

A SPATIAL DATABASE FOR REROUTE PLANNING

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Abstract

Current storage and retrieval of air traffic management data by the FAA allows for sufficient control of aircraft flows in the National Airspace System. However, these storage methods allow neither for deep historical analysis nor for use of advanced, standards-compliant tools. Another shortcoming of these storage methods is that air traffic management data are not readily accessible by all interested parties. The contributions of this paper are a new approach to describing, storing, and serving air traffic management data, and its software implementation. This approach is compliant with relevant published standards and, therefore, is easily incorporated into current and future systems. We fully develop a schema for describing reroute advisories, implement a database based upon that schema, then implement an example tool that can use this new system to provide information in a way not possible in the current system. This schema is an extension of the Aeronautical Information Exchange Model and allows for geometric queries to databases based upon the model. The example tool uses this feature by requesting previously implemented reroutes that do not intersect a supplied region of interest. The results enable a traffic manager to base a new reroute on past decisions of all traffic managers, which is not an approach used today. In today's operations, the sharing of past decisions between traffic managers given similar situations is not a formal process. The disconnect between what various managers might implement leaves room for inefficiencies in the system and helps motivate this study. As an example of the potential benefits of the system described here, there was a savings over 1000 nmi in total flight distance over all flights affected by a particular reroute advisory.

Background

This section consists of three parts, each covered in a separate subsection: a detailed exposition of reroute advisory planning; current storage and

retrieval of the related reroute data; and the various standards that will shape our new approach to storing and retrieving reroute data.

Reroute Advisory Planning

A reroute advisory is issued when an air traffic flow's demand for an airspace resource (typically a volume of airspace) exceeds the capacity for that resource. Among the common causes of a reroute are convective weather in the en route airspace, naturally occurring excess demand, and facility outages. The main features of a reroute advisory include filters for which flights are involved. These filters include origin airport, destination airport, departure time, and aircraft type. For the included flights, a specific route from their respective origins and destinations is provided to help alleviate congestion en route related to the causes listed above.

The primary tool for planning a response to these demand-capacity imbalances is the Traffic Situation Display (TSD) [1]. TSD allows viewing traffic, weather, and airspace resources as well as communicating potential reroutes and constrained areas of airspace with other (potentially remote) users of TSD. After planning a reroute advisory using TSD, the traffic manager uses the same tool to actually implement the advisory. The data generated by such an implementation are discussed in the next section.

We now give a brief review of the past research efforts to develop alternative methods for planning and implementing reroutes. Using mathematical programming techniques and a network flow model of the airspace, Bertsimas and Patterson develop a method for rerouting aircraft [2]. Mayhew and Manikonda use an airspace simulator and a shortest path algorithm to route aircraft around weather obstructions [3]. Similarly, Grabbe, Sridhar, and Mukherjee use a different airspace simulator coupled with a regular grid of waypoints to find a shortest path around weather [4]. One of the major drawbacks to each of these three techniques is the

lack of validation of the routes for operational implementation. Currently in the National Airspace System, flights are routed using various named waypoints and jetways to ease the control and guidance of aircraft in the system. Taylor and Wanke explicitly address the operational viability of dynamically generated reroutes [5, 6]. Their work, however, is more focused on generating such reroutes on a flight-by-flight basis rather than generating advisory-level reroutes for entire flows of flights. In this work, we will address the creation of operationally acceptable reroutes suitable for issuance as advisories. The operational acceptance of the reroutes generated by the methods in this paper will rely on the fact that the FAA has previously implemented all suggested reroute segments.

Data Related to Reroute Advisories

When a reroute is implemented using TSD, several data sets are generated. Specifically, TSD is the source for reroute data supplied to the National Traffic Management Log (NTML) and the Traffic Flow Data to Industry (TFMDI) feed. The structure and content of these data, which we now describe, crucially affect the development of new models of storage and retrieval.

National Traffic Management Log

The TSD has a connection to the primary database for traffic management initiatives in the National Airspace System (NAS). This database is called the NTML [7]. The NTML is the repository for all data related to traffic management initiatives, the communication conduit between the various air traffic control facilities, and the official record of related decisions in the NAS. The primary function of the NTML is to facilitate day-of-operations activities, ensuring safe and efficient traffic flow throughout the system. NTML is sometimes used for post-operations analysis of performance.

When a reroute is planned with the TSD, the parameters of the reroute are stored in the NTML within the ‘Advisories’ table. This table is populated by traffic decisions related to Ground Delay Programs, Ground Stops, Airspace Flow Programs, and other initiatives with a somewhat national scope. By contrast, any Miles-in-Trail restrictions are not stored as Advisories, but are stored in a separate ‘Restrictions’ table. More detailed information on

the NTML and the data stored within is provided by Rios [8].

The way in which the reroute data are stored within the Advisories table suffers from the drawback that the most important parameters are stored as a single text field within one column of the table. Parsing this text field is error-prone, since many of the elements within it are entered by hand. This database column is the basis for what the public would see related to a reroute advisory on the FAA’s website [9]. For an example of a reroute advisory taken from the publicly available FAA website, see Figure 1. All of the text after the “RAW TEXT:” label is what is available in the database text field described above. Note that the entire reroute advisory is described in detail, including which traffic is to be included, the reason for the reroute, the valid times for the reroute, and complete routes for flights from their origin (ORIG) to destination (DEST). This particular advisory is examined in more detail in *Experiment Details* section of this paper.

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ATCSCC Advisory
ATCSCC ADVZY 035 DCC 06/16/2012 ROUTE RQD /FL
RAW TEXT: ATCSCC ADVZY 035 DCC 06/16/12 ROUTE RQD /FL
NAME: PNH_1_PARTIAL
CONSTRAINED AREA: ZKC
REASON: WEATHER
INCLUDE TRAFFIC: ADW/BWI/DCA/IAD/PHL DEPARTURES TO
ABQ/DEN/LAS/LAX/LGB/OAK/PHX/SAN/SFO/SJC/SNA/VNY
FACILITIES INCLUDED: TAB/ZDC/ZDV/ZFW/ZID/ZLA/SLC/ZME/ZNY/TOA
FLIGHT STATUS: ALL FLIGHTS
VALID: ETD 161900 TO 170000
PROBABILITY OF EXTENSION: MODERATE
REMARKS:
ASSOCIATED RESTRICTIONS: PASSED VIA NTML IF NEEDED
MODIFICATIONS:
ROUTES:

FROM:
ORIG                                ROUTE - ORIGIN SEGMENTS
-----
IAD DCA BWI ADW                    >LDN J134 COLNS J6 BWG ARG FSM
PHL                                  IRW PNH
                                      >MKE MKE278 PENSY J110 FLIRT J6
                                      BWG ARG FSM IRW PNH

TO:
DEST                                ROUTE - DESTINATION SEGMENTS
-----
ABQ                                  PNH J58 FTI FRIH04<
PHX                                  PNH J6 ZUN EAGUL5<
DEN                                  PNH HGO QUAIL6<
LAS                                  PNH J58 FTI J8 GUP J72 PGS
                                      TYSSN3<
LAX                                  PNH J6 DRK J231 TNP SEAVU2<
LGB                                  PNH J6 DRK J231 TNP PSP KAYOH4<
SAN                                  PNH J78 PKE LYNDI3<
SNA                                  PNH J6 DRK J231 TNP PSP KAYOH4<
VNY                                  PNH J58 FTI J8 GUP J72 PGS HEC
                                      LYHX8<
OAK                                  PNH RSK J58 MLF ILC TATOO DUGLE
                                      MADN5<
SFO                                  PNH RSK J58 MLF ILC RUMPS OAL
                                      MOD3<
SJC                                  PNH RSK J58 MLF ILC TPH CANDA
                                      HYP5<

TMI ID: BRDCC035
161746-170000
12/06/16 17:46 DCCOPS./nfs/lxstn28

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Figure 1. Reroute Advisory Example

Traffic Flow Management Data to Industry

The FAA offers a service to stakeholders in the NAS that provides reroute and other data in a timely and well-formatted manner. The TFMDI service is a

“pull” service: users can request updated data from an FAA server if it is available.

The available data are public reroutes (i.e., those reroutes not internal to the FAA); affected flights; public Flow Evaluation and Flow Constrained Areas; alert data (i.e., resources that are predicted to be over capacity); and some weather products. Full details on these data are supplied in the TFMDI overview document provided by the FAA [10].

For this work, the reroute data provided by the TFMDI service is the most important. These data are provided in XML format and include full route information including all segments in a given reroute. This route information includes latitude and longitude data, missing from the NTML data discussed above, but critically important to a spatial description of the segments. The TFMDI data feed is the preferred source for reroute data for this work, given that it is well-structured (i.e., XML-formatted) and includes latitude and longitude data rather than just waypoint names.

Figure 2 gives a diagrammatic summary of the creation and flow of reroute data as it exists today. Currently, to obtain NTML or TFMDI access, one needs to obtain approval from the FAA. We aim to provide a service that does not rely on approving particular users of the data. Rather, our goal is the policy of approving particular data suitable for public release. That data will then be available in a well-documented and standards-compliant manner. To illustrate and contrast this intended approach against that in Figure 2, see Figure 3.

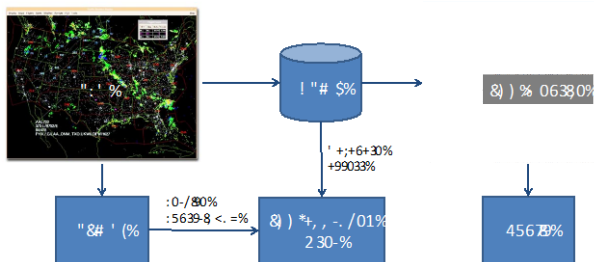


Figure 2. Current Reroute Data Flow

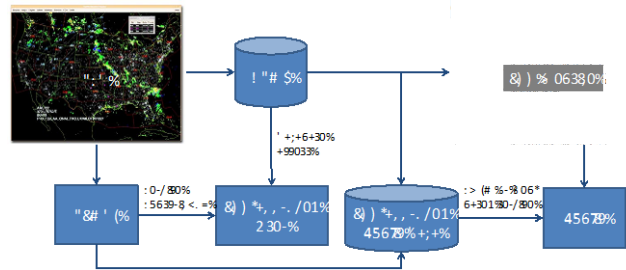


Figure 3. Proposed Reroute Data Flow

Relevant Standards to Guide Development

In order to ensure that the data and services provided for accessing it are interoperable with as many other systems as possible, the development of our system is guided by recognized standards. We describe those standards here.

Geography Markup Language

Geography Markup Language, or GML, is an XML language defined by Open Geospatial Consortium (OGC) to describe geographical features [11]. GML serves as a modeling language and a data exchange format for geographic information systems. It defines a set of data types that are used to build application specific schemas. These types include feature, geometry, coordinate reference system, time, unit of measure, coverage, and topology, among others. Application schemas developed using GML allow easy data exchange with GML-supporting tools such as Google Earth, NASA’s World Wind, and ESRI ArcGIS desktop.

Aeronautical Information Exchange Model

The Aeronautical Information Exchange Model (AIXM) is designed to enable the management and distribution of aeronautical information service data in digital format. The latest version of AIXM (version 5.1.) was a joint development by the FAA and the European Organization for Safety of Air Navigation (EUROCONTROL) [12].

AIXM uses a UML conceptual model to describe the aeronautical features and their properties. The AIXM XML schema is an implementation of the AIXM conceptual model for data exchange. AIXM incorporates a number of key concepts/components to represent real-world aeronautical features. One of them is the temporality model that supports time-based information and events [13]. Another is the alignment with ISO geospatial standards using GML. AIXM model is

modular and extensible. In particular, it allows extensions to data models for different operation and service domains, such as air traffic management.

System Wide Information Management

The System Wide Information Management (SWIM) system is an integral part of the transformation from the current NAS to its NextGen system. The operational concept of SWIM is to provide a sharing architecture in the NAS and secure information management that are open, flexible, modular, and manageable. SWIM is based on the principles of Service Oriented Architecture (SOA). SOA is a system architecture design pattern for organizing and using services to support interoperability. The SWIM data service interface standard allows for XML-based message passing over web services or Java Messaging Service (JMS) transport protocols.

SWIM has four core capabilities:

- Interface Management – allows service providers to expose services and service consumers to find services.
- Messaging – provides mechanisms to service invocation including publish/subscribe and request/reply data exchange style.
- Security – includes mechanisms to enforce security policies at service and message level.
- Enterprise Service Management – enforces governance and monitoring of services.

SWIM advocates a SOA infrastructure that leads to a distributed system for service, interoperability and loose coupling. The FAA website has comprehensive documentation on SWIM [14].

Implementation of New Reroute Data Service

Given the frameworks of currently existing data and the widely-accepted standards described above, we now describe a new method for storing reroute data that complies with those standards and will allow for new services not possible in today's system.

Reroute Advisory Schema

Since we are aiming for interoperability and compliance with AIXM systems and data, this schema will depend upon AIXM. We briefly describe the relationship between AIXM and the reroute schema and then provide an explicit description of the reroute schema, which we have named the Traffic Management Information Exchange Model or TMXM (pronounced “t-mix-m”).

TMXM depends upon AIXM because TMXM implements several abstract classes of AIXM and uses some of AIXM's concrete data types. A central concept of AIXM is its temporality model, of which TMXM takes advantage. Every reroute is constructed to consist of one or more time slices. A new time slice is created whenever any of the features of the reroute changes. For example, when a reroute is initially created, there is only one time slice describing all of its features. If, say, an hour later the end time of the reroute changes, a new time slice is generated to indicate this change in the feature value related to the end time of the reroute. Now the entire reroute advisory would be completely described by these two time slices. Each time slice will have one or more reroute segments that describe the various legs of the reroute. Each of those segments will have a set of filters specifying the flights to be assigned that reroute segment (e.g., all jets flying from SFO to DEN).

TMXM can be extended to describe other traffic management initiatives. This extension can be accomplished by creating a similar description of those initiatives to those described here for reroutes. For instance, a ground delay program would be made up of one or more time slices with the appropriate fields to describe the program. These extensions are further discussed in the Future Work section of this paper.

Database Implementation

PostgreSQL, an open source database management system, has been used to store and retrieve traffic management initiative (TMI) data. The database has spatial extension using PostGIS support. PostGIS supports GML geometries such as Point, LineString, and Polygon. In addition to the geometries, there are several native functions that act upon these geometries including intersections, distances, containment, and many others.

Figure 4 shows the four database tables for reroutes advisories. The relationships follow the TMXM schema discussed in the previous section. At the top is the table *RerouteTimeSlice*, uniquely indexed by the primary keys. This table references one or more reroute segments related to time slices in a *RerouteSegment* table. The *RerouteWaypoint* table stores each segment's waypoints. Finally, the *RerouteSegmentFilter* holds segment filter conditions, which are the conditions to determine which flights are affected by that reroute segment.

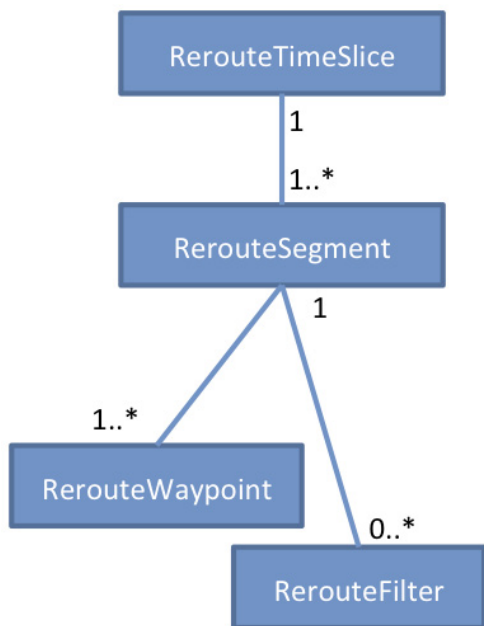


Figure 4. Reroute Database Schema

There are two geography columns in the tables. One is the *geog* column in *RerouteWaypoint*, which is a GML Point datatype. The other is the *geog* column in *RerouteSegment*, which is a GML *LineString* type constructed from the waypoints.

Proposed System

We now describe how the above components can be assembled into a functional system with capabilities unavailable today.

By building the reroute advisory schema and database as described in the previous two sections, the data will be delivered in compliance with AIXM. This allows a future system to ingest the reroute data without any custom data-handling routines. Any software that is used to handle AIXM data could also handle the reroute data as described.

With the data available in an AIXM-compliant form (and, thus, as well-formed XML), reroute information can be served and consumed appropriately in SWIM. All future information-based systems will need to fit into the FAA's plans for SWIM. As a byproduct of being GML-compliant, the reroute data are also easily consumed by various standards-compliant geospatial clients like Google Earth, NASA WorldWind, and ESRI ArcGIS desktop.

Reroute Planning With Historical Data

In this section, we describe a new prototype tool that leverages the data organization described above. This tool can aid traffic managers in routing decisions during a reroute event. Our description will show, in particular, why such a system is not possible given today's TMI data storage and methods.

Database Population

Initially the database is populated with historical, static data taken directly from the TFMDI data feed. The TFMDI had been archived in its native XML format since April 2011 through August 2012 with some gaps in the data. In total, there are 366 days of reroute data stored within the database for the experiments to be described below. Over that time period, there were 2982 different reroute TMIs put into place by the FAA Command Center. For all of those reroutes, there were 5482 distinct reroute time slices generated, averaging to about 1.8 time slices per reroute TMI. The simplest interpretation of these data is that for every reroute there was about one change in the plan, usually a change in the planned end time by either extension or early termination resulting in an additional time slice for each reroute.

For this study, we will use the reroute segments table of the database. Recall that for each reroute TMI, there are several reroute segments (see Figure 1 for explicit examples of 'origin' and 'destination' segments). For instance, a single reroute advisory directing traffic into the New York area may have different segments for traffic from various airports. Overall, there are 87,309 rows in the reroute segment table of the database. Of those, 82,534 correspond to *distinct* reroute segments. All of the relevant data described is summarized in Table 1.

Table 1. Reroute Data in Database

Data Element	Count
Days	366
Reroutes	2982
Reroute Time Slices	5482
Reroute Segments	87,309
Distinct Reroute Segments	82,534

Experiment Outline

Typically traffic managers look at the predicted traffic and weather and use their personal experience and discussions with colleagues to determine the appropriate reroute TMI to put into place. Historical reroute data does not play a direct role in the decision making process. As described in the previous section, there is a large volume of data available that can aid in making decisions. Other than through direct training or planning discussions, there is not an institutional knowledge transfer between traffic managers responsible for making reroute decisions, especially at the time of making the decision. While traffic managers generally make effective decisions with which the airlines and other managers concur, it will be beneficial to use the whole body of prior decisions to guide the process in order to provide a greater number of options from which to choose. This notion is the main motivation of the experiment presented here.

We propose to take a predicted weather scenario and a desired flow of traffic to control as input. As output, the system will provide a set of historically validated reroute segments (i.e., those that have been implemented as least once in the past) that avoid the desired weather polygons. This list of segments might be weighted based on any number of factors. In the future, one might imagine a score assigned to each previously implemented reroute based on its effectiveness and those with higher scores might be offered as choices for the current scenario. Given that sort of scoring system does not yet exist, we take as a simple proxy providing the reroute segments in order of shortest distance. In practice, this would likely be a key criterion for choosing a particular reroute anyway.

User Input

One of the key weather products in air traffic management is the Corridor Integrated Weather System (CIWS) [15]. CIWS describes the precipitation (in the form of vertically integrated liquid) and echo tops of storms. Another promising product built using CIWS data is the Convective Weather Avoidance Model (CWAM) [16]. Using CIWS together with lightning data, the model describes the probability that a pilot will deviate his or her course to avoid a particular area of weather activity. We have implemented CWAM and can generate polygons representing areas where pilots are likely to avoid. For the experiments presented here, we used a deviation likelihood of 60%.

There are two more steps to generating CWAM polygons. First, we ignore small polygons. Any CWAM polygon with a perimeter less than 100 nmi is discarded. Second, we group neighboring CWAM polygons to avoid issuing reroutes that “shoot the gap” between two or more nearby polygons. To simplify calculations, the gap is estimated using the centroid of the polygons. Thus, any polygons whose centroids are within 50 nmi are clustered to avoid routing between them. An example of clustered CWAM polygons over the state of Colorado is given in Figure 5. Note that the parameters discussed in this paragraph are not offered as the ideal values to be used operationally, rather they appear to provide acceptable results for the experiments at hand. For more details on various aviation weather models, see Krozel’s work on the topic [17]. For a more detailed exploration of CWAM clustering, Rubnich and DeLaura [18] detail a more robust algorithm to the one described here.

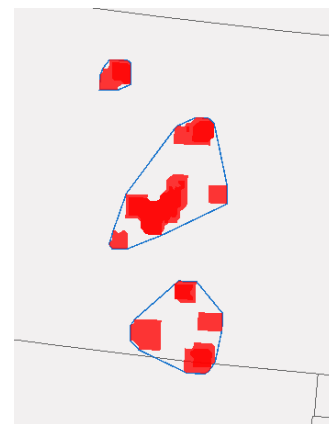


Figure 5. Example of CWAM Polygon Clustering

The final key input values are the flights that should be considered for rerouting. This system is not designed to offer suggestions as to which city pairs should receive a reroute. The user specifies this information simply by denoting an origin and destination for the flights to be rerouted. For example, the user may want to reroute all flights originating from PHL (Philadelphia) destined for LAX (Los Angeles).

These input values are synthesized into a database query that can take advantage of the spatial nature of the tables contained therein. Specifically, using the origin and destination of the reroute segments in the database, we query for all previously implemented segments such that those segments do not intersect any of the clustered CWAM weather polygons. The user is returned a list of candidate routes ordered by distance (in lieu of any other ranking system). The entire process is summarized in Figure 6. Note that we only consider avoidance of CWAM polygons, however, the process would be exactly the same to avoid other volumes of airspace due to excess traffic, equipment outages, or special use airspaces. All that matters is the definition of the polygon to avoid.

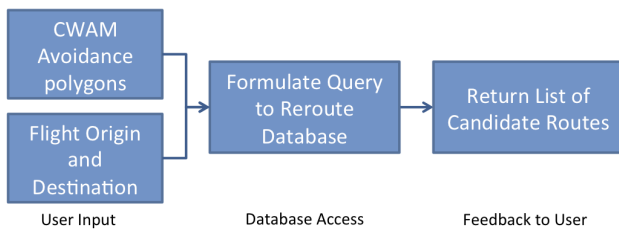


Figure 6. Proposed Tool Flow Chart

Experiment Details

After analyzing the available reroute data together with their respective weather data, the 16th of June, 2012 was chosen for detailed analysis. On that date there were 23 distinct reroute advisories with 20 of them attributed to weather. We chose one of those reroutes as the basis for further analysis. Within that reroute, we identified particular city pairs to illustrate the capabilities of the proposed system. We use the routes from PHL (Philadelphia International) to SFO (San Francisco International) and PHL to LAX. The particular reroute advisory along with highlights for the implemented PHL-SFO and PHL-LAX routes is shown in Figure 7. The PHL-SFO route specifies that all flights departing PHL between 1900 UTC on

June 16th through 0000 UTC on June 17th destined for SFO need to follow:

**PHL.MXE.MXE278.PENSY.J110.FLIRT.J6.BW
G.ARG.FSM.IRW.PNH.RSK.J58.MLP.ILC.RUM
PS.OAL.MOD3.SFO.**

This is a series of airport names, waypoints, and jetways. By examining the reroute advisory in Figure 7, one can discern that it was issued at 1746 UTC, roughly an hour and 15 minutes before the advisory was to begin.

ATCSCC Advisory	
ATCSCC ADVZY 035 DCC 06/16/2012 ROUTE RQD /FL	
RAW TEXT: ATCSCC ADVZY 035 DCC 06/16/12 ROUTE RQD /FL	
NAME: PNH_1 PARTIAL	
CONSTRAINED AREA: ZKC	
REASON: WEATHER	
INCLUDE TRAFFIC: ADW/BWI/DCA/IAD/PHL DEPARTURES TO	
ABQ/DEN/LAS/LAX/LGB/OAK/PHX/SAN/SFO/SJC/SNA/VNY	
FACILITIES INCLUDED: ZAB/ZDC/ZDV/ZFW/ZID/ZLA/ZLC/ZME/ZNY/ZOA	
FLIGHT STATUS: ALL FLIGHTS	
VALID: ETD 161900 TO 170000	
PROBABILITY OF EXTENSION: MODERATE	
REMARKS:	
ASSOCIATED RESTRICTIONS: PASSED VIA NML IF NEEDED	
MODIFICATIONS:	
ROUTES:	
FROM:	ROUTE - ORIGIN SEGMENTS
ORIG	-----
IAD DCA BWI ADW	>LDN J134 COLNS J6 BWG ARG FSM IRW PNH
PHL	>MXE MXE278 PENSY J110 FLIRT J6 BWG ARG FSM IRW PNH
TO:	ROUTE - DESTINATION SEGMENTS
DEST	-----
ABQ	PNH J58 FTI FRIH04<
PHX	PNH J6 ZUN EAGUL5<
DEN	PNH HGO QUAIL6<
LAS	PNH J58 FTI J8 GUP J72 PGS TVSSN3<
LAX	PNH J6 DRK J231 TNP SEAVU2<
LGB	PNH J6 DRK J231 TNP PSP KAYOH4<
SAN	PNH J78 PKE LYNDI3<
SNA	PNH J6 DRK J231 TNP PSP KAYOH4<
VNY	PNH J58 FTI J8 GUP J72 PGS HEC LYNXX8<
OAK	PNH RSK J58 MLF ILC TATOO DUGLE MADNS<
SFO	PNH RSK J58 MLF ILC RUMPS OAL MOD3<
SJC	PNH RSK J58 MLF ILC TPH CANDA HYP5<
TMI ID: RRDC035	
161746-170000	
12/06/16 17:46 DCCOPS./nfs/lxstn28	

Figure 7. Reroute Highlighting Key Segments

Given that we know when the planning took place via the issue time of the advisory, we model our experiment to use the same weather information that would have been available at the issue time. CIWS files are available at 5-minute intervals with predictions of weather 2 hours in advance. Thus we took the file from 1745 UTC on that date and looked specifically at the prediction valid at that time for 1900 UTC when the reroute advisory was to take effect. We processed that look-ahead time into CWAM polygons (with a 60% avoidance parameter as discussed above) and generated the CWAM map shown in Figure 8.

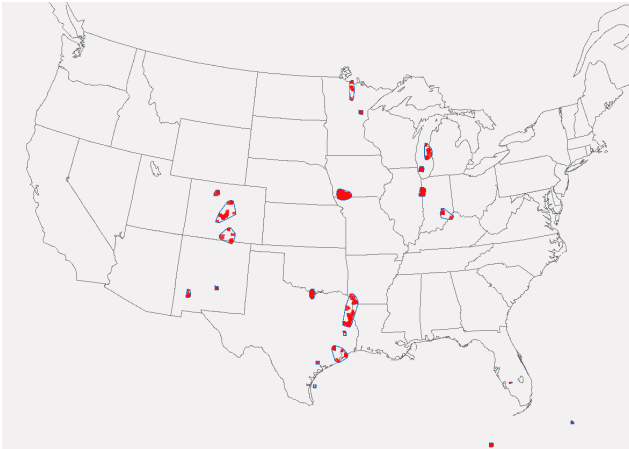


Figure 8. Clustered CWAM Polygons for 1900UTC as Predicted at 1745UTC 16 June 2012

With the weather polygons and the origin and destination of interest available, a query is generated to retrieve all complete routes from PHL to LAX that avoid the provided polygons. This was repeated for flights from PHL to SFO. These queries completely exercise the capabilities of a spatial database and require no other custom code to perform geometric computations. For the queries presented in this paper, the response time was on the order of seconds without any database optimizations that might improve this time. The resulting historical reroutes to LAX and SFO are plotted in Figures 9 and 10, respectively. The resulting data from the query is quickly validated for weather avoidance with a visual check. To aid the user in decision-making, feedback includes the distance for each reroute option.

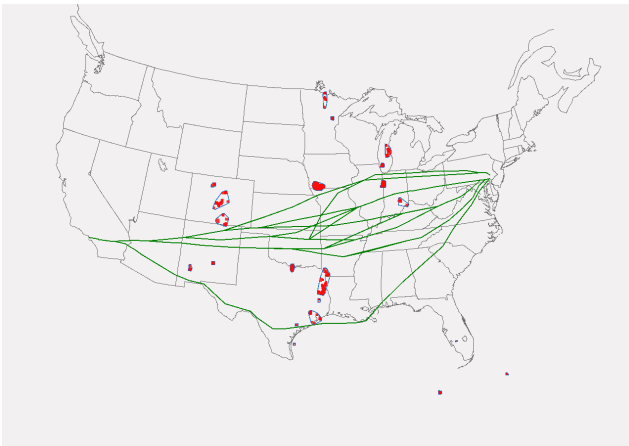


Figure 9. Historical Route Options from PHL to LAX Avoiding Weather

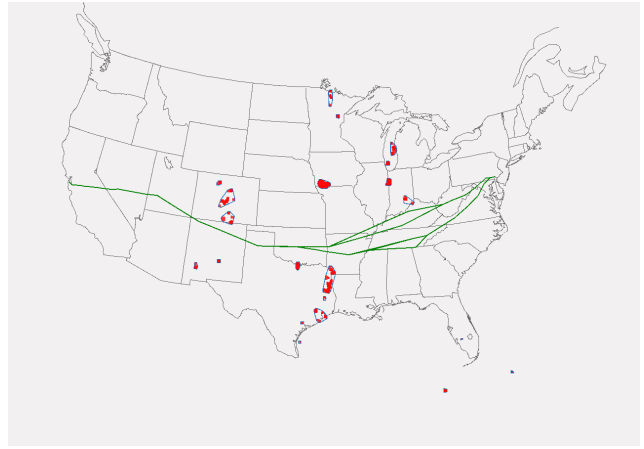


Figure 10. Historical Route Options from PHL to SFO Avoiding Weather

Seeing all of the data that would have been returned upon neglecting the requirement to avoid the CWAM polygons is instrumental in assessing the role of these polygons. The full set of potential reroutes from PHL to LAX is shown in Figure 11, considerably different from Figure 9 due to the exclusion of routes intersecting weather polygons.

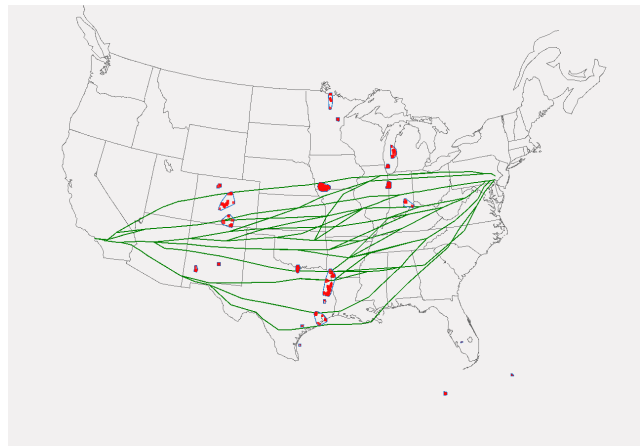


Figure 11. Historical Route Options from PHL to LAX Ignoring Weather

Further analysis of the results indicates that the route chosen for implementation on June 16th (which was one of the routes returned by the query) was almost 83 nmi longer than the shortest route implemented in the past that would have avoided the same CWAM weather polygons. The travel distance savings for a particular flight seem somewhat small, but further investigation is warranted to determine the effect a more efficient reroute plan may have had on that day.

To mitigate the effect of other TMIs that were in effect on June 16th, 2012, we use the traffic data from a less weather-impacted day together to analyze potential distance savings. Specifically, we take the traffic from June 2nd, 2012 (a mild weather and TMI day) and apply the reroute initiative produced above. There would have been 10 flights affected by this reroute departing from PHL to the various airports during the designated time window. If each flight were given the most efficient reroute based on historically implemented reroutes avoiding the predicted CWAM polygons, there would be a savings of over 1000 nmi in overall air traffic that day. Table 2 details these numbers. If we considered the flights originating from the other airports involved in that reroute advisory (IAD, DCA, BWI, and ADW as show in Figure 8) there would be even more flight distance savings to be had. Extrapolating from this initial work is difficult without more instances analyzed, but considering the fact that roughly 3000 reroute advisories are put into place each year, one could imagine a significant amount of flight time might be saved by using a tool as described here.

Table 2. Improvements in Reroute Using Database Results

Destination Airport	Savings Using Shortest Reroute (nmi)	Flights Effected	Total Savings (nmi)
LAX	83	2	166
PHX	50	3	150
DEN	237	2	474
LAS	79	2	158
SAN	54	1	54
Total			1002

Conclusions and Future Work

The way advisory data are generated, stored and delivered in today’s National Airspace System leaves little opportunity to leverage past decisions in making current decisions. By designing a new way to store and retrieve data, many new tools can be developed. We have implemented a new database and retrieval system capable of interfacing with various other systems without excessive development effort

required by those other systems. This is due to the focus on building this new system with an eye toward standards compliance. We have demonstrated the potential utility of this new data service by building a reroute planning tool that leverages all previously implemented reroutes in a way that is not possible in today’s system.

This research can be extended in a number of ways. The most obvious is the inclusion of other types of advisories such as ground delay programs, ground stops, and airspace flow programs. This work is currently underway. Beyond improving the data service, one could envision several new tools that would leverage the service in ways that are difficult or impossible today. The stakeholders in the National Airspace System might each have different uses for such a service. For example, an airline may like to use the data to plan alternate routes for the day’s operations or even longer-term routes for the coming year using knowledge of commonly implemented advisories. An interactive tool for consumers might give them better insight into why their flights have been delayed versus the static webpage-based tools available today. The FAA might have several internal uses for more readily accessible data in the spirit of the hypothetical tool presented here. Each of these uses is possible given an architecture as described herein.

References

- [1] Volpe National Transportation Center, April 2007, Common Constraint Situation Display User Manual, Version 8.4, Cambridge, MA, U.S. Dept. of Transportation.
- [2] Bertsimas, Dimitris, Sarah Stock Patterson, August 2000, The Traffic Flow Management Rerouting Problem in Air Traffic Control: A Dynamic Network Flow Approach, Transportation Science, Vol. 34, No. 3, pp. 239-255.
- [3] Mayhew, David, Vikram Manikonda, August 2008, Constrained Airspace Rerouting Planner for ACES, AIAA Modeling and Simulation Technologies Conference, Honolulu, HI.
- [4] Grabbe, Shon, Banavar Sridhar, Avijit Mukherjee, May-June 2009, Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics, Journal of Guidance, Navigation, and Control, Vol. 32, No. 3, pp. 810-820.

- [5] Taylor, Christine, Craig Wanke, September 2009, Dynamic Generation of Operationally Acceptable Reroutes, AIAA Aviation Technology, Integration, and Operations Conference, Hilton Head, SC.
- [6] Taylor, Christine, Craig Wanke, September 2010, Generating Operationally-Acceptable Reroutes Using Simulated Annealing, AIAA Aviation Technology, Integration, and Operations Conference, Fort Worth, TX.
- [7] FAA, February 2012, Order JO 7210.3X, Facility Operation and Administration.
- [8] Rios, Joseph, September 2010, Aggregate Statistics of National Traffic Management Initiatives, AIAA Aviation Technology, Integration, and Operations Conference, Fort Worth, TX.
- [9] FAA, Advisories Database Website, <http://www.fly.faa.gov/adv/advAdvisoryForm.jsp>.
- [10] Volpe National Transportation Center, August 2004, Traffic Flow Management Data to Industry: Overview, Version 1.0, Cambridge, MA, U.S. Dept. of Transportation.
- [11] Open Geospatial Consortium, February 2012, OGC Geography Markup Language (GML) – Extended Schemas and Encoding Rules, Version 3.3.0.
- [12] EUROCONTROL, AIXM Website, <http://www.aixm.aero>.
- [13] EUROCONTROL, FAA, 2010, AIXM 5 Temporality Model, Version 1.0, http://www.aixm.aero/public/standard_page/download.html.
- [14] FAA, SWIM Website, <http://www.faa.gov/nextgen/swim>.
- [15] Evans, James E., Elizabeth R. Ducot, 2006, Corridor Integrated Weather System, MIT Lincoln Laboratory Journal, Vol. 16, No. 1.
- [16] DeLaura, Rich, Mike Robinson, Margo Pawlak, Jim Evans, 2008, Modeling Convective Weather Avoidance in Enroute Airspace, 13th Conference on Aviation, Range, and Aerospace Meteorology (ARAM), New Orleans, LA.
- [17] Krozel, Jimmy, September 2012, Survey of Weather Impact Models Used in Air Traffic Management, AIAA Aviation Technology, Integration, and Operations Conference, Fort Worth, TX.
- [18] Rubnich, Mikhail, Rich DeLaura, September 2012, An Algorithm to Identify Robust Convective Weather Avoidance Polygons in En Route Airspace, AIAA Aviation Technology, Integration, and Operations Conference, Fort Worth, TX.

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