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OPERATIONAL TEST RESULTS OF THE PASSIVE FINAL APPROACH SPACING TOOL

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Abstract: A prototype decision support tool for terminal area air traffic controllers, referred to as the Final Approach Spacing Tool (FAST), was recently evaluated in operation with live air traffic at the Dallas/Fort Worth, Texas Airport. Controllers utilized FAST's runway and sequence advisories to manage and control arrival traffic during more than twenty-five peak rush traffic periods. This paper presents the results of these tests, describing data on FAST's impact on airport capacity, in-trail separation on final approach, safety, and controller workload. Results demonstrate airport throughput increases of more than 13 percent with no negative impact on controller workload or safety.

Keywords: Air traffic control, decision support systems, automation, human factors.

1. INTRODUCTION

The development of decision support tools for aiding air traffic controllers in managing and controlling air traffic has long been the subject of extensive research. The continued growth of air traffic throughout the world has caused increases in air traffic delays and has put considerable stress on both existing air traffic control (ATC) systems and on the air traffic controllers. Early work in the automation of terminal air traffic control was presented in the late 1960's (Martin and Willet, 1968). Martin and Willet described a system that provided speed and heading advisories to controllers to help increase spacing efficiency on final approach. Although tests of the system showed an increase in landing rate, controllers found that their workload was increased and rejected the system. An examination of the concept suggests that while some aspects of the design were sound, its acceptance was limited by the technology of the time period, especially the lack of an adequate controller interface. More recently, several automation systems have found their way into operational use in Europe due in large part to the introduction of modern computer processing and interfaces, and because of more careful design approaches (Volckers, 1990; Garcia, 1990). While these systems provide significant decision support functions for the overall management of arrival air traffic, they do not contain detailed modeling of complex terminal area arrival procedures and runway operations.

A decision support system for the management and control of terminal area traffic that combines detailed models of aircraft performance, ATC procedures, and controller reasoning, has been under development by the NASA Ames Research Center. The system, referred to as the Center/TRACON Automation System (CTAS) (Erzberger *et al*, 1993), is comprised of the Traffic Management Advisor (TMA), the Descent Advisor (DA) (Green and Vivona, 1996), and the Final Approach Spacing Tool (FAST) (Davis *et al*, 1994, Lee and Davis, 1996). The advisories generated by these tools assist controllers in handling arrival aircraft starting at about 200 n.mi. from the airport and continuing to the final approach fix. These elements of the CTAS system have been evaluated in a series of operational tests during the past year at facilities serving the Denver, Colorado and Dallas/Fort Worth, Texas areas.

This paper focuses on the operational testing of the terminal area portion of CTAS referred to as FAST. The main function of FAST is to provide advisories for landing sequence, landing runway, speed, and heading that assist controllers in managing arrival traffic and achieving an accurately spaced flow of traffic on final approach (Davis *et al*, 1994). The recent operational tests of FAST were limited to the sequence and runway advisory functions. This subset of FAST functionalities is referred to as Passive FAST or P-FAST. The paper will describe the objectives, conduct, and results from the operational tests of P-FAST. These tests, which were conducted at the Dallas/Fort Worth (DFW) International Airport, provided a unique opportunity to test a prototype decision support tool at a major, high volume hub airport at a phase in the development which allows for further refinement before the operational system is specified and built. The tests validated P-FAST as the first-ever advisory tool for TRACON air traffic controllers to be successfully demonstrated in a live operational environment.

2. OPERATIONAL TEST

Over the course of several years of development, more than two thousand hours of real-time, controller-in-the-loop simulations of DFW traffic were conducted with P-FAST at the NASA Ames Research Center. These real-time simulations, along with analytical studies, demonstrated a significant potential for improvements in capacity and controller workload for TRACON air traffic controllers with the introduction of the P-FAST system. Based on these results, it was determined that an operational test of the system was necessary in order to validate these potential savings. Dallas/Fort Worth was chosen by the FAA because of its high capacity, complex airspace, many runway configurations, and high user demands. It was felt by the Federal Aviation Administration (FAA) that if the system could demonstrate benefits while achieving controller acceptance at the second busiest airport in the world, the risk of deployment to other sites would be substantially mitigated.

2.1 Air Traffic Procedures at Dallas/Fort Worth

The DFW TRACON is the fourth busiest terminal area facility in the world, serving the second busiest airport in the world (DFW International Airport) along with several other major airports (e.g. Love Field, Alliance). During 1996, DFW TRACON averaged 3,320 aircraft operations per day. DFW TRACON is responsible for control of arrival, departure, and overflight traffic below 17,000 ft. and within 35 n.mi. of the DFW Airport.

Fig. 1 shows a layout of the nominal DFW TRACON arrival flight paths as well as the runway layout for a South Flow configuration (aircraft landing and departing to the south). Because of the high volume of traffic, DFW Airport has six runways and typically operates with three arrival runways and three departure runways (a fourth arrival runway was added shortly after the tests, in late 1996). As shown in Fig. 1, arrival traffic lands primarily on runways 13R, 18R, and 17L. Departure traffic departs primarily from runways 18L, 17R, and 13L. During certain periods of the day, arrival and departure runways are used interchangeably.

DFW uses a four-corner-post system in which arrivals transition from enroute, or Center, airspace to the TRACON airspace over an arrival meter or feeder fix, approximately 35 n.mi. from the airport. These four feeder fixes are labeled in Fig. 1 as Bridgeport and Blue Ridge to the North and Acton and Scurry to the South.

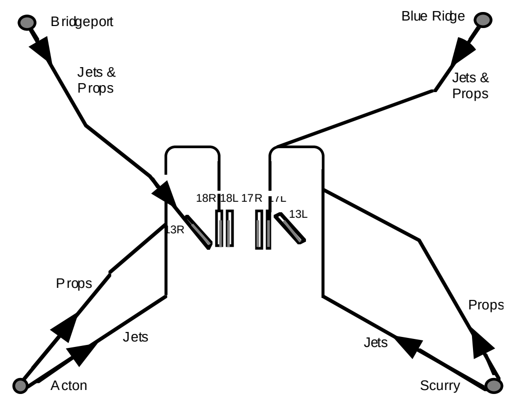

Fig. 1. Dallas/Fort Worth TRACON arrival procedures.

Generally, aircraft will descend and be vectored along the flight paths shown in Fig. 1 to the runways depicted (Bridgeport arrivals to 13R, Blue Ridge and Scurry arrivals to 17L, Acton arrivals to 18R). During low volume traffic periods, controllers will attempt to vector aircraft to the runway closest to their parking terminal. During high volume traffic periods, controllers will attempt to balance the arrival traffic across the three arrival runways by vectoring aircraft to runways not necessarily closest to their arrival feeder fix so as to meet capacity on each runway and therefore maximize capacity for the airport.

2.2 Role of Passive FAST at Dallas/Fort Worth

Controllers from DFW were involved in the definition and development of the entire FAST concept (Lee and Davis, 1996). Through controller involvement, combined with many months of observation of terminal area operations, it was theorized that combining advanced trajectory synthesis technology with detailed models of the controller's reasoning process would allow one to build an accurate, real-time prediction of near-future traffic situations (near-future is defined as 10-20 minutes from the present time). Accurate predictions would then allow a decision support tool such as FAST to advise controllers on a more strategic plan which, if followed, would increase capacity and maintain acceptable workload levels.

Each traffic rush into DFW arrives predominantly from the east or west. Because of the North/South runway directions, a significant issue arises with vectoring traffic to the opposite side of the airport such that all runways are equally utilized. By utilizing all runways on a near-equal basis, the full airport capacity can be realized.

However, because of the volume of traffic and its associated high workload at DFW, the control of the arrival traffic to DFW Airport is split into as many as five sectors; two feeder sectors and three final approach sectors. Controllers working in any of these sectors find it difficult during high volume traffic rushes to have knowledge of traffic load or available landing slots in any other sector not adjacent to their own. As a result, controllers resort to making highly tactical decisions on runways and sequences late in the arrival process, thus adding to the overall workload and decreasing the efficiency of the operation.

The runway advisories in P-FAST, which are displayed to the controller as the aircraft arrives over the feeder fix, provide the data necessary to balance the runways and the workload between controllers at the entry point into the TRACON arrival process. The P-FAST sequence advisories, which are updated and displayed to the controller on a continuous basis from entry into the TRACON until landing, provide the information on how to efficiently merge separate traffic streams and where to build arrival slots for aircraft, not yet seen, arriving from other sectors. With the P-FAST advisories, controllers gain a situational awareness of the entire traffic flow and a strategy for efficiently controlling it. Both the runway and sequence advisories are non-binding and continuously adjust to the actual traffic flow and the controllers' actions including disagreement with the advisories.

2.3 Objective and Conduct of the Test

The objectives of the P-FAST operational tests were to: 1) validate the capacity and throughput benefits of the P-FAST system in a live traffic environment, 2) confirm the controller acceptance observed in real-time simulations of the system, and 3) complete the definition of the functionality of P-FAST for the national operational system.

The DFW facility provided a test team that included members of the FAST System Design Team (SDT) (Lee and Davis, 1996), a controller assessment team, and traffic management personnel. The test team operated the relevant traffic management, supervisory, and controller positions for the majority of the operational test.

The operational tests were conducted intermittently over a period from January through July, 1996. Because only a small group of controllers (the assessment team) was trained to use P-FAST, the tests could only be conducted during periods when the majority of the assessment team was available. Typically, test periods spanned three days during the mid-week and were conducted for two weeks per month. The tests spanned all major arrival rush periods at DFW, included both Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) operations, North and South Flow runway configurations, two and three arrival runway operations, and a variety of inclement weather conditions including severe thunderstorm activity.

3. RESULTS

The air traffic system is highly dynamic and sensitive to a wide range of conditions. The system can change dramatically due to weather, airline schedules, and controller staffing on a daily basis. Because of these dynamics, it is difficult to objectively assess the impact of a system such as P-FAST. This difficulty leads to long searches for matching traffic samples and ultimately a limited set of data with which to compare operations with and without the tool.

This section focuses on several overall aircraft/ATC performance metrics. Following the categorization of performance metrics as described by Den Braven (1995), the metrics cover throughput, safety, and control performance. For throughput, the metrics considered are airport throughput and excess in-trail separation on final approach. For safety, the metric is in-trail separations on final approach. Workload and controller acceptance are the metrics for control performance. In addition to these performance metrics, two engineering metrics are also analyzed: sequence advisory adherence and runway advisory adherence.

It is essential to look at system performance from different, complementary viewpoints, to ensure that an improvement in one area is not negated by a decline in another area. For example, an increase in throughput may result in increased controller workload. Safety, on the other hand, should not be diminished under any circumstance. It is therefore important to remember that while the desired result may be that improvements are demonstrated in all areas, a practical result may well be that some metrics are held constant relative to current operations while others are improved.

The following three subsections on Airport Throughput, In-trail Separation, and Safety will focus on an analysis of the 11:15 am “noon balloon” rush at DFW. The two subsections on Advisory Adherence and Workload and Controller Acceptance present data from the entire test. It should be noted that all rush periods were included in the test matrix during the DFW tests and that results for the other rushes are currently under analysis and will be presented in a later report. This rush was chosen because it is generally considered to be one of the longest, busiest, and most difficult rush periods at DFW, with complex operations beginning as a primarily east arrival rush and shifting to a west arrival rush after approximately thirty minutes. The 11:15 am rush is characterized by high arrival rates, high controller workload, and often results in the use of a fourth inboard runway (normally a departure runway) being opened for arrivals to accommodate the high volume. The results presented here appear to be indicative of the trends seen in the other rush periods at DFW. However, because of the small number of samples for each rush at DFW, due in part to the large number of variables across the various test cases (e.g. four samples with P-FAST for this particular rush), the results presented here can only be considered an indicator of probable trends when the system is installed on a permanent basis.

3.1 Airport Throughput

Airport throughput is a measure of the rate at which aircraft arrive or depart during a specified period of time. Throughput is typically reported as either the rate of arrival or departure aircraft per hour. For the P-FAST tests at DFW, the arrival aircraft throughput is the most relevant measurement since the advisories were intended to improve the arrival traffic flow.

Fig. 2 shows the mean throughput for arrival aircraft during the peak portion of the 11:15 am rushes at DFW. The peak is defined as the period of the rush in which the arrival rate rose and held above 96 aircraft/hour. Short dips in the arrival rate which fall below 96 aircraft/hour are still considered to be in the peak period. A typical rush is generally characterized by a rise from a steady-state arrival rate of 50 aircraft/hour to a peak period lasting 20-40 minutes.

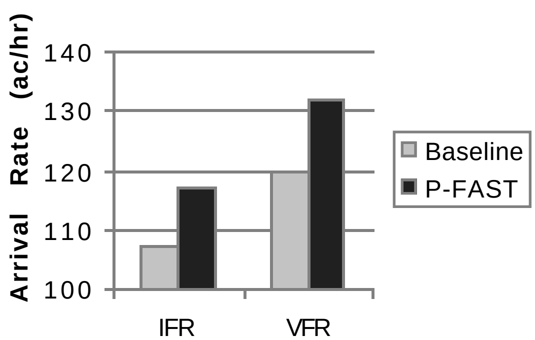

Fig. 2. Comparison of mean airport throughput during peak portion of 11:15 am rushes.

Fig. 2 indicates that the average peak arrival rate rose 10 aircraft/hour from baseline (or 9.3%) during IFR operations with P-FAST and 12 aircraft/hour (or 10%) during VFR operations with P-FAST. In the cases of the VFR rushes, all baseline rushes included inboard runway landings of 3-5 aircraft/hour. Inboard landings are a result of unbalanced runway loads and are needed when the volume of traffic on a runway's final approach course exceeds that runway's capacity. No inboard runway landings were required during any of the P-FAST advised rushes. When the inboard landings are removed from the baseline throughput data (i.e. correcting for the number of runways used), the average peak arrival throughput rises by 16 aircraft/hour (or 13.3%).

Before the operational test, there was some concern that P-FAST might increase surface congestion and departure delay because of the increased throughput. Because of this concern, observers were stationed in the DFW Tower to collect data on tower operations and to obtain feedback from the tower controllers (Crown, 1996). These observations netted several important results. First, a manual count of traffic over entire baseline and P-FAST rushes was conducted which resulted in an observed average increased landing rate of 15 aircraft/hour. Second, the same observations resulted in an observed average increased departure rate of 13 aircraft/hour and an average departure queue backlog reduction of 9% during P-FAST operations. Tower controllers indicated that these improvements were due to the improved runway balancing and the fact that the use of inboard departure runways for arrivals was not necessary during P-FAST operations. Finally, data from one of the major hub operators at DFW collected during baseline and P-FAST operations indicated no increase in taxi-in or taxi-out times despite the increases in arrival and departure traffic rates. These results suggest that the concern over increased surface and departure congestion appears to be negated.

3.2 Excess In-trail Separation

Excess in-trail separation on final approach is a measure of the efficiency of runway utilization. While controllers currently perform the task of in-trail separation well, they provide a buffer of excess separation to account for uncertainties in weather, pilot response, and other factors. Their performance in separating aircraft is a function of the volume of traffic, their own skill, and the complexity of other decisions, such as sequencing and runway assignments, that they must perform at the same time.

In the absence of established visual separation between two aircraft, FAA regulations require that aircraft flying below 18,000 ft. shall be separated in altitude by either 1,000 ft. or that they be horizontally separated by a distance based on their weight class.

Fig. 3 shows a statistical comparison between the baseline and P-FAST excess in-trail separations above the required in-trail separation at the outer marker during the peak arrival periods of the 11:15 am rushes at DFW. The graph shows the mean and standard deviation for both IFR and VFR rushes. The graph shows a decrease in both mean and standard deviation of excess in-trail separation for both IFR and VFR during use of the P-FAST system. For IFR operations, the mean excess in-trail separation is decreased by 0.48 n.mi. during P-FAST operations and the standard deviation is decreased by 0.60 n.mi. For VFR operations, the mean excess in-trail separation is decreased by 0.33 n.mi. during P-FAST operations and the standard deviation is decreased by 0.96 n.mi.

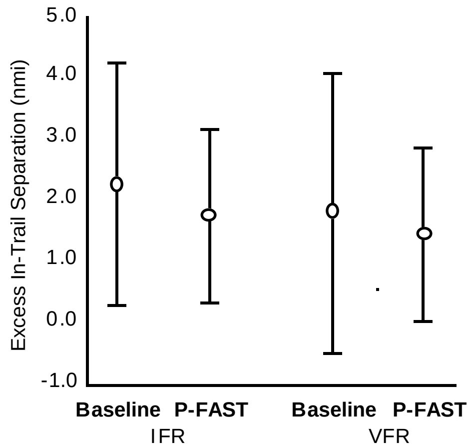

Fig. 3. Comparison of excess in-trail separations at the outer marker during 11:15 am rushes.

This data supports and is consistent with the earlier finding of an increase in airport throughput during P-FAST operations. It is interesting that while P-FAST does not issue advisories that directly affect in-trail separations, there still appears to be such a significant improvement. Controller debriefings indicated a possible reason for this trend: P-FAST advisories give controllers more time to focus on their primary task of separating aircraft. The reasons for this appear to be the improved runway and resulting workload balancing between controllers, as well as a rebalancing of the decision-making tasks, i.e. less time spent on runway and sequencing decisions and more time spent on separating aircraft.

3.3 Safety

During VFR operations, it is legal and a common practice for controllers to permit visual separation between two aircraft as they are intercepting final approach. Once the controller has gained acknowledgment from the pilots, responsibility for maintaining "safe" separation with the other aircraft resides with the pilots. This process allows for a pilot to fly closer to adjacent aircraft with which he/she has visual contact than allowed by the regulations for IFR operations. A primary benefit that results from this practice is an increase in capacity, as seen in the earlier throughput results, due to a reduction in in-trail separations between aircraft.

It is commonly accepted that the current practice of gaining visual separation between aircraft during VFR operations and the resulting reduction below IFR separation standards is safe; in addition, it could be argued that if a system increased throughput, decreased the variation in inter-arrival separation distances, and either maintained or decreased the number of in-trail separations below IFR standards during VFR conditions, the system was providing an enhancement in safety. Note that the standard deviation of the excess in-trail separation presented in Fig. 3 indicates that for the baseline data, there are more aircraft which are being separated below IFR minimums during VFR operations.

Fig. 4 shows the mean total in-trail separations per rush below IFR standards during the peak period of the 11:15 am VFR rushes. Each peak rush period contains 85-95 aircraft. Note that the P-FAST data shows a reduction in in-trail separations below IFR standards by a factor of more than five. This result is representative for that particular rush period at DFW in which visual separation and inboard runway landings are common for the baseline cases. Other rushes at DFW in which inboard landings are not as common do not show as dramatic of a difference. Controllers commented that the increased organization in the traffic flow provided by the runway and sequence advisories in P-FAST more evenly balanced the arrival runways, resulting in more landings without using inboard runways for landing, without increased workload, and with more time to spend on the task of separating aircraft.

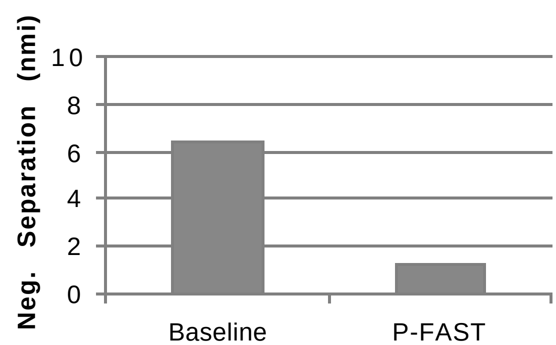

Fig. 4. Mean negative in-trail separation per rush sample at the outer marker during VFR operations.

3.4 Advisory Adherence

An important element in confirming that the P-FAST advisories played a critical role in improving the airport throughput, in-trail separation, and safety is the degree to which the controllers followed the advisories. The system was designed to work with the controllers and to adapt to their actions when they differed from the advised plan. Without the system recognizing and adapting to the controllers' implicit changes, the system would become ineffective.

Fig. 5 shows the percentage of aircraft that were vectored to the P-FAST advised sequence for each runway at the five and ten minute flight time location from the runway. The five minute point corresponds approximately to the point where the downwind and base aircraft are merged. The ten minute point corresponds approximately to the location where the aircraft are turning to the downwind and base legs. In all but one case (runway 17L, ten minutes flight time from the runway) the adherence to the sequence advisories is between 83-93%. Controller disagreement with the sequence advisories was primarily centered in the downwind-base merge area. While this was initially considered to be a high adherence, controller surveys and debriefings indicated that the sequence advisories should be improved to always be above 90% before a permanent installation of the P-FAST system.

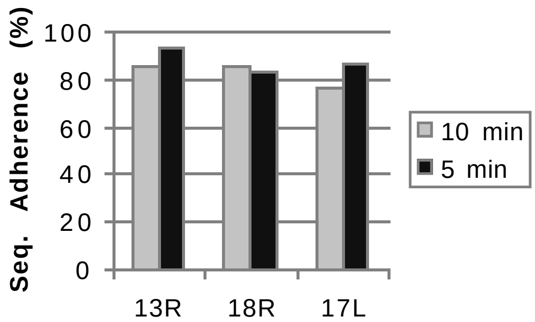

Fig. 5. Adherence to P-FAST sequence advisories.

This result led to a refinement of the sequencing algorithm following the completion of the test. The algorithm was modified to more accurately reflect the controllers' use of altitude and speed differences in determining sequence. Subsequent simulations and shadow observations have shown that the refined sequencing algorithm will have an acceptable sequence adherence of over 95% (Robinson, *et al*, 1997).

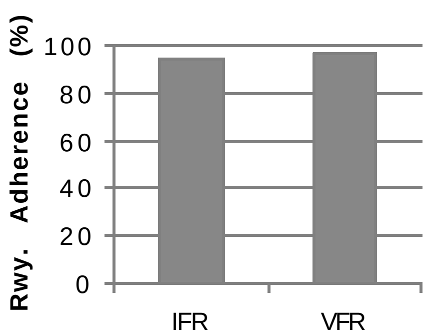

Fig. 6. Adherence to P-FAST runway advisories.

Fig. 6 shows the percentage of aircraft that were vectored to the P-FAST advised runway for IFR and VFR traffic scenarios (Isaacson, *et al*, 1997). Fig. 6 shows a high adherence of 94.8% during IFR operations and 97.1% during VFR operations. Overall, for the entire test, 96.4% of the runway advisories were accepted and utilized by the controllers. Nearly all controller disagreements with the advised runways were related to personal preferences and styles of the various controllers. In some cases, the disagreement related to either a perceived conflict with other aircraft if the advisory was followed while in other cases, disagreement centered on a desire to land aircraft on a runway closest to their parking terminal. In many cases, controllers commented during the debriefing sessions that the advised runway would have been more efficient than the runway that was chosen by the controller. Based on these results, no further modifications of the runway advisory logic are planned.

3.5 Workload and Controller Acceptance

Human factors data was collected to provide a qualitative measure of controller workload that is not available by assessing the engineering data alone. These ratings provide a measure of the benefits of increased throughput and runway balancing from the controllers' perspective. Questionnaires were administered to the controllers following each rush in which the P-FAST advisories were used. Each controller rated workload using a modified NASA Task Load Index (TLX) and acceptance using the Controller Acceptance Rating Scale (Lee & Davis, 1996).

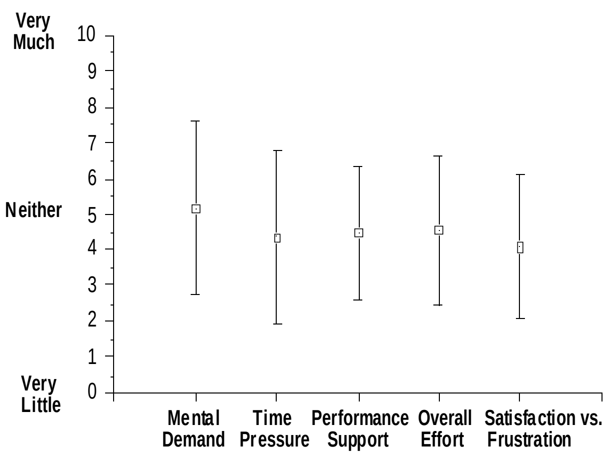

Fig. 7. Modified NASA-TLX workload ratings.

Workload: The modified NASA-TLX scale used to collect workload data included questions regarding mental demand, time pressure, performance support (provided by the P-FAST advisories), overall effort, and the satisfaction vs. frustration experienced. All workload ratings were on a 0 to 10 point scale, with 0 representing the lowest score (lowest workload, most favorable rating) and 10 representing the highest score (highest workload, least favorable rating). Fig. 7 depicts the mean workload ratings. As can be seen from the graph, all of the responses are clustered around the middle of the scale. This data shows that despite the added throughput, the controllers did not experience any significant increase in mental demand, time pressure, or overall effort. P-FAST was not rated as increasing their workload or reducing their job satisfaction. Perceived workload remained at about the level to which controllers have been accustomed.

Controller Acceptance: After each test rush, the controllers provided Controller Acceptance Rating Scale (CARS) ratings to indicate acceptance. The CARS is a scale adopted from, and based upon, the Cooper-Harper Scale for pilot evaluation of aircraft handling qualities (Cooper & Harper, 1969). In addition to changes in content, the CARS is modified from the original Cooper-Harper by reversing the order of the anchors, such that a rating of "1" reflects a lower, more undesirable rating, and a rating of "10" reflects a higher, more desirable rating. The CARS has been consistently used in simulation testing of P-FAST prior to the beginning of the field test (Lee & Davis, 1996).

The mean CARS rating across the entire field test was 7.82 (std dev=1.10). This rating is associated with the numerical rating of 8, with the following description: "System is acceptable and minimal compensation is needed to meet desired performance." Controller debriefings indicated that with the exception of the sequence advisory adherence, the system was acceptable as configured for the tests.

4. CONCLUSIONS

A decision support tool for terminal area air traffic controllers has been developed and successfully tested with live traffic at the Dallas/Fort Worth TRACON. The tool, referred to as the Passive Final Approach Spacing Tool (P-FAST), issues sequence and runway advisories to the controllers on a continuous basis, via the controller's radar display. The operational tests of P-FAST represented the first successful demonstrations of an advisory tool for TRACON controllers. The tests included periods encompassing a wide range of weather, airport configuration, and rush periods.

The P-FAST performed well during the test with the controllers accepting and utilizing over 83% of the sequence advisories and over 96% of the runway advisories. P-FAST supported the controllers in increasing the airport landing rate, or throughput, and decreasing the mean in-trail separation between aircraft on final approach. In addition, P-FAST appears to have provided a safety benefit by decreasing the number of in-trail separations below IFR standards that occurred during VFR operations. Departure rates at the DFW Airport also increased during P-FAST operations due to the more efficient and organized arrival traffic flow.

Controllers provided workload ratings that indicate neither an increase nor decrease in workload with the P-FAST system despite the significantly increased airport throughput. Overall, this was considered a positive result and the controllers rated the system as "acceptable with minimal compensation needed to meet desired performance."

The test results are based on a relatively small sample size for each individual case, however, they do point towards a significant trend of improvement over current operations without P-FAST. Ultimately, the true enhancement that the system will provide will not be fully measured until the system has been installed and operating continuously for several months. The P-FAST is currently being re-adapted for the DFW airspace with an additional runway which was added in October, 1996. The FAA plans to re-install the system at DFW on a permanent basis in mid-1997.

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