Air Traffic Management Technology Demonstration – 3 (ATD-3) Dynamic Weather Routes Domestic En Route Concept of Operations Synopsis
Version 1.0

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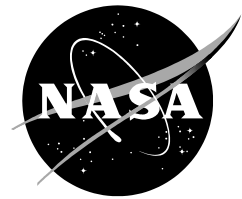
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V1.0	September 23, 2016	-	Initial baseline version. Includes revisions from SFMA team review feedback.	D. Helton, A. Ging

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1 INTRODUCTION

Increasing the capacity and efficiency of the National Airspace System (NAS) is a primary goal of the FAA's NextGen program. With the advent of area navigation capability and direct routing enabled by air traffic automation upgrades over the past decade, capacity and efficiency for en route operations is generally high during fair weather conditions. However, the same is not true for en route operations during adverse weather. Automation system limitations and the associated policies and procedures, continue to present challenges in coping with adverse weather, and lead to excessive delays, fuel consumption and environmental impacts. Adverse weather, namely convection/thunderstorms, winds, turbulence, snow/ice, and visibility/low ceilings, is responsible for roughly 70% of the delays in US operations. Weather related delays were responsible for 32,000 minutes of average delay in the NAS during the summer of 2014 [1]. During significant convective activity, the FAA traffic managers use severe weather avoidance plans, or Playbook routes, to safely divert traffic around weather-impacted regions. These strategic plans devised two or more hours in advance of departure provide predictability, but introduce large deviations from the nominal routes. Automation that would notify traffic managers when weather constraints have changed and that avoidance routes may no longer be necessary is not available today. As a result, aircraft fly longer distances, consuming more time and fuel, with higher costs for the flight operators and the general public.

2 SCOPE

NASA conducted a survey in 2015 of stakeholders in industry, flight operators, and others to collect data on the most pressing air traffic management (ATM) issues impacting en route operations. Weather related delays and interruptions were identified as the most significant and costly problem impacting en route operations in today's system. Additionally, future traffic demands will place greater demands on the FAA's air traffic control system, necessitate a more efficient and integrated traffic management system and provide controller tools to leverage human productivity. Consequently, NASA is assembling a suite of integrated ground and aircraft-based technologies and decision-making aids under the Airspace Technology Demonstrations 3 (ATD-3) project to continuously search for more efficient weather-avoidance routes and to rapidly respond to weather changes and associated traffic management initiatives. These route efficiency enhancements are targeted at en route airspace and will enable continued use of en route and arrival metering in the presence of weather.

NASA's Dynamic Weather Routes (DWR) concept represents a subset of those technologies and focuses primarily on the cruise phase of flight. It leverages existing air traffic weather, airspace, and traffic data, as well as improvements in navigation, surveillance, communication and digital network technologies, and builds upon existing ATM automation to address the shortcomings associated with strategic traffic flow management initiatives and weather forecasting uncertainties. The potential benefits in the form of time, fuel, and cost savings are significant. This concept of operations synopsis provides a detailed description of DWR, its potential benefits and notional implementation paths.

3   CURRENT SYSTEM - SHORTFALLS

In today's operations, Traffic Management Initiatives, or TMIs, are necessary to ensure aircraft safely avoid areas of adverse weather and to meter traffic when demand in a given area exceeds air traffic control's capacity to safely separate aircraft. Although necessary for safety, route diversions and metering can be overly conservative due to uncertainty in weather forecasts and air traffic control capacity limitations in sectors adjacent to the weather.

When significant convective activity is forecasted to develop in an area of the NAS, FAA traffic managers identify those areas as Flow Constrained Area (FCA), and may implement Severe Weather Avoidance Plans (SWAP), or Playbook routes, to safely divert traffic around those weather-impacted regions. Playbook routes are identified 2 to 8 hours prior to the time the constraint is predicted to develop, to provide traffic managers and aircraft operators with ample time to prepare and assign the necessary resources where needed. This lead time combined with uncertainties in weather forecasts often results in overly conservative deviations around actual weather.

Playbook routes tend to be very conservative both geographically and temporally to account for uncertainties in forecast accuracy. This typically results in the selected playbook routes giving predicted weather-impacted areas a wide berth to account for those forecast uncertainties, and helps minimize subsequent changes, which can be complicated and time-consuming to implement once the SWAP routes are in play.

Additionally, these large-scale rerouting actions also tend to use a static approach by finding the best compromise between weather avoidance, controller workload, and route efficiency...prioritized in that order. Due to the difficulty in applying changes, aircraft often remain on conservative routes which are not required for weather avoidance. Modifying those routes for aircraft already in flight requires a lot of coordination and can be time-consuming. And there is no automation in the current system to help operators identify workable opportunities for time and fuel- saving corrections to weather avoidance routes that have become stale due to changing weather and forecast uncertainty.

Air traffic controllers, airline dispatchers and pilots can manually identify and request or amend these conservative routes as things progress to improve efficiency. However, the associated workload to do so is very high at a time when controllers and dispatchers are very busy. Consequently, aircraft often remain on circuitous routes long after the driving constraint is gone thereby incurring costly and unnecessary delays, and fuel consumption.

Airline flight dispatchers must file flight plans at least 45 min before push-back from the gate using their best available weather forecasts, but in practice flight plans are typically filed 1-2 hours before take-off. When SWAP routes are in effect, dispatchers determine which SWAP routes are applicable to a flight's planned route of flight and file a revised route accordingly.

Efforts have been made to apply more tactical operational tools to account for changes. A good example is the Collaborative Trajectory Options Program (CTOP), which allows operators to file multiple routes on a single flight plan based on the amount of departure delay to which the flight is subjected and the operators associated preferences for that flight. Although this provides a level of improvement over traditional single-route flight plans and rerouting procedures, it is still strategic in nature.

Therefore it provides no improvement in efficiency, flexibility and responsiveness to changes after departure.

Additionally, flight crews lack the tools to identify more efficient routes that will avoid congested airspace or conflicts with other aircraft. And although they can identify more efficient trajectories using flight management systems and weather radar, they are unable to see convective weather anywhere beyond the limits of their on-board radar. They often must consult either the controller or airline dispatch about alternate trajectories that will avoid large areas of adverse weather and flow restrictions, and must coordinate with the controller to ensure an alternate trajectory will not conflict with another aircraft.

Therefore, automation tools for controllers, dispatchers, and/or flight crews that can continuously monitor real-time and short-term weather forecasts, and dynamically find workable opportunities for time- and fuel-saving corrections to weather avoidance routes, have the potential to significantly improve the efficiency in both en route and terminal transition airspace.

4   DYNAMIC WEATHER ROUTES (DWR) SYSTEM DESCRIPTION

Over the past several years, NASA has developed and tested a ground-based concept called Dynamic Weather Routes (DWR) to automatically identify opportunities for more efficient trajectories around convective constraints [2][3][10]. DWR is trajectory-based concept that continuously and automatically analyzes in-flight aircraft within en route airspace to find simple amendments to flight plan routes that can save significant flying time, while accounting for convective weather, traffic conflicts, airspace sector congestion, special use airspace, and FAA routing restrictions. DWR then alerts the user to proposed route corrections and allows them to view and modify the route prior to requesting or issuing a new route clearance. Additionally, the DWR user interface provides strong warnings if a user modifies a DWR route such that its trial trajectory conflicts with forecast weather or traffic. Because there are various methods and degrees to which DWR could be implemented in FAA automation systems, the term "automation" as used in this paper is intended to be generic unless specified otherwise.

DWR is an extension of the Direct-To tool developed and tested at NASA from 1998 through 2001 [4], and as a result the Direct-To functionality of identifying conflict free, operationally acceptable, direct route clearances is an integral part of DWR. Any Direct-To route that meets the minimum wind-corrected, time-savings criteria (user-definable) will appear as a DWR route correction advisory regardless of the presence of convective weather.

Although DWR is designed to address weather related inefficiencies, its underlying logic of identifying and avoiding constraints defined by polygons would enable it to be applied to non-weather related obstacles. Doing so could result in substantial benefits in the form of fuel, emissions and controller/pilot workload savings.

DWR works by continuously and automatically analyzing in-flight aircraft operating within en route airspace above 10,000 ft to find opportunities for time- and fuel-saving corrections to weather avoidance routes, or simple wind-favorable direct to routes. Route corrections are simple route changes like those typically used in today's operations.

DWR analyzes and updates trajectories as new radar track and flight plan data are received [2]. DWR identifies flights that could save a user-defined minimum amount of time (default of five minutes) by short-cutting their current trajectory and returning to the flight plan trajectory via a downstream waypoint on their current flight plan route.

The DWR flight selection and route correction advisory logic are illustrated in Figures 1 and 2 and summarized as follows. All flights at or above 10,000 ft are continuously and automatically analyzed to determine if a direct route trajectory from a Maneuver Start Point (MSP) to a default Return Capture Fix (RCF) could save the user-defined minimum time or more in wind-corrected flight time. The MSP is programmable and currently defaults to a point 5 min downstream of present position or to the first point in the high altitude airspace. The default RCF for any flight is intended to approximate an operationally acceptable direct route clearance given the location and routing of the flight, the local airspace, and arrival routing limits at the destination airport. RCF selection is described in more detail below. It is assumed that if a direct route to the RCF, the so-called reference direct route, can save 5 min or more, the flight is likely on some kind of weather avoidance route. The reference direct route is then probed for weather and traffic conflicts. If weather conflicts are detected, DWR automation inserts one or two auxiliary waypoints as needed in an attempt to identify a minimum delay route around the weather. The MSP or any inserted waypoints may optionally be further adjusted automatically to achieve an integrated resolution to weather and traffic conflicts. If a solution is found that can save the minimum wind-corrected flight time as defined by the user (5 min default), then a DWR route advisory is posted to an alert list on the user display.

Figure 1: DWR Concept Overview
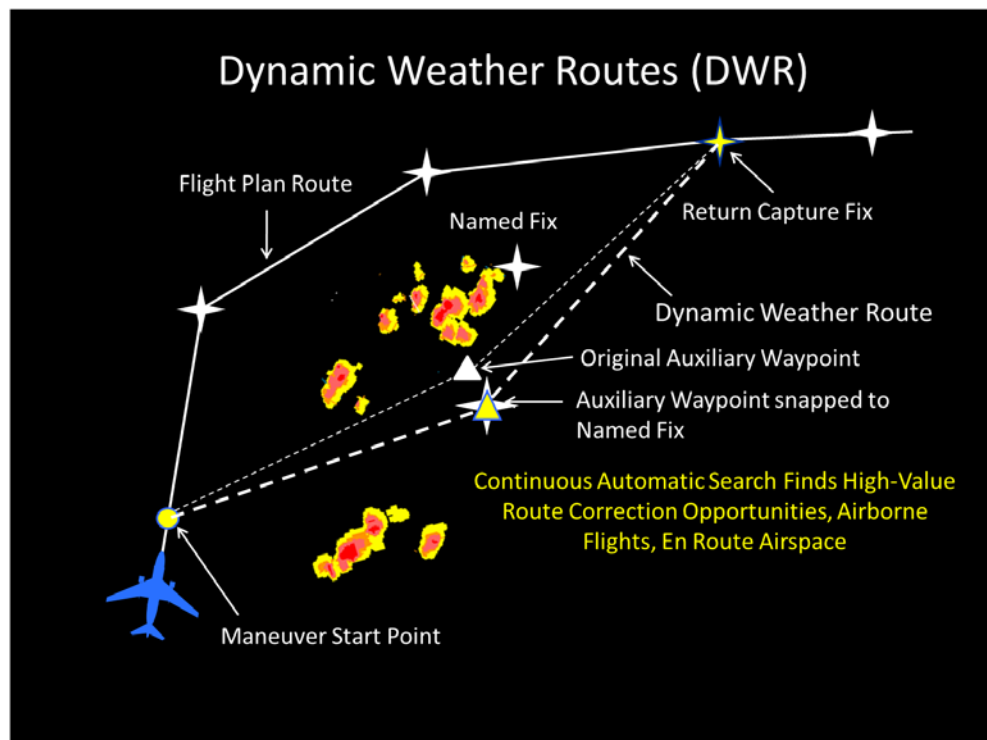
Inserted auxiliary waypoints are initially computed using fix-radial-distance points which may be placed anywhere for a minimum delay solution. A snap-to named fix option automatically replaces any auxiliary waypoints with nearby named fixes for ease of use in voice-based operations.   Snap-To solutions that avoid weather, or optionally weather and traffic, are posted to the DWR alert list if they meet the minimum flight-time savings criteria.   The current flight plan trajectory and the DWR-advised trajectory are both analyzed for conflict with congested airspace sectors and with Special Use Airspace (SUA). The traffic congestion and SUA status are incorporated into the user interface display so the user may consider these factors when evaluating the DWR route advisory. By clicking the DWR advisory the user activates an automated interactive trial planning function to visualize the route and if necessary modify the RCF, the MSP, and any inserted auxiliary waypoints.   Flight-time savings and weather and traffic conflicts status update rapidly (within 1 sec) and automatically as the user modifies the DWR route.

Figure 2: DWR Automation Process
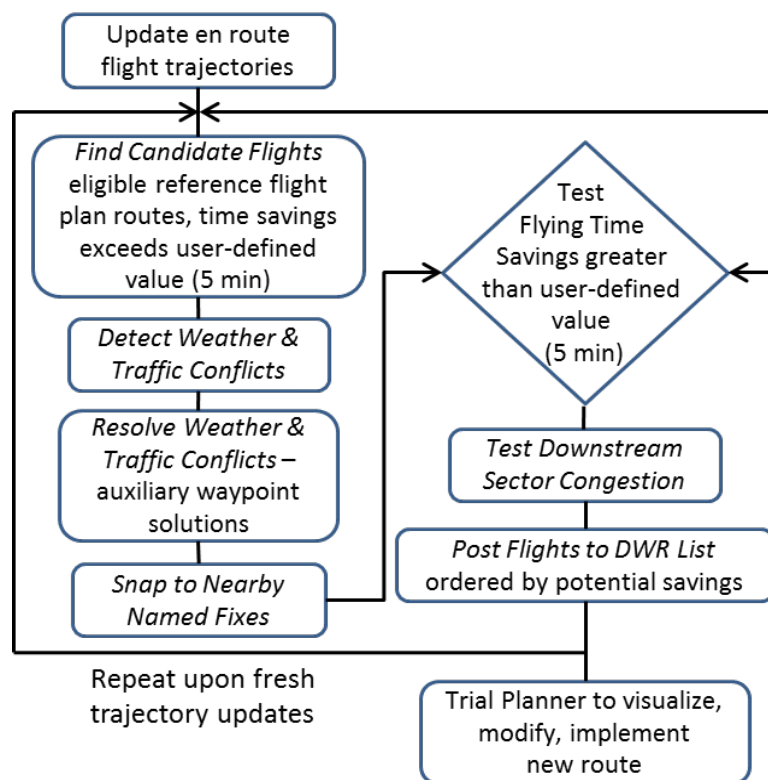
The RCF is a downstream fix on the current Center route of flight at which the DWR route correction rejoins the original flight plan trajectory. A limit function unique to the particular airspace region (i.e., unique to each Center's airspace) determines the default RCF to be used for DWR route correction computations. The purpose of the limit function is to define a default RCF for any flight given its present position and current route of flight such that a direct route from present aircraft track position to the RCF is generally operationally acceptable if weather were not a factor. The RCF is a function of Center airspace and arrival routing limits, and may be a function of other factors such as the particular routing (city pair routing for example) in the given Center airspace and the first-tier adjacent Center airspace. The RCF is generally not the last fix within the Center boundary where the aircraft is currently located.   The NASA DWR automation for Fort Worth Center employs a limit rectangle that extends roughly 200 nmi beyond the ZFW boundary (see Figure 3).   The default RCF is either the last flight plan fix inside the limit rectangle or, for aircraft landing inside the limit rectangle, the last fix before the arrival STAR.   Another approach is to analyze historically observed direct route clearances in each Center and use frequently occurring direct route clearances to define a convex limit polygon. In this approach the limit polygon replaces the simpler limit rectangle, but the fix selection logic is otherwise the same.   This empirically derived limit polygon approach has been implemented in the Future ATM Concept Evaluation Tool (FACET) implementation of

DWR called National Airspace System Constraint Evaluation and Notification Tool (NASCENT). Other methods, such as choosing the RCF based on the particular city pair routing within a Center, could also be implemented.

Figure 3: Capture Fix Limit Regions (rectangle and polygon)
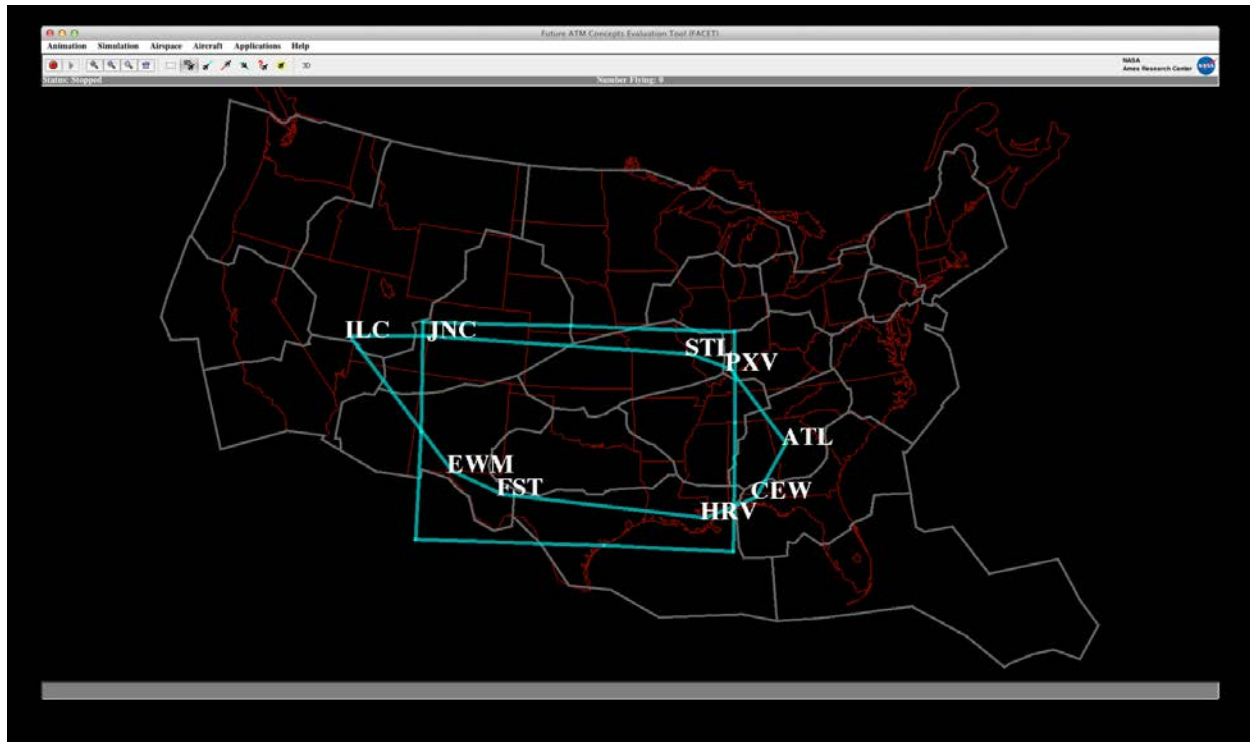
Early in the testing of DWR at American Airlines, users identified the need for an MSP in the DWR trajectory modeling. Depending on workload and other factors, users may need several minutes of coordination time before the point at which a flight is expected to depart the current trajectory to fly a DWR route. An MSP located a user-definable number of minutes downstream of present position on the current flight plan trajectory, or for climbing flights, the point at which the flight is predicted to be in high-altitude airspace (FL240 for ZFW), enables users to see the effect of coordination delay on trajectory status parameters like weather proximity, flying time savings, traffic conflicts, and level flight status, which is particularly important for climbing flights that may not have reached the high altitude airspace. Five minutes was generally the accepted default value used during the trials with American Airlines [3]. All DWR advisories initially incorporate the default MSP. Once in trial planning, the user may adjust the MSP using click and drag inputs and assess the effect on status parameters. If the MSP is within 10 nmi of a flight plan fix, the MSP snaps to the flight plan fix.

Auxiliary waypoints are added when needed to avoid weather, or optionally weather and traffic, and provide the minimum-delay route based on geometry and winds. If a route correction is found that can save the user-defined minimum time or more relative to the current flight plan, the flight is posted to a list displayed to an FAA traffic manager or to an airline ATC coordinator (see Figure 4). The user is provided with a DWR reroute advisory for each flight that fits the weather-avoidance and time-savings

criteria, and can select and modify the new route prior to clearing the aircraft to fly it. Auxiliary waypoints are defined using fix-radial-distance format, and a "snap-to" option utilizes nearby named fixes for ease of use in today's operations (see Figure 1).

DWR route correction advisories are posted to a DWR flight list as shown in Figure 4. The list, ordered by potential flight-time savings, includes all flights for which a route correction advisory has been identified, and for which the user has responsibility, and is prominently displayed on the user's traffic display. Each list element includes the flight ID (call sign), the estimated flight-time savings, and other relevant summary information such as city pair, aircraft type, route correction summary (e.g., RCF and number of inserted auxiliary waypoints), and summary information pertinent to the status of traffic conflicts, traffic congestion, and any FAA routing restrictions.   Any given flight for which a route correction advisory has been identified at the last trajectory update remains on the flight list.

Figure 4: DWR List

Also shown for each list entry there are traffic (TR), sector load (SC), and weather (WX) conflict status indicators. A number in the TR column indicates minutes to a detected conflict on the DWR route. An "SC" entry in the SC column is color coded yellow or red indicating the DWR route is predicted to pass through a sector in yellow or red congestion status. An R in the TMI columns indicates that the flight is currently impacted by an active Route TMI.

Figure 5 shows the display interface for DWR. The big window on the left is the Plan-view Graphical User Interface. In this window, a flight's 'Current flight plan route' is shown in a solid-white line and represents a SWAP/Playbook route. The proposed 'DWR' advisory is shown as a dashed-white line.

The downstream 'Capture fix' used to compute the direct route, and the 'Auxiliary waypoint' used to find the route around convective weather polygons, are displayed as well. Flights that have sufficient user-defined flight-time savings are displayed in the 'DWR list' on the top-left part of the big window.

Figure 5: DWR Route Display
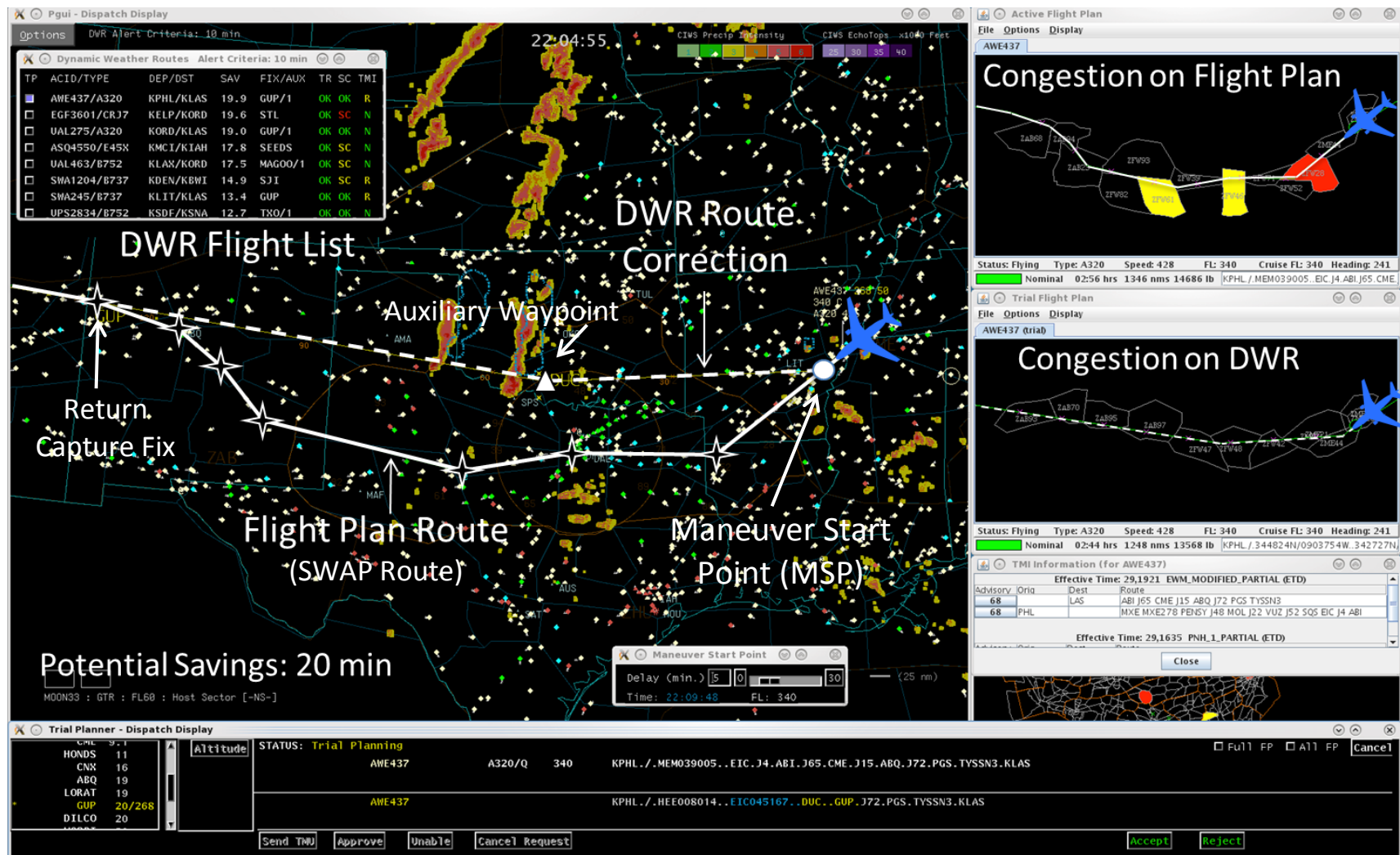
The long window at the bottom shows the current flight plan route and DWR advisory, along with time-savings for various downstream fixes at left. This is labeled as the 'Capture fix menu & flying time savings' in the figure.

The two windows on the right show the sector congestion for the current flight plan route (top) and the DWR advisory (bottom). The corresponding sector congestion values (as red or yellow sectors) for those routes are shown within. Red sectors are those where the congestion is caused by aircraft that are all currently airborne, while yellow sectors have proposed departure aircraft causing predicted congestion. This allows DWR users to visualize proposed routes and modify them if necessary using point, click, and drag inputs.

Users can adjust the RCF, the number and position of auxiliary waypoints, and the MSP through interactive points, click, and drag actions if needed. Metrics, including flight time savings (or delay), proximity to current and forecast weather, downstream sector congestion, traffic conflicts, and SUA conflicts, all update dynamically as the user modifies a proposed route. Conflicts with weather or traffic cause DWR to dismiss a potential reroute (trial plan) and keep searching for another (see Figure 6).

Figure 6: Example of trial plan with weather and traffic conflicts that would prevent DWR from suggesting this route.

Research indicates that digital communication of proposed DWR routes between ATC and the flight deck combined with on-board display of proposed route, would allow much faster review and approval of the DWR route [4] [5].

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4.1 CONVECTIVE WEATHER MODEL

DWR utilizes convective weather forecast data from FAA's Corridor Integrated Weather System (CIWS) and Convective Weather Avoidance Model (CWAM) [15-17] to identify routes that will avoid convective cells. CIWS forecasts the growth, decay, and movement of convective weather and updates every 5 minutes with a 2-hour look-ahead time in 5-minute increments (see Figure 7). This allows DWR to identify alternative routes that are predicted to remain clear of weather at the time the flight is calculated to pass the cell(s).

Figure 7: CIWS and CWAM Forecast Sample
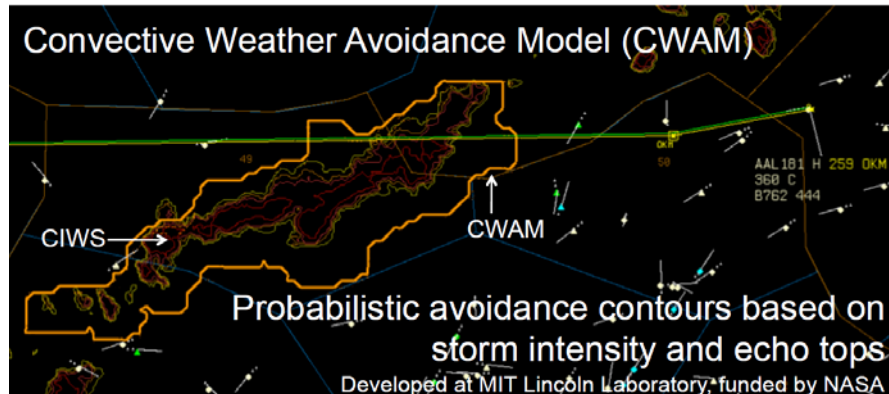
Figure 8: CIWS cell and corresponding 60, 70, & 80% CWAM polygons

CWAM identifies boundaries around convective cells that represent the distance by which flight crews are expected to deviate around the cell [15][16][17]. The boundary polygon, known as a Weather Avoidance Field (WAF), represents the probability a flight crew will deviate around the cell based on storm intensity, echo tops, and look-ahead time. A WAF is identified by the probability that a given percentage of pilots would deviate around the storm at that distance based on extensive historical data. For a given weather cell and altitude, 70% of WAF polygons are generally smaller with their boundaries closer to the weather cells than are 60% WAF polygons (see Figure 8). WAF polygons (60, 70, and 80%) are identified for every 5-minute CWIS forecast interval out to 2 hours, at flight levels ranging from FL250 to FL450 in 1,000' increments. DWR normally utilizes 70% WAF polygons when generating route advisories, but the default WAF parameter can be selected at system start up.
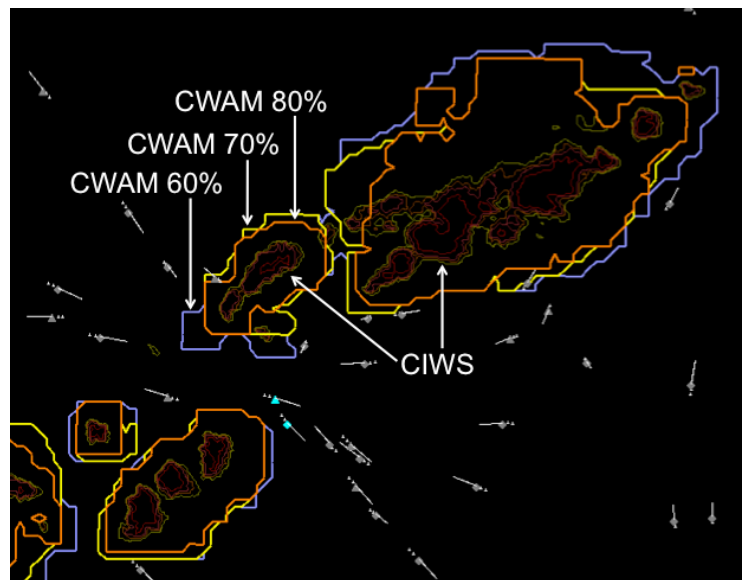
4.2 CONVECTIVE CELL GAP DETECTION AND REJECTION

DWR logic includes gap detection and rejection logic to ensure a gap is large enough to safely route aircraft. This function includes a distance buffer that will reject a route amendment if it will go through a gap that is narrower than 50nm laterally (user-adjustable parameter) either side of route and 75nm longitudinally (user-adjustable parameter) to the predicted cells at the time the aircraft reaches the point closest to the cells (see Figure 9).

If convective cells are predicted to encroach on one side of a trajectory but not on the other, (blue polygons in left graphic of Figure 9) it is generally not considered an operational problem because there is room for flight crews to maneuver around the cell. DWR avoids narrow gaps, which are defined as a condition where cells are predicted to be on both sides of the trajectory at points within 75 nmi along-track distance of one another (pair of yellow polygons in right graphic of Figure 9).

Figure 9: DWR Gap Detection
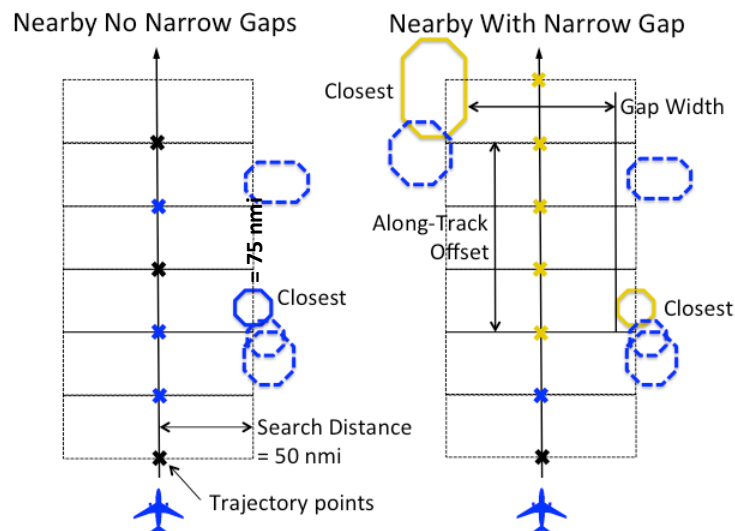
4.3 AIRSPACE CONSTRAINTS

As mentioned above, DWR also searches for congested sectors, traffic conflicts, and transit through special use airspace (SUA). DWR will advises of those conflicts along with the proposed reroute (see Figure 6).

DWR helps identify airspace constraints for the proposed reroute across sector and Center boundaries prior to recommending them to the user. This reduces controller workload by avoiding conflicts that would otherwise require controllers more time to resolve.

4.4 GROUPING FLIGHTS

DWR can be extended to identify multiple flights that would benefit from the same reroute thereby allowing groups of flights to take advantage of a gap in convective cells (see MFCR in section 8, Potential Future Enhancements). This is similar to procedures used by traffic managers and controllers today to

vector multiple flights in a line through a gap in convective weather, and could reduce controller and pilot workload.

5 BENEFITS

5.1 COSTS OF CURRENT SYSTEM INEFFICIENCIES

Adverse weather is the leading cause of delay in domestic en route operations, and is responsible for roughly 70% of the delays. Weather related delays were responsible for 32,000 minutes of average delay in the NAS during the summer of 2014 [6]. In 2007, delayed flights consumed 740 million additional gallons of jet fuel at a cost of $1.6 billion (or $2.13 billion at an average 2013 fuel price of $2.88/gal), and 20% of total domestic flight time was wasted in delay [7].

Convective weather accounts for 60% of weather related delays [8], and is the leading cause of traffic flow management (TFM) actions (see Figure 10) that cause flights to deviate from preferred flight trajectories [9]. Convective weather is common in the spring and summer months and can extend for hundreds of miles and reach altitudes well in excess of 40,000 feet.

Figure 10: Flight Delays by Cause
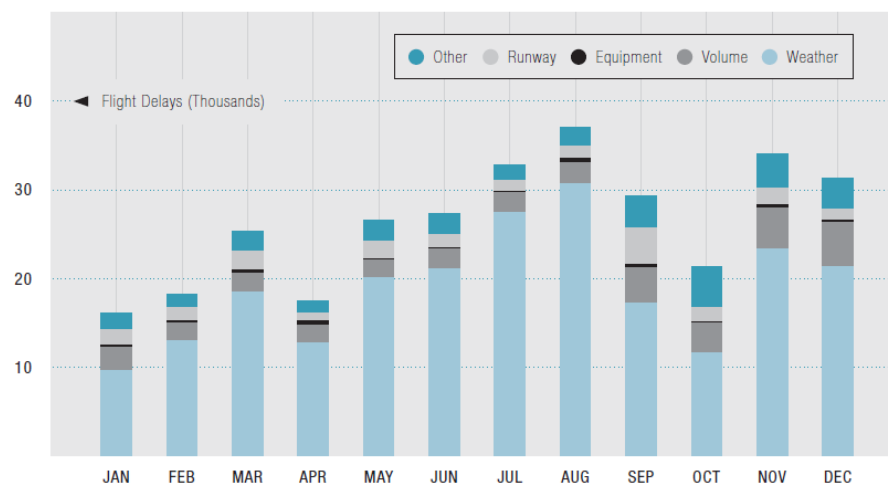
5.2 POTENTIAL DWR BENEFITS

Potential DWR benefits in the NAS vary depending on the speed at which reroutes can be approved and implemented. If DWR can be integrated with air traffic automation systems and Data Comm, analysis indicates direct operating benefits could be in the neighborhood of $125 million annually. This level of integration will likely be evolutionary and take time. However, DWR can be implemented with a much lower level of integration, and both empirical and analytical data show that direct operating benefits would still amount to approximately $55 million annually. Additional details on these benefits figures and methodologies are provided in the following subsections.

5.2.1 Estimated Benefits for All Flights in ZFW

In an effort to determine potential DWR benefits, NASA conducted an analysis of all ZFW traffic above 10,000 feet for every day in 2013 (23 hours/day, 7 days/week), except arrivals to DFW or DAL [10]. Figure 11 shows potential DWR savings by airline totaling about 146,000 minutes (dark blue bars) for 14,800 ZFW flights in 2013, equating to 9.9 min per flight on average.   This analysis indicates that only 32% of these savings could have been captured using today's traditional methods. Therefore, DWR saved about 100,000 minutes over 15,000 more flights, or about 6.7 minutes per flight on average (corrected potential savings indicated by the light blue bars). Assuming average block-time cost of $81.18 per minute, total annual savings equate $8.1 million in airline operating costs in one ZFW Center alone.

Figure 11: Corrected potential DWR savings for all ZFW flights in 2013.
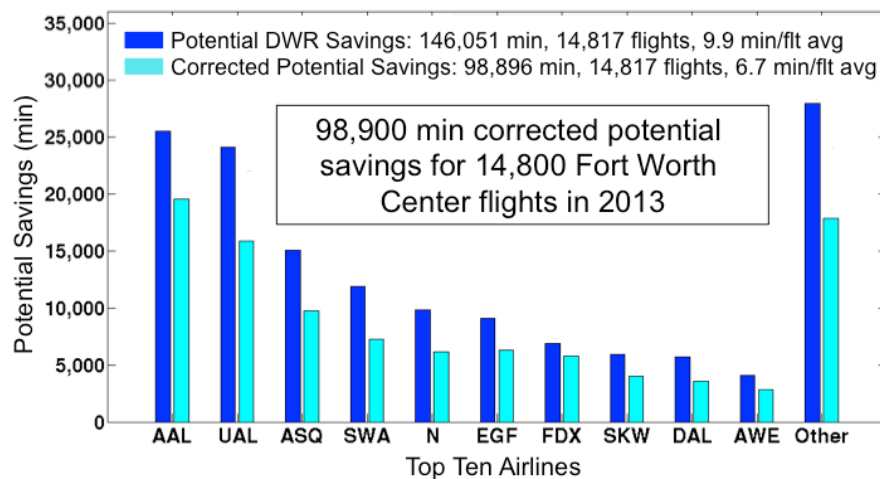
It should be emphasized that the potential savings shown in Figure 12 reflects only those flights where the DWR route amendment provided five minutes or more of savings.

5.2.2 Automation Integration Impacts on Benefits

As described earlier, the DWR software is easily configurable to capture all simple direct routes with a wind-corrected savings of more than one minute or more in addition to the larger savings opportunities typically triggered by corrections to weather avoidance routes. NASA and American Airlines (AA) conducted a trial of DWR at AA's Integrated Operations Center (IOC) in Fort Worth Center (ZFW) from July 2012 to September 2014 [10].

Figure 12: Distribution of AA flights by magnitude of estimated actual savings.
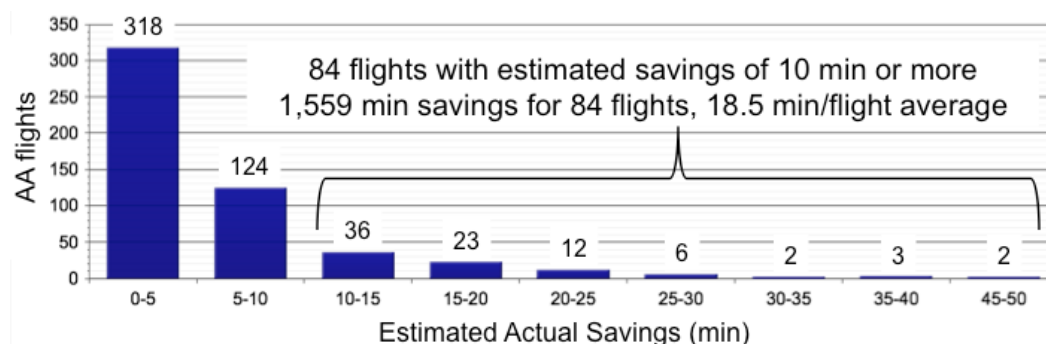
Figure 12 shows the distribution and magnitude of savings for 526 AA flights. This distribution illustrates two important benefits considerations. First, 60% of the total savings came from flights that were able to save five minutes or less. Although this is a relatively small savings per flight, the volume of flights able to do so emphasizes the importance of a rapid turnaround in DWR route advisory and approval. The benefits gained from rapid approval rates are also supported by another NASA study [12] that shows a 25% increase in benefits if the approval process were fast enough to apply DWR routes with an MSP one minute ahead on a flight plan as opposed to five minutes ahead. Any savings less than five minutes for a large number of flights may only be practical with automated methods of DWR route review, communication, and approval.

The second consideration of note is the relatively high estimated savings, for a small percentage of flights, of 10 minutes or more using RCFs further downstream. This resulted in an average saving per flight of 18.5 minutes. This implies that potential savings would be higher if DWR is able to use capture fixes in two or more Centers beyond the host Center. Enabling return capture fixes to stretch into these adjacent Centers would require tighter integration of DWR with constraint data across Centers. The benefits of such integration would potentially reduce costly delays caused by missed connections, flight diversions and cancellations, crews exceeding their crew time limits, and customer inconvenience and dissatisfaction.

During the two-year evaluation, limitations in human resources, automation and system integration, led American Airlines to only capture $267,000 of a potential $4.5 million in estimated flight time savings.

While capturing benefits from 100% of DWR advisories is likely unrealistic, the substantial increase in monetary benefits that come from integration of DWR with automation and digital communications systems is clearly significant.

5.2.3   Extrapolation of Annual ZFW Benefits to the NAS

A complete annual DWR benefits analysis for all 20 en route Centers is not available, but there are a number of pertinent benefits analyses that have been conducted to estimate trajectory efficiency benefits in the NAS [10][11][12][13][14]. Combining select results with additional analysis, they provide an idea of potential NAS-wide DWR benefits.

One NASA study looked at delays every day between April 1 through October 31, 2014 where convective weather was the main cause of delay, and identified the 30 worst days in the NAS during that time [12]. The potential DWR flight-time savings for every Center over those 30 days is shown in Table 1, with a total estimated flight-time savings of 134,710 minutes for 15,234 flights or about 8.8 min per flight on average. That equates to $10.9 million using a block-time savings figure of $81/min. These results are for a five-minute MSP and reflect only those DWR corrections with savings of five minutes or greater.

Table 1: Results for proposed DWR reroutes for 20 Centers over 30 worst days using limit polygons and MSP=5 minutes

Center	Flights	Time-Savings (min.)	Fuel-Savings (lbs.)	Sector Congestion (min.)	SUA Traversal (#)
ZMA	1,498	10,685	415,890	-43	-3,558
ZFW	1,468	14,086	469,176	47	-4
ZHU	1,417	14,355	483,817	2,236	-66
ZME	1,305	11,045	379,758	108	-13
ZKC	1,193	11,045	325,499	189	1
ZJX	1,063	8,839	269,750	334	-471
ZID	1,009	9,085	259,509	429	-1
ZMP	955	8,501	279,754	3,512	1
ZDV	841	7,958	239,671	408	-1
ZTL	827	7,485	234,419	8	-4
ZDC	738	6,436	184,407	-402	3
ZBW	710	5,863	194,163	100	0
ZAU	566	4,863	149,103	-9	-2
ZOB	411	3,748	72,693	44	0
ZAB	313	2932	63,567	137	-82
ZLA	303	2,689	67,908	155	-243
ZNY	263	2,432	60,195	35	-2
ZLC	212	1,521	62,691	-25	-30
ZOA	84	650	9,680	0	-35
ZSE	58	493	14,109	0	-5
Total	**15,234**	**134,710**	**4,235,759**	**7,263**	**-4,512**

(Positive sector congestion values indicate that DWR saved minutes of sector congestion for that Center over the current flight plan, negative values indicate that DWR added minutes of sector congestion. Likewise, negative values of SUA Traversal (last column) indicate how many SUA traversals were added by DWR advisories. For further detail see reference [12].)

Given DWR provides reroute advisories even when convective weather is not a factor, these results do not capture potential benefits for the remainder of the year. NASA also conducted an analysis of Fort Worth Center (ZFW) traffic data for every day in 2014 to determine potential DWR flight-time savings for all flights that would have benefited from DWR within ZFW. That analysis estimated that 26,145 flights would have saved a total of 261,286 minutes. Comparing this figure with the 51,553 minutes estimated DWR savings during 30 worst convective weather delay days in 2014 results in a ratio of 5.07.

Ratio = SavingsTotal/SavingsTop30 = 5.07; (261,286/51,553=5.07).

Applying this ratio total estimated savings for all Centers in table 1 above, yields a potential NAS-wide DWR benefits of 682,980 minutes in estimated time savings in 2014. Assuming direct block-time costs of $81 per minute, this equates to a potential NAS-wide savings in airline operating costs of $55.3 million in 2014. These numbers are for flights that were able to save at least 5 minutes on the DWR reroute and for which the MSP was at least 5 minutes ahead on the original route.

If automation enabled flights to take advantage of smaller savings down to 1 minute per flight, the American Airlines evaluation mentioned in section 5.2.2 suggests those benefits could increase by almost 60%, or $33.2 million ($55.3 million x .6). Additionally, if automation and Data Comm integration enabled DWR reroutes that began between 1 and 5 minutes in the future, the benefits would increase by 25%, or $36 million (($55.3M + $33.2M) x .25 = $35.95M). All totaled, a DWR system integrated with automation and Data Comm could potential save 1.5 million minute of flight time and $124.5 million in annual airline operating costs.

5.2.4   Indirect Benefits

There are a number of potential indirect benefits provided by DWR. One which has been measured is reductions in sector congestion. A sector congestion analysis conducted in the DWR trials and simulation indicate congestion could be reduced 19-38% if the DWR capability was available to all flights rather than restricting it to only weather-avoidance routes [10].

DWR could identify and help remove stale playbook routes. If that happens, the associated miles-in-trail (MIT) would also be eliminated. MITs are one of the most inefficient traffic management initiatives.

6   SYSTEM DEPENDENCIES

NASA's DWR concept currently operates with its Center Trajectory Automation System (CTAS) and its National Airspace System Constraint Evaluation and Notification Tool (NASCENT), which mimic various functions of FAA air traffic automation systems, including Traffic Flow Management System (TFMS), Time-Based Flow Management (TBFM), En Route Automation Modernization (ERAM) and associated displays. The degree to which the DWR application will use these systems will depend on the implementation path and level of system integration chosen by the FAA. However, the inputs required will be relatively consistent.

Traffic Data – The DWR application is capable of using 12-second or 1-minute track and flight plan updates depending on the operational need and how it is integrated into air traffic automation systems. Twelve second updates are used for single-flight DWR advisories and obtained from ERAM so that flight plan intent is up to date and conflict detection is reliable. This implementation would support rapid approvals enabled by automation and Data Comm integration, and would support direct use by sector controllers. One minute updates are used when providing a common reroute for groups of flights (multi-flight common route), and is obtained from the TFMS. Due to the lower update rate, conflict detection is not provided. Traffic managers are the intended users for this NAS-wide implementation.

Weather data – FAA Corridor Integrated Weather System (CIWS) provides DWR with convective weather data and forecast. Convective Weather Avoidance Model (CWAM) provides DWR with pilot deviation probabilities of which DWR uses 70% probability polygons for its weather avoidance algorithm.

Rapid Refresh (RR) winds from National Oceanic and Atmospheric Administration (NOAA) are used for trajectory modeling and to compute the wind-corrected flight-time savings.

Base of Aircraft Data (BADA) aircraft-type performance tables are used for computing fuel-savings numbers.

Dynamic airspace sectorization data are obtained from the FAA's Host ATM Data Distribution System (HADDS).

Special Use Airspace (SUA) data are from the FAA's sua.faa.gov website. The latter are the scheduled SUA data since the real-time data are not available.

Sector congestion is determined by using the monitor alert parameter (MAP) in TFMS.

The functional block diagram on the next page provides a graphic summary of these inputs.

Figure 13: Simplified Functional Block Diagram
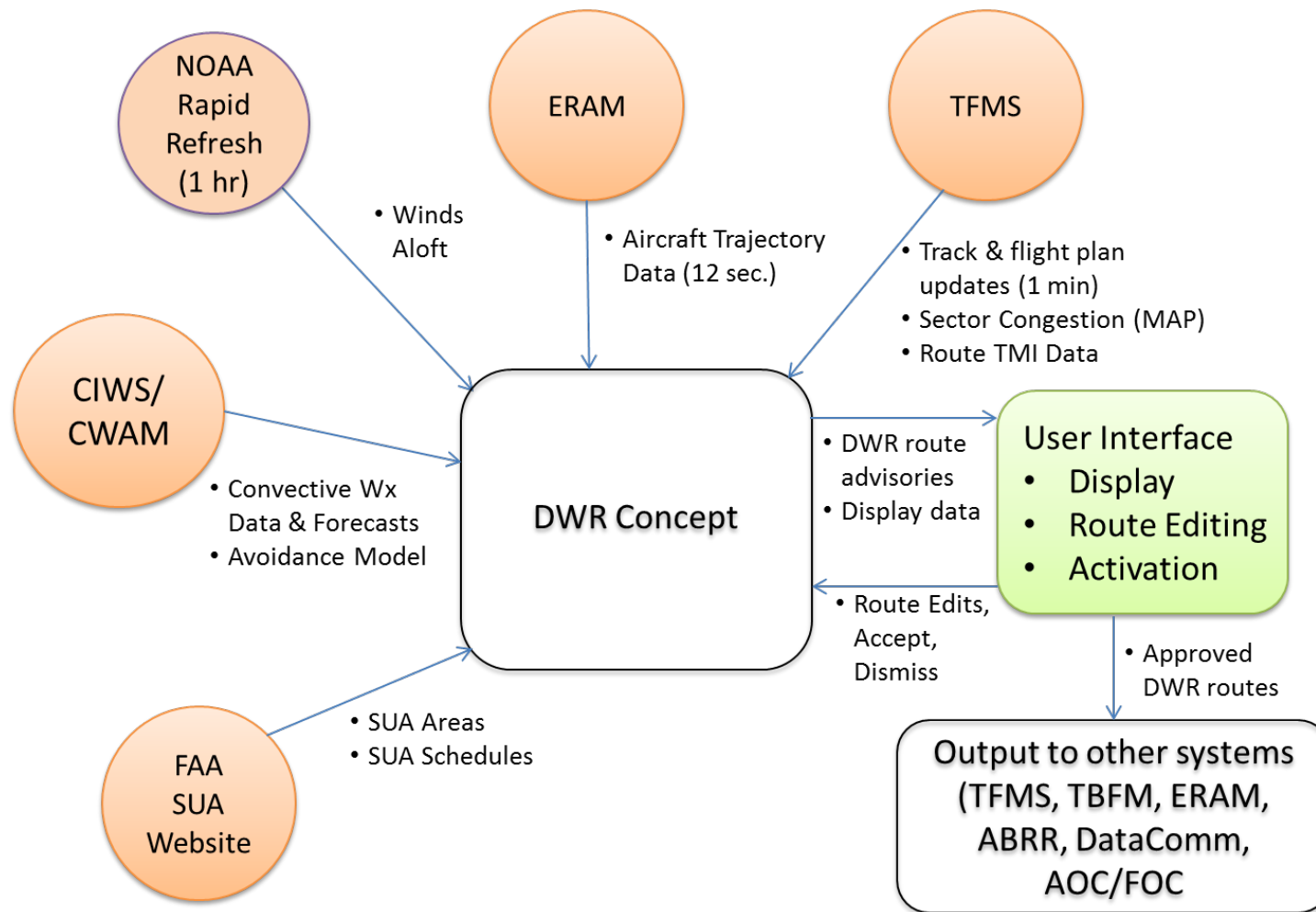
7 USE CASES AND IMPLEMENTATION STRATEGIES

The manner in which DWR is implemented in the system will have an impact on system dependencies and integration requirements. This will in turn have a significant impact on controller workload, system costs and operational benefits. The tighter the integration with information and automation systems, the higher DWR's performance and benefits, and the lower the controller workload is to operate the system. However, higher levels of integration will take more time and be more costly. Although some of these decisions will be driven by benefit/cost analyses, others will be a matter of management goals and policies.

DWR has been designed to take advantage of automation systems and information to minimize workload while maximizing benefits. NASA realizes the optimal level of automation integration will take time and that compromises will need to be made in the near term in order to gain early benefits and experience. Consequently, integration into TFMS and in Traffic Management Units (TMUs) appears to be the most viable in this time frame, and is therefore the primary strategy proposed in this initial concept.

An Airline Operation Center (AOC) use case is included because NASA DWR field trials with American Airline's IOC has provided the bulk of the user experience and feedback to date, and commercial implementation in AOCs may serve as a viable augmentation to implementation in FAA Centers.

Because DWR has been designed to take advantage of automation systems and information to minimize workload while maximizing benefits, additional information is provided below to support a long-term vision.

It should be noted that although DWR has been developed and implemented in software systems similar to those used by FAA TMUs, DWR has not been tested in FAA facilities or automation systems. Controller feedback has been obtained using simulations. Therefore, the FAA implementation strategies described below are conceptual.

7.1 TMU IMPLEMENTATION

Figure 14: TMU DWR Procedure Flow
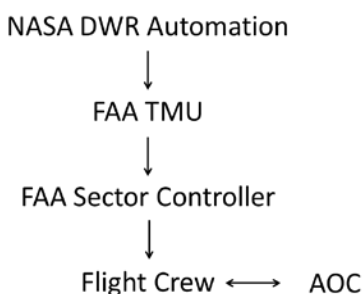
In the near-term, integration into ERAM may not be possible due to funding and schedule constraints. A viable alternative would be to integrate DWR into TFMS and TBFM to allow traffic managers to review, approve and distribute revised clearances to sector controllers via voice communications through the area supervisor or digital communications through the Airborne Reroute (ABRR) tool. This level of human review and coordination will reduce the percentage of DWR routes that are activated, but will provide early benefits without significant automation integration costs.

| TMU DWR Use Case	
Step 1: FAA Traffic Management Unit (TMU) Approval and Dissemination	• The DWR display and interface resides in the TMU and continually runs in the background. The adjustable parameters, i.e. savings threshold, convective cell buffers (NAS-based system...not in center based system, limit polygon, etc. are set by the operator. • When DWR identifies flights that meet the savings criteria settings, it posts each of those flights to a list on the display in order of flight time savings. Each new DWR route posted to the list triggers an audible alert*. • The traffic manager on duty hears the alert, reviews and modifies the proposed DWR route(s) as needed, and forwards approved routes to the sector controller currently handling the flight via voice communication or ABRR where available.
Step 2: Sector Controller Review and Clearance	• The Sector Controller receives the proposed DWR route amendment via voice communication or ABRR where available. Sector controller amends route if needed to avoid traffic and SUA conflicts using their trial planner tool, and offers route amendment to flight crew via voice communications (or via data communications when available).
Step 3: Flight Crew Review, Coordination and Acceptance	• The flight crew receives proposed DWR route clearance, reviews new route on on-board navigation and weather detection systems and aids, and either accepts or declines clearance. • If declining, the crew may offer an amendment, which the controller will either approve or continue to negotiate a compromise. • If the proposed DWR route impacts airline management plans, the flight crew may ask the controller to standby while they coordinate the change with their dispatcher prior to accepting the clearance. • Once the controller and flight crew agree on DWR route, the controller will issue the clearance and the flight will accept and fly that clearance. • Should storm cells encroach on their new route, they will use normal avoidance and ATC communication procedures. • DWR will continue to search for additional savings.

* While DWR audible alerts have been well received by airline dispatchers, they may not be acceptable in a TMU setting.

7.2   AOC IMPLEMENTATION

As previously mentioned, NASA and American Airlines conducted an operational evaluation of its DWR application at American's IOC in Fort Worth, TX to determine its effectiveness in identifying viable routes

around convective weather.   The IOC served as the DWR operator, and coordinated reroutes through its ATC coordinators, dispatchers and flight crews.

Figure 15: AOC DWR Procedure Flow

NASA DWR Automation
↓
Airline ATC Coordinator
↓
Airline Dispatcher
↓
Pilot
↓
FAA Controller
↓
Route Clearance
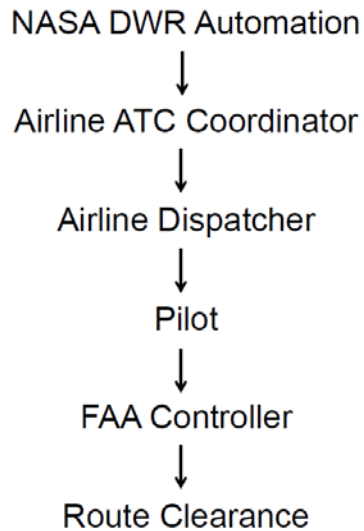
Due to the coordination complexities, level of workload and benefits compromises, utilizing the AOC as the primary means of implementation is not being recommended. However, DWR utilization in AOCs may provide some advantages in conjunction with FAA DWR implementation by:

1.   Allowing the FAA to automatically update AOCs on flight route changes,
2.   Providing a mechanism for airlines to update flight preferences for FAA automation systems with respect to DWR advisories, and
3.   Allowing AOCs to be proactive in coordinating DWR advisories directly with FAA.

Figure 15 summarizes the work flow across the participants.

The following use case details the process, roles and responsibilities used during the American Airlines trials.

*Table 3: Airline Operations Center DWR use case scenario*

AOC DWR Use Case	

Step 1:
Airline Operations Center (AOC) review, amendment and acceptance of DWR routes
	• The DWR display and interface reside in the AOC at the ATC coordinator's and dispatcher's positions, and continually run in the background. The adjustable parameters, i.e. savings threshold, convective cell buffers, capture fix distances, etc. are set by the operator.
	• When DWR identifies flights that meet the savings criteria settings, it posts each of those flights to a list on the display in order of potential minutes saved. Each new DWR route posted to the list triggers an audible alert.
	• The airline's ATC coordinator hears the alert, evaluates the proposed DWR route, and then either:
	    ○ Accepts the route (after coordinating with the flight dispatcher),
	    ○ Rejects the route, or
	    ○ Modifies the route as needed using click, drag and drop actions.
	    ○ and accepts the modified route. If the trial route proves unacceptable, the coordinator may cancel the modification and, either reject or accept the original proposed route.

AOC DWR Use Case	
	• Once the ATC coordinator identifies an acceptable route, he coordinates the new route with the dispatcher in charge of the flight.
Step 2: Dispatcher review, acceptance and dissemination of DWR route to flight crews	• The dispatcher reviews the route to determine if it falls within acceptable operational parameters for the flight schedule, aircraft limitations and flight crew limitations, and discusses any concerns with ATC coordinator if necessary. • The ATC coordinator may call the FAA Center TMU to "pre-coordinate" the DWR route prior to sending the proposed reroute to the flight crew. • Once the ATC Coordinator and dispatcher agree, the ATC coordinator clicks Accept, and the DWR route is sent to the flight crew via the Aircraft Communications, Addressing, and Reporting System (ACARS) data communications system. • DWR will continue to search for additional savings.
Step 3: Flight Crew Review, amendment and coordination of DWR route with controller	• The flight crew receives proposed DWR route clearance, and evaluates the new route using on-board navigation and weather display systems. • If the route appears acceptable, the flight crew requests the route change from the sector controller using normal voice communication procedures. • Once the flight crew receives an approved clearance from the sector controller, they will update the route in their FMS system and advise the dispatcher. • Should storm cells encroach on their new route, they will use normal avoidance and ATC communication procedures.
Step 4: Sector controller review, coordination and approval of flight crew route request	• The Sector Controller receives the crews request for the route amendment, evaluates it using their trial planning tool. • The controller will coordinate the changes with other sectors or the adjacent Center as necessary. • The controller may amend route if needed to avoid conflicts with traffic, SUA or ATC constraints using their trial planner tool, and offer a route amendment to flight crew via voice communications (or via data communications when available). • Once the flight crew accepts the new clearance, the Sector Controller updates the flight plan in the automation system.

7.3 AOC/TMU IMPLEMENTATION

The above use case would change if the AOC implementation was an augmentation to the DWR implementation in FAA TMUs. In this case, the DWR system would consist of displays in both AOCs and FAA TMUs.
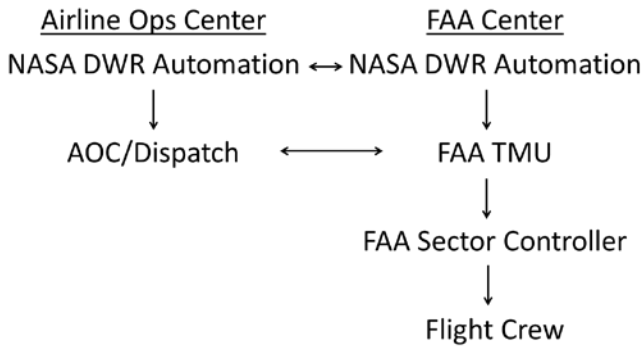
The primary difference between the two displays is that the FAA display would show DWR advisories for all airlines, whereas the AOC DWR display would include only that airline's flights. DWR routes initiated by the TMU would still function as described in section 7.1, but DWR reroute requests could be initiated by an AOC and sent to the appropriate TMU through an automated coordination system. The automated coordination system combined with the DWR trial planning capability would allow the TMU to receive and display the specific reroute request electronically. An example of this coordination system involving an AOC-initiated reroute request is described below.

Table 4: Integrated TMU and AOC DWR Use Case

Integrated TMU and AOC DWR Use Case	

Step 1:
Airline Operations Center (AOC) review, amendment and acceptance of DWR routes
	• The DWR display and interface reside in the AOC at the ATC coordinator's and dispatcher's positions, and continually run in the background. The adjustable parameters, i.e. savings threshold, convective cell buffers, capture fix distances, etc. are set by the operator.
	• When DWR identifies flights that meet the savings criteria settings, it posts each of those flights to a list on the display in in order of potential minutes saved. Each new DWR route posted to the list triggers an audible alert.
	• The airline's ATC coordinator hears the alert, evaluates the proposed DWR route, and then either:
	  ○ Accepts the route (after coordinating with the flight dispatcher),
	  ○ Rejects the route, or
	  ○ Modifies the route as needed using click, drag and drop actions.
	  ○ and accepts the modified route. If the trial route proves unacceptable, the coordinator may cancel the modification and, either reject or accept the original proposed route.
	• Once the ATC coordinator identifies an acceptable route, he coordinates the new route with the dispatcher in charge of the flight.

Integrated TMU and AOC DWR Use Case	
Step 2: Dispatcher review, acceptance and dissemination of DWR route to flight crews	• The dispatcher reviews the route to determine if it falls within acceptable operational parameters for the flight schedule, aircraft limitations and flight crew limitations, and discusses any concerns with ATC coordinator if necessary. • The ATC coordinator may call the FAA Center TMU to "pre-coordinate" the DWR route prior to sending the proposed reroute to the flight crew. • Once the ATC Coordinator and dispatcher agree, the ATC coordinator clicks Accept, and the DWR route is sent to the appropriate TMU via the automated coordination system. • DWR will continue to search for additional savings.
Step 3: TMU Review, Amendment and Coordination of DWR Route with Sector controller	• The traffic manager in the TMU receives proposed DWR route clearance from the AOC, and evaluates the new route on their DWR display. • If the route is not acceptable as proposed, the TMU traffic manager may reject the request, or use the trial planning feature to amend to route prior to forwarding to the sector controller. The traffic manager may also send the amended route back to the AOC for coordination and acceptance. • Once the proposed DWR route is acceptable, the traffic manager sends the reroute to the appropriate sector using voice communication or ABRR where available. • The sector controller offers the reroute to the flight crew via voice communications. • Should storm cells encroach on their new route, they will use normal avoidance and ATC communication procedures.
Step 4: Flight Crew Review, amendment and coordination of DWR route with controller	• The flight crew receives proposed DWR route clearance from the sector controller, and evaluates the new route using on-board navigation and weather display systems. • If the route appears acceptable, the flight crew accepts the route change from the sector controller using normal voice communication procedures and updates the route in their FMS system. • Should storm cells encroach on their new route, they will use normal avoidance and ATC communication procedures. • The controller may amend route if needed to avoid conflicts with traffic, SUA or ATC constraints. • Once the flight crew accepts the new clearance, the Sector Controller updates the flight plan in the automation system.

7.4 AUTOMATION INTEGRATION

DWR was designed to be integrated with FAA air traffic system automation and information system to maximize system efficiency and minimize human workload, especially during changing weather

conditions. Therefore, DWR should be integrated into TBFM, ERAM, and TFMS automation tools as well as digital communications (both ground and air) to realize its full potential and gain maximum benefit.

With full knowledge of airspace and ATC constraints across the NAS (TMI restrictions, sector constraints, SUA activity, turbulence, etc.), DWR helps controllers carry out time-consuming coordination tasks. The TMU would not need to review changes for individual flights, but would need to review larger scale changes involving multiple flights before distributing them to sector controllers for action.

Data Comm integration and associated displays and applications in aircraft would permit flight crews to see graphical representations of proposed DWR amendments, enable the use of dynamic, coordinate-based waypoints, and permit various levels of negotiation of proposed routes based on equipage.

Flight plans/Flight objects could include any airline preferences, e.g. no overwater DWR routes, etc. AOCs may still be able to use their own DWR tool to request changes through flight crews or via secure internet interface to the TMU as mentioned in section 7.2, but coordination between ATC and the flight crew would likely be the primary mode of operation.

Figure 17: DWR Integrated with Automation Work Flow
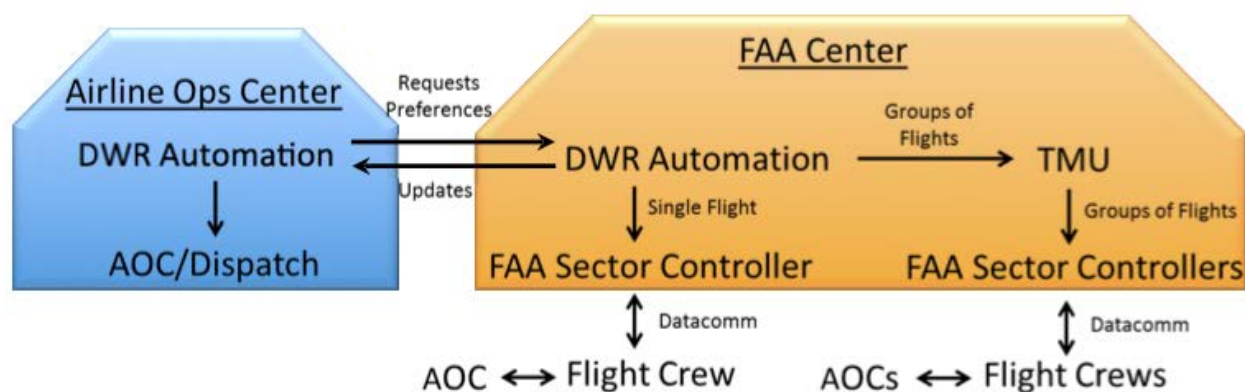
8   POTENTIAL FUTURE ENHANCEMENTS

- Multi-flight Routings - DWR is capable of grouping flights that would all be able to take advantage of a gap in convective weather and benefit from a common reroute. This function is known as Multi-Flight Common Route (MFCR).
- Real-time SUA Avoidance- Currently, DWR uses scheduled SUA/TFR data. The users of this airspace do not always conform to the schedule. Consequently, DWR informs the user when a proposed DWR route transits SUA, but it does not avoid it. If real-time SUA status data were provided to DWR, it could avoid active areas and ignore inactive areas.
- Center Constraint Interface – there are a number of airspace constraints that are not currently available to DWR, including arrival routes and other restrictions that could constrain where DWR routes could transit the Center's airspace. Providing TMUs with DWR interfaces in which such constraints could be defined and networking DWR locations would allow DWR to avoid those constraints and propose routes that would not need to be negotiated between Centers.

- Flight Level Improvements - DWR currently looks for more efficient routes laterally. There may be times when flights are flying non-optimal altitudes due conflicts with other flights at optimal altitudes along the planned route. DWR routes may alleviate some of those conflicts and permit the flight to move to its optimal altitude once on the DWR route. Adding the vertical dimension to DWR route capabilities would increase the benefits.
- Turbulent areas/altitudes – Convective weather avoidance does not ensure all turbulence is avoided. DWR is capable of avoiding areas of predicted and reported turbulence if defined by polygons.
- Operator Preferences defined in Flight Plan/Object – Providing operator flight preferences in the flight plan/object relative to DWR would inform DWR whether or not operator wants DWR routes and the magnitude or weather avoidance parameters the operator would automatically accept and those that it would want to review first.
- Data Comm – The use of Data Comm would greatly reduce the workload of controllers, pilots and dispatcher. By allowing more rapid communication and negotiation (by properly equipped aircraft) of DWR routes, it would enable a larger number of flights to take advantage of smaller individual savings opportunities, thereby substantially increasing benefits. Data Comm would also allow DWR routes to be defined and communicated using dynamic coordinates, and permit flights crews operating appropriately equipped aircraft with the ability to review those routes on moving maps and potentially modify/negotiate those routes when needed [14].

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