P12.11 QUANTIFYING AIR TRAFFIC CONTROL PRODUCTIVITY ENHANCEMENT FOR AVIATION CONVECTIVE WEATHER DECISION SUPPORT SYSTEMS[†]

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1. INTRODUCTION

Major Federal Aviation Administration (FAA) planning documents (e.g., the FAA Flight Plan 2005-2008, the FAA Air Traffic Organization Fiscal Year 2005 Business Plan, and the Operational Evolution Plan) stress the importance of:

- Improving National Airspace System (NAS) operations efficiency by increasing safety and capacity (e.g., reducing delays)

- Providing FAA services more efficiently, such that operations costs can be reduced while improving safety and capacity

Continued improvements in air traffic delay mitigation in the NAS are imperative, given expectations for significant increases in near-term air traffic demand. The latest FAA aerospace growth forecast projects a 30% increase in Air Route Traffic Control Center (ARTCC) operations by 2015 (FAA Office of Aviation Policy and Plans, 2005).

Improving Air Traffic Control (ATC) productivity during convective weather impact events is particularly important. Air traffic demand is escalating in an airspace network near capacity even in clear-weather. This will limit the ability to exploit advancements made in mitigating en route convective weather delays, unless fielded decision support systems are able to improve traffic management efficiency. Moreover, it is also essential that ATC productivity (e.g., as measured by the number of employees and overtime) be improved, given the reduction in Aviation Trust funding from the passenger ticket tax and overall federal funding constraints.

We have previously described how a contemporary convective weather decision support system - the Corridor Integrated Weather System (CIWS) - can facilitate significantly improved capacity enhancing decisions, such as keeping routes open longer and proactive rerouting (e.g., Evans et al. 2005; Robinson et al. 2004). These CIWS-enabled capacity enhancements were shown to result in significant reductions in air traffic delays, airline operating costs, and delay-incurred passenger costs (Robinson et al. 2004).

A study of the CIWS contributions to ATC productivity enhancements began in 2005. As part of this effort, real-time observations of CIWS product usage and the time to accomplish weather impact mitigation planning decisions during multi-day thunderstorm events were carried out at 8 U.S. ARTCCs. A description of the design (and methodological challenges) of this experiment are presented in Section 2 of this paper.

Improved ATC productivity was found to have two components:

(1) Reduced workload and increased operational efficiency, as characterized by the amount of time required to develop and implement convective weather mitigation plans and the ability to enhance staffing decisions

(2) Increased frequency of capacity enhancing decisions

Results demonstrating how CIWS helped traffic managers reduce workload and increase operational efficiency through time-savings and improved decision-making are presented in Section 3. Important factors such as the variation in performance from ARTCC to ARTCC are discussed in some detail. We show that a very important factor in this performance is whether the Area Supervisors at an ARTCC have direct access to CIWS products. The paper concludes by discussing future plans for CIWS ATC productivity enhancement investigations.

[†] This work was sponsored by the Federal Aviation Administration under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

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2. 2005 CIWS BENEFITS ASSESSMENT METHODOLOGY

A review of literature found virtually no articles on quantitative workload assessments associated with air traffic management decision making for the class of problems typified by convective weather impacts. Our methodology for assessing the impact of CIWS on ATC productivity was developed by focusing on prior CIWS assessment techniques that had proven successful, along with published studies of traffic flow management tasks.

2.1 Identifying ATC Workload Metrics for Study

The current principle users of the deployed CIWS prototype are Traffic Management Units (TMU) at ARTCCs in the heavily-congested and workload-intensive Midwest and Northeast NAS Corridors.

During thunderstorm impacts, TMU Traffic Management Coordinators (TMC) use CIWS and other weather and traffic flow decision support tools to execute the operational weather impact mitigation decision loop shown in Figure 1. A major problem in executing this decision loop is that the process of determining ATC impacts, developing appropriate mitigation plans, and selecting from among them must be accomplished in a time period commensurate with the ability to accurately forecast the weather impact.

This is particularly difficult to do in the congested airspace in which CIWS is deployed (Figure 2) because convection in this region is often chaotic and disorganized and thus difficult to predict (Robinson et al. 2004). Moreover, the ATC facility interactions involved with managing this region of the NAS can be very complicated. A decision support tool that improves situational awareness of ongoing thunderstorm impacts in highly-congested and complex airspace regions, and identifies future convective weather impacts on system capacity, should therefore reduce TMC workload concerns and improve TMU operational efficiency.

We have not been able to find any published literature on TMU workload that specifically addresses the bulk of the operational decision loop elements shown in Figure 1. The most pertinent study, which has proved useful in designing the CIWS productivity enhancement investigations, was the Master's Thesis of Haley Davidson of M.I.T. (Davidson and Hansman, 2001). Through a series of site visits to the Boston (ZBW) and New York (ZNY) ARTCCs, as well as the Air Traffic Control System Command Center (ATCSCC), Davidson and Hansman noted that the TMC was a critical decision maker for achieving efficient airspace management, particularly during disruptive weather impact events.

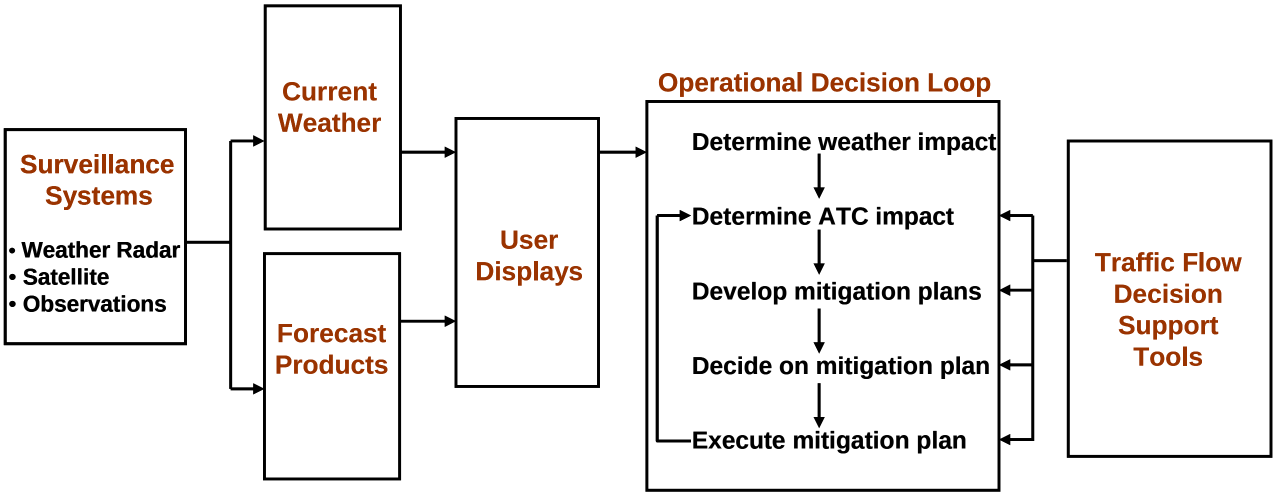

Figure 1. Overall convective weather impact mitigation process. The TMU workload associated with convective weather management includes all 5 elements shown in the "operational decision loop".

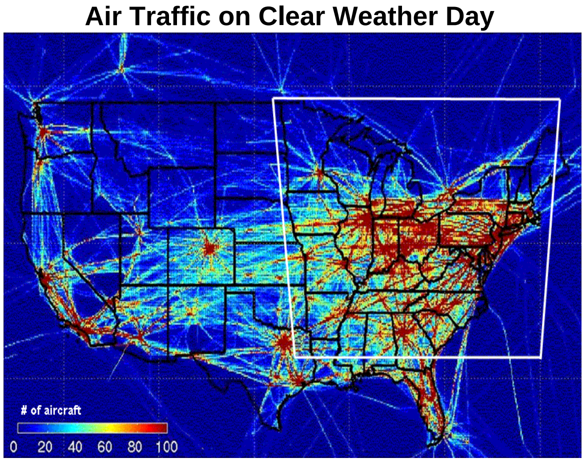

Figure 2. NAS traffic density for a 24-hour fair weather period in 2002. The white overlay shows the CIWS coverage grid for the 2005 demonstration. The 2005 CIWS coverage area includes all 7 major "bottle necks" identified in the FAA Airport Capacity Enhancement (ACE) Plan.

General TMC tasks that were identified include:

- Controlling airspace availability and traffic rates into and out of a facility
- Monitoring operations within a facility to ensure appropriate controller workloads
- Communicating and negotiating with other facilities' TMCs to coordinate appropriate traffic management initiatives
- Communicating initiatives and restrictions to tactical controllers in a timely manner

An example of the TMC coordination tasks for just two ARTCCs is shown in Figure 3 (from Davison and Hansman, 2001). Completion of critical ATC tasks listed above, in such a complex coordination environment for traffic plan development and implementation, requires much more effort during convective weather.

As part of the routine observations of CIWS traffic management applications at the facilities (discussed in detail in Section 2.2), care was taken to identify the time required to (a) identify a weather impact concern, (b) develop an appropriate impact mitigation plan, (c) coordinate this plan both internally and with other facilities, and (d) execute the plan. When using CIWS, ATC user experts were asked to estimate how long the plan development and implementation process would have taken had CIWS not been available[1].

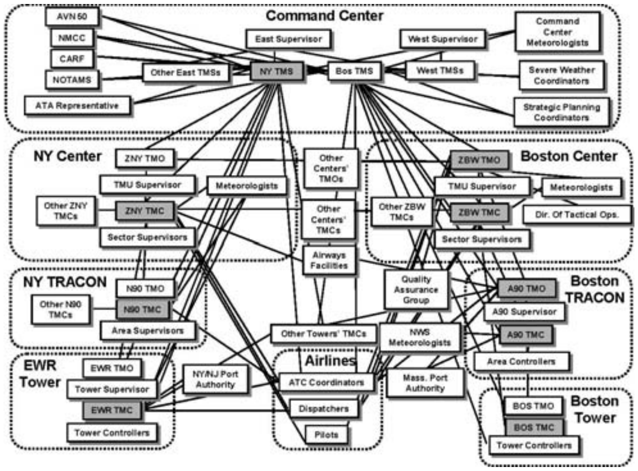

Figure 3. Complexity of NAS system coordination process associated with solving traffic flow management problems at ZNY and ZBW ARTCCs. Complexity grows significantly with each additional facility required for traffic management coordination (from Davison and Hansman, 2001).

2.2 FAA Facility Observation Strategy for Assessing CIWS Benefits

The CIWS operational benefits studies conducted in 2003 broke new ground in terms of methodology employed to assess convective weather delay reduction benefits (Robinson et al. 2004). The 2003 data collection design used knowledgeable observers at a number of FAA facilities during convective weather events for real-time identification of operational CIWS uses. Annual delay and airline cost savings benefits, which were also estimated on per case study, per traffic management benefit category, and per facility bases, were explicitly identified by using the following data gathered during convective weather events:

- Observations of traffic managers' utilization of CIWS displays
- User statements of ATC decisions made using CIWS products
- TMC expert feedback on what alternative decisions they would have made in that

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[1] Precedent for reliance on ATC user estimates to determine alternative operational courses of action for CIWS-derived benefits had this decision support tool not been available has already been established and accepted with the 2003 CIWS Benefits Assessment study (Robinson et al. 2004).

specific situation had CIWS not been available

This benefits assessment approach, accepted by an independent FAA investment analysis review, proved quite successful and was adopted as the basis for the CIWS 2005 productivity enhancement assessment study design.

2.2.1 Tasks of CIWS Field Use Observers

During convective weather impact events, observers at selected ARTCCs obtained feedback from traffic managers (and Area Supervisors) on:

1. Convective weather impact mitigation decisions made using CIWS products
2. The workload associated with monitoring existing convective weather impact mitigation initiatives
3. The workload associated with the mitigation plan development and execution process in relation to expected workload for similar convective events prior to CIWS

Additionally, observers sought to determine whether substantive differences existed in the operational effectiveness of convective weather impact mitigation plans developed with and without CIWS. Our results (see Section 3) suggest that the quality of the convective weather impact mitigation decisions facilitated by CIWS can be even more important for achieving ATC workload savings than the use of CIWS to decrease the time required for traffic managers to develop a worthwhile plan.

2.2.2 FAA Facilities in 2005 CIWS Assessment

FAA ARTCCs were selected for in situ CIWS usage observations in 2005 according to the following criteria:

1. ARTCCs exhibited a high frequency of 2003 CIWS delay reduction benefits and/or required highly complex TMU decisions with potentially significant NAS-impacts
2. There was at least one "new" ARTCC CIWS user
3. A mix of facilities with and without access to CIWS displays at Area Supervisor positions were represented

The facility participants for the 2005 CIWS field-use assessment are shown in Figure 4. Chicago (ZAU), Cleveland (ZOB), New York (ZNY), Washington, D.C. (ZDC), and Boston (ZBW) ARTCCs satisfied the first criterion for inclusion in this study.

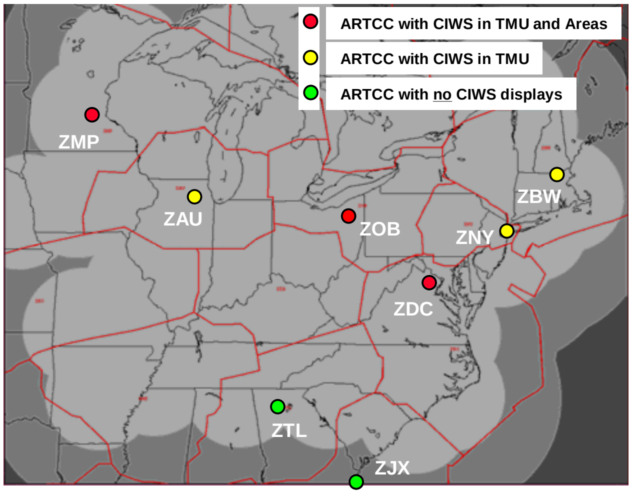

Figure 4. FAA ARTCC facility participants for the 2005 CIWS Benefits Assessment Campaign. ARTCCs in red had CIWS displays in both the TMU and Area Supervisor positions (though CIWS access at all Areas is available only at ZDC). ARTCCs in yellow had CIWS displays only in the TMU. ARTCCs in green had no access to CIWS displays.

The Minneapolis ARTCC (ZMP) was considered a new CIWS user (criterion 2), since 2005 was its first full Severe Weather Avoidance Program (SWAP) season with access to this convective weather decision support tool. Thus we could look to them to provide valuable new user insights on the changes that CIWS has made to their weather impact mitigation planning. Additionally, observations were conducted at two non-CIWS facilities [Atlanta (ZTL) and Jacksonville (ZJX) ARTCCs] to obtain supplementary data used to confirm CIWS user estimates of the workload associated with weather impact mitigation planning had they not had access to this decision support tool.

Finally, significant care was taken to ensure observations were taken at ARTCCs both with and without CIWS displays at Area Supervisor positions (criterion 3). During the 2003 CIWS benefits study, it was found that ZDC accomplished the major delay reduction benefits 50-100% more frequently per convective weather day than any of the other

ARTCCs (Robinson et al. 2004, Table 7-3). A key difference between ZDC and the other ARTCCs in 2003 was that only ZDC had CIWS displays at Area Supervisor positions in addition to the TMU. It was deduced that greater effectiveness at ZDC in achieving delay reduction benefits may have arisen in part from more efficient ATC decision support capabilities, due to enhanced, common situational awareness between the TMCs and Area Supervisors. However, we could not rule out the possibility that the differences arose from some other factor specific to ZDC (e.g., a greater willingness of the TMCs to use the CIWS products).

Given the coordination efforts associated with TMC weather impact mitigation plan development and execution (see Figure 3), we had hypothesized that use of CIWS in the Areas would not only benefit sector supervisors and tactical controllers, but also help reduce TMU workload during significant convective events.

The facility observation scheme used in 2005 allowed us to explore this hypothesis:

- ZDC: CIWS available in TMU and <u>all</u> Area Supervisor positions

- ZOB: CIWS available in TMU and 4 of 8 Area Supervisor positions

- ZMP: CIWS available in TMU and 5 of 6 Area Supervisor positions

- ZAU, ZNY, ZBW: CIWS available in TMU only

Observations were conducted in the TMU in all cases and in the sector Areas at facilities where CIWS was available to Area Supervisors.

2.3 Methodological Challenges of CIWS Assessment Campaign

Several challenges existed when attempting to document and quantify ATC productivity enhancements attributed to the CIWS:

<u>Baseline TMU Productivity Assessments</u>: TMU staffing standards are established based upon individual facilities; however, they do not explicitly address impacts of convective weather. Therefore, we must rely on ATC user estimates of workload assessments, with and without CIWS, and observations from non-CIWS ARTCCs regarding TMU productivity characteristics, in order to identify potential operational efficiency enhancements.

<u>Operational Differences Amongst ARTCCs Under Study</u>: Previous CIWS benefits assessment studies highlighted the ARTCC to ARTCC variability that exists with respect to convective weather characteristics, ATC operational focus, airspace complexity concerns, terminal vs. en route air traffic impacts, linear vs. queue air traffic delays, and CIWS capacity enhancement benefits (Robinson et al. 2004). These differences are compounded by ARTCC variability in TMU protocol and staffing levels during SWAP events. Therefore, as with the 2003 study, the 2005 assessments of CIWS field usage and evaluations of productivity assistance treated each ARTCC as an individual operational entity. This required additional observers and also significantly increased the difficulty of forecasting convective weather events accurately enough to ensure that observers were in place during adverse weather impacts.

<u>In Situ Observation Challenges</u>: During severe weather avoidance plan (SWAP) events, ARTCC TMCs and Area Supervisors are extremely busy. Observers sought to document not only each time the CIWS decision support tool was applied for traffic management assistance, but to directly query the user in order to capture (a) the effect of weather on air traffic, (b) how CIWS was being used to address the weather impact, (c) what plan would have been devised (and using what tools) had CIWS not been available, and (d) the effort required for any potential, alternative plans. Obtaining this information at a time when TMU personnel were at their busiest was difficult. Moreover, anywhere from 3-7 TMCs in a TMU could be handling different weather impact concerns at the same time, all potentially using CIWS to assist in planning. Ideally, all these CIWS field uses would be observed (a difficult task for 1-2 observers). For those facilities with CIWS displays in Areas as well as the TMU, the number of CIWS applications increased significantly, further stretching limited observation resources.

3. CIWS BENEFITS EVALUATION RESULTS

FAA facility observation visits in 2005 for real-time evaluation of CIWS field usage were conducted on the following dates:

- 4 - 7 June

- 27 June - 1 July

- 12 - 15 July (all except ZMP), 3 Aug (ZMP)

Convective weather present during these 3 intensive observation periods varied among large, organized squall line systems, short-lived quasi-organized clusters, large-scale disorganized thunderstorm outbreaks, typical summertime air mass convective events, and nontrivial embedded stratiform rain systems. Since each major type of storm organization and coverage regime occurred at each of the facilities in 2005, these intensive observation periods were considered a representative sampling of the population of significant convective weather events.

ATC impacts caused by convective weather during these 3 observation periods ranged from minor to extraordinarily severe. Reported air traffic delays on 13 July 2005 for example (during the third observation period) set an all-time daily record for delays as prolonged en route and terminal convective weather impacts from southern Canada to Florida to Texas greatly reduced NAS capacity. Observations of CIWS usage during heavy TMU workload events such as 13 July were valuable in diagnosing both airspace capacity and ATC productivity enhancements provided by CIWS.

In the following sections, we discuss:

1. TMU plan development and implementation time savings attributed to CIWS
2. Benefits contributions (including ATC staffing assistance) attributed to CIWS product access in ARTCC Areas
3. Quality vs. time-for-decision relationship for CIWS-derived ATC decisions
4. CIWS operational effectiveness changes from 2003 to 2005

3.1 TMU Plan Development and Implementation Time Savings Attributed to CIWS

The primary task of observers during the 2005 CIWS field-use assessment was to determine how long it took traffic managers to complete the operational decision loop (see Figure 1), with and without the use of CIWS. Specifically, for each weather impact concern addressed in part with CIWS, observers documented:

- When the impact concern was first identified
- How long it took for ATC to develop an impact mitigation plan
- How long it took to coordinate the plan (internally and with other facilities), and how long to execute

When possible, these direct observations of CIWS plan management timelines for individual ATC decisions were then followed-up immediately by on-the-spot interviews of TMU personnel, soliciting their expert opinion as to how long it would have taken to achieve each element of the operational decision loop without access to CIWS. TMC responses to these frequent, impromptu user interviews generally consisted of one of the following:

1. Without CIWS, it would have taken X minutes longer to make this decision because of Y
2. We would have made the same decision in the same amount of time without CIWS
3. We would not have been able to make this decision without CIWS
4. No time was available for the users to discuss the decision

With these interview responses, coupled with CIWS field-use observation data, detailed statistics were calculated for ARTCC weather impact plan management time savings attributed to CIWS.

Table 1 shows estimated CIWS time-savings at each individual ARTCC. At most facilities, several critical TMU weather impact mitigation decisions per day (e.g., keeping routes open, where to reroute aircraft, directing pathfinders, etc.) were made approximately 10 minutes faster by using CIWS. Due to the difficulty in interviewing the CIWS users during severe convective events (discussed above), we estimate that these “more timely” decisions constitute only 21-36% of total observed CIWS usage (varying from facility to facility).

Some CIWS decisions yielded no plan development/coordination time savings. On numerous occasions, TMCs were unable to comment on the workload associated with a specific CIWS-derived traffic plan because of the extremely busy SWAP environment. Finally, TMCs often informed observers that a particular CIWS-derived decision would not have been possible without CIWS, and they would have had to settle for a less-beneficial plan instead (in terms of seeking to optimize capacity without overwhelming tactical controller workload).

Total TMU time savings attributed to CIWS per convective weather day, demonstrating productivity enhancements for individual elements of the operational impact mitigation planning loop (see Figure 1), are presented in Figure 5. These results have two primary, compelling components:

1. *Most time saved in plan development stage of decision loop:*

CIWS proved most beneficial to traffic managers when identifying and prioritizing thunderstorm impact concerns and developing high-quality impact mitigation plans. When interviewed, TMCs routinely pointed out that if a particular impact plan was still recognizable as an option without CIWS, extra time would have been required to either:

- Query the ARTCC Center Weather Service Unit (CWSU) meteorologists on duty for the needed weather information[2],
- Make manual extrapolations, estimates, and educated guesses of perceived weather situations using other convective weather decision support tools, or
- Scour the Internet for additional sources of weather information (least frequent).

Since extra time to secure this tactical weather information is often unavailable to traffic managers, they explained regularly that without CIWS, the impact mitigation plan in question would either (a) not have been devised or (b) been devised in the same amount of time with other weather decision support tools, but with far less confidence in the decision.

2. *Amount of TMU time-savings related to availability of CIWS in ARTCC Areas*

Results highlighting total TMC weather impact planning time-savings per day from CIWS demonstrate a significant relationship between enhanced TMU productivity and availability of CIWS displays in ARTCC Areas (see Figure 5). Total TMC time-savings from the 3 ARTCCs with CIWS in both the TMU and the Areas was 164% greater than TMC time-savings from 3 ARTCCs with CIWS only in the TMU. The relationship between improved TMU productivity and availability of CIWS displays at ARTCC Area Supervisor positions is discussed in the next section.

3.2 Benefits Contributions Attributed to CIWS Usage in ARTCC Areas

In situ field use assessments of FAA decision support tools are valuable not only for determining operational benefits of a system, but also for observing how ATC operates during traffic impact events. During both the 2003 and 2005 CIWS field-use assessment campaigns, observations at ARTCCs and discussions with traffic managers revealed that all operational ATC positions in an En Route Traffic Center, from controller to Area Supervisor to TMC, need to function as a tightly knit team. Decisions made at the TMC level directly affect Area personnel (supervisors and controllers). Similarly, decisions made by controllers and Area personnel will also impact TMU planning decisions. Given this synergistic ARTCC environment, it stands to reason that any benefits gained in the TMU through use of a convective weather decision support tool such as CIWS should increase when Areas have access to the same tool. Mutual availability of a decision support tool increases common situational awareness of air traffic management concerns throughout the facility. Decisions made by Area personnel are as significant to overall traffic management plans as those made by the TMU (personal communications and interviews with ARTCC Traffic Management Officers, TMCs, and Area Supervisors). The availability of decision support information in the Areas, such as provided by CIWS, can therefore greatly assist in plan development and implementation efficiency, resulting in traffic management decisions that increase airspace capacity without adversely affecting controller workload.

As discussed in Section 2, the design of the 2005 CIWS benefits assessment campaign experiment explicitly allowed for an assessment of the impact of having CIWS products available in the Areas (see Figure 4).

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[2] The ARTCC CWSU is normally not staffed by a meteorologist after 10 PM local. If significant weather impacts occur late in the evening, extending beyond 10 PM, traffic managers must rely even more heavily on convective weather decision support tools. TMCs using CIWS for weather impact mitigation planning after CWSU meteorologists have left for the evening were often unable to cite specific plan development time-savings. Instead, absent of other sources of the weather information needed, they often stated that without CIWS, an alternate (and usually less-beneficial) plan would have been devised and implemented.

Table 1. TMU Time-Savings Attributed to CIWS for Convective Weather Impact Mitigation Plan Development and Implementation, Normalized by Convective Weather Day **

ARTCC	Number of CIWS Time Saving Decisions	% of Total Observed CIWS Applications	Mean Plan - Development Time Savings (min)	Mean INTERNAL Coordination Time Savings (min)	Mean EXTERNAL Coordination & Implementation (min)	Mean TOTAL CIWS Time Savings (min)	Time-Saved Decisions where CIWS used in Areas for COORDINATION	TMU Decisions Proactively Developed and/or Managed in Area via CIWS (Area INITIATION)	CIWS Assistance with FAA Staffing Decisions
ZMP	**6.2**	**36%**	**8.6**	**0.6**	**0.8**	**10.0**	**3.0**	**1.2**	**1.2**
ZAU	**2.7**	**21%**	**5.0**	**1.1**	**2.4**	**8.5**	**-**	**-**	**0**
ZOB	**8.2**	**30%**	**6.2**	**2.9**	**2.4**	**11.5**	**5.3**	**5.8**	**0.8**
ZDC	**8.2**	**31%**	**7.3**	**1.4**	**1.5**	**10.2**	**4.3**	**4.0**	**0.2**
ZNY	**1.8**	**23%**	**11.0**	**0**	**0**	**11.0**	**-**	**-**	**0**
ZBW	**5.0**	**23%**	**7.1**	**1.0**	**1.5**	**9.6**	**-**	**-**	**0.7**

*** Time-savings results from the 2005 CIWS Benefits Assessment Campaign*

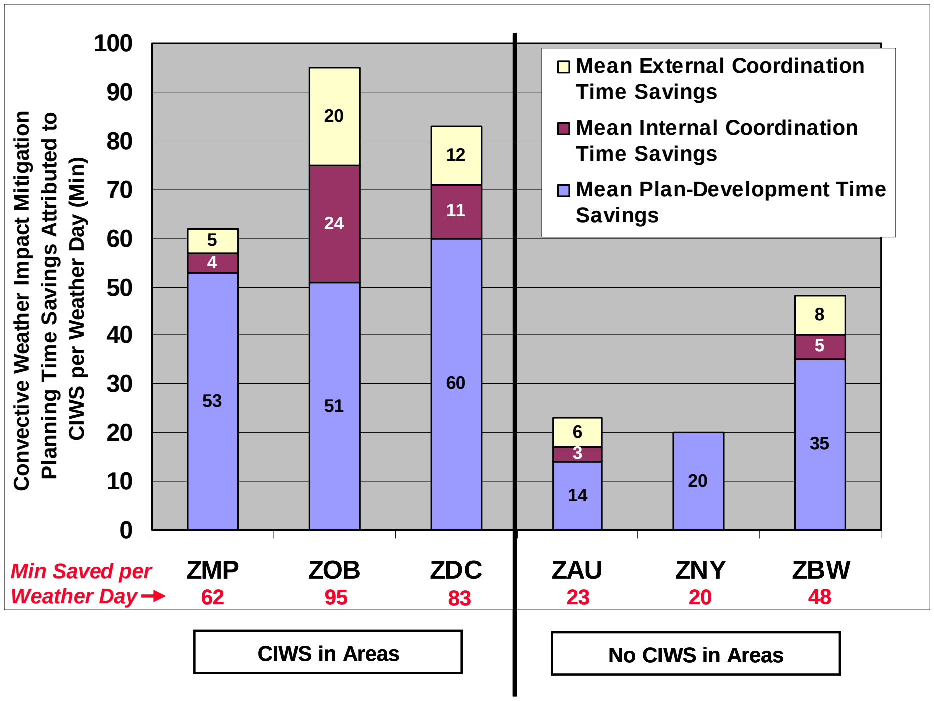

Figure 5. TMU time-savings attributed to CIWS at each ARTCC investigated in 2005. Productivity enhancements per convective weather day are segmented to demonstrate CIWS contributions to the specific legs of the operation decision loop for weather impact mitigation. ARTCCs with and without access to CIWS displays in the Areas are noted.

Four primary benefits of having CIWS available to Area Supervisors (in addition to the TMU) were identified:

1. Improved weather impact plan coordination
2. TMU plan development/monitoring workload eased by enhanced Area initiative via CIWS
3. Increased frequency of higher-quality weather impact mitigation decisions
4. FAA staffing assistance

3.2.1 Improved ARTCC plan coordination with Area CIWS access

CIWS availability in the Areas at ZOB, ZDC, and ZMP ARTCCs greatly increased TMU time-savings for weather impact mitigation plan development (compared to ARTCCs with CIWS only in the TMU). We found that at these three ARTCCs, Area personnel were often more involved at the plan development stage, since they were able to utilize CIWS to quickly affirm a plan proposed by the TMU or to offer a high-quality "counter-plan".

Once weather impact plans were devised in the TMU (with or without Area Supervisor assistance), CIWS availability in the Areas helped reduce the Area coordination time. (See Figure 5, "mean internal coordination time savings").

Mean, daily internal coordination time savings attributed to CIWS at ZOB and ZDC were roughly 4 times greater than mean savings at ZAU, ZNY, and ZBW. Internal plan coordination time-savings at ZMP lagged the other facilities with CIWS in Areas and the TMU, likely because TMCs at this ARTCC were relatively new users of this decision support tool and thus, experience in utilizing CIWS for Area collaboration was still limited.

Figure 6 demonstrates the higher rate at which plan coordination and TMU workload reduction benefits were achieved at ARTCCs with CIWS available in both the TMU and Areas. Also, observed use of CIWS for "situational awareness" of convective weather impacts on air traffic was generally higher at ZOB, ZDC, and ZMP (ARTCCs with Area CIWS displays), though it is important to note that CIWS was used heavily within the ZBW TMU, which helped this facility overcome some plan development and coordination challenges associated with not having CIWS in the Areas (discussed further in Section 3.2.3).

3.2.2 TMU workload reduction from enhanced Area initiative via CIWS

Observations at ZOB, ZDC, and ZMP in 2005 revealed that substantial reductions in TMU workload were achieved when Area supervisors utilized CIWS to avoid traffic management initiatives (TMI). This is illustrated by the following observation of Area usage of CIWS at ZDC at 2000 UTC on 13 July 2005:

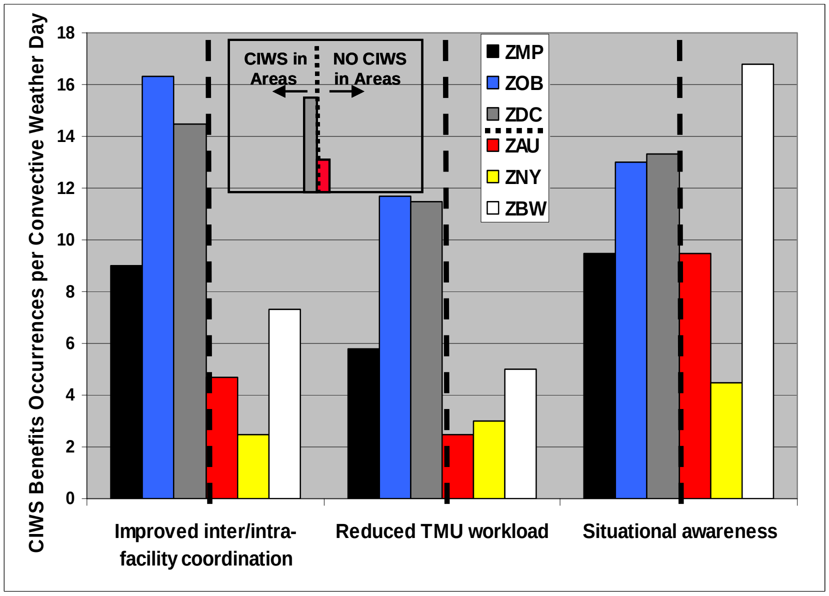

Figure 6. Operational benefits per ARTCC per convective weather day for 3 specific CIWS benefits categories. ARTCC results are separated into two groups, those facilities with access to CIWS at Area Supervisor positions and those without.

- *Strong storms near OOD fix in ZDC (key NY departure fix)*

- *ZDC Area Supervisor uses CIWS Growth and Decay Trend product to note that these storms are dissipating; based on CIWS, Supervisor keeps the route open, without restrictions*

- *ZDC Area Supervisor convinces NY ATC that this decision is the right one*

- *ZDC TMU involvement not required for this decision.*

In an interview after this air traffic management decision was made, this Area Supervisor stated that had CIWS not been available, he would have requested the ZDC TMU to either close this route completely or implement significant Miles-in-Trail (MIT) restrictions. By using CIWS to keep this route open with no TMI, the TMU did not have to develop a plan for this route impact. Moreover, if a plan for this route were implemented, it would have required constant, iterative monitoring and revisiting by the TMU. The impact on heavy NY traffic would have been substantial, with significant delays, and pressure to remove TMIs on this route as quickly as possible would have been immense. Keeping the route open not only reduced ZDC TMU workload, but also potentially reduced ATC workload for:

- ZDC Area controllers: allowing traffic to stay on route would limit/prevent air traffic complexity issues that increase controller workload

- ZNY: TMU, Areas would have had to react to a TMI

- NY TRACON: the TMI would have directly impacted large terminals in their airspace

- NY/Philadelphia ATC Towers: backup of aircraft and building “queues” resulting from a significant departure slowdown would have increased airport surface management workload

- Airline System Operations Centers (SOC) and dispatchers: extra workload would have been required in seeking alternative routes for aircraft impacted by route TMI, accounting for downstream delay impacts, flight crew timeout concerns, etc.

Finally, and perhaps most important, this decision, made independently of the TMU by an Area Supervisor using CIWS, increased airspace capacity and helped save considerable delay on a day when air traffic impacts were already at record levels[3].

3.2.3 Increased frequency of higher-quality weather impact mitigation decisions enabled through CIWS use in Areas

Figure 7 compares the number of times per convective weather day that key en route delay reduction benefits were observed at each ARTCC under study during the 2005 CIWS usage assessment. Overall, CIWS en route airspace efficiency and capacity enhancement benefits at ZOB, ZDC, and ZMP (CIWS in Areas) were significantly greater than the corresponding CIWS benefits at ZAU, ZNY, and ZBW (CIWS in TMU only). On average, for the 5 CIWS en route benefit categories shown in Figure 7, ARTCCs with CIWS in the Areas and TMU implemented capacity enhancing TMIs *140% more often* than ARTCCs with CIWS only in the TMU.

The outlier in this analysis was ZBW, which compensates for the lack of Area displays through prolific use of CIWS in the TMU, where this decision support tool is consulted regularly during convective weather events. Even with such strong TMU use at ZBW, the frequency of high-quality CIWS delay saving decisions at ZBW such as “Keeping Routes Open Longer”, “Proactive Reroutes”, and “Improved Management of Arrival/Departure Transition Areas (ATA/DTA)” was lower than rates for the same benefits decisions at ZOB and ZDC. Since TMC use of CIWS at ZOB and ZDC is comparable to that at ZBW, we attribute this higher overall ARTCC efficiency for executing beneficial weather impact mitigation plans to the Area use of CIWS[4] at those facilities.

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[3] Recall, it was noted earlier in Section 3 that reported air traffic delays on 13 July 2005 set an all-time daily record. Without CIWS-enabled decisions such as the one described here, both delays and ATC workload concerns on this day would have been much worse.

[4] The frequency of some CIWS en route benefits at ZBW (CIWS in TMU only) exceeded the rate of achieved benefits at ZMP (CIWS in TMU and Areas), as the latter “new user” group was still becoming accustomed to using this decision support tool. This operational “burn-in” period was seen at almost all FAA facilities during their first year of CIWS usage.

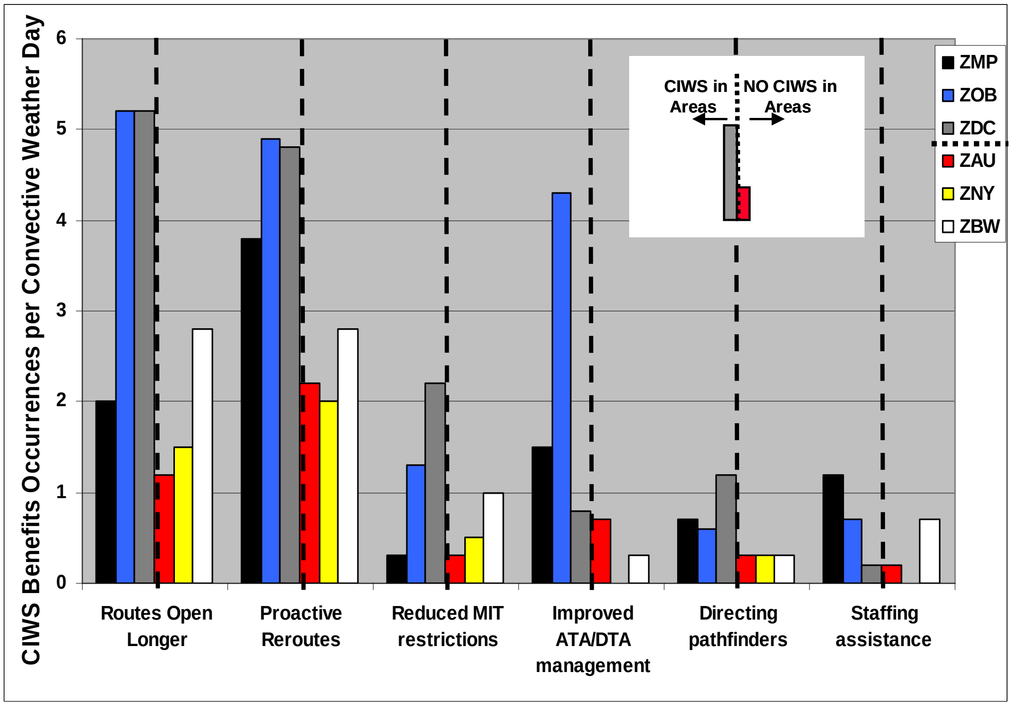

Figure 7. CIWS benefits per convective weather day at each ARTCC included in the 2005 CIWS field use assessment. Benefit categories shown here are typically considered key en route delay reduction benefits attributed to CIWS at ARTCCs. ARTCC results are separated into two groups, those facilities with access to CIWS at Areas Supervisor positions, and those without.

It has been previously demonstrated that improved weather impact mitigation plans derived from CIWS can save substantial delay, as well as airline operating and passenger costs (Robinson et al. 2004). In the context of the 2005 CIWS productivity enhancement assessment, improved *quality* of decisions also proves important in reducing controller and traffic manager workload. Results in this section demonstrate that realized productivity benefits, through improved weather impact planning using CIWS, increase at facilities with CIWS available at Area Supervisor positions. A discussion of the impact of traffic management plan *quality* on facility and NAS operational efficiency is presented in Section 3.3.

3.2.4 Increased FAA staffing assistance through CIWS use in Areas

Availability of CIWS displays at Area Supervisor positions also allowed for more facility-wide opportunities to consult this decision support tool to assist with ATC staffing decisions. The frequency of CIWS-assisted FAA staffing decisions per ARTCC is presented in Table 2. Though the trend is not as clear as the relative rates of achieved en route benefits, results suggest that CIWS availability in ARTCC Areas increases the use of this decision support tool for assistance with staffing decisions. Observations from the 2005 field-use assessment captured a number of uses of CIWS weather products in the Areas to assist in making staffing decisions, including:

- Justification for controller overtime based upon weather impacts forecasted by CIWS
- Adding “D-side” controllers to reduce ATC workload based upon current or pending weather impacts as depicted by CIWS
- Optimizing Area controller break schedules based upon CIWS weather information
- Managing ATC staffing in super-high sectors based upon CIWS Echo Tops and Echo Tops Forecast products
- Determining controller staffing levels needed for diversion recovery programs
- Avoiding controller overtime (staffing levels acceptable, despite convective weather impacts, based upon CIWS weather depictions and forecasts)

Staffing decisions made by Area Supervisors using CIWS to add or extend overtime for controllers at first glance appears counter to FAA goals to reduce operating costs. However, from an air traffic management perspective, these staffing decisions, which decrease controller workload and thus maintain or increase sector capacity, allow ARTCCs to proactively address convective weather impact concerns. The potential end result of this proactive staffing approach in the Areas, based upon CIWS, was often reduced air traffic delays, managed airport departure queues[5], and reduced duration of late evening impacts, when controller staffing is extremely limited and costs for off-peak ATC overtime (needed to handle ongoing peak traffic demand) would be significantly greater.

CIWS was used in the TMU, to assist in making staffing decisions, as well, although less frequently than in the Areas due to fewer TMC personnel working per shift. Table 2 shows that CIWS was used at ZBW nearly once per convective weather day to help manage TMU staff scheduling. As in the Areas, CIWS current weather depiction and forecast products proved useful in the TMU for determining the optimal staff force (more or less), given ongoing or pending convective weather impacts.

Table 2. Frequency of CIWS-Assisted FAA Staffing Decisions per ARTCC

ARTCC	FAA Staffing Decisions Made with CIWS per Convective Weather Day
ZMP	**1.2**
ZOB	**0.7**
ZDC	**0.2**
ZAU	**0.2**
ZNY	**0.0**
ZBW	**0.7**

🟦 **CIWS in TMU and Areas**

⬜ **CIWS in TMU only**

🟨 **CIWS in TMU only, but prolific usage**

3.3 Quality vs. Time-for-Decision Relationship for CIWS-Derived ATC Decisions

Recall from earlier discussions of CIWS plan development time savings (Section 3.1) that a significant fraction of TMC responses to CIWS workload assistance queries were that a specific impact mitigation plan would not have been devised and implemented without CIWS[6]. TMCs stated that in the absence of CIWS, there would most likely not have been enough time to obtain the necessary information from the CWSU meteorologists (e.g., storm movement, evolution, height, and forecast) needed to make an educated tactical traffic management decision. Moreover, ATC personnel explained that other convective weather decision support tools, available in the TMU, lacked most specific weather information provided by CIWS. Therefore, without CIWS, they would not have been aware that more optimal storm impact mitigation plans could be developed.

CIWS proved extremely valuable in the fast-paced, workload-intensive SWAP environment in an ARTCC TMU by exposing options for weather impact mitigation that were better than the other alternatives (in terms of enhancing capacity and/or addressing controller workload concerns), yet could still be incorporated into a plan and iteratively monitored in a timeframe acceptable within the limits of tactical airspace management. In addition, with additional storm severity information provided by CIWS, higher quality mitigation options might be proposed, and the resulting impact mitigation plans selected, even though more work by the TMU might be required initially to put the plan in place.

An example of an observed CIWS application that greatly increased airspace capacity, but required extra work by the TMU to achieve the benefit, is presented in Table 3. During this event on 29 June 2005, a large cluster of storms was impinging on the Mid-Atlantic coast, along which several high demand en route ZDC airways, that serve New York, Boston, and Florida traffic, run. At the same time, an organized thunderstorm complex was directly impacting ZNY airspace, causing mounting delays at the major metro NY airports. Additional strong storms began building in northern ZDC airspace after 1400 UTC. Given the significant weather already affecting NY traffic flows at this time, additional storm-related capacity reductions in ZDC would have severely hampered NAS

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[5] Airport queuing delays (Robinson et al. 2004; Allan et al. 2001; Evans, 1997) invariably occur at high demand/limited capacity terminals serviced by routes through the CIWS domain (e.g., Chicago O'Hare, Newark, LaGuardia, JFK, Teterboro, Boston, Dulles, Washington National, Baltimore, and Detroit airports).

[6] If different impact mitigation plans were expected by TMCs if CIWS was not available, the decision was not included in workload time-savings calculations. This is because estimates for the time required to devise and implement a plan with and without CIWS in these instances would have been for two completely different TMIs and thus not comparable.

operations along the east coast (and likely beyond). Despite storms of level 5 intensity in the CIWS VIL precipitation product,[7] ZDC TMCs used CIWS echo tops products to identify that en route over flight traffic on very high demand airways could continue (Figure 8). This particular event was very dynamic as thunderstorms continued to build in the airspace region of concern. Therefore, the decision to keep key routes through northeast ZDC open required continuous TMU monitoring to be sure this plan remained safe and operationally viable. TMU personnel and Area Supervisors were observed "conferencing" around the CIWS Situation Display (SD) at approximately 20-30 min intervals to reassess the decision to keep routes open based upon echo tops information. Increasing echo top heights finally led to the closure of the route at 1630 UTC.

Post-decision interviews confirmed that without CIWS, this heavily-traveled route would have closed two hours earlier. NY airport arrival/departure rates were already reduced because of convection in ZNY airspace; an earlier closing of this ZDC route servicing NY traffic would have further reduced terminal throughput at several large airports, resulting in rapid, nonlinear escalations of queuing delays.[8] Airports affected would have included metro NY (3 airports), Atlanta, Orlando, Tampa, Miami, Boston, Hartford, Providence, and surely others.

In this traffic management example, the decision to keep routes in ZDC open based upon CIWS required more work from (a) TMCs to iteratively monitor and assess the route impact, (b) Area controllers who were still handling significant traffic through their sectors despite heavy weather and occasional, local pilot deviations, and (c) Area Supervisors, working with both the TMCs and controllers to continually ensure that this traffic plan remained manageable. However this decision substantially enhanced en route airspace capacity during a significant SWAP event, providing significant relief for several high demand airports and minimizing delays. Moreover, given that the NAS operates as a network, not only in terms of general air traffic flow, but also in terms of the symbiotic relationship between all ATC facilities managing this flow, the extra effort at ZDC to postpone highly intrusive TMIs and increase en route capacity helped improve operational productivity elsewhere during the 2-hour benefit period.

High-quality ATC decisions through use of CIWS such as the one exemplified in this section, requiring extra near-term effort to reap significant airspace capacity enhancement benefits, were observed at each ARTCC and on every convective weather day studied in the 2005 CIWS benefits assessment campaign. This delicate balance between the quality of weather impact mitigation plans and the time/effort required to develop and implement plans must be considered when attempting to assess ATC productivity enhancements attributed to decision support tools, especially since extra work at one facility may result in significant workload savings at numerous others.

3.4 CIWS Operational Effectiveness Changes from 2003 to 2005

Two other important objectives of the 2005 CIWS operational effectiveness assessment were to:

- Confirm previously established CIWS benefits categories and identify new applications

- Determine if frequency of realized CIWS delay reduction benefits had changed since 2003

The CIWS operational effectiveness benefits categories and their frequency per ARTCC per convective weather day are presented in Table 4. Frequencies of CIWS benefits are color-coded to denote increases or decreases in the rate of decision support tool applications per ARTCC in 2003 vs. 2005. The rate at which CIWS improved the quality of ATC weather impact planning decisions has increased significantly since 2003[9]. For example, use of CIWS to improve convective weather rerouting (Table 4, Category 3) increased by greater than 100% since 2003 at all ARTCCs included in both studies.

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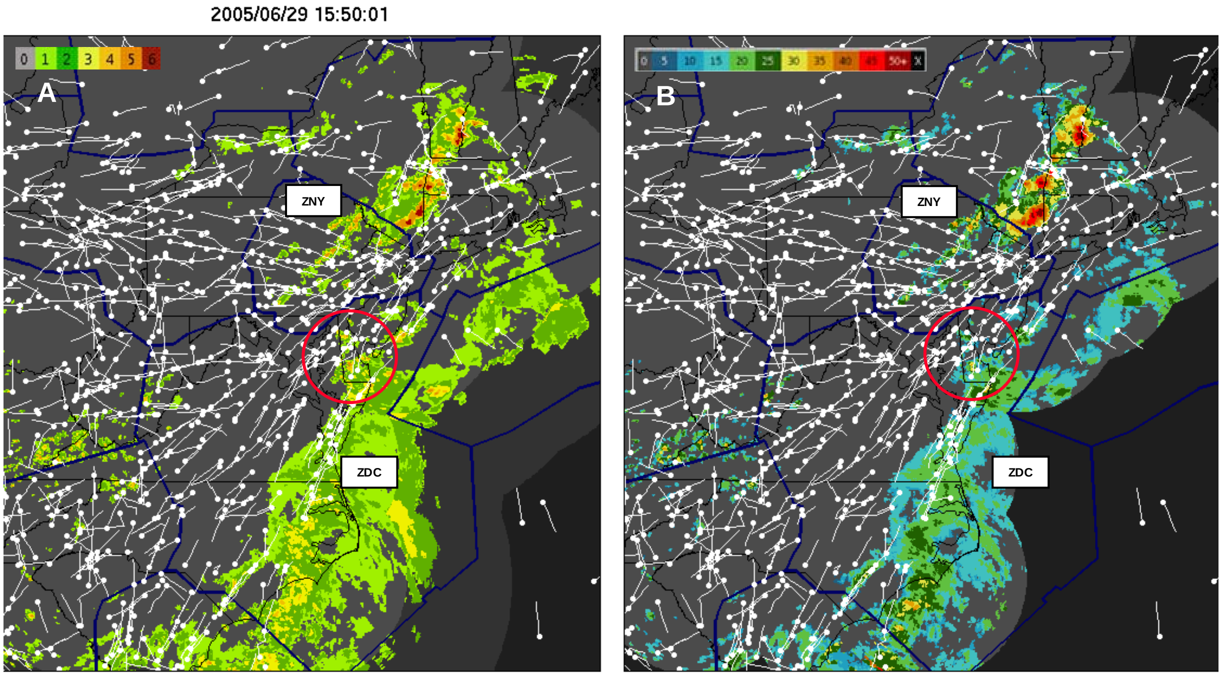
[7] Robinson et al. (2002) demonstrated that less-intense weather depictions based upon CIWS VIL precipitation are a more accurate representation of en route storm severity than the radar reflectivity products available from other decision support tools such as WARP or ETMS. Therefore, a level 5 storm on 29 June 2005, as depicted by CIWS, likely looked even stronger (and thus more alarming) on other weather decision support tools.

[8] See Appendix B in Robinson et al. (2004) for quantified CIWS delay savings case studies involving route-based queuing delays.

[9] See Robinson et al. (2004; Table 7-3) for frequency of ARTCC CIWS benefits in 2003.

Table 3. Observed, Iterative Use of CIWS at ZDC TMU on 29 June 2005

Weather Impact Plan Management Using CIWS	Without CIWS
• **1436 UTC:** Level 3-5 storms near OOD/SBY (key ZDC airspace for en route NY traffic); southbound traffic deviating – conference between TMCs and Area Sups at TMU CIWS display, discussing stopping OOD departures or heavy MIT restrictions. Realizing significant impact on NY departures, ZDC use CIWS (Precip, Echo Tops, Lightning, Growth and Decay Trends products) to reach decision to leave route open without restrictions, and absorb deviations.	Route heavily restricted or closed; if closed, no more TMU work on this plan until weather clears or deviations cease
• **1504 UTC:** Strong storms still near OOD/SBY fixes. Area Sup uses CIWS to note echo tops at 34 kft, increasing from 30 kft – feels still acceptable and leaves route open.	Route closed - concern for deviations and airspace complexity cease until route reopened
• **1533 UTC:** Storms near SBY fix. Area Sup tells TMU (using CIWS) that flights are still deviating and echo tops are 30 kft. STMC notes "positive growth" is NOT present in CIWS Growth and Decay Trends product. Deviations larger now, and near military warning areas, so 30 MIT restriction implemented on route. TMU confirms route would have closed completely without CIWS – route remains open 55 min longer.	Route potentially closed – concern for deviations and airspace complexity cease until route reopened
• **1550 UTC:** Strong storms still near SBY fix. Area Sup and STMC (using CIWS) discuss NY/PHL departures deviating around weather. STMC decides to continue to keep route open because CIWS shows "manageable" echo tops and no lightning. CIWS does show "growth" (via Trends product), which is a concern and thus impact is continuously monitored.	Route closed – TMU workload reduced until decision to reopen route
• **1630 UTC:** Route finally closed.	
• **Conclusion: Decision made using CIWS to keep route open saved considerable delay, but iterative plan monitoring required more work in TMU.**	



CIWS VIL Precipitation

CIWS Echo Tops Mosaic

Figure 8. CIWS weather depictions showing (A) VIL precipitation and (B) Echo Tops at 1550 UTC on 29 June 2005. Overlaid on CIWS weather products are all flight tracks for aircraft at or above 16,000 feet. The ZDC airspace region where CIWS used to keep heavily-traveled jet routes open (despite level 3-5 intensity) based upon CIWS echo tops information is circled in red. At this time, strong, high-topped thunderstorms in southern NY and PA had closed key airways servicing metro NY traffic. This resulted in additional traffic volume on routes west and south from NY. Without CIWS, ZDC TMU personnel confirmed that routes through the circled airspace region would have closed two hours earlier, resulting in increased demand on fewer available routes and thus, increased air traffic delays for numerous airports.

Table 4. CIWS Benefits Categories and Frequency per ARTCC per Convective Weather Day

Benefit Category	ZMP **	ZAU	ZOB	ZDC	ZNY	ZBW
(1) Keeping routes open longer and/or reopening closed routes earlier	**2.0**	🟨 **1.2**	🟥 **5.2**	🟨 **5.2**	⬜ **1.5**	🟨 **2.8**
(2) Closing routes proactively	**0.2**	🟨 **0.2**	🟥 **0.9**	🟦 **0.5**	🟥 **1.5**	🟨 **0.8**
(3) Proactive, efficient reroutes	**3.8**	🟥 **2.2**	🟥 **4.9**	🟥 **4.8**	🟥 **2.0**	🟥 **2.8**
(4) Improved Ground Stop program management (shorter/fewer stops, ground stops avoided, more efficient use of ground stops)	**0.5**	🟥 **0.5**	🟥 **1.1**	🟨 **1.2**	🟥 **0.5**	🟥 **1.2**
(5) Reduced MIT restrictions (proactive management of routes in use)	**0.3**	🟥 **0.3**	🟥 **1.3**	🟥 **2.2**	🟨 **0.5**	🟥 **1.0**
(6) Traffic directed through gaps	**0.5**	🟥 **0.5**	🟦 **0.6**	🟦 **0.2**	🟥 **0.5**	🟥 **0.5**
(7) Improved management of weather impacts on terminal ATA/DTA's	**1.5**	🟦 **0.7**	🟥 **4.3**	🟨 **0.8**	🟦 **0.0**	🟦 **0.3**
(8) Optimization of runway usage; enhanced runway planning	**0.0**	⬜ **0.0**	🟦 **0.0**	⬜ **0.0**	⬜ **0.0**	⬜ **0.0**
(9) Improved Ground Delay program management	**0.0**	⬜ **0.0**	🟥 **0.6**	🟨 **0.2**	⬜ **0.0**	⬜ **0.0**
(10) Greater departures during SWAP	**0.5**	🟦 **0.5**	🟥 **0.9**	🟦 **0.3**	🟦 **0.0**	⬜ **0.3**
(11) Directing pathfinders	**0.7**	⬜ **0.3**	🟥 **0.6**	🟦 **1.2**	🟦 **0.3**	⬜ **0.3**
(12) Interfacility, intrafacility coordination assistance	**9.0**	🟥 **4.7**	🟥 **16.3**	🟥 **14.5**	🟥 **2.5**	🟥 **7.3**
(13) Improved safety	**0.2**	⬜ **0.0**	🟨 **0.4**	🟨 **0.7**	🟦 **0.0**	🟦 **0.0**
(14) Reduced workload (includes proactive impact mitigation planning)	**5.8**	🟥 **2.5**	🟥 **11.7**	🟥 **11.5**	🟥 **3.0**	🟥 **5.0**
(15) FAA facility staffing assistance	**1.2**	**0.2**	**0.7**	**0.2**	**0.0**	**0.7**
(16) Situational awareness	**9.5**	🟥 **9.5**	🟥 **13.0**	🟨 **13.3**	🟥 **4.5**	🟨 **16.8**
# Days LL/FAA observers present	*6*	*6*	*9*	*6*	*4*	*6*

🟨 **0 – 100% increase from '03**
🟥 **> 100% increase from '03**
🟦 **decrease from '03**
⬜ **no change from '03**

***ZMP did not have CIWS in 2003 so comparisons between 2003 and 2005 were not possible*

Category #15 (staffing assistance) was new CIWS benefits classification in 2005

MIT: Miles-in-Trail
ATA/DTA: Arrival/Departure Transition Areas

A comparison of cumulative estimates of annual CIWS benefit occurrences for ARTCCs included in both 2003 and 2005 field use assessment campaigns is shown in Figure 9[10]. The increased frequency in operational effectiveness benefits is likely due to a combination of (a) CIWS product enhancements like the introduction of the 0-2 hour Echo Tops Forecast (Dupree et al. 2006), (b) increased confidence by ATC users in the deployed CIWS prototype, and in some cases, (c) availability of CIWS displays at ARTCC Area Supervisor positions (see Section 3.2).

The previous Section discussed how the improved *quality* of weather impact mitigation plans, even when requiring more near-term effort by a TMU, can be more beneficial to overall NAS facility productivity than alternative decisions made more quickly. Interviews with numerous FAA personnel suggest that ATC workload can best be reduced by maintaining nominal traffic flows or, when this is not possible, adopting flow impact plans in as proactive a manner as possible, then returning to nominal operations at the first available opportunity. Use of CIWS, as evident from benefits categories identified in Table 4, helps the FAA achieve this user-defined workload management axiom, and does so at an exceptional rate that has increased significantly over the last two years (see Figure 9).

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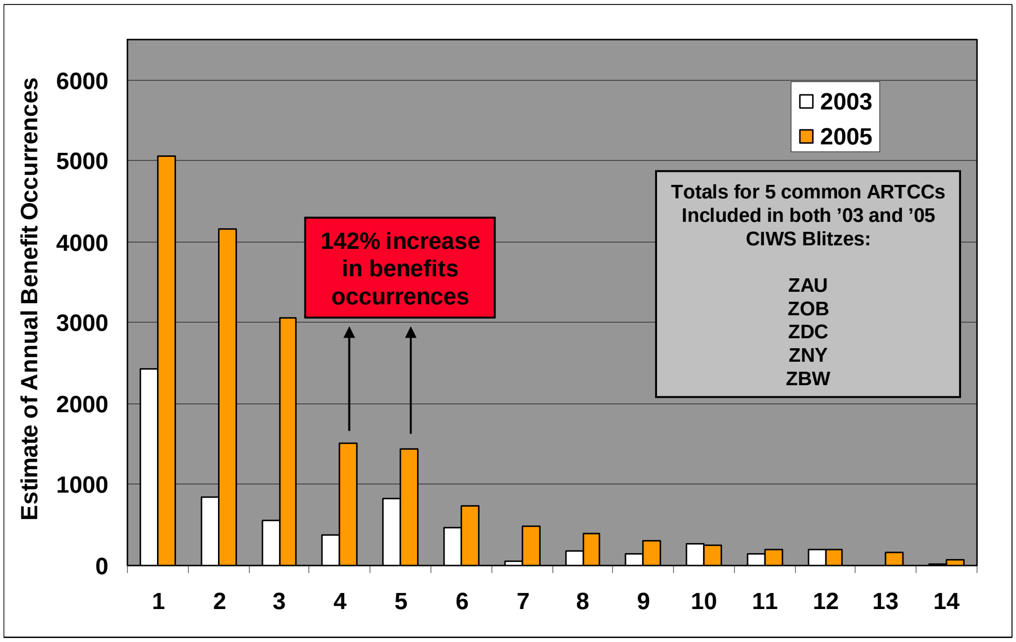
[10] Methodology for estimating annual "roll-ups" of CIWS benefits occurrences is described in Evans et al. (2005) and Robinson et al. (2004). Common, climatologically-adjusted ARTCC convective weather day metrics are used for 2003 and 2005 annual benefits roll-ups.



1 Situational awareness
2 Inter/Intra-facility coordination
3 Reduced workload
4 Proactive reroutes
5 Routes open longer
6 Improved ATA/DTA management
7 Reduced MIT restrictions
8 Improved GS program management
9 Close routes proactively
10 Directing pathfinders
11 Directing traffic through gaps
12 More SWAP departures
13 FAA facility staffing assistance
14 Improved GDP management

Figure 9. Estimate of annual occurrences of CIWS benefits realized at 5 ARTCCs in 2003 vs. 2005. Two specific en route benefit categories, "Proactive Reroutes" and "Keeping Established Routes Open Longer/Reopening Closed Routes Earlier", are highlighted to indicate the increased user frequency for realizing these significant delay and workload saving applications.

4. CONCLUSIONS

The 2005 CIWS benefits assessment is the first published attempt to identify ATC productivity contributions from a convective weather decision support tool. In this experiment, knowledgeable observers (in terms of CIWS products and ATC operations) visited ARTCCs during thunderstorm impacts to note real-time uses of CIWS products and the time required to devise, coordinate, implement, and iteratively monitor weather impact mitigation plans. Feedback from ATC experts at these FAA facilities was used to determine the expected workload associated with the mitigation plan development and execution process for similar convective weather events prior to CIWS availability. ARTCC TMU traffic management coordinators (TMC), the current, principle users of the deployed CIWS prototype and critical decision making position for achieving efficient airspace management, were the primary focus of CIWS productivity enhancement studies. Additional efforts were made to document TMU productivity contributions attributed to CIWS at ARTCCs with and without access to this decision support tool at sector Area Supervisor positions.

Field use observations of CIWS during 14 convective weather impact days demonstrated the following:

1. CIWS reduced the time required by the TMU to develop, coordinate, and implement weather impact mitigation plans by ~20-90 minutes per thunderstorm day.

2. CIWS saved most time in the plan development stage of the operational weather impact decision loop.

3. CIWS was utilized to help address FAA staffing decisions during convective weather impact events.

4. Use of CIWS facilitated higher quality weather impact mitigation plans that resulted in greater airspace capacity, more efficient routing strategies, and reduced air

traffic delay, *even at the cost of increased near-term TMU workload*. These plans, and resulting benefits, positively affected ATC operations at other FAA facilities, thus contributing to overall NAS efficiency and productivity improvements.

5. Availability of CIWS in ARTCC TMUs and sector Areas *significantly* increased ATC productivity and the frequency of realized operational effectiveness benefits. Specifically, when comparing use of CIWS at ARTCCs with and without CIWS displays in the Areas:

    a. Time savings for intrafacility coordination of traffic management initiatives at ZOB and ZDC (CIWS in TMU and Areas) was four times greater than the savings at ZAU, ZNY, and ZBW (CIWS in TMU only).

    b. Significant reductions in TMU workload at ZOB, ZDC, and ZMP (CIWS in TMU and Areas) were achieved when Area Supervisors used CIWS to avoid traffic management initiatives. Traffic management workload reductions from these CIWS-derived ARTCC Area decisions often extended to other ATC facilities.

    c. The frequency of realized CIWS en route delay reduction benefits was significantly higher at ARTCCs with CIWS displays in both the TMU *and* Areas.

    d. Areas Supervisors used CIWS to assist with controller staffing decisions during convective weather impacts.

6. The frequency of CIWS operational effectiveness benefits increased substantially from 2003 to 2005. With observed and forecasted near-term air traffic demand increases, it is encouraging that the rate of achieved CIWS benefits described in this paper demonstrates a similar trend.

In summary, findings from CIWS field use assessment experiments demonstrate that benefits from this convective weather decision support tool provide significant capacity and ATC productivity enhancement benefits that contribute to major NAS improvement goals identified by the FAA.

5. FUTURE WORK

Ongoing post-analysis investigations to extend the results presented in this paper will include:

- Examining observations of ZTL and ZJX (ARTCCs with no CIWS displays in 2005) TMU operations pertaining to convective weather impact management. These data will be used to confirm estimates from ATC experts as to how long impact mitigation plans would have taken had CIWS not been available.

- Detailed analyses of weather and aircraft flight track data in ARTCCs with and without access to CIWS, to independently confirm that CIWS resulted in fewer missed opportunities for mitigating the adverse impacts of convective weather.

- Investigations of potentially improved decisions and plan coordination time savings between TRACONs and ARTCC TMUs resulting from increased access to CIWS at both facilities.

- Use of sector/route capacity assessment models to quantify improvements in effective sector capacity attributed to CIWS-derived convective weather impact mitigation plan enhancements. Implications of these results in regards to both delay savings and ATC productivity improvements will be explored.

6. ACKNOWLEDGEMENTS

The following individuals participated as observers in the 2005 CIWS benefits assessment field campaign: Kim Calden, Brian Collins, Brad Crowe, Chris Gross, Richard Ferris, Tim Hancock (FAA), Diana Klingle-Wilson, Starr McGettigan (FAA), Jerry Mellon, and Darin Meyer. Special thanks to FAA personnel at ZAU, ZBW, ZDC, ZJX, ZMP, ZNY, ZOB, and ZTL for accommodating CIWS observers, taking time to explain in detail ATC operations at their facility, and taking part in numerous interviews, all during busy storm impact events. Elizabeth Ducot provided very helpful comments in her review of the paper and her efforts were much appreciated. Finally, we would like to note the contribution by Mike Klinker (formerly the Traffic Management Officer at ZDC; now at MITRE

CAASD) who suggested that CIWS displays be provided to the Area Supervisors as well as to the TMCs. His operational insight was clearly very helpful in helping the CIWS program provide better service to the NAS users.

7. REFERENCES

Allan, S., S. Gaddy, and J. Evans, 2001: Delay Causality and Reduction at the New York City Airports Using Terminal Weather Information Systems, MIT Lincoln Laboratory Project Report ATC-291.

Davison, H and R.J. Hansman, 2001: Identification of Inter-facility Communication and Coordination Issues in the U. S. Air Traffic Control System, MIT International Center for Air Transportation Paper 2001-11-21 (available at http://icat-server.mit.edu/Library/)

Dupree, W., M. Robinson, R. DeLaura, and P. Bieringer, 2006: Echo Tops Forecast Generation and Evaluation of Air Traffic Flow Management Needs in the National Airspace System, 12th Conf. on Aviation, Range, and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Evans, J., M. Robinson, and S. Allan, 2005: Quantifying Convective Delay Reduction Benefits for Weather/ATM Systems, 6th USA/Europe Seminar on Air Traffic Management Research and Development, ATM-2005, Baltimore, MD, http://atmseminar.eurocontrol.fr/.

Evans, J., 1997: Safely Reducing Delays Due to Adverse Terminal Weather, *Modeling and Simulation in Air Traffic Management*, Lucio Bianco, Paolo Dell 'Olmo, and Amedeo R. Odoni, Eds., New York: Springer-Verlag, 185-202.

FAA Office of Aviation Policy and Plans, 2005: FAA aerospace forecasts fiscal years 2005-2016, http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2005-2016/

Klingle-Wilson, D. and J. Evans, 2005: Description of the Corridor Integrated Weather System (CIWS) Weather Products, MIT Lincoln Laboratory Project Report ATC-317.

Robinson, M., J. Evans, B. Crowe, D. Klingle-Wilson and S. Allan, 2004: CIWS Operational Benefits 2002-3: Initial Estimates of Convective Weather Delay Reduction, MIT Lincoln Laboratory Project Report ATC-313.

Robinson, M., J. Evans, and B. Crowe, 2002: En Route Weather Depiction Benefits of the NEXRAD Vertically Integrated Liquid Water Product Utilized by the Corridor Integrated Weather System, 10th Conf. on Aviation, Range, and Aerospace Meteorology, Portland, OR, Amer. Meteor. Soc.