COLLABORATIVE AIRSPACE CONGESTION RESOLUTION (CACR) BENEFITS ANALYSIS

Sally E. Stalnaker, James S. DeArmon, and Raphael D. Katkin
The MITRE Corporation, McLean, VA

Abstract

Severe en route weather is one of the major challenges for both Federal Aviation Administration (FAA) airspace managers and for airline and other airspace users. Uncertainty associated with changing weather patterns and severity, coupled with uncertainty in how airlines and other aircraft operators will react to the changing weather creates a significant challenge for traffic managers (TMs). TMs must decide, with limited information, how best to handle likely imbalances between available airspace capacity that will change over time due to dynamic weather conditions and air traffic demand for that airspace which also is changing over time as different aircraft operators seek to best meet their respective business needs. A planned enhancement to the traffic management automation system, the Collaborative Airspace Congestion Resolution (CACR) capability allows TMs to effectively and efficiently manage airspace congestion in a tactical time frame (0-2 hours). CACR has four key components: it predicts sector demand and its associated uncertainty; it predicts sector capacity including the impact of weather; it identifies the problem; and, it generates congestion resolution plans. The purpose of the analysis was to determine the benefits of using the CACR capability.

The benefits analysis was performed by assessing the reduced flight and ground delays achieved by using the capability in a severe weather situation which also occurred in the tactical timeframe. The approach for estimating the benefits of CACR was to rerun two historical bad-weather days in the NAS, and to create a situation in which the analysts played the role of TM to solve the problem of excess air traffic demand in light of weather-impacted sector capacities. Two simulated runs were performed for each day, with one simulating today's operations using playbooks for rerouting and the other one simulating the future by utilizing the CACR capability. The benefits were determined by calculating the difference of the ground delay and flight time for each simulated run.

Introduction

Uncertainty associated with changing weather patterns and severity, coupled with uncertainty in how airlines and other aircraft operators will react to the changing weather creates a huge challenge for traffic managers (TMs). TMs must decide, with limited information, how to best handle likely imbalances between available airspace capacity that will change over time due to dynamic weather conditions and air traffic demand for that airspace which also is changing over time as different aircraft operators seek to best meet their respective business needs. This paper provides an overview of the Collaborative Airspace Congestion Resolution (CACR) capability and the analysis performed to estimate the benefits for this capability. The analysis was used by the FAA for the support of the CACR capability investment decision.

Earlier work

Much research has been done in the last few years on airspace capacity during severe weather. Two references used here are [1] and [2]. The former paper estimates a general statistical relationship between horizontal weather coverage in a sector and the associated reduction in the flight occupancy of the sector. The latter paper describes concept work and prototype development associated with the modeling tool used in this analysis. Also of interest is a benefits analysis [3] on airspace congestion resolution: that paper examined a theorized probabilistic model, whereas the capability investigated here is deterministic.

Capability Overview

CACR capability allows TMs to effectively and efficiently manage airspace congestion in a tactical time frame (0-2 hours). CACR has four key components: it predicts sector demand and its associated uncertainty; it predicts sector capacity including the impact of weather; it identifies the problem; and, it generates congestion resolution plans. CACR operates in the tactical timeframe because sufficiently accurate convective weather forecasts will be available for this timeframe. For an identified area of congestion, CACR will propose a resolution to reduce traffic to an acceptable congestion (capacity/demand) risk level. CACR will:

- Identify flights that traverse an area of predicted congestion;
- Sequence flights in priority order (e.g., on a first-come first-served basis, or perhaps using another approach such as giving priority to airborne flights over pre-departure flights);
- Remove flights from the area of congestion and then put them back in based on a priority scheme. When a flight that is put back in causes the congestion risk of the area to exceed an acceptable risk level, then the flight is moved out of the congestion area 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 National Airspace System (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.) If there are no NAS customer-submitted preferences that are acceptable, a spectrum of ground delays in conjunction with reroutes from a database (including Coded Departure Routes [CDRs] and historical routes) will be evaluated and the option with the least delay will be assigned; and,
- Make available the assigned flight-specific maneuvers for dissemination to NAS customers and to Air Traffic Control (ATC) staff for implementation.

An important aspect of CACR is that it does *not* attempt to resolve all predicted congestion problems all at once. Rather, the probability of congestion is reduced to an acceptable level through the use of an incremental resolution approach that relies upon small-scale actions. Only those maneuvering actions that have a high likelihood of actually being necessary are implemented for specific aircraft. In this way, unnecessary and costly resolution actions due to highly uncertain information are reduced. As time moves forward, CACR will reassess what, if any, additional traffic maneuvering actions are needed in light of the most recent knowledge of expected airspace capacity and demand. It is a recognized issue that the incremental resolution approach comes at a cost and implies an additional workload for the TM. This benefits analysis does not address this issue.

Figure 1 illustrates a CACR-generated flight-specific congestion resolution plan with aircraft maneuvers to ensure that congestion in the area bounded by the smaller green polygon will not be overloaded with an excessive number of aircraft and, at the same time, will not cause congestion problems to develop in the area bounded by the larger green polygon. The figure also illustrates the operational impact of the CACR congestion resolution plan (see Figure 1).

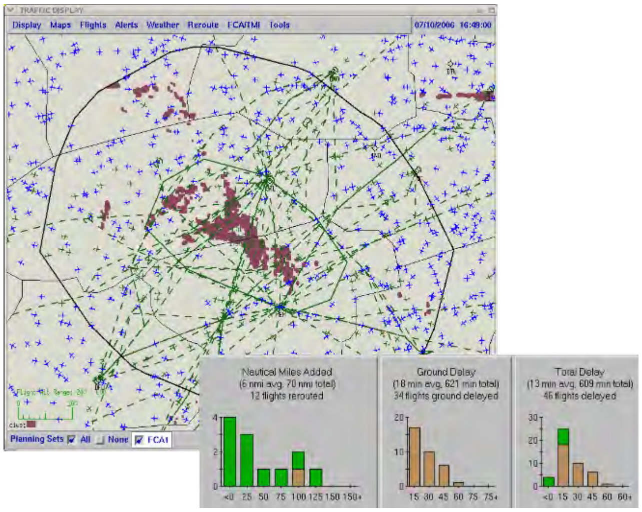

Figure 1. Example CACR Congestion Resolution Plan

CACR offers several key operational benefits. First, CACR increases the utilization of reduced airspace capacity and thus reduces flight delays. Today's tools and methods create a few alternate routes, often deviating 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, CACR 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. A second major benefit of CACR is that it uses NAS customer-submitted preferences to the extent possible and keeps flight impacts within levels deemed acceptable by the NAS customer. A third major benefit of CACR is that it allows TMs to manage congestion more effectively in a tactical time frame and therefore fewer traffic flow initiatives will need to be put in place in a strategic time frame when the uncertainty is greater.

Note that the full operational value of CACR is dependent upon its ability to get predicted weather information (whose likely source would be the Corridor Integrated Weather System, [CIWS]). CACR would, in turn, convert that information into predictions of reduced sector capacity. CACR’s operational value is also dependent upon the Collaborative Air Traffic Management Technologies (CATMT) Work Package 2 (WP 2) airborne rerouting capability which would be needed to support the operational execution of any CACR-developed congestion resolution plan that included airborne reroutes.

Benefits Analysis

The benefits analysis was performed by assessing the reduced flight and ground delays achieved by using the capability in a severe weather situation which also occurred in the tactical timeframe. For this analysis, however, NAS user preferences were not taken into account.

The approach for estimating the benefits of CACR was to rerun two historical bad-weather days in the NAS, and to create a situation in which the analysts played the role of TM to solve the problem of excess air traffic demand in light of weather-impacted sector capacities.

Assumptions

The following assumptions were made in this benefits analysis:

- Probabilistic Automation-Assisted Congestion Management for En Route (PACER), a prototype tool developed by The MITRE Corporation’s Center for Advanced Aviation System Development (CAASD), is a reasonable prototype tool to simulate the implementation of planned traffic management initiatives (TMIs). The rules in PACER that govern whether or not a particular flight may be maneuvered/changed in a particular manner are reasonable and assumed to be consistent with the CACR concept. These rules govern changes such as rerouting, delaying a flight on the ground, or allowing a flight to fly its original route (even though, in this latter case, doing so might cause the capacity of a managed sector to exceed its nominal acceptable threshold or might cause the flight to fly through severe weather). Use of PACER corridors, discussed in the next subsection, is a reasonable proxy for rerouting aircraft along playbook reroutes and ad hoc reroutes. Corridors are a construct in the PACER modeling system allowing the analyst to tailor alternate routing. A PACER solution to a set of airspace constraints includes the consideration of routing onto constructed corridors, subject to rules such as: 1) minimizing distance flown, and 2) turn angle for entry to and exit from corridor.
- The MITRE analysts, acting as the TM, have perfect knowledge of the severe weather date, time, and locations. Although obviously unrealistic, the assumption benefits both the Today and Future scenarios (definition of scenarios to follow).
- The weather problem starts and stops abruptly.
- Flights fly the routes they are assigned without deviation. The routes are assigned either by the MITRE analysts via the construction of corridors (in the role of traffic flow manager [TFM] in the Today scenario) or by PACER (using its database of available reroutes in the Future scenario). [Note: The following section explains the usage of the Today scenario and the Future scenario in this benefits analysis.]

Methodology

Select a Bad Weather Day and 2 Hour Time Period within the Bad Weather Day

The CACR capability will be particularly beneficial when it is used to provide automated support for managing airspace congestion due to bad weather. The capability will also assist during good weather if demand exceeds capacity and reroutes or ground delays are necessary.

For the first analysis day, we relied on the Massachusetts Institute of Technology's Lincoln Laboratory staff to select the specific bad weather day of 7/27/2006 for this CACR benefits analysis. This day was a good choice for several reasons: first, Lincoln Lab previously studied this day as part of their CIWS work program; second, the day is part of the Lincoln Lab CIWS benefits analysis; and third, 7/27/06 turned out to be one of the worst bad-weather days in the NAS in over four years.

Upon completion of the initial day, a subsequent day was to be selected. The thought was to pick a day not quite as severe as the first day. Using a 'misery index' based on previous work [4] to categorize the effects of weather on NAS performance, an additional day was selected. The index is a number ranging from 1 to 13, expressed out to one decimal place. The index reflects the level of NAS-wide disruptions on a daily basis. A value of 1.0 indicates a very good weather day and 13.0 is the worst of the severe weather days. The first day utilized, 7/27/2006, was a 7.5. The second day selected was 7/10/2007 with an index of 9.4. Even though Day 2 had a higher misery index value, the time period chosen within that day was less severe than that of Day 1.

NOTE: The following two subsections refer to Day 1 only; Day 2 approach was analogous.

Identify the Bad Weather to be Avoided and the Specific Flights that must Avoid the Bad Weather

To indicate to PACER the bad weather to be avoided, six regions of bad weather were visually identified by a MITRE analyst serving as a proxy TFM. For each such bad weather region, a Flow Constrained Area (FCA) was defined to encompass the bad weather and the start and end times for each FCA were set to match the 2000-2259 Greenwich Mean Time (GMT) problem time period. The border of each FCA was deliberately chosen to extend generously beyond the perimeter of each severe weather region. This was done in order to ensure that PACER would manage those flights that may have already been maneuvered by the user pre-departure or early in the flight due to the bad weather as represented in the actual NAS data playback. As an example of the FCAs utilized in the PACER runs, the Day 1 Today and Future scenarios FCAs are illustrated in Figure 2. In the case of Day 1, there are six weather related FCAs. In addition, the larger FCA, called the Congestion Resolution Area, (CRA) is used to identify the sectors which PACER will manage, including a 200 nautical mile radius around the CRA. This 200 nautical mile radius buffer around the CRA is referred to as the Congestion Management Area (CMA).

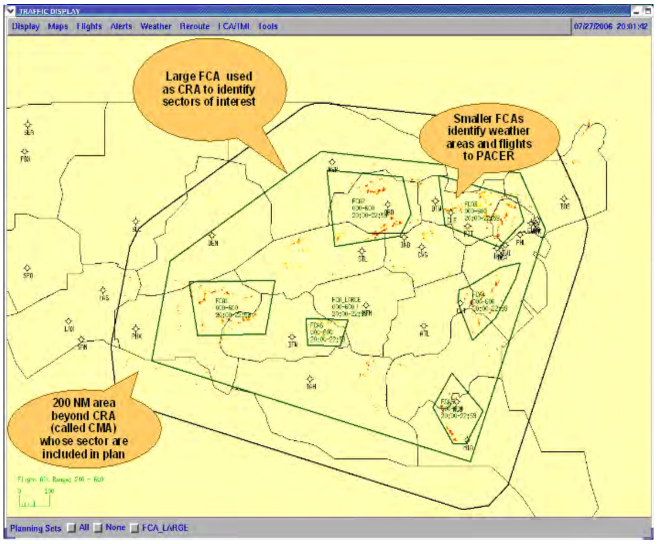

Figure 2. FCAs Used in Simulation Scenarios

Establish Traffic Management Plan

At 2 hours (in Day 1 - 1800 GMT) before the start of the bad weather (in Day 1 - at 2000 GMT), a plan to deal with that bad weather (which lasts thru 2259 GMT in Day 1) is established. Note that CACR is a tactical tool, designed to manage problems up to 2 hours in the future. The operational concept for CACR would be the use of incremental solutions i.e., at 18:30 solve the problem for the 19:30-20:30 interval. This approach would involve a smaller number of flights and would therefore be less disruptive. Then at 19:00, CACR is used to solve the problems for 20:00-21:00. During the half-hour between solutions, weather predictions are updated, as is the state of the NAS. It is assumed that a capability that automates the execution of flight specific changes is available. The execution of flight-specific change is delayed to the extent possible (e.g., 30-40 minutes prior to departure) so that a flight is assigned a flight-specific change based on the most up-to-date resolution.

The experimental setup utilized to calculate the CACR benefits differs from the proposed operational concept in that the experiment was constrained to a "single-shot" solution (time, weather and flight movement is frozen while a plan is calculated), which may admittedly be "heavy" on the ground delays, since the look-ahead is so long (up to 5 hours). However, the incremental approach may likely produce even higher benefits than the "single-shot," suggesting that our solution approach may be conservative with respect to estimation of benefits.

In the experiment, we consider the impact of that plan on operations. In particular, we compare how, using the CACR capability, a more effective plan results in reduced delay due to rerouting and reduced ground delay. Note that there was no simulation of the execution of this plan for this CACR benefits analysis. We assumed that the plan was faithfully executed per the issued TMIs.

Today Scenario

PACER required some tailoring of capabilities in order for the simulation to operate as TFM would in operations today. The idea was to simulate today's TFM capabilities including airspace flow programs (AFPs), ground delay programs (GDPs), playbook reroutes, ad hoc reroutes, and ground delays (GDs). The flight changes for AFP in effect for the two scenario days were included in the Enhanced Traffic Management System (ETMS) input data as well as the Expect Departure Clearance Times (EDCTs) generated by GDPs. The playbook and ad hoc reroutes were simulated in PACER utilizing the corridor feature. Corridors are hand-drawn routes to be used by PACER as the available reroutes for a flight. Thirty one corridors were generated to simulate the playbook routes in effect during the simulation day. These included applying the reroute to selected flights such as flights from specific arrival-departure pairs. The actual playbooks were used in the generation of the corridors and the analysts attempted to adhere to all routes and restrictions as provided in the playbooks. The use of corridors in PACER, from the Day 1 run, to simulate Playbook Plays is illustrated in Figure 3.

The ad hoc reroutes were generated more free-hand but were based on actual rerouted air traffic flows, graphically displayed using playback data. The PACER simulation was played forward to look at available routes through the weather as it progressed over time. Thirty four ad hoc reroutes were used for the Today scenario. The use of corridors in PACER to simulate Ad Hoc Reroutes, in Day 1 is illustrated in Figure 4.

For the Today scenario, all other routing options were turned off (for example, available CDRs). PACER had to choose one of the 65 corridors to reroute the flights. This created a number of flights which could not be rerouted or failed to be rerouted. Reasons for a failure might be PACER could not get the flight onto a corridor due to turn angle, arrival/departure restrictions, or the flight was outside of the timeframe for the plan. Only flights which were successfully rerouted by PACER were used for the benefits analysis. These flights were matched with the successful flights from the Future scenario.

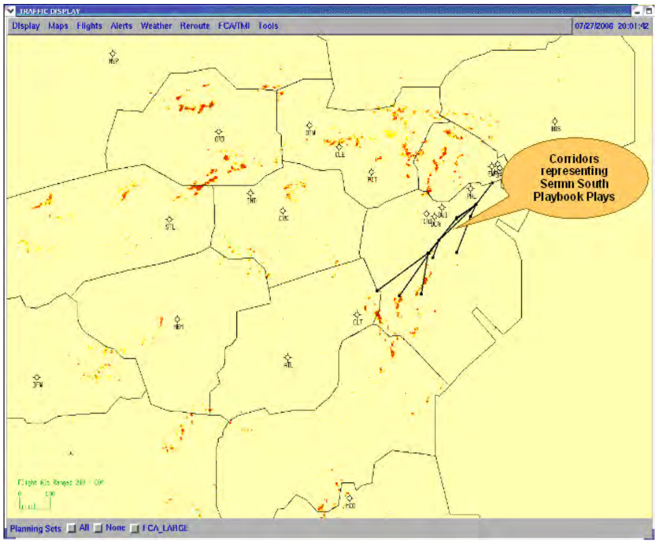

Figure 3. Corridors in PACER to Simulate Playbook Plays

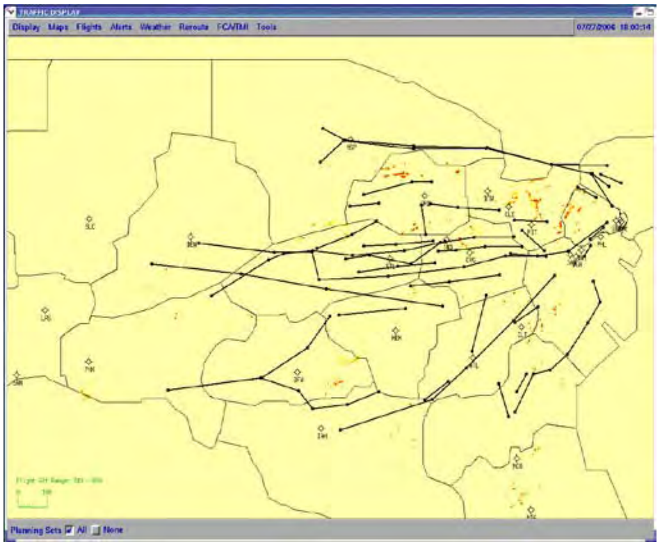

Figure 4. Corridors in PACER to Simulate Ad Hoc Reroutes

Future Scenario

To simulate operations when the CACR capability becomes available, a Future scenario was run. In the Future scenario, the CACR capability is simulated by allowing PACER to reroute flights using all available routes that it knows about; that is, CDRs and historical routes. These routes are stored in a database and are available, as alternate routings, for active and inactive flights. The important point here is that the TM does not need to manually select particular plays, or create particular ad hoc reroutes, or then apply individual flights to those plays or ad hoc reroutes. Instead, CACR automation can draw on a vast store of routes, assess the operational acceptability of them, and efficiently assign individual flights to available routes—and, do so in such a way as to take advantage of all available capacity even if that capacity is below its normal good-weather level. Equally important, the CACR automation can perform these activities quickly so that there is sufficient time to actually implement the CACR recommended maneuvers.

Benefits Mechanism

The benefits mechanism derives from CACR more effectively exploiting scarce airspace capacity, thereby reducing ground delay and reroute distance flown. That is, airspace capacity that would, today, go unused (because it is too close to the weather in terms of its route and/or time) will be used in the future. Today, too often, flights are rerouted unnecessarily wide around weather; or, they may be held on the ground longer than necessary with the expectation that the weather will, in fact, constrain the airspace which the aircraft is expected to traverse.

Calculate Delay

The calculation for delay included two metrics: reduction in delay due to rerouting and reduction in ground delay. To determine the reduction in delay due to rerouting for our experiment days and times, we compare time-to-fly (TTF) and ground delay for matched flights. The matches are determined by comparing flight IDs. The difference in the time to fly is calculated by subtracting the Future TTF from the Today TTF. The calculated time to fly for each scenario (Today and Future) is computed by subtracting the arrival time (wheels on) from the departure time (wheels off). To determine the reduction in ground delay, the Future's matched flights total GD was subtracted from the Today's matched flights total GD. Table 1 provides the Total TTF difference and the total GD difference for the two days.

Table 1. Two Days TTF and GD Differences

Day	TTF Difference	GD Difference
1	9013 min (7.2 min/flight)	23,363 min (18.8 min/flight)
2	7771 min (7.1 min/flight)	5,740 min (5.2 min/flight)

min = minutes

Summary

This paper provides an overview of the CACR capability and the analysis performed to estimate the benefits for this capability. The benefits analysis estimated significant benefits for the CACR capability without addressing the potential benefits of considering NAS user input. The analysis was used by the FAA for the support of the CACR capability investment decision.

References

[1] Davis, E., B. Hargroves, and T. Holden, September 2005, *The Effect Of Convective Weather On Sector Capacity*, MP050000200, McLean, VA, The MITRE Corporation.

[2] Wanke, C., S. Zobell, and L. Song, 26-28 September 2005, *Probabilistic Airspace Congestion Management*, McLean, VA, Presented at the AIAA

Aircraft Technology, Integration and Operations Forum, Arlington, VA, The MITRE Corporation.

[3] DeArmon, J., C. Wanke, D. Greenbaum, L. Song, S. Mulgund, S. Zobell, and N. Sood, 25-27 September 2006, *Solving Probabilistic Airspace Congestion: Preliminary Benefits Analysis*, 6th AIAA Aviation, Integration and Operations Conference, Wichita, KS.

[4] Callaham, M., J. DeArmon, A. Cooper, J. H. Goodfriend, D. Moch-Mooney, and G. Solomos, 3-7 December 2001, *Assessing NAS Performance: Normalizing For The Effects Of Weather*, Santa Fe, NM, 4th USA/Europe Air Traffic Management R&D Symposium.

Disclaimer

This work was produced for the U.S. Government under Contract DTFA01-01-C-00001 and is subject to Federal Aviation Administration Acquisition Management System Clause 3.5-13, Rights In Data-General, Alt. III and Alt. IV (Oct. 1996).

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. ©2009 The MITRE Corporation. All rights reserved.

Email Addresses

James DeArmon: jdearmon@mitre.org

Rafael Katkin: rkatkin@mitre.org

Sally Stalnaker: sfrench@mitre.org