Design and Operational Evaluation of the Traffic Management Advisor at the Fort Worth Air Route Traffic Control Center

By

Harry N. Swenson*, Ty Hoang*, Shawn Engelland*
Danny Vincent[§], Tommy Sanders[†]
Beverly Sanford[£], Karen Heere[¶]

Summary

NASA and the Federal Aviation Administration (FAA) have designed and developed an automation tool known as the Traffic Management Advisor (TMA). The TMA is a time-based strategic planning tool that provides Traffic Management Coordinators (TMCs) and En Route Air Traffic Controllers the ability to efficiently optimize the capacity of a demand-impacted airport. The TMA consists of trajectory prediction, constraint-based runway scheduling, traffic flow visualization and controller advisories. The TMA was used and operationally evaluated for thirty-nine rush traffic periods during a one month period in the Summer of 1996 at the Fort Worth Air Route Traffic Control Center (ARTCC). The evaluations included all shifts of air traffic operations as well as periods of inclement weather. Performance data were collected for engineering and human factor analysis and compared with similar operations without the TMA. The engineering data indicate that the operations with the TMA show a one to two minute per aircraft delay reduction during rush periods. The human factor data indicate a perceived reduction in en route controller workload as well as an increase in job satisfaction. Upon completion of the evaluation, the TMA has continued to be a primary traffic management tool of daily operations at the Fort Worth ARTCC.

1. Introduction

The growth of commercial air travel within the United States has put a severe strain on the nation's air traffic capacity. This coupled with the "Hub & Spoke" procedures used by the major air carriers and the marketing requirements to take-off and land at optimum times has led to the need to improve the air traffic control system. There are two ways to increase the capacity of the system. The first is the building of more runways. Though this might be the obvious solution, the economic, geographic and political difficulties make this an undesirable solution for most airports and communities. The second is the addition of decision support tools that allows the capacity to be more efficiently utilized. The Center-TRACON Automation System (CTAS) is a set of decision support tools being developed to improve airport capacity and reduce delays while maintaining controller workload at a reasonable level[1].

CTAS is comprised of three major decision support tools: the Traffic Management Advisor (TMA), the Final Approach Spacing Tool (FAST), and the Descent Advisor (DA). The goal of these tools is to assist air traffic controllers efficiently manage and control arrival traffic within the extended terminal area (100 to 200 miles from touchdown to landing). The core element of each tool is the CTAS 4-Dimensional (4D) trajectory synthesis algorithms[2,3]. These algorithms, similar to those used for Flight Management Systems (FMS) for modern equipped commercial air transports, have a demonstrated 20 min. prediction accuracy of approximately 15 sec. root-mean-square error[4]. Each tool is being designed to provide a level of automation and capability that is not dependent on the other tool functions, but can work in concert to provide enhanced benefit. The primary capabilities of the TMA are time-based arrival traffic flow visualization, strategic planning based upon aircraft separation and flow rate constraints, and limited tactical ARTCC controller advisories for metering. The capabilities of FAST are to provide landing sequence and runway assignments that assist Terminal Radar CONtrol (TRACON) controllers to efficiently manage arrival traffic in the complex terminal environment[5]. FAST has been operationally evaluated at the Dallas/Ft.

* Research Engineer
NASA Ames Research Center
Moffett Field, CA, USA
§ Traffic Management Supervisor
† Traffic Management Coordinator
Federal Aviation Administration
Fort Worth Air Route Traffic Control Center
Fort Worth, TX USA
£ Human Factors Engineer
¶ Engineering Analyst
Sterling Software
Redwood Shores, CA, USA

Worth airport and has demonstrated a 13% increase in airport throughput without a significant increase in controller workload[6]. DA is being designed to assist en route controllers by generating accurate, fuel-efficient conflict-free clearance advisories to meet TMA-generated schedules[2].

The primary users of the TMA are the Traffic Management Coordinators (TMCs), whose primary function is to predict the “demand” of air traffic and the “capacity” of their facility. The TMC’s key responsibility is to ensure the “demand” in excess of the facility’s capacity is safely and efficiently absorbed throughout the airspace. A simple definition of “demand” is the number of aircraft destined to a common merge point within a facility’s airspace during a specified time interval. Two obvious examples of merge points are the runway threshold and the TRACON gate/fix. The TRACON gate/fix is a position or area through which the primary flow of traffic enters from enroute to terminal airspace. This position will be referred to as a meter fix throughout this paper. “Capacity” is the maximum number of aircraft that a facility can safely transition through its boundaries during a given period of time, usually measured as a flow rate or the number of aircraft per hour. A facility’s capacity can be very dynamic and is heavily influenced by weather conditions, runway availability, capacity changes of nearby facilities, and controller staffing level. The realization of this complexity as well as the current demand of the National Airspace System, has lead to the growth of the Traffic Management Unit (TMU) and TMC specialty.

A major problem the TMC’s need to address is a phenomenon known as an air traffic “rush”. A rush is a period of time when the number of aircraft destined to the same point exceeds the number that can be accommodated without significant delay and controller and pilot interaction. During these rush periods TMCs impose restrictions upon air traffic movement to insure that a facility’s capacity is approximately met, but not exceeded.

The current tools available to a TMC to predict demand are a combination of 1) historical knowledge 2) radar derived positional information from both the facility’s radars and the Airport Situation Display(ASD), which provides integrated but somewhat limited radar information from all ATC facilities and 3) the En Route Spacing Program (ESP)/ Arrival Sequencing Program (ASP)[7,8]. These tools require a significant amount of heuristics and guess-work on the part of the TMC to predict the current and future demand. The numerous uncertainties associated with the National Airspace System (NAS) and air traffic movement in general make this prediction a highly challenging task.

The demand prediction requirement of a TMC has to be coupled with his/her understanding of a facility’s capacity. Capacity in arrival management is based on such physical constraints as runways, traffic mix, size of usable airspace for traffic movement and weather. Also the TMC needs to consider the intangibles; which controller or controller teams are working, how long they have been working, and the agreed-upon coordination with adjoining facilities. Again, there is limited information that a TMC can draw upon to make this capacity evaluation. Mostly the TMC uses historical knowledge, experience and attempts to err on the conservative side. The tools that the TMCs have at their disposal to affect the period of time when the demand exceeds capacity are flow reduction techniques. The primary technique used is the requirement that the in-trail separation for a series of aircraft is to be greater than the legal minimum of 5 miles; these restrictions are known as miles-in-trail (MIT) restrictions. Some limited research has been conducted to develop automation to assist in the efficient use of MIT[9]. The operational use of MIT restrictions is based upon vast experiential knowledge and many heuristics that are not mathematically tractable. The TMC’s also have the ability to close or open particular aircraft routings to affect traffic demand. The final current tool available to the TMC is the ASP flow rate algorithm[7]. The tool uses demand predictions based upon the filed speed and current ARTCC routing coupled to a very simple route from the ARTCC boundary to a common point within the TRACON representing all runways, known as a vertex. Aircraft are then scheduled to this vertex to meet an airport acceptance rate (AAR) without regard to separation requirements or standards at individual runways or adjacent dependent runways.

This paper will present a brief description of the TMA and how it is used to optimize the capacity of a demand impacted airport. This will be followed by a discussion and analysis of an operational evaluation of the TMA conducted at the Fort Worth Air Route Traffic Control Center (ARTCC) managing the traffic flows into the Dallas/Fort Worth airport, the second busiest airport in the world[10].

2. TMA System Description

The TMA is a time-based strategic planning and control tool that consists of trajectory prediction, constraint-based runway scheduling, traffic flow visualization and controller arrival sequence, time and delay advisories. The TMA software components are hosted on a network of modern UNIX workstations. A simple hardware/software diagram is shown in figure 1. On the left side is the operational air traffic control system from which the TMA receives aircraft track data, flight plans and various controller entries. These data are passed to the communications manager (CM) for distribution to the prediction, scheduling and visualization processes. The CM also transfers the atmospheric data to the prediction and visualization algorithms. The time prediction process generates estimated times of arrival (ETA) for all aircraft to the meter fixes and all eligible runways. This is the most computationally intensive process and is a function of the number of aircraft in the system. It was thus designed to be scaleable with more computers. The figure shows four processors allocated for this purpose. The ETA data are used with ATC constraints to generate scheduled time of arrivals (STA). The ETA, STA and other information of interest are displayed in various graphic formats on the TMA displays. The CM also transmits STA and ETA information back to the operational ATC HOST computer in the form of aircraft sequence, scheduled meter fix and outer metering arc crossing times and delay advisories to be presented on the controllers' Planview Displays (PVD).

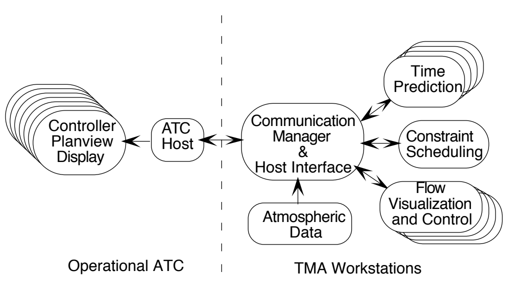

Figure 1. TMA simplified hardware/software diagram

2.1 Time Prediction

The time prediction algorithms are the foundation of TMA. The fundamental basis of the time prediction process are algorithms designed for flight management systems of modern commercial aircraft. The time prediction is separated into two modules: the route analyzer (RA) and trajectory synthesis (TS). The RA generates, based upon user generated site specific adaptation logic and heuristics, a two-dimensional path from the aircraft's current position to its final destination. The complexity of this path is determined via the necessary adaptation. This two-dimensional path is coupled by the TS with the aircraft's current energy state and atmospheric data to calculate a fuel optimal four-dimensional trajectory using aircraft specific mathematical performance models. ETAs are extracted from this trajectory for specific points of interest. The TS trajectories include all modes of flight including ascent, cruise and decent. A complete description of the trajectory synthesis can be found in reference 3 along with prediction accuracy performance measurements in reference 4.

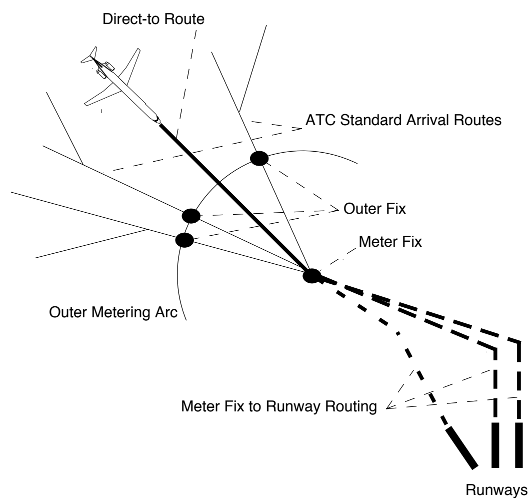

Figure 2. Typical TMA routeing

The typical routing used by the TMA for ETA determination is the one which will generate the earliest time of arrival for a particular aircraft. This routing is referred to as the "direct-to" route. The direct to route extends from the aircraft's current location to the transition fix between the ARTCC and TRACON (meter fix) as shown in figure 2. At the meter fix transitional routes are generated to all eligible runways based upon current airport landing configuration. The figure shows the example of possible TRACON routings for an aircraft landing in a South flow airport configuration from a Northwest meter fix. These transitional routes are also based upon the shortest possible path from the meter fix to the runway. The RA determines these potential routings based upon the adapted airport configuration information. As discussed earlier, the route information is used in the TS to determine the earliest ETA's to the meter fix, an outer metering arc, shown in figure, and all eligible runways. The ETA's for each aircraft are updated with each track or flight plan update. The grouping of the ETA's represents the arrival "demand" on the runways, airport and meter fixes. This demand information is the input required for the constraint based scheduling.

2.2 Constraint Scheduling

The constraint scheduling logic and algorithms necessary for the diverse operational requirements of ATC is beyond the scope of this paper and will only be covered briefly. A complete discussion can be found in references 11 and 12. The functional logic for the scheduling algorithm is a modified first-come-first-serve (FCFS) algorithm. The scheduling constraints used to modify the FCFS schedule are the factors associated with the separation safety requirements specified by FAA regulations. The FCFS algorithm is coupled with delay reduction runway allocation logic and a Center/TRACON delay distribution function (DDF). The scheduling algorithms ensure conflict-free schedules simultaneously at both the meter fix and runway threshold or the final approach fix (FAF) during visual meteorological conditions.

2.2.1 Meter Fix Constraints

Scheduling is accomplished in a multi-step process. First is the generation of an initial schedule to each of the meter fixes. The sequence is determined based upon the earliest ETA to the meter fix. The first aircraft in the sequence is scheduled at its earliest ETA. The next aircraft in sequence is then scheduled to its earliest ETA or the time necessary to ensure in-trail separation constraints are met. The in-trail separation constraints can be specified as any value greater than or equal to the minimum separation standards of 5 miles for similar aircraft types crossing the same meter fix to the same airport destination. Thus an initial meter fix separation based schedule is established for all fixes.

2.2.2 Runway Constraints

Scheduling to ensure required threshold or FAF separation is met is the next major step. The threshold separation requirements are the minimum of the FAA wake vortex standards based on aircraft weight class. The TMC may increase these values due to weather or other significant events. The scheduling algorithm selects the first aircraft from each of the initial meter fix schedules. From this group of aircraft an "order of consideration" (OOC) is generated by using the ETA to the runway threshold. The aircraft with the earliest runway is selected as the first aircraft of the OOC. Then, using the meter fix scheduled time of arrival (STA) and the meter fix to runway transition time, the first aircraft in the OOC is scheduled to the threshold. The next aircraft from that meter fix is added to the order of consideration for possible selection. The next aircraft is scheduled using its meter fix STA, transition time and the specified threshold separation requirements. Once the second and subsequent aircraft are scheduled, threshold separation delay is known. If this delay is greater than the Center/TRACON DDF then the amount greater than the DDF is fed back to the meter fix STA. The modified meter fix STA causes modification to the aircraft's in-trail separation based meter fix schedule. The process is repeated until all aircraft are scheduled.

2.2.3 Flow Rate Constraints

Once these separation based constraints are considered the flow rate constraints are evaluated. The primary flow rate consideration is the Airport Acceptance Rate (AAR). Flow rates can also be placed on a particular runway, meter fix or even the TRACON as a whole. The AAR is normally defined as the rate of aircraft permitted to land at the airport over a specified time period. This flow rate constraint is added because controllers cannot land aircraft at minimum separation for an extended period of time, due to workload and other considerations. Among these considerations that affect the selection of an AAR by a TMC are: airport ground movement or congestion, departure demand, airspace complexity as well as the basic capacity factors discussed earlier. The current scheduled flow rate is computed by a simple algorithm that counts the number of aircraft scheduled to land over an adaptable time interval. This scheduled flow rate is compared with the specified flow rate constraint. If the scheduled flow rate during the specified time interval exceeded the specified rate, the excess aircraft are pushed back into the next time interval.

2.2.4 Runway Allocation

The runway allocation algorithm within the scheduling process is event driven. The events are (1) initial aircraft knowledge as determined by TMA receipt of an estimated or departed flight plan from the ATC computer; (2) a stable track-based ETA is determined; (3) freezing of the schedule prior to transmission to the ATC Host computer for display on the controllers' PVDs. At each of these events the total system delay associated with the particular aircraft scheduled to its current runway is compared with the total system delay if the aircraft was allocated to an alternate runway. The comparison includes any delay incurred in the TRACON due to a longer meter fix to runway routing. The runway allocation algorithms are controlled by TMC heuristics. These heuristics are captured in adaptation parameters that are a function of airport configuration and aircraft type. The parameters are eligible runways, primary, secondary, and in some cases tertiary along with the amount of system delay savings necessary to allocate to an alternate runway. The adaptation can also be used to favor longer TRACON routes if it is beneficial for controller workload due to airspace complexity issues.

2.2.5 Center/TRACON Delay Distribution
The allocation of economically efficient delay between the Center and TRACON for commercial jet transports is discussed in references 11 and 13. The basic premise is that the delay distribution is a function of the uncertainty of the actual meter fix delivery time and fuel burn as a function of altitude. Another key consideration, not discussed in the references, is efficient workload distribution between the Center and TRACON airspace. Delay is directly related to controller workload and the scheduler has a parameter that allows the delay distribution to be set between the Center and TRACON. The effect of the delay distribution is to place enough pressure on the TRACON to maintain a fully utilized final approach course throughout a rush. Typically the TMA DDF is set to maintain a 3 to 4 aircraft final with the TRACON controllers using heading and speed control. The effect of the delay distribution in the Center is to postpone the onset of holding thereby reducing the overall amount of time that holding is required.

3.0 Flow Visualization

The TMC interaction with the TMA's time prediction, schedule and delay information is a graphically based TMA traffic flow visualization user interface. Figure 3 shows a suite of four TMA displays as installed at the Ft. Worth ARTCC. The display formats are the timelines (lower left), load graphs (upper left), planview display (upper right) and linear list (lower right). The display formats are described in detail in reference 12. Each of the displays presents different views of the flow of air traffic in the

Figure 3. TMA display Suite at Ft. Worth ARTCC

arrival airspace. The timelines display the predicted arrival demand, schedule, and delay for each aircraft in an analog format. The format is a series of vertical lines with time reference to the meter fixes and runway threshold. The individual aircraft identification size and track status are displayed juxtaposed to the time-to-go reference. The bottom of the timeline is current time. The load graphs display a running average of the aircraft demand, schedule and delay. The load graphs provide flow information that allow demand size and duration to be determined. The Planview display provides a spatial display of individual aircraft track information. The information is presented over scaleable chart overlays of the Center and TRACON airspace. The final format is a list or tabular presentation of demand, schedule and delay. This format was developed just prior to the operational evaluation and is similar to the existing ASP TMC display with color coding enhancements. Its development was necessary to accommodate the current TMC staff training, familiarity and extensive experience with the ASP format.

4.0 Controller Advisories

TMA generates controller advisories which are transmitted to the operational ATC Host computer. The advisories are displayed superimposed on the sector controller PVD as a list of aircraft designators in a time ordered sequence. The aircraft identifier is displayed adjacent to the scheduled crossing time and

Figure 5. Controller PVD with TMA advisories displayed

delay to be absorbed. These advisories are referenced to both the meter fix and outer metering arc for jet aircraft and only the meter fix for low altitude turbo prop and prop aircraft. Only the advisories relevant to a specific sector are displayed on that controller's PVD. The delays are distributed between the sector controllers working the jet traffic in both high (above 24,000 ft.) and low altitude. The high altitude controller absorbs all but an adapted minimum amount of the center required delay where jet aircraft are most fuel efficient. The delay distributed to low altitude controllers is for both workload distribution and to maintain pressure on the TRACON meter fixes to ensure a volume of aircraft are available in the event that the TRACON determines that capacity can be increased. The low altitude controllers are also required to absorb delays associated with all other traffic.

The advisories are similar to those used currently by ASP with the following exceptions. The advisories are presented to the high altitude controllers in a single time ordered list referenced to the outer metering arc. The outer metering arc is at an adaptable fixed radial distance from the meter fix. The outer metering arc is usually 50 to 60 n.mi from the meter fix. Figure 5 shows the controller advisory presentation to the outer metering arc on a sector PVD. The PVD is for the Northeast corner of the Ft. Worth Center airspace. The advisory list is on the left side of the picture with AAL1557 as the first aircraft in the sequence, currently crossing the outer metering arc. The photo was taken when the Center was not engaged in flow control, thus the negative delays indicate that no controller flow control action is required. This presentation is different from the current ASP advisories which are referenced to outer fixes and presented in multiple lists per arrival sector. Another TMA enhancement is the ability for the controller to swap or change sequence of the aircraft within the list for sector tactical considerations.

5.0 Evaluation Description

TMA's flow visualization elements and its time prediction capabilities were evaluated at the Denver ARTCC and TRACON[15]. The study documented benefits associated with the TMA use as it relates to TMC traffic management decisions. The evaluation conducted at the Ft. Worth ARTCC and DFW TRACON extends the previous research and focuses on the time-based scheduling aspects and controller advisories. A complete description of the evaluation along with its challenges are available in the references 16 and 17. As described in the references, field evaluation of the TMA in an operational ATC facility is opportunistic in nature. There are innumerable independent variables over which the evaluator has little or no control. In response to this fact, a two-phase approach was taken in the evaluation. The first phase was designed as an engineering and suitability evaluation. The two goals were to operate the TMA and present controller advisories during every normal rush period, and then progress towards the use of the TMA throughout each operational shift that required flow control. Systematic data collection was conducted during the second phase of the evaluation.

The first phase of the evaluation was conducted over a three week period followed by a two week second phase. Both phases were conducted during the summer of 1996. The evaluation team conducted operations in the Traffic Management Unit (TMU) and the DFW arrival sectors in all areas of the Ft. Worth ARTCC. The controller advisories were transmitted to 8 to 12 sector PVDs depending on Center configuration and staffing. Human factor observers were stationed in the busy arrival sectors as well as the TMU. Engineering performance and human factors data were collected throughout the evaluation. The evaluation included a total of 39 rushes in which the TMA was used for flow control operations. Prior to and during the evaluation period, engineering performance data were also collected for rush periods when ASP was being used for flow control. This data is referred to as "shadow" data, and was collected without intervention with actual ATC operations.

The TMA is designed to allow flow control schedules for multiple airports, however the evaluation concentrated on the arrivals into the DFW airport, the second busiest airport in the world. The DFW TRACON used a four corner post operation to land at the three primary DFW arrival runways. There were eight rush periods per day when the DFW airport demand required flow control. Since the evaluation, this operation has been modified to a dual arrival fix at each corner post. This modification was made to make more efficient use of the increased DFW capacity enabled by the addition of a new runway.

6.0 Results and Discussion

The TMA operated successfully throughout the entire evaluation period. Because the evaluation was conducted in an operational Air Traffic

Control facility, considerable planning and procedures were necessary to be able to react to a wide range of conditions[16]. Nevertheless, at no time during the evaluation were the backup procedures necessary. The TMA's entire operational envelope was explored during the evaluation period. The TMA's operational envelope went beyond their current ASP flow control system, including periods of dynamic weather-related phenomena, and periods of airport closure and reopening due to the passage of storm fronts. The reason that the TMA can remain operational is that the TMA updates the prediction on every radar track update, whereas the ASP system stops updating if its frozen scheduled arrival time passes current time.

A representative example of a rush period under TMA flow control is shown in figure 6. The plot shows the radar tracks for all arrivals to the DFW airport from 15:43 to 17:20 universal time coordinates (UTC). The plot covers the airspace

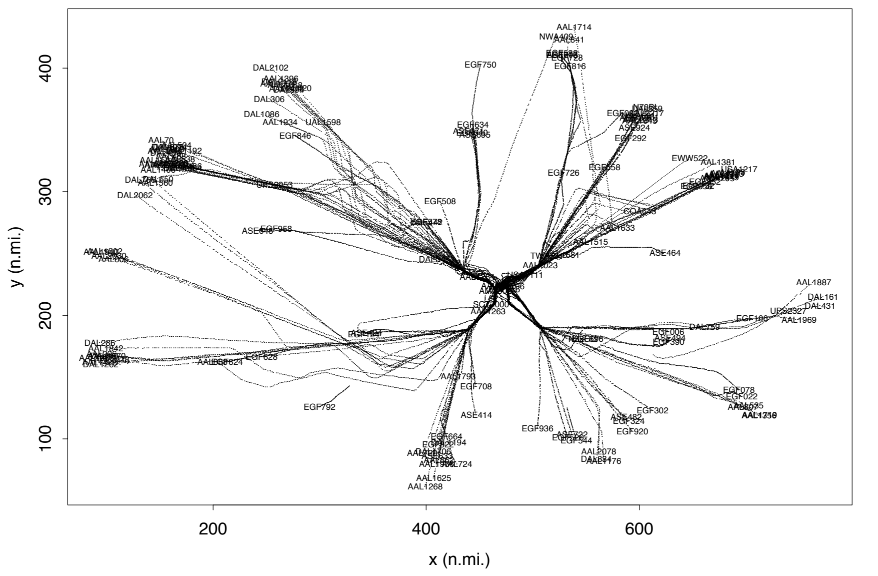

Figure 6. Arrival radar tracks from Ft. Worth ARTCC to DFW airport

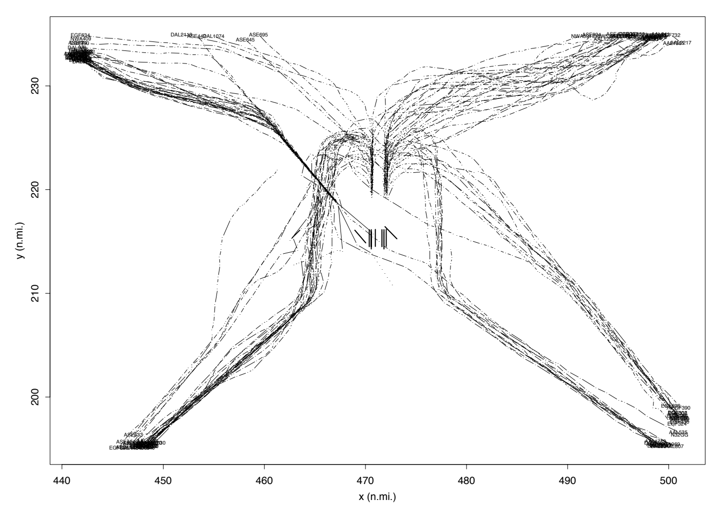

Figure 7. Meter fix to runway aircraft arrival radar tracks

controlled by the Ft. Worth ARTCC (approximately 800 by 500 n.mi.), with the DFW airport at its approximate center. As can be seen in figure 6, aircraft arrive from all directions and merge to the four meter fixes prior to TRACON entry. The figure also illustrates that ATC vectoring is being conducted prior to each meter fix, thus imposing traffic delay. The TRACON portion of figure 6 is expanded in figure 7. Figure 7 shows the tracks from the meter fixes to the runways. The DFW runways are also displayed. The tracks are shown only to the outer marker due to an artifact of the radar data source. As can be seen in fig. 7 the final approach course intercept point is extended to approximately 15 n.mi. during the rush period.

Figure 8 shows individual aircraft delay as a

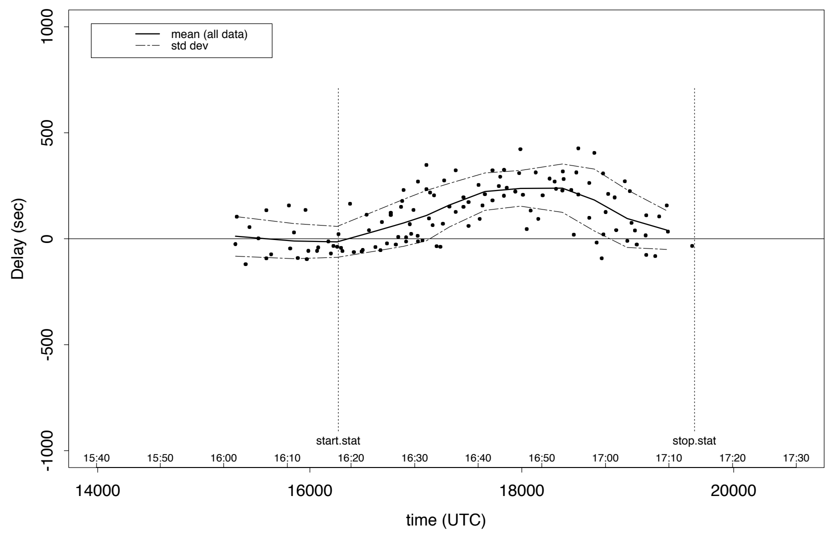

Figure 8. Aircraft delays for the sample rush

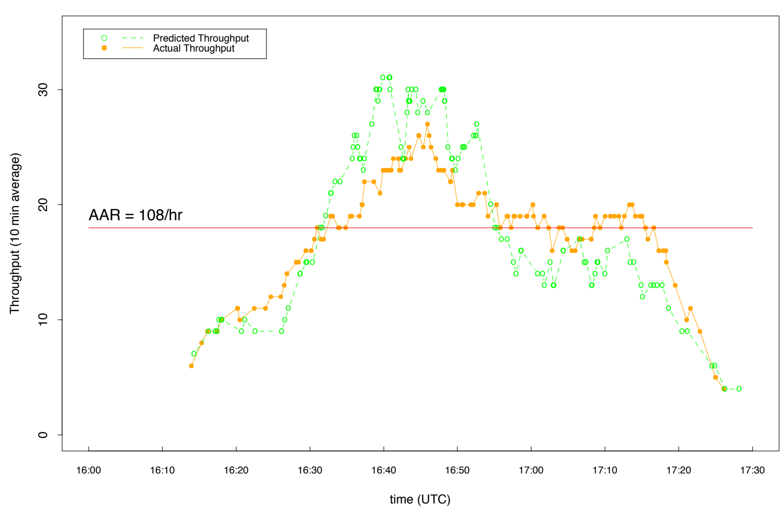

Figure 9. DFW predicted and actual throughput with TMA

function of time. Delay is defined by using the aircraft's earliest ETA to the meter fix at a reference time of 19 minutes from the meter fix (approximately 150 n.mi. from the meter fix). This earliest ETA value is then subtracted from the actual meter fix crossing time to determine delay. The delay for each aircraft is shown. The mean delay for all aircraft and the 1-sigma standard deviation, averaged using a sliding ten minute period, are plotted as a function of time. The start and stop references, determined as the times when the mean delay crosses the zero delay axisThese references are used to determine periods of time when significant delay is imposed on a large number of aircraft for analysis.

The predicted throughput or “demand” of the DFW airport is shown in figure 9. This prediction is based on each aircraft’s ETA to the runway threshold at the 19-minute from the meter fix freeze point. The predicted, or demand, throughput, shown as a dashed line, represents the number of aircraft with predicted arrival times within a 10 min. sliding averaging interval. The demand on the airport shows a characteristic arrival rush. The rush starts with a steady state (pre-rush) demand of approximately ten aircraft per a 10 minute interval (60 aircraft/hour). The rush starts to ramp up from this steady state value at 16:25 to predicted arrival demand of 180 aircraft per hour at 16:38. The desired AAR was specified by the TRACON as 108 aircraft per hour, shown as a reference line on the plot. The solid line is the actual airport throughput or landing rate. Note that for an initial period of time, the actual throughput exceeded the AAR. This is done purposely and is called “front loading.” Since the airport has been operating below the AAR, exceeding the AAR by front loading permits a faster buildup to the actual airport capacity. The front loading period lasts for approximately 15 minutes during which the TRACON is landing aircraft at a rate of approximately 132 aircraft per hour. This front loading period is followed by the steady state landing rate of 108 aircraft per hour for the next 30 minutes. The amount of front loading is controlled by the choice of the Center/TRACON DDF. It is interesting to note that this desired ATC response shows a classic well damped second order dynamic system response to a step function.

As discussed earlier, the TMA was used during the evaluation period for all DFW rush periods to demonstrate its adaptability to a wide range of operational situations. The TMA has been designed to provide an accurate, usable flow control system to support safe and efficient traffic management operations. The system also was being evaluated to determine if benefits were provided when compared to the existing ASP flow control metering system. Because of the resource requirements of the evaluation, it was not possible to collect enough rush periods to make a true statistical comparison for all rushes.

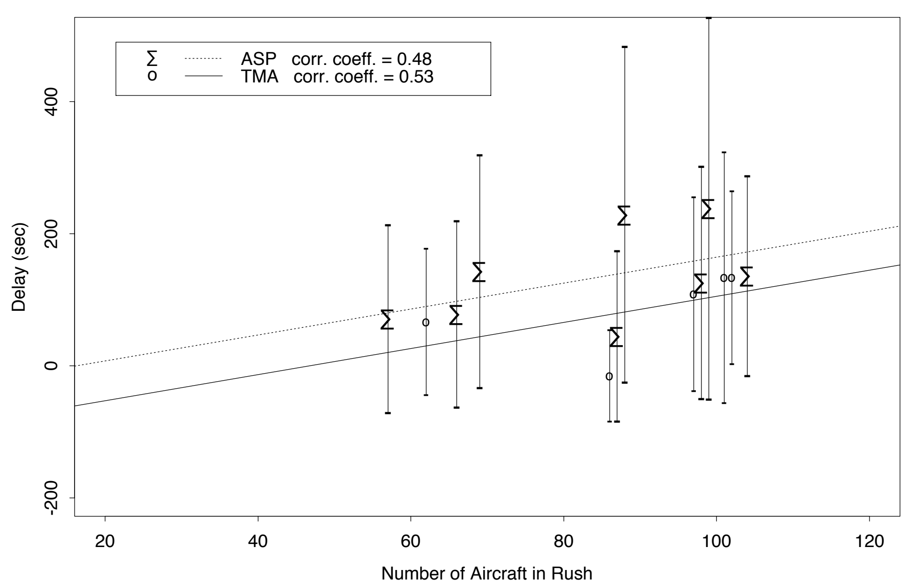

Figure 10. TMA and ASP statistical delay comparison for 11:30 am rush

Therefore the comparison results indicate trends. Shadow data was collected for all rushes. However, due to the complex nature of the ATC environment and the opportunistic nature of field evaluations, the comparison of the TMA and ASP focused on the 11:30 am rush period. This period was chosen because the 11:30 am rush period is one of the more difficult to manage. The rush normally starts with a moderate to heavy demand from the East and light traffic from the West. The demand direction then switches to be very heavy from the West with moderate traffic from the East. This directional shift is one of the more challenging problems for TMCs, and was therefore chosen to stress the TMA for the statistical comparison. During the weeks leading up to the TMA evaluation, comparable data were collected for the 11:30 am rush period when ASP was operational. Figure 10 shows the combination of all the delay data for the 11:30 am rush periods. The data is for rush periods while either the TMA or ASP was being used for ATC flow control. Figure 10 shows the mean delay surrounded by the 1-sigma standard deviation for each 11:30 am rush as a function of the number of aircraft with in the rush. The ASP operational data are represented as a filled circle and the TMA data are shown as an open circle. The delay data are shown as a function of the number of aircraft within a rush. Linear regressions were performed on both the ASP and TMA datapoints resulting in 70 second average delay reduction for the TMA operations. The data also show approximately 30% reduction in the 1-sigma delay distributions. This indicates that the delays were more equitably distributed among the aircraft within the rush while using TMA.

A statistical comparison of the meter fix crossing time accuracy's with TMA and ASP flow control advisories is shown in figure 11. The plot shows the mean difference and 1-sigma standard deviation between the meter fix crossing advisories and the actual aircraft crossing times during the 11:30 am rush periods. The plot shows the crossing times were more precise with the TMA advisories, as demonstrated by the mean error being much closer to zero and the 40% reduction in the 1-sigma standard deviation. The fact that the mean and standard deviation of the error was smaller using the TMA indicates that it significantly improves the controllers ability to meter traffic.

Human factor data were also collected from the controller staff and the TMC users both in the Center and TRACON. The data consisted of questionnaire, observations, and post rush interviews. The detailed results of this data will be published in the future and only highlights are presented. The sector controllers indicated that the TMA considerably reduced the workload associated with metering based flow control. The most significant reasons cited for the workload reduction: 1) the development of a single outer metering arc reference for high altitude jet sectors, 2) more representative aircraft crossing sequences, 3) more accurate and realizable

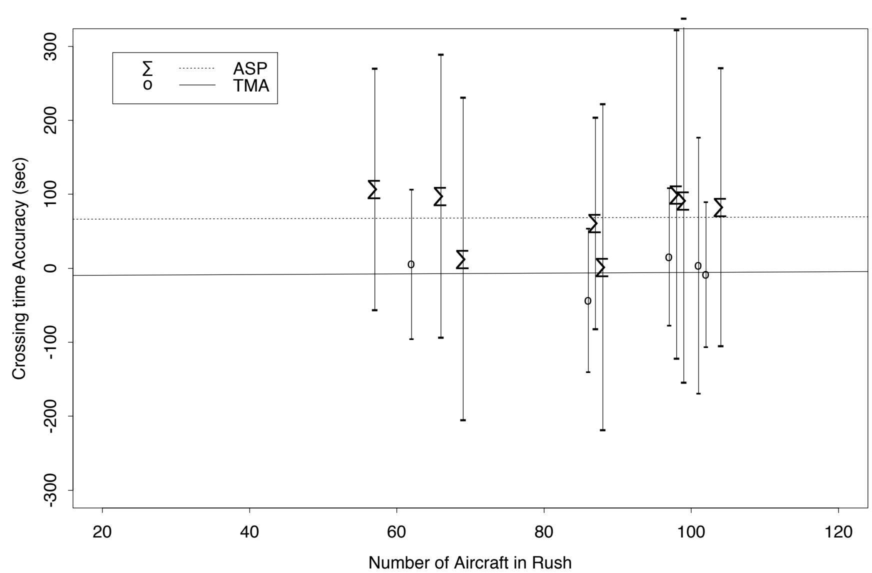

Figure 11. TMA and ASP meter fix crossing accuracy for 11:30 am rush

crossing advisories, 4) the added crossing advisory feedback provided by the delay countdown feature, and 5) the added ability to modify the sequence of the meter list via the controller sequence swap function thus, allowing tactical considerations to be reflected in the advisories. Facility personal also subjectively reported a 2 to 3 min. delay reduction while the TMA was in operation. The difference between the data in figure 9 and this perception was discussed during the post evaluation period when the analysis was shown to the controllers. The controllers indicated that their experience spans thousands of rushes using ASP and that if TMA operational data were collected over a similar number the results in figure 9 would be closer to the 2 to 3 min. delay reduction value. The Center's TMCs reported that the time based information provided by the TMA allowed them to be more aware of the arrival situation within the Center and TRACON airspace, and allowed them to be more proactive in their traffic management activities.

The TRACON TMCs reported that the accuracy and predictability provided by the TMA allowed them to increase the airport acceptance rate by about 5% from an average of 102 to a 108 aircraft per hour. The TRACON TMCs also reported that using TMA for flow control provided a smoother traffic flow into the TRACON. This observation is currently under analysis but, is likely due to two primary factors. First, the amount of delay assigned to be absorbed in the TRACON is directly controllable by a parameter in the scheduler. Second, the TMA uses a controller derived model of the TRACON runway eligibility rules in its scheduling, thus the schedules are closer to actual operations.

The original evaluation plan called for the removal of the TMA at the conclusion of the evaluation period. However, due to the benefits observed during the evaluation period and the positive response from facility personal, the Ft. Worth ARTCC, DFW TRACON, The National Air Traffic Controller Association (NATCA) and the Air Transportation Association requested that the FAA and NASA maintain the TMA in operation at the Ft. Worth ARTCC and DFW TRACON. The FAA and NASA agreed to support the TMA system until the FAA implements a system that is fully supported by the appropriate FAA operational support organizations. This decision has led to significant challenges in system development primarily due to the complete redesign of the Ft. Worth ARTCC and DFW TRACON Airspace. The Airspace was changed to accommodate the opening of a new runway at DFW as well as projected traffic growth. The airspace redesign was completed in October 1996 after 10 years of planning and preparation. This change required the equivalent of adapting the TMA for a completely new Center and TRACON. Since, the TMA software was designed to be highly adaptable, it was operating when the DFW airspace change (a.k.a. DFW Metroplex Plan) was put in place on October 10,1996, and the TMA has been used on a daily basis since.

7.0 Concluding Remarks

TMA, an air traffic control decision support tool that integrates time prediction, ATC constraint based scheduling, flow control visualization and controller advisories has been developed and evaluated extensively at the Ft. Worth ARTCC. The tool generates minimal delay advisories that distribute delay efficiently between Center and TRACON operations. The tool was used to achieve delay reductions of an average of 70 seconds per aircraft when compared with current operations during periods when ATC demand exceeded capacity. The TMA also allowed the TRACON to increase the average airport acceptance rate by 5%. The system was utilized for all periods requiring flow control at Dallas/Ft. Worth Airport, the worlds second busiest including periods of dynamic inclement weather conditions. The system reduced controller workload and increased traffic management coordinators arrival traffic awareness. The tool has been integrated into the daily operations at the Ft. Worth ARTCC and DFW TRACON facilities.

References

1. Erzberger, H.; Davis T. J.; and Green, S. M.: Design of Center-TRACON Automation System. Proceedings of the AGARD Guidance and Control Panel 56th Symposium on Machine Intelligence in Air Traffic Management, Berlin, Germany, 1993.

2. Erzberger, H.; Tobias, L.: A Time-Based Concept for Terminal Area Traffic Management. Proceedings of the 1986 AGARD Conference, No. 410 on Efficient Conduct of Individual Flights and Air Traffic, Brussels, Belgium, 1986.

3. Slattery, R.; Zhao, Y.: En-Route Descent Trajectory Synthesis for Air Traffic Control Automation. American Control Conference, Seattle, WA, June 21-23, 1995.

4. Green, S.; Vivona, R.: Field Evaluation of Descent Advisor Trajectory Prediction Accuracy.

AIAA Guidance Navigation and Control Conference, San Diego, CA, July 29 -31, 1996.

5. Davis, T. J.; Krzeczowski, K. J.; Bergh, C.: The Final Approach Spacing Tool. Proceedings of the 13th IFAC Symposium on Automatic Control in Aerospace, Palo Alto, CA, 1994.

6. Davis, T. J.; Isaacson, D., R.; Robinson, J., E.; den Braven, W.; Lee, K., K.; Sanford, B. S.: Operational Field Test Results of the Passive Final Approach Spacing Tool. 8th IFAC Symposium on Transportation Systems, Chania, Greece, June 1997.

7. Cherone, R.L.; Ostwald, P. A.: Traffic Management Coordinator User's Guide for ESP/ASP. The MITRE Corporation Technical Report MTR-90W00111, Sept. 1990.

8. Sokkapa, B.G.: The Dynamics of Arrival Flow Management. Journal of ATC, June 1987.

9. Synnestvedt, R.G.; Swenson, H.N.; Erzberger, H.: Scheduling logic for Miles-in-Trail Traffic Management. NASA TM 4700, Sept. 1995.

10. Admistrator's Fact Book. Federal Aviation Administration, ABC-100, Feb. 1997.

11. Erzberger, H.: Design Principles and Algorithms for Automated Air Traffic Management. AGARD Lecture Series 200, AGARD-LS-200, Nov. 1995.

12. Wong, G.: The Dynamic Planner. NASA Technical Memorandum.

13. Hunter, G.; et. al.: CTAS Error Sensitivity, Fuel Efficiency, and Throughput Benefits Analysis. Seagull Technology, Inc. 96150-02, Cupertino CA, July 1996.

14. Traffic Management Advisor TMA Procedure Summaries under Solaris Release 5.0.0t. Air Traffic Management Branch, NASA Ames Research Center, Moffett Field, CA., January 31, 1997.

15. Harwood, K.; Sanford, B.: Denver TMA Assessment. NASA Contractor Report 4554, October 1993.

16. Hoang, T.; Swenson, H.N.: The Challenges of Field Testing of the Traffic Management Advisor in an Operational Air Traffic Control Facility. Proceedings of the AIAA Guidance, Navigation and Control Conference, New Orleans LA, August 1997.

17. Nichol,R.: Good Times at Ft. Worth Center. Journal of Air Traffic Control, Oct-Dec 1996.