Airspace Technology Demonstration – 3 (ATD-3)

Dynamic Routes for Arrivals in Weather (DRAW) Operational Concept

V2.0

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PREFACE

NASA's Airspace Technology Demonstration 3 (ATD-3) project integrates several tools for trajectory and demand management around airspace constraints in en route operations. The Dynamic Routes for Arrivals in Weather (DRAW) is one of these tools designed to assist traffic managers to more effectively manage arrival metering operations, improve efficiency, and balance arrival demand in all weather conditions prior to entering terminal airspace.

REVISION HISTORY:

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1 INTRODUCTION

NASA's Airspace Technology Demonstration-3 (ATD-3) is the applied traffic flow management activity, and third in the series of ATD projects. ATD-3 provides a suite of en route automation tools, both ground and flight-deck based, that focus on improving the efficiency of en route operation from initial cruise to arrival into the Terminal Radar Approach Control (TRACON). Dynamic Routes for Arrivals in Weather (DRAW) is a technology in the ATD-3 suite that is designed to provide Traffic Managers with a capability to efficiently manage arrival traffic flow and help sustain metering operations when weather is impacting arrivals into major airports. DRAW mitigates convective weather impact on arrival metering operations by providing tools to Traffic Managers that enable efficient reroutes free of convective weather conflicts, and integrated with the arrival metering schedule(s).

The ATD-3 overall operational concept is covered in the "Operational Concept for the Integration of Airspace Technology Demonstration -3 (ATD-3) Capabilities"[1]. Additional details for the other ATD-3 core technologies are provided in the "Dynamic Weather Routes (DWR) Domestic En Route Concept of Operations Synopsis," the "Multi-Flight Common Routes (MFCR) Concept of Operations Synopsis," the "Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations," and the "Multi-Agent Air/Ground Integrated Concept (MAAGIC) Concept of Operations." This document describes the operational concept for DRAW.

2 OPERATIONAL ENVIRONMENT

Overall traffic flow management across the entire National Airspace System (NAS) is managed by the Air Traffic Control System Command Center (ATCSCC, or "Command Center"). The ATCSCC coordinates with the Air Route Traffic Control Centers (ARTCCs, or "Centers") to assess forecast weather and traffic demand throughout the day. When predicted airspace or airport capacity falls short of forecast demand for that same resource, the ATCSCC and the impacted ARTCCs collaborate to manage demand and capacity toward the most efficient operations practical. When arrival demand exceeds airport capacity, arrival metering is employed; the following section briefly describes current arrival metering operations.

2.1 CURRENT ARRIVAL METERING OPERATIONS

Time-Based Flow Management (TBFM) is used to manage arrival flows at major airports. TBFM uses radar track data and 4-D trajectory predictions to compute Estimated Times or Arrival (ETAs) for arrival flights. These ETAs are then used by a single TBFM scheduler to calculate Scheduled Times of Arrival (STAs) at the assigned meter fix (MF) and runway for each arrival flight based on meter fix/runway configurations and constraints adapted for the local facility. TMCs perform a variety of tasks to manage TBFM arrival metering operations: ensuring downstream constraints (e.g., airport acceptance rate or AAR) are effectively enforced by the TBFM scheduler, monitoring demand in the context of real-time constraints and coordinating schedule or routing changes with area supervisors and airline operators. TMC workload increases during periods of high traffic demand and/or reduced capacity (e.g., due to convective weather impacting arrival routes, metering fixes, or arrival airports).

TBFM monitors each flight's progress, and continuously updates its ETA, STA, and schedule delay at the arrival meter fix and runway until the flight crosses the TBFM scheduling freeze horizon. Upon crossing the freeze horizon, the flight's STA and sequence are no longer automatically updated (i.e., "frozen"), while the flight's ETA and resulting schedule delay do continue to update. Freezing the STA stablizes the schedule, thus, allowing the controller to absorb schedule delay and maintain flight sequence. The freeze horizon distance for a specified meter fix for the jet category can range from approximately 150 to 350 nautical miles away, but varies for each airport/airspace configuration and arrival stream class.

In a typical single Center metering configuration, flights are scheduled to the adapted meter fixes on the TRACON boundary and associated airport/runways within the primary Center. With Adjacent Center Metering (ACM), however, the TBFM arrival scheduler in the adjacent Center can be configured to assist metering to an adjacent Center airport by scheduling flights at a specified rate to meter fixes upstream of the primary arrival airport (e.g., Center boundary). The primary Center then meters the flights the rest of the way as they would for single Center metering. In either case, each TBFM arrival scheduler calculates its schedule based on its own independent set of constraints.

Reroutes to mitigate impacts of convective weather are typically either strategic in nature (e.g., Playbook routes assigned prior to departure) or tactical/reactive as a result of pilots requesting deviations around weather within the range of onboard weather radar (~100nm and typically contained within a controller's sector and/or ARTCC). Efficiently rerouting airborne flights for weather avoidance is currently hampered by the following factors: 1) Weather conflict prediction is not provided on a per-flight basis, 2) the workoad associated with manually identifying flights to reroute and forming a viable reroute and 3) coordinating each reroute with adjacent facilities (and likely through the ATCSCC) make such airborne strategic rerouting impractical for routine application.

2.2 Extended Metering and Coupled Scheduling Operations

TBFM Extended Metering (XM) and Coupled Scheduling (CS) are multi-scheduler configurations of current arrival metering operations. They are operationally similar to ACM in that traffic is partially metered upstream before being metered to the primary airport. Unlike ACM, the schedulers used for XM/CS share scheduling constraints with each other. The downstream scheduler shares constraints with the upstream scheduler in the XM configuration. For the CS configuration, scheduling constraints are shared in both directions, downstream to upstream and vice versa. XM/CS includes multiple metering points (i.e., Metering Fix, Extended Metering Point, Coupled Metering Point), each with an associated metering list. As such, most scheduled arrivals will cross more than one freeze horizon: one for each metering point the flight crosses. Thus, rerouting arrivals in an XM/CS environment has the potential to impact more controllers and TMUs than traditional metering operations, and evaluation of proposed reroutes necessarily includes assessment of impacts at each involved facility, sector and on the arrival schedule.

While metering points in XM/CS may be located within an adjacent facility's airspace, the schedules are dictated by the TBFM system of the primary arrival airport (the 'home' TBFM system). For example, the ZFW TBFM system schedules DFW arrivals both to metering fixes (MFs) within ZFW, as well as to any Extended Metering Points (XMPs) and Coupled Metering Points (CMPs), some of which may be located in adjacent ARTCCs (e.g., ZAB or ZME). Schedules for all Metering Points (MFs, XMPs and CMPs) can be displayed on the TBFM Timeline Graphical User Interface (TGUI) for their associated TBFM 'Group': Metering Fixes are within the 'Arrival Group,' while XMPs and CMPs are within the 'En Route/Departure Coordination Group' (or EDC Group). TBFM TGUIs for the Arrival or EDC Groups may be displayed in either the 'home' TBFM TMU or any adjacent facility TMU managing XMPs/CMPs. As with standard (single scheduler) TBFM operations, metering delays (for each MP) are determined based upon a flight's frozen STA and its ETA.

TBFM communicates delays for flights with frozen STAs (at each MP) to the En Route Automation Modernization (ERAM) system for display at the appropriate controller's station. These delays are typically displayed as a 4-digit metering list that controllers use to achieve the desired delay (and thus time of arrival) at each MP en route to the destination. Any changes to flight route will most likely result in a significant ETA change; a significant ETA change for a flight with a frozen STA would result in a significant change in prescribed delay on the 4-digit metering list. Thus, weather avoidance reroute complexity is only exacerbated by the tiered scheduling paradigm of XM/CS.

3 Problem Description

The FAA's Time-Based Flow Management (TBFM) system is currently used to manage arrival traffic demand into major airports. The TBFM systems provides scheduling, spacing, and sequencing guidance to Traffic Managers and Controllers to facilitate time-based metering operations that maximize use of available airport capacity. TBFM relies on accurate flight trajectory predictions to generate effective arrival schedules and to allocate metering delay for implementation by air traffic controllers. Convective weather in arrival airspace leads to route unavailability, tactical flight deviations for weather avoidance, and increases the difficulty of and uncertainty in flight trajectory prediction. Traffic managers often employ traffic management initiatives (TMIs) to mitigate these effects. The following sections briefly detail the challenges to arrival metering in the presence of convective weather under the current system.

3.1 Inefficient or Obsolete Weather Avoidance Routes

In order to preempt potential disruption in the arrival flow and metering, arrivals may be routed to a different, but often less efficient, arrival route to avoid forecasted weather hours before the flight would arrive (i.e., a time when weather forecasting error is high). Even if weather does not impact the arrival route or fails to materialize as forecasted, arrivals will often continue to fly these less efficient arrival routes (e.g., Severe Weather Avoidance Plan, or SWAP, routes) because the current Traffic Flow Management System (TFMS) and TBFM systems lack automation to identify and alert TMCs about these routing inefficiencies.

3.2 Discontinued Arrival Metering Due to Weather

Studies have shown that weather in the vicinity of an airport is one of the primary causes for time-based metering to be discontinued[2]. One reason for this is due to the current TBFM system's inability to adjust its predicted times of arrival for aircraft that need to deviate around weather. In this situation, controllers will likely revert back to miles-in–trail (MIT) operations, a simpler but less efficient method of managing arrival traffic flow into a constrained airport.

3.3 Lack of Decision Support Tools for Arrival Traffic Management

The TBFM system is designed for the metering of arrivals during periods of high demand. Meter times are based on the current position of aircraft, their assigned flight plan routes, and the estimated times of arrival (ETAs) at the runway. A change in the routing and ETA of a single flight will impact the metering STA and delay for that aircraft, and may potentially impact the STA and delays of other aircraft in the sequence. Tools for the Traffic Manager to evalaute the impact of arrival rerouting on STAs before the reroutes are implemented (i.e., a trial planner) are not currently available. TBFM is unable to determine the impact of such changes until they actually take place. This makes it very difficult for traffic managers to accurately evaluate the impact of any prospective change, especially when multiple flights are involved. XM/CS operations may exacerbate the impact of convective weather on arrival metering operations due to schedule interactions between Metering Points.

4 Proposed Solution (DRAW)

The Dynamic Routes for Arrivals in Weather (DRAW) system is a trajectory-based decision support capability for traffic managers, and is aimed at improving arrival traffic flow. DRAW aids Center Traffic Managers in identifying and evaluating route changes that improve arrival traffic flow efficiency and mitigate impact of weather constraints on their arrival metering operations [3]. DRAW combines the weather avoidance capability of NASA's Dynamic Weather Routes (DWR) with arrival-specific rerouting algorithms [4]. The arrival-specific rerouting algorithm continuously searches for reroute opportunities as track and flight plan data are updated. The DRAW's route trial planning capability is integrated with arrival scheduling components to allow the Traffic Management Coordinators (TMCs) at Centers to evaluate the impact of proposed DRAW reroutes on arrival scheduling before implementing them (see Figure 1). This integrated route and schedule trial planner could also be used by traffic managers to manually build and trial plan a route of their own choosing.

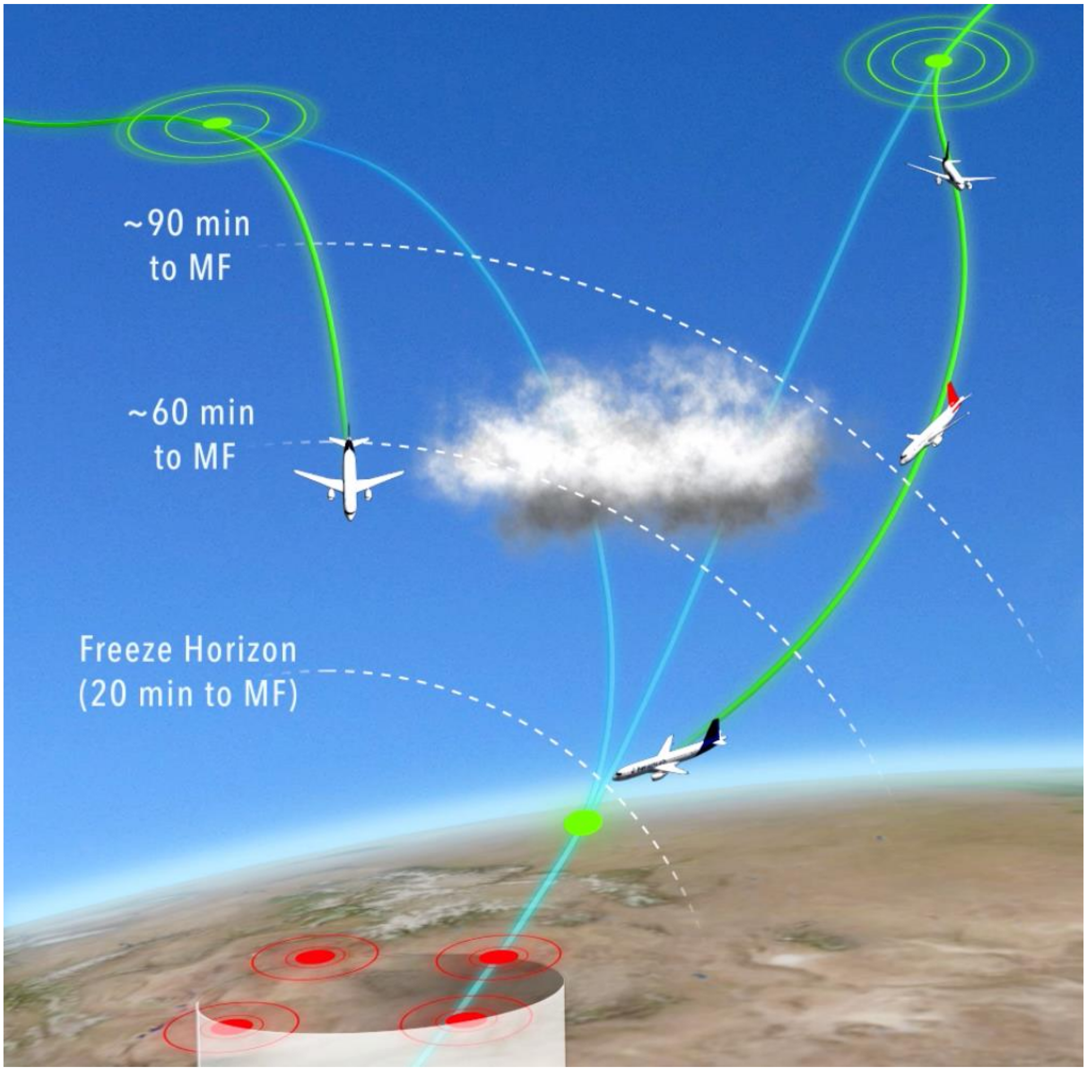

Figure 1: DRAW Operational Environment: Current Arrival Metering Operations

4.1 DRAW System Description

The DRAW system is intended to reside in Center Traffic Management Units (TMUs) as a decision support tool for TMCs. DRAW is capable of providing route advisories early enough to be implemented before the flight reaches the scheduling freeze horizon (Figure 2), or in the case of XM/CS operations, after crossing a MP and before the downstream freeze horizon. Rerouting a flight before the scheduling freeze horizon is operationally preferable because it allows the arrival scheduling system (e.g., TBFM) to adjust its STAs and resulting schedule delay before arrival controllers need to work the flight. However, DRAW may be configured to provide route advisories for flights with frozen STAs; manual STA assignment or schedule rippling by the TMC may be necessary to accommodate such advisories, or they may be acceptable if the resultant delay is manageable within the existing schedule. Due to the effect of weather uncertainty on trajectory predictions, this capability may be particularly useful in cases where the freeze horizon is especially long/distant.

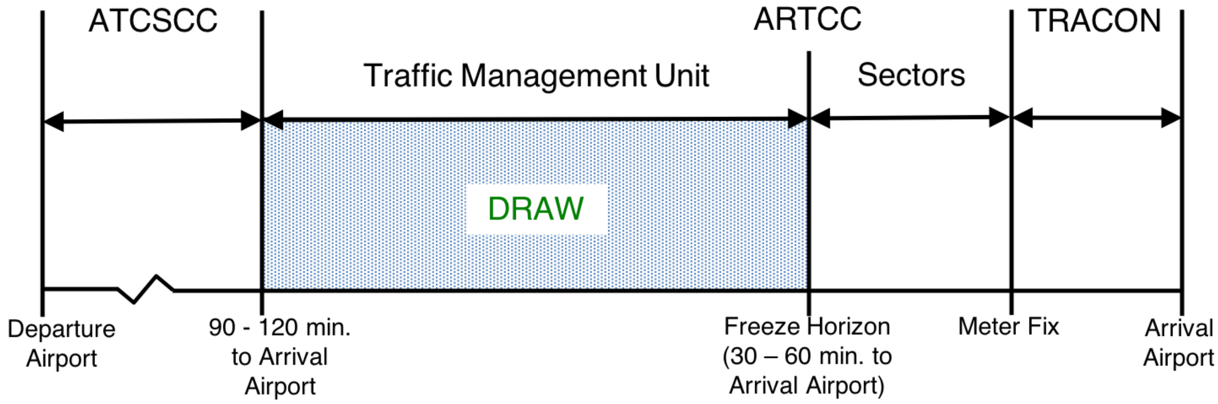

Figure 2: DRAW Operational Time Horizon

The DRAW interface utilizes two displays, a planview map display (e.g., Planview Graphical User Interface, PGUI) and a scheduling timeline display (e.g., Timeline Graphical User Interface, TGUI). An example of the current DRAW interface is shown in Figure 3. Key features include the DRAW Advisory List which displays proposed reroutes, and an integrated route and schedule trial planner that allows routes and corresponding schedule impact to be evaluated simultaneously.

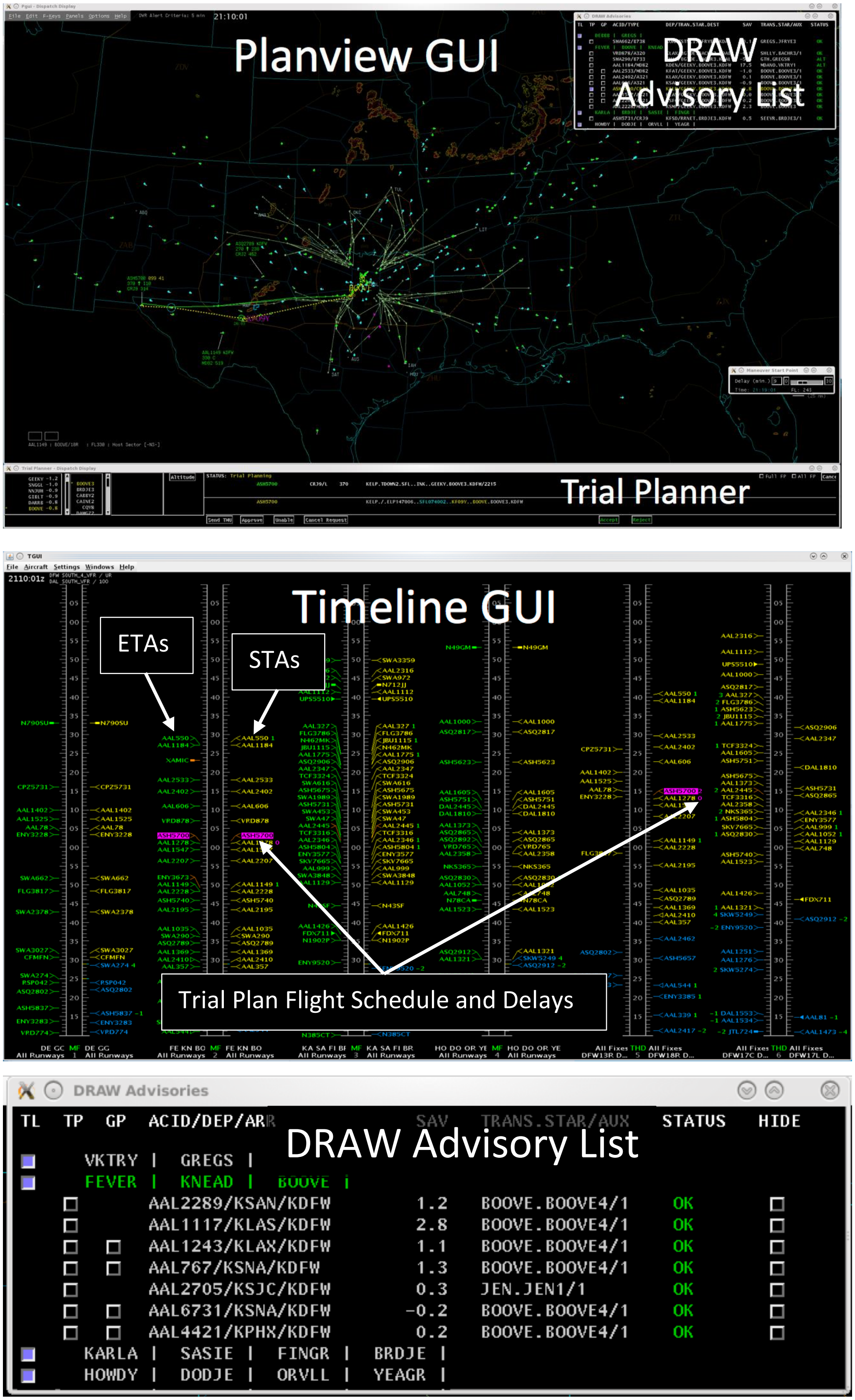

Figure 3: DRAW System Interface

DRAW's trajectory-based route trial planner functionality is implemented on the PGUI, which provides TMCs the ability to initiate a trial plan by modifying either a DRAW-proposed route or the flight's current flight plan route (including the assigned Standard Terminal Arrival Route or STAR). Modifications can be made to the point at which the flight deviates from the flight plan route (maneuver start point or MSP), the point at which the flight returns to the original flight plan route (return capture fix or RCF), and additional auxiliary waypoints. The trial plan trajectory automatically updates the flight's ETA, weather conflict status, and/or changes to the flight trajectory. The PGUI may be displayed in both the 'home TBFM' ARTCC TMU as well as adjacent facilities. DRAW trial planning functionality is available at each TBFM PGUI.

The impact of the trial plan route and the updated ETA on the meter point(s) and runway ETAs/STAs for all impacted flights are calculated by the integrated trial scheduler (embedded in the TBFM system), and displayed on the TGUI(s), without actually implementing the reroute. TGUIs can be configured to display trial plan impacts on schedules to both Arrival Group (MFs, runways) and EDC Group (XMPs, CMPs) metering points and may reside in either the 'home' ARTCC TMU or the adjacent facility TMU (if desired and as needed).

The DRAW system utilizes current and forecasted convective weather data to calculate polygon-based weather avoidance fields. DRAW currently uses MIT Lincoln Labs developed Corridor Integrated Weather System (CIWS) and Convective Weather Avoidance Model (CWAM) for convective weather data and weather avoidance polygons, respectively[5]. However, other convective weather models could be used by DRAW so long as the resulting weather avoidance fields are represented by polygons.

DRAW combines a Center-based trajectory to the meter fix with a TRACON trajectory, such as the one developed for Terminal Sequencing and Spacing (TSAS), to give full weather detection coverage from en route airspace to runway. An example of DRAW's trajectory-based weather detection capability and forecasted convective weather models is shown in Figure 4. Two weather products are displayed: current weather and forecast weather. Figure 4 shows current weather (thin, nested contours indicating severity) provided by the CIWS. When the TMC uses the trial planner capability, DRAW detects and highlights forecasted weather conflicts and nearby convective weather avoidance polygons corresponding to the flight's predicted time along the trajectory. Weather avoidance polygons are derived from weather forecasts to model regions that flights should avoid when considering a reroute. The weather avoidance fields (WAFs) in Figure 4 (bold yellow and cyan polygons) are derived from CIWS forecast data by CWAM and represent the regions that 70% of pilots are likely to avoid. *Note: Weather polygons are only displayed during trial planning but not when DRAW's rerouting algorithm is analyzing trajectories for conflicts internally.*

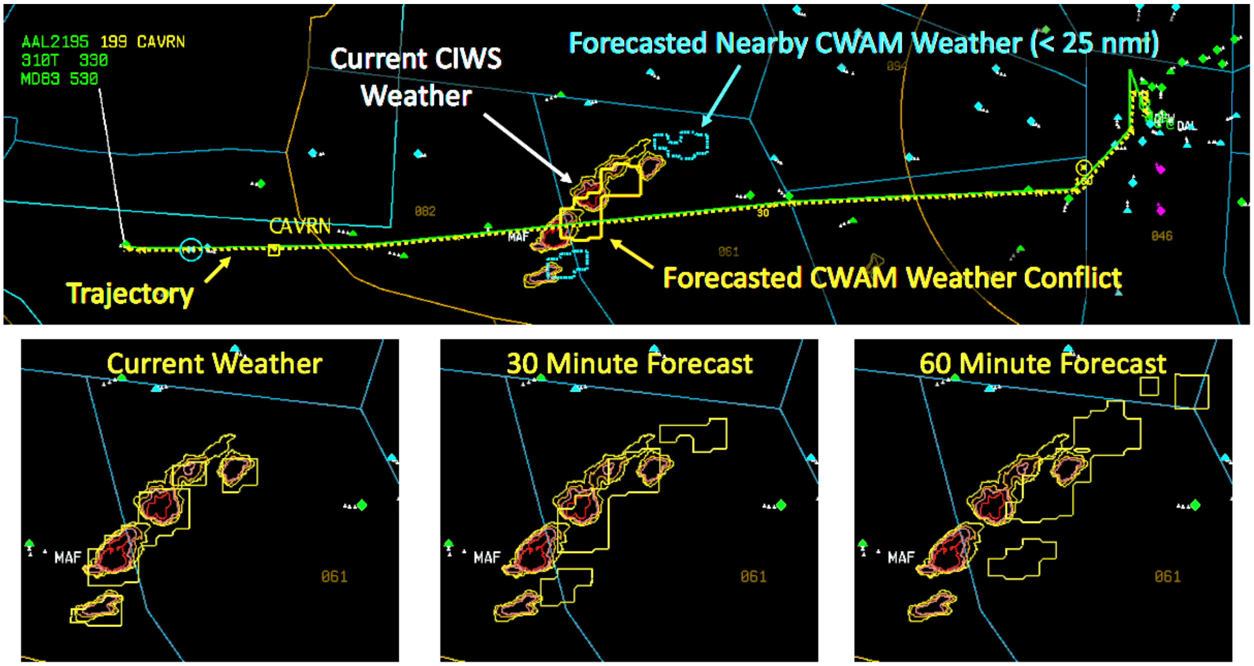

Figure 4: Trajectory-Based Weather Modeling

4.2 DRAW Route Advisory Types

The DRAW routing algorithm continuously analyzes flight trajectories for opportunities to improve arrival traffic flow. Arrival trajectories are analyzed to determine if they meet criteria that would trigger DRAW to generate one of two types of DRAW route advisories, time-saving routes to alternate meter fixes and route corrections to avoid weather. DRAW route advisories are calculated for individual flights and for groups of flights when the specified criteria are met. The trial planner may also be used to manually create a route at any point including inside of the freeze horizon.

4.2.1 Time-Saving Routes to Alternate Meter Fixes

Section 2.1 describes the problem of inefficient or obsolete weather avoidance routes. In these situations, the weather may move or not materialize as predicted, thus providing an opportunity to reroute flights to save time. For each arrival flight, DRAW searches for time-savings opportunities by comparing the flight's current flight plan trajectory with a series of trajectories along STARs to alternate meter fixes and STAR transitions. If time-savings is in excess of the user defined threshold (e.g., 5 minutes), a DRAW route advisory will be triggered.

In the example shown in Figure 5, STARs to Meter Fix 1 (MF1) were originally blocked by weather, causing flights to file less efficient southerly routes to Meter Fix 2 (MF2, shown in green). DRAW analyzes more direct routes available to MF1 and triggers route advisories for multiple flights (AC4 and AC5) that save 5 minutes or more in flight time due to weather movement away from Meter Fix 1. The proposed DRAW routes and their corresponding metering impacts are shown in magenta.

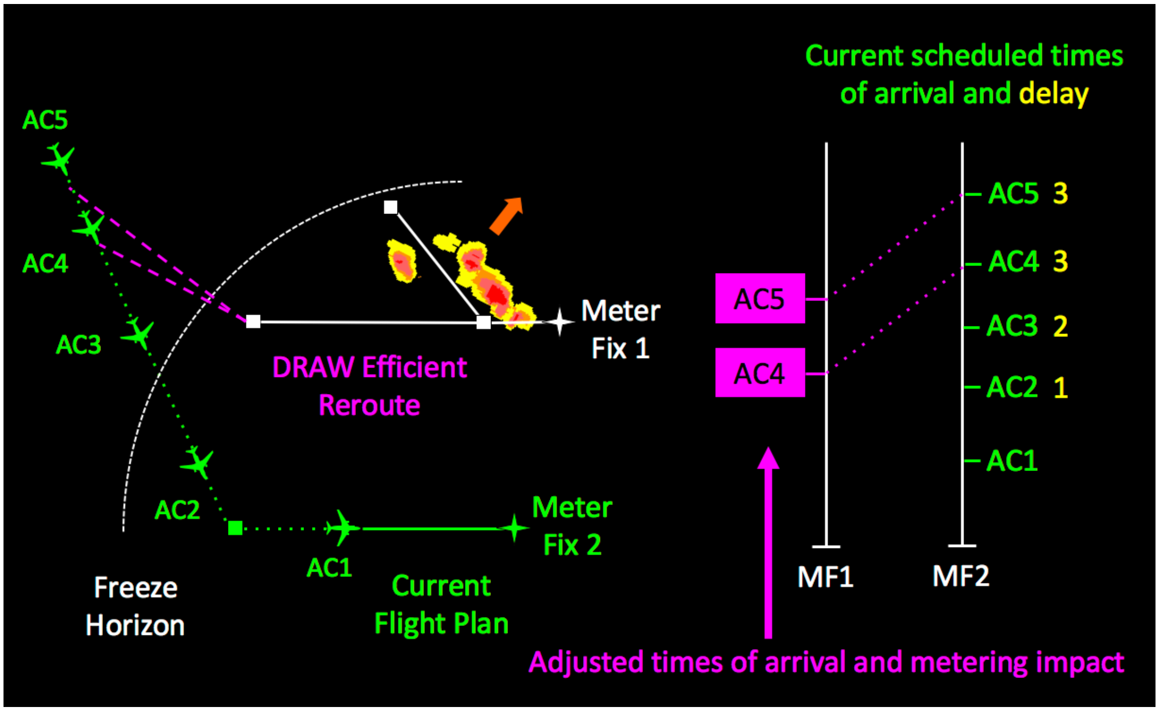

Figure 5: DRAW Time-Saving Routes

4.2.2 Route Corrections to Avoid Weather

DRAW provides reroutes advisories intended to help sustain metering operations in the presence of weather. A notional example illustrating a DRAW reroute for weather is shown in Figure 6. The current flight plan of AC1, shown on the left in green, is predicted to conflict with weather. A simplified TGUI timeline for Meter Fix 1 (MF1), on the right in Figure 6, shows the current times of arrival for AC1, as well as AC2, in green. These STAs are based on the current flight plans, and do not reflect the need to deviate around weather. As a result, these STAs are outdated and cannot be used for metering.

DRAW's dynamic weather avoidance function detects the weather conflict, which in turn triggers DRAW to calculate a route correction around the weather and post it on the DRAW Advisory List. The proposed reroute around the weather and the corresponding STA and delay are shown in magenta in Figure 6. DRAW calculates a reroute to avoid the conflict and return to the currently assigned STAR, if possible. If returning to the current STAR is not possible, DRAW will attempt to reroute the flight to the most efficient weather-free alternate STAR. The minimum user defined time-savings criteria described in 4.2.1 does not apply in this case because avoiding weather takes precedence over saving time.

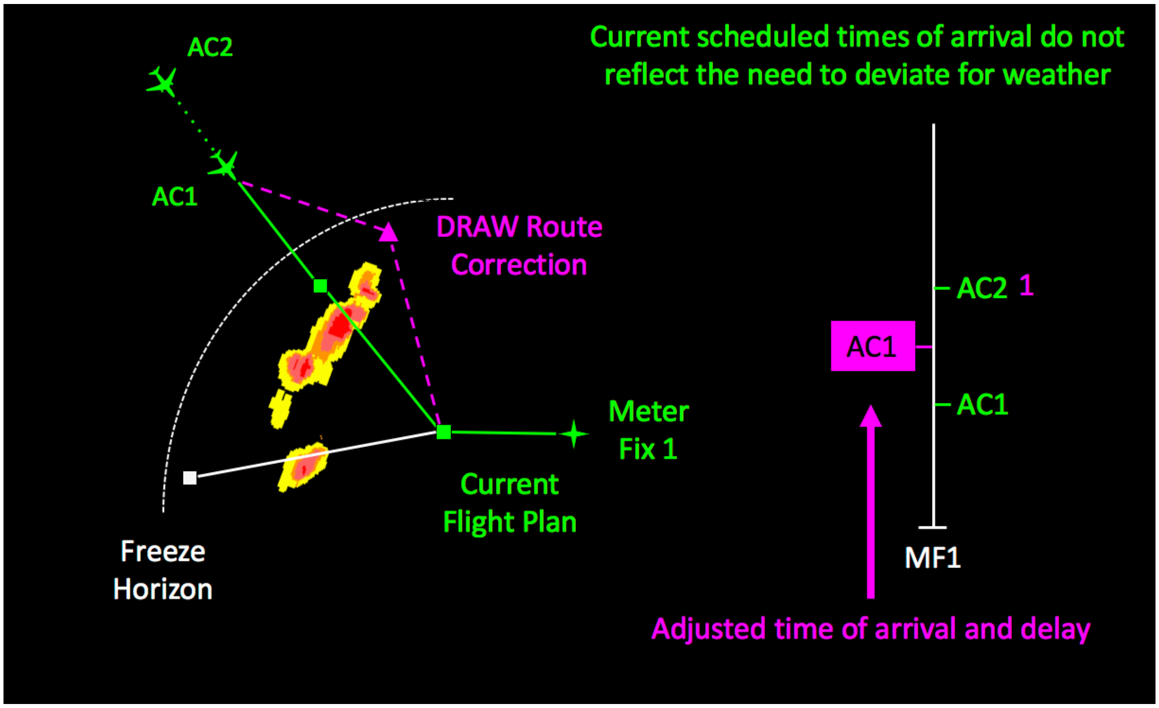

Figure 6: DRAW Route Correction for Weather

4.3 DRAW Procedures

The DRAW system is a decision support tool for TMCs and does not change the current procedures by which reroutes are implemented in the NAS. Figure 7 depicts a notional coordination procedure for implementing a DRAW route advisory. Using the DRAW system, the TMC selects a DRAW route advisory from the DRAW Advisory List. In doing so, the advised DRAW route(s) is loaded into the integrated route and schedule trial planner so that the TMC can evaluate before implementing. The DRAW trial planner provides functionality for the user to modify and evaluate the route being trial planned as desired. The TMC would then coordinate (via adjacent Center TMU, if necessary) with the Area Supervisor who would in turn coordinate with the appropriate sector controller to implement the reroute. Figure 7 also shows alternate means of rerouting should Airborne Reroute (ABRR) and/or Data Comm become available: mechanisms that DRAW would employ to relay reroutes to the controller's En Route Automation Modernization (ERAM) display and to digitally communicate reroutes to the flight crew, respectively.

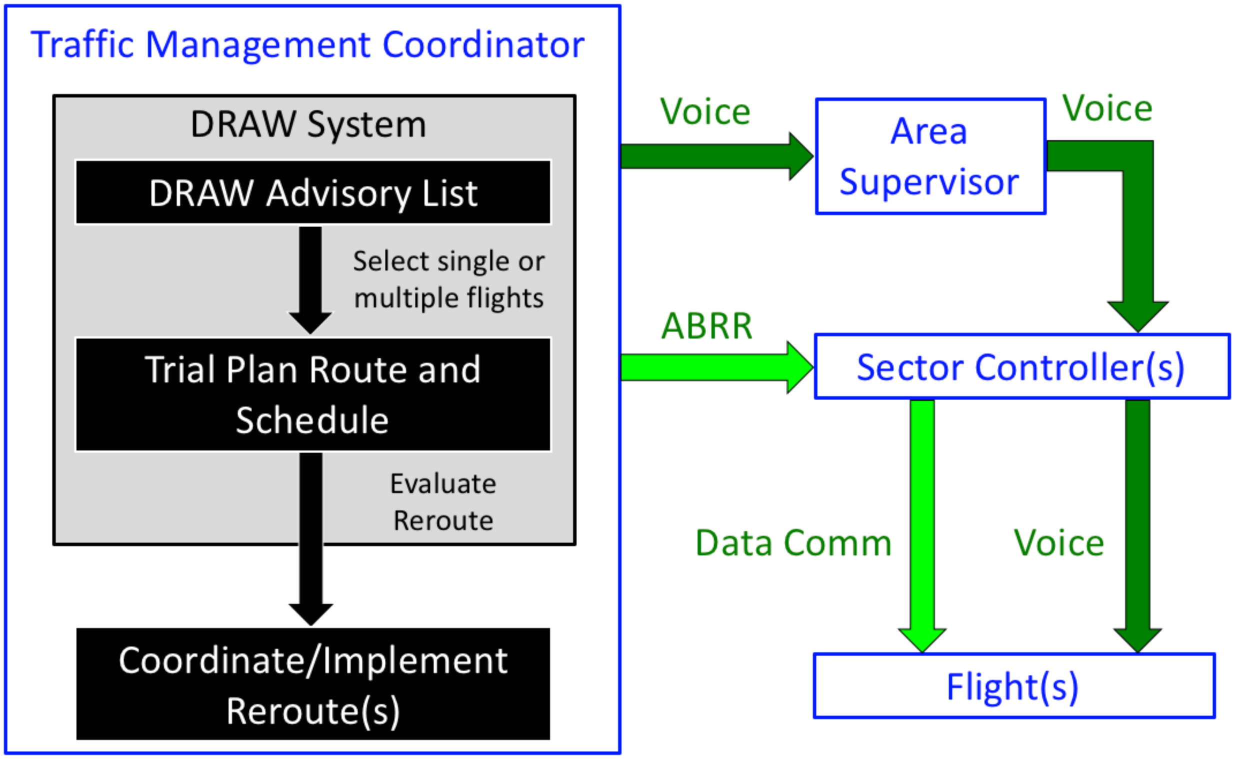

Figure 7: Notional Reroute Procedure for DRAW Advisories

4.3.1 Reroute Coordination

While DRAW does not introduce new procedures for implementing reroutes, the way in which current procedures are utilized to coordinate reroutes may impact the viability of the DRAW tool and/or the extent of its use. The level and extent of required coordination is determined by the operational constraints on reroutes and the facilities involved in imposing those constraints. Three levels of required coordination are considered here: Intra-Facility Coordination, Tier-One Facility Precoordination, and Multi-facility Coordination.

Intra-Facility Coordination: Some reroutes (e.g., those internal to the 'home' TBFM ARTCC) require no inter-facility coordination and can be coordinated with relative ease between the TMU, area supervisors and controllers within the same ARTCC (even for individual or small groups of flights). Personnel within the same facility are likely to already be aware of key operational constraints on arrivals and be able to effectively assess/modify proposed weather avoidance reroutes. Such coordination could be achieved via telephone between TMCs and Area Supervisors and verbally between Area Supervisors and Controllers.

Tier-One-Facility Precoordination: When flights are rerouted while located in an adjacent Center's airspace, coordination with that facility is required since TMCs in the 'home' ARTCC may not be aware of operational constraints in the adjacent facility that would preclude a proposed reroute. A number of methods have been proposed by TMC participants for precoordinated DRAW reroutes across facility boundaries. For example, by precoordinating navaids/sectors and preferred arrival transition routing for flights arriving from a given flow (e.g., DFW arrivals from Chicago area), real-time inter-facility coordination for individual reroutes may be largely eliminated and replaced by perishable agreements that ‘grease the skids’ for near-term reroutes. This method of precoordination would require input from sectors/areas to the TMCs coordinating the reroute plan. This approach is analogous to a more tactical/dynamic playbook rerouting. Alternatively, each facility would be responsible for rerouting as necessary to avoid weather and meet internal operational constraints while meeting agreed-upon inter-facility boundary conditions. The extent to which boundary conditions can be precoordinated (e.g., telecon or Letter of Agreement) is a topic for further research.

Multi-Facility Coordination: Coordination of reroutes across multiple facilities could be managed in real time (without precoordination) either manually or supported by electronic requests/approval. Manual coordination would employ the same methods currently used for reroutes, but would be informed by DRAW weather conflict prediction and integrated trial planning capability. Integrated trial planning would allow each facility to review both weather and schedule impact of proposed reroutes. Thus, the number of iterations on a viable reroute may be reduced and the efficacy of reroutes in actually avoiding convective weather would improve. Due to the complexity of manually coordinating operational constraints across multiple facilities in real-time, this method would be used primarily for groups of aircraft and be relatively infrequent for individual flights (likely limited to acute situations or at operator request, time permitting).

Electronic approval requests (APREQs) could replace many telephone calls to expedite the approval process and allow TMCs to conduct other tasks while awaiting approval for route modifications outside their airspace. Using APREQs, a TMC could build a trial plan reroute that includes changes beyond the boundaries of their airspace, and await electronic approval of those changes. If the proposed reroute was approved by the other involved TMU(s) without modification, the reroute would be implemented as originally proposed. If additional changes are required by other TMUs, those changes could be coordinated with additional APREQs or (if sufficiently complex) via telephone. The APREQ approval chain for DRAW reroutes are only intended to facilitate coordination and is not intended as a safeguard against reroutes without proper coordination; the facility with track control of a flight may issue a reroute without proper coordination in the current system, and DRAW is not intended to change that capability.

4.3.2 Reroute Implementation

Successful coordination of a DRAW trial plan results in a pending flight plan amendment (or group of amendments) that is either explicitly or implicitly approved by the proper authority within the TMU of each involved facility. Implementation of this would be accomplished in one of three ways: 1) current practice (voice implementation), 2) Airborne Reroute (ABRR), or 3) a combination of 1) and 2). Lacking integrated ABRR capability (with TBFM or via a TFMS connection), a pending flight plan amendment would be communicated by voice to sector controller (directly or through the area supervisor) for clearance to the flight crew and entry into ERAM. Because of the requirement for entry into ERAM and because of the potential for error in communication and readback of route amendments, it is desirable that reroutes are not overly complex (i.e., routes should avoid use of Fix-Radial-Distance waypoints if possible).

In a more advanced implementation, TBFM could send a reroute directly to ERAM via the ABRR interface even across facilities since, presumably, a pending amendment has been fully coordinated and approved. It is unclear, though, if this use of ABRR (direct to ERAM from a system other than TFMS) is envisioned or advisable at this point in time.

More likely in an ABRR environment is that some mix of voice communication of reroutes (or electronic log messages to those with access to intrafacility ABRR) and ABRR implementation of reroutes within a single facility will be employed. This solution would reduce systems integration requirements, instead relying on telephone calls and electronic messages to employ existing reroute methods.

4.4 DRAW Use Cases

DRAW assists traffic managers by continuously evaluating flights to identify opportunities to improve arrival traffic flow. Use cases for the two types of DRAW route advisories are described below.

4.4.1 Time-Saving Route to Alternate Meter Fix

Use Case Name:	DRAW Advisory for Time-Saving Route to Alternate Meter Fix or STAR transition route
Summary:	The DRAW system receives current arrival flight plan trajectories and analyzes them for opportunities to save time. Note: DRAW advisories are proposed for airborne arrival flights only.
Pre-conditions:	Data from external sources must be acquired to define the constraints and the filed flight plans: • ERAM: Flight plan and tracks from home and first-tier adjacent Centers • (At least) hourly wind updates (e.g., NOAA Rapid Refresh) • Current and forecasted weather data (e.g., CIWS) • Polygon-based weather avoidance fields (e.g., CWAM) • TBFM: metering data such as metering status, scheduled times of arrival (STAs) for metered flights, schedule delay, metering constraint definitions (and rules for applying them)
Trigger Events:	New or periodically updated flight track information
Nominal Actions:	1. DRAW continuously analyzes current arrival flight plans for opportunities to save time by rerouting to an alternate meter fix. **A flight that can save more than a user specified time (e.g., 5 minutes) triggers a DRAW route advisory**. 2. The traffic manager observes the DRAW advisory list and/or receives audible alert indicating a DRAW route advisory for time-saving reroute has been proposed. 3. The traffic manager initiates DRAW's integrated route and schedule trial planner by selecting the DRAW route advisory. 4. The traffic manager reviews the DRAW advisory trial plan (i.e., route and schedule impact) and either approves, modifies or rejects the DRAW route advisory. 5. If rejected, DRAW will continue to evaluate flights for unresolved weather conflicts. 6. Once approved (as proposed or modified), the reroute is communicated to the controller currently handling the flight with voice communications via the front-line manager, or via ABRR digital communications.
Alternative Paths:	In addition to individual flight advisories, the DRAW system is capable of proposing group advisories involving multiple flights with similar solutions

4.4.2 Route Correction to Avoid Weather

Use Case Name:	DRAW Route Correction Advisory to Avoid Weather on Current Flight Plan
Summary:	The DRAW system receives current arrival flight plan trajectories and analyzes them for conflicts with weather. For those flight trajectories where weather conflicts are detected, DRAW proposes route correction advisories to avoid the weather. Note: DRAW advisories are proposed for airborne arrival flights only.
Pre-conditions:	Data from external sources must be acquired to define the constraints and the filed flight plans: • ERAM: Flight plan and tracks from home and first-tier adjacent Centers • (At least) hourly wind updates (e.g., NOAA Rapid Refresh) • Current and forecasted weather data (e.g., CIWS) • Polygon-based weather avoidance fields (e.g., CWAM) • TBFM: metering data such as metering status, scheduled times of arrival (STAs) for metered flights, schedule delay, metering constraint definitions and applicability rules
Trigger Events:	New or periodically updated flight track information
Nominal Actions:	1. The DRAW system continuously monitors current arrival flight trajectories for conflicts with weather. **A flight with a detected weather conflict triggers DRAW to automatically search for a route correction that will avoid the weather**. 2. The traffic manager observes the DRAW advisory list and/or receives audible alert indicating a DRAW route advisory to avoid a detected weather conflict has been proposed. 3. The traffic manager initiates DRAW's integrated route and schedule trial planner by selecting the DRAW route advisory. 4. The traffic manager reviews the DRAW advisory trial plan (i.e., route and schedule impact) and either approves, modifies or rejects the DRAW route advisory. 5. If rejected, DRAW will continue to evaluate flights for unresolved weather conflicts. 6. Once approved (as proposed or modified), the reroute is communicated to the controller currently handling the flight with voice communications via the front-line manager, or via ABRR digital communications.
Alternative Paths:	In addition to individual flight advisories, the DRAW system is capable of proposing group advisories involving multiple flights with similar solutions

5 Technologies and Dependencies

The DRAW concept utilizes NASA-developed, trajectory-based routing technology and operational FAA scheduling automation.

5.1 NASA Technologies

Dynamic Weather Routes (DWR) – This trajectory-based routing capability continuously searches active en route flight trajectories and recommends more efficient routes that avoid convective weather, and other airspace constraints, and return to the original flight plan routes prior to assigned STARs [4]. DRAW integrates DWR's field tested, trajectory-based weather avoidance functions with a newly developed, arrival specific route and schedule trial planning capability.

5.2 FAA Automation

Time Based Flow Management (TBFM) – The FAA's operational system for time-based metering operations. Integrating DRAW into TBFM ensures that scheduling impacts of proposed reroutes can be accurately assessed by the TMC before they are implemented. This is a result of DRAW's utilization of TBFM's trajectory modeling at the core of its arrival-specific rerouting algorithm and integrated route-schedule trial planner.

Airborne Reroute (ABRR) – The FAA's Airborne Reroute capability provides Traffic Managers and controllers an efficient electronic means of implementing reroutes. Although the DRAW concept does not propose to change rerouting procedures, reroute enablers such as ABRR promise to enhance the effectiveness of rerouting tools such as DRAW. ABRR functionality resides within the Traffic Flow Management System (TFMS), while DRAW functionality resides within TBFM. Two possible solutions are: 1) develop an electronic interface between TBFM and TFMS for ABRR functionality to be available for DRAW benefit/efficiency, or 2) Allow DRAW to send reroute requests via the ABRR protocol directly to ERAM (similar to metering lists). ABRR is a capability-enhancing dependency; DRAW performance using other means of coordination may be fully acceptable without ABRR, but DRAW operations are expected to benefit from ABRR availability.

Data Comm – Data Comm is not expected to be available or mature enough for arrivals until well after DRAW demonstrations or initial implementation. However, it is a critical and integral part of future air traffic automation. It is expected to significantly reduce controller and flight crew workload, reduce radio frequency congestion, and greatly improve air/ground system integration. Integration of Data Comm will allow controllers and flight crews to more easily exchange data (e.g., operator preferences, proposed trajectory changes), review and negotiate reroutes, load proposed reroutes into ground and flight deck automation systems, and improve the situational awareness of both parties. Data Comm is a capability-enhancing dependency; DRAW performance may be fully acceptable without Data Comm, but DRAW operations are expected to benefit from Data Comm availability.

6 POTENTIAL FUTURE ENHANCEMENTS

This section describes potential future enhancements that could be made to DRAW. The research and development of potential enhancements described below is out-of-scope for the current DRAW project plans.

6.1 METER FIX DEMAND OFFLOADING

In nominal conditions, arrival traffic demand across available arrival fixes and runways results in a managable amount of delay. Delay and, consequently, controller workload may become high when convective weather or other constraints block access to some arrival routes requiring traffic to be rerouted to the remaining available fixes. This scenario may continue even after the constraint subsides or fails to materialize as expected. A similar situation may occur during a period of high demand when a large number of flights are assigned the same arrival route and arrive at nearly the same time [6][7]. This can result in excess demand and delays on some routes, while other routes go underutilized.

High arrival scheduling delay is an indicator of excessive meter fix demand. Excessive meter fix demand may be mitigated by rerouting select flights to underutilized fixes. Because DRAW is integrated into TBFM, it monitors all arrival flights for excessive scheduling delay. When scheduling delay above a user-specified threshold is detected (e.g., 7 minutes), an analysis is triggered to determine if there is an opportunity to offload meter fix demand with DRAW route advisories to alternate meter fixes via published Standard Terminal Arrival Route (STAR) transitions. DRAW would use a number of cost metrics such as individual schedule delay, individual flight time, and overall system delay to determine if meter fix demand can be efficiently offloaded with flight reroutes alone. If reroutes are not enough, some flights may still need to be delayed using traditional methods (e.g., Miles-in-Trail or MIT).

In the example shown in Figure 8, AC7 and AC8 each have scheduling delays at the specified threshold of 7 minutes, indicating Meter Fix 2 has excessive demand. This would trigger DRAW to analyze flights that may be efficiently rerouted, or offloaded, from MF2 to reduce schedule delay. A DRAW route advisory is found for AC6 which reroutes the flight to the transition fix leading to MF1. Flight time for AC6 is increased as indicated by its later time of arrival shown in magenta. However, schedule delay for AC7 and AC8 are reduced below the 7-minute threshold as a result of reduced demand at MF2. Although AC6 experiences a slight longer delay due to being routed to another fix (i.e. 4 vs 3 minutes), that is offset by 12 minutes in delay reduction for AC7 and AC8, thus there is an aggregate system delay reduction of 11 minutes across all arrivals.

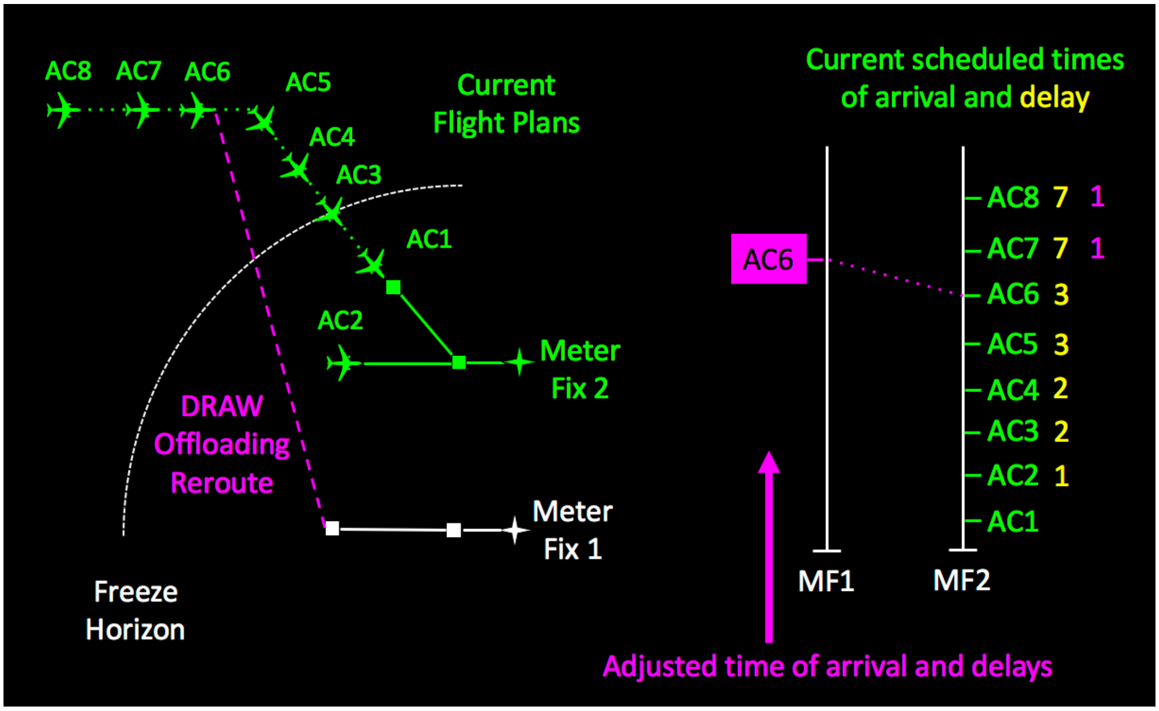

Figure 8: DRAW Meter Fix Demand Offloading

6.2 ‘What-if’ Scheduling

TBFM is used by TMCs to schedule arrivals according to a set of operational constraints (e.g. flow constraints, airport configuration, acceptance rate, etc.). The impacts of changes in these parameters on metering delays are not known until after a change is entered into the TBFM system; TMCs must anticipate the impact of proposed changes based solely on prior experience. When a change to the scheduling constraints results in undesirable schedule attributes (e.g., excessive delay), it is not possible to restore the original metering plan. TMCs must either mitigate the impacts or attempt to back out the recent changes. As a result, there can be some reluctance on the part of TMCs to evaluate a potential change in the metering plan. A ‘What-if’ capability would allow TMCs to assess estimated impacts to the TBFM schedules prior to implementation of a proposed change and still enable them to revert to the existing metering plan if the provisional plan did not produce the desired improvement. DRAW employs a reroute trial planning capability that creates multiple scheduling ‘threads’. While limited to the assessment of scheduling impacts resulting from proposed reroutes in this operational concept, the software design supports evaluation of other proposed schedule changes (e.g., airport configuration change) with limited modifications to the software.

7 SUMMARY

The ATD-3 DRAW concept promises a step forward in arrival traffic flow management capability. DRAW provides automation tools to support TMC identification and planning of reroutes that may lead to increased efficiency during arrival operations that are impacted by convective weather or other airspace constraints. It leverages existing and planned Control, Navigation, and Surveillance (CNS) and automation technologies to provide enhancements not possible with legacy systems. Given a significant percentage of total flight delays are caused by convective weather in the arrival phase of flight, DRAW has the potential to greatly reduce the cost of such delays in the National Airspace System. Additionally, DRAW capabilities permit expanded use of traffic metering and supports NextGen trajectory-based operations (TBO) by providing 4D reroutes in lieu of undefined radar vectors and pilot deviations around weather. In doing so, DRAW integrates en route and terminal operations.

8 REFERENCES

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9 GLOSSARY

Acronym	Name	Description
4-D	Four Dimensional [trajectory]	Planned trajectory defined laterally in two dimensions, plus altitude and time/speed
ABRR	Airborne Reroute	A digital communication tool built into TFMS to allow traffic managers to send electronic data to ERAM to communicate reroutes to sector controllers.
ACM	Adjacent Center Metering	A capability used to distribute arrival metering delay to an upstream, adjacent Center when arrival delay exceeds a prescribed threshold within the host TBFM Center.
ARTCC	Air Route Traffic Control Center	Also known as a 'center', this facility is responsible for controlling aircraft en route in a particular volume of airspace at high altitudes between airport approaches and departures. There are 20 ARTCCs in the contiguous United States.
ATC	Air Traffic Control or Controller	A person or group of people responsible for managing, directing and separating air traffic.
ATCSCC	Air Traffic Control System Command Center	The FAA facility that oversees the system-wide flow of air traffic and coordinates the actions of ARTCCs and TRACONS.
ATD	Airspace Technology Demonstration	A project under NASA's Airspace Operations and Safety Program intended to advance traffic management operations in the NAS. ATD-1=Approach, ATD-2=Departure, ATD-3=En route & arrival
CIWS	Corridor Integrated Weather System	3D convective weather forecasts with 0-2 hours predictions

		of cell development and movement.
CWAM	Convective Weather Avoidance Model	Utilizes CIWS predicted convective cell movement to determine if a candidate reroute will avoid convective cells by a large enough margin to satisfy flight crews.
Data Comm	Data Communications	Generic term used to describe a digital communication system between controllers and pilots to exchange data, issue clearances or instructions, and make requests.
DWR	Dynamic Weather Routes	ATD-3 component: A ground-based trajectory automation concept that continuously analyzes in-flight aircraft in en-route airspace to find time- and fuel-saving corrections to convective weather avoidance routes.
DRAW	Dynamic Routing for Arrivals in Weather	NASA technology prototype to improve arrival route efficiency and metering.
ERAM	En Route Automation Modernization	The FAA's computer system for tracking and predicting the flow of air traffic.
ETA	Estimated Time of Arrival	Time a flight is predicted to reach a defined point based on current position, assigned route and planned speed(s)
MFCR	Multi-Flight Common Route	ATD-3 component: DWR extended to multiple flights for weather and other airspace constraints in en route phase.
MIT	Miles in Trail	An air traffic spacing procedure used to meter traffic along a route in order to manage demand.
MSP	Maneuver Start Point	The point along a flight planned route at which a DWR reroute begins.
NAS	National Airspace System	The National Airspace System is the interaction of commercial aviation, civilian aviation, the FAA, vendors, suppliers, and related parties and agencies.

RCF	Return Capture Fix	The waypoint at which a DWR reroute joins the original flight plan route.
STA	Scheduled Time of Arrival	Metering time assigned to a flight to sequence and separate it as desired
STAR	Standard Terminal Arrival Route	Published procedures that provide routing information to take aircraft from the en route cruise phase of flight to the beginning of an instrument approach procedure to an airport.
SWAP	Severe Weather Avoidance Plan	SWAP is a TMI that utilizes a subset of national predefined routes (Playbook routes) to divert traffic around significant current or predicted constraints, usually convective weather
TASAR	Traffic Aware Strategic Aircrew Request	NASA technology program that enables aircrews to identify and request more efficient routes while in flight.
TBFM	Time Based Flow Management	Time-based traffic metering system used to monitor and meter airborne traffic demand.
TFM	Traffic Flow Management	Generic term for personnel, procedures, and decision support tools used to meter and manage traffic demand.
TFMS	Traffic Flow Management System	Traffic flow automation utilized by traffic managers to monitor demand and manage TMIs.
TMC	Traffic Management Coordinators	FAA employee responsible for the flow of aircraft through or within the center’s airspace, not for maintaining separation between individual aircraft.
TMI	Traffic Management Initiative	Generic term used to describe various traffic flow management operational tools and procedures to manage and meter traffic demand.

TMU	Traffic Management Unit	Department of ARTCC or TRACON in which TMCs manage traffic using TFM tools.
TRACON	Terminal Radar Approach Control	FAA air traffic control facility responsible for managing traffic at airports with high traffic demand.
TSAS	Terminal Sequencing and Spacing	NASA technology developed by ATD-1 that enables metering in the TRACON.