tower. TMA is not used very much in the West Tower, beyond helping to determine staffing or the current location/STA of aircraft. In general, the East Tower uses TMA to plan staffing, to determine the direction of the rushes, and to determine when the rushes are going to start. TMA helps them to deal with unusual events, such as closing a runway for maintenance and delays due to departures.

During the observations conducted one afternoon, TMA aided in airport planning for the arrival of an emergency aircraft. The Tower was able to access the flight plan information and meter fix crossing time of the emergency aircraft so that they knew when to alert the fire department. The Tower has found the timelines to be beneficial, but at the time of the Daily Use Field Survey, the runway assignments were not always accurate (since the Center radar tracks, which feed their TMA displays, are dropped near the airport). The Tower indicated that they would like to get pFAST, or at least the TRACON radar, fed into their TMA display so that they have a better indication of the actual landing runway assignments.

4.5 1998 Daily Use Field Survey Summary

The 1998 Field Survey addressed many of the questions and issues raised in the 1996 Operational Evaluation. Although more data were collected from a wider range of TMCs and Center Sectors than in the 1996 Operational Evaluation, it was still necessary to focus on the busier sectors in order to capture more information regarding metering operations. For some less-busy sectors, the metering list did not really affect how the controller would control traffic. Data were also collected from the TRACON and the Tower, and this will serve as useful baseline information for future TMA assessments of those facilities. The results are summarized in terms of the six objectives outlined in Section 4.1. Where these issues have changed since the 1998 Field Survey are also discussed.

1. Investigation of Issues Raised in the 1996 Operational Evaluation.

Manual Swap and Manual Sequence Feature Usage:

The manual swap and manual sequence features were not widely used. This could be attributed to a number of issues: controller habits with regard to metering operations, insufficient training, and insufficient opportunity.

Some Center Sector Controllers use the metering list as a list of times to hit (rather than strictly associating each aircraft with its respective time). The controllers may write down the times and make sure one aircraft crosses the meter fix at each of the specified times. This serves the purpose of metering the flow into the TRACON, but if the high sectors do not make entries into the system to reflect the sequence, then the low sector list does not correspond to the aircraft sequence, and the low sector cannot plan as effectively. The implications of not using these features and the resulting effects on the schedules may not be apparent to the controllers. Some controllers who were aware of these features often said they were too busy to use them. Some controllers reported that they preferred to make swaps mentally. A few controllers did report using the manual swap feature all the time, and that they felt it was helpful. It is possible that with training, added documentation or reminders, as well as practice, these features would be used more frequently.

The majority of the controllers we spoke to were either not aware of the manual swap and manual sequence features, or were not aware that the D-side as well as the R-side could make these inputs, reflecting insufficient (or not recent-enough) training. Related to this training issue is the opportunity to exercise the features themselves. If metering occurs less frequently, controllers will generally have limited opportunities to try these features and stay proficient at using them.

Since the 1998 Field Survey, ZFW has installed the Display System Replacement (DSR) consoles in their facility. Controllers are now using a new user interface and a new radar display. Quick reference cards have been created and provided to the controllers to remind them how to use the manual swap and manual sequence features (see Section 5.4 and Appendix D). It remains to be investigated in future surveys how the DSR interface may or may not influence the use of the swap features.

TRACON and Tower Data:

Data were gathered from the TRACON TMCs, who report that TMA is helpful to their operations by providing reliable scheduling information. The TRACON also makes use of comparisons between their system and the repeater of the Center system to understand the Center’s traffic management plans. Unlike the Center, the TRACON has fewer TMCs and did not experience as much turnover. There were consequently several TMCs who have been working with TMA for quite some time. As new TMCs are introduced into the TRACON, it will be important to make sure they are quickly and thoroughly trained on TMA in order to avoid some of the training-based problems that the Center has experienced.

The Tower operations with TMA were not well-defined; as mentioned above, the Tower has a limited TMU staff, and at the time of the Daily Use Field Survey, only had experience with TMA information for a few months. As more accurate information is provided via pFAST or TRACON radar, it would be instructive to again investigate if TMA is providing better situational awareness and planning for the Tower operations.

2. Transition to Full-Time Usage.

The data collected from the 1998 Daily Use Field Survey provides a baseline for understanding Metroplex operations with TMA. TMA has been adapted to the new airspace, and the Center has created the new dual route operations that they are able to plan and monitor using TMA. There are procedures in place for addressing system problems, and the NTX engineering support team are on-site to troubleshoot and monitor the system. TMA is the primary metering system that is used under most conditions.

Overall, the frequency of metering appears to have been reduced. This has been attributed to not only the changes to procedures and airspace, but to changes that the airlines have made to their schedules. The facilities reported that Delta Airlines has adjusted its schedule so that its banks of aircraft do not compete directly with American Airlines. As a result, the rushes have gotten longer, and the peak levels of traffic are not as high.

In the 1998 Daily Use Field Survey, Center TMCs reported reverting to ASP if TMA was not “working properly.” The definition of “working properly” varied among TMCs; some were more likely to revert to ASP than others, and this might have reflected the level of training. Sometimes if the delay values seemed unusual (such as if the TMA delay values seemed too high, or were higher than ASP), they would revert to ASP. The level to which a delay was considered unusual may have also reflected the level of training. Even with the Red-X warning, the TMCs reported that they could not adequately judge the severity of a problem with the system. Sometimes if metering was just about to begin, and there appeared to be problems with CTAS, the TMCs may have decided to use ASP.

Since the 1998 Daily Use Field Survey, the TMCs have reported that the TMA system has proven to be more reliable and experiences fewer failures that in the past would have necessitated reverting to ASP. TMCs are now more likely to call the NTX engineering support team with questions regarding the TMA schedules, than to report a system failure. In general, the ZFW TMCs prefer not to revert to ASP if it can be avoided; they have noted that if ASP is utilized, the DFW TRACON will reduce its AAR because of reduced confidence in the ASP system, and may not allow the use of the dual route procedure.

3. Anticipation of New Traffic Flow Management Strategies.

New strategies in traffic flow management have evolved at ZFW since the 1996 Operational Evaluation. While we cannot speculate whether these strategies would have evolved even without TMA to help visualize the effect of such changes, it is clear that TMA is able to support these new strategies. TMA provides the means to integrate new procedures (such as the dual route procedure) with the existing system. Using a dual route procedure is seen to reduce workload. As dual route operations have increased, both TMCs and controllers recognize that controllers may be showing some degradation of their sequencing skills under metering operations. This trend could continue and further reduce opportunities to practice sequencing techniques. If controllers are perceived as becoming less proficient at sequencing, TMCs may opt to use the dual route procedure more frequently. However, as traffic levels are likely to increase, the need for metering operations will increase again as well.

In response to the concerns (described in Section 4.4.2.3) that aircraft schedules were frozen inconsistently in some sectors due to weather, TMA was be modified to incorporate the Spatial Freeze Horizon. The ability to set a new freeze horizon was something that controllers requested; they were very pleased to know that this change was on the way.

Single Gate Free-Flow (SGFF) is a new feature that is scheduled to begin operational testing in the spring of 2000. SGFF will be used to remove metering restrictions from a busy corner during a metered rush. The busy corner will not receive meter times, and will only delay aircraft as needed for in-trail spacing (sequencing) purposes. Delays that would have been assigned to the aircraft arriving over the free-flowing corner post will have to be redistributed equally to aircraft at the remaining gates. SGFF will allow for all the aircraft in the free-flowing corner to be counted in the AAR (unlike the dual route procedure, which meters the aircraft on the primary route and does not count the aircraft over the dual route in the AAR). TMA will be modified to incorporate these changes to the scheduling process, and the TMCs will be able to directly view the impact of such changes on the overall schedule.

The use of the dual route procedure may continue to evolve with the use of SGFF; there are some suggestions that a dual route will still be required with the free-flowing corner, and how this will be accomplished procedurally will need to be investigated. It will also be important to examine the coordination implications of SGFF. Both the Center and the TRACON will need to evaluate the possible effects of using SGFF, and how TMA will support those operations. SGFF operations may prove to be the type of procedure that can be introduced at MiT Centers who will be using TMA as they transition to metering operations.

4. Anticipation of New TMA Use Strategies.

The Denver Center Assessment of TMA in 1993 identified two distinct strategies in the use of TMA, focusing on either load graphs or timelines to determine when to meter (ref. 5). These approaches reflected the TMCs using TMA without having had the benefit of extensive training. The TMCs who participated in the 1996 Operational Evaluation, however, had had a great deal more exposure to TMA, and in fact had worked closely with the developers to define the use strategies. They also benefited from the lessons learned in Denver. As a result, the ZFW TMCs' approach for using TMA was to consult the traffic load graphs to understand the overall load, and then refer to the timelines to decide on the metering time. This approach is consistent with the "load graph" strategy defined in the 1993 Assessment. Because it was not clear prior to the 1998 Field Survey that there would be a variety of training and experience levels in the TMU, this use strategy issue was not investigated. But during the 1998 Field Survey, TMCs indicated using both load graphs and timelines in this manner. It is likely that the training the TMCs received reflected this approach as well.

The TRACON also relied on the load graphs and timelines. PGUI timelines continue to be used, despite the fact that TGUI timelines are available for the same purpose. It may be that since PGUI timelines are available on a display separate from the TMA/TGUI, they are viewed differently at a conceptual level. The addition of pFAST to daily TRACON operations further underscores the importance of PGUI timelines used for comparison with TMA information.

It can be assumed that new strategies for TMA use will emerge as the SGFF operations are tested and implemented. Thus far, TMA has demonstrated great flexibility in adapting to new procedures and operations and continues to assist the TMCs to visualize the traffic conditions and make effective operational decisions based on this information.

5. New Status and Scheduling Panel Information in the TGUI.

The Status and Scheduling Panel (F1) in the TGUI was designed with significant input from the ZFW TMCs. Combining the scheduling and configuration information into one place in the TGUI makes it easy to view current and future scheduling settings and allows the user to make changes and see the effects of these changes. The new panels were generally viewed as helpful and there were no negative comments. The structure of the panels also includes instructions on the proper sequence of steps to enact a particular configuration or scheduling change. This should help with making the TGUI more understandable to new users. As this was a new feature introduced in 1998, it will be instructive to determine how the F1 panel has helped in training since then.

6. Continued Follow-Up as Part of the CTAS Development Process.

TMA development has continued even as TMA is implemented for daily use and a version of TMA is part of the Free Flight Phase I national deployment plan. While much of the basic functionality was well-defined at the end of the 1996 Operational Evaluation, there were significant user-interface changes made to accommodate the daily use of the system. There were also many other human factors challenges and many engineering challenges that arose from the daily use of TMA that were not anticipated throughout the development process.

How well a tool and its features are utilized must be investigated beyond the final proof-of-concept evaluation that is conducted in the field. The long-term effects of staff turnover, lapses in training, and changes to airspace and procedures are all variables that cannot be properly examined in the context of a single operational evaluation. They are all variables that influence the utility of a tool, and the benefits that can be realized from the tool. From the experience with TMA, there were clearly new research areas to be explored that affect the development of other tools for the Center and TRACON TMCs and controllers.

It is also critical to investigate such long-term issues because they raise pertinent questions about the development of follow-on decision-support tools and enhancements. Continued investigation provides insight into the evolving air traffic control environment, and can highlight problems and new areas for research. For example, due to staff turnover, the training of the TMCs at the Center was uneven. As a result, it was not a simple matter to draw conclusions on all of the potential benefits of TMA for traffic management decision-making. While insufficient training makes assessment more difficult, it also can point to the need for improvements in the user interface and the documentation so that less-experienced users are better able to understand the system. As traffic management is a complex process, the TMA training may need to include discussion of the techniques and approaches used in traffic management. Specific training recommendations are described in Section 5.

5. RECOMMENDATIONS

Based on the 1998 Daily Use Field Survey, a number of recommendations are made to improve CTAS functionality and enhance ATC operations. These recommendations fall under the following categories: user interface, added functionality, training, and documentation.

5.1 User Interface

There were no significant interface changes requested for the TGUI as an outcome of the Daily Use Field Survey. Some of the new functionality that is being defined (such as SFH and SGFF) will require associated interface changes. The Center TMCs did make a recommendation to simplify the entry of the metering message to the Host, which is accomplished through the CM (or Communications Manager) process of CTAS. This change is being evaluated.

With the recent implementation of the DSR consoles, there may be changes in the usability of the manual swap or manual sequence features given the new user interface; this will be an issue to investigate in a future survey of TMA daily use.

5.2 Functionality

Changes to the proposed SGFF functionality, provided by the ZFW TMCs, are being researched. In addition to changes to the scheduler, these proposed changes include additions to the TGUI F1 Status and Scheduling panel, and the representation of SGFF information on the timelines and in the overlays.

5.3 Training

Training is probably the most significant issue that affected the interpretation of TMA at ZFW. While overall, CTAS/TMA has provided many benefits for ZFW operations, not all the TMCs understood what TMA does, and how it does it. Some TMCs didn’t know how to set up TMA, and what options are available. There was no regular mechanism, either through memos, briefings, or documentation, to alert the users to updates or the availability of new features. While training sessions were conducted following the 1996 Operational Evaluation, since then, the turnover rate in the TMU has become more regular. At the time of the Daily Use Field Survey, there were about 10 senior TMCs who knew ASP well, and the remainder of the TMC staff “grew up with” CTAS.

Most of the newer Center TMCs learned about CTAS/TMA through word-of-mouth, trial and error, and talking to the NTX engineers and researchers. Some of the TMCs learned a great deal about CTAS because they were willing to sit down and work through the manuals, but in general, it appeared that the manuals were not accessed very frequently. One of the TMCs said that it takes 6-12 months to get familiar with everything on CTAS. Another TMC estimated that he uses probably a fourth of TMA's total capabilities because he doesn't completely understand the system.

Because the new TMCs rely on other TMCs for training, they are subject to the biases of whomever is conducting the training. A TMC who doesn't like CTAS, prefers ASP, or prefers not to meter, will influence how a new TMC will learn about CTAS. The TMCs all agreed that any new training effort should be hands-on/on-the-job (OJT). Shadowing an operational system where users can observe the effects of traffic flow management decisions would also provide training benefits. The training recommendations based on the 1998 Daily Use Field Survey are as follows:

- Additional training for the Center TMCs is needed, in the form of OJT, or other exercises with an operational system. This training should be offered periodically to coincide with significant staff turnover in the TMU. Additionally, periodic information on updates to the software should be provided so that TMCs are aware of new features. This periodic information could be incorporated into regular TMC briefings. The NTX engineering support team could provide updates on the status of the CTAS system to the TMCs on a regular basis so that upcoming changes are anticipated.

- The TRACON TMU turnover rate was much lower than that observed at the Center TMU. Therefore, additional training for the TRACON is only recommended for new personnel. New training should also take the form of OJT or operational exercises. Regular briefings on system updates should be provided.

- Refresher training is recommended for the Tower users to provide an overview of the CTAS system. Regular briefings on system updates should be provided.

- While the Center Sector controllers could also benefit from refresher training on the CTAS features, as noted in Section 4.5, it could be a complicated issue to address as their opportunities to try out the CTAS features are available only when metering. Whether the sector controllers view any benefit to updating the schedules according to manual swaps or sequences remains to be investigated.

5.4 Documentation

The CTAS software is extensively documented in user reference manuals describing how features can be utilized. The documentation can be used as a tutorial for understanding all of the different functionality within CTAS. However, to support daily use operations, additional documentation, in the way of quick reference guides for the TMCs and controllers, are recommended to provide a brief synopsis of the information that TMCs and controllers use most frequently.

For the Center TMCs, a quick reference card has been developed to provide guidance on interpreting data tags, delay information, and for quickly determining what information is contained in the different set-up panels in the TGUI and PGUI. It is helpful that, in general, the TMA displays are set up in a standard configuration that is rarely changed. The quick reference card may be additionally helpful for less-experienced users to understand the more subtle changes that are made to a TMA display. For the sector controllers, a quick reference card has also been developed summarizing the keyboard inputs to use the manual swap and manual sequence features. Drafts of these cards are included in Appendices C and D.

6. CONCLUDING REMARKS

Overall, TMA is working well at all the Dallas/Ft. Worth ATC facilities. The human factors results of the 1996 Operational Evaluation showed that there were significant benefits to using TMA, and that there were some anticipated increases in workload with TMA usage, but that overall, traffic management operations were enhanced, making such workload increases acceptable. Since the 1996 Operational Evaluation, many changes have taken place in the form of new ATC procedures, airline practices, and airspace configuration. TMA has been in daily use throughout those changes, and has been shown to be adaptable to such changes. Even during periods of clear weather, in which metering is not occurring as frequently as expected, TMA still provides a useful means of visualizing the traffic, determining delays, and aiding in decisions regarding dual route operations and staffing. As staff are introduced into the TMUs, TMA is becoming the new standard for visualizing the traffic flow. It is anticipated that with more increases in traffic expected over the next several years, TMA will still be able to provide significant benefits to traffic flow management, and certainly if metering operations are increased, more of TMA's functionality will be exercised. Additional training and documentation is needed to better familiarize new TMCs and provide reminders to the TMU as a whole about the capabilities that can be exercised with TMA.

The single outer arc meter list continues to be a useful CTAS feature. The manual swap feature appears to be something that is useful but which requires controllers' familiarity with the keyboard inputs and with the purpose of this feature. Traffic levels and staffing (the availability of a D-side, and the coordination between the D-side and R-side controllers) influence the use of the manual swap feature. Additional training is needed to familiarize controllers with the benefits that could be provided by using the manual swap feature.

TMA has proven to be a robust system which has evolved in its usage even as the facilities and the operations themselves have changed. As a result, the daily support activities provided by the (FAA-contracted) NTX engineering support team become more important in keeping the users apprised of new system functionality and identifying when training and additional documentation are needed. The NTX engineering team has been very responsive to all the users in addressing problems when they occur.

The 1998 Daily Use Field Survey human factors results are instructive as baseline data for future CTAS/TMA enhancements (such as SFH and SGFF). The human factors results and recommendations in this report should also provide guidance in the more wide-scale deployment of CTAS and development of follow-on DSTs especially with regard to training, documentation, and long-term system use issues that may be encountered at other facilities.

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APPENDIX A. EXAMPLES OF THE TGUI AND THE PGUI

The Timeline Graphical User Interface (TGUI) consists of a basic timeline display, a load graph display, various overlays of information, and a number of function panels from which the user may access the TMA features and make changes to the scheduling constraints that govern the CTAS schedules.

Figure A.1. TGUI timelines. This figure shows the basic TMA display of timeline information. Each timeline is referenced to meter fixes or runway threshold.

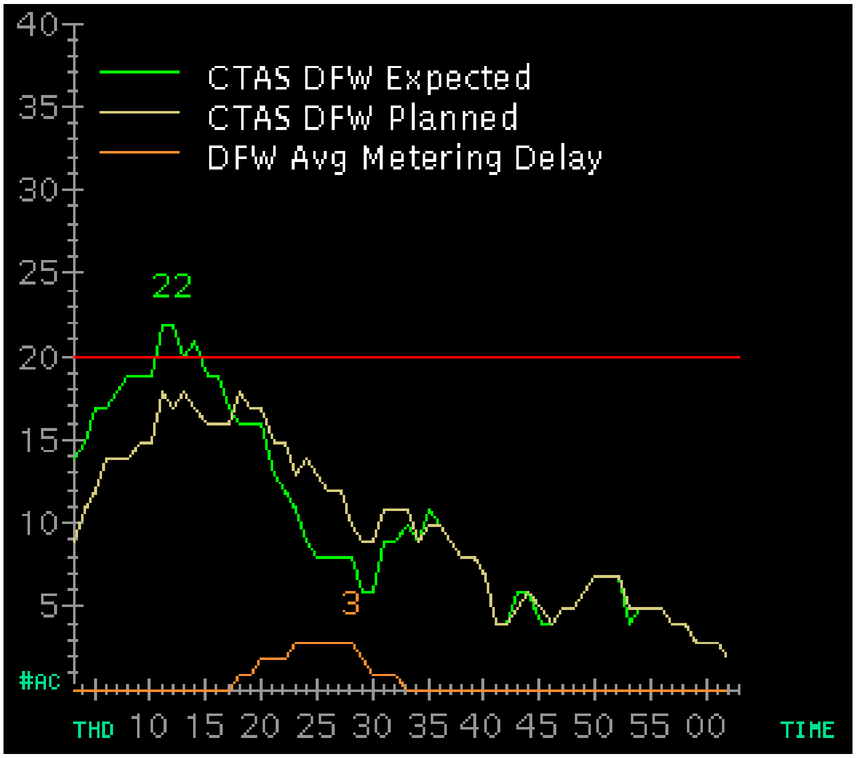


Figure A.2. TGUI traffic load graph. This is an example of the traffic load graphs available in TMA. Up to nine graphs can be displayed at a time.

The Planview Graphical User Interface (PGUI) consists of a basic map display, upon which other information such as sequence list, timelines and other traffic information can be displayed. The PGUI also has various function panels upon which the user may specify the display parameters.

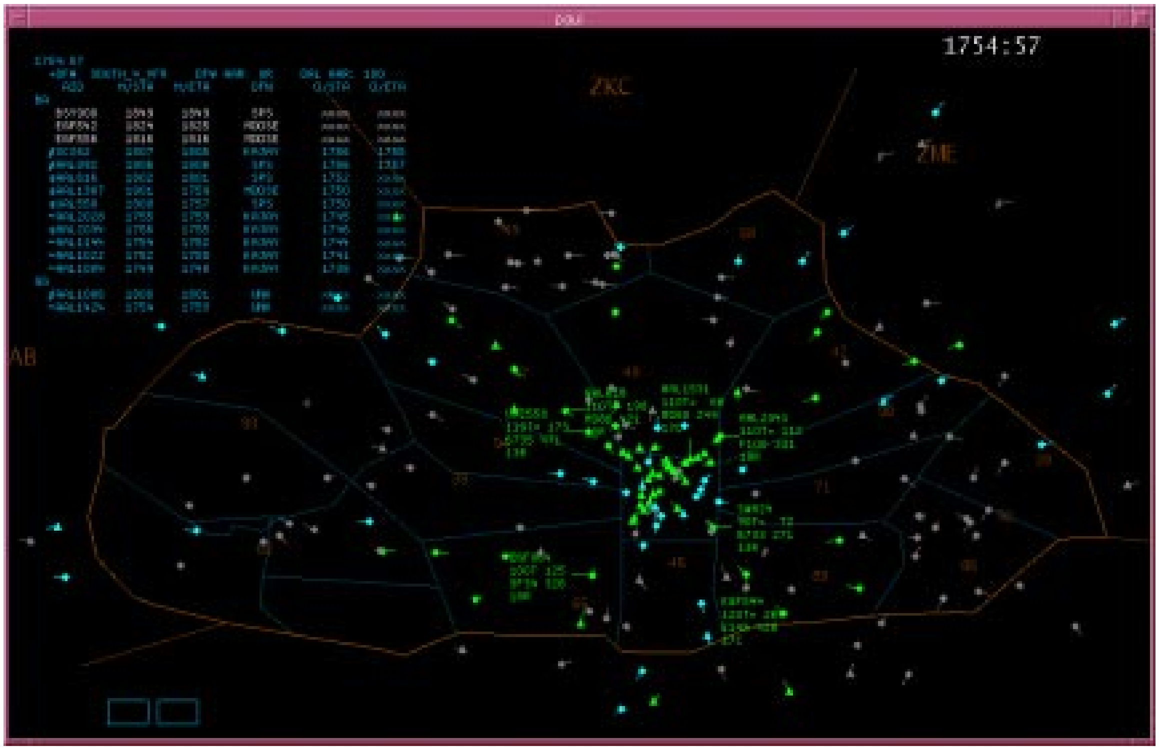


Figure A.3. PGUI Display. This PGUI displays a Center map of the Ft. Worth Center airspace, with a sequence list displayed in the upper left corner.

APPENDIX B. QUESTIONNAIRES USED IN THE 1998 DAILY USE FIELD SURVEY

The following questionnaire will be used to gather information on how Ft. Worth Center TMCs are impacted by the use of the Center/TRACON Automation System (CTAS) for metering purposes. Your responses will help us to make improvements to CTAS or provide input into documentation or training. We will also use your responses to determine how to assess CTAS during a field study this summer. We appreciate your taking the time to fill out this questionnaire, and welcome any comments you might have. If you would like to talk to someone about these concerns, please feel free to contact the following CTAS personnel:

Kathy Lee   phone: 650-604-5051   e-mail: kklee@mail.arc.nasa.gov

Cheryl Quinn   phone: 650-604-5793   e-mail: cquinn@mail.arc.nasa.gov

Thanks for your participation! Please return this form to the marked box.

Center TMC Questionnaire

Demographics

1. How many years of ATC experience do you have? __________
2. How many years have you worked in a level 3 facility? __________
3. How many years have you worked at ZFW? __________
4. How many years of TMC experience do you have? __________
5. Approximately how much training have you had using CTAS? __________ hours

6. Please rate (by marking on the scale below) how comfortable you feel working with the CTAS TMA system, in general:

0	1	2	3	4
Very Uncomfortable; System seems difficult to use				Very Comfortable; System seems easy to use

General Traffic Management

7. Please rate (by marking on the scale below) the general traffic complexity of the facility during the past month:

0	1	2	3	4
Very Simple		Neither Simple nor Complex		Very Complex

8. Approximately how often does the facility meter? ______ times/day

9. Approximately how often do you use dual routes in addition to metering?______ times/day

10. How many times do you need to revert to ASP? ______ times/month

11. Please describe the conditions that cause you to revert to ASP for metering instead of CTAS:

____

12. What features do you like/dislike about using the ASP system for metering?

____

13. What features do you like/dislike about using the CTAS system for metering?

____

14. Under ASP metering, on average, how many times per rush do you need to ripple the list? ___________ times/rush

15. Under CTAS metering, on average, how many times per rush do you need to ripple the list? ___________ times/rush

Center CTAS Features

Please rate how often you use the following CTAS features, over the course of a typical month, using the scale below:

Frequency of Use of CTAS/TMA Features Scale

0	1	2	3	4
never		sometimes		often

16.	Timelines	
17.	Traffic Load Graphs	
18.	Traffic Count	
19.	Status and Scheduling Information Panel (F1)	
20.	Delay Numbers (attached to aircraft tags on the timelines)	
21.	Configuration Summary (F7)	

Frequency of Use of CTAS/TMA Features Scale

0	1	2	3	4
never		sometimes		often

22.	Pop-up Aux Display Information (F8)	
23.	Flight Plan Information from TGUI (F11)	
24.	Blocked Intervals	
25.	Blocked Slots	
26.	Proposed Flights (F4)	
27.	Not on Timeline Flights (F4)	
28.	Departure Time Panel (for Proposed and Not on Timeline Flights) (F4)	
29.	Delay Reporting Status (F6)	
30.	Previously Recorded Delay Reports	
31.	Scheduling Options: STA Freeze Horizon Settings (shift-F10)	
32.	Scheduling Options: Scheduler Settings (shift-F10)	
33.	Scheduling Options: Data Sources (shift-F10)	
34.	Manual Rescheduling	
35.	Change Runway Assignment	
36.	Allocate Runway	
37.	Changing Meter Fix Assignment	
38.	Proposed Meter Fix Change	
39.	Suspending Aircraft	
40.	Reset Aircraft	
41.	Priority Aircraft	
42.	Find Slot for Aircraft	
43.	PGUI (Planview) Traffic Display	
44.	PGUI Timelines	

Frequency of Use of CTAS/TMA Features Scale

0	1	2	3	4
never		sometimes		often

45.	PGUI Sequence List	
46.	PGUI Flight Plan Information	
47.	How frequently do you monitor the sectors by using the information in the single outer arc meter list?	

Please provide any comments or suggestions in the space below.

The following questionnaire will be used to gather information on how Ft. Worth Center controllers are impacted by the use of the Center/TRACON Automation System (CTAS) for metering purposes. Your responses will help us to make improvements to CTAS or provide input into documentation or training. We will also use your responses to determine how to assess CTAS during a field study this summer. We appreciate your taking the time to fill out this questionnaire, and welcome any comments you might have. If you would like to talk to someone about these concerns, please feel free to contact any of the following CTAS personnel:

Kathy Lee phone: 650-604-5051 e-mail: kklee@mail.arc.nasa.gov

Cheryl Quinn phone: 650-604-5793 e-mail: cquinn@mail.arc.nasa.gov

Thanks for your participation! Please return this form to the marked box.

Center Controller Questionnaire

Demographics

Specialty: ________________________

1. Approximately how many CTAS metering periods have you worked, in the arrival sectors, in the past month? __________

2. How many total years of ATC experience do you have? __________

3. How many years have you worked in a level 3 facility? __________

4. How many years have you worked at ZFW? __________

For the following questions (#5-#24), please keep in mind the traffic operations you have worked/experienced in the past month.

CTAS Effects

Please use the following scale in answering questions 5-8:

Frequency of List Effects Scale

0	1	2	3	4
never		sometimes		often

5. How often do you notice ripples in the metering list? __________

6. How often do you make manual swap (X B) entries at your position? __________

7. How often do you make sequence swap (X C) entries at your position? __________

8. How often do list ripples increase your workload during a metering period? __________

9. How often do you notice sequence swaps generated at another sector that affect your list? __________

CTAS Effects, continued:

Please use the following scale in answering questions 10-13:

<u>Difficulty of Feature Use Scale</u>

0	1	2	3	4
Very Difficult		Neither Easy nor Difficult		Very Easy

10. How difficult is it to work metered traffic in your area? __________

11. If you have made manual swap (X B) entries, how easy is it to use this feature? (Leave blank if you have never used this.) __________

12. If you have made sequence swap (X C) entries, how easy is it to use this feature? (Leave blank if you have never used this.) __________

13. If you have used the delay countdown feature, how easy is it to use this feature? (Leave blank if you have never used this.) __________

14. If you do not make any manual swap entries, why?
(Please check all that apply)

_________ not enough metered traffic to make manual swaps

_________ too busy to make swap entries

_________ D-side controller makes the swap entries

_________ too many keyboard entries are required

_________ easier to make the manual swap with the strips themselves

_________ prefer to make the manual swaps with the strips

_________ prefer to make swaps mentally

<u>other</u> (please describe):

Acceptability

Please rate the acceptability of the following CTAS features and events, as you have experienced them, using the scale below:

Acceptability Scale

X	0	1	2	3	4
Not Applicable	Completely Unacceptable		Neither Acceptable nor Unacceptable		Completely Acceptable

15. Scheduled times at your sector __________
16. Aircraft sequences __________
17. Delays at your sector __________
18. Delay countdown feature __________
19. Single outer arc metering list __________
20. Overall acceptability of CTAS for metering purposes __________

Workload

Please rate how the following events and CTAS features compare to ASP under similar traffic conditions, as it influences your workload, using the scale below:

Workload Scale

X	0	1	2	3	4
Not Applicable (have never used)	Better with ASP				Better with CTAS

21. Scheduled times at your sector __________
22. Aircraft sequences __________
23. Delays at your sector __________
24. Delay countdown feature __________

Comments

Please provide any comments or suggestions in the space below.

The following questionnaire will be used to gather information on how DFW TRACON TMCs are impacted by the use of the Center/TRACON Automation System (CTAS). Your responses will help us to make improvements to CTAS or provide input into documentation or training. We will also use your responses to determine how to assess CTAS during a field study this summer. We appreciate your taking the time to fill out this questionnaire, and welcome any comments you might have. If you would like to talk to someone about these concerns, please feel free to contact the following CTAS personnel:

Kathy Lee phone: 650-604-5051 e-mail: kklee@mail.arc.nasa.gov

Cheryl Quinn phone: 650-604-5793 e-mail: cquinn@mail.arc.nasa.gov

Thanks for your participation! Please return this form to the marked box.

TMC Questionnaire: TRACON

Demographics

1. How many years of ATC experience do you have? __________ years

2. How many years have you worked in a level 5 facility? __________ years

3. How many years have you worked at DFW? __________ years

4. How many years of TMC experience do you have? __________ years

5. Approximately how much training have you had using TMA? __________ hours

6. Marking on the scale below, please rate how comfortable you feel working with the CTAS TMA system, in general:

0	1	2	3	4
Very Uncomfortable; System seems difficult to use				Very Comfortable; System seems easy to use

When answering the following questions, please keep in mind the traffic operations you have experienced in the past month.

General Traffic Management

7. Please rate (by marking on the scale below) the general traffic complexity during the past month:

0	1	2	3	4
Very Simple		Neither Simple nor Complex		Very Complex

8. How often do you refer to the Center TMA repeater system, versus the TRACON TMA system?

0	1	2	3	4
Never		Sometimes		Always

9. How often do you compare the information on the two systems?

0	1	2	3	4
Never		Sometimes		Always

10. How often do differences in the information that is presented in the two systems create problems or difficulties in your interpretation of information?

0	1	2	3	4
Never		Sometimes		Always

TRACON TMA Features

Please rate <u>how often</u> you use or reference the following CTAS features, over the course of a typical month, using the scale below:

<u>Frequency of Use of CTAS/TMA Features</u>

0	1	2	3	4
Never		Sometimes		Often

11. Status and Scheduling Information Panel (F1) __________

12. Delay Information (numbers attached to aircraft tags on the timelines) __________

13. Traffic Load Graphs __________

14. Traffic Count __________

15. Current and Future Configuration Information (F7) __________

16. Flight Plan Information from TGUI (F11) __________

17. Pop-up Aux Display information (F8) __________

18. PGUI (Planview) Traffic Display __________

19. PGUI Timelines __________

20. PGUI Sequence List __________

21. PGUI Flight Plan Information __________

Metering

How helpful (in terms of workload) were the following CTAS/TMA features in the past month during metering operations (or in helping to decide whether to meter)? (Please use the scale below):

<u>Workload Scale</u>

X	0	1	2	3	4
Not Applicable (have never used)	Greatly Increases Workload (not very helpful)		No Effect		Greatly Decreases Workload (very helpful)

22. Status and Scheduling Information Panel (F1) __________

23. Delay Information (numbers attached to aircraft tags on the timelines) __________

24. Traffic Load Graphs __________

25. Traffic Count __________

26. Current and Future Configuration Information (F7) __________

27. Flight Plan Information from TGUI (F11) __________

28. Pop-up Aux Display information (F8) __________

29. PGUI (Planview) Traffic Display __________

30. PGUI Timelines __________

31. PGUI Sequence List __________

32. PGUI Flight Plan Information __________

Dual Route Operations

33. Approximately how often have you used dual routes in the past month? ______ times/week

34. Approximately how often do you use dual routes in addition to metering? ______ times/week

Please rate (using the scale below) how helpful, in terms of workload, CTAS/TMA information is during dual routes operations (or in making the decision of whether to use dual routes):

<u>Workload Scale</u>

X	0	1	2	3	4
Not Applicable (have never used)	Greatly Increases Workload (not very helpful)		No Effect		Greatly Decreases Workload (very helpful)

35. Status and Scheduling Information Panel (F1) _________

36. Delay Information (numbers attached to aircraft tags on the timelines) _________

37. Traffic Load Graphs _________

38. Traffic Count _________

39. Current and Future Configuration Information (F7) _________

40. Flight Plan Information from TGUI (F11) _________

41. Pop-up Aux Display information (F8) _________

42. PGUI (Planview) Traffic Display _________

43. PGUI Timelines _________

44. PGUI Sequence List _________

45. PGUI Flight Plan Information _________

Staffing Decisions

Please rate (using the scale below) how helpful, in terms of workload, CTAS/TMA information is in making staffing decisions:

Workload Scale

X	0	1	2	3	4
Not Applicable (have never used)	Greatly Increases Workload (not very helpful)		No Effect		Greatly Decreases Workload (very helpful)

46. Status and Scheduling Information Panel (F1) __________

47. Delay Information (numbers attached to aircraft tags on the timelines) __________

48. Traffic Load Graphs __________

49. Traffic Count __________

50. Current and Future Configuration Information (F7) __________

51. Flight Plan Information from TGUI (F11) __________

52. Pop-up Aux Display information (F8) __________

53. PGUI (Planview) Traffic Display __________

54. PGUI Timelines __________

55. PGUI Sequence List __________

56. PGUI Flight Plan Information __________

CTAS Features

Keeping in mind what you need to do to achieve desired system performance, how acceptable are the following events and CTAS features? (Please use the scale below)

Acceptability of CTAS in Achieving Desired System Performance

X	0	1	2	3	4
Not Applicable	Completely Unacceptable		Neither Acceptable nor Unacceptable		Completely Acceptable

57. Physical manipulation required (keyboard entries, mouse movements, etc.) __________

58. Time spent working with the system (to manipulate features, waiting for updates, etc.) __________

59. Required inter-facility communication __________

60. Required intra-facility communication __________

61. Delay distribution __________

62. Delay accuracy __________

63. STAs/Schedules __________

64. Aircraft sequences __________

65. Summary of traffic information __________

66. Traffic Load Graphs __________

67. Time required to feel comfortable using TMA __________

68. Overall acceptability of using TMA/CTAS __________

69. The most recent reference manuals (TMA and Passive FAST) __________

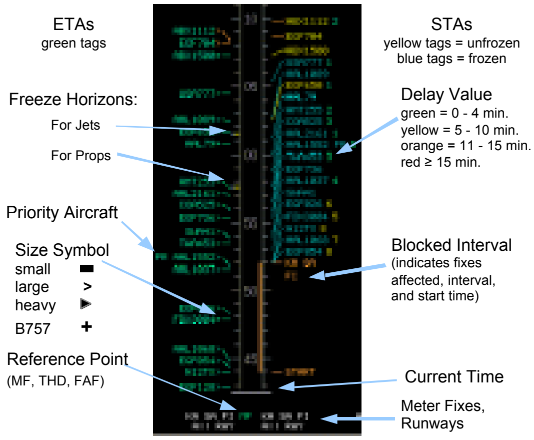
70. Quick Reference Guide (Passive FAST) __________

Please provide any comments or suggestions in the space below.

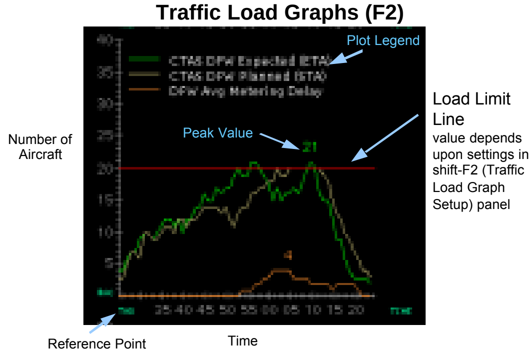
APPENDIX C. DRAFT TMA QUICK REFERENCE CARD FOR CENTER TMCS

TMA Quick Reference Card

TMA Timelines



Traffic Load Graphs (F2)



TMA Quick Reference Card

TGUI Functions

items in red: change actual schedules and sequences
items in black: change display of information

TGUI F-Panels	Description
F1: Status and Scheduling	*Select parameters (TRACON & Gate) and configuration (AAR & Rwy Flow)*
F2: Load Graph	View load graphs
shift-F2: Load Graph Setup	Select load graph features
F3: Current Display Format	Load/save user-defined display files
F4: Aircraft Information	*View/schedule proposed, not-on- timeline, satellite departures*
F5: Traffic Count	
F6: Delay Reporting Status	
F7: Configuration Summary	Current time, configuration status
F8: Popup Aux Data Overlay	Toggle overlay of auxiliary data
F9: Timeline Options	Set timeline features
shift-F10: Scheduling Options	Set scheduling options
F11: Flight Plan Readout	Toggle overlay of aircraft flight plan

PGUI Functions

PGUI F-Panels	Description
F1: Map View	Select desired map
F2: General Setup Options	Set display features
F3: Map Options	Set map features
F4: Defaults File Load Options	Load/save display files
F5: Timeline Options (if enabled)	*Set PGUI timelines features*
F6: Sequence Options	Set sequence list features
F7: HELP: Quick Keys	List of quick key shortcuts
F12: Refresh	Refresh the display

Find flight on TGUI or PGUI:
1. Type “a”
2. Enter aircraft ID
3. Press Return

Find waypoint on PGUI:
1. Type “w”
2. Enter waypoint ID
3. Press Return

Available beginning with 5.4.1ceft release:
Turn on PGUI Sequence List display: Scroll Lock key

APPENDIX D. DRAFT TMA QUICK REFERENCE CARD FOR CENTER SECTOR CONTROLLERS

R-side
Quick Reference Card

1. **Trackball over Meter list button on "R" CRD.**
2. **Press Enter on trackball.**
3. **Use Manual Swap or Sequence Swap:**

- Trackball over **Manual Swap**.
- Press Enter on trackball, or select F5 key.
- Type in 2 CIDS (separated by a space).
- Press Enter.

Aircraft order will swap.

-or-

- Trackball over **Ripple List.**
- Press Enter on trackball, or select F9 key.
- Type in up to 5 CIDs in the sequence you want (each CID separated by a space).
- Press Enter.

Aircraft will be re-ordered in the list.

CRD Function Menu

On/Off Lists	F1
Arpt Config	F2
Arpt Rate	F3
Manual Assign	F4
Manual Swap	F5
Arrival Delay	F6
Arpt Combine	F7
Manual Delete	F8
Ripple List	F9

Notes:
1. You must have track control of the aircraft you are planning to swap.
2. You can only swap or sequence the same types of aircraft (prop for prop, jet for jet, up to 5 props, up to 5 jets).

Purpose of these Features:
Manual Swap: to swap the order of 2 aircraft in the meter list.
Sequence Swap (Ripple List): to sequence up to 5 aircraft in the meter list.

Using these features will help match slots to the scheduled times. High sectors using the feature will help the low sectors to know what order to expect the aircraft.

CTAS Problems or Troubleshooting:
Please contact CTAS Ops Support at x 7635

D-side
Quick Reference Card

Manual Swap:

- Enter "NE"
- Type in 2 CIDs (separated by a space).
- Press Enter.

Aircraft order will swap.

Sequence Swap:

- Enter "NJ"
- Type in up to 5 CIDs in the sequence you want (each CID separated by a space).
- Press Enter.

Aircraft will be re-ordered in the list.

Purpose of these Features:
Manual Swap: to swap the order of 2 aircraft in the meter list.
Sequence Swap (Ripple List): to sequence up to 5 aircraft in the meter list.

Using these features will help match slots to the scheduled times. High sectors using the feature will help the low sectors to know what order to expect the aircraft.

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13. ABSTRACT *(Maximum 200 words)*

The Traffic Management Advisor (TMA) is a component of the Center-TRACON Automation System (CTAS), a suite of decision-support tools for the air traffic control (ATC) environment which is being developed at NASA Ames Research Center. TMA has been operational at the ATC facilities in Dallas/Ft. Worth, Texas, since an operational field evaluation in 1996. The Operational Evaluation demonstrated significant benefits, including an approximately 5% increase in airport capacity. This report describes the human factors results from the 1996 Operational Evaluation and an investigation of TMA usage performed two years later, during the 1998 TMA Daily Use Field Survey. The results described are instructive for CTAS-focused development, and provide valuable lessons for future research in ATC decision-support tools where it is critical to merge a well-defined, complex work environment with advanced automation.

14. SUBJECT TERMS
Traffic Management Advisor, TMA, Air traffic control, Traffic flow management, Center/TRACON Automation System, CTAS, Human factors, Decision-support tools

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