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Using Data Communications to Manage Tailored Arrivals in the Approach Domain: A Feasibility Study

Ronald S. Chong, Ph.D and Elida C. Smith
Center for Advanced Aviation System Development
The MITRE Corporation
7515 Colshire Drive
McLean, VA USA 22102 -7539
rchong@mitre.org, esmith@mitre.org

***Abstract*—The Tailored Arrivals (TAs) concept proposes routes that are generated by automation on a per-flight basis and communicated to the aircraft via Data Communications (Data Comm). A human factors concern with this concept is whether approach controllers would be able to maintain "the picture" in an operational environment with many types of arrival operations. Another concern is how the presence of Data Comm might affect controller performance in such an environment. To address these concerns, we performed a human in the loop (HITL) simulation study that examined the effect of Operational Condition, Data Comm Equipage Level, and Traffic Load on controller performance metrics that fall into three broad classes: traffic management strategies and decisions, efficiency of service, and safety. We also collected the opinions of Subject Matter Experts (SMEs) regarding the operational feasibility of using Data Comm to manage Tailored Arrivals.**

Keywords—data communications; tailored arrivals; approach domain; TRACON; terminal domain; optimized profile descent; route familiarity; best-equipped, best-served.

I. Introduction

The Federal Aviation Administration's (FAA) Air Traffic Operations Planning Division Concept Development and Validation Group (AJP-66) has developed a multi-step Research Management Plan (RMP) v0.9 for Segment 2 Data Communications (Data Comm) Implementation [1]. The RMP describes various development activities for Data Comm. MITRE Corporation's Center for Advanced Aviation System Development (CAASD) was tasked to perform one of the RMP activities, a study to begin to identify Air Traffic Control (ATC) human factors issues associated with using Data Comm to manage a traffic environment with Tailored Arrivals (TAs). The FAA is committed to increasing the efficiency of today's operations through greater use of optimized vertical and lateral profiles and TAs provide one option for meeting this goal.

The RMP expressed a concern of the controller's ability to maintain "the picture" in an operational environment that included many types of arrival operations, e.g. conventional, Area Navigation (RNAV) Standard Terminal Arrivals (STARs), Optimized Profile Descents (OPDs) on an RNAV STAR, and TAs. Another concern was if and how controller performance would be affected by the presence of Data Comm. To address these concerns, we conducted a human in the loop (HITL) simulation to collect objective and subjective controller performance data [2]. We also performed an assessment of the operational feasibility using Subject Matter Experts (SMEs). The simulation focused on the Terminal Radar Approach Control domain (hereafter referred to as the *approach domain*) where OPDs are often interrupted due to traffic conflicts.

II. Background

A. Tailored Arrivals

TAs [3, 4] are based on a concept of operations, currently under development, that enables some of the largest arrival efficiency benefits. At the time this study was performed[1], the definition of a TA was a route clearance that is tailored, both laterally and vertically, on a per-flight basis, to reduce emissions, fuel consumption, flight time, flight distance, and noise under real-time constraints such as traffic, weather, obstacles, and terrain. It is generated on a per-flight basis by ground-based automation that produces an initially conflict-free route clearance based on the current and anticipated constraints of the airspace environment. The TA route, which begins before top of descent (TOD), combines an OPD arrival and a published approach to define a continuous path to the runway.

Since the TA clearance is requested, issued, and initiated while the aircraft is in the cruise phase of flight, careful inter-facility coordination between en route, approach, and tower domains is required. A TA provides the most system, user and environmental benefits if uninterrupted, but a controller may, at any time, vector or reroute the flight and sacrifice these benefits in order to maintain the safe, orderly, and expeditious flow of traffic.

B. Enabling Technologies for Tailored Arrivals

Several technologies are needed to enable the TA concept. As already mentioned, one is ground-based automation capable of generating the optimized route to the runway. Once a route has been generated, it needs to be communicated to the flight deck. The route can include a large number of waypoints as well as altitude and speed constraints. The voicing and read-back of such a complex route clearance would be a lengthy and error-prone process [5]. Data Comm is an enabler to the TA

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[1] Since the completion of this study, the TA concept has evolved, as a result of concept refinement activities conducted separately and in parallel to this study. The current state of the concept proposes routes with more conservative tailoring than originally envisioned.

concept because it provides a way to quickly and reliably communicate a complex TA route to the aircraft.

Once the route has been uplinked to the aircraft, it needs to be entered into the aircraft's Flight Management System (FMS) in order to be flown. There are two Data Comm configurations; one with and one without FMS integration. FMS integration allows uplinked route clearances to be automatically loaded ("auto-load") into the FMS. Once auto-loaded, the pilot, after confirming its soundness, can select and execute the route for the aircraft to fly the clearance. FMS integration is another enabler since it avoids the timely and error-prone keying in and read-back (if required) of a complex route that would be necessary if it was sent to a non-FMS integrated aircraft. Finally, for the aircraft to physically fly the TA, the aircraft must have RNAV capability which enables it to accurately fly trajectories without reliance on ground-based navigation aids.

C. *Initial Tailored Arrivals (ITAs)*

TA operations cannot be performed today since some of the aforementioned enabling technologies have not yet been developed or deployed. However, since 2004, aspects of the concept have been evaluated at several United States (US) (San Francisco, Los Angeles, and Miami) and international (Melbourne, Australia, and Amsterdam, The Netherlands) sites. These operations, previously called Oceanic Tailored Arrivals, are now called Initial Tailored Arrivals (ITA) and, in the US, have been elevated from limited trials to being in regular use (with participating airlines) in San Francisco and Los Angeles. ITAs therefore represent an interim step between today's arrival operations and the future TA concept.

ITAs are limited to coastal sites and available only to international flights because presently Data Comm service for airborne aircraft exists only in the oceanic domain via the Advanced Technologies and Oceanic Procedures Ocean21™ ATC ground automation system. Also, many aircraft that operate in the oceanic domain are Future Air Navigation System equipped and able to communicate using Data Comm.

Since the ground-based automation needed to generate TA routes is not available, pre-defined (i.e., static) routes are used in ITA operations. A chart of the ITA route is available to both controller and pilot, but the route is not published and is therefore not in the aircraft's FMS database. ITAs must be uplinked to the aircraft via Data Comm and auto-loaded into the FMS in order to be flown. Like TAs, ITAs define a path from TOD to the runway. Once the clearance has been issued, controllers may vector or reroute the flight as needed. See TABLE I for a comparison of STARs, ITAs and TAs.

III. Arrival Route Familiarity

Our hypothesis, which this study investigated, was that controller performance would be affected by their familiarity with the arrival route. ITAs (like published RNAV STARs and conventional arrivals) are routes that controllers can reference using charts. (While ITAs are not published, charts of the routes are provided to controllers and participating airlines.) ITAs therefore have a level of familiarity similar to published routes. TAs, in contrast, are generated by automation on a per-flight basis and may have greater lateral and vertical variability relative to charted routes and to each other. For this reason, we expect TAs will be less familiar to controllers than ITAs and published routes. This lower familiarity could negatively impact their performance. Further, per the ITA/TA concept, the route is generated and the clearance issued before TOD; i.e., in the en route domain. This means that approach controllers would have the least familiarity with TAs and consequently could have their performance impacted the most.

TABLE I Comparison of STARs, ITAs, and TAs

Route Characteristics	STAR	ITA	TA
specifies an arrival path	✓	✓	✓
arrival is an OPD	*possible*	✓	✓
specifies an approach		✓	✓
is a path to the runway		✓	✓
is published	✓		
is predefined		✓	
is generated per aircraft			✓
is in the FMS database	✓		
is uplinked via Data Comm		✓	✓
waypoints may be lat/lon		✓	✓
best update frequency	*months*	*weeks*	*per aircraft*

IV. Experimental Design

A. *Independent Variables*

A within-subjects design was used for this study. Three independent variables were manipulated to create the traffic scenarios used in the simulation. The manipulated variables and their levels are as follows:

Operational Condition: This variable reflects whether scenarios included ITAs or TAs. ITAs were included in the study to facilitate a stepwise comparison of the evolution from the ITA with voice-only environment used today, to ITA with Data Comm of the nearer future, to the final TA concept.

Data Comm Equipage Level: This variable reflects the percent of aircraft that were equipped with Data Comm. Levels were: 0% (voice), low (35%-45%), or high (65%).

Traffic Load: Two traffic load levels ("medium" and "high") were derived based on 80% and 100% of a day in 2009 with the highest hourly Airport Acceptance Rate (AAR) for north arrival operation into Washington Dulles International Airport (IAD). In this airport configuration, the AAR is 100.

TABLE II presents the experimental design based on the independent variables. Six scenarios (A-F) are ITA scenarios while four (G-J) are TA scenarios. The first two ITA scenarios (A, B) are voice-only while the remaining scenarios (C-J) use some level of Data Comm equipage. The scenarios alternate in their level of traffic; medium or high. Each participant performed all ten scenarios using a Latin square design to determine the order of presentation.

TABLE II EXPERIMENTAL DESIGN MATRIX

Scen	Oper Cond		Equipage Level			Traffic Load	
	ITA	TA	voice	low	high	med	high
A	✓		✓			✓	
B	✓		✓				✓
C	✓			✓		✓	
D	✓			✓			✓
E	✓			✓		✓	
F	✓				✓		✓
G		✓		✓		✓	
H		✓		✓			✓
I		✓		✓		✓	
J		✓			✓		✓

B. Controlled Variables

Several variables were held constant across all scenarios. They are as follows:

Airspace and Route Design: The airspace for the approach control position we evaluated was a combination of portions of the BINNS and MULRR positions of the Potomac Consolidated Terminal Radar Approach Control facility (see Figure 1). This position received traffic from New York Center (ZNY) and delivered traffic to a downstream approach control position. In addition to the published STARs already designed for this airspace (see Figure 1), we created three ITA routes (see Figure 2) and six TA routes (see Figure 3). Two of the ITA routes were based on a variation of the published STARs and the third was an overlay of a published STAR. The TA routes were each novel designs in order to reflect the variability of routes that are tailored on a per-flight basis.

Data Comm Type, Message Set, and FMS Integration: The SC-214 message set standard was assumed for all Data Comm aircraft. In all scenarios where there was Data Comm equipage, 60% of Data Comm equipped aircraft were non-integrated and 40% were FMS integrated. Only aircraft with FMS integration were assigned to fly ITAs or TAs.

Mix of Aircraft and Arrival Types: Each scenario contained a mix of aircraft—jets and turboprops—and arrivals—ITAs or TAs (depending on the Operational Condition), RNAV STAR OPDs, RNAV STAR non-OPDs, and conventional arrival operations. TABLE III shows the distribution of arrival types per scenario.

Scenario Events: Six pair-wise separation conflicts (merges and crossings) were scripted into all scenarios. The pairings involved all combinations of arrival types (ITA, TA, RNAV or conventional STAR) and Data Comm Equipage (equipped or voice-only). Although these events were scripted, there was the possibility that some would not occur once the controller started working the traffic.

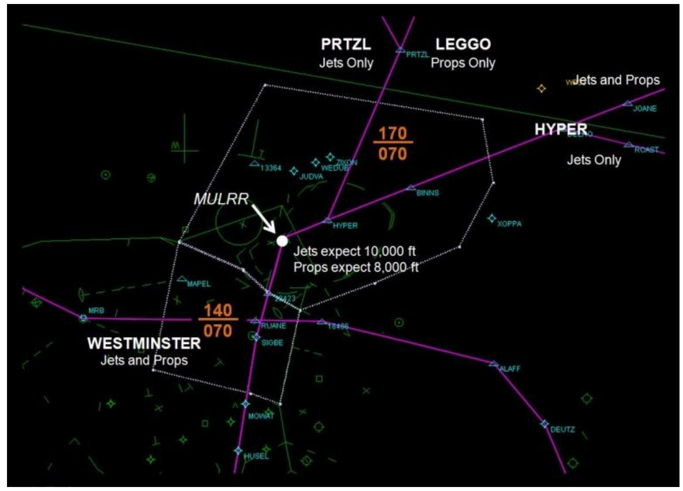

Figure 1 Airspace design and published STARs used in the study

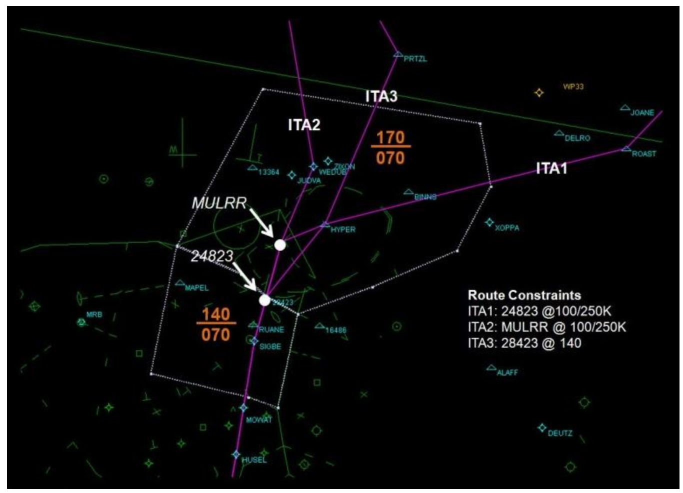

Figure 2 ITAs used in the study

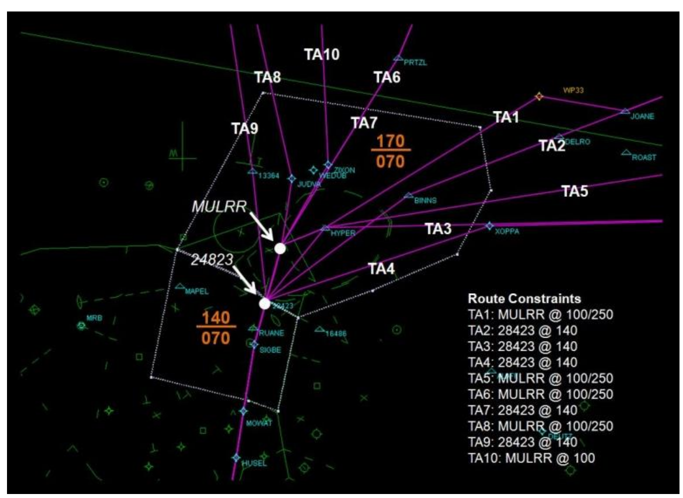

Figure 3 TAs created for the study; only six were used

TABLE III DISTRIBUTION OF ARRIVAL TYPES BY SCENARIO

Scen	STARS	OPDs	ITA	TA
A	19	2	4	
B	22	2	4	
C	21	2	4	
D	22	2	4	
E	20	2	5	
F	24	2	6	
G	21	2		3
H	25	2		3
I	21	2		5
J	20	2		6

C. *Dependent Variables*

We collected metrics of controller performance that fall broadly into three classes: traffic management strategies and decisions, efficiency of service, and safety (see TABLE IV). A subset of these variables will be discussed later in the RESULTS section.

D. *Simulation Configuration*

The simulation environment consisted of an en route airspace sector and two approach control positions. A confederate controller managed the en route sector and delivered traffic to the approach control position managed by a study participant who, in turn, delivered traffic to a downstream approach control position managed by another confederate controller.[2]

E. *Apparatus*

This study was performed in CAASD's Integrated Demonstration and Experimentation for Aeronautics Laboratory. The Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) tool, a powerful airspace and procedure design and simulation application developed by CAASD, was used as the simulation platform. TARGETS also generated a controller radar display that emulates the basic functionality and user interface of the Common Automated Radar Tracking System (CARTS) automation systems. In a TARGETS simulation, voice clearances are executed by a human simulation pilot who enters the clearances into an application that controls the trajectory of simulated aircraft. In this study, clearances sent by Data Comm required no simulation pilot intervention and no read-back was provided. See the Appendix for a brief description of our Data Comm implementation.

The controller workstation consisted of a Barco® two kilopixel (2K) by 2K, 28-inch situation display monitor, a standard PC QWERTY keyboard, a PC mouse, and a hand or foot-actuated headset for voice communication with the simulation pilot. An Applied Science Laboratories Mobile Eye™ head-mounted eye tracker was used to record participant eye movements. At five-minute intervals, an audible tone prompted participants to indicate their subjective workload on a 9” touchscreen monitor The monitor displayed the Air Traffic Workload Input Technique (ATWIT) [6], a seven-point workload rating scale designed for use in ATC studies that requires controllers to rate their workload in real-time while they are controlling traffic.

TABLE IV DEPENDENT VARIABLES

Performance Class	Dependent Variable Class	Dependent Variable
Traffic Management Strategies and Decisions	Use of Voice	use counts
		time on frequency
	Use of Data Comm	use counts
		use time
	Use of Voice to Data Comm Aircraft	% of voice clearances to Data Comm aircraft
	Modality Used to Resolve Scripted Spacing Conflicts	% of Data Comm aircraft where voice was used for separation
	Subjective Workload	raw score
Efficiency of Service	Uninterrupted OPDs	% of interrupted OPDs (RNAV, ITA, and TA)
	Uninterrupted OPDs	% of interrupted ITAs and TAs
	OPD Path Completed	% of OPD path flown uninterrupted
	Vectoring	number issued
		% issued to all OPDs
		% issued to ITAs & TAs
		net miles incurred (all)
		net miles incurred (voice vs Data Comm)
Safety	Separation Violations	number of OEs
	Pre-Conflict Margin	time before loss of separation (all)
		time before loss of separation (ITA vs TA)

Reference materials provided at the participant workstation included: aeronautical charting for all published and pre-defined routes (STARs and ITAs); a table of voice radio frequencies for adjacent airspace positions; and two controller reference lists that provided instructions for managing the traffic at-position and the keystrokes for interacting with the TARGETS-generated radar display.

[2] The term *confederate* refers to someone who is part of the research team and has knowledge of the study objectives. CAASD personnel were used as confederates.

Participants could use TARGET's route display capability. This feature was of particular value during the TA scenarios since the approach controller could use it to view a graphical depiction of the TA's novel lateral path and altitude and speed constraints.

F. Participants

Twelve participants were recruited from within the workforces of the FAA, MITRE, and a government contractor. They met the following criteria: current or retired Front Line Manager or Certified Professional Controller with experience managing traffic using CARTS or Standard Terminal Automation Replacement System (STARS) automation. Their age was mean (M) = 53; standard deviation (SD) = 6 years. The years controlling traffic was M = 21; SD = 8. Eleven participants were retired with M = 6.2; SD = 8.2 years since last controlling traffic. One participant was not retired and reported having last controlled traffic 14 months prior.

G. Procedure

Participants committed 1.5 consecutive workdays to participate in this study. Participants had a half-day of training which consisted of briefings and scenarios. Three customized training scenarios, each 30 minutes in duration, were completed to provided hands-on training on the: simulation environment; Data Comm use and its instantiation in TARGETS; the airspace, arrival procedures and "rules of the position"; managing the various arrival types.

Participants were told that voice communication was always available and that they had discretion over which communication modality they used with Data Comm equipped aircraft. They were also told that there would be no read-back for clearances sent by Data Comm clearances and that aircraft receiving a clearance by Data Comm would comply with the clearance.

Participants were also briefed on the "best-equipped, best-served" policy as described in [7, 8]. This possible future air traffic management policy states that aircraft services are provided to users according to the principle of "best-equipped, best-served" rather than the "first come, first served" principle utilized today. One interpretation of this policy would mandate that best-equipped aircraft receive preferential service. However, the interpretation used in this study was that "a better equipped aircraft may be given priority over a lesser equipped aircraft provided the controller maintains the safe, orderly, and expeditious flow of traffic."

A full day of data collection began on the next workday. Participants were fitted with an eye-tracker, briefed on the ATWIT workload scale and how to use the touchscreen monitor to input their subjective workload rating. They were provided a push-to-talk headset to communicate to the simulation pilot. They completed the third training scenario again as refamiliarization of the concepts learned during training. Data collection then commenced where, at the beginning of each of the ten data collection scenarios, the experimenter briefed the participant on the scenario's Operational Condition (ITA or TA) and whether or not Data Comm was present.

V. RESULTS

For each scenario, air traffic tracks, clearances issued and modality used, voice communications, workload ratings, and eye movements were recorded. Several metrics were extracted from these data sources (see TABLE IV). We performed paired t-tests to identify the statistically significant effects of the independent variables using an alpha of 0.05 for all tests. Four tests were performed on each metric as follows: [3]

Operational Condition: To investigate the effect of Operational Condition (ITA versus TA), we contrasted ITA with Data Comm scenarios (C, D, E, and F) against TA scenarios (G, H, I, and J).

Equipage Levels: To investigate the effect of low and high Data Comm Equipage Levels, we used only high traffic load scenarios, contrasting D against F and H against J.

Traffic Load: Traffic Load effects were investigated using only Data Comm scenarios. For this analysis, we contrasted scenario C against D, and scenario G against H. (The other contrasts—E against, F and I against J—were not possible since these pairs differed on both the Equipage Level and Traffic Load factors.)

Data Comm Present?: We investigated the effect of the presence of Data Comm in the approach domain by contrasting ITA with voice only (scenarios A and B) against ITA with low Data Comm equipage—scenarios C and D. To facilitate this analysis, scenarios A and C were designed to be identical except that scenario C had some Data Comm equipped aircraft. Similarly, scenarios B and D were identical except that scenario D had some Data Comm equipped aircraft.

A. Use of Voice

Figure 4 and Figure 5 show the counts of voice communications and time on frequency. For all graphs, the left and right bars for each factor (e.g., Operational Condition) refer respectively to the levels under the factor (e.g., ITA with Data Comm vs. TA). The error bars depict the standard error.

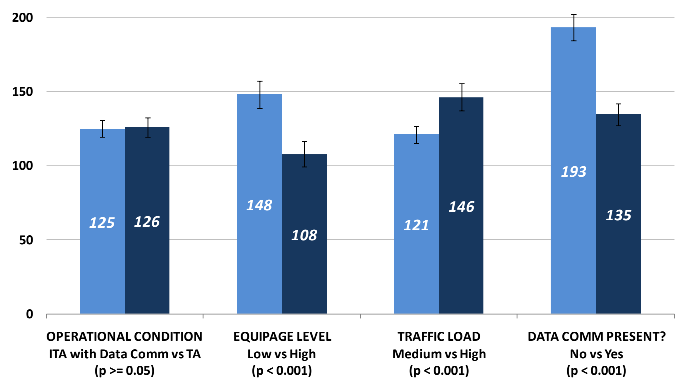

Figure 4 Number of voice communications

[3] Alpha was not adjusted using, for example, a Bonferroni correction. For the reader that wishes to make such corrections, the four tests were applied to each of nineteen dependent variables.

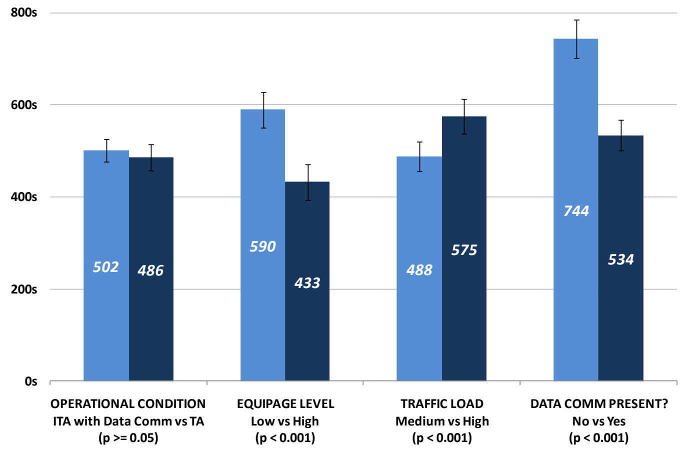

Figure 5 Time on frequency

For the number of voice communications, there was a significant effect of the presence of Data Comm on the number of voice communications, $t(20) = 12.69$, $p < 0.001$, Equipage Level, $t(22) = 4.50$, $p < 0.001$, and Traffic Load, $t(22) = 4.21$, $p < 0.001$. Similarly, for time on frequency, there was a significant effect of the presence of Data Comm on the number of voice communications, $t(20) = 11.25$, $p < 0.001$, Equipage Level, $t(22) = 4.52$, $p < 0.001$, and Traffic Load, $t(22) = 4.03$, $p < 0.001$. These results replicate previous findings that Data Comm reduces the voice communications and time on frequency [9]. This effect is due to the presence of an alternative communication modality and because there was no read-back for Data Comm clearances.

B. *Use of Data Comm*

Figure 6 and Figure 7 show the Data Comm use counts (the number of messages sent using Data Comm) and times (the approximate time the user spent interacting with the Data Comm user interface to issue clearances). As would be expected, both use counts and times were significantly affected by higher Data Comm Equipage Levels, $t(22) = 7.44$, $p < 0.001$ and $t(22) = 4.75$, $p < 0.001$ respectively. There was no effect of Operational Condition.

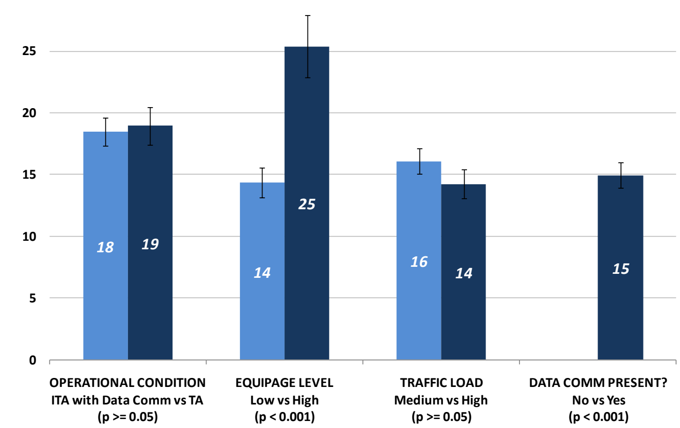

Figure 6 Data Comm use counts

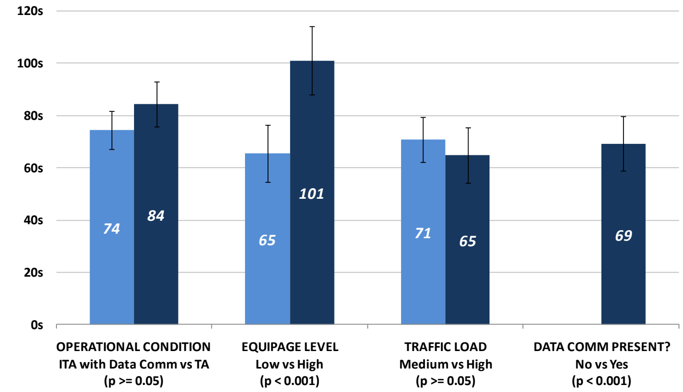

Figure 7 Data Comm Use Times

C. *Subjective Workload*

A significant effect of Operational Condition, $t(39) = 2.09$, $p < 0.05$, was found indicating that TA scenarios were rated as imposing higher workload than ITA scenarios (see Figure 8).

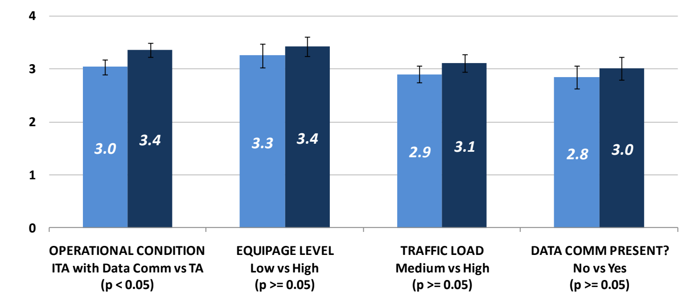

Figure 8 Subjective workload (on a scale of 1 to 7)

D. *Use of Voice to Data Comm Aircraft*

No significant effects were found for the percent of clearances to Data Comm equipped aircraft that were voiced (except, trivially, for Data Comm Present). Half of the clearances to Data Comm aircraft, regardless of manipulation, were sent by voice (see Figure 9).

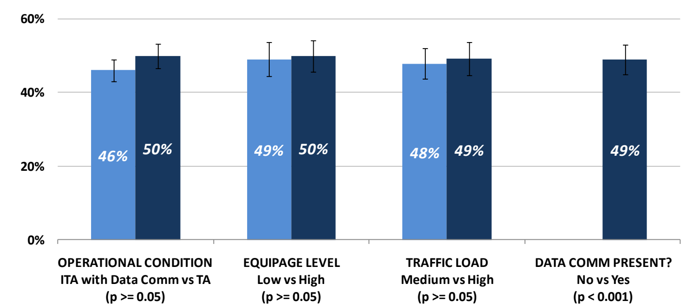

Figure 9 Use of voice to Data Comm aircraft

E. *Modality Used to Resolve Scripted Separation Conflicts*

To see which communication modality was used to separate the scripted conflict pairs, we computed the percent of Data Comm aircraft involved in scripted conflicts that received a first clearance by voice *prior to the time of the scripted* *conflict*.[4] No significant effects were found, except for Data Comm Present (see Figure 10). Regardless of condition, roughly one-third of Data Comm aircraft involved in scripted conflicts received a pre-conflict clearance by voice. The remaining two-thirds were either: sent a pre-conflict clearance by Data Comm; their first clearance (regardless of modality) came after the time of the scripted conflict (i.e., the other aircraft in the conflict pair was moved); or the aircraft was untouched as it traversed the airspace (i.e., it flew an OPD).

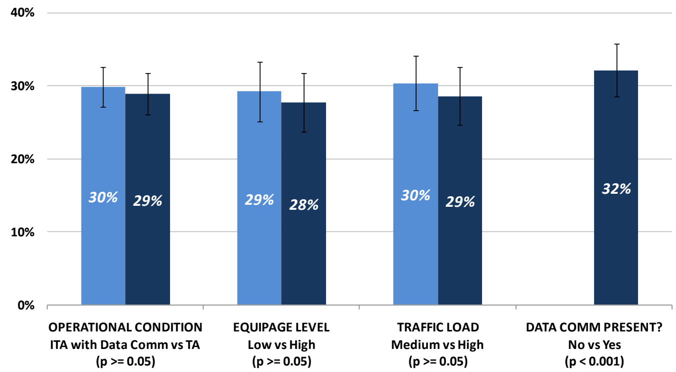

Figure 10 Use of voice to Data Comm aircraft involved in a conflict

F. Pre-Conflict Clearance Time

Continuing to look at controller performance in handling the scripted separation conflicts, we investigated how far from the time of a scripted conflict that the controller issued a clearance to one of the aircraft in the conflict pair. As before, we make the simplifying assumption that this first clearance is for the purpose of separating the conflict pair. As seen in Figure 11, there was a significant (and expected) effect of Traffic Load, $t(23) = 4.18$, $p < 0.001$. There was also a significant effect of Operational Condition, $t(45) = 9.51$, $p < 0.001$. In the TA scenarios, an aircraft in a conflict pair received a first clearance 104 seconds before the time of the scripted conflict whereas a separating clearance was sent more than a minute earlier (at 173 seconds prior) in the ITA with Data Comm scenarios.

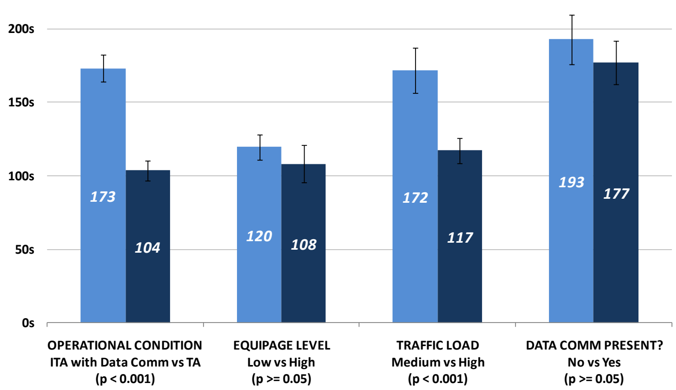

Figure 11 Pre-conflict clearance time

[4] We make the simplifying assumption that the first clearance issued prior to the time of the scripted conflict is for the purpose of separation, recognizing that it is possible the controller didn't recognize the scripted conflict and instead issued, say, a direct-to-fix, simply to seize an opportunity to shorten an aircraft's path or to fill a gap in an arrival stream.

A follow-up analysis was performed that focused on the treatment of ITA and TA *aircraft* themselves. The results, shown in Figure 12, indicates that there was a significant effect of Arrival Type, $t(25) = 2.65$, $p < 0.05$ between the pre-conflict clearance time for ITA and TA aircraft. TA aircraft were allowed to fly roughly fifty (50) seconds longer before receiving a clearance to separate. The finding here suggests an effect on controller performance of route familiarity since this is the only difference between the ITA and TA aircraft. To determine if this was a durable finding, we examined if pre-conflict clearance time changed as a function of the amount of experience participants had with the study. Such an analysis would reveal a learning trend that, if present, would mean that the difference we found between ITA and TA aircraft would diminish, and perhaps disappear, with further experience. No learning trends were found in the data.

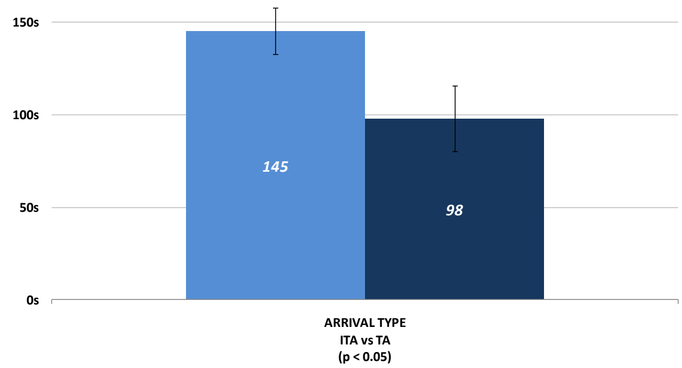

Figure 12 Pre-conflict clearance time for ITA versus TA aircraft

G. Uninterrupted OPDs

Figure 13 shows the percent of uninterrupted OPDs—collectively, the uninterrupted RNAV OPDs, ITAs, and TAs. OPDs are used to increase system, user, and environmental benefits so controllers have an incentive to not intervene on the descent of these flights. We considered an OPD to be interrupted if the aircraft received any clearance affecting its trajectory (e.g., altitude, speed, heading or direct-to-fix clearances). No significant effects were found.

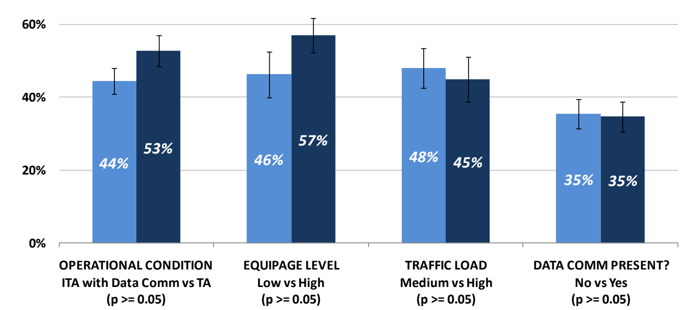

Figure 13 Percent of uninterrupted OPDs

H. Percent of OPD Path Completed

The longer an aircraft can fly an OPD without being interrupted will result in greater user and environmental benefits. Figure 14 shows how much of the OPD path (collectively, the RNAV OPDs, ITAs, and TAs) was flown uninterrupted, calculated as an aggregate of all OPD flights in a scenario. For example, if there are four OPDs in a scenario and each path is 25 miles long through the airspace in question, there is a total OPD path length of 100 miles. If two OPDs were uninterrupted, a third was interrupted at 10 miles, and the fourth removed from the OPD as soon as it arrived in the airspace, the percent completed would be 60% (25mi + 25mi + 10mi + 0mi = 60mi/100mi = 60%).

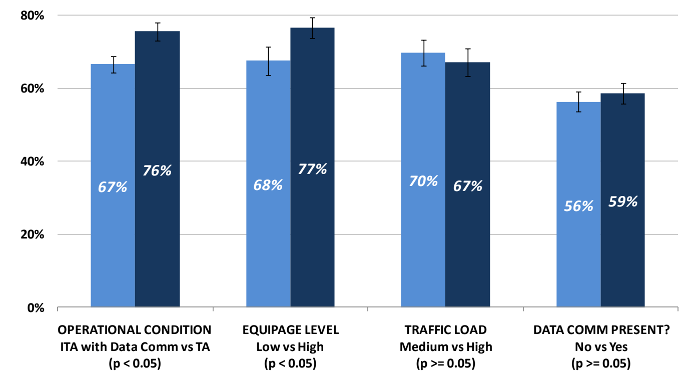

Figure 14 Percent of OPD path completed

There was a significant effect of Operational Condition, $t(45) = 2.62$, $p < 0.05$, and of Equipage Level, $t(22) = 2.28$, $p < 0.05$. Better service was provided under the TA operational condition in comparison to the ITA with Data Comm condition and also when there was a higher number of Data Comm equipped aircraft. We repeated the analysis, this time focusing on OPD type (RNAV OPD, ITA and TA). No significant effect was found (see Figure 15).

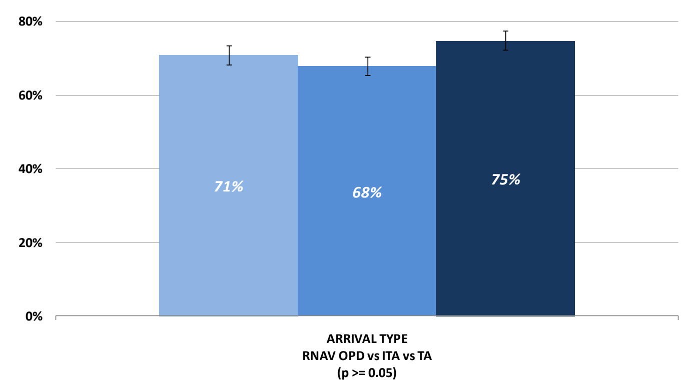

Figure 15 Percent RNAV OPD, ITA and TA path completed

I. *Vectoring*

Figure 16 shows a significant effect on the amount of vectoring—any clearance that takes the aircraft off its lateral path (e.g. headings or direct-to-fixes)—due to Traffic Load, $t(23) = 3.01$, $p < 0.01$. This is an expected finding since increased traffic would tend to increase the need to vector.

There was also a significant effect of Operational Condition, $t(45) = 2.21$, $p < 0.05$, indicating that there was more vectoring in TA scenarios than in the ITA with Data Comm scenarios. This finding begs the question of who was receiving the extra vectoring in the TA scenarios. Was regular traffic being moved in deference to the ITA and/or TA traffic? If so, this might signify controllers adopted (rather than it being mandated) a best-equipped, best-served management policy. Using only the ITA with Data Comm and TA scenarios, we tallied the percentage of vectors sent to ITA and TA aircraft. We found a significant effect of Operational Condition, $t(45) = 2.34$, $p < 0.05$, indicating that TA aircraft received less vectoring than ITA aircraft (see Figure 17).

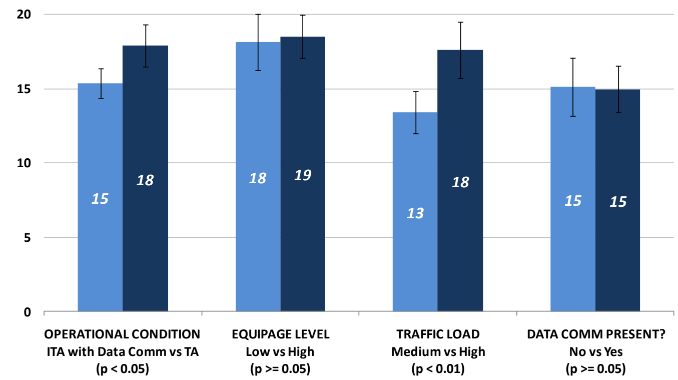

Figure 16 Vectors: Number issued

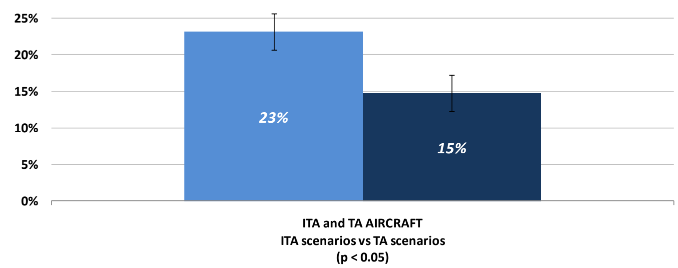

Figure 17 Vectors: Percent issued to ITA vs TA aircraft

This result shows that in scenarios with TA aircraft compared to those with ITA aircraft, more vectors were given and those extra vectors were given to non-TA aircraft. This suggests that controllers were attempting to leave TA flights untouched and instead move the less well equipped aircraft. This appears to be a best-equipped, best-served effect: controllers, knowing that TAs are generated by automation, initially conflict-free and include an OPD, all for the sake of system and user benefits, may have been motivated to leave them untouched and instead move less well-equipped aircraft.

VI. Assessment of Operational Feasibility

One of the purposes of performing this simulation was to produce a controller-centric assessment of the operational feasibility of using Data Comm to manage traffic with TA operations in the approach domain. We performed this assessment using input from seven MITRE ATC SMEs; four were participants in the study and three were advisors for the airspace and traffic design used in the study. We provided them with an early draft of our analysis for their review. We convened a meeting to present the results and then asked them to make an assessment of the operational feasibility, based on their subjective experience and the objective results.

Concerning the use of Data Comm for approach control, the SME group immediately felt it was very well suited for feeder and departure positions. After some discussion, they came to the consensus that Data Comm could also be helpful for a busy final position by allowing multi-modal communications at a phase of flight where voice frequency congestion can be a problem. Routine acknowledgements of initial check-ins and initial speed controls could be provided by Data Comm while time-critical tactical transmissions to other aircraft (e.g., turns to final) could be issued by voice. The final controller could also use Data Comm to automatically transfer aircraft to the tower frequency, further reducing voice frequency congestion.

The SME group's opinion on the arrivals concepts depended on arrival type. For ITA operations exclusively, they felt that these were operationally feasible principally because the paths, constraints, and merge points with published routes are known a priori. As noted by one SME, an ITA, when viewed from the position (i.e., ignoring the fact that an ITA defines a path to the runway) is no different than an OPD flown along a published RNAV STAR.

Their opinion concerning the feasibility of TA operations, however, was quite different. There was a recognition and concern that, in principle, TA routes could merge at any point with published arrival routes and this variability and hence uncertainty would impose cognitive loading on controllers. The cognitive loading is compounded by the uncertainty of the vertical profile inherent in the OPD aspect of a TA. Consequently, they felt it would be imperative to have decision support tools, such as conformance monitoring, conflict probe, or merging and spacing tools so that they could allow the TAs to fly uninterrupted and hence gain the system and user benefits promised by the concept. This would be especially true when the complexity of the airspace and/or the traffic is greater than those experienced in our study.

The SMEs identified a situation where TAs and Data Comm would together help maintain system capacity and lower controller workload. When a disruptive event occurs, such as a closed arrival fix due to weather, the Center often bears the brunt of the workload by having to re-route and sequence traffic. The lateral variability of TAs can provide the Center with greater flexibility for delivering traffic to the approach domain. Provided the approach domain is not saturated and has decision support tools to efficiently manage this traffic, TAs and Data Comm together can, for these situations, ease workload and maintain system capacity.

VII. Conclusions

To address the question of the operational feasibility of using Data Comm in the approach domain to manage TA, we performed a HITL simulation to examine the impact of Operational Condition, Data Comm Equipage Level and Traffic Load on controller performance. The SMEs, providing an assessment of the operational feasibility in this operational environment, felt that while ITAs were operationally feasible and manageable with the automation systems represented in our study, they strongly felt that TAs, as simulated in our study, would not be at all feasible in the approach domain without decision support tools. They also felt that Data Comm could be effectively utilized in all approach domain positions provided that voice communication remained available for situations where immediate communication between controller and pilot was needed.

This study showed that providing an on-screen depiction of the TA's lateral path and altitude and speed was adequate to manage TAs, albeit not efficiently. To realize the full system and user benefits promised by the TA concept, decision support tools would be required, as noted by the SMEs.

We hypothesized that there would be effects on controller performance of route familiarity. We found a subjective effect on workload where TA scenarios were rated as more difficult than ITA with Data Comm scenarios. In term of objective performance, we found only one case that we believe could be a route familiarity effect: ITA aircraft received a separating clearance 148 seconds before the scripted conflict whereas TA aircraft received a separating clearance 98 seconds prior. While a statistically significant finding, it remains to be determined if this difference is operationally significant. If it is found to be so, one must keep in mind that this study was performed using a simulation of today's approach domain automation. Before a final conclusion could be drawn, a follow-up study would be needed that provided the kinds of decision support tools recommended by our SMEs.

Our results replicated the finding that the use of Data Comm reduces number of voice communications and time on frequency. We also showed that adding Data Comm services in the approach domain had no effect on the other metrics. This result is plausible since Data Comm was a complementary modality and controllers reported using it when it was safe or appropriate to do so.

Finally, the number of ITA flights into the United States at present is on the order of four to twelve flights per site per day. A question, unanswered thus far in the development and evaluation of ITAs, is would there be traffic management issues at higher ITA participation levels and a more diverse mix of aircraft and arrival types in a voice-only environment. The ITA with voice-only condition in this study represented the voice-only approach domain that ITAs are flown in today. Each scenario had four ITA aircraft in a 30-minute scenario, a rate of 192 ITA arrivals per day. Our results provide a positive indication that ITAs, with greater participation than observed today, may be manageable in a voice-only environment using currently available automation.

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Author Biography

Ronald S. Chong, Ph.D. is a Lead Human Factor Engineer at CAASD. He has worked on the evaluation of future operational concepts and related human factors issues. He has a B.S. and M.S. in Computer Engineering from Wright State University, and a Ph.D. in Computer Science and Engineering (with a focus on Artificial Intelligence and Cognitive Psychology) from the University of Michigan.

Elida C. Smith is a Project Team Manager of the Arrival/Departure Airspace Concepts and Simulation group at CAASD. She has worked primarily on the development and evaluation of future air traffic control concepts of operation and on addressing human factors issues related to the implementation of new procedures and ground automation tools. She has a B.S. in Aerospace Engineering from Texas A & M University, and an M.S. in Human Factors Engineering from Tufts University.

Appendix

Our Data Comm implementation adopted the functionality and Graphical User Interface design found in the Future En Route Workstation (FEWS) and Future Terminal Workstation (FTWS) [10, 11] being developed at the FAA's RDHFL. The data block has a *Data Comm Availability and Type* icon in the upper right corner which, if present, indicates that an aircraft is Data Comm equipped; see Figure 18[5]. The fields of the datablock are clickable and are the primary method for initiating a Data Comm uplink. To send an altitude clearance, the user clicks the altitude line of the datablock of the aircraft to receive the clearance. As shown in Figure 18, a "flyout" menu will appear next to the datablock. The controller selects the altitude and clicks SEND. Similar flyouts are available for speed and lateral (heading or direct-to-fix) clearances.

Figure 18 Data Comm altitude flyout activated by clicking the altitude field

Data Comm promises many benefits including a reduction in congestion of the voice frequency, as well as the potential to interact with multiple aircraft at once. There are trade-offs, however, with the foremost being the response latency. Responses to voice clearances occur almost immediately after they are issued. Data Comm, however, has the concept of *transaction time*: the time from when the controller clicks the "SEND" button to uplink a Data Comm message to the time when the controller receives a response from the pilot. Data Comm transaction time consists of *infrastructure* and *pilot reaction* time. Infrastructure time refers to the communications system processing time needed for the message to reach its destination. Once an uplinked message has arrived and been displayed in the cockpit, the pilot reaction time component comes into play. From the perspective of the approach controller, the Data Comm transaction time can be a significant source of uncertainty and workload.

In this study, we simulated a Data Comm infrastructure time of five (5) seconds and estimated pilot reaction time to be five (5) seconds for altitude, speed, and heading clearances and twenty (20) seconds for direct-to clearances. All Data Comm clearances received a "WILCO" response. Our implementation supported hand-offs, transfer of communications, check-ins, as well as the following SC-214 messages: UM23 (Descend to [level]); UM74 (Proceed Direct to [position]); UM113 (Reduce Speed to [speed]); UM117 (Contact [unitname] [frequency]); UM190 (Fly Heading [degrees]); DM0 (WILCO).

NOTICE

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[5] A triangle indicates the Data Comm equipment in the aircraft is not integrated with the FMS. A rectangle indicates the Data Comm equipment in the aircraft is integrated with the FMS.