Laboratory Evaluation of Dynamic Routing of Air Traffic in an En Route Arrival Metering Environment

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Arrival air traffic operations in the presence of convective weather are subject to uncertainty in aircraft routing and subsequently in flight trajectory predictability. Current management of arrival operations in weather-impacted airspace results in significant flight delay and suspension of arrival metering operations. The Dynamic Routing for Arrivals in Weather (DRAW) concept provides flight route amendment advisories to Traffic Management Coordinators to mitigate the impacts of weather forecast uncertainty. DRAW provides both weather conflict and schedule information for proposed route amendments, allowing air traffic managers to simultaneously evaluate weather avoidance routing and potential schedule and delay impacts. The effectiveness of the Dynamic Routing for Arrivals in Weather tool was evaluated in a Human-in-the-Loop of study at the National Aeronautics and Space Administration Ames Research Center. Subject matter experts consisting of retired traffic management coordinators and retired air traffic controllers with arrival metering experience participated in a simulation study of Fort Worth Air Route Traffic Control Center arrival operations. Data were collected for Traffic Management Coordinator and Sector Controller participants over three weeks of simulation activities in October, 2017. Analysis of route amendment advisory timing characteristics, participant workload, metering performance and weather avoidance data is being conducted. Results of this analysis are pending: sample analyses are provided.

I. Introduction

Recent advances in air traffic operations and decision support allow for more efficient air traffic operations than previously observed.[1,2] Increased flight path predictability resulting from use of RNAV and RNP procedures enables more strategic air traffic management and control. However, to date, the procedures and technologies developed to help controllers and flight crews fully utilize the precision navigational capabilities of modern aircraft are not available for use when convective weather impacts planned flight routes. Arrival flows are nominally planned along known published routes, but deviations from planned routes for convective weather are often required. These deviations generally take two forms: strategic, flow-based solutions coordinated between all impacted air traffic facilities through the Air Traffic Control System Command Center (ATCSCC), and tactical deviations initiated by either the flight crew or (less often) air traffic controllers to avoid weather in the near future (i.e., <15 minutes to weather conflict).

Coordinated strategic solutions can be viewed as a temporary redefinition of the nominal routes for a given air traffic flow. Strategies for rerouting aircraft flows around common weather patterns are included in the ATCSCC National Severe Weather Playbook. Such one-size-fits-all solutions are generally effective in avoiding weather conflicts, but often introduce significantly longer flight paths and higher delays. Tactical deviations are sometimes still necessary due to the inherent uncertainties in the weather forecasts (e.g., 4-hr TFM Convective Forecast) used to select routing strategies (plays) from the Severe Weather Playbook. Due to this uncertainty, strategic solutions to weather avoidance are often applied conservatively (e.g., larger deviaitons than necessary to avoid the weather, or for a longer duration than necessary).

Tactical weather avoidance avoids the pitfalls of overly conservative strategic solutions at the expense of risking acute impacts such as flight deviations, excessive controller and/or flight crew workload, holding patterns or unplanned airspace closures. While tactical weather deviations are ultimately necessary to some extent due to weather forecast uncertainty, they reduce the predictability of flight trajectories and the ability to coordinate movement of multiple flights. As such, even if tactical weather avoidance had no adverse safety or flight efficiency impact, routine tactical weather avoidance would preclude the use of the aforementioned operational advances that rely on flight path predictability. Termination of arrival metering operations when convective weather impacts Standard Terminal Arrival Routes (STARs) is standard operating procedure today for this reason.

Weather forecast uncertainty will continue to impact air traffic operations for the foreseeale future. Thus, if the operational advancements currently being deployed within the U.S. National Airspace System (NAS) are to be available in the presence of convective weather, solutions are required that enable more resposive weather avoidance routing while maintaining the required fligt path predictability. The remainder of this document is organized to first present the reader with an understanding of the prior research and the need for the integration of dynamic weather routing and time-based flow management capabilities (Section II). Section III provides an overview of the capability developed to fill this need and a summary of an initial evaluation of this concept. With an understanding of the potential utility of the integrated weather avoidance capability, the reader is next presented with the experimental methodolgy employed to evaluate the proposed decision support tool (Section IV). Preliminary results of the experiment are provided in Section V along with discussion of their relevance to and impact on future research and development activities. Lastly, concluding remarks are presented in Section VI.

II. Background

This section provides a brief overview of the research that preceded the development of Dynamic Routing for Arrivals in Weather (DRAW) and was central to the concept of integrated dynamic weather routing and time-based metering. Two areas of prior research are presented: (1) Dynamic weather avoidance routing, and (2) Time-Based Flow Management (TBFM)

A. Dynamic Weather Avoidance Routing

Massachusetts Institute of Technology Lincoln Laboratory (MITLL) research led to the development of the Convective Weather Avoidance Model (CWAM). Using weather Corridor

Integrated Weather System (CIWS) forecasts and emprical observations of pilot weather avoidance behavior, CWAM provides a probabilistic model of convective weather regions flight crews are likely to avoid, called Weather Avoidance Fields (WAFs). CWAM WAFs are used by the MITLL Route Availability and Planning Tool (RAPT) and the Arrival Route Status and Impact (ARSI) concept to predict route availability in the presence of weather for static, published departure and arrival routing, respectively.[3,4] Krozel, et. al., proposed a dynamic programming approach to finding available routing that used simulated Markov chain propagation of convective weather. This concept was tested in simulation for controller and pilot acceptability, but the performance of the weather propagation algorithm and subsequent avoidance efficacy was not evaluated.[5]

NASA developed the Dynamic Weather Routes (DWR) tool to provide Airline Operations Centers (AOCs) and flight dispatchers with more efficient departure and en route routing. DWR uses forecast CWAM WAFs and predicted flight trajectories to generate more efficient, weather-conflict-free routes for departures and overflights. DWR does not address arrival flight weather avoidance, nor is does it consider ATC/ATM implications of proposed route changes.[9-11]

A. Time-Based Flow Management

The Traffic Management Advisor (TMA) was developed by NASA in collaboration with the FAA and currently forms the basis for time-based metering of arrival air traffic into congested Terminal Radar Approach Control (TRACON) facilities. Air Route Traffic Control Center (ARTCC, or Center) controllers employ TMA-provided delay values for each flight to efficiently meet a schedule of arrivals into terminal airspace that complies with necessary arrival constaints (e.g., airport arrival rates). Recent efforts have built on the TMA foundation to improve the efficiency and predictability of arrival operations.

While the TMA provides effective arrival metering for legacy air traffic operations, it does not provide any information to TRACON controllers for implementation. TMA was developed prior to the more recent roll out of arrival procedures requiring Performance Based Navigation (PBN) capabilities. Thus, TRACON controllers need to make tactical adjustments to flight paths between the metering fix and the approach to separate and space arrival aircraft: heading vectors, step-down descents and speed assignments. PBN arrival procedures are intended to provide significant improvements in predictability and efficiency maintaining a prescribed aircraft route and efficient descent profile from the cruise phase of flight to final approach; speed adjustments are the preferred method for spacing and separating arrival flights in PBN operations. The Terminal Sequencing and Spacing (TSS) concept enhances the TMA scheduler to account for the limited control authorty of speed adjustments along PBN procedures and additionally provides tools for controllers to effectively space aircraft along PBN routes using predominantly speed adjustments. The TSS has been evaluated in hundreds of hours of high-fidelity laboratory simulations, refined through limited operational trials and is to be included in the FAA Time-Based Flow Management deployment over the next few years.[1,2]

TBD-Future TBFM (extended metering, coupled metering, Optimized Route Capability (ORC))[7,8]

III. DRAW Concept

A. Overview

The Dynamic Routes for Arrivals in Weather (DRAW) system is based on the foundation of the DWR concept and shares a number of the DWR components. Both DRAW and DWR provide trajectory-based routing solutions to avoid WAFs (currently provided by CWAM forecasts). While DWR was developed to provide weather avoidance routing to AOC personnel, DRAW is designed to integrate weather avoidance routing and time-based flow management, and thus employed by air traffic personnel in the ARTCC Traffic Management Unit (TMU). The integration of weather avoidance routing and arrival metering is seen as a necessary step to enabling TBFM in weather-impacted airspace. DRAW meets this need by providing weather avoidance routing that is more responsive than playbook operations and results in more predictable flight trajectories than tactical weather avoidance. The following sections provide a brief overview of the core DRAW elements. Reference XXX provides a more detailed description of the DRAW concept.

DRAW is an advisory-based system that proposes route amendments to Traffic Management Coordinators (TMCs) in the ARTCC TMU. Proposed route amendments take two forms: more efficient routing to an alternate arrival metering fix, and adjustments for weather avoidance on the currently assigned arrival route. Figure 1 depicts an alternate arrival meter fix route that results in a shorter route; the resultant change in the scheduled time of arrival (STA) for the flight at the arrival metering fix is also shown in magenta on the schedule timeline at the right of Figure 1. Similarly, Figure 2 depicts a route modification to avoid convective weather while remaining on the currently assigned arrival; the schedule delay impact is also shown in magenta on the schedule timeline in Figure 2.

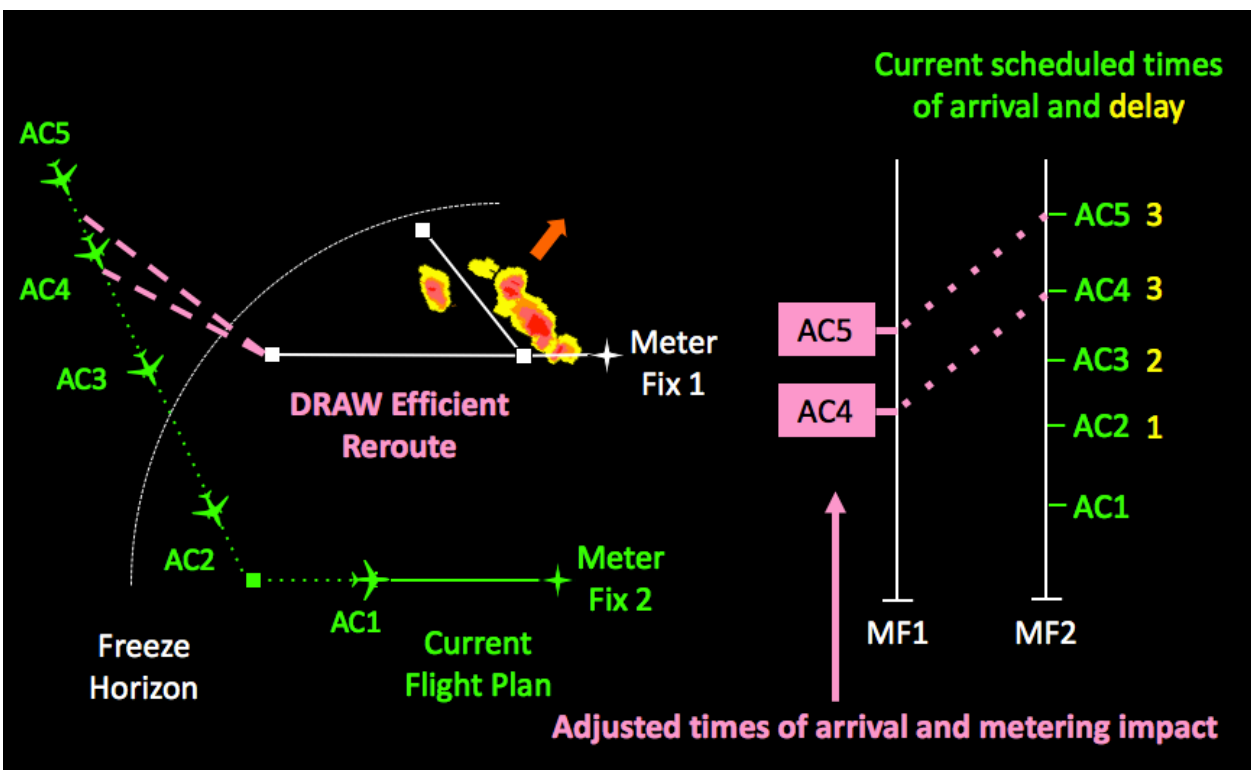


Figure 1: Time-saving Alternate Meter Fix Reroute Advisory

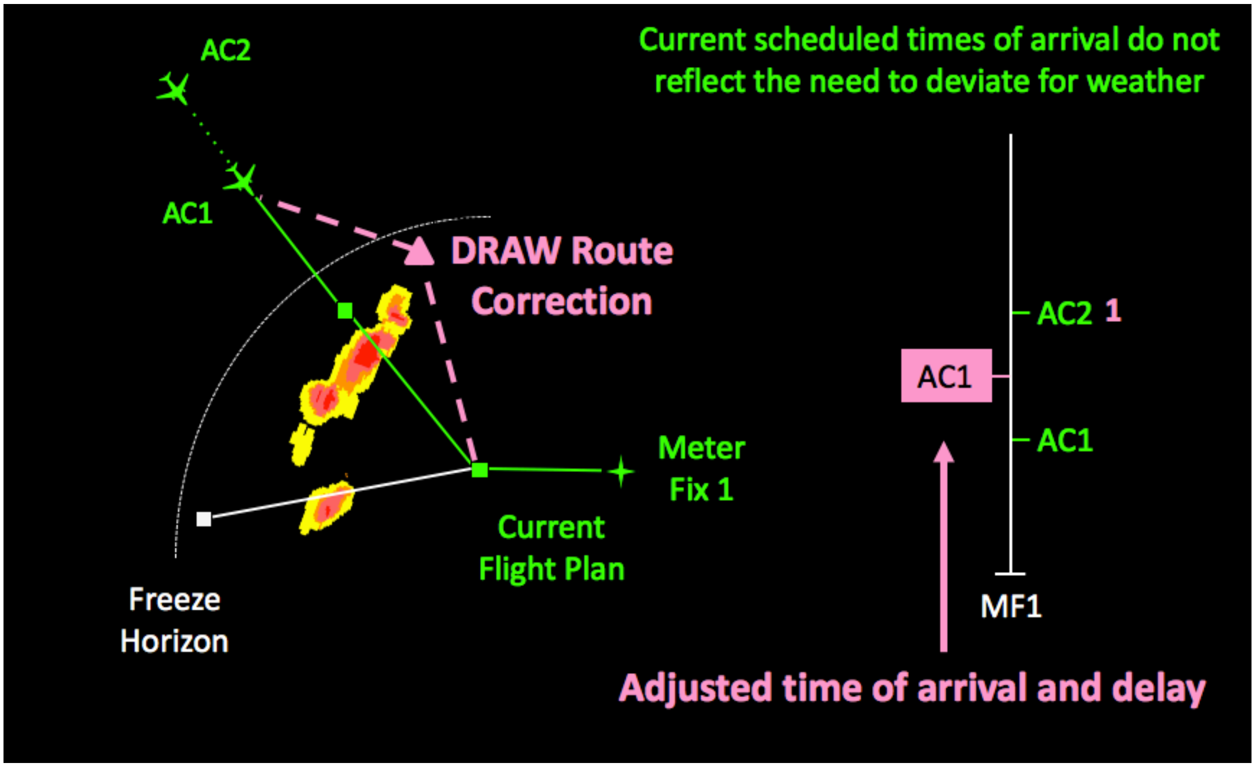


Figure 2: Weather Avoidance Route Amendment Advisory

Propsed route amendements are updated every 12 seconds with each ARTCC flight track update cycle and provided to the TMC in an advisory list (Figure 3). The advisory list provides basic information for each advisory, including: Flight callsign, proposed arrival procedure and transition, flight time savings/delay resulting from the proposed reroute, and the type of advisory. Additional information (not shown) is included in the advisory list that helps the TMC manage the advisory list (e.g., color coding for recently evaluated advisories and the ability to suppress individual advisories). Multiple, similar advisories for proximate flights can also be evalued by the TMC as a 'group advisory' if desired, with an accepted advisory resulting in amended routes for all aircraft in the group. Advisories in the list are ordered according to predicted flight time to the metering fix, with the flights furthest from the metering fix at the top of the list (for consistency with schedule timeline convention). TMCs select individual or group advisories for evaluation, and employ a trial planning interface providing basic flight plan and route amendment information. An advisory trial plan window is presented to the TMC once an advisory has been selected for evaluation (Figure 4, not shown). The trial plan window includes the current and proposed flight plan route, as well as selectable lists of arrival procedures, arrival transitions, and along-route waypoints, allowing the TMC to modify the advised route amendment (e.g., to select a different arrival procedure, a different transition for a given arrival, or a different initial capture fix). The flight-time savings (or delay) compared to the current flight plan is presented with each arrival transition in the trial plan window.

Advisory weather avoidance status and metering schedule impact are provided to the TMC to aid evaluation/modification and are discussed in the following section.

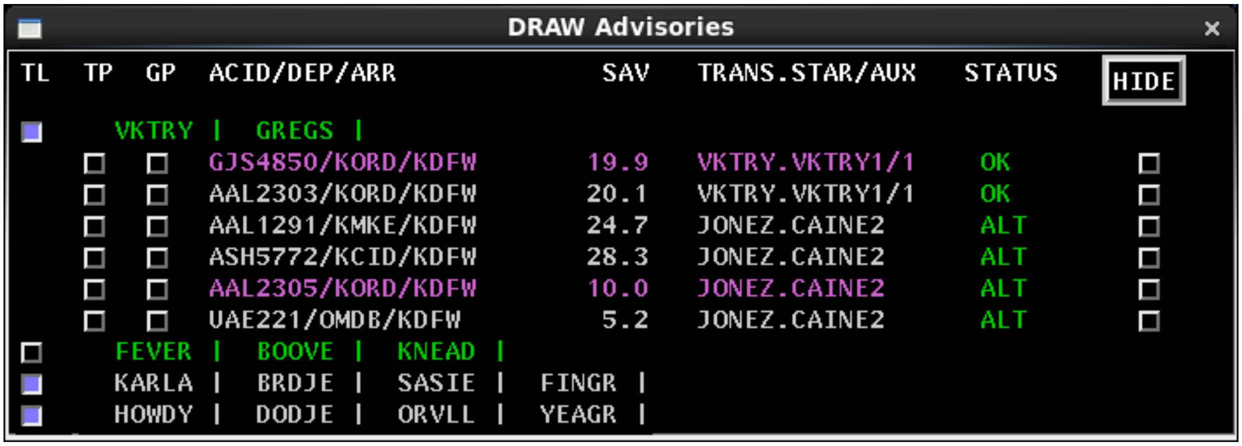


Figure 3: DRAW Advisory List

After selecting an advisory for evaluation, the TMC is presented with continuous feedback on weather avoidance status for the proposed route amendment; the status is updated to reflect any modifications the TMC makes to an advised route amendment. Figure 5 shows the weather avoidance status feedback provided to the TMC on the planview map display (similar to the current Traffic Situation Display (TSD) found in current TMUs). The yellow dashed line in Figure 6 depicts a trial plan route conflicting with forecast weather (orange-bordered polygon). Using a click-and-drag interface on the planview map display, the TMC can directly modify the trial plan route while receiving weather avoidance feedback. Figure 7 shows a the flight from Figure 6 with a route that has been modified to avoid the weather; nearby (but non-conflicting) forecast weather is indicated by the cyan-bordered polygon. Current CIWS weather can be included on the planview map display if desired by the TMC (as shown in Figures 6 and 7), but DRAW uses 5-minute CWAM WAF forecasts to predict weather conflicts. Weather avoidance feedback provides the TMC with the ability to evaluate arrival route modifications for conficts with forecast weather up to two hours into the future. This ability reduces the need for tactical weather avoidance and increases flight path predictability (subject to weather forecast errors). Increased trajectory predictability allows DRAW to estimate route amendment schedule impact.

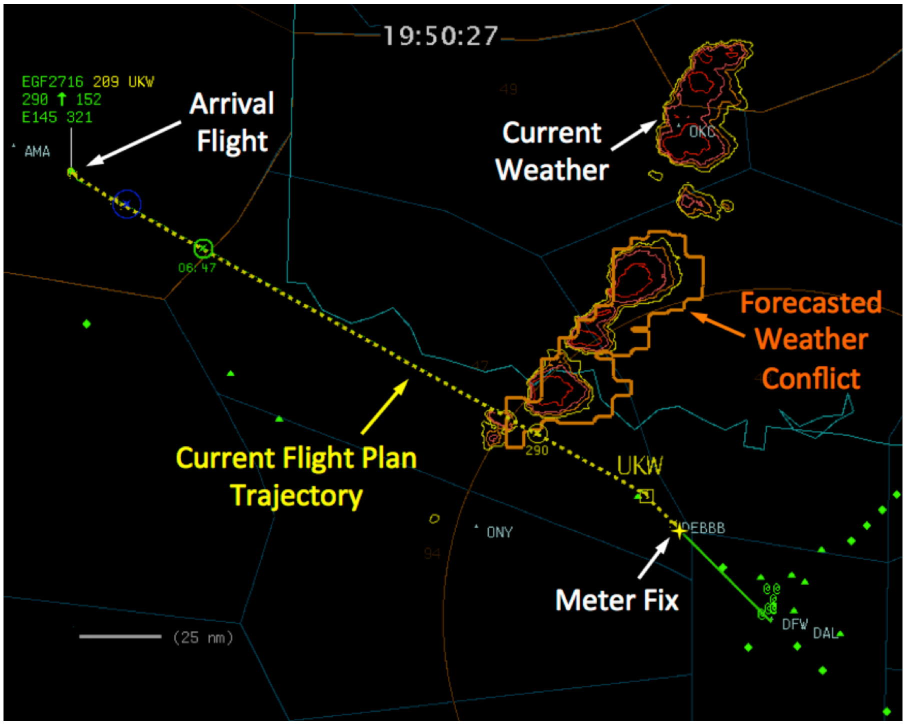


Figure 6: Trial Plan with Predicted Weather Conflict

Schedule impact is estimated by creating an alternate arrival schedule with the propose route amendment(s) for the selected advisory of advisory group. The estimated schedule impact is provided to the controller on the TMA timeline graphical user interface (TGUI). Figure 8 shows the schedule feedback for an alternate metering fix advisory and the earlier estimated times of arrival (ETA on left, STA on right) are highlighted on the timeline for the proposed meter fix. TMCs can use this feedback to assess whether their will be adverse delay and/or radar controller workload associated with propsed route amendment. TMCs are provided with continuous updates to both weather avoidance status and schedule/delay impact as modificaitons are made to the proposed route amendment to efficiently evaluate advisory acceptability and to arrive at a rerouting decision.

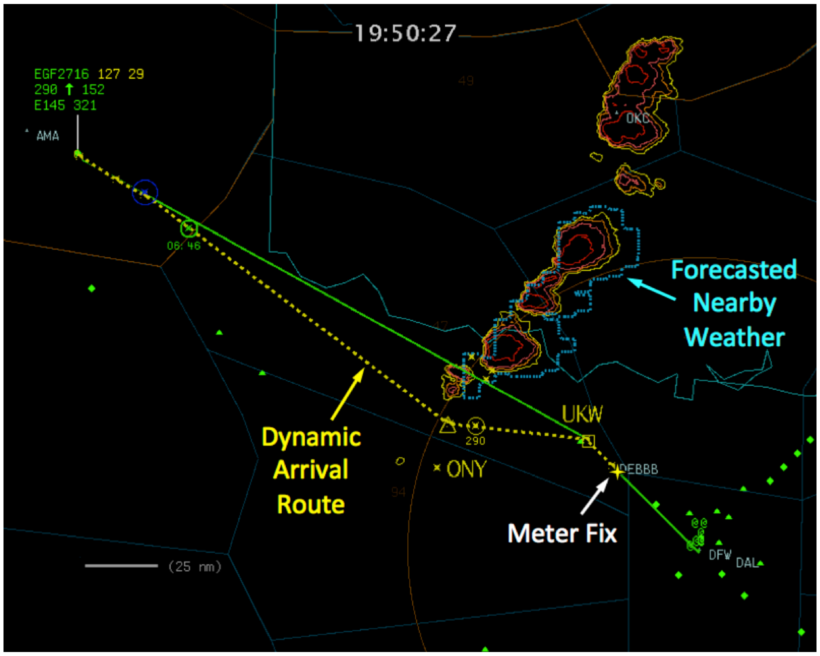


Figure 7: Trial Plan Avoiding Dynamic Weather and Rejoining Arrival

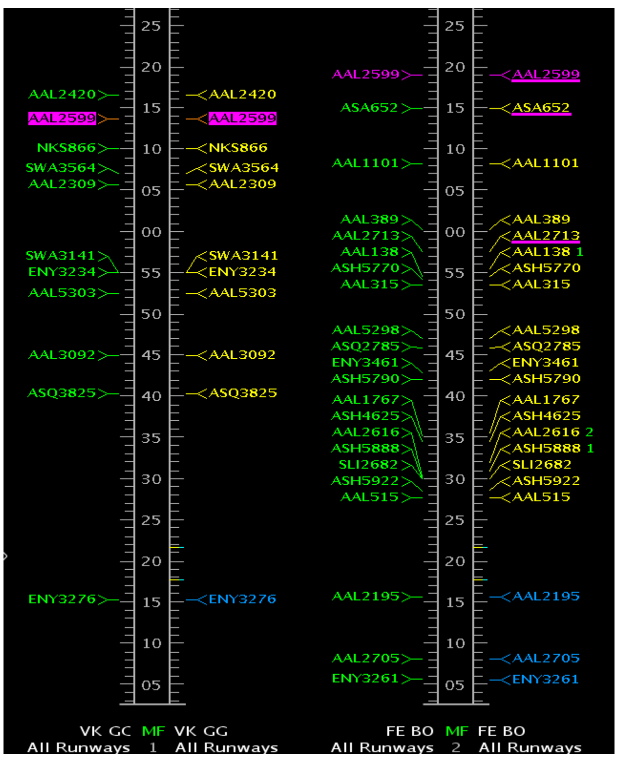


Figure 8: Schedule Impact Feedback for Alternate Meter Fix Reroute

TMC evaluation of DRAW advisories has four possible outcomes: 1) acceptance of proposed route amendment, 2) acceptance of a TMC-modified route amendment, 3) deferal for later evaluation of proposed amendment, or 4) suppression/rejection of proposed route amendment. Mechanisms to effect each decision are included in either the trial plan window or the advisory list. If a route amendment advisory is either accepted as-is or accepted after modification, the TMC must simply select the ‘AMEND’ button in the trial planning window. If an advisory is deferred for later evaluation, the TMC must select the ‘CANCEL’ button in the trial planning window, or deselect the advisory in the advisory list. To reject/supress an advisory, the TMC must check the ‘HIDE’ checkbox next to the advisory in the advisory list. An accepted route amendment initates a route amendment message to be implemented by the sector controller with current flight ownership. Because this sector controller is generally located in an adjacent ARTCC, DRAW relies on electronic rather than voice communication of the amended route to the adjeacent facility. It is assumed that this communication occurs via the Airborne Re-Routing (ABRR) functionality, but further consideration of inter-facility coordination of DRAW route amendments is required and beyond the scope of this paper.

B. Initial DRAW Concept Refinement Study

The DRAW concept was evaluated by retired TMCs and ARTCC controllers in a series of simualtions and storyboarding activities in April, 2017. The three of objectives of this study were: to gain experience in conducting Human-in-the-Loop simulations of DRAW-enabled operations, to evaluate DRAW effect on sustaining metering operations in weather-impacted airspace, and to solicit TMC feeback on a variety of DRAW use cases. Due to DRAW feature shortcomings, training inadequacies and simulation artifact, it was not possible to accurately assess if DRAW had significant impact on sustained metering operations. However, the experience gained and lessons learned from the April study were a necessary step toward effective HitL evaluation of DRAW operations. Scenario development, training protocols and subject instruction, as well as feature additions derived from the April effort were all crucial to successful conduct of the study that is the focus of this paper. These concept refinements and simulation methodology improvements are discussed in the following sections.

<Add description of implemented concept refinements>

IV. Methodology

This section presents the study methodology employed to evaluate DRAW operations in the NASA ATC Laboratory. An overview of the ATC Laboratory configuration for DARW evaluation is first presented. The experimental design is next detailed with detail on the justification and procedure for independent TMC and sector controller simulation activities. Experimental Matrices for TMC and Controller runs are provided as well as overviews of the data collected for each. Finally the scenario generation process for TMC and Controller runs is described to justify scenario characteristics that may differ from observed operations.

A. ATC Laboratory Configuration

Simulations were conducted in the NASA Air Traffic Control Laboratory (ATC Lab). The ATC Lab configuration for DRAW evaluation is depicted in Figure 9 (not shown, To Be Completed). The key components of DRAW evaluation in the ATC Lab are: ERAM Consoles, TMU Station(s), Pseudopilot Stations, Tactical Weather Avoidance Position, and the Simulation Manager Station.

ERAM stations are staffed by sector controlle participants and are intended as sufficiently accurate representations of ERAM consoles in operational use. Because the ERAM consoles are emulations of complex operational systems, some differences are inevitable. Any noted differences are discussed with particpants to assess impact and develop mitigations if necessary. ERAM stations include a traffic display, keyboard, trackball and voice communication hardware.

Each TMU stations consists of a keyboard, mouse and two displays: a planview map display and a TGUI display. The TMC staffing a TMU station interacts with the DRAW system as previously described.

Pseudopilot Stations are used by pseudopilots to control multiple flights as instructed by the participant controllers via voice communication. Pseudopilots employ a mulitple flight interface and are assigned to execute all clearances given for flights owned by a single sector controller.

The Tactical Weather Avoidance Position provides tactical weather avoidnace capability to approximate the behavior of flight crews acting to avoid convective weather within ~80nm of flight position. Any necessary weather avoidance maneuvers are communicated to the pseudopilot and are subsequently requested as weather deviations to the sector controller.

The Simulation Manager station is used by research staff to monitor simulation conduct.

B. Experimental Design

1. Independent TMC-Sector Control Approach

Consistent feedback from participants and researchers during the aforementioned Concept Refinement study conducted in April 2017 indicated the ~2-3hr length of scenarios experienced during that study were excessive and inconsistent with operational time-on-station. Scenario length was largely dictated by flight time between when the first flight was evaluated by TMC for DRAW route amendment until the last flight considered by the TMC crossed the meterign fix into the TRACON. ZFW transit time along the study arrival is nominally 45 minutes. The ARTCC tranbsit time, coupled with the desired subject participation time of at least 45 minutes for TMCs and sector controllers dictated that scenarios exceed 2 hours run time. To shorten on-station time while retaining sufficient data collection time for each run, a divide-and-conquer approach was employed for the study herein. Two weeks of simulations were conducted which only included TMC subjects and data were collected to record their actions and assessements through data recording and questionnaire adminstration, respectively. The data from the TMC runs were then used to develop input scenarios for simulations that only included sector controller subjects. This enabled researchers to limit scenario length to 90 mimnutes: more consistent with operational on-station time. The procedure for generating controller input scenarios from TMC simulation data is described in a later section.

2. Participants

Two retired ZFW TMCs participated each week of the TMC runs. TMC experience and facilities are listed in Table 1-1.

Table 1-1. ZFW TMC Participants (DRI- UPDATE for HitL2)

TMC Participant ID	Total TMC Years	Retired in	Other FAA ATM Experience (Years)
T1	8	2015	ZFW (24)
T2	3	2011	ZFW (6), ZAB (12)
T3	3	2017	ZMP (9), ZMP TMC (7), ZFW (12)
T4	4	2016	ZFW (20), ZAB (7)
Average	4.5	2014.8	

In addition, 7 sector controllers participants performed simulated ZFW sector tasks on the flows coordinated by the TMC participants the during the preceding weeks. One controller was a retired ZFW Area Supervisor, while the remaining four controllers retired from ZOA. Table 1-2 summarizes their experience.

Table 1-2. Sector-Controller Participants (DRI- UPDATE for HitL2)

Sector-Controller Participant ID	ARTCC	Years	Retired in
C1	ZFW (Area Supervisor)	17	2016
C2	ZOA	26	2016
C3	ZOA	23	2012
C4	ZOA	28	2011
C5	ZOA	33	2015
C6	-	-	-
C7	-	-	-
Average		25.4	2014.0

Seven pilot participants were recruited from the local GA community to perform the pseudo pilot duty in the simulation (DRI- UPDATE for HitL2)

3. TMC Runs Experimental Matrix

The first two weeks of the study included TMC-only runs. During the TMC runs, the ATC Lab was configured with two TMC stations such that two TMCs runs could be conducted concurrently. The experimental matrix for the TMC runs are included in Tables 2 and 3. Table 2 includes the matrix for runs whose outputs were subsequently used as the basis for controller-run input scenarios. The run order for these runs was counterbalanced for the scenario condition both within and between subjects. Table 3 includes additional TMC runs that were only used for TMC data collection and were not used for controller runs. The assigment of scenarios for controller runs was made prior to TMC data collection.

Table 2: TMC-Controller Run Experimental Matrix

Run	DRAW	Scenario	TMC
3a	No DRAW	1	A/C
3b	No DRAW	2	B/D
4a	No DRAW	2	A/C
4b	No DRAW	1	B/D
6a	DRAW	2	A/C
6b	DRAW	1	B/D
8a	DRAW	1	A/C
8b	DRAW	2	B/D

Table 3: TMC-Only Run Experimental Matrix

Run	Scenario	TMC
1a	3	A/C
1b	3	B/D
2a	4	A/C
2b	4	B/D
5a	5	A/C
5b	5	B/D
7a	6	A/C
7b	6	B/D

4. Controller Runs Experimental Matrix

Sector controller runs were conducted during the third and final week of data collection. Table 4 includes the experimental matrix for these runs. Controller run order was counterbalanced for DRAW, Scenario and TMC conditions for both within and between controller seat condition.

Table 4: Controller Runs Experimental Matrix

Run	DRAW	Scenario	TMC	Controller Seat
1	DRAW	1	A	1
2	No DRAW	2	A	1
3	No DRAW	1	B	1
4	DRAW	2	B	1
5	No DRAW	1	A	2
6	DRAW	2	A	2
7	DRAW	1	B	2
8	No DRAW	2	B	2
9	No DRAW	2	A	2
10	DRAW	1	A	2
11	DRAW	2	B	2
12	No DRAW	1	B	2
13	DRAW	2	A	1
14	No DRAW	1	A	1
15	No DRAW	2	B	1
16	DRAW	1	B	1

5. Data Definitions

Table 5: Data collected during TMC and Controller Runs

Data	Description
Meter Fix Arrival Rate	Rate of flight arrivals at a given meter fix (aircraft/hr)
Weather avoidance clearances	Controller-issued clearances for the purpose of avoiding convective weather
Metering clearances	Controller-issued clearances for the purpose of spacing arrival aircraft or absorbing prescribed metering delay
DCT values at FH	Flight metering delay at the moment an aircraft's STA freezes
Route Amendment Time	Estimated Time-to-fly to arrival metering fix at time of route amendment
Route Evaluation Time	Esimtated Time-to-fly tio arrivaly metering fix at initiation of advisory evaluation
Trial Plan Frequency	Rate of trial plan initiations (1/hr)
ATA Error	difference between actual and scheduled meter fix crossing time
Flight Time Change	Change in flight for the same flight in different runs
TMC workload	TMC SWAT workload rating
TMC Confidence	Measure of TMC confidence in general operations
Controller Workload	self-reported in-situ workload assessment (1-6 scale)
Advisory Acceptance Rate	Rate of acceptance of accepted advisories (1/hr)
Usability of DRAW tools	
DRAW list length at amendment	number of advisories present in the advisory list at time an amendment is accepted
Advisory Age at amendment	Time since advisory first appeared (and stayed) on advisory list at time of accepted amendment
% of DRAW reroutes accepted by TMC	Percent of DRAW advisories accepted/modified (%)

6. Experiment Conduct

a) TMC Runs

(1) Training

TMC runs were conducted over two weeks, 3 days each week, Tuesday-Thursday. Two TMCs participated each week, for a total of four TMC participants. On Tuesday of each week, DRAW Researchers conducted training of DRAW operations prior to the first DRAW run, and non-DRAW trial planning training prior to the first non-DRAW run. An overview of DRAW features was provided to the TMCs, and hands-on time with DRAW operations during a training scenario allowed TMCs to become familiar advisory evaluation tools and the general interaction with the planview map and TGUI displays.

(2) Data Collection

TMC runs were conducted each week at two independent TMU stations in the ATC Lab. Table 4 presents the run schedule for each of the TMC weeks. Mid-run, post-run and post-study questionnaires were administered to collect TMC workload, advisory acceptability and timing, confidence in general operations and usability measures. Objective performance measures were also collected durign the course of each run, as described in the data definition section.

<table>
<tr><th>Start Time</th><th>Session 1: Day 1</th><th>Session 1: Day 2</th><th>Session 1: Day 3</th></tr>
<tr><td>8:30</td><td rowspan="3">Classroom/
DRAW Training</td><td rowspan="6">Run #4: No-DRAW
S2 (TMC a), S1 (TMC b)</td><td rowspan="6">Run #8: DRAW
S1 (TMC a), S2 (TMC b)</td></tr>
<tr><td>8:45</td></tr>
<tr><td>9:00</td></tr>
<tr><td>9:15</td><td>Break</td></tr>
<tr><td>9:30</td><td rowspan="4">Run #1: DRAW S3</td></tr>
<tr><td>9:45</td></tr>
<tr><td>10:00</td><td rowspan="2">Questionnaire, break</td><td rowspan="2">Questionnaire, break</td></tr>
<tr><td>10:15</td></tr>
<tr><td>10:30</td><td rowspan="2">Questionnaire, break</td><td rowspan="4">Run #5: DRAW S5</td><td rowspan="4">Backup run</td></tr>
<tr><td>10:45</td></tr>
<tr><td>11:00</td><td rowspan="4">Run #2: DRAW S4</td></tr>
<tr><td>11:15</td></tr>
<tr><td>11:30</td><td>Questionnaire</td><td>Questionnaire</td></tr>
<tr><td>11:45</td><td rowspan="4">Lunch</td><td rowspan="2">Debrief</td></tr>
<tr><td>12:00</td><td>Questionnaire</td></tr>
<tr><td>12:15</td><td rowspan="4">Lunch</td><td rowspan="15"></td></tr>
<tr><td>12:30</td></tr>
<tr><td>12:45</td><td rowspan="6">Run #6: DRAW
S2 (TMC a), S1 (TMC b)</td></tr>
<tr><td>13:00</td></tr>
<tr><td>13:15</td><td rowspan="3">No-DRAW Training</td></tr>
<tr><td>13:30</td></tr>
<tr><td>13:45</td></tr>
<tr><td>14:00</td><td>Break</td></tr>
<tr><td>14:15</td><td rowspan="6">Run #3: No-DRAW
S1 (TMC a), S2 (TMC b)</td><td rowspan="2">Questionnaire, break</td></tr>
<tr><td>14:30</td></tr>
<tr><td>14:45</td><td rowspan="4">Run #7: DRAW S6</td></tr>
<tr><td>15:00</td></tr>
<tr><td>15:15</td></tr>
<tr><td>15:30</td></tr>
<tr><td>15:45</td><td>Questionnaire</td><td>Questionnaire</td></tr>
</table>

b) Controller Runs

(1) Training

Training on the ERAM console emulation was conducted for each seating condition to allow familiarization with the simulation sector and to provide instruction to controllers on expected procedures for ERAM input (e.g., for temporary altitude clearances). Placards were provided at each ERAM station that included VHF voice communications frequencies, sector maps (with commonly used fixes/navaids), and arrival routes/transitions for the arrival procedure including vertical profile constraints.

(1) Data Collection

Controller runs were conducted over 5 days of data collection during the third and final week of the study. Table 5 shows the schedule of data collection and training for controller runs. Controllers reported self-assessed workload using a Workload Assessment Keypad at 10-minute intervals. Post-run and post-study questionnaires were collected, as well as objective data as detailed in the data defintion section.

Start Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:30					
8:45					
9:00	MACS/ERAM Training Seating 1		Run #7: DRAW S1b Seating 2	Run #11: DRAW S2b Seating 2	Run #14: No-DRAW S1a Seating 1
9:15					
9:30		Run #4: DRAW S2b Seating 1			
9:45	Break				
10:00			Questionnaire, break	Questionnaire, break	Questionnaire, break
10:15					
10:30	Run #1: DRAW S1a Seating 1	Questionnaire, break			
10:45					
11:00		MACS/ERAM Training Seating 2	Run #8: No-DRAW S2b Seating 2	Run #12: No-DRAW S1b Seating 2	Run #15: No-DRAW S2b Seating 1
11:15					
11:30	Questionnaire				
11:45					
12:00	Lunch	Lunch	Questionnaire	Questionnaire	Questionnaire
12:15					
12:30			Lunch	Lunch	Lunch
12:45					
13:00					
13:15	Run #2: No-DRAW S2a Seating 1	Run #5: No-DRAW S1a Seating 2			
13:30					
13:45			Run #9: No-DRAW S2a Seating 2	Run #13: DRAW S2a Seating 1	Run #16: DRAW S1b Seating 1
14:00					
14:15	Questionnaire, break	Questionnaire, break			
14:30					
14:45			Questionnaire, break	Questionnaire, break	Questionnaire
15:00					Debrief
15:15	Run #3: No-DRAW S1b Seating 1	Run #6: DRAW S2a Seating 2			
15:30					
15:45			Run #10: DRAW S1a Seating 2		
16:00					
16:15	Questionnaire	Questionnaire			
16:30					
16:45			Questionnaire		

C. TMC Run Scenario Development (To Be Completed)

1. Wx Condition Selection- West Side Arrival Flow Impact based on HitL1
2. Traffic Recording Selection - non Wx-Impacted Day (same day of week)
3. MACS Scenario Generation (SmartNAS)
4. Traffic Augmentation-Targeted sustained 2-3 minutes of metering delay
5. Flight Validation- altitudes, speeds, routes
6. Traffic Deconfliction- Entry Separation after MACS flight path simulation

D. Controller Run Scenario Development (To Be Completed)

1. Snapshot MACS Scenario Generation
2. Flight Validation- altitudes, speeds, routes
3. Traffic Deconfliction- Entry Separation after MACS flight path simulation

V. Results

A. TMC-Run Results

1. Human Factors Analysis

Mid-run, post-run and post-study questionnaires were administered for the TMC runs in weeks 1 and 2 of the study. Data collected in these questionnaires included workload ratings, subjective assessments of advisory quality and quantity, usability ratings and others. Results of human factors data anlysis will likely include Linear Mixed Model (LMM) repeated measures regression analysis. Table XX provides sample results for similar data collected prior to the current study.

Table XX. LMM results – effects found to be significant (SAMPLE ANALYSIS… NOT ACTUAL RESULT)

(a) SWAT ratings

Effect	**Coefficient**	**SE**	***t***	***p***
Phase 2	23.63	9.47	2.494	0.016

(b) Time Load ratings

Effect	**Coefficient**	**SE**	***t***	***p***
Phase 3	7.69	3.45	2.229	0.030

(c) Mental Effort Load ratings

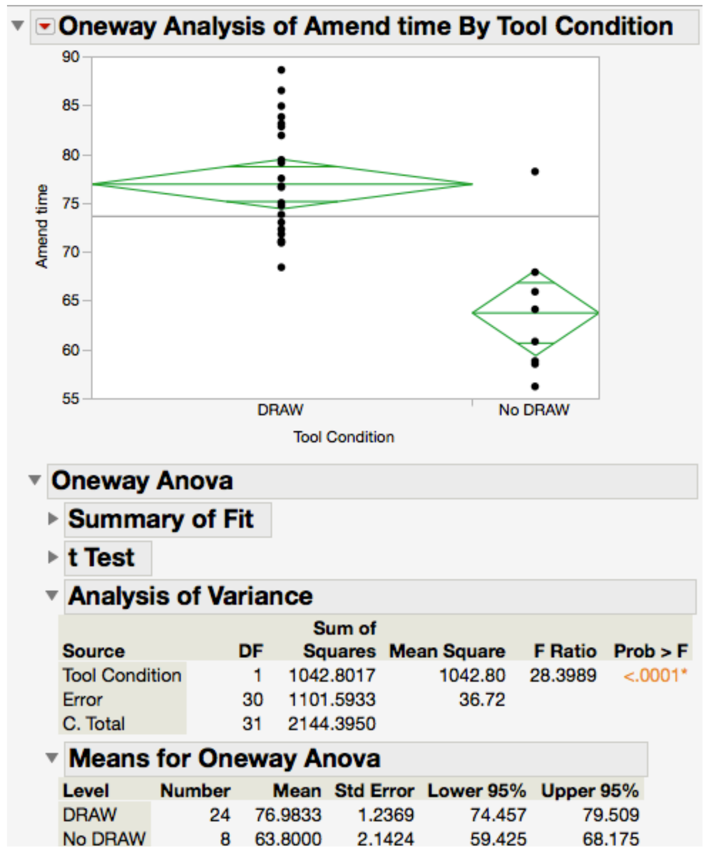
Effect	**Coefficient**	**SE**	***t***	***p***
(Intercept)	13.35	4.62	2.886	0.032
Phase 2	10.13	3.86	2.621	0.012
DRAW x Phase 2 (DRAW x Phase)	-11.88	5.46	-2.174	0.034
DRAW x Phase 3 (DRAW x Phase)	-11.00	5.39	-2.041	0.046

(d) Psychological Stress Load ratings

Effect	Coefficient	SE	*t*	*p*
Phase 2	7.00	2.86	2.450	0.018
Outside (WxLoc)	-3.12	1.43	-2.175	0.034

2. Performance Metrics Analysis

Recorded data for the TMC runs included advisory evaluation and amendment timing, advisory acceptance frequency, advisory list length, and advisory acceptance ratio. Similar analysis to the above may be included for this data, or alterntive methods may be employed as best suited to the observations and data collection methods. Sample Figure SF 1 shows a sample one-way ANOVA treatment of fligth route amendment time.



Sample Figure SF 1 (SAMPLE, NOT ACTUAL RESULT)

3. Controller-Run Results

Data analysis for the controller runs will be performed in similar fashion to the TMC runs. Because proficiency in managing flights within the simulation airspace varied considerably between the controller participants, LMM or similar methods will likely be necessary for analysis of controller runs due to the random effect of controller participant. Results for the controller runs are also pending analysis.

4. Human Factors Analysis
5. Performance Metrics Analysis
6. Other interesting/anecdotal measures (e.g., flight paths showing vectoring, etc.)

VI. Conclusion (To Be Completed)

A. Key takeaways

Expected results will highlight any significant differences between DRAW and non-DRAW conditions in the study. SME feedback will be discussed and challenges to conducting and analyzing data from the study will be noted.

B. Next Steps

Future DRAW studies are planned to evaluate DRAW capability in different airspace and with enhanced capability (e.g., with inclusion of key TBFM capabilities). These studies are planned over the next several years, and will be supplemented with closed-loop analyses to evaluate DRAW in a greater set of weather and traffic conditions than practical with HitL studies.

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