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WEATHER INFORMATION REQUIREMENTS FOR TERMINAL
AIR TRAFFIC CONTROL AUTOMATION *

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1. INTRODUCTION

Aviation operations in the airport terminal area, where flights converge from a number of directions onto one or two active runways, create a fundamental limitation on the capacity of the national airspace system. The U.S. Federal Aviation Administration (FAA) has recognized that the throughput of existing terminals can be increased significantly by providing the terminal air traffic control team with Terminal Air Traffic Control Automation (TATCA) tools that increase the efficiency of individual controller tasks and provide a dynamic, overall plan for traffic management throughout the terminal control region (Andrews and Welch, 1989). This latter function relies on accurate projection of traffic flow into the future (0-30 minutes) in order to automatically examine the many possible permutations of control actions. The result is a coordinated plan for the multiple (four to ten) control positions involved in the decision making processes that determine end-capacity at the runways.

The FAA has launched an intensive effort to develop and implement TATCA capabilities by taking advantage of preparatory work done at NASA Ames Research Center, MITRE Corporation, and M.I.T. Lincoln Laboratory. An initial TATCA configuration, the Final Approach Spacing Tool (FAST), will be evaluated in the field beginning in 1993 and will be scheduled for possible national implementation two years later. Estimates of the economic value of TATCA-generated operational improvements, when implemented at major airports nationwide, are expected to be over \$1 billion yearly by the year 2000 in reduced fuel consumption, other air carrier operating costs, and passenger time (Boswell et al., 1990).

Since TATCA is first and foremost a planning system, the primary impacts of weather upon TATCA performance involve disruption of planning. This can occur because of sudden or unexpected changes in routing, runway availabil-

ity, or separation standards. In addition, errors in estimated wind produce errors in time-to-fly predictions made by the TATCA planning logic. The TATCA system must be robust with respect to weather events that commonly occur in its region of operation.

This paper describes an initial study of the weather information requirements for TATCA, and their relationship to current and future systems for measurement, integration, forecasting and dissemination of meteorological data in the terminal area. A major goal is to stress the need for close coupling between ongoing initiatives in weather sensing/forecasting in the airport terminal area, and air-space capacity enhancement programs.

2. WEATHER AND TERMINAL AREA DELAY

With few exceptions, major air terminals in the U.S. operate with excess capacity under visual flight rule (VFR) conditions. TATCA benefits will come into effect primarily when instrument flight rule (IFR) conditions restrict available runways, preclude use of visual separation techniques, and increase the likelihood of missed approaches and pilot requests for flight path deviations. This section provides estimates of the relative contribution of various weather conditions to delay at major airports.

Robinson (1989) used weather and delay data for three years (1977, 1978, 1983) to determine the weather conditions contributing to delay at Atlanta's Hartsfield International Airport. Aircraft delay data were obtained using the Standardized Delay Reporting System (SDRS), operated by participating airlines under contract with the FAA. These data consider delays of all durations, broken down by flight phase (taxi-out, taxi-in, airborne, gate-hold). Daily weather conditions were extracted from the Local Climatological Data Summaries (LCD) available through the National Climatic Data Center. Baseline delay was established using average delay on clear days; additional delay occurring on weather days was attributed to the particular type of weather in effect.

*The work described here was sponsored by the Federal Aviation Administration. The United States Government assumes no liability for its content or use thereof.

We have correlated LCD and delay information for 1989 at Chicago's O'Hare Airport. Delay data were obtained from the National Airspace Performance System (NAPRS), compiled from all airlines but treating only "serious" delays of at least 15 minutes duration. No breakdown by flight-phase is provided.

Table 1 summarizes results for the two studies. Average delay time per operation for days with thunderstorms, heavy fog (visibility less than one-quarter mile) or reduced visibility (greater than one-quarter mile but less than seven miles) is compared to average delay on clear days. Note that the numbers for Chicago reflect contributions only from flights delayed in excess of 15 minutes.

Table 1. Average delay per operation for various types of weather based on Atlanta (all delays) and Chicago (serious delays only) data.

Average Delay (Minutes) per Operation		
	Atlanta (all)	Chicago (>15 minutes)
Thunderstorms	20.4	5.1
Heavy Fog	24.7	2.8
Reduced Visibility	18.6	0.9
Clear	15.0	0.1

Robinson's Atlanta study indicated that heavy fog and thunderstorms produced the greatest contribution to weather related delay, resulting in daily average increases of 65% and 36% respectively, relative to VFR conditions. The breakdown of delay by flight-phase shows that for thunderstorms, most of the excess delay was accrued in the airborne phase, whereas excess delay for heavy fog conditions was approximately equally divided between the airborne and flight preparation phases. Robinson points out that delays on foggy days were more numerous and of smaller duration than the delays caused by thunderstorms; thunderstorm activity typically affects operations for short periods (0.5 to 1.5 hours) but may cause long duration delays for some aircraft.

Serious delays at O'Hare were most likely to occur on thunderstorm days. The smaller relative contributions from fog and reduced visibility are consistent with Robinson's observations that delays under such conditions are numerous but of short duration.

These results can be generalized if we neglect the airport-specific effect of runway configuration and operational procedures. Table 2 applies the delay statistics from these two studies to the 20 busiest U.S. airports in order to derive a rough estimate of the contribution of the weather categories treated in Table 1 to incremental delay over VFR conditions. The weather data reflect long-term means for each airport.

Table 2. Estimate of annual incremental delay due to weather at 20 highest volume U.S. airports. Delay estimates are derived using (a) delays of all durations from Atlanta study; (b) delays of at least 15 minutes duration (Chicago study).

Airport	Daily Ops	Number of Days Th Fog Vis			All Durations				Greater than 15 min			
					Incremental Wx Delay (min x 1000)			Total Non- Wx Delay (min x 1000)	Incremental Wx Delay (min x 1000)			Total Non- Wx Delay (min x 1000)
					Th	Hvy Fog	Low Vis		Th	Hvy Fog	Low Vis	
Chicago	2175	38	16	109	450	338	853	11884	412	94	185	103
Atlanta	2156	50	30	136	588	629	1056	11780	538	174	229	102
Los Angeles	1589	3	44	121	26	680	692	8682	24	188	150	75
Dallas	1578	45	11	86	387	169	489	8622	354	47	106	75
Denver	1438	41	10	57	321	140	295	7857	294	39	64	68
San Francisco	1255	2	17	101	14	207	456	6857	13	57	99	60
St. Louis	1178	45	11	156	289	126	662	6437	265	35	143	56
Boston	1162	19	23	125	120	260	523	6349	110	72	113	55
Phoenix	1142	23	2	5	143	22	21	6240	131	6	4	54
Detroit	1137	33	22	121	204	243	495	6213	187	67	107	54
Newark	1134	26	20	112	161	220	457	6196	147	61	99	54
Minneapolis	1096	36	11	85	215	117	335	5989	197	32	73	52
Memphis	1047	53	11	119	302	112	449	5721	277	31	97	50
Philadelphia	1036	27	25	150	152	252	559	5661	140	70	121	49
NY-LaGuardia	1003	24	14	118	131	136	426	5480	120	38	92	48
Honolulu	1008	7	0	15	38	0	55	5508	35	0	12	48
Pittsburgh	1003	36	19	158	197	185	571	5480	180	51	124	48
Las Vegas	1000	15	1	1	82	10	4	5464	75	3	1	47
Miami	962	75	7	30	393	65	104	5256	360	18	23	46
Wash/Nat'l	893	30	11	134	146	95	431	4879	134	26	93	42

These numbers do not provide a reliable face-value estimate of weather-related delay since, for example, the statistics do not differentiate between delays due to local conditions and delays caused because aircraft are held on the ground at one airport due to circumstances at their destination airport. They are, however, useful for comparing the relative impact of the different types of weather at the various airports. When weather related delays of all durations are considered, the largest overall contribution (52%) comes from reduced visibility, owing to the frequency of this weather condition. Thunderstorms (25%) and heavy fog (23%) produce similar contributions overall, although one or the other condition may be significantly more important at a specific airport. Serious delay time is mostly attributable to thunderstorm days, except at airports such as those on the West Coast where thunderstorms are rare.

These analyses suggest that a significant portion of TATCA's benefits can be derived simply from improving operations under conditions of reduced visibility. The annual number of thunderstorm days at the airports examined average 31 days. It thus appears that system availability will also be enhanced by designing a TATCA system that is able to provide useful planning functions when thunderstorms are present. Some of the tabulated delay for thunderstorm days may actually be residual traffic congestion following dissipation of the weather; thus TATCA can also realize benefits by allowing more rapid recovery from the residual delay.

3. WIND FIELD MODEL

3.1. Accuracy Requirements

To accurately project future aircraft positions, TATCA must incorporate an estimate of the wind along the track, presumably derived from a gridded wind field model. The following simple analysis illustrates the effect of errors in the wind estimate on the time-to-fly estimates, and the resulting impact on TATCA performance. For simplicity, only the along-track component of the wind is considered (this is appropriate as long as the cross-track component is small relative to aircraft airspeed).

With this assumption, the error in the predicted arrival time associated with a prediction for a time T into the future is:

$$e = \int_0^T \frac{-\epsilon(t)}{v(t)+\epsilon(t)} dt = - \int_0^T \frac{\epsilon(t)}{v(t)} dt \dots\dots\dots (1)$$

where $\epsilon(t)$ is the along-track wind estimate error and $v(t)$ is the estimated along-track ground speed. The second equality assumes that $\epsilon(t) \ll v(t)$. Thus the magnitude of the relative error in the time-to-fly estimate -- e/T -- is approximately the magnitude of the average ratio of the along-track wind error to the ground speed of the aircraft.

Next consider flight through a gridded wind field model at a uniform ground speed v . If the average wind estimate errors in each grid cell are zero-mean, normally distributed (with equal variance = σ_v) and independent from cell to cell, it can be shown from (1) that the expected value of the time-to-fly prediction error is 0, and its RMS value is:

$$\sigma_{\text{ttf}} = \sqrt{E(e^*e)} = \frac{\sigma_v T}{v\sqrt{N}} \dots\dots\dots (2)$$

where N is the number of grid cells along the flight path. Table 3 plots this RMS time-to-fly prediction error as a function of the (assumed equal) RMS uncertainty in the along-track wind component for each grid cell, and the number of cells through which the flight path passes. The table assumes a time-to-fly prediction of T=900 seconds at an estimated ground speed of 200 kts.

Table 3. Time-to-fly RMS error (seconds) for N grid segments (900 sec of flight at 200 knots).

N	$\sigma(v)$				
	2 kts	4 kts	6 kts	8 kts	12 kts
1	9.0	18.0	27.0	36.0	54.0
2	6.4	12.7	19.1	25.4	38.2
3	5.2	10.4	15.6	20.8	31.2
4	4.5	9.0	13.5	18.0	27.0

Time-to-fly prediction errors have the effect of reducing TATCA's window of controllability (defined as the difference between the latest and earliest landing times that the TATCA scheduler is allowed to plan for). The prediction errors force the planner to avoid use of the extreme region of the controllability window, in effect reducing the controllability of the aircraft. The effects of reduced controllability on terminal acceptance rates have been analyzed by Vandevenne et al. (1989).

For terminal arrival routes, the controllability window is typically 240 seconds or more if path stretching and speed control are employed. Wind model error should not have an important impact on TATCA performance if the time-to-fly prediction error can be kept to a small fraction of this window. From Table 3, a wind field model with a small number of independent grid cells can support controllability window reductions of less than 10% if the RMS wind model error is less than about 8 knots.

3.2. Terminal Wind Sensors

The wind sensors being considered for TATCA are automatic pilot reports (ACARS), National Weather Service (NWS) regional forecasts and wind profilers. In addition, techniques for winds aloft estimation based upon analysis of radar tracks of turning aircraft have been developed. Although the FAA's planned Integrated Terminal Weather

System (ITWS) is expected to be the eventual source of multi-sensor wind data for TATCA (Evans, this conference), early implementations are expected to make direct use of one or more individual data sources. A brief discussion of each of the sensors follows.

3.2.1. ACARS

Aeronautical Radio, Inc. (ARINC) has developed the Meteorological Data Collection and Reporting System (MDCRS) to collect winds and temperatures aloft automatically from planes equipped with Aircraft Communications Addressing and Reporting System (ACARS). Currently more than 2000 aircraft are equipped with ACARS; ARINC forecasts that this number will increase to 4000 by 1995. Capability to access the MDCRS data base via query exists and is expected to be operational in the near future.

Evaluation of the accuracy of ACARS wind reports from aircraft en route (Brewster et al., 1989) indicated RMS errors of 6 kts in speed and 3 degrees in direction. ACARS reports are currently collected en route at 7.5 minute intervals.

While detailed analysis of the ability of ACARS to provide wind profiles during descent has not been conducted, we have examined data downlinked from aircraft descending into the Orlando terminal during a day in 1990. Figure 1 compares the ACARS reports (x's) of wind speed, direction and temperature with the NWS sounding at 17Z (solid line). Owing to the infrequency of reports from descending aircraft under current procedures, ACARS data were accumulated over a 24 hour period. Winds on this day were southerly and light. RMS discrepancies in wind speed and direction between the ACARS reports and the sounding are respectively 3.3 kts and 30 degrees when averaged over the altitude interval from 12 to 16 kft. At low altitudes, discrepancies were larger -- 6.2 kts and 55 degrees averaged over the interval from 1 to 3 kft. Temperature reports from ACARS matched the sounding well, except at the surface where the diurnal heating cycle is evident in the ACARS reports. We stress that the indicated wind errors may not be representative. The aircraft data were accumulated over a 24 hour period and although winds were light at the time of the NWS sounding, thunderstorm activity during the day may have resulted in significant perturbation during some periods.

We are currently making arrangements with ARINC and participating aircraft to conduct a careful evaluation of ACARS wind measurements for aircraft descending into Orlando during summer 1991. Data will be downlinked at approximately 1000 ft intervals from all suitably equipped aircraft and compared with sounding and Doppler radar data.

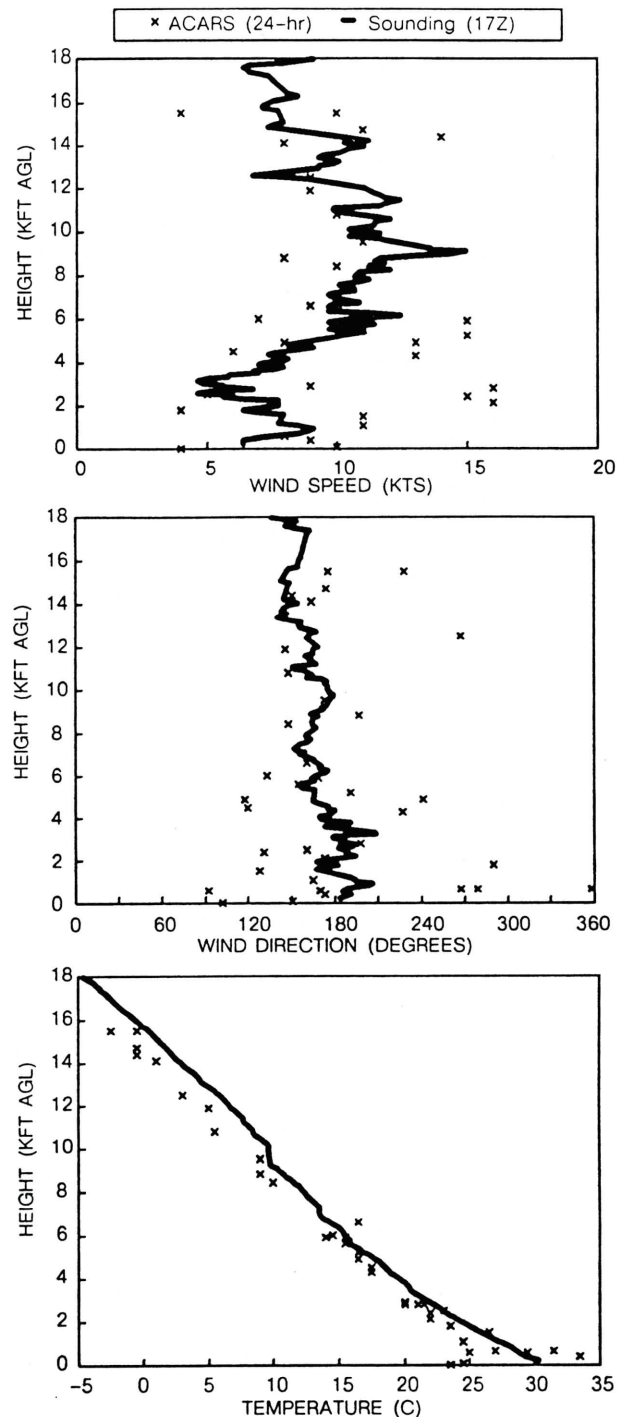


Figure 1. Profiles of wind speed, wind direction, and temperature from the surface to 18 Kft AGL on August 25, 1990 in Orlando are shown. The balloon sounding is represented by the solid line, and the measurements from aircraft by Xs. Forty ACARS reports from 30 different aircraft in a 24 hour period are shown.

3.2.2. National Weather Service (NWS) Nested Grid Model (NGM) Forecasts

The NWS's Regional Analysis and Forecast System (RAFS) generates forecasts every 12 hours using measurements at 0000Z and 1200Z. These forecasts are routinely

available at 1.25 deg longitude x 2.5 deg latitude grid with 16 vertical levels over the contiguous 48 US states. They can be obtained at higher resolution (80 km minimum) with special arrangements. Accuracy of current 6–18 hr wind forecasts is approximately 15 kts RMS.

Current accuracy, resolution and frequency of the RAFS wind forecasts are not adequate for TATCA and are hence being considered as a back up source. However, NWS is developing a Rapid Update Analysis System (RUAS) using asynoptic measurements (e.g., ACARS and wind profilers). RUAS will generate higher accuracy forecasts at 3 hr cycles on an 80 km mesh grid in summer of '91 and will make them available for testing by NWS one-half hour after measurement cut-off. The resolution is expected to increase to 40 km, and frequency to 1–2 hr cycle, by 1994.

3.2.3. Profiler

Wind profilers are experimental Doppler radars that measure vertical profiles of the orthogonal components of the winds aloft in near real time. Currently four profilers in Colorado and one in Massachusetts are operational. An operational network of 30 profilers is to be deployed across the central United States in early 1990's.

The wind profilers sample the winds aloft once every 6 minutes and the report is sent to a hub at NOAA in Boulder Colorado for objective quality control and averaging. The hub generates hourly reports with a stated accuracy of 2 kts RMS in each of the components. TATCA is considering use of profilers, where available, as winds aloft sensors.

3.2.4. Radar Tracks

Lincoln Laboratory has developed a wind estimation algorithm using radar tracks of turning aircraft (Hollister, et al., 1989). The basic assumptions made are that wind speed, wind direction and aircraft true airspeed do not change during the turn. Preliminary results using MODE S secondary radar tracks in Boston terminal area found 1–2 usable turns per minute with an average turn angle of 125 deg. The standard deviation of the averaged wind estimates was approximately 5 kts near the airport and 10 kts at longer radar ranges. However these estimates need to be validated with independent measurement of winds aloft. Performance of this algorithm will degrade when radar tracks from currently installed ATCRB radars are used. Accuracy of ATCRB radar returns is approximately three times worse than that of MODE S.

4. CONVECTIVE WEATHER

As indicated in Section 2, a TATCA system will often encounter convective weather conditions in which planning must occur in the presence of hazardous weather cells. For initial implementations, the reconciliation of TATCA planning functions and the need to avoid hazardous weather will be a manual function in which traffic coordinators manually alter TATCA planning parameters (such as which routes the

planner can use) in response to weather. Looking further into the future, it would seem inevitable that the output of weather sensing systems will be explicitly considered in TATCA planning, thus providing automation assistance in responding to observed weather problems.

Major weather-sensing systems and their expected impact on terminal procedures are described below.

4.1. Terminal Area Convective Weather Sensors

The newest terminal control radar, the ASR-9, incorporates a dedicated digital signal processing channel to provide six calibrated levels of precipitation reflectivity for display on air traffic controller radar displays (Taylor and Bronins, 1985). The ASR-9's weather data are generated to 60 nmi range on a 0.5 nmi by 1.4 degree grid. Evaluations have indicated that the RMS error in the measured precipitation intensity is less than the quantization interval imposed by use of the six-level National Weather Service scale (Weber, 1986).

Terminal Doppler Weather Radars (TDWR) (Evans and Turnbull, 1989) will be deployed at 45 major air terminals in the U.S. These provide three-dimensional coverage of weather reflectivity and radial velocity over about one-third of the terminal area. (TDWRs will typically be sited 15 km away from the airport and will execute a volume scan over a 120 degree sector every 2.5 minutes). These radars will detect and (in some cases) predict low-altitude wind shear activity such as microbursts (Fujita, 1985) and gust fronts (Goff, 1976). Microburst activity may cause runways to become unusable owing to safety concerns, whereas long-term changes in wind speed and direction behind a gust front can require a change in the runways used for arrivals and departures. In the sector of TRACON airspace covered, three-dimensional TDWR precipitation reflectivity data complement measurements from the ASR-9 in defining the vertical development, and therefore the severity, of a thunderstorm.

The new National Weather Service radars (WSR-88D) will often be sited near enough to air terminals to augment ASR-9 measurements of precipitation reflectivity. Data from WSR-88Ds could provide three-dimensional storm structure over the portion of terminal airspace not covered by TDWR.

4.2. Thunderstorm Impact on Terminal Air Traffic Control

During testing in 1990 of TDWR and ASR-9 derived wind shear products at the Orlando International Airport, Lincoln Laboratory observers were stationed in the TRACON to note the effect of thunderstorm activity on terminal area operations. Their notes, and a similar study for Denver terminal airspace (Stevenson (1984)) provide an indication of the operational conditions which TATCA must address if it is to continue providing effective flight sequencing advisories during convective weather.

During convective weather outbreaks, numerous aircraft request and execute course deviations to avoid penetration of cumulus build-up; this in turn affects the time required to fly between fixes and can eventually lead to the closing of specific flight corridors. Figure 2 gives an indication of the likelihood of weather-induced deviation as a function of precipitation intensity. The figure is a tally of the Orlando observers' logs of aircraft penetrations or deviations around weather areas; the observations are sorted according to the associated NWS precipitation level measured with the Orlando ASR-9. The level 1 tally is unrepresentative since the display used by the observers' was typically configured such that the lowest displayed weather regions were level 2 (30 dBz).

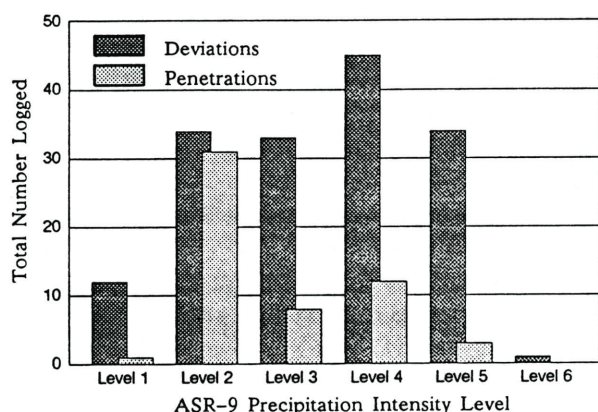


Figure 2. Number of weather-induced deviations and penetrations logged by observers at Orlando TRACON during summer 1990.

The observations indicate a sharp reduction in the number of weather penetrations when the storm intensity reached level 3 (41 dBz) or higher. The observers noted that when deviations occurred, aircraft typically maintained two to eight mile separation from the level 2 echo. Stevenson (1984) stated that pilots in the Denver terminal area likewise avoid penetration of precipitation exceeding level 2 intensity, and that they maintain six to ten miles separation from the edges of any level 5 (50 dBz) cell. During initial descent into the terminal area, where straight line paths are typically 20 nmi, deviation around an isolated, 5 nmi radius thunderstorm -- including a 5 nmi safety buffer -- would require at least an 8 nmi increase in path length (150 seconds at 200 kts). This is significant relative to TATCA's controllability window (Section 3) and changes to the planned landing schedule would probably result whenever such deviations occurred.

Penetrations of level 3 or greater precipitation at Orlando were primarily on final approach at low altitude, often below the cloud base where the runways could be sighted. When thunderstorm lines set up situations where deviations required to avoid the weather were excessive, controllers assisted the pilots in finding slots through the weather. In both

of the above circumstances pilot discretion as to whether or not to penetrate the weather introduces considerable uncertainty as to the future flight path of a specific aircraft.

Whenever controllers can find alternate routing that results in no great change in the planned flight times, then TATCA planning will function normally. This is most likely when storm cells are isolated and do not form widespread barriers that close flight corridors or inhibit final approach operations. Under such conditions, weather-related deviations from planned flight paths can be handled on a case-by-case basis in exactly the same way as deviations for non-weather reasons. Ultimately, TATCA automation could provide routing assistance by noting the precipitation cells that are likely to result in significant flight path deviations and suggesting an adjusted route of flight that avoids such cells.

The "hazardous cell" product from the Integrated Terminal Weather System (based on weather radar measurements, thermodynamic profiles and data from national and terminal-area lightning sensors) may facilitate identification of storms that will require avoidance. Demonstrated storm tracking algorithms can project storm advection with sufficient accuracy to support flight path planning for at least 10 minutes into the future. Chornoboy (1991) presents performance analyses indicating that the TDWR storm tracker estimates storm advection with RMS errors of 1.5 m/s in speed and 20 degrees in azimuth. This corresponds to RMS uncertainty of about 4 km in a 10 minute position prediction for a fast-moving (20 m/s) thunderstorm. Previous analysis of storm tracking algorithm performance (Alaka, et al., 1979) indicates that, over 10 minutes, storm growth and/or shape deformation (not accounted for in the tracking algorithms) do not prevent the algorithms from displaying considerable skill relative to a persistence forecast.

Situations where terminal area capacity is dramatically reduced owing to thunderstorm-induced closing of arrival corridors or airport runways require coordinated decision making that involves terminal and en route air traffic supervisors and the FAA's central flow facility. Such situations invoke operational regional or national flow control decision-making that is the responsibility of systems other than TATCA.

5. SHORT TERM CEILING/VISIBILITY PREDICTION

The TATCA scheduler bases its planning on a knowledge of the available final approach paths and runways for its 20 to 30 minute planning horizon. In the presence of rapidly changing ceiling height, simple persistence forecasting may not support the generation of a traffic plan that fully utilizes available capacity.

The automated planning and coordination capabilities of the TATCA system will allow the terminal controller team to more rapidly adjust to changing visibility conditions. Pro-

vision of forecasting that anticipates visibility changes may further improve the ability of controllers to react to changing conditions. Miller (1988) examined the performance of a statistical forecasting procedure that is applicable to ceiling and visibility prediction. His method uses a Markov model to relate dependent forecast variables (e.g., future operational conditions such as LIFR, IFR, MVFR and VFR) to measured predictands (current operational conditions and measurements of pressure, temperature, relative humidity, surface winds). Analysis indicates superior performance to persistence forecasting for projection of 1 to 6 hours; performance relative to persistence for shorter term prediction is not clear.

NWS is developing data assimilation and analysis techniques to forecast ceiling and visibility in the context of the Aviation Gridded Forecast System (Sherretz, this conference). An example is the Mesoscale Analysis and Prediction System (MAPS) which assimilates data from soundings, radar, surface weather observations, aircraft downlink, wind profilers and satellite imagery. Initial analysis indicates skill superior to persistence forecasting.

6. SUMMARY

Available data on the breakdown of incremental IFR delay as a function of weather type indicates that, nationwide, roughly one-half of the delay occurs under relatively stable weather conditions involving ceiling and/or visibility reductions not associated with thunderstorms or heavy fog. In this circumstance, TATCA's principal weather information requirement is a wind model to support time-to-fly predictions. As discussed in Section 3, sensing techniques currently developed will provide wind measurements of sufficient accuracy provided that suitable data assimilation and smoothing mechanisms are developed.

Sections 4 and 5 considered TATCA operations in thunderstorms or heavy fog. In the short term, careful attention must be given to providing the TATCA system with the flexibility needed to adapt to the complex operational situations associated with thunderstorm activity. In the long term, TATCA can be envisioned as supporting dynamic flight routing around storm cells as long as the convective activity is isolated and does not affect the airport runways. Current research directed towards short term prediction of visibility or ceiling changes may allow TATCA to enhance terminal capacity by anticipating runway capacity changes.

Full realization of benefits associated with Terminal Air Traffic Control Automation will require coupling between the automation system and current/planned weather sensing and forecast systems. New FAA weather initiatives such as the Integrated Terminal Weather System, the Regional Aviation Weather Products Generator (McCarthy, 1991) and the NWS Aviation Gridded Forecast System will provide an effective means for providing TATCA with necessary weather information without the need for TATCA to

perform duplicative processing of data or to implement multiple interfaces to individual sensors. Ongoing research in conjunction with the development of these systems will improve techniques for assimilation and integration of data from terminal area weather sensors. This in turn will result in more accurate modeling of current weather conditions in the terminal area, and improved ability to forecast these conditions over the time interval of concern for TATCA.

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