3rd USA/Europe Air Traffic Management R&D Seminar Napoli, 13-16 June 2000

The Computerized Analysis of ATC Tracking Data for an Operational Evaluation of CDTI/ADS-B Technology

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Summary

In 1999, the Cargo Airlines Association and the Federal Aviation Administration conducted an operational evaluation (OpEval) of Cockpit Display of Traffic Information (CDTI) and Automatic Dependent Surveillance - Broadcast (ADS-B) technologies at the Airborne Express Airpark in Wilmington, Ohio. This evaluation was designed to demonstrate the benefits of CDTI, including safety, efficiency, and capacity. The evaluation included 13 aircraft of various types and their flight crews.

The aircraft flew multiple flight patterns during the morning and the afternoon of a single day. Each traffic pattern flown by each aircraft was assigned to either the CDTI or baseline (no CDTI) condition. Human factors observers recorded data from the flight decks and the control tower. In addition, air traffic control (ATC) data were recorded by the participating ATC facilities. An important part of the analysis of such a demonstration is the examination of objective flight data. Because of the complexity of the OpEval, new computerized analysis techniques were developed and conducted. This paper describes those techniques in detail, as well as the results of the analysis. Methods such as those described here will be increasingly important as new technologies are developed and evaluated operationally.

Introduction

The availability of new technologies for the cockpit and air traffic control facilities is creating new capabilities for enhanced aircraft operations and, with them, the need to evaluate the effectiveness of these new technologies in operational settings. Two such systems, Cockpit Display of Traffic Information (CDTI) and Automatic Dependent Surveillance - Broadcast (ADS-B), were recently demonstrated in an operational evaluation (OpEval) conducted at the Airborne Express Airpark in Wilmington, Ohio. The OpEval was sponsored by the Cargo Airlines Association (CAA) and the SafeFlight21 Office of the Federal Aviation Administration (FAA), and included aircraft and flight crews from industry, government, and private organizations.

The purpose of the OpEval was to demonstrate the use and expected benefits of CDTI, which consist of increased safety, efficiency, and capacity. Some specific examples of these benefits are: enhanced visual acquisition for “see and avoid,” enhanced visual approaches, and efficient departure and final approach spacing. An important part of this evaluation, from an ATC human factors perspective, was the analysis of objective flight data to quantify and confirm the demonstrated benefits of the new technologies. However, because of the complex nature of the OpEval, innovative field assessment techniques had to be developed and conducted to accomplish that purpose. This paper describes the development of these assessment procedures and the resulting analysis.

Method

The OpEval was conducted on July 10, 1999, at Airborne Express Airpark in Wilmington, Ohio. Thirteen aircraft of different types (primarily B727’s and DC-9’s) were involved in flying multiple traffic patterns using two parallel runways, 22L and 22R (see Figure 1). Flights took place between 0900-1100 hours and between 1300-1600 hours (local time). Each pattern for each aircraft was assigned to either the CDTI or baseline (no CDTI) condition, according to the experimental design. A total of 168 patterns were flown throughout the day. All aircraft were in radio contact with Dayton TRACON and Wilmington Tower. Air traffic controllers from both facilities provided instructions and clearances as needed.

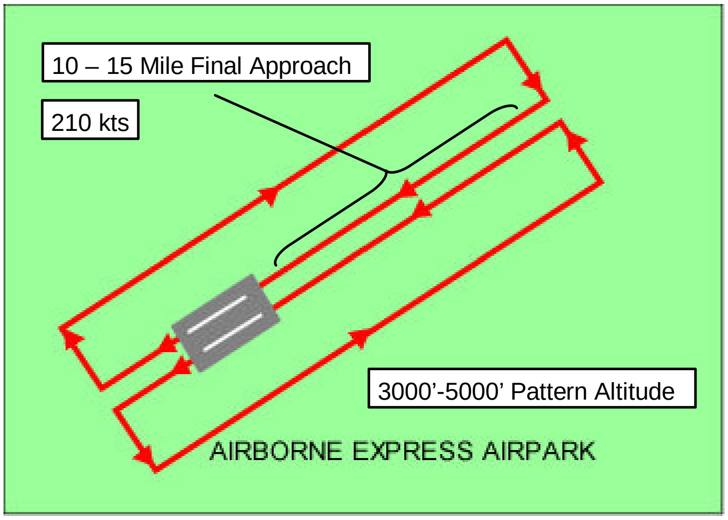

Figure 1. Flight Profiles

Both subjective and objective data were recorded as part of the OpEval. Human factors observers were stationed on the flight decks of participating aircraft and collected various types of data, including crew response times to air traffic control (ATC) communications and crew interaction with CDTI systems. Observers were also present in the Dayton TRACON to assess the effects of CDTI use on subjective controller workload. ATC system data were routinely recorded by the control facilities involved: Radar and voice communication data were recorded by Dayton TRACON, and tower voice communications were recorded by Wilmington Tower. Indianapolis Air Route Traffic Control Center recorded radar data for activities occurring outside the TRACON's airspace. These data were made available to researchers for analysis.

Data Analysis

An important objective of this analysis of ATC data was to develop databases of aircraft locations (as indicated by radar), as well as important characteristics of each traffic pattern flown, such as when events occurred (e.g., crossing the runway threshold on completion of a pattern). These databases were used as input for other analyses, such as the measurement of aircraft pair distances at the time of approach clearances.

Another objective of this analysis was to obtain measures of accuracy and variance for CDTI-based spacing during the stage of flight known as the final approach. Comparison of these measures with those collected during the baseline condition can provide evidence as to the effectiveness of CDTI use. Accomplishing this objective required the identification of discrete spacing events, including specific times and aircraft pairs. Additionally, the distances between aircraft during the events had to be calculated. Achieving both of the analysis objectives, database construction and final approach spacing, required the development of a series of procedures, described in detail below.

Three primary data sources provided the basis for analyses. These included ATC radar system recordings provided by Dayton TRACON, transcripts of all voice communications between the TRACON and participating aircraft (in the form of electronic spreadsheets), and records that indicated under which condition—CDTI or baseline—each aircraft flew on each pattern. Information from these sources was used to accomplish the objectives of the analysis, as described in the steps below.

Step 1: ATC Reduction of Radar Data.

The radar system recordings provided by Dayton TRACON had to be further processed by an FAA National Airspace System software program, "CDR Editor," on an Automated Radar Terminal (ARTS) mainframe computer. Because the volume of data for this analysis was so great, it was not practical to process the data at the Dayton facility. Such processing requires the allocation of significant memory and processing resources on the ARTS computer; because TRACON facility computers continuously process live traffic data, it was not possible to use one of them for such a task. Consequently, the OpEval data were processed by the ARTS computer located at the FAA Academy in Oklahoma City. This system is routinely used for training and instructional purposes.

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TRACKING DATA              7/10/99       PAGE 71500
TIME          ACID         ABC  RBC FRM RALT    X       Y   HDG SPD …
19:56:16.445          255 1200 1200 38 3500 -13.69 -19.19 266 90 …
19:56:16.445          112 1200 1200 19 2400  11.25  46.81 256 57 …
19:56:16.446 FDX9002 143 4515 4515 30 2600  -1.06  -1.25 191 188 …
19:56:16.447 UAL1288  18 1364 1364 38 8600   5.38  17.38 175 294 …
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Figure 2. CDR Editor Output - Tracking Records

The CDR Editor produced approximately 4.3 million lines of textual output, consisting mainly of aircraft position reports and ATC system messages. The output was transferred to a Windows NT-based computer network, upon which subsequent analyses were performed (See Figure 2). The Windows-based computer platform allowed maximum flexibility for researchers to use application software such as spreadsheet and database programs and to develop the customized software (written in Visual Basic) that performed much of the subsequent analysis. The CDR Editor output was also transferred to a Unix-based computer network for use with the Systematic Air Traffic Operations Research Initiative (SATORI) software, designed to utilize TRACON data. (Rogers, 1993).

Step 2: Development of Aircraft Location and Pattern Events Databases.

To perform analyses involving aircraft positions, databases were needed that contained information about the recorded locations of all participating aircraft throughout the OpEval. In addition, a database was needed that defined each pattern flown by each aircraft and the important events within each pattern. Once developed, these databases served as the basis for further analyses, as well as for archival purposes.

Radar Track Records for Relevant Aircraft. To develop the database of aircraft locations, all radar tracking records for the participating aircraft had to be identified. These records were produced each time the ATC radar sweep maked contact with an aircraft. The CDR Editor output data consisted of all TRACON system messages and radar tracking reports recorded from two radar sites (Dayton and Wilmington) during an eight-hour period that encompassed the OpEval. Radar tracking reports comprise several data fields, including time of day, aircraft identification code (ACID), assigned beacon code (ABC), reported beacon code (RBC; reported by the aircraft's transponder), and x,y coordinates, relative to the radar site (see Figure 2).

Software was developed that extracted tracking records for which the ACID matched one of the participating aircraft in the OpEval. However, inspection of the results of this procedure revealed that no records existed for participating aircraft at altitudes below 1500 feet (mean sea level), even though the field elevation at the airpark was approximately 1100 feet. Further examination showed that tracking records *did* exist for aircraft at altitudes below 1500 feet, although the ACID data fields were blank. These records did, however, have values in the ABC field, which could also be used to identify aircraft.

To identify an aircraft by the ABC, it is necessary to know which beacon code had been assigned to that aircraft at the time of the data record. Knowing the specific time is necessary because the beacon code assignment for a particular aircraft can be changed during the day (see Figure 3 for examples of these characteristics of the CDR editor output). Therefore, software was written that scanned the CDR Editor output and determined which beacon codes were assigned to which aircraft at specific times. This was done by sorting the records that had values in the ACID field by time and then determining the periods during which each ACID was assigned to specific beacon codes. Once this was accomplished, other software extracted all records that corresponded to participating aircraft by matching either on ACID or on ABC. This process resulted in a complete database, coded by ACID, of tracking records for all aircraft involved in the OpEval.

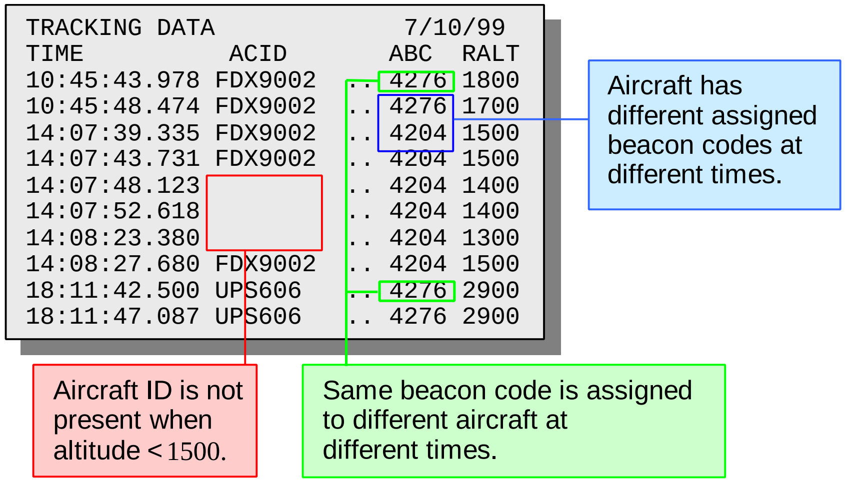

Figure 3. CDR Editor Output – Aircraft Identification

Development of the Pattern Events Database. Many of the analyses planned for the OpEval required the development of a database that described key events and characteristics of each pattern flown. Examples of these include the times the aircraft began and completed the pattern, the pattern altitude, and the experimental condition (CDTI or baseline). The determination of these values was accomplished in a variety of ways as described below. As events and characteristics were identified, the related information was entered into a database either electronically or manually, depending on the method of identification (See Figure 4).

Several events (Departure, Downwind Leg, and Start of Descent) were identified by scanning the altitude profile of each aircraft. To do this, the database of tracking records was sorted by ACID and then by time of day. The beginning of the Departure stage for each pattern was obtained by scanning these records. The end of the Departure stage and the beginning of the Downwind Leg were similarly determined and defined as the point at which the aircraft reached pattern altitude (for that pattern, altitudes were assigned by ATC and were sometimes changed from one pattern to the next). Start of Descent was identified as the point at which the aircraft began descending from pattern altitude.

Approach clearance times were manually extracted from the voice communications transcripts. This was accomplished by searching for keywords such as "cleared," as in the ATC message, "…CLEARED ILS TWO TWO RIGHT APPROACH." Another key event was the time at which the aircraft passed the outer marker. The outer marker is a navigational aid that aircraft typically cross after they have been cleared for runway approach. Outer marker crossing times were determined by software that tracked the aircraft's locations (using x,y coordinates) from the time of the approach clearance to the time it crossed the coordinate location of the outer marker for the appropriate runway. Similarly, runway threshold crossing time was determined by tracking the aircraft from the time of crossing the outer marker to the coordinate location of the threshold of the correct runway. Figure 5 illustrates several of the these events for a hypothetical flight pattern.

<u>Step 3: Identification of Approach Events.</u>

To measure the spacing performance of aircraft during the final approach stage of flights, it was necessary to identify when specific aircraft pairs were both on final approach and lined up with the same runway. These

Pattern	ACID	Runway	Condtn	Dep	Level	Ptrn Alt	Clear	Marker	Threshold	…
1	FDX9001	22L	baseline	13:27:17	13:29:19	4000	13:36:23	13:39:30	13:41:07	…
2	FDX9001	22L	CDTI	13:41:07	13:43:13	4000	13:48:34	13:51:59	13:53:45	…
…										
1	ABX33	22R	CDTI	18:03:58	18:05:34	3000	18:08:57	18:08:59	18:09:04	…
2	ABX33	22R	CDTI	18:12:07	18:13:11	3000	18:18:09	18:20:23	18:22:48	…

Figure 4. Pattern Events Database

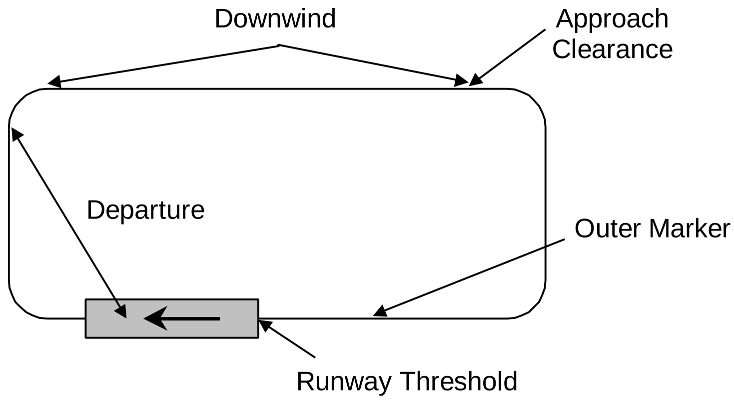

Figure 5. Stages of Flight

periods will be called *approach events.* An approach event was identified for a trailing and leading aircraft pair from the time both were aligned with the same runway until the lead aircraft crossed the runway threshold. (see Figure 6.)

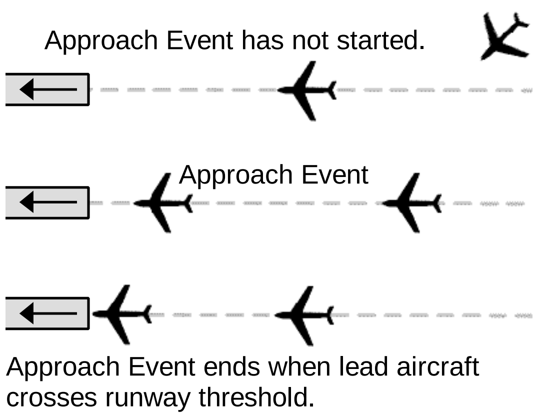

Figure 6. Approach Event Identification.

The identification of the OpEval approach events was accomplished with the use of the TRACON SATORI system. SATORI presents a graphical re-creation of TRACON radar information, including the synchronized replay of voice communications. This system allowed researchers to review aircraft movements and identify approach events. The identity of the aircraft pairs plus the start and end times of each event were then entered into a database for further analyses.

<u>Step 4: Calculation of Aircraft Locations and Distances.</u>

To measure the accuracy of aircraft spacing, the distance between each trailing and lead aircraft during each approach event had to be calculated. Therefore, the coordinate locations of each aircraft at specific times during the event had to be obtained. The radar antenna at the Dayton TRACON sweeps the airspace in a circular direction approximately every five seconds, resulting in a position report for each aircraft each five seconds. Figure 7 illustrates how this tracking procedure results in position reports at different times for different aircraft during an individual sweep. Therefore, direct distance calculations from the tracking records are not possible. To address this situation, software was developed that uses linear interpolation to obtain the coordinate positions of aircraft at specific times. These positions were then used to calculate distances between aircraft during each approach event.

<u>Step 5: Production of Graphical Profiles.</u>

To enable a better understanding of OpEval aircraft dynamics, the TRACON Radar Charting System (TRACS) was developed. TRACS is a software system that allows researchers to view graphical radar profiles of flights that occurred during a specified time interval, such as the OpEval. The program presents the movements of data blocks on a screen. The textual information in the blocks indicate aircraft identity and altitude, and the position of the blocks indicates lateral position. It is also capable of displaying symbols that represent the histories of the movement of the aircraft.

TRACS can also use information from the Pattern Events database to graphically code these histories to indicate the occurrence of key events, such as approach clearances, or to indicate characteristics of individual patterns, such as the experimental condition in effect. In addition, the screen output from TRACS can be printed to provide permanent records of these profiles.

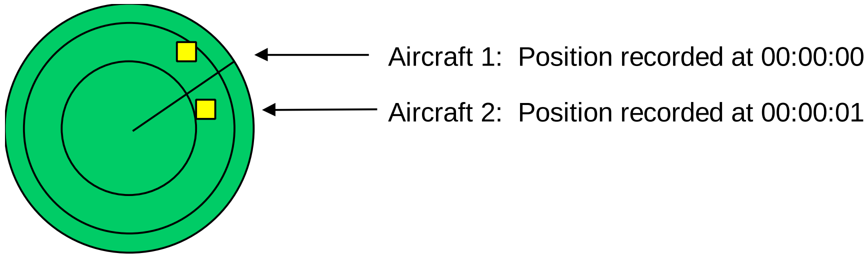

Figure 7. Radar Aircraft Position Recordings

Results

Many of the results derived from the analyses of tracking data are reported and discussed in the OpEval Final Report (Operational Evaluation Coordination Group, in press).

Several results that emerged specifically from the analysis of the tracking data are presented here. A comprehensive review and discussion of the OpEval findings are available in the referenced report. Because of the demonstrational nature of the OpEval, inferential statistical analyses were not conducted on these data. However, analyses involving descriptive statistics may provide some insight into the effects of CDTI use during the OpEval, and are therefore reported below.

Approach Event Occurrence

A total of 88 approach events occurred during the OpEval. Of these, 47 occurred in the morning, and 41 occurred in the afternoon. The duration of the events ranged from a minimum of 22 s to a maximum of 160 s (See Table 1).

Table 1. Approach Event Occurrence and Durations.

Approach Event	Number of Approach Events	Mean Duration of Events (Seconds)
Morning		
Baseline	18	82.9
CDTI	29	81.1
Afternoon		
Baseline	6	72.5
CDTI	35	65.8

Approach Event Spacing

Because of low visibility conditions in the morning, those approaches were flown using instrument landing systems (ILS), as opposed to the afternoon, during which all approaches were visual. Because of this significant difference in flying conditions, spacing measurements are presented separately for morning and afternoon approaches. Table 2 includes means and standard deviations for approach event spacing. Figures 8 and 9 depict the frequency distributions of spacing distances for the baseline and CDTI patterns, flown in the morning and afternoon, respectively.

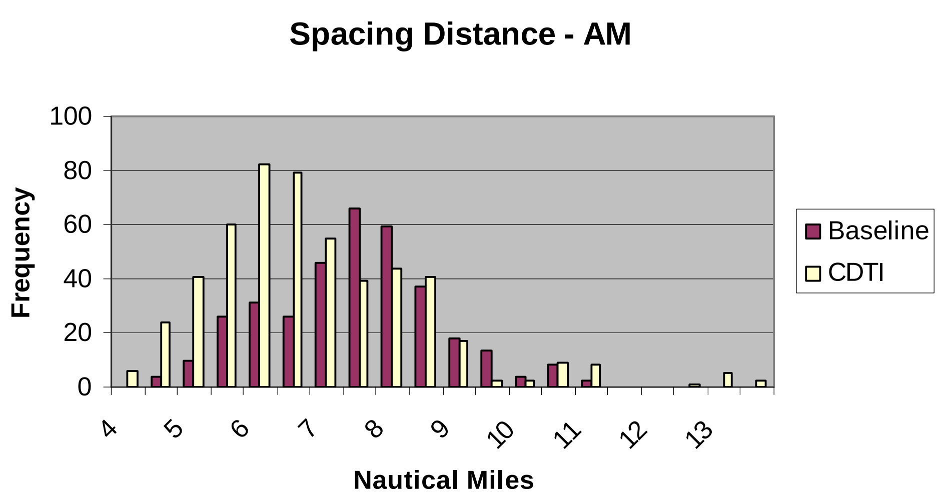

Figure 8. Frequency distribution of spacing measurements for the AM session.

Table 2. Approach Event Spacing.

Approach Event	Mean (nautical miles)	Standard Deviation
Morning		
Baseline	7.3	1.2
CDTI	6.8	1.8
Afternoon		
Baseline	4.6	1.2
CDTI	3.6	1.4

For a number of reasons it is difficult to form conclusions about differences in spacing performance between the baseline and CDTI conditions. The required use of ILS in the morning probably reduced the opportunity for flight crews to use CDTI, especially during the last portion of final approach, when spacing was determined by ATC instructions and the use of the ILS. During the afternoon, comparisons were also problematic because of the small number (6) of baseline approach events, compared with CDTI approach events (35). Nevertheless, the distributions seem to indicate reduced spacing for the CDTI conditions during both morning and afternoon. The smaller spacing distances observed for the afternoon patterns, compared with those in the morning, are expected because crews were able to perform visual approaches.

Graphical Flight Profiles

Figures 10 and 11 depict output samples from the TRACS program. Figure 10 illustrates all morning OpEval flights, coded by baseline or CDTI condition. Each small circle on the display represents a tracked aircraft position. Each larger circle indicates an aircraft's position at the time it was issued an approach clearance by ATC.

Figure 10 reveals that in general, approach clearances were issued for runway 22R (top runway in figure) earlier in the pattern than those issued for runway 22L. It also appears that more aircraft flew in the CDTI condition on runway 22L, and more flew in the baseline condition on runway 22R. Both of these observations are examples of the types of information that could be valuable during the course of data analysis.

Figure 11 represents all afternoon flights, also coded by condition. Comparison of the afternoon flight profiles with those from the morning illustrates an interesting characteristic of the OpEval—that in general, the shapes of patterns flown in the morning conformed more to a "typical" flight pattern, such as that depicted in Figure 5, than did the patterns flown in the afternoon. Afternoon pattern shapes were markedly more variable than those from the morning, perhaps due to differences in ATC instructions associated with visual approaches.

Conclusion

The introduction of new technologies in aviation, such as improved communication, navigation, and surveillance systems, is leading to an evolution of the complex interaction between aircrews and ATC. While these technologies offer significant benefits to users of the aviation system, their applications must be evaluated operationally prior to widespread deployment. Programs such as the demonstration conducted in Wilmington will become increasingly important, as will the analyses of objective flight data from such operations. The evaluation of the large volume of data generated by such complex demonstrations is challenging, but it can be accomplished by combining modern software tools

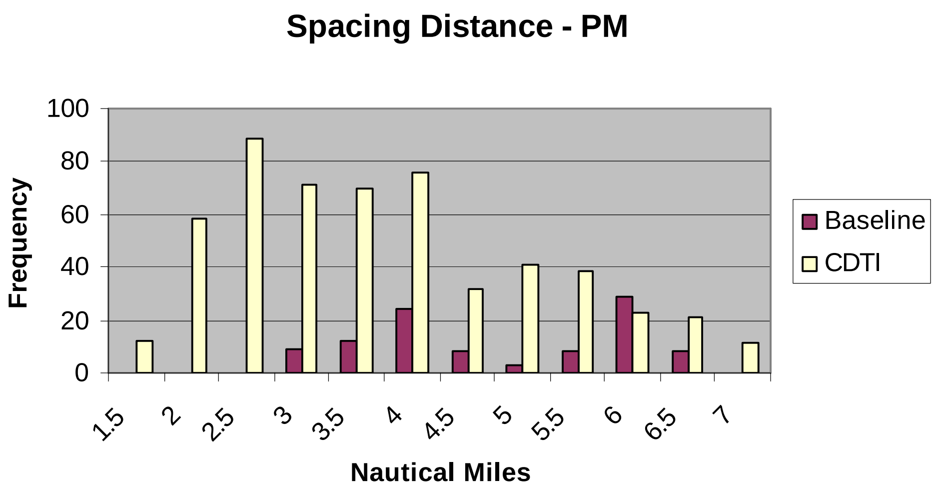

Figure 9. Frequency distribution of spacing measurements for the PM session.

with the development of new procedures and analysis techniques.

References

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Rogers, M. D., & Duke, D. A. (1993). SATORI: Situation Assessment Through Re-creation of Incidents. *The Journal of Air Traffic Control*, 35(4), 10-14.

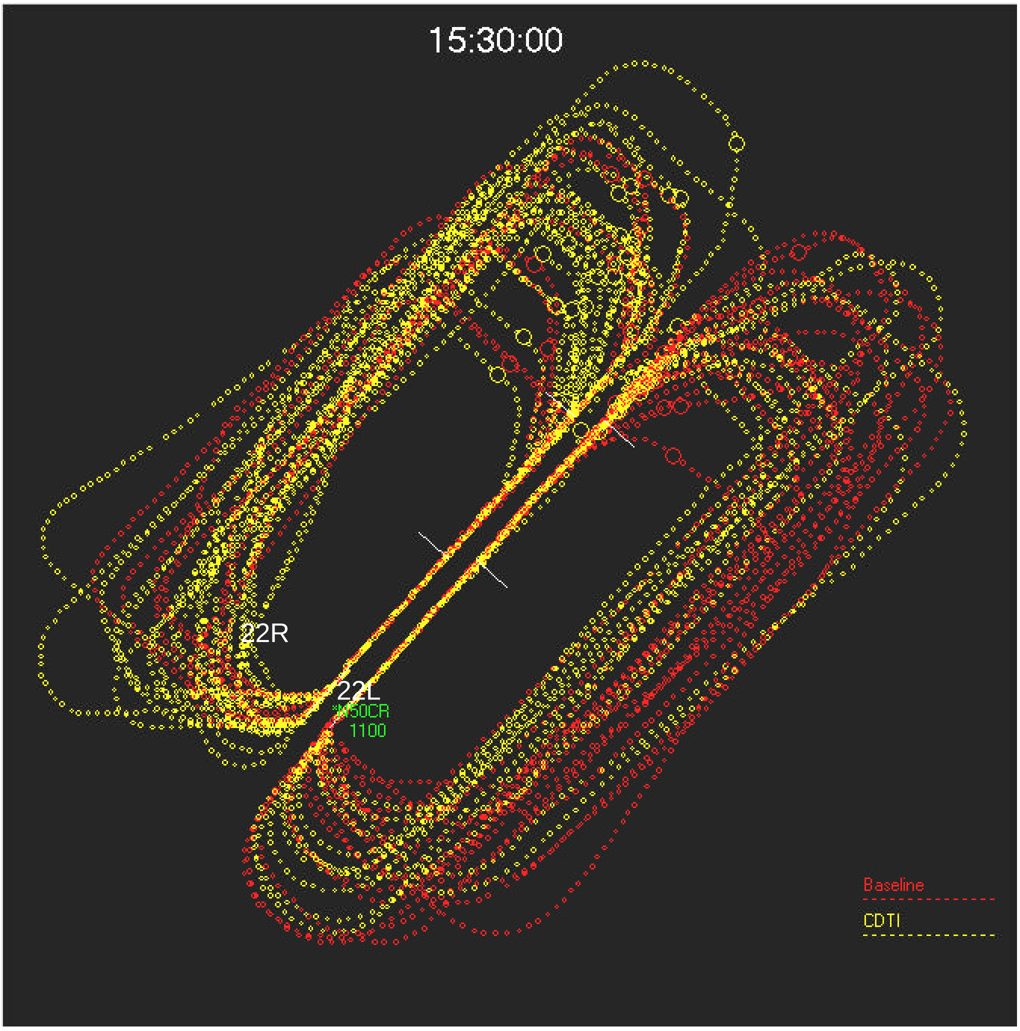

Figure 10. TRACS output – All morning flights.

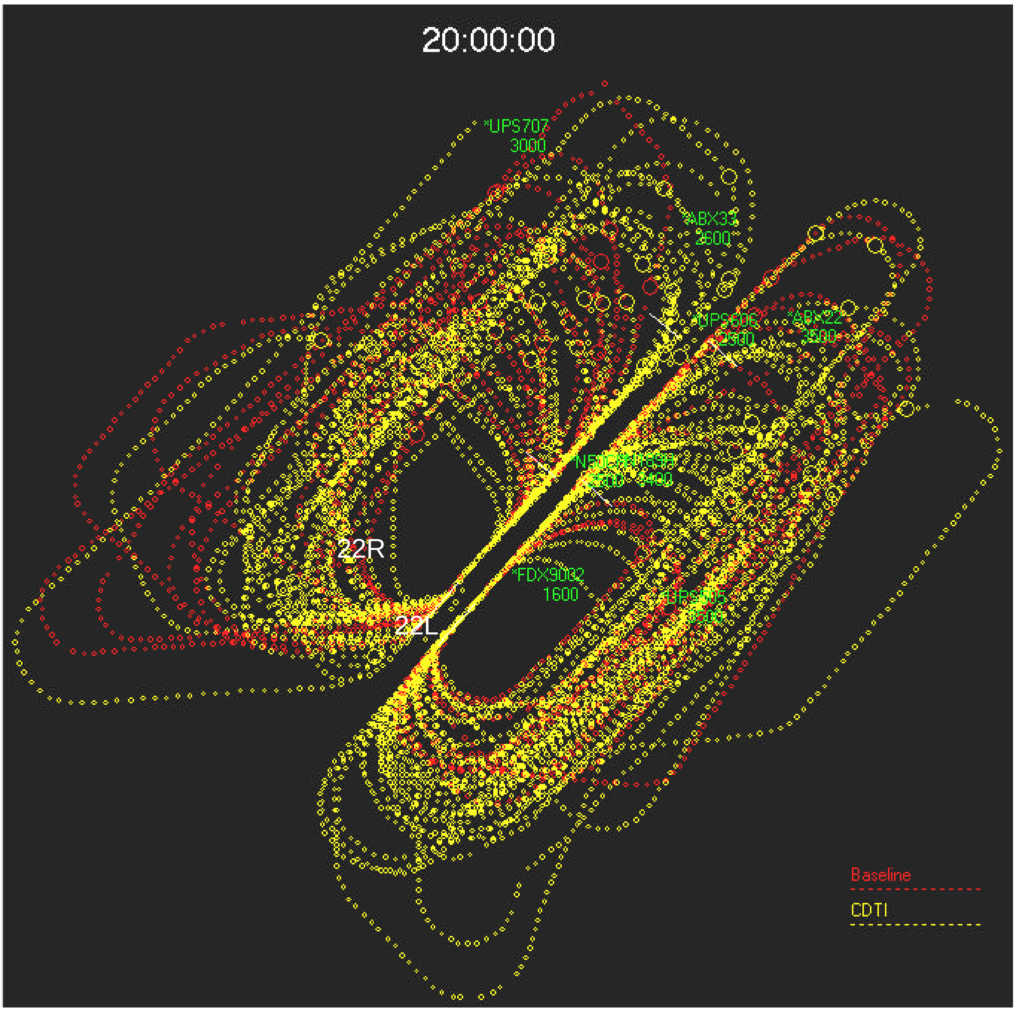

Figure 11. TRACS output – All afternoon flights.

Biographical Notice for Scott Mills

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Scott Mills is an engineering research psychologist in the Human Factors Research Laboratory at the FAA Civil Aeromedical Institute (CAMI), located in Oklahoma City, Oklahoma. He has been with CAMI since 1995. Scott was awarded a Ph.D. in Experimental Psychology from the University of Oklahoma in 1995 with an emphasis in cognitive task performance and workload assessment.

Recently, Scott has been involved in the development and validation of taskload and activity measures of en route air traffic control. He has also been involved in efforts to evaluate and redesign the error/incident reporting system used by U.S. air traffic control facilities.