Project Report
ATC-313-1

Corridor Integrated Weather System Operational Benefits 2002–2003: Initial Estimates of Convective Weather Delay Reduction

Executive Summary

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Lincoln Laboratory

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16. Abstract

The Corridor Integrated Weather System (CIWS) seeks to improve safety and reduce delay by providing accurate, automated, rapidly updated information on storm locations and echo tops along with two-hour high-resolution animated growth and decay convective storm forecasts. An operational benefits assessment was conducted using on-site observations of CIWS usage at major en route control centers in the Northeast and Great Lakes corridors and the Air Traffic Control Systems Command Center (ATCSCC) during six multi-day periods in 2003.

This first phase of the benefit assessment characterizes major safety and delay reduction benefits and quantifies the delay reduction benefits for two key Traffic Flow Management (TFM) user benefits: "keeping air routes open longer/reopening closed routes sooner" and "proactive, efficient reroutes of traffic around storm cells." The overall CIWS delay reduction for these two benefits is 40,000 to 69,000 hours annually with an equivalent monetary value of $127 M to $260 M annually. Convective weather delays at most of the major airports in the test domain, normalized by thunderstorm frequency, decreased after new CIWS echo tops and forecast products were introduced.

Recommendations are made for near-term, low-cost improvements to the CIWS demonstration system to further increase the operational benefits.

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EXECUTIVE SUMMARY

This report summarizes the preliminary results of a two-year study to determine if the Corridor Integrated Weather System (CIWS) concept would enable airspace users to increase safety and significantly reduce convective weather delays in the highly congested Great Lakes and Northeast corridors. The CIWS concept being evaluated provides en route and terminal air traffic flow managers with accurate, automated, rapidly updated information on storm locations and echo top heights along with two-hour, high resolution animated growth and decay storm forecasts. The CIWS test region for 2002–03 included five of the eight major metropolitan areas/corridors that are highlighted as focus areas for improving capacity in the recently released FAA Flight Plan 2004–08.

Operational Needs Addressed by CIWS

The FAA Operational Evolution Plan (OEP) identifies *en route severe weather* and *airport weather conditions* as two key problems that must be addressed if the U.S. air transportation system is to alleviate the growing gap between the demand for air transportation and the capacity to meet that demand. Most of the air traffic delay that is so costly to the airlines and the flying public is incurred during severe weather in the congested Great Lakes and Northeast Corridor region shown in Figure ES-1.

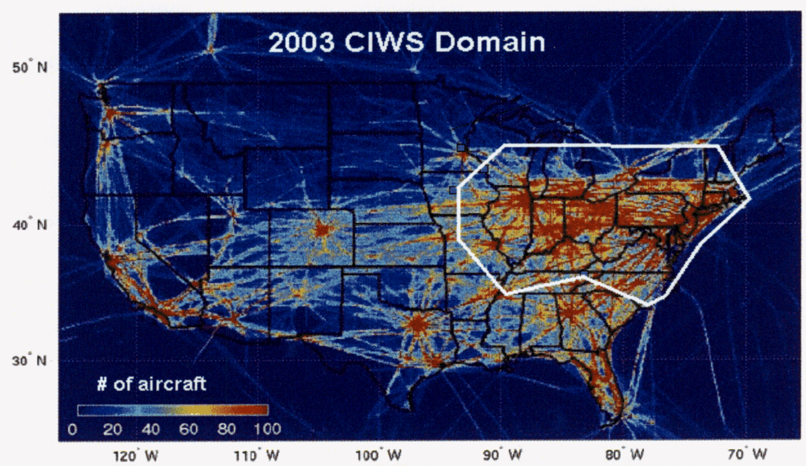

Figure ES-1. National Airspace traffic density on a fair weather day in 2002 with an overlay showing the CIWS spatial coverage for the 2003 testing. Thunderstorm impacts are most significant in areas where there is already significant congestion in fair weather. The CIWS 2003 coverage area includes all the 7 major "bottle necks" identified in the FAA Airport Capacity Enhancement (ACE) Plan (2001). The production CIWS coverage will be significantly larger than the coverage shown above.

It is essential that the National Airspace System (NAS) also maintain safe operations in congested airspace when there is severe convective weather. The major safety objectives listed in the FAA Flight Plan include "reducing cabin injuries due to turbulence." Feedback from major airlines that are leaders in turbulence avoidance have indicated that a main cause of cabin injuries to their flights is encounters with convectively induced turbulence in en route airspace.

Better information on current and forecast weather severity (e.g., heavy rain, storm tops, and regions of storm growth), spatial extent, and future storm locations can help Air Traffic Control (ATC) personnel and airline dispatch assess the safety implications of various alternative plans for dealing with convective weather impacts. Examples of operational decisions that can be facilitated by using CIWS weather information include decisions on whether implementation of a ground stop for specific airports is needed and whether a closed air route could be reopened in the immediate future.

Most en route weather decision support systems show only past or current storm locations, and existing operational forecast products within en route airspace are limited. Two national-scale forecast products are provided by the Aviation Weather Center: the automated National Convective Weather Forecast (NCWF) 1-hour forecast, and the Collaborative Convective Forecast Product (CCFP) 2, 4, and 6-hour forecasts that are updated every two hours. While these products are helpful, the highly congested airspace requires very accurate, current, high-resolution weather information and forecasts to safely improve air traffic flow during thunderstorms.

Additionally, CIWS can provide important enhancements to the precipitation products and forecast capability of terminal areas as shown in Table ES-1. In Figure ES-2, we summarize the relationship of the CIWS products to various weather systems and forecasts in use today.

TABLE ES-1
Operational Domains Impacted by Convective Weather where CIWS Can Improve Safety and Efficiency

Domain	Existing Systems[1]	CIWS Role	2002/2003 Test
En route	WARP, ETMS wx, CCFP, NCWF, CWSU	Improve storm severity and tops information plus provide 2-hour automated forecasts Support ATM decision support systems such as ETMS and RAPT	Yes
Major terminals	ITWS, TDWR, ASR-9	Improve long range weather surveillance plus 2-hour forecasts. Support RAPT	Yes
"Important" terminals	WSP	Provide long range weather surveillance plus 0-2 hour forecasts	No
Small airports	MIAWS	Provide basic precipitation with 2-hour forecasts	No
Other		Sensing for forecasts > 2 hours	No

[1] The existing systems are as follows: WARP is Weather and Radar Processor, ETMS wx is weather displayed on the Enhanced Traffic Management System, CCFP is Collaborative Convective Forecast Product, NCWF is National Convective Weather Forecast, CWSU is Center Weather Service Unit, ITWS is Integrated Terminal Weather System, TDWR is Terminal Doppler Weather Radar, RAPT is Route Availability Planning Tool, ASR-9 is the operational Air Surveillance Radar, WSP is ASR-9 Weather Systems Processor, and MIAWS is Medium Intensity Airport Weather System.

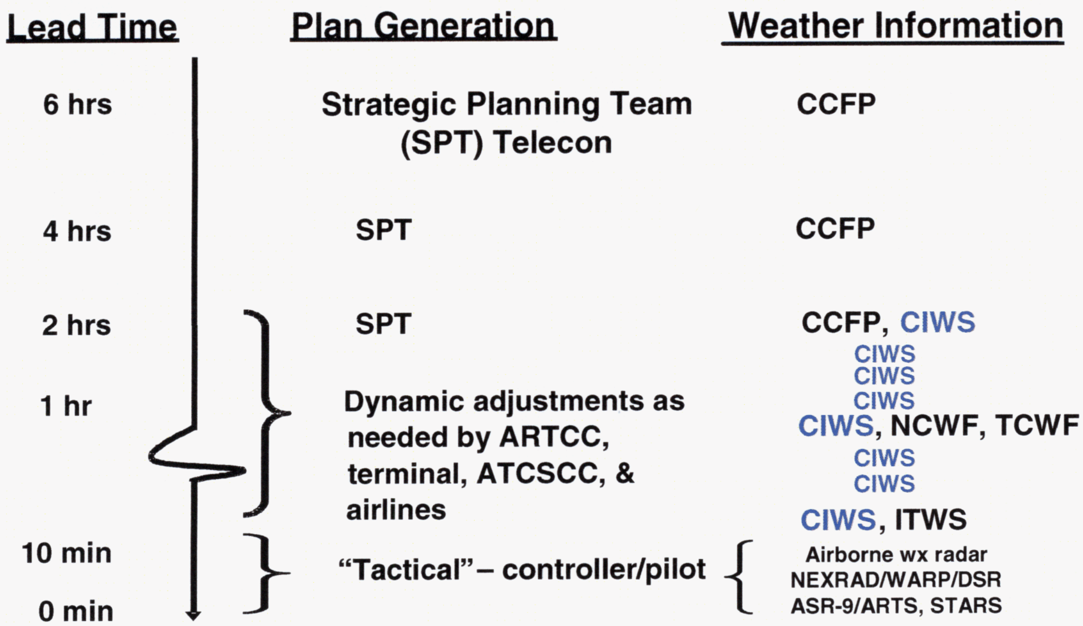

Figure ES-2. Use of various forecasts and weather information as a function of time for convective weather planning in congested airspace. The CIWS products are used to make dynamic adjustments to the strategic plans developed from longer term forecasts. The CIWS provides forecasts every 15 minutes from 15 minutes to 2 hours.

Approach to Meeting the Operational Needs

The solution adopted for the CIWS demonstration system was to take advantage of the high density of existing FAA and NWS weather sensors (Figure ES-3), and the FAA-funded research conducted on thunderstorm evolution, to provide en route and terminal traffic flow managers with accurate, automated, high update rate information on storm locations and echo tops, along with 2-hour animated growth and decay forecasts of storms (Figure ES-4). These state-of-the-art weather products are intended to assist traffic managers to achieve more efficient tactical use of the airspace, reduce controller workload and significantly reduce delay.

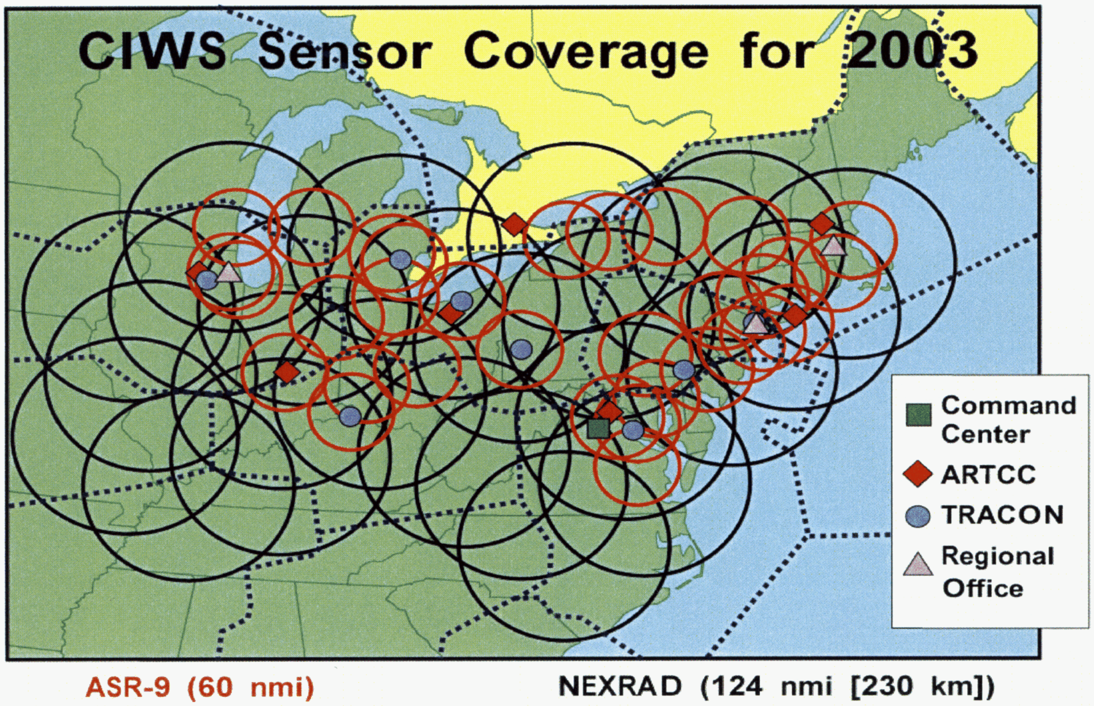

Figure ES-3. Terminal and en route weather sensors used to create the CIWS products for 2002–03 testing. The rapid update rate of the ASR-9 radars (30 seconds) is utilized to detect rapidly growing cells, while the NEXRAD radars provide information on 3-D storm structure and on boundary layer winds. Data from TDWR and Canadian radars will be included in the future. Data from lightning sensors and GOES satellite (not shown) are also integrated with the radar data.

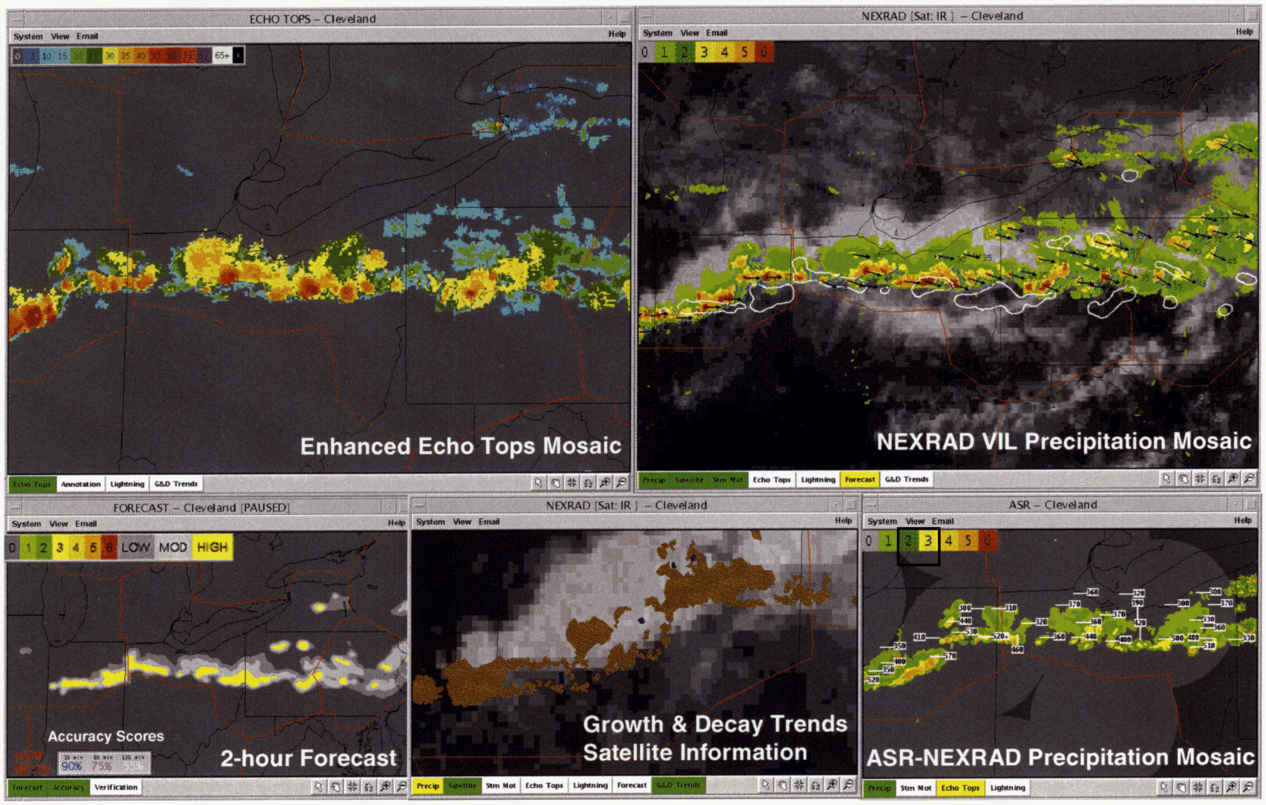

Figure ES-4. Principal CIWS products for 2003 testing. The Echo Tops product (upper left window) shows the height of storms and has been used in conjunction with the radar-based precipitation data to permit aircraft to safely fly over storms, thus significantly reducing aviation delays. The upper right window shows the NEXRAD VIL Precipitation mosaic product displayed with satellite data, storm motion vectors, and two-hour forecast contours. The Regional Convective Weather Forecast (RCWF) provides two-hour animated forecasts in 15-minute intervals (lower left window). Key features of the forecast include the real time indication of forecast accuracy and an explicit depiction of areas of storm growth (orange/black pattern) and decay (blue; see the lower middle window). The lower right window shows the mosaicked ASR and NEXRAD VIL Precipitation product with labels of echo tops.

Results of the Study

Specific objectives of this first phase of the CIWS operational benefits study were to:

- Determine the major operational benefits of the CIWS products when used for real time decision support in the Great Lakes and Northeast corridors
- Quantify the delay reduction for two of the identified principal operational benefits
- Develop a methodology that could be applied to quantifying the delay reduction of other identified operational benefits
- Empirically determine whether changes in gross delay statistics occurred at key facilities that could be attributed to the use of the CIWS products.

All of these specific objectives were met.

Development of a methodology for quantifying delay reduction

The methodology used in this study to quantify CIWS operational benefits (Figure ES-5) is a new approach that utilizes on site observations during "benefits blitz" periods[2], together with studies of individual cases identified from the blitz observations and ongoing post event feedback from the operational users. The analysis of individual cases often involved detailed calculations of queue sizes and durations.

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[2] During the "benefits blitz" observation periods, several observers from Lincoln Laboratory were stationed at various ATC facilities to obtain real-time observations of CIWS product usage during convective weather impacts.

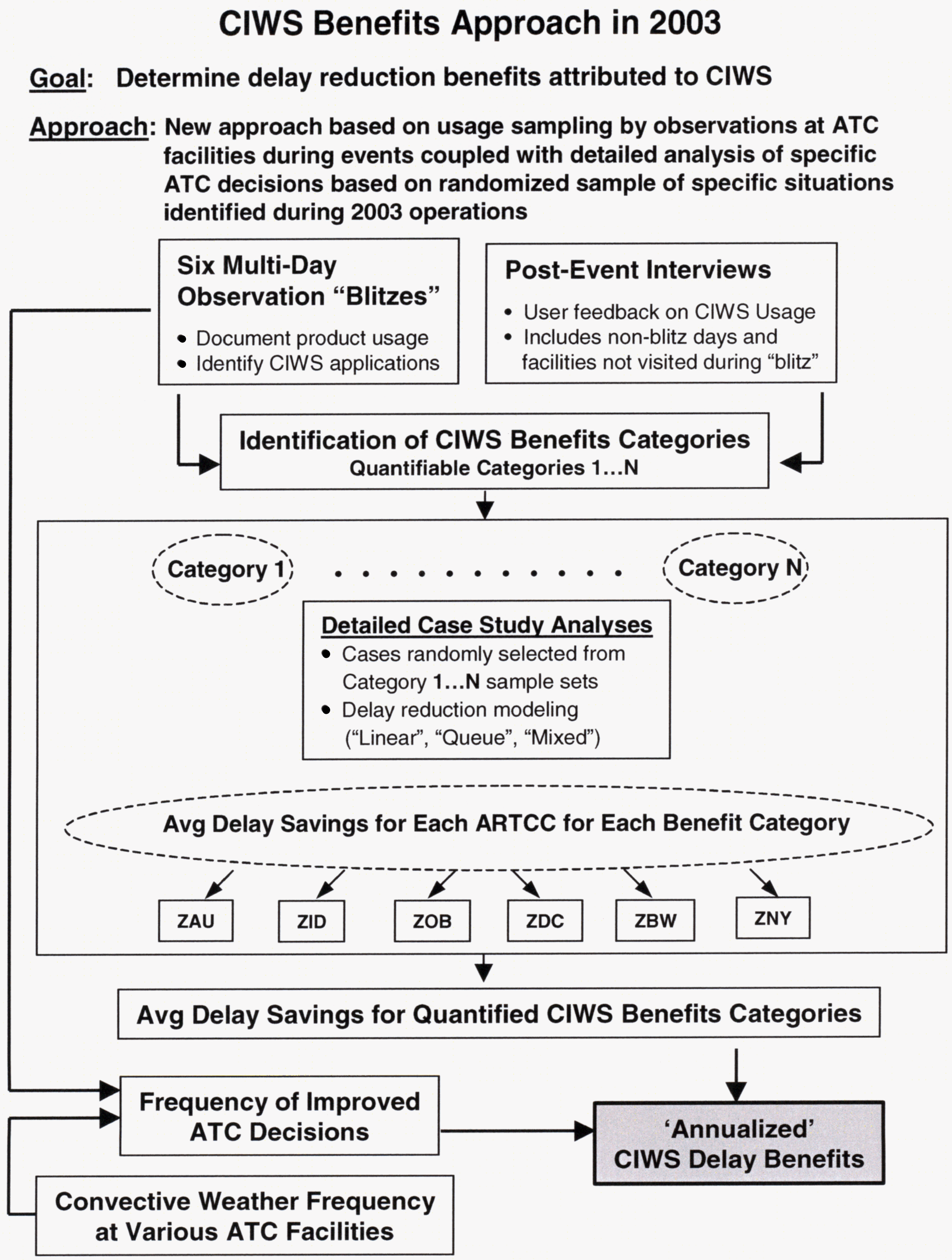

Figure ES-5. Methodology used to determine CIWS operational benefits.

Identification of major benefits

Major benefits that were identified during the 22 days of simultaneous "benefits blitz" observations at different ARTCCs and the ATCSCC in six different time periods in 2003 are summarized in Figure ES-6.

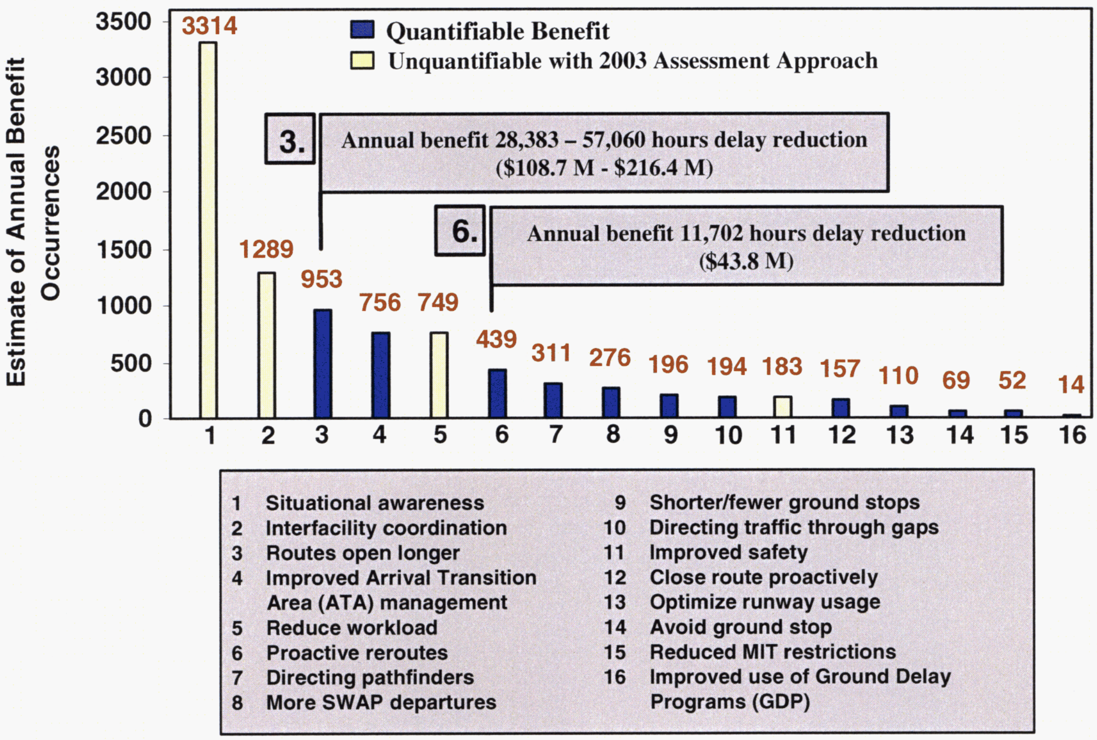

Figure ES-6. Summary of CIWS annual operational benefits identified in 2003 "blitz" observations. Total occurrences of various CIWS benefits categories do not include ATCSCC contributions in order to prevent inflation of benefits occurrences resulting from assigning events to more than one facility. In practice, observed usage benefits (on which these roll-ups are based) were only assigned to the ARTCCs using CIWS to initiate traffic decisions, even if coordination with other facilities was needed or if benefit event occurred along facility boundaries. Exceptions where ATCSCC benefits occurrences were added to the final totals include categories, "Interfacility coordination", "Reduced workload", and "Situational awareness". These specific benefits could not be easily separated by facility and may in fact have proved of more importance at ATCSCC compared to elsewhere in terms of enacting efficient delay mitigation schemes. Benefits 4, 8, 9, 13, and 16 would be shared (to varying degrees) with ITWS.

Note in particular that over 180 cases occurred in 2003 where the CIWS products were used to identify safety concerns associated with a proposed TFM initiative to reduce delays. These safety enhancing situations were typically concerned with the evaluation of alternative traffic flow management initiatives such as:

- Deciding whether an attempt should be made (e.g., with a "pathfinder") to reopen a closed route
- Determining whether a ground stop was warranted at an airport

The most commonly identified benefits—better situational awareness and better interfacility coordination—are not easily quantified in terms of hours of delay saved. However, we view both of these as very important because they speak to the issue of improving the overall productivity of the ARTCC TMUs and thereby the NAS.

Coping with rapidly changing convective weather in highly congested airspace is an extremely challenging job. Reducing the amount of time required by the TMU staff to maintain situational awareness and coordinate with other facilities is critical to effectively accomplishing the weather impact mitigation process that is described in Chapter 2 of this report.

We believe that the very high frequency with which increased situational awareness and better inter-facility coordination were observed indicates a significant increase in TMU productivity that may not be fully captured in the analysis of other more readily quantifiable benefits.

The overall CIWS delay reduction benefits for:

- Keeping routes open longer and/or reopening closed routes earlier, and
- Proactive, efficient reroutes

were quantified in this first phase of the CIWS benefits study. **The delay savings for these two categories <u>alone</u> was 40,000 to 69,000 hours annually. The monetary value of this delay reduction assuming airline operations costs are incurred with downstream delay was $152 M to $260 M per year. The cost savings assuming no airline cost is associated with downstream delay was $127 M to $214 M per year.**

This range of variation in annual delay estimates reflects the wide range of individual case benefits, which in turn reflects the high sensitivity of delays in congested airspace to issues such as the number of available routes, queues due to excessive demand at multiple locations in the network, and differences in the time duration of storm events. To illustrate, the individual event benefits for "keeping routes open longer and/or reopening routes earlier" ranged from 1 hour to 236 hours.

A number of major delay reduction events were separately analyzed. Of these, several had individual event delay reduction benefits exceeding 800 hours, translating to cost savings of several million dollars. Since these were noted as extreme benefits cases at the time of occurrence and resources available for case analysis were limited, these cases were excluded from the overall annual benefits "roll up" analysis to avoid introducing an upward bias in the results.

We should reemphasize that the quantitative benefits discussed above understate the operational benefits of the CIWS as tested in 2003 for three reasons:

- As noted in Figure ES-6 and in the previous discussions, the available time and resources did not permit us to accomplish quantitative estimates for a number of other high frequency benefits such as better management of ground stops and ground delay programs in support of severe weather avoidance plans (SWAP).
- There were a number of key ATC facilities that did not have CIWS situation displays in 2002–03 (discussed below), which resulted in a number of missed opportunities for delay reduction.
- The benefits of increased departure rates during SWAP events, including the use of the Route Availability Planning Tool (RAPT), have not been considered. RAPT has provided very significant benefits at New York using the ITWS Terminal Convective Weather Forecast (TCWF). RAPT is in the process of being interfaced to the CIWS products to take advantage of the CIWS forecasts, spatial coverage and echo tops products.

Evidence from delay statistics of CIWS operational benefits

Several of the ARTCCs that had significant delay reduction benefits for keeping routes open longer/reopening closed routes earlier and proactive, efficient reroutes (e.g., ZOB and ZID) also showed significant reductions in the delay events at the major airports (CVG, DTW, and PIT) within the ARTCC in 2003 relative to 2002. These reductions in delay events were evident even though the number of convective storm events in the respective ARTCCs was constant or increased from 2002 to 2003.

The overall number of delay events at EWR dropped in 2003 albeit the number of delay events with delays greater than one hour at EWR increased. Since other convective delay reduction systems (specifically RAPT) also commenced operation in 2003, it is unclear to what extent CIWS assisted in reducing the number of overall delay events at EWR.

The significant decrease in delay events (over 66%) at BOS in 2003 relative to 2002 can be attributed in part to ZBW use of CIWS in 2003 and in part due to a 10% drop in overall storm activity.

The number of longer delay events at ORD increased in 2003 while shorter delay events decreased despite constant overall convective activity within ZAU ARTCC and a 12% increase in NWS-identified thunderstorm days at the airport. This unexpected increase in longer delay events may reflect the particular nature of storm events in the two years, procedures issues [e.g., rules governing land and hold short operations (LAHSO) changed in April 2003] as well as other factors. We discuss below options for improving the operational effectiveness of CIWS in reducing delays at ORD.

NEXT STEPS IN QUANTIFYING CIWS DELAY REDUCTION

The results reported here are the results of the first phase of the CIWS operational benefits study.

In the next phase, we will examine additional case studies for the two benefits categories analyzed (so as to reduce the spread in benefits estimates for those two categories). We will also obtain quantitative benefits estimates for several of the other major benefits discussed above including the safety benefits.

During the next phase of the study we plan to include coupled analyses of flight tracks and weather before and after the principal new CIWS products were introduced in late 2002. The motivation is to find additional objective substantiation for the operational user feedback that traffic flow management is evolving towards a new dynamic adjustment paradigm for managing convective weather through use of the CIWS products.

Other important elements of the second phase study include:

- Extrapolating the benefits observations in the Great Lakes and Northeast corridors to other parts of the NAS to assist in determining the appropriate spatial extent of the operational CIWS functional capability
- Estimating the fraction of the overall convective weather delay in the CIWS region that is being reduced by the use of CIWS
- Addressing key aspects of the service being provided to the commercial airlines who are principal "customers" of the FAA's new Air Traffic Organization (ATO). A key issue for customer impact of delay reduction is improving the model for the "down line" impact of delays. We plan to use more elaborate models for the downstream impacts of initial delays [e.g., using the delay multiplier model of Beatty et al., (1999)] to better capture the impacts of delay propagation on airline operations resources (crews and aircraft).

Studies also will be carried out to determine if CIWS delay reduction can be estimated by appropriate analysis of FAA delay statistics and the CIWS weather products.

NEAR TERM OPPORTUNITIES FOR INCREASING THE OPERATIONAL BENEFITS PROVIDED BY THE CIWS DEMONSTRATION SYSTEM

The operational feedback provided by the various CIWS users and the benefits analyses reported here have identified some low cost, near term opportunities to significantly increase the operational benefits provided by the CIWS demonstration system. Work proceeds in parallel to provide an operational capability in 2007 or 2008.

These opportunities are as follows:

Improve safety by providing real time access to CIWS products in digital format to airlines and the vendors that provide dispatch decision support systems, so that dispatch can better perform their statutory requirements under the Federal Aviation Regulations (FAR)

Although the FAA ATC has no responsibility to provide warnings to pilots about possibly hazardous en route weather, airline dispatch does have very explicit responsibilities. Specifically, FAA Regulation (FAR) 121.601 includes the following requirements for dispatchers:

> "Before beginning a flight, the aircraft dispatcher shall provide the pilot in command with all available weather reports and forecasts of weather phenomena that may affect the safety of the flight, including adverse weather phenomena, such as clear air turbulence, thunderstorms, and low altitude wind shear, for each route to be flown and each airport to be used.
>
> During a flight, the aircraft dispatcher shall provide the pilot in command any additional information of meteorological conditions (including adverse weather phenomena, such as clear air turbulence, thunderstorms, and low altitude wind shear), and irregularities of facilities and services that may affect the safety of the flight."

The CIWS demonstration system has provided real time displays to major airline systems operations centers (SOCs) that are typically used by the airline ATC coordinators and chief dispatchers. However, the responsibility for individual flight safety resides with individual dispatchers who typically have access only to the airline dispatch decision support (DDST) displays. By providing the CIWS products in digital format, the developers of the various airline DDSTs could provide the CIWS products as a user selectable overlay. Requests to provide this information have been received from two DDST vendors already.

Deploy CIWS situation displays at all the TRACONS that manage traffic into major metropolitan areas within the current CIWS domain that were identified in the Flight Plan 2004–08

Specifically, install situation displays (SDs) at Philadelphia (PHL), the Boston consolidated TRACON, and Washington/Baltimore consolidated TRACON (PCT). There have been several requests from TMUs at both ZDC and ZNY to have CIWS displays installed at PHL and PCT. These displays would significantly improve the ARTCC/TRACON coordination and reduce the ARTCC TMU workload associated with managing internal traffic. This in turn would provide the ARTCC TMUs with more time to handle over flight problems and hence reduce overall NAS congestion.

Deploy CIWS situation displays at all the ARTCCs that border ZAU and the Chicago Tower

The Chicago ARTCC has noted on a number of occasions that there exists a very heavy interfacility coordination workload associated with flights to and from the west, which would be significantly improved if ZKC had a CIWS SD. The Canadian playbook routes that pass north of Toronto are critical for moving east-west traffic when severe convective weather blocks the routes through ZOB and ZID. However, use of the Canadian playbook routes results in a significant increase in traffic from ZAU into ZMP. Since there often is convective weather near key transitions between ZMP and ZAU, and between ZKC and ZAU, improving common situational awareness would significantly improve the overall capability of the ZAU Traffic Management Unit.

Chicago O'Hare Control Tower has also expressed a strong interest in acquiring a CIWS SD. Today, O'Hare Tower does not have the capability of observing the same weather products as the TRACON (located 30 miles away from the Airport) and Chicago ARTCC, but must deal reactively with severe weather around the airport. Runway configurations play a large part in determining the efficiency for Chicago O'Hare Airport; specifically, dynamic use of the appropriate runways allows for efficient departure and arrival throughput. Since the choice of appropriate runway configuration is heavily dependent on knowledge of the en route weather, the Chicago airport could be much better served were the tower to have a consistent weather product in common with the TRACON and ZAU.

Provide weather radar coverage for the Canadian playbook routes

The CIWS case studies highlighted the importance of having at least one route open at all times between Chicago and New York/Philadelphia/Boston/Washington. When severe convective weather (e.g., a north-south oriented squall line moving slowly eastward) blocks the east-west routes through ZID and ZOB, east-west traffic must either go north or go south around the weather. Rerouting ZID and ZOB traffic to the south causes extreme congestion over Atlanta and along the east coast. The alternative is to use the Canadian playbook routes that pass north of Toronto[3].

If the Canadian playbook routes are to be used effectively, one needs to have reliable information on possible convective impacts within Canada (especially Ontario). It would be necessary to add several Canadian weather radars to the CIWS mosaic (see Figure 9.3 in the full report) to fully cover these routes. NavCanada has offered to fund the real time feed of Canadian weather radar data for the CIWS demonstration system.

Provide Route Availability Planning Tool (RAPT) capability at one of the other major metropolitan areas identified in the FAA Flight Plan

The RAPT system at New York will be interfaced to the CIWS forecasts and echo tops in 2004. The use of RAPT at another major metropolitan area within the current CIWS domain, identified in the Flight Plan 2004–08, is relatively straightforward. Chicago would seem to be a high-priority candidate, considering the level of delays at ORD in 2003 and the local ATC and airline interest.

[3] The Canadian playbook routes are the most frequently used playbook reroutes during the summer NAS operations.