3.23 **EXTENDING THE INTEGRATED TERMINAL WEATHER SYSTEM (ITWS) TO ADDRESS URGENT TERMINAL AREA WEATHER NEEDS***

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1. INTRODUCTION

Major terminals and the surrounding en route airspace are critical elements of the US National Air System (NAS). A large fraction of the US population lives near these terminals, and the bulk of the hub connecting operations are at these airports as well. Adverse weather in these terminal areas and surrounding en route airspace is a major safety concern for the NAS as well as causing a large fraction of all US aviation delays.

The principal weather decision support tool for these terminals is the Integrated Terminal Weather System (ITWS) which commenced full-scale development by the FAA in 1995, with first articles to be deployed shortly. In this paper, we discuss how the initial ITWS operational capability needs to be extended to address performance problems identified in operational use and to meet the many new user needs that have developed in the past five years.

The paper proceeds as follows. In Section 2, we provide some necessary background on the ITWS operational capability, followed by a discussion of new capabilities to meet urgent user needs. Section 3 discusses refinements to the initial capability to address problems/issues that have been identified based on five years of operational use of ITWS products from ITWS demonstration systems at eight major airports. Next, we consider extending planned ITWS coverage to other major terminals. The final section summarizes the paper's results and suggests additional studies.

2. BACKGROUND

Over the past 15 years, the FAA has deployed or is deploying highly capable stand-alone wind shear detection systems [Terminal Doppler Weather Radar (TDWR), enhanced Low Level Wind Shear Alert System (LLWAS) and the Weather System Processor (WSP)]. However, there are urgent, critical aviation weather information needs that require real-time data fusion from multiple sensors:

- Predictions of wind shear and storm movement
- Gridded winds information to provide time of flight estimates for traffic merging and sequencing
- Information on storm severity (e.g., lightning, mesocyclones, hail)
- Robust handling of individual sensor deficiencies (e.g., attenuation, false alarms, limited coverage, limitations associated with radial velocity data, etc.)

The Integrated Terminal Weather System (ITWS) program commenced in 1991 to address the above needs. Figure 1 shows the sensors used by the initial capabilities of the ITWS and by the principal users of the ITWS products.

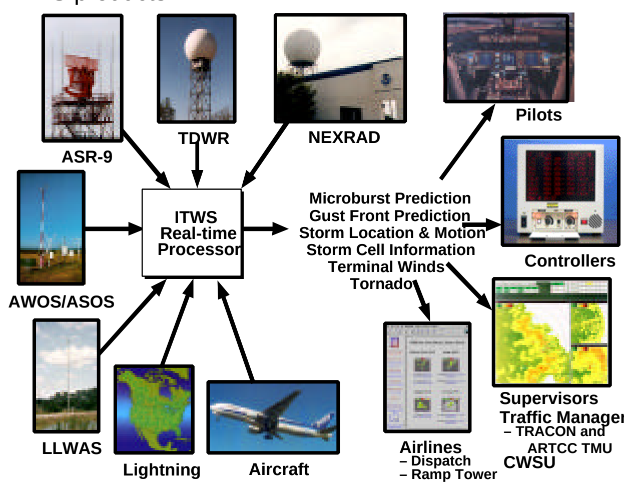

Figure 1. Integrated Terminal Weather System.

Demonstrations of real-time data fusion for operational evaluation started in 1993, and a relatively complete set of initial products were formally evaluated in real time by air traffic and airline users at Memphis and Orlando in 1994. Additional demonstrations started at Dallas in 1995 and New York in 1998. These ITWS demonstrations extended the historic FAA approach to terminal weather decision support in several directions:

1. Real-time, fully automatic integration of data from FAA, National Weather Service, and airline sensors,
2. Product distribution to towers, TRACONs and en route control centers (ARTCC), with products from both domains (terminal and en route) available to all users,
3. Real-time displays (with the same capability as the FAA displays) at airline operations centers to facilitate coordination between the FAA traffic management units and airlines dispatchers as well as helping dispatchers achieve a higher level of safety.[1]

The new product capabilities and wide-reaching product dissemination demonstrated in the 1994-1995 ITWS demonstrations were extremely successful

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[1] This started in 1994, well before the CDM program.

operationally. It was discovered that major reductions in convective weather delays could be accomplished while safety was being significantly enhanced. For example, improved decisions by the en route traffic management units were found to be a key factor in reducing delays. Also, it was learned that many of the delay problems attributed to the airports in fact arose from weather in the transitional en route airspace surrounding the terminal area. Table 1 summarizes the initial ITWS operational benefits.

Table 1.
National Implementation Benefits from Improved Air Traffic Decision Making with ITWS Initial Products

User Identified Payoff Area	Latest Estimate* ($M/year)
Higher effective airport capacity during thunderstorm	18
Anticipated arrival and departure area closure/reopening	134
Anticipated runway impacts and shifts	94
Better terminal area traffic pattern	10
Optimizing traffic flow	125
Improved merging and sequencing using terminal winds	71
Total	452

* Includes terminal winds benefits and improved climatological estimates of convective impacts on terminal areas.

The FAA commenced full-scale development (FSD) of the ITWS in 1995. The scientific knowledge encompassed in the demonstration product generation algorithms was formally documented. An air traffic control users group, with participants from the demonstration sites, reviewed and extended the display concepts from the 1994 demonstration to create a refined display concept which was formally documented.

These specifications were the basis for a competitive procurement which started in 1995 and culminated in the selection of the Raytheon Company as the FSD contractor. The FSD is actively underway, with deliveries of four first articles expected in late 2000. Deployment to 34 terminal areas covering 45 major airports should be complete by 2004. The airports scheduled to receive an ITWS are those which have a TDWR.[2] When completed, the ITWS deployment will include all of “pacing airports” east of (and including) Las Vegas, NV.

3. URGENT NEEDS FOR WEATHER DECISION SUPPORT PRODUCTS

In the five years since the ITWS initial capabilities were defined, major new terminal/transitional en route weather decision support needs have emerged:

- Air passenger and cargo carrier accidents have highlighted the need for enhancements in the ITWS convective weather forecast lead time and product distribution,
- Dramatic increases in NAS operations and weather related delays have highlighted the critical importance of traffic flow management decision support, and
- A new era in FAA/airline partnership in air traffic flow decision making as exemplified by the Collaborative Decision Making (CDM) program.

Let us now discuss representative examples of these new weather decision support needs.

3.1 Convective Weather Information

Convective weather accidents involving air carrier and cargo carriers in 1997 and 1999 have highlighted the need for improved information on severe and rapidly changing weather near airports, with rapid dissemination of the information to pilots and airline dispatch. Of particular interest here is information that needs to be provided to pilots and airline dispatchers. Historically, the FAA approach had been to provide warnings from the tower controllers. However, a recent study of pilot decision making in and around Dallas-Ft. Worth International Airport (DFW) has shown that some pilots will fly through very high reflectivity storms when within about 10 miles of the runway (Rhoda and Pawlak, 1999), even though they will deviate around similar cells when encountered at greater distances from the airport.

The causes for these differences in pilot decision making are fairly complex and not well understood at this time. One contributing factor is the very intense workload on pilots when in the final stages of approach which makes it difficult to consult the airborne weather radar frequently. Another important factor is the ground clutter contamination of most airborne weather radar displays when at low altitudes in terminal airspace.

Based on analysis of the information available to pilots, air traffic controllers, and airline dispatchers, we suggest that providing predictive information on the weather that will exist in the area near the airport when the pilot is 20-40 minutes away from the airport should be an effective approach to reducing unwanted penetrations of high-reflectivity storms [see Evans, (2000) for a discussion of the rationale for this suggestion].

The initial capability ITWS provides only 20-minute extrapolated storm positions using a cell tracking approach. Since 20 minutes is a large fraction of the lifetime of an “average” thunderstorm cell, it is not possible to increase the prediction time meaningfully for that product. Rather, one must use a forecasting approach that considers cell growth and decay, such as the Terminal Convective Weather Forecast (TCWF) (Wolfson, 1999) depicted in figure 2. Key attributes of this product include frequent updates (every six minutes), high spatial resolution (1-2 km), high resolution in the forecast times (every 10 minutes), and self scoring so that the user has a quantitative measure of the product’s accuracy.

[2] The TDWR deployment was driven by wind shear exposure index [= (the frequency of microburst and gust front induced wind shear at an airport) (enplanements at the airport)] (Rovinsky, 1994).

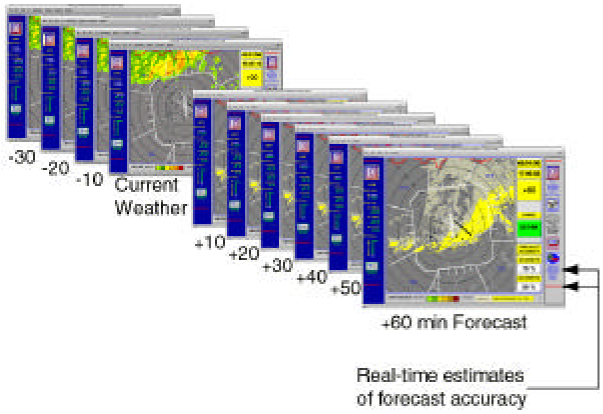

Figure 2. Prototype display concept for Terminal Convective Weather Forecast. The two shades of dark and light grey indicate moderate and high probability of "level 3" weather (typically heavy rain). The continuous forecast loops from the past 30 minutes to the forecast time (30 or 60 min in the future). Various time subsets can be looped. Users can also select a stationary display of any forecast time. The accuracy of the forecast is continually updated in real time, based on pixel overlap criteria, and displayed as soon as it is available.

Although the discussion above has emphasized the safety elements of the TCWF product, it should also be noted that the TCWF product is a key tool for more effective traffic flow management by "filling the gap" between the IOC ITWS 20-minute forecasts and the 2-hour Collaborative Convective Forecast Product (CCFP) (http://ftb1.kc.noaa.gov/ccfp/). The TCWF product has been enthusiastically received by operational FAA and airline decision makers at all four ITWS demonstration sites in 1999-2000. In particular, the TCWF has been very effective at Dallas and Orlando (Sunderlin and Paull, 2000) in helping traffic management units:

- Pre-plan severe weather avoidance procedures, avoiding ground delays during coordination period,
- Return aircraft back to normal routes sooner, avoiding unnecessary re-routes,
- Avoid premature reaction to the beginning of closures so that more planes avoid airborne holds/diversions,
- Better position airborne holds to the backside of weather so they can be landed quickly after the weather impact ends, and
- Re-route arrivals further from terminal airspace, avoiding airborne holds and deviations at lower altitudes.
- A detailed quantitative benefits analysis of the TCWF by MCR Federal, Inc. is underway. Very preliminary results of the MCR study suggest that the TCWF would increase the IOC ITWS convective weather delay benefits shown in table 1 by 50-75%.

The technical risk associated with implementing the TCWF is quite low. The original LISP implementation for TCWF has been reimplemented in C/C++ code that is similar to the C/C++ code already utilized in the ITWS. A concept for incorporating the TCWF display screens into the overall ITWS situation display user interface has been developed and is being utilized at the ITWS demonstration sites.

3.2 Providing Products to Airlines

The ITWS demonstration systems have provided products to airlines via two mechanisms:

1. Dedicated color situation displays (SDs) (identical to the FAA user SDs) via dedicated phone lines to the demonstration systems, and
2. Images of the SDs that can be displayed by conventional web browsers, with the products being provided by servers on the Internet and the CDMnet [(see figure 2 in (Maloney, 2000)].

The airline experimental use of these products has shown that important safety and delay reduction benefits to the airline passengers are achieved by this common situational awareness. Airline dispatchers have routinely advised their pilots of terminal and transitional en route weather hazards as well as being able to make much more effective decisions on diversions and hub operations. A more detailed discussion of these uses is provided in (Evans, 2000).

The production ITWS is not designed to drive displays at a large number of airline operations centers nor does it provide web browser viewable images. The ITWS currently has a NADIN2 data port that provides the products in a numerical format similar to the format by which products go from the ITWS product generator to the SDs.

In view of the safety and delay reduction benefits that can be obtained by providing airline dispatch with timely, convenient access to the ITWS products, work is underway to provide:

- The products in numerical format that could be used to create SD-like graphical depictions of the ITWS products in the various airline dispatch decision support systems, and
- Web browser viewable images [similar to those described in (Maloney, 2000)]

on a CDMnet server operated by the Volpe Transportation Center. An ad hoc group of potential airline users operating under the auspices of the Air Transport Association has been generating functional requirements for the product content and update rates.

Implementation of the airline product distribution capability should be relatively straightforward using current technology, albeit it should be noted that providing TRACON-scale products at the high spatial resolution (1 km) and update rates (once per minute) for some 44 airports to a large number of users will be a significant load for the server and CDMnet communications capabilities. There probably will also be a need for an ITWS product server on the Internet which will have additional issues (e.g., access control, loading, and security) that may not be as important on CDMnet.

4. REFINEMENTS TO THE INITIAL ITWS CAPABILITIES

The initial capability ITWS has been used at eight airports for some six years since the initial capability product generation algorithms were specified. These operations were conducted using real-time systems that had a number of diagnostic displays that provided detailed information on the data from the various sensors as well displaying the results of intermediate calculations in creating the products. The demonstration system operators are experienced radar meteorologists (many with graduate degrees) that identify sensor and product generation problems that need to be addressed. In this section, we discuss some of the principal problems identified through the ITWS demonstration system operations.

4.1 Sensor Problem Identification and Compensation

The ITWS product quality is closely tied to the quality of the products from the various sensors. The IOC ITWS is in many cases able to compensate for errors in various products by comparisons with data from other sensors. For example, AP clutter contamination on ASR-9 weather channel data is edited by comparing the ASR-9 data with corresponding data from NEXRAD and TDWR. Also, where there is multiple coverage from ASR-9s, the mosaic rules used frequently can compensate for individual ASR-9 problems such as attenuation by heavy precipitation and unedited AP.

However, the ongoing testing of the ITWS with the demonstration systems has identified a number of individual sensor problems that need to be explicitly addressed. Examples of these include:

1. Excessive attenuation due to rain on the TDWR radome.
   The TDWR precipitation product is uniquely useful for characterizing the precipitation reaching the runway. This information is important both for summer convective weather and as an aid to deicing decision making in snow and freezing precipitation. However, C-band TDWR is much more susceptible to rain attenuation than are the S-band NEXRAD and ASR-9. The TDWR has an algorithm that flags the TDWR precipitation data when there is excessive loss on the path from the radome to the weather target, but heavy rain on the radome can cause very large losses (over 20 dB has been observed on several occasions) that are not flagged by the TDWR itself. Figure 3 shows an example of this observed in Memphis. Since the ITWS has access to reflectivity data over the TDWR from NEXRAD and ASR-9s, it is quite straightforward to identify heavy radome rain situations and take appropriate measures (e.g., flag the TDWR precipitation product and lower certain thresholds that are based on the TDWR reflectivity values).

2. Detection of LLWAS false alarms due to sensor failures.
   At eight major airports, the microburst detections generated from the TDWR data are merged with microburst alerts provided by the enhanced LLWAS at those airports. The current merging rule issues an integrated microburst alert if either the TDWR or the LLWAS data warrant a microburst alert. Since both systems virtually never issue a false microburst alert when operating correctly, this merging rule seemed very reasonable. Analysis of unexpected (e.g., clear air) microburst alerts at the ITWS demonstration sites and at other locations has shown that there are peculiar LLWAS failure modes (e.g., anemometer over speeding and cables draped over the LLWAS anemometers) that are very hard to detect from the LLWAS data alone. Since the ITWS has access to other data (e.g., radar reflectivity above the LLWAS sensors), it should be possible to identify and flag cases where the LLWAS generated alerts are inconsistent with the overall meteorological situation.

3. Detection of problems with the ASR-9 weather channel.

The ASR-9 weather channel is the principal source of storm location information for terminal controllers. False weather returns due to anomalous propagation (AP) have long been an important operational limitation which is addressed by the initial capability ITWS. However, testing at the New York ITWS site has shown that there are a number of other ASR-9 performance problems which need to be address (Crowe, et al., 1999). For example, the ASR-9 automatically switches between linear and circular polarization to detect aircraft in heavy precipitation. At New York, it was learned that this switch can malfunction such that it is in a state midway between the two polarization states, which results in heavy signal attenuation. Since this attenuation adversely impacts the performance of the ASR-9 aircraft detecting channel as well as the weather data, it is clearly important that this anomalous condition be flagged rapidly. Algorithms are being developed to detect this condition by use of time continuity tests.

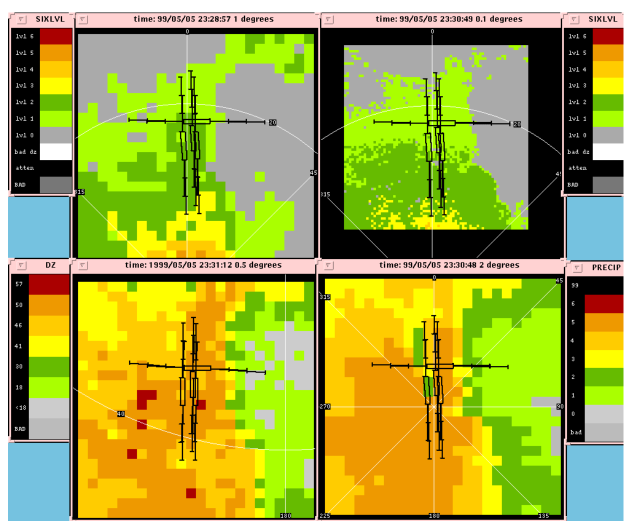

Figure 3. Illustration of TDWR attenuation due to heavy rain on the radome. Top left and right are TDWR data from 5 May 1999 in Memphis. Bottom left and right panels are NEXRAD and ASR-9 precipitation at times close to the TDWR measurement times. Note that NEXRAD and ASR-9 suggest VIP level 4-5, whereas TDWR indicates VIP level 1 at the airport.

4.2 Deficiencies in the Product Generation Algorithms

ITWS is one of the most sophisticated, fully-automated weather decision support systems in operation in the world. Achieving reliable automatic product generation for terminal weather phenomena at 44 major airports is a very challenging task. Hence, it is not surprising that some needed refinements have been identified through demonstration system testing. In this section, we present representative examples of the algorithm issues currently under investigation.

Detection and Prediction of Dry Microbursts

Although the ITWS demonstration systems have detected thousands of microbursts since 1994, virtually all of these were “wet microbursts” (i.e., the ground is wetted during the microburst outflow). To reduce false alarms, the ITWS looks at the reflectivity aloft [specifically the vertically integrated liquid water content (VIL)] to validate microburst alerts.

However, it is well known that there exist situations where very dry sub cloud environments can yield microbursts with very low radar reflectivity aloft (Fujita, 1985). In such cases, a valid microburst detection might be invalidated by the VIL threshold test. Simply reducing the VIL threshold for all storms would result in excessive false alarms in many cases.

The preferred approach is to reduce the VIL threshold selectively when there are environmental conditions where a dry microburst may occur. Fortunately, the ITWS does generate a real-time environmental sounding that can be used to determine when a microburst may occur. However, this capability has not yet been exercised on appropriate data sets from locations (e.g., western airports such as Denver and Salt Lake City) where dry microbursts are relatively common.

Mosaicking of Information on Gust Fronts Approaching Major Airports

At eight of the ITWS sites, there are multiple TDWRs within the terminal area. Many of these sites (e.g., ORD, DFW, EWR, IAD) have some of the highest operations rates in the world. Highly capable prediction of runway shifts at these airports is an extremely important ITWS function. Currently, ITWS detects and predicts gust fronts for an airport using only the TDWR allocated to that airport. Testing at DFW has shown that there would be significant performance improvements in gust front detection and prediction at the major airport if the gust front information from all of the TDWRs near that airport were combined. However, simply combining gust front detections from the individual radars is not adequate. Rather, it will be necessary to combine “evidence” from the various radars before thresholding to yield detections.

5. EXTENDING ITWS SERVICE TO MAJOR WEST COAST AIRPORTS

None of the major west coast airports is scheduled to receive an ITWS even though a number of these airports have significant delays due to adverse weather. This is because the airports scheduled to receive an ITWS were those that had already been scheduled to receive a TDWR and, none of the west coast airports have a TDWR. It should be noted that the FAA wind shear deployment study (Rovinsky, et al., 1996) leading to TDWR deployments only considered protection against microburst and gust front wind shear arising from thunderstorms. No consideration was given to other types of wind shear and terminal weather hazards, nor was any attention given to the use of terminal weather sensors to improve aircraft merging and sequencing.

Winter weather phenomena similar to those at New York are principal causes of delays at major west coast airports such as SFO and SEA. The ITWS operations at New York have demonstrated that ITWS substantially reduces delays during coastal storms characterized by low ceilings and visibility with extreme vertical wind shears aloft. Additionally, the TCWF has been shown to be quite skillful at predicting the onset and cessation of low visibility associated with rain and snow in winter storms.

The terminal winds information that would be provided by an ITWS would be important for the operation of the Center TRACON Automation Systems (CTAS) scheduled for delivery on the west coast. Providing adequate winds information during west coast winter storms would be challenging since these airports do not have a TDWR and the west coast NEXRADs are poorly located to measure airport winds. However, there are a large number of wind profilers (for air pollution studies) which could be used in addition to the aircraft reports. An algorithm to use profiler data in ITWS has been demonstrated (Evans, et al., 1999) but is not part of the initial capability system.

Additionally, there are a number of site-specific west coast terminal area weather hazards which could best be addressed by an ITWS (Evans, et al., 1999).

6. INFRASTRUCTURE FOR RESEARCH ON TERMINAL WEATHER DECISION SUPPORT

Based on the past experience with the TDWR and the NEXRAD, we anticipate ongoing site specific research will need to be conducted on the initial capability ITWS algorithms and data quality problems as the initial ITWS deployment proceeds. This is because budget constraints prevented key operational areas such as the upper midwest and the High Plains from having extended ITWS demonstration system operations such as have been conducted in the southeast, southwest, and northeast corridor. Additionally, there are many candidate advanced terminal information products in various levels of maturity that will need to be demonstrated and refined at the ITWS terminal areas.

The TDWR program has benefited significantly from having a wideband data port that could be used to evaluate and extend the TDWR capability. For example, the Machine Intelligent Gust Front Algorithm (MIGFA) has been deployed on an outboard workstation. The ITWS system uses the TDWR wideband data port to access the TDWR base data.

Unfortunately, the initial capability ITWS does not have a real time port capable of providing the local sensor data and the national data used by that ITWS to an external user. The ITWS recorder can record only 6 hours of sensor data before requiring a media change.

Thus, if research needs to be conducted to resolve an important ITWS site specific problem and/or to demonstrate an advanced terminal weather prediction problem, it will be very costly and logistically difficult to acquire the sensor data needed to resolve the problem.

Implementation of such wideband sensor data port for the ITWS would be quite straightforward and yield very high long term benefits to the operation of major terminal areas.

7. SUMMARY

The ITWS is a critical element of the FAA program to provide improved safety and efficiency in the NAS. The 2000-2004 deployment of the initial capability ITWS will make a major contribution to the achievement of this FAA goal.

It is generally agreed that the steadily increasing volume of air carrier traffic in the NAS, together with the difficulties in increasing terminal capacity by adding runways, has the potential to cause unacceptable delays in the NAS. These significant delays will very likely appear first during adverse terminal weather. New automation and collaborative decision making systems [e.g., Center-TRACON Automation System (CTAS), User Request Evaluation Tool (URET), Collaborative Routine Coordination Tool (CRCT), CDM, En Route Descent Advisor (E/DA) and Free Flight Phase 2] will require much better terminal weather information than was the case when the ITWS IOC capability was defined.

In this paper, we have discussed some representative enhancements to the ITWS that could substantially improve the ability of the ITWS to meet the rapidly increasing NAS needs for better aviation weather decision support. All of the enhancements discussed in this paper are at a relatively advanced state of development such that they could be added to the production ITWS over the next two years.

There are at least another 20 important enhancements (e.g., snowfall information, ceiling and visibility predictions) that also could be provided by ITWS in the relatively near future which were not discussed here due to space constraints (see Souders and Showalter, 2000). This large number of candidate enhancements illustrates the importance of an ongoing program to update the ITWS to meet the overall NAS operational needs.

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