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14.8 DEVELOPING A WEATHER SYSTEM ARCHITECTURE AND WEATHER PRODUCT MIX THAT CAN EFFECTIVELY ADDRESS THE EXPECTED CAPACITY CRISIS AT MAJOR TERMINALS: INSIGHTS FROM OPERATIONAL USAGE OF THE INTEGRATED TERMINAL WEATHER SYSTEM * †

James E. Evans
Massachusetts Institute of Technology
Lincoln Laboratory
244 Wood Street
Lexington, MA 02420-9185

1. THE CHALLENGE

A number of major terminal areas already experience very high delays during adverse terminal weather, and weather currently accounts for approximately 70-75% of all delays greater than 15 minutes in the US National Airspace System (NAS) [1]. The latest FAA Aviation Capacity Enhancement plan [1] projects 20-50% increases in operations and 50-90% increases in enplanements at major airports by 2006. If substantial improvements are not made in the NAS's ability to handle adverse weather at major terminals, one can anticipate overall system weather-induced delays going up much faster than the projected increase in operations. This is because:

1. Airports which have insufficient capacity during Instrument Meteorological Conditions (IMC) weather typically have much greater delays for a given operations rate than do airports which have sufficient IMC weather capacity [2],
2. The number of airports with insufficient capacity during IMC weather will increase as the operations increase [1], and
3. The delays that arise at airports with insufficient capacity during adverse weather will increase dramatically as the number of operations increase at those airports (see appendix 1 below and [2]).

The current weather decision support system architecture has not explicitly addressed the problems of improving the effective capacity of major terminal areas during adverse weather. Moreover, there is a paucity of published results on weather delay causality and "avoidability" based on detailed experimental data to guide refinements to the weather system architecture.

It is essential that an intensive data gathering and analysis effort commence now to better understand how the adverse weather capacity of major terminal areas can be improved by 2006. As a start to this effort, this paper describes preliminary results of analyzing Integrated Terminal Weather System (ITWS) operations at Dallas and Orlando. Based on these results, we make some recommendations for changes to aviation system architecture to address the challenging demands of the next century.

2. RESULTS OF THE ITWS TESTING

Over the past four years, tests have been conducted at four major airports using a functional prototype Integrated Terminal Weather System (ITWS). The ITWS acquires data from the various FAA and National Weather Service (NWS) sensors and combine these with products from other systems [e.g., NEXRAD and the NMC Rapid Update Cycle (RUC)] to generate a new set of safety and planning/capacity improvement weather products for the terminal area and adjacent en route airspace ([3] describes the ITWS product generation algorithms). Operational users of the ITWS products to date include pilots, controllers, TRACON supervisors, terminal and en route traffic flow managers, airlines, Flight Service Stations and the Center Tracon Advisory System (CTAS) terminal automation system.

A key focus of the ITWS functional prototype operational usage has been the assessment of its capability to achieve significant delay reduction and the identification of "missed opportunities" wherein further delay reduction may be possible.

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[†] Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Air Force. Corresponding author address: James E. Evans, Massachusetts Institute of Technology, Lincoln Laboratory, 244 Wood Street, Lexington, Massachusetts 02420-9185; e-mail: jime@ll.mit.edu

(a) Dallas-Ft. Worth Insights

Dallas-Ft. Worth airport provides insights into "megaterminal" operations in the next century. DFW now has the highest number of operations in the world and is the major test site for the CTAS. The ITWS system at DFW integrates two TDWRs, a NEXRAD, four ASR9s, and an enhanced LLWAS.

Two aspects of the DFW ITWS product suite are particularly germane to this paper:

(1) The ASR-9 mosaic provides a 1 km spatial resolution precipitation map that updates every 30 seconds and extends 40 to 80 km beyond the terminal area boundary into the en route airspace. The extrapolated storm leading edge positions for 10-and 20-minute prediction times are updated every two minutes over the same region. When there is rapid storm development, this product quickly detects the new growth and shows its future locations so that Air Traffic can proactively route traffic to weather-free regions.

(2) A high spatial resolution (2 km horizontally, 400 m vertically) wind grid that is updated every five minutes via triple Doppler analysis.

The DFW product suite is provided to some four airport towers (three at DFW, one at Love), to traffic coordinators at the terminal radar room (TRACON) and en route center, to the Center Weather Service Unit (CWSU), and to the TRACON supervisor as well as to flight dispatch for all of the principal airlines operating in the terminal area (American, Delta, Southwest).

Analysis of convective weather events at DFW has shown the critical importance of the "transitional" en route airspace that surrounds the terminal airspace and the "gates" through which aircraft pass from en route airspace to terminal airspace (and vice versa). Figure 1 shows 15 minutes of arrival plane tracks at DFW for a weather case where convective weather unexpectedly prevented use of the northeast gate and in which there was scattered convective weather in the terminal area. We see that aircraft had to make a major detour on the north side of the terminal area to get to the northwest gate (not shown is a holding pattern yet further north where the paths are clipped at the top of the figure). Delays associated with such a major detour can easily exceed 20 minutes. By contrast, the delays associated with the much shorter detour paths in the terminal area would be on the order of 1-3 minutes. At DFW, we have noted a number of occasions where the en route traffic do not take advantage of opportunities to "thread" their way through storms in situations where, on the terminal side at similar ranges and altitudes, aircraft are being vectored around storms. This difference is very important if the result is that "gate" is effectively closed.

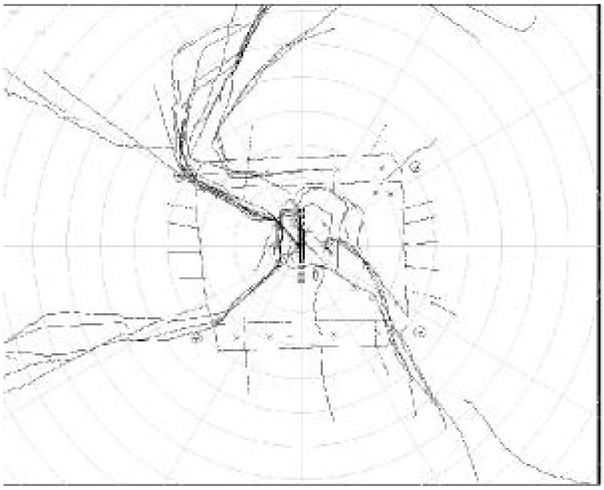

Figure 1. DFW flight tracks over a 15-minute period for a 1995 convective event.

Another key insight gained at DFW in the 1995-1996 time frame was the importance of providing high quality terminal winds information that can enable controllers to optimize the merging and sequencing of aircraft when there are abnormal (e.g., highly sheared) winds aloft during IMC conditions that yield an effective capacity less than scheduled arrivals [4]. In such cases, seemingly small increases (e.g., 5-10 %) in the effective capacity of a runway can yield delay reductions of 30-40 % (see [4] and appendix 1).

(b) Orlando insights

The ITWS at Orlando has only one ASR9 and one TDWR and about one-third of the traffic at Dallas, with a similar number of runways. However, the "transitional" en route airspace at Orlando is much more constrained than that at Dallas. The bulk of the Orlando traffic is to and from the north. The en route airspace to the north is often restricted dramatically due to the military special -use areas (SUA) on both the east and west coasts of Florida (e.g., at one point, the en route traffic corridor can be as small as 32 nmi wide). As a result, much of the delay at Orlando arises from flow restrictions in the en route airspace due to convective weather.

To illustrate, Figure 2 shows plane tracks for a rapidly moving (45-50 knots) storm complex in Florida in February 1998. Track positions for the last two minutes for each aircraft in en route and terminal airspace are shown along with weather reflectivity in the 6 NWS VIP levels. The storms on this occasion moved and evolved quite rapidly, with major differences in the weather coverage noticeable at many times between the ASR9 1 km spatial resolution precipitation updating every 30 seconds versus the NEXRAD 4 km spatial resolution precipitation updating once every 6 minutes. We see from the curved tracks that aircraft to the northwest of the Orlando terminal area are in a holding pattern because aircraft were reluctant to penetrate the weather that had moved into that area. One of these aircraft in a holding pattern was struck by lightning. The severe weather was found in both the en route airspace and the terminal, but nearly all of the delays over 15 minutes associated with this incident occurred in the transitional en route airspace as opposed to the terminal area.

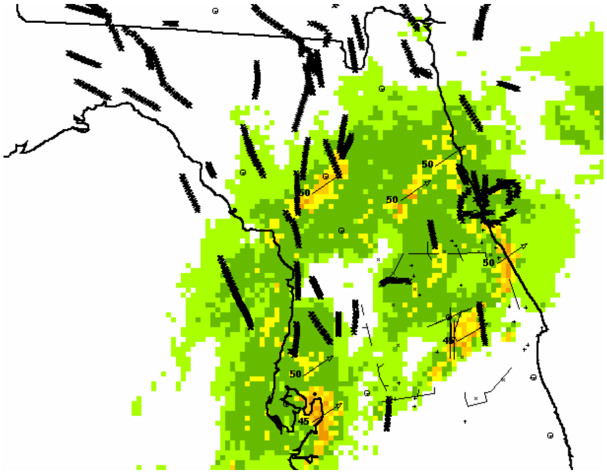

Figure 2. Orlando flight tracks over 2 minute period for a 1998 storm.

3. SYSTEM ARCHITECTURE CHANGES TO ADDRESS THE ISSUES EXPOSED IN THE ITWS TESTING

Based on the ITWS operational experience at several major terminals, we recommend some significant changes to the US weather system architecture and product mix:

(1) The "transitional" en route airspace that surrounds major terminals (e.g., out to approximately 100 nm from the terminal boundary) needs to be treated as a very different entity in terms of weather products and display capability than the "overflight" portion of en route airspace. In a number of very important terminals, this airspace has a high density of terminal and enroute sensors which can be effectively mosaiced to provide a much higher quality of weather information than is possible for en route airspace well away from major terminals.

This point is illustrated in Figure 3 which shows the coverage of an ASR9 mosaic that could be created for northern Florida using the software and displays already in operation at New York. By creating such a mosaic and providing the data to en route traffic management and area supervisors[1], it would be possible to dramatically improve the ability of the Jacksonville en route facility to address the extremely rapid convective storm evolution that currently makes effective traffic management in this region so difficult. A similar mosaic could be created for the Northeast Corridor from Washington to Boston where en route airspace is constrained by SUA and the many major terminals in the corridor.

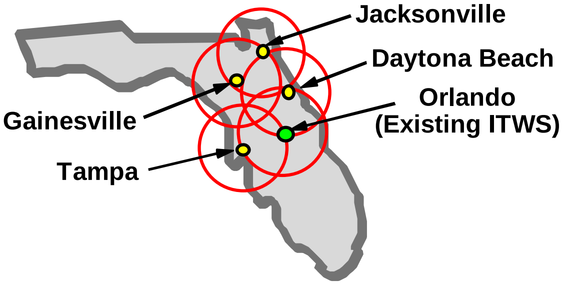

Figure 3. Red circles show the region covered by ASR-9 radars in northern Florida. A single map, which updated every 30 seconds, could be created and made available through the Orlando (MCO) ITWS.

(2) Major terminals need to be treated as a set of "special cases" where special weather sensors may be deployed to meet the specific site's meteorological and operational needs. For example, atmospheric profilers and/or privately operated Doppler weather radars could be of significant use in a number of locations in achieving the aircraft merging and sequencing benefits identified at DFW. The ITWS architecture needs to be extended to deal with these "special cases" in a cost-effective manner. A detailed study is underway of additional sensors that are or would need to be available at the high-delay major west coast airports if an ITWS were to be deployed at those airports.

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[1] such a limited coverage mosaic product could be provided as an adjunct to the planned WARP 4 km mosaic product. Both WARP displays and the en route controller displays are color bit mapped displays that can easily update every 30 seconds.

Special cooperative agreements between the FAA and the airport authorities (as has been accomplished at New York City) may be necessary to develop a weather information system which will address the significantly different challenges posed by the relatively small number of major terminals that cause most of the delays.

(3) Weather product research and development needs to include the possibility of deploying special sensors to address the unique problems of certain en route transitional airspace and terminal areas as an important aspect of product development rather than being restricted by today's implicit assumption that all of terminal areas will have the same minimal sensor mix. These special sensors would need to be justified on a cost/benefit basis.

In closing, we would again emphasize that the traffic increases expected in the year 2006 could result in extremely large increases in weather-induced delays if corrective actions are not undertaken in the next six years. The very limited study carried out here has identified some near-term options for improving on the current system architecture. It is essential that a much more intensive data-gathering and analysis effort commence now to better understand how the effective capacity of major terminal areas during adverse weather can be improved by 2006.

4. REFERENCES

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3. "*Special Issue on Air Traffic Control*" Massachusetts Institute of Technology, Lincoln Laboratory Journal, vol. 7, no. 2, fall 1994.
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APPENDIX 1

Why operations rate increases at capacity constrained airports yield disproportionate increases in weather delays

At terminals where the capacity during adverse weather is less than the demand, delays arise from the development of queues of aircraft waiting to use the facility resources. Weather situations that result in queues include:

1. instrument meteorological conditions (IMC) and/or surface winds which prevent the use of some runways or cause aircraft separations to increase

2. adverse winds aloft which make aircraft merging and sequencing less efficient,

3. loss of runway capacity for a period due to convective storms or runway changes, or

4. reduced capacity of en route airways [e.g., increased miles-in-trail (MIT) spacings] due to convective weather.

Assuming constant demand and terminal capacities, the accumulated delay for all of the aircraft involved in the queue can easily be shown to be:

$$\Sigma \text{ delays} = 0.5\, T^2 (D - C_W)\,(C_V - C_W)/(C_V - D) \quad \mathbf{(1)}$$

where T is the duration of the restricted period of aircraft operations, D is the demand, C_W is the capacity during the adverse weather and C_V is the benign weather capacity. The term $(C_V\text{-}D)$ is the fair weather excess capacity while $(D\text{-}C_W)$ is the excess demand during adverse weather. When the operations rate (i.e., D) at such a terminal facility increases with no corresponding increase in the capacities, the excess demand increases <u>and</u> the fair weather excess capacity decreases. Since these appear as nonlinear terms in equation (1), the overall percent increase in delays is much greater than the percent increase in demand:

$$\text{fractional increase in delays} = \{[\,D / (D - C_W)] +$$

$$[\,D / (C_V - D)]\}\ \{\text{fractional increase in demand}\} \quad \mathbf{(2)}$$

Note as the fair weather excess capacity approaches zero, the percent increase in delays goes to infinity unless the demand is reduced by canceling flights [this is why cooperative decision making (CDM) is of great interest to the airlines].

At such capacity-constrained terminals, weather system architecture and/or weather product changes that increase C_W and/or reduce T provide extremely high delay reductions.