BENEFITS ANALYSIS OF AN AIR TRAFFIC FLOW MANAGEMENT CAPABILITY

James S. DeArmon,* Sarah E. Stalnaker,*
Rafael D. Katkin,* Michael McKinney**

*The MITRE Corporation
**Federal Aviation Administration

Abstract

Air Traffic Management in the U.S. can logically be divided into two major components: (1) air traffic control (ATC) ensures pairwise separation of proximate aircraft, and (2) traffic flow management (TFM) seeks a general balance between demand and capacity for airspace and airport resources. A set of new capabilities for TFM is in the process of being developed, for deployment in the 2009-2014 timeframe. In this paper, we describe an analysis of the benefits of one capability – a capability called Automated Airborne Congestion Resolution (AACR).

AACR is a capability that allows TFM staff to model, and then implement, alternatives for flight rerouting and take-off time delays when there are airspace constraints, i.e., reduced airspace sector capacity, typically because of severe weather.

Our benefits analysis compares today's approach with the proposed 2015 approach in which AACR provides automation support to augment and enhance human decision-making. Today's approach is mostly manual – TFM staff plan and coordinate alternate routing as possible under conditions of the disorder and pressure-to-act associated with severe weather impacting airspace. The future approach relies more on a computed solution – AACR generates

scores of reroutes, each with a spectrum of plausible take-off delays. The AACR approach can exploit scarce airspace resources when they are at a premium.

In the paper, we present a comparative analysis of the current vs. future scenarios, with quantitative results.

Introduction

In the U.S. National Airspace System (NAS), en route Traffic Flow Management (TFM) is the function which balances air traffic demand against available airspace capacity, to ensure a safe and expeditious flow of aircraft. A variety of flow control actions, such as weather avoidance routes, miles-in-trail (MIT) flow restrictions, and ground delay programs (systematic assignment of take-off delay for aircraft bound for a capacity-reduced arrival airport) are used to achieve this. Planning these actions requires predictions of both traffic demand and airspace (en route sector) capacity. Since TFM decisions are typically made 30 minutes to several hours in advance of anticipated congestion, these predictions are subject to significant uncertainty. However, the magnitude of this uncertainty is not known, presented, or understood. As a result, decisions are often overly conservative, and may be taken at inappropriate times based on the actual accuracy of prediction data. Capabilities are needed that can predict the demand and capacity of sectors (including the impact of weather) and the uncertainties associated with these predictions. In addition, automation is needed to propose resolutions to airspace congestion, taking uncertainty into account.

Considerable research is being done to predict sector demand and sector capacity and the uncertainty associated with these predictions. See [DeLaura and Evans 2006], [Mukherjee and Hansen 2005], [Wanke, Zobell and Song 2005]. As mentioned, the major problem is forecasting the capacity of airspace sectors, which may be a function of direction and complexity of air traffic, capacities of proximate sectors, controller staff levels, etc. It is expected that convective weather forecasts will be sufficiently accurate to support predicting sector capacity with a 0-2 hour look-ahead.

Automated Airspace Congestion Resolution (AACR) capability can use predicted sector demand and capacity and propose resolutions to manage congestion consistent with the uncertainty in predictions. The subject of this conference paper is the benefit analysis for AACR.

The TFM Modernization (TFM-M) program is modernizing the existing TFM infrastructure that was introduced in the early 1980s. There are three components: First, a hardware refresh was completed in Fiscal Year 2005 (FY05). The second component is to modernize the TFM system design and software for a phased implementation beginning in FY08. The third component includes new TFM decision support capabilities that are part of the Collaborative Air Traffic Management-Technologies (CATM-T) initiative. The CATM-T initiative is being planned in phases. The first phase is referred to as Work Package 1 (WP1), and is scheduled for deployment during the time frame FY06-FY10. Candidate capabilities for the following phase, referred to as Work Package 2 (WP2) for the time frame FY09-FY14, have been identified. One of these capabilities is Automated Airspace Congestion Resolution (AACR). The benefits analysis for AACR is one input that the Federal Aviation Administration (FAA) will use to determine what capabilities will be implemented as a part of WP2.

Background

En route airspace congestion, often due to convective weather, causes system-wide delays and disruption in the U.S. NAS. Today's methods for managing congestion are mostly manual, based on uncertain forecasts of weather and traffic demand, and often involve rerouting or delaying entire flows of aircraft [FAA 2006]. Decisions often need to be made in a strategic timeframe (2-6 hours) as the process of identifying congestion, coordinating strategies of how to manage congestion among TFM staff and with the NAS customers, and disseminating the flight specific ground delays and reroutes to air traffic control (ATC) staff is time consuming. Decisions made in a strategic time frame are based on weather forecasts that have significant uncertainty and can result in unnecessary flight delays.

The AACR capability allows TFM staff to effectively and efficiently manage congestion in a tactical time frame (0-2 hours). (Note that AACR operates in the tactical timeframe because sufficiently accurate convective weather forecasts will be available only for this timeframe.) Because congestion can be managed more effectively in a tactical time frame, less needs to be done in a strategic time frame when the uncertainty in weather forecasts is greater. For an identified area of congestion, AACR will propose a resolution to reduce the congestion to an acceptable congestion risk level. AACR will perform the following:

- Identify the flights that traverse the area of congestion
- Sequence the flights in priority order (this could be first come first serve or it could give priority to airborne flights versus pre-departure flights)
- Remove the flights from the area of congestion and then put them back in based on priority. When a flight that is put back in causes the congestion risk of the sector to exceed an acceptable risk level, the flight is moved out of the congestion using a ground delay (if the flight is pre-departure) or a reroute. If possible, the flight will be removed from the congested area using one of the NAS customer submitted preferences. The NAS customer can submit a prioritized list of preferences of how the flight should be moved out of the congested area.
- For each flight involved in the congestion, propose a flight specific maneuver (reroute, ground delay). Make available the flight specific maneuvers for dissemination to the NAS customers and to ATC staff for implementation.

Benefits Analysis Experiment Definition

The approach for the benefits analysis was to use simulation modeling and create a Current Capabilities case vs. a Future Capabilities case, hereafter referred to as "CC" and "FC", respectively. The simulation software used is called Probabilistic Automation-Assisted Congestion Management for En Route ("PACER"). This software is the prototype capability that has been used for several years to research concepts of operations and visualization of situations. A full description may be found in [Wanke, Zobell and Song 2005]. It contains the congestion resolution algorithms representing the future capability. It was accoutered to run as a simulation platform for this project.

It was decided that an actual date from the past would define the scenario: July 27, 2006 was a very bad weather day in the Conterminous U.S. (CONUS) – there were widespread thunderstorms, impacting en route airspace. (Airspace with respect to air traffic management can broadly be divided into terminal airspace, within about 50 miles of a major airport, and en route airspace, beyond the 50 miles. In very general terms, weather impacts aviation in two major ways: thunderstorms impede air routes in en route airspace, and rain and snow storms reduce visibility at airports, reducing the landing rate.) Colleagues from the Massachusetts Institute of Technology (MIT) kindly provided the estimated [Martin 2007] actual airspace capacities for that day. In the simulation modeling, MITRE analysts played the role of traffic managers and acted to expedite air traffic in light of constrained airspace.

Consider Figure 1, a map of the CONUS. It shows areas mottled with spatters of various gray scales. These are locations of thunderstorms and other precipitation in the CONUS, at a "snapshot" in time (20:00 Greenwich Mean Time [GMT], or 4:00 PM in the Eastern Time zone in North America). For our simulation modeling, we needed to first decide on a set of flights that needed to have some intervention by TFM. See Figure 2, where large circumscribing polygons were hand-drawn around the major severe weather regions. These areas are called "Flow Evaluation Areas" (FEAs), and were used to select flights, in our modeling scenario, for flow control actions. PACER looks forward in time, and determines the set of flights predicted to intersect the FEAs during a period of interest, and these flights are subject to intervention. That is, since their original desired path is constrained because of diminished airspace capacity, then either alternate routing, ground delay, or both of these may be necessary.

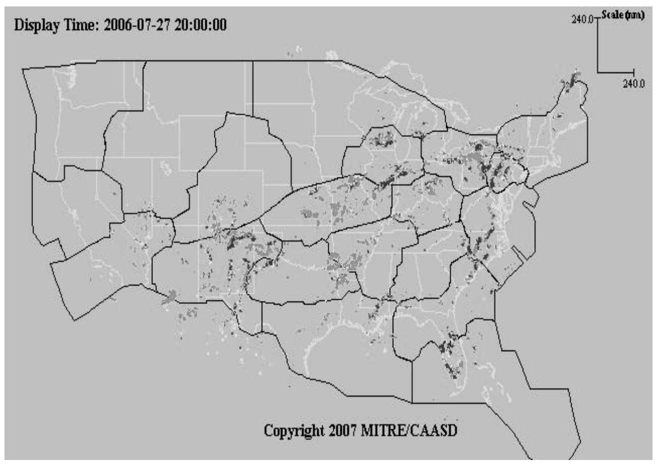

Figure 1. Severe Weather in the NAS (27 July 2006, 20:00 GMT)

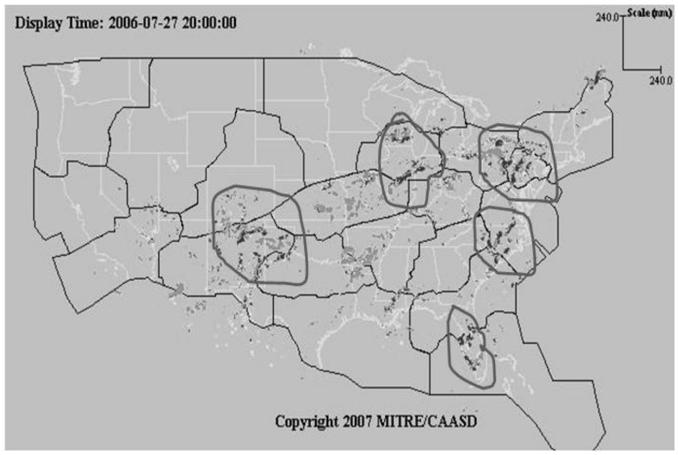

Figure 2. Hand-drawn Polygons Circumscribing Regions of Severe Weather

As part of the definition of the simulation scenario, it was decided that, for the simulated day, the weather would abruptly start at 20:00 GMT and end abruptly at 22:59 GMT. Although unrealistic, it was necessary to make some simplifying assumptions so that the simulation modeling would be tractable. For example, the weather forecast product actually goes out only two hours. Other assumptions for the modeling were as follows:

- TFM intervenes just once, at 17:00 GMT
- Flights comply with TFM advisories
- Weather forecast is 100% accurate

Modeling Current Capabilities Case

With this modeling set-up and these assumptions, the two contrasting cases were constructed. For the CC case, the real-world tools and techniques were mimicked. In today's system there are limited tools for generating re-route plans and disseminating them to pilots, airlines, and ATC. One helpful strategic tool (i.e., with a planning horizon of 3-6 hours) in use today is “Playbooks” which are sets of pre-coordinated alternate routings. They are stored in a database, and easily retrieved for use by traffic managers. In Figure 3 a map of the CONUS is shown, with bold division lines that reflect the geographic responsibilities of the en route ATC facilities (there are 20 of them in the CONUS). The various long, sinuous lines on the map are some of the Playbook routes used on the subject day. Although convenient, Playbooks are necessarily small in number, and the best one selected may not be a great match with current weather forecasts – traffic may be routed rather far away from the weather, adding flight miles and fuel costs. The actual Playbooks from the subject day were modeled in PACER, as routing options.

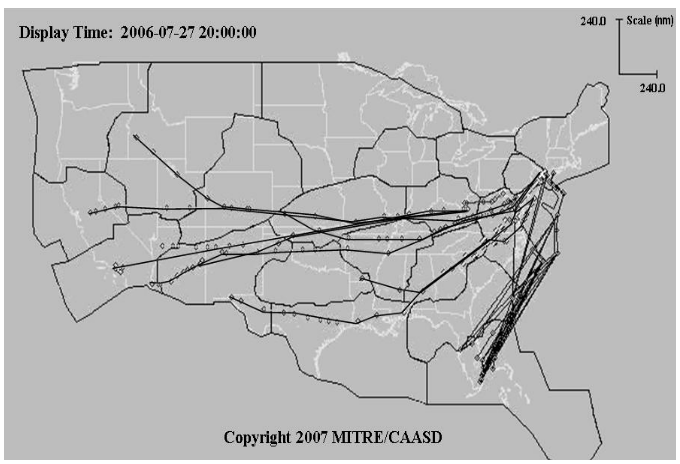

Figure 3. Alternate “Playbook” Routings (27 July 2006)

Playbooks represent strategic rerouting options, and, as the weather problem gets closer in time, a more tactical approach was undertaken. The regional ATC facilities contain Traffic Management Units (TMUs) whose staff perform tactical flow control. In conditions of severe en route weather, the TMUs implement “ad hoc” re-route advisories. These are sort of a local version of Playbooks – they may be pre-stored, or created dynamically, but they cover a smaller geographic region than Playbooks. If the ad hoc reroutes span facilities, then coordination is required between the facilities. As a second set of alternate routings, ad hoc re-route paths were created in the simulation model, to handle flights whose original route was infeasible.

Modeling Future Capabilities Case

AACR should provide significant improvements in operational ease and in NAS efficiency during the disruption associated with severe en route weather. It is not yet decided precisely what automation components and underlying algorithms will be included in AACR, but, for now, MITRE has a prototype tool, PACER, which is likely a reasonable stand-in for AACR for now. PACER was used for this simulation study. PACER includes a "greedy" algorithm for generating flight advisories. (A greedy algorithm makes locally optimum choices at each stage, ignoring global conditions, and may perhaps achieve a globally optimum solution. The approach is useful for a number of problems. See [Cormen et al. 2001].

PACER considers the set of flights requiring action, and the set of airspace capacity constraints. Flights are sorted according to their take-off times. Each flight is considered in turn, with the following logic:

- An historical database of routings between the flight's origin and destination supplies between 5 and 15 route options.
- With each of these route options, a spectrum of take-off delay times are generated: no delay, 15 minute delay, 30 minute delay, etc.
- Route/delay combinations are considered, and the least-cost combination is selected and assigned to the flight, consistent with available airspace capacity.
- Given this assignment, airspace capacities are updated. I.e., the flight transits a set of airspace sectors, and their time-specific capacities are decremented by one.

It can be easily imagined that flights considered early in the process tend to grab the best available capacity and end up with lower delay than flights considered later in the process. In fact, a possibility exists for “selection failure” in which no feasible route/delay combination is available. In this case, a flight assumes its original route and take-off time, even if capacity constraints are violated. In practice, this has not been found to be a problem – few flights become selection failures. Moreover, the selection failures may in some sense reflect the chaos in the NAS on a bad weather day. Also, airspace capacities tend not to be firm maximal values, but often have some flex in them, so that slight violation of counts is acceptable.

Benefits Mechanisms

AACR is an improvement over today’s more manual methods in two ways. First, there are time savings for personnel. After initial identification of a problem, e.g., construction of FEAs delineating the weather and creating of a list of affected flights, AACR works “behind the glass” to generate flight advisories. Today’s tools and methods require TFM staff to suffer several manual steps that are onerous and time-consuming. No evaluation of this labor benefit is included in this paper.

A second major benefit of AACR is the improvement in flight advisories. Today’s tools and methods create a few alternate routes, often deviating too far away from the weather. If too many flights adopt these few routes, that can create congestion and delay due to route over-subscription. By contrast, AACR is able to perform fine-grained selection of alternate routes, on a per-flight basis. By accessing a historical database of routings, many paths are generated around and through gaps in the severe weather mass. In addition, by considering a spectrum of take-off times, flights are efficiently “packed” in both time and space. Positive benefits results below reflect these features.

Results

At the time of writing this paper, results are very preliminary, although they indicate high benefits attributable to AACR. Notional values are used below, which may likely understate the final benefits values. Final results will be presented at the conference in June 2008. Since PACER creates two kinds of actions, we have two kinds of improvement: shorter flying time for reroutes, and differences in assigned ground delay minutes (based on a set of 1500 flights whose FlightIDs match in the CC and FC solution):

Reroute flight minutes, CC-FC = 5000

Ground delay minutes, CC-FC = 8000

To assign a dollar value, it is necessary to recognize that ground delay has a lower cost than airborne delay – ground delay allows the possibility that the aircraft engines are not running, and fuel cost is a major component of total cost. (Typically, when an aircraft is waiting at gate for departure, the pilot will activate Auxiliary Power Units which will supply electrical power, at a cost much lower than running the jet engines.) As of this writing, February 2008, costs are estimated at $45 per flight minute airborne and half of that, $22.50 per flight minute on-the-ground. These values represent Airline Direct Operating Costs ("ADOC") only, and do not include passenger value of time.

Completing the multiplication:

5000 minutes @ $45 = $225,000
8000 minutes @$22.50 = $180,000
Total for the 3-hr problem: $405,000

It is necessary to annualize this benefit, for presentation to financial personnel and policy-makers. The approach here is to represent the modeled weather event in terms of aviation and weather characteristics via one or more metrics, then compare that quantity for an entire year. Two such metrics for four years of available data were considered: 1) number of flights subject to reroute advisories, and 2) number of reroute advisories. With these two metrics, candidate annualization factors were computed as:

$$\frac{\text{Metric Value for Entire Year}}{\text{Metric Value for the Modeled 3-hour Problem}}$$

for four years, 2004—2007. The median value of these eight candidate annualization factors was selected for use, the value being 290. The annualization of benefits calculation is then:

$405,000 x 290 = $117 Million, rounded

Conclusion

The study presented a description of a planned future capability called Automated Airborne Congestion Resolution (AACR), which should improve air traffic flow management under conditions of airspace constraints such as severe weather. The capability creates flight-specific routings and take-off times consistent with a more efficient use of available airspace resources. Estimated dollar benefits are likely sufficient for the funding and implementation of the capability.

REFERENCES

Cormen, Leiserson, Rivest, and Stein (2001), *Introduction to Algorithms*, Chapter 16 "Greedy Algorithms," MIT Press and McGraw-Hill.

DeLaura, R. and Evans, J. (2006), "An Exploratory Study of Modeling Enroute Pilot Convective Storm Flight Deviation Behavior," *12th Conference on Aviation, Range and Aerospace Meteorology*, Atlanta, GA, 28 January – 2 February.

Federal Aviation Administration (FAA) (2006), *Severe Weather and Route Management Handbook*, http://www.fly.faa.gov/Operations/Strategic_Planning/svrwx_handbook.html

Martin, B. and Evans, J. (2007), "Model Estimates of Traffic Reduction in Storm Impacted En Route Airspace," *7th AIAA Aviation, Integration, and Operations Conference,* Belfast, Northern Ireland, 18 - 20 September.

Mukherjee, M., and Hansen, M. (2005), "Dynamic Stochastic Optimization Model for Air Traffic Flow Management with En Route and Airport Capacity Constraints," *6th USA/Europe Air Traffic Management Research and Development Seminar*, Baltimore, MD, June.

Wanke, C, Zobell, S., and Song, L. (2005), "Probabilistic Airspace Congestion Management," *5th Aviation Technology, Integration, and Operations Conference,* Arlington, VA, September.

Disclaimer

The contents of this material reflect the views of the authors. Neither the Federal Aviation Administration nor the Department of Transportation makes any warranty, guarantee, or promise, expressed or implied, concerning the accuracy of the views expressed herein.