Dynamic Weather Routes: Overview for Technology Transfer

Dave McNally, Kapil Sheth, Hassan Eslami, Chester Gong
Aviation Systems Division
NASA Ames Research Center

Airspace Systems Program Webinar
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Take Away Message

• Ground automation, continuous automatic search finds high-value route corrections, airborne flights, en route airspace

• Integrates convective weather, wind-corrected flying time, traffic conflicts, sector congestion, special use airspace, FAA route restrictions

• Net potential savings 100,000 flying minutes for 15,000 flights, Fort Worth Center in 2013

• Operational testing, American Airlines Integrated Operations Center, Fort Worth, TX, July 2012 to present
What’s the Problem
What’s the Problem

Convective weather leading cause of delay in US airspace

Weather avoidance routes planned 1-2 hours before takeoff, include large buffers to forecast weather

Opportunities for time and fuel saving route corrections are missed as weather changes

No automation to help operators determine when weather avoidance routes have become stale
Outline

Building Blocks

• DWR Concept, Tool, Functional Components
• Operational Trial at American Airlines
• Analysis Results
  – Potential Benefits all Fort Worth Center Flights
  – American Airlines Test Results
  – Sector Congestion Analysis

• Software Architecture and Required Inputs
• How to Acquire DWR Software
• Next Steps
Center/TRACON Automation System (CTAS)

Ground-Based Trajectory Analysis Methodology and Software

Traffic Management Advisor

En Route Descent Advisor

Conflict Probe

Weather & Traffic Conflicts Integrated

Direct-To

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How Does DWR Detect Conflicts with Convective Weather?

Convective Weather Avoidance Model (CWAM)

Probabilistic avoidance contours based on storm intensity and echo tops

Developed at MIT Lincoln Laboratory, funded by NASA

Corridor Integrated Weather System (CIWS) → Convective Weather Avoidance Model (CWAM)
Future ATM Concepts Evaluation Tool

FACET
NAS Wide Simulation and Analysis Capability
Sector Congestion Analysis using National Traffic Feed
Outline

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How does DWR select flights and propose route corrections?
Analyze Airborne Flights, En Route Airspace

Current active Center flight plan route
Find Inefficient Route Segments

Current active Center flight plan route

Return capture fix, inside limit region, or last fix before STAR

Reference route, savings > 5 min wind corrected
Resolve Weather and Traffic Conflicts

Current active Center flight plan route

Return capture fix, inside limit region, or last fix before STAR

Dynamic Weather Route

Insert waypoints (two max) for minimum delay weather or weather and traffic resolution

Reference route, savings > 5 min wind corrected

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Snap to Nearby Named Fixes

Current active Center flight plan route

Return capture fix, inside limit region, or last fix before STAR

Dynamic Weather Route

Insert waypoints (two max) for minimum delay weather or weather and traffic resolution

Reference route, savings > 5 min wind corrected

Snap-to nearby named fix option for voice communications
Continuous Automatic Search

Current active Center flight plan route

Dynamic Weather Route

Repeat search continuously and automatically every 12 seconds
Sample: UAL975 IAD to SFO

Direct-To
11 min savings
Sample: UAL975 IAD to SFO

Auxiliary Waypoint
9.8 min savings
Sample: UAL975 IAD to SFO

Snap to Named Fix
9.1 min savings
Sample: CPZ5663 DFW to MSP

Direct-To
13 min savings
Sample: CPZ5663 DFW to MSP

Resolve Weather
11 min savings
Sample: CPZ5663 DFW to MSP

Resolve Traffic
9 min savings
Sample: CPZ5663 DFW to MSP

Snap to Named Fix
8 min savings
## Dynamic Weather Routes

<table>
<thead>
<tr>
<th>TP</th>
<th>ACID/TYP</th>
<th>DEP/DST</th>
<th>SAV</th>
<th>FIX/AUX</th>
<th>TR</th>
<th>SC</th>
<th>TMI</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAL2188/B752</td>
<td>KATL/KSEA</td>
<td>29.4</td>
<td>JNC/1</td>
<td>OK</td>
<td>SC</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAL2295/MD82</td>
<td>KDFW/KSLC</td>
<td>15.0</td>
<td>JNC/1</td>
<td>OK</td>
<td>OK</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAL745/B752</td>
<td>KLAGA/KDEN</td>
<td>10.7</td>
<td>TODDE/1</td>
<td>9</td>
<td>OK</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAL652/B752</td>
<td>KDEN/KIAD</td>
<td>9.0</td>
<td>SJI/1</td>
<td>OK</td>
<td>SC</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAL473/MD82</td>
<td>KDFW/MMGL</td>
<td>7.2</td>
<td>JCT</td>
<td>OK</td>
<td>SC</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NKS719/A319</td>
<td>KDFW/KDEN</td>
<td>6.7</td>
<td>FTI</td>
<td>OK</td>
<td>OK</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGF3601/CRJ7</td>
<td>KELP/KORD</td>
<td>6.3</td>
<td>STL</td>
<td>OK</td>
<td>OK</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWA2714/B737</td>
<td>KLAX/KSTL</td>
<td>5.8</td>
<td>SGF/1</td>
<td>OK</td>
<td>SC</td>
<td>N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Potential flying time savings (min)**
- **Capture fix / number aux waypoints**
- **Minutes to traffic conflict**
- **Sector congestion on DWR route**
- **Reroute Traffic Management Initiatives**
- **Adjustable Alert Criteria**
User Interface with Trial Planner

Flight Plan
Congestion on Flight Plan
DWR Route
Congestion on DWR
Maneuver Start Point
Flying Time Savings (or Delay)

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CTAS/FACET Integration

Real-time two-way communication

Trial Route
(DWR or manual trial plan)

CTAS

FACET

- Congested sectors on flight plan route, DWR route/trial plan route
- Special Use Airspace
- Reroute Traffic Management Initiatives

Congested Sectors: Predicted red or yellow based on Monitor Alert Parameter (MAP)
Future Air Traffic Management (ATM) Concepts Evaluation Tool (FACET) Integrated for Sector Congestion Analysis

For user information only, currently no filtering based on sector congestion data
Movie 1
Sample DWR Routes from AA Trial
How are snap to fixes selected for auxiliary waypoints?

Current DWR uses three-letter fixes and NRS waypoints (the “K” fixes)

Option for user preferred list of eligible waypoints

100 nmi search radius, select combination that results in minimum delay, no weather conflicts
Weather Gap Detection

Default Width: 25 nmi
Default Distance Along Track: 50 nmi
Special Use Airspace

SUAs Scheduled to be Active

Crosses SAA 5107B_partC, 5107B_partF

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Reroute Traffic Management Initiatives

almost 2 hours old

Click more info

<table>
<thead>
<tr>
<th>Advisory</th>
<th>Orig</th>
<th>Dest</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>83</td>
<td>ZTL</td>
<td></td>
<td>MGM J37 PEKON J86 ELP</td>
</tr>
<tr>
<td>83</td>
<td>ZTL</td>
<td></td>
<td>MGM J37 PEKON J86 JCT</td>
</tr>
<tr>
<td>83</td>
<td></td>
<td>DEN</td>
<td>JCT FTI BRAZO LDORA1</td>
</tr>
</tbody>
</table>
Movie 2
Key DWR Functions
• Building Blocks

• DWR Concept, Tool, Functional Components

Operational Trial at American Airlines

• Analysis Results
  – Potential Benefits all Fort Worth Center Flights
  – American Airlines Test Results
  – Sector Congestion Analysis

• Software Architecture and Required Inputs

• How to Acquire DWR Software

• Next Steps
Trial at American Airlines

American Airlines Integrated Operations Control Center, Fort Worth, Texas

DWR Display → ATC Coordinator → Dispatcher → ACARS → Pilot → Controller → Route Clearance

Trial at American Airlines

Integrated Operations Control Center, Fort Worth, Texas
Test Operations

- Fort Worth Center traffic only
- System runs 23 hrs/day, 7 days/week since July 2012
- Usually staffed during heavy weather
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Potential DWR Savings and Today’s Savings without DWR

Center flight plan route

Potential Savings: First DWR advisory for any flight (time = t1)

Today’s Savings without DWR: Observed route amendments for corresponding flight (time > t1)
Potential Savings in 2013
All Flights, Fort Worth Center, Savings ≥ 5 min

100,000 minutes corrected potential savings for 15,000 flights, one year, one Center

Potential DWR: 148,922 min, 15,096 flights, 9.9 min/flt avg
Today’s Savings: 47,747 min, same flights, 3.2 min/flt avg

Top Ten Airlines

AAL  UAL  ASQ  SWA  N  EGF  FDX  SKW  DAL  AWE  Other
Potential Savings by Day 2013/2014

Fort Worth Center Flights, 1/1/2013 to 4/13/2014
Potential Savings by Day 2013/2014

Fort Worth Center Flights, 1/1/2013 to 4/13/2014

Potential Savings (min)

5/29/13

Top 30 Days

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Sample: Las Vegas/Chicago

Potential Savings: 15 min
Sample: Denver/Baltimore

Potential Savings: 12 min
Sample: Atlanta/Seattle

Potential Savings: 27 min
Sample: Atlanta/Seattle

Potential Savings: 27 min
How long does a flight stay on the DWR flight list?

Fort Worth Center
Top 30 Days in 2013/2014

Number of Flights

Longevity of DWR Advisories (min)
Potential Savings All Flights
Fort Worth Center, Top 30 Days in 2013/2014

Total Flights: 5,692
Potential Savings: 65,740 min
Average Savings: 11.5 min/flight
How many DWRs are pure direct routes vs. those with auxiliary waypoints?

Total Flights: 5,692
Potential Savings: 65,740 min
Average Savings: 11.5 min/flight
How many flights get DWR route advisories over 15 minute intervals?

DWR Advisories, Fort Worth Center, 5/29/2013

UTC Time (15 min Intervals)
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Data Recording

Accept, Reject, Cancel

Advised
Email Alerts and the Daily Report

Note: sample email alerts and daily report are from different days.

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DWR Advised Routes and AA User Actions

AA Flights 1/1/2013 to 4/13/2014

63% of routes evaluated by AA users rated acceptable

Potential flying time savings (min)

Week in 2013 and 2014

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What is the Estimated Actual Savings for American Airlines flights?

Center flight plan route

AA Dispatcher Accepted DWR (time = t1)

Savings Attributed to DWR:
Observed Center route amendments (time > t1):

Assume observed amendments for AA flights following dispatcher accepted DWRs are attributed to DWR.
DWR Activity at American Airlines

July 31, 2012 to April 13, 2014

Flying Time Savings (min)

- Evaluated: 10,327 min, 1,622 flights
- Accepted: 5,970 min, 994 flights
- Rejected: 920 min, 125 flights
- Cancelled: 503 flights
- Estimated Savings Attributed to DWR: 1,815 min, 327 flights

Estimated Actual Savings Overall
1,815 minutes for 327 revenue flights
**DWR Activity at American Airlines**

27 Days with High AA Value (Potential AA Savings ≥ 200 min), High AA Use (Potential Evaluated ≥ 20%)

<table>
<thead>
<tr>
<th>AA user’s rating of advised DWR routes</th>
<th>Flying Time Savings (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluated</td>
<td>5,632 min, 621 flights</td>
</tr>
<tr>
<td>Accepted</td>
<td>3,567 min, 418 flights</td>
</tr>
<tr>
<td>Rejected</td>
<td>581 min, 62 flights</td>
</tr>
<tr>
<td>Cancelled</td>
<td>1,177 min, 138 flights</td>
</tr>
</tbody>
</table>

**Estimated Actual Savings on 27 High-Value, High-Use Days**

1,177 minutes for 138 revenue flights

$4,300/day at $100/min
Sample: Tampa/Chicago

Estimated Actual Savings: 24 minutes
Sample: Dallas/Minneapolis

Estimated Actual Savings: 20 minutes
Six recently retired ZFW Traffic Management Coordinators and Area Supervisors evaluated 39 actual DWR routes rated “Accept” by AA users.

- 62% of AA routes approved
- 57% (151 minutes) of DWR savings
- Rejects primarily due to Airspace configuration
  - Center boundaries
  - Arrival stream/sector

Reasons for Rejected DWRs

- Request in Other Center
- Arrival Stream
- Too Close to Weather
- Too Much Coordination
- Other
- Downstream Congestion
- Route TMI
- Start Time/Altitude
- Current Sector Congestion
- Too Much Work

Percent Rejected
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Sector Congestion Analysis

• How many DWR flights encounter congestion? How much travel time in sectors with congestion?

• What happens if all flights are granted DWRs?
How Many DWR Flights Enter Congested Sectors? Proposed DWRs for 4,327 ZFW Flights, Top 24 days 2013/2014

Flights fare better with DWRs for congested sector encounters
Time Spent in Congested Sectors
Proposed DWRs for 4,327 ZFW Flights, Top 24 days 2013/2014

DWR trajectories spend less time in congested sectors
(39% fewer min in red sectors, 53% fewer min in yellow sectors)
In the first 45 min flights on flight plan routes encounter more congestion than flights on DWR routes.
What if all DWRs are Granted?
Proposed DWRs for 4,327 ZFW Flights, Top 24 days 2013/2014

Time in Congested Sectors
Flight Plan: 40 hrs 29 min
DWR: 37 hrs 10 min

DWRs reduce congestion 8 percent overall
Most savings occur over 5 days in 3 sectors

<table>
<thead>
<tr>
<th>Sector Name</th>
<th>Time in congested sectors (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>40 hrs 29 min</td>
</tr>
<tr>
<td>DWR</td>
<td>37 hrs 10 min</td>
</tr>
</tbody>
</table>

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Software Architecture and Required Inputs

- How to Acquire DWR Software
- Next Steps
## External Live Data Sources

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
<th>Update Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host/ERAM data (Flight plan, Track, etc.).</td>
<td>Direct from FAA</td>
<td>12 sec</td>
</tr>
<tr>
<td>ASDI - Aircraft Situation Display For Industry data.</td>
<td>Direct from FAA</td>
<td>1 min</td>
</tr>
<tr>
<td>CIWS - Corridor Integrated Weather System Convective Forecasts</td>
<td>Direct from FAA</td>
<td>5 Min, 120 min forecast</td>
</tr>
<tr>
<td>RR – Rapid Refresh Weather information</td>
<td>Direct from NOAA ftp site</td>
<td>60 min, 60 min forecast</td>
</tr>
<tr>
<td>TFMDI - Traffic Flow Management Data to Industry for route traffic management initiative information</td>
<td>Raw data from FAA, stored locally in a database</td>
<td>5 min</td>
</tr>
<tr>
<td>SUA - Special Use Airspace data</td>
<td>From FAA public website</td>
<td>5 min</td>
</tr>
</tbody>
</table>
## Derived and Static Input Data

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
<th>Update Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWAM - Convective Weather Avoidance Contours</td>
<td>Derived from CIWS by DWR weather processing scripts</td>
<td>5 min, 120 min forecast, 5 min time step</td>
</tr>
<tr>
<td>Adaptation - NAS configuration Chart Change Update</td>
<td>Direct from FAA</td>
<td>56 days</td>
</tr>
<tr>
<td>Aircraft performance data</td>
<td>Internal to DWR software, used to generate trajectories</td>
<td>N/A, Static</td>
</tr>
</tbody>
</table>
DWR Software Architecture

Live Data: Track, Flight Plan, Weather, Winds, Special Use Airspace

- Mixture of C, C++, Java, scripts
- Roughly 1.5M lines of code
- Multi-processes, multi-threaded
- Prototype system:
  - 1 computer: 24 Cores, 48 GB
  - Linux (CentOS 6.4)
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• Next Steps
How Do I Get the DWR Software?

• DWR is available for licensing on a non-exclusive basis both for commercial purposes as well as for internal evaluation.

• Details on licensing and NASA license request requirements can be accessed at

https://www.nasa.gov/ames-partnerships/opportunities/licensing

• Point of Contact for Licensing:

  Trupti Sanghani, Technology Partnerships Division
  NASA Ames Research Center
  Telephone: (650) 604-6889
  Email: Trupti.D.Sanghani@nasa.gov

• Technical Point of Contact:

  Dave McNally, Flight Trajectory Dynamics and Controls Branch
  NASA Ames Research Center
  Telephone: (650) 604-5440
  Email: dave.mcnally@nasa.gov
Next Steps

• Adjacent center traffic for more coordination time, more benefit, better analysis of merging arrival streams

• Smart filtering and route adjustment to avoid merging arrival streams – separate DWRs from traffic not airspace

• Support commercialization of DWR technology

• Streamline evaluation and coordination, faster delivery to dispatcher display, web-based DWR advisories

• Leverage DWR technology for groups of flights, identify and correct stale weather avoidance routing restrictions