Project Report
ATC-249

Assessment of the Delay Aversion Benefits of the Airport Surveillance Radar (ASR) Weather Systems Processor (WSP)

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2 July 1996

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Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

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Springfield, VA 22161

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. ATC-249	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessment of the Delay Aversion Benefits of the Airport Surveillance Radar (ASR) Weather Systems Processor (WSP)		5. Report Date 2 July 1996 6. Performing Organization Code
7. Author(s) Dale A. Rhoda and Mark E. Weber		8. Performing Organization Report No. ATC-249
9. Performing Organization Name and Address Lincoln Laboratory, MIT 244 Wood Street Lexington, MA 02173-9108		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA01-93-Z-02012
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Washington, DC 20591		13. Type of Report and Period Covered Project Report 14. Sponsoring Agency Code

15. Supplementary Notes

This report is based on studies performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-95-C-0002.

16. Abstract

The Weather Systems Processor (WSP) modification to existing Airport Surveillance Radars (ASR-9) significantly enhances the functionality of the radar with respect to hazardous weather detection and tracking. Dedicated alphanumeric and color graphic displays alert controllers to hazardous wind shear conditions on the runways or final approach/initial departure flight corridors, show current location and anticipated movement of thunderstorm cells, and provide short-term forecasts of operationally significant wind shifts. Operational tests of a prototype WSP and related terminal area hazardous weather detection systems (the Terminal Doppler Weather Radar (TDWR) and the Integrated Terminal Weather System (ITWS)) have shown that, in addition to reducing the risk of aircraft accidents associated with wind shear encounters on landing or takeoff, the information provided by these systems is a significant aid in terminal air traffic management during adverse weather. The resulting efficiency enhancements reduce delay and associated costs.

This report assesses the magnitude of the delay aversion benefits that will be realized through national deployment of the WSP. These are quantified both in terms of aircraft delay-hour reductions and corresponding dollar benefits. The analysis indicates that these benefits will total approximately $18M per year given year 2000 expected traffic counts at the planned WSP airports. This exceeds, in equivalent dollar value, the safety benefits realized through WSP deployment by a factor of approximately five.

17. Key Words Weather Systems Processor, Airport Surveillance Radar, delay aversion, dollar benefits, traffic counts, safety benefits, hazardous weather detection, air traffic management	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	42	

FORM DOT F 1700.7 (8-72) Reproduction of completed page authorized

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This report assesses the magnitude of the delay aversion benefits that will be realized through national deployment of the WSP. These are quantified both in terms of aircraft delay-hour reductions and corresponding dollar benefits. The analysis indicates that these benefits will total approximately $18M per year given year 2000 expected traffic counts at the 34 planned WSP airports. This exceeds, in equivalent dollar value, the safety benefits realized through WSP deployment by a factor of approximately five.

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1.0 INTRODUCTION

The Weather Systems Processor (WSP) modification to existing Airport Surveillance Radars (ASR-9) significantly enhances the functionality of the radar with respect to hazardous weather detection and tracking. Dedicated alphanumeric and color graphic displays alert controllers to hazardous wind shear conditions on the runways or final approach/initial departure flight corridors, show current location and anticipated movement of thunderstorm cells, and provide short-term forecasts of operationally significant wind shifts. Operational tests of a prototype WSP and related terminal area hazardous weather detection systems such as the Terminal Doppler Weather Radar (TDWR) and the Integrated Terminal Weather System (ITWS) have shown that, in addition to reducing the risk of aircraft accidents associated with wind shear encounters on landing or takeoff, the information provided by these systems is a significant aid in terminal air traffic management during adverse weather. The resulting efficiency enhancements reduce delay and its associated costs to the airlines and passengers.

In this report, we assess the magnitude of the delay aversion benefits that will be realized through national deployment of the WSP. These are quantified both in terms of aircraft delay-hour reductions and corresponding dollar benefits. The latter are realized through reduction of:

1. Airline direct operating costs; that is, incremental fuel and crew salary expenses on delayed flights and costs associated with unnecessary diversions;

2. Passenger delay in arrival at their destination airports. Accepted conversions are used to ascribe dollar value to this delay;

3. "Downstream" delay costs accrued when delayed aircraft and/or flight-crews are unable to complete subsequent flight legs on schedule.

Our analysis indicates that these benefits exceed, in equivalent dollar value, the safety benefits realized through WSP deployment by a factor of approximately five.

The organization of this report is as follows. Section 2 provides information on the WSP, its prototype test history and resulting evidence that the products it provides to Air Traffic controllers and their supervisors aid in efficient handling of traffic during adverse weather. Since our analysis relies heavily on results developed from Integrated Terminal Weather System operational testing, comparison of the WSP's product suite and accuracy to that of ITWS is included. Section 3 details the methodology used in assessing the delay-related benefits that will be accrued through WSP deployment. Assumptions and limitations of the analysis are noted as appropriate. Results of this assessment are presented in Section 4, separately for each airport targeted for WSP deployment and in aggregate. "Sanity checks" for the results derived are presented. Section 5 discusses implications of this assessment.

2.0 BACKGROUND

2.1 WEATHER SYSTEMS PROCESSOR OVERVIEW

Figure 1 shows the location of the 34 airports currently slated to receive the ASR Weather Systems Processor. These are generally medium-density airports with significant exposure to thunderstorm activity. Two high-density airports–Los Angeles (LAX) and Honolulu (HNL)–with moderate to low thunderstorm activity are also targets for the system. Selection of these airports was accomplished based on an "Integrated Wind Shear Systems Cost-Benefit and Deployment Study" [1], hereafter designated "IWS." The IWS considered primarily safety benefits for ground-based wind shear equipment that accrue from reduced risk of accident due to aircraft wind shear encounters.

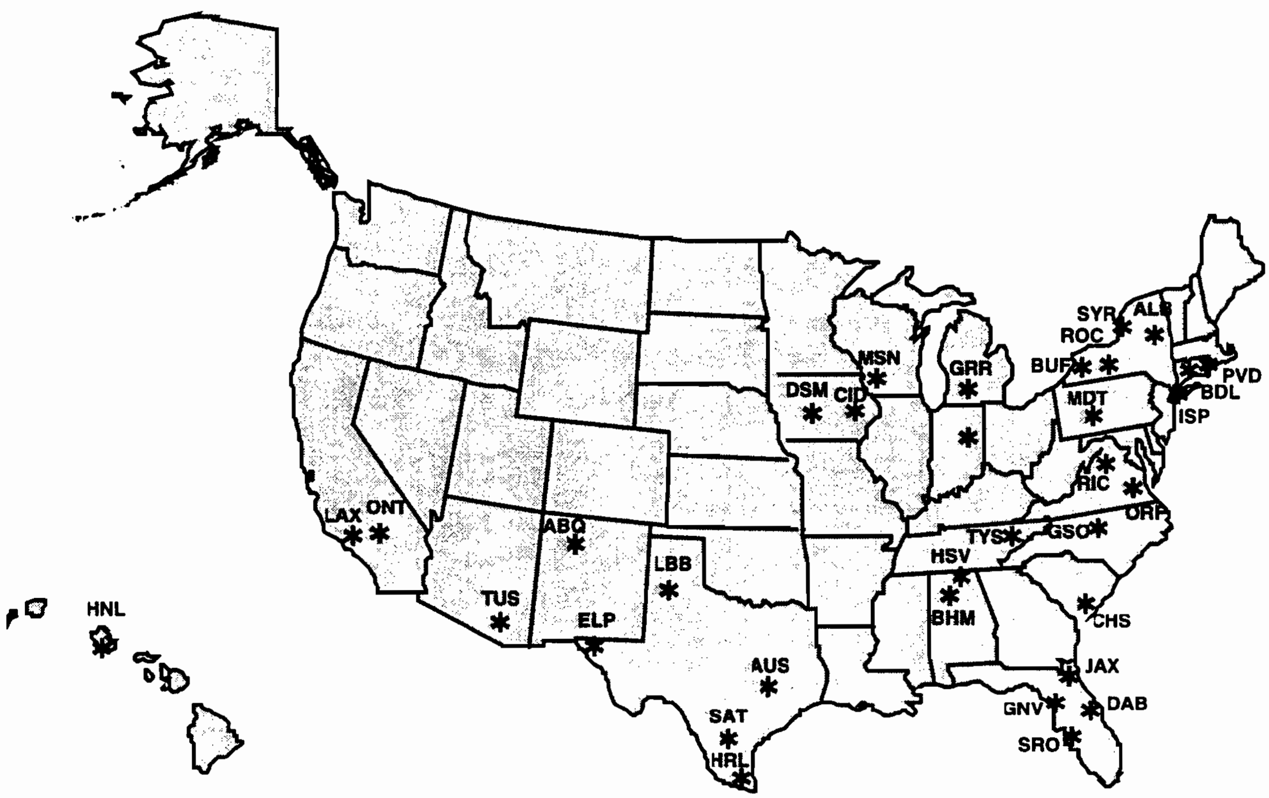

Figure 1. Planned locations for ASR-WSP deployments.

The WSP is comprised of:

1. Interfaces to the host Airport Surveillance Radar to extract radio frequency, digital and timing signals necessary to drive a separate receive chain optimized for detection of wind shear phenomena;

2. A digital signal processor that suppresses interference–principally ground clutter–and generates "base data" imagery of vertically integrated precipitation reflectivity and low-altitude Doppler velocity;

3. Product generation computers that analyze the base data imagery to detect and track wind shear phenomena and generate estimates of thunderstorm speed and direction of movement, and extrapolated position;

4. Dedicated color graphical (Geographic Situation Display or GSD) and alphanumeric (Ribbon Display or RDT) displays that convey the wind shear and storm movement data to Air Traffic Control users;

5. An interface to existing terminal radar control room (TRACON) Data Entry and Display System (DEDS) monitors and tower cab BRITE displays that replaces existing ASR-generated weather reflectivity data with more accurate data generated by the WSP. In particular, the WSP reflectivity data are free from false weather indications caused by ground clutter breakthrough during anomalous atmospheric propagation (AP) conditions. AP contamination has been a significant problem in operational usage of the ASR-9 weather reflectivity data.

Figures 2 and 3 show the displays used to convey ASR-WSP generated weather information to Air Traffic Controllers, supervisors and traffic management specialists.

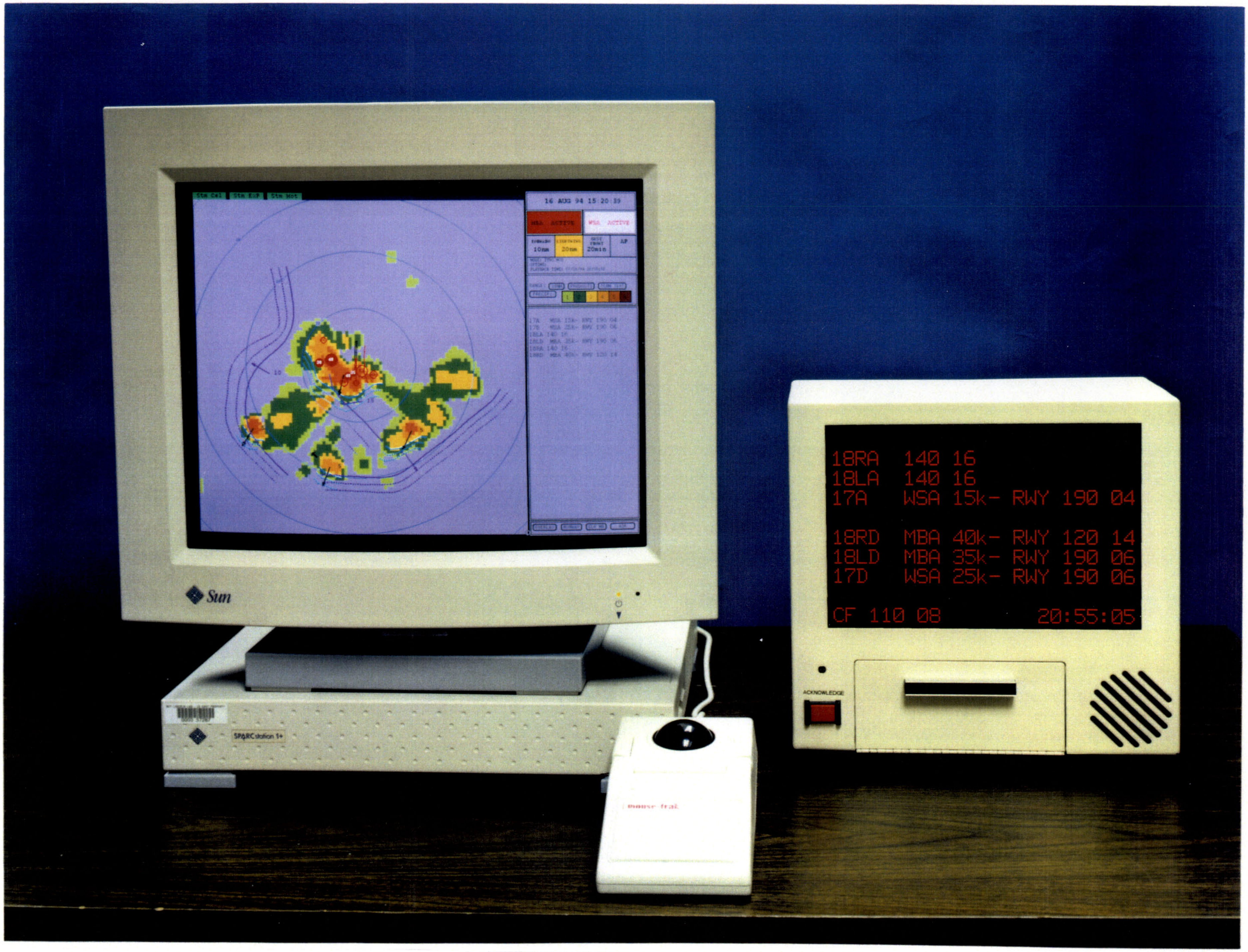

Figure 2. Dedicated Geographic Situation Display (GSD) (left) and ribbon display terminal (RDT) (right) that convey information on wind shear and other weather phenomena to controllers and ATC supervisory personnel.

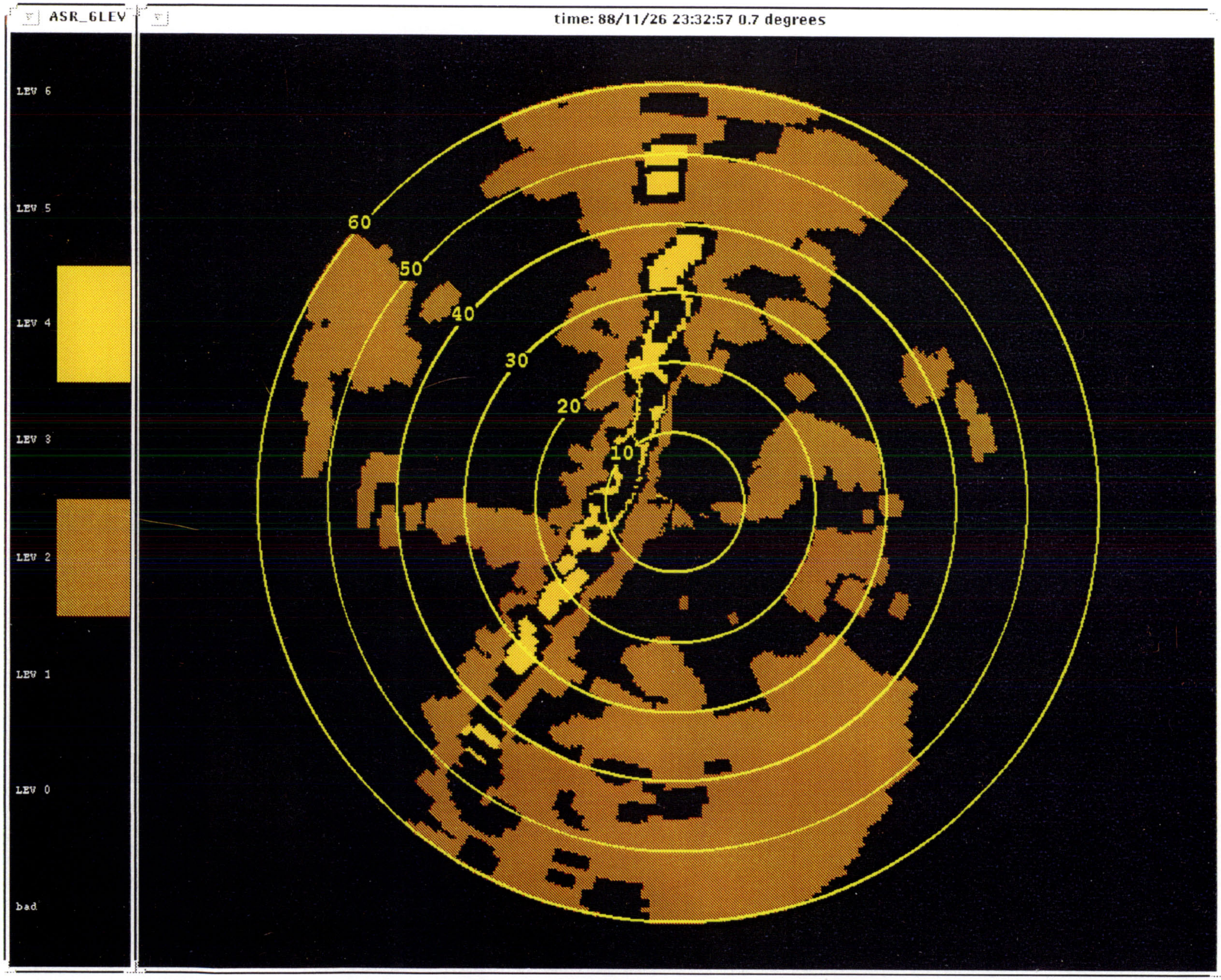

Figure 3. Mock-up of ASR-9 six-level weather display in controllers' DEDS and BRITE displays. Two of the six available precipitation intensity levels are selected for presentation as shown.

The weather products provided by the WSP are listed in Table 1. For each product, the display(s) used to convey the information and the primary recipient(s) are shown. Runway specific alphanumeric alarms are generated on the RDT shown in Figure 2 when microbursts affect an active runway, three mile final approach or two mile departure corridor. These are read verbatim to affected pilots by the tower local controller. The location and extent of the area affected by the wind shear are depicted graphically on the GSD. Tower, TRACON and en route center (ARTCC) supervisors using this display can accurately judge the location of the wind shear relative to operational flight corridors, assess the intensity of associated precipitation and obtain an estimate of whether the wind shear region is moving onto or off of the operational flight corridors via the storm motion product.

Gust front induced wind shear detected by the WSP on runways or approach/departure corridors likewise gives rise to RDT alphanumeric alarms for verbal relay to affected pilots by the tower local controller. The GSD shows the current location of the front, extrapolated positions 10 and 20 minutes in the future, and an estimate of the wind speed and direction that will prevail behind the front. The GSD provides air traffic supervisory personnel explicit information on the estimated arrival time of wind shifts that may force runway use changes. The ability to anticipate such wind shifts reduces inappropriate taxi-out and approach clearance instructions from air traffic control (ATC) personnel.

Table 1
ASR WSP Weather Information Products

Product	Displays	Primary User
Microburst or Wind Shear with Loss Alphanumeric Alarm	RDT	Tower Local Controller (Pilot)
Microburst or Wind Shear with Loss Graphic	GSD	Tower, TRACON, ARTCC Supervisors
Gust Front Alphanumeric Alarm	RDT	Tower Local Controller (Pilot)
Gust Front Graphical Detection, Forecast Position and Associated Wind Shift	GSD	Tower, TRACON, ARTCC Supervisors
Six-Level Weather Reflectivity Map	GSD DEDS, BRITE	Tower, TRACON, ARTCC Supervisors TRACON Controllers, Tower Local Controller (Pilot)
Storm Movement and Extrapolated Position	GSD	Tower, TRACON, ARTCC Supervisors

The WSP generates weather reflectivity (i.e., precipitation intensity) maps each 30 seconds for display to Tower, TRACON and ARTCC supervisors on the GSD. Identical data are provided to TRACON and tower controllers on their DEDS and BRITE displays, respectively. WSP reflectivity maps are well matched to the needs of terminal Air Traffic Control in that:

1. Their frequent update (30 seconds) supports the fine temporal and spatial tolerances of aircraft flight route planning in TRACON airspace;

2. The ASR-9's non-attenuating wavelength (10 cm) eliminates concerns that intervening precipitation may attenuate returns from more distant storms;

3. The ASR-9's broad elevation beam patterns detect precipitation echoes throughout the altitude interval of concern for terminal ATC (0-20,000 ft.), and project these onto an easily interpretable plan-view format.

In contrast to the current ASR-9 weather reflectivity product, WSP reflectivity maps will be essentially free of false weather indications caused by ground clutter breakthrough during anomalous propagation conditions [2].

A correlation tracker applied to the precipitation reflectivity images provides estimates of the speed and direction of storm movement. Storm front "leading edges" are identified and extrapolated 10 and 20 minutes into the future based on the storm movement estimates. ATC supervisory personnel utilize the movement estimates and storm front extrapolations to anticipate when thunderstorms will close the runways, TRACON flight routes, or Arrival Transition Areas (ATAs) and Departure Transition Areas (DTAs) between terminal and en route center airspace. These storm movement products likewise allow for anticipation that these operationally significant arenas will shortly re-open.

2.2 PROTOTYPE TESTING

Under contract to the Federal Aviation Administration (FAA), Lincoln Laboratory has operated a prototype WSP since 1987. Beginning in 1990, this has supported operational testing of the above product suite each summer in Air Traffic Control facilities at Orlando, FL (1990-1992) and Albuquerque, NM (1993-1995). The dedicated WSP displays (GSD and RDT) were deployed in these airports' Tower Cabs and TRACONs for use as described above. In 1995 only, a GSD was also deployed at the Albuquerque en route center for use by the area manager in charge of air traffic into the Albuquerque TRACON. This allowed for assessment of the value of shared weather situational awareness between the terminal and en route facilities in facilitating aircraft transitions between their respective airspaces. Note that the prototype WSP did not include interfaces necessary to feed six-level weather reflectivity maps free of AP contamination to controllers' DEDS and BRITE displays. Thus, this capability of the WSP could not be evaluated by direct demonstration.

The FAA Technical Center conducted independent operational evaluations of the prototype WSP during each demonstration period at Orlando and during the first year of testing at Albuquerque [3, 4, 5, 6]. Less formal evaluations of operational effectiveness were conducted by Lincoln Laboratory staff following the 1994 and 1995 Albuquerque demonstrations. Each of these evaluations solicited feedback from Air Traffic controllers and supervisors on the operational suitability of the WSP and benefits realized through utilization of its products. Figure 4 excerpts specific controller comments on enhanced traffic management capabilities afforded by the WSP products. As illustrated by the highlights, the ability to anticipate weather impact on terminal flight routes and plan accordingly was viewed as key value added in coping with adverse weather situations.

ATC COMMENTS ON PERCEIVED BENEFITS

SITUATIONAL AWARENESS

"SEVERAL PILOTS COMMENTED ON WHAT WE WERE ABLE TO PROVIDE THEM, INCLUDING AN ESTIMATE ON WHEN WE WOULD LIKELY BE ABLE TO RESUME ARRIVALS AND DEPARTURES."

"SEEING AND ANTICIPATING WHERE THE WEATHER WILL BE."

"ABILITY TO PREDICT MBA AND WSA IMPACT AND TO PLAN ACCORDINGLY; IMPROVE TRAFFIC FLOW."

"BETTER SERVICE TO PILOTS, ESPECIALLY PREDICTING RUNWAY CHANGES AND ANTICIPATING PILOTS' REQUESTS FOR DEVIATIONS."

"GIVES CONTROLLERS A VERY USEFUL TOOL TO PROVIDE UP-TO-DATE WEATHER INFORMATION IN THE TERMINAL AND RADAR ENVIRONMENTS. PILOTS SEEMED VERY IMPRESSED WITH THE PRODUCT."

SAFETY ENHANCEMENT

"VERY GOOD TOOL -- WILL SAVE SOME LIVES -- LEAVE IT HERE."

"THIS EQUIPMENT PROVIDES AN ADDED MARGIN OF SAFETY FOR OUR FLIGHT CUSTOMERS."

"THE CAPABILITY TO ADVISE PILOTS OF INSTANTANEOUS WSA AND MBA ACTIVITY IS A TREMENDOUS IMPROVEMENT OVER LLWAS."

Figure 4. Excerpts from FAA Technical Center evaluation of WSP prototype.

Less formal, but equally compelling, testimonies to the efficiency-related benefits of the WSP are provided by the requests of the Orlando and Albuquerque Air Traffic Control facilities for the prototype WSP to remain operational well beyond the dates and time periods specified for the evaluations. In the case of the Orlando evaluations, where back-to-back demonstrations of the WSP and TDWR were conducted for three successive years, terminal ATC management made clear that they had no preference for which system provided the additional coverage. We believe this reflects the fact that safety-related benefits provided by the wind shear alarm functions (greater for the optimized TDWR than the WSP) were viewed by Orlando controllers as second order relative to the "every-day" traffic management benefits provided by the systems' ability to display thunderstorm location and movement and to predict associated wind shifts.

More recently, Albuquerque ATC has requested that a WSP "hardened prototype"–capable of 24-hour per day, year round operation–be deployed at their facility. Their stated rationale is that the current prototype's benefits are realized any time significant precipitation affects terminal airspace and that the current demonstration periods (roughly, seven hours per day during the convective storm season) do not provide the time coverage necessary to fully realize the efficiency benefits provided by the system.

2.3 COMPARISON TO THE INTEGRATED TERMINAL WEATHER SYSTEM

Although the WSP prototype evaluations discussed above provided strong evidence that the system significantly enhances the ability of terminal ATC to cope with thunderstorm activity, these evaluations were not structured to quantitatively assess associated reductions in delay. Fortunately, corresponding evaluations involving the prototype ITWS at Memphis, TN, Orlando, FL and Dallas/Ft. Worth, TX during 1993 and 1994 provided data that can be "scaled" to assess WSP delay reduction capability. To understand the methodology used in accomplishing this, it is necessary to appreciate the similarities and differences between the WSP and ITWS systems.

The 1993-1994 ITWS prototype demonstrations focused on Initial Operating Capability (IOC) products primarily addressing convective weather. These were provided on graphical and alphanumeric displays identical to those shown in Figure 2. ITWS's delay benefits were realized through use of the color Situation Displays in the tower, TRACON and at the Traffic Management Unit (TMU) position in the affected en route center. Table 2 lists IOC ITWS products in order of operational utility (most to least) as perceived by ATC personnel at the demonstration airports [7].

Table 2
IOC ITWS Products

(1) Storm Motion
(2) Gust Front
(3) Microburst Detection and Prediction
(4) Precipitation Maps with AP Removed
(5) Storm Extrapolated Position
(6) Long Range Precipitation
(7) Terminal Winds
(8) ASR-9 Precipitation with AP Flagged
(9) ATIS Countdown Timers
(10) Storm Cell Information
(11) Tornado
(12) Lightning

Products (1), (4) and (5) above are essentially identical to those provided by the WSP. ITWS utilizes the existing ASR-9 six-level weather reflectivity product as its primary input for locating and tracking storm cells within terminal airspace. Advantages of the ASR-9 over ITWS for this application, relative to the other weather radar inputs (TDWR, NEXRAD), are as described in Section 2.1. ITWS compares the ASR-9 weather channel output to NEXRAD composite reflectivity images to identify and remove anomalous propagation-induced clutter breakthrough from the ASR-9 data. Product (8) explicitly shows where such censoring has been invoked; this allows ATC supervisory personnel using the ITWS Situation Display and radar controllers using DEDS and BRITE to reconcile differences in the precipitation maps displayed at their positions. This feature is unnecessary for the WSP which replaces the precipitation maps feeding DEDS and BRITE with the same AP-free data that are displayed on its GSD.

ITWS' wind shear products–(2) and (3) in Table 2–are generated using base data images from the Terminal Doppler Weather Radar. Although the displayed products are identical in format to those provided by the WSP, the capabilities of the TDWR sensor make the information provided by ITWS more accurate. Demonstrated detection probability (P_d) for the ITWS microburst function exceeds 90 percent for all divergent wind shears and approaches unity for events with differential velocity exceeding the generally accepted "hazard threshold" of 30 kts [8]. The volumetric scanning afforded by the pencil beam TDWR allows for identification of upper altitude storm features that presage the development of microbursts at the surface. The ITWS microburst prediction function generates microburst warnings for controllers nominally two minutes before the actual appearance of significant divergence at the surface. Weber et al. [9] discuss the accuracy of the WSP wind shear detection algorithms. For microburst detection, these vary–depending on environment–between 70 percent and 85 percent for all divergent shears and from 80 percent to 95 percent for events with differential velocity in excess of 30 kts.

More relevant from the viewpoint of delay aversion are the differences in gust front detection capability between the two systems. Scoring of the ITWS gust front algorithm using representative data from the test site at Orlando yielded a probability of detection of 83 percent for gust fronts with convergent shear exceeding 10 m/s. Corresponding analysis of WSP performance in Orlando determined a P_d of 67 percent. The WSP gust front P_d for Albuquerque was lower, 50 percent for all fronts with shear in excess of 10 m/s, owing to the challenging environmental features of this site [9].

Data from the National Weather Service Doppler radars (WSR-88D or "NEXRAD") are used by ITWS to provide precipitation maps and storm motion/extrapolated position products out to ranges significantly greater than the 60 nmi instrumented range covered by the ASR-9. These products–item (6) in Table 2–were used by traffic management specialists in the en route center in directing air traffic from flight cruise level to or from terminal area gates. The WSP system will not provide this product since it does not interface to the WSR-88D. Terminal gates at the smaller airports for which the WSP is targeted are generally about 30 nmi from the airport. Thus, the 60 nmi range of the WSP will generally provide an adequate surveillance buffer for the transitions into and out of terminal airspace.

Products (7), (10), (11) and (12) in Table 2 are not provided by the WSP owing to lack of appropriate sensor input data. Terminal Winds is not primarily a convective weather product and was therefore not a major benefits driver for the ITWS demonstrations drawn from here. Storm cell information provides user-selectable ancillary information on particular thunderstorm cells (e.g., whether hail, lightning or meso-cyclonic circulations are present). While valuable, this information was generally viewed by the Memphis and Orlando controllers as secondary in importance to the depiction of location, precipitation intensity and movement of thunderstorm cells [7, 8]. The tornado product was primarily safety-oriented. Finally, warnings of cloud-to-ground lightning near the airport, while beneficial to airline ground operations such as refueling and baggage handling, were not considered an element in reduction of in-flight delay.

The Automatic Terminal Information Service (ATIS) timers–product (9) above–aid controllers in determining whether to advise of wind shear conditions in routine and "special" ATIS messages. The WSP GSD provides these timers in a format identical to that of the ITWS Situation Display.

3.0 WSP DELAY BENEFITS ASSESSMENTS METHODOLOGY

3.1 ITWS BENEFITS APPROACH

Our methodology and data draw heavily from the ITWS benefits assessment [10], conducted following the 1993-1994 demonstrations in Memphis, Orlando and Dallas/Ft. Worth. FAA/Lincoln Laboratory ITWS prototypes were used to demonstrate the system's products at ATC and airline facilities during the thunderstorm season. Following the demonstrations, ATC users were interviewed in order to compile a list of "benefit categories"; that is, tasks that the products facilitate by providing information that is relevant to operational decision making. These are summarized in Table 3 of the following subsection and are described in more detail in Appendix A.

For each benefit category, the users were asked to estimate:

1. The number of aircraft that benefit in a particular instance where the category is realized;
2. The amount of delay reduction per aircraft;
3. The number of times per year that this benefit category would be applicable.

For the airport which the users served, the product of these three estimates yields total yearly delay aversion associated with this benefit category. Adding the corresponding estimates for all benefit categories provided an estimate of the total delay averted by use of the ITWS products.

At airports other than those involved in the demonstration programs, it was assumed that the amount of delay that would be averted scales proportionally to the product of the number of aircraft operations and thunderstorm occurrence rate. The constant of proportionality is derived by dividing the estimated benefit at the demonstration airports by the corresponding yearly aircraft operations and thunderstorm day counts. These proportionality constants, or "benefits coefficients," were computed separately for various airport categories represented in the ITWS demonstration programs:

1. Non-hub airports whose capacity is well above the level of demand (MCO);
2. Small hubs whose demand sometimes approaches capacity (MEM);
3. Larger hubs whose demand often approaches capacity (MSP, PHL);
4. Double hubs and airports with very little excess capacity (DFW, ORD).

Government accepted figures for the value of passenger time and industry estimates for the rate of fuel consumption and other operating costs were used to convert the benefit coefficients for delay hours into corresponding coefficients for the dollar costs of the delay.

3.2 ADAPTATION TO WSP BENEFITS CALCULATION

With the exception of LAX and Honolulu, all WSP airports fall into the non-hub airport category. The ITWS benefits coefficients were modified according to the considerations of the following paragraphs in order to account for differences between the ITWS and WSP product suite and for differences in the nature of air traffic operations at airports served by the respective systems.

3.2.1 WSP versus ITWS Product Suite

As discussed in Section 2.3, not all ITWS products are generated by the WSP, and the accuracy of some products is less than the corresponding ITWS product. A relative "effectivity" (*vis a vis* ITWS) for the WSP to avert delay was estimated for each of the identified benefit categories using the reasoning detailed in Appendix A. Table 3 lists the benefit categories considered and the relative effectivity ascribed to the WSP. For each benefit area, the ITWS benefit coefficient was scaled downwards by this relative effectivity.

3.2.2 Exclusion of Benefits Categories

Certain benefit categories were excluded altogether as being inapplicable to the smaller, non-hub airports served by WSP (for example, the category "fewer missed connections"). These benefit categories were retained only in estimation of benefits for the two large WSP airports, LAX and HNL. Delay benefits for the remaining 32 WSP airports were estimated using only those categories with a "yes" entry in the third column of Table 3.

3.2.3 Aircraft Mix

Again, with the exception of LAX and HNL, the mix of aircraft at WSP airports differs significantly from that at many ITWS airports. Figures 5a and 5b compare the number of yearly operations by aircraft type–general aviation, military, air taxi and air carrier–for the WSP and ITWS airports. On average, WSP airports support a significantly lower fraction of air carrier operations relative to the ITWS airports. Overall, about 30 percent of aircraft operations at the WSP airports are air carriers versus 57 percent at the ITWS airports.

For our assessment, no delay related benefits were ascribed for general aviation and military operations at the WSP airports. The benefit coefficient for air taxi operations considered an average load of nine passengers (versus fifty for an air carrier) and a factor of four reduction in hourly operating costs relative to those of an air carrier. Costs associated with diversion of air taxi operations to an alternate airport were reduced relative to an air carrier diversion in proportion to the relative passenger loads and operating costs.

Table 3
ITWS Benefit Categories and Relative Effectivity for WSP

Benefit Area	Relative Effectivity	Applicable to all WSP airports?
DTA Closure Anticipation	0.75	yes
DTA Traffic Balance	0.75	LAX and HNL only
Runway Shift Anticipation (tstm)	0.78	yes
Shorter Distances in TRACON	0.79	yes
Runway Shift Anticipation (GF)	0.6	yes
One Runway Opens	0.82	LAX and HNL only
ATA Re-openings Anticipation	0.80	yes
ATAs Remain Clear Anticipation	0.75	yes
ATA Closures Anticipation	0.78	yes
Land More before Shutdown	0.78	yes
Arrival Airport Re-openings	0.82	yes
Better Airport Holds	0.76	yes
More Arrivals before AAR Reductions	0.76	LAX and HNL only
Hold Jets Higher	0.76	LAX and HNL only
Fewer First Tier Ground Stops	0.81	LAX and HNL only
Better Ground Stops	0.81	LAX and HNL only
Fewer Diversions before Airport Shutdown	0.78	yes
Downstream Delay	1.0	yes
Fewer Diversions	0.82	yes
Early Diversions	0.78	yes
Fewer Missed Connections	0.78	LAX and HNL only
Shorter Ground Stops	0.78	LAX and HNL only
Don't Need an Alternate	0.78	yes
Better Fuel Estimation	TBD	yes
Less Wind Damage to Equipment	0.4	yes
Better Handling of Priority Aircraft	0.79	LAX and HNL only
Less Ramp Gridlock	0.78	LAX and HNL only

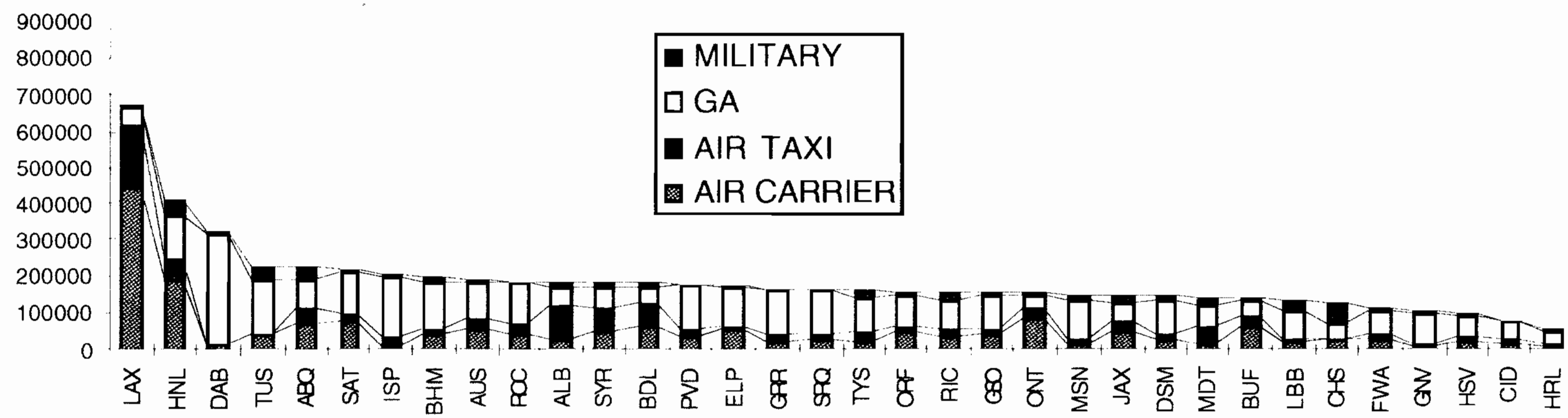

Figure 5a. 1990 WSP airport traffic counts by type of aircraft.

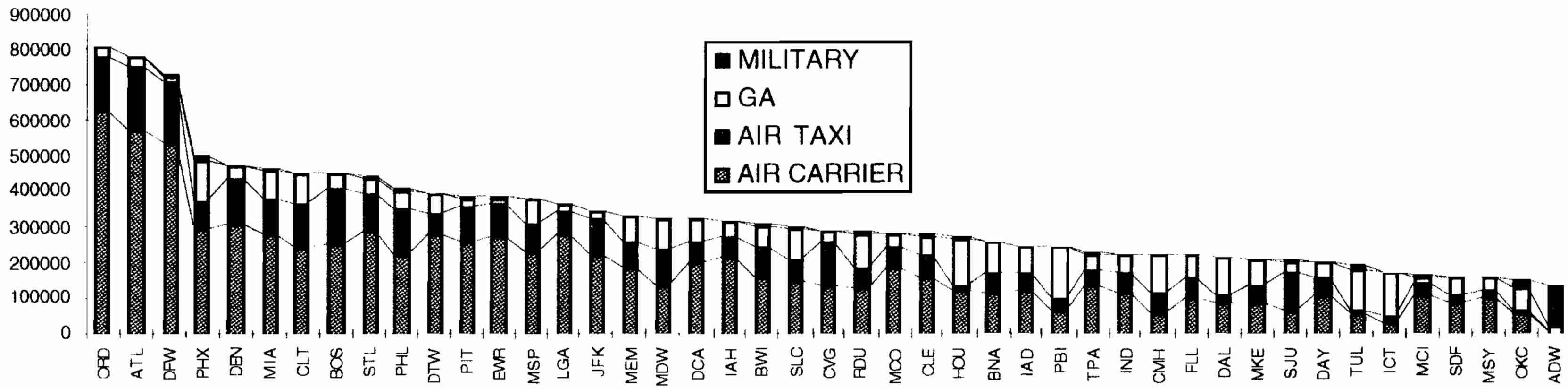

Figure 5b. 1990 ITWS airport traffic counts by type of aircraft.

3.3 ASSUMPTIONS AND LIMITATIONS

Overall, we believe that our assessment represents a conservative extrapolation of the methodology used to estimate the delay benefits for IOC ITWS. It is worth listing in one place, however, the key assumptions and potential limitations of our analysis.

3.3.1 Applicability of ITWS Demonstration Results

Because the WSP operational demonstrations and post-test controller interviews and questionnaires were not structured to quantitatively estimate delay savings realized by the system, the basis for our assessment here was "extrapolation" from the ITWS prototype demonstrations. Informal feedback from controllers and supervisors at the WSP demonstration airports, and the testimonies of efficiency benefits provided in response to the FAA Technical Center questionnaires, mirror statements provided by users of the ITWS prototypes. Based on these, and the substantial product overlap between the two systems discussed in Section 2.3, we believe that this extrapolation is well justified.

3.3.2 Anecdotal Basis

The ITWS delay benefits in turn were based on "anecdotal" estimates, provided by supervisors and traffic management specialists, of the frequency of delay benefit realization and the amount of delay averted per realization. These estimates have been substantiated to the degree possible by:

1. Our own observations of traffic flow and controller actions during demonstrations of the ITWS, WSP and TDWR prototypes;
2. Straightforward calculations–for example, the amount of time required for an unalerted aircraft to unnecessarily fly to an ATA closed by a thunderstorm before diverting to an acceptable ATA.

It is important to note, however, that our benefit estimates are not based on direct measurement of delay aversion. Given that the delay benefits realized by either the ITWS or WSP during the complex dynamics of thunderstorm impact on terminal air traffic operations will generally be a small fraction of the total delay incurred, such a direct measurement is probably not possible.

3.3.3 Passenger Time

As in the ITWS assessment, we ascribe value to passenger time at the Government-accepted rate of $41 per hour. While it is easy to construct circumstances where this value seems high (e.g., most non-business travel), this rate has been estimated by Office of Management and Budget (OMB) as the best estimate of average true costs incurred to passengers. Passenger delay accounts for approximately 40 percent of the WSP program dollar benefits tabulated in Section 4.

3.3.4 En Route Center GSD

An important assumption is that each WSP deployment will include a GSD at the position of the en route center supervisor responsible for traffic flow in and out of terminal airspace.

Efficiencies of ATA and DTA management associated with accurate, shared weather data between terminal and en route supervisors were the basis for many of the benefits categories identified in the ITWS demonstrations.

4.0 RESULTS

4.1 DELAY BENEFIT COEFFICIENTS

Table 4 lists the aggregate dollar delay benefit coefficients for the WSP, estimated using the methodology described in Section 3. The smaller values for air taxi versus air carrier reflect our reduced passenger load and operating cost assumptions for air taxis. HNL and LAX have larger benefit coefficients than the smaller WSP airports owing to their realization of additional benefit areas as detailed in Table 3.

Table 4
WSP Aggregate Dollar Benefits Coefficients for Delay

	Benefit (Dollars per operation per thunderstorm day)
Air Carriers	
HNL and LAX	0.440
Other WSP Airports	0.249
Air Taxis	
HNL and LAX	0.106
Other WSP Airports	0.049

Estimates of the delay-related benefit at any WSP airport are derived by summing air carrier and air taxi contributions, each computed by multiplying the appropriate benefit coefficient by the product of yearly thunderstorm days and yearly air carrier (or air taxi) operations. As an example, Albuquerque has an average of 42 thunderstorm days per year and the ABQ airport is projected to have 125,583 air carrier operations and 71,253 air taxi operations in the year 2000. Expected yearly delay reductions for ABQ through provision of the WSP at appropriate terminal and en route center supervisor positions would therefore total

$$42 \times [\ 125{,}583 \times 0.249 + 71{,}253 \times 0.049\ ] = \$1{,}456{,}993.$$

Aggregate delay hour benefit coefficients for the WSP are listed in Table 5. These are, of course, the basis for the dollar benefit coefficients above and are the same for air taxis and air carriers. Repeating the above calculation for Albuquerque, we estimate that deployment of the WSP there would avert roughly

$$42 \times 7.59 \times 10^{-5} \times [\ 125{,}583 + 71{,}253\ ] = 627 \text{ hours of delay each year.}$$

Table 5
WSP Aggregate Delay Hour Benefits Coefficients

	Benefit (Hours per operation per thunderstorm day)
Air Carriers and Air Taxis	
HNL and LAX	1.16×10^{-4}
Other WSP Airports	7.59×10^{-5}

4.2 DELAY REDUCTION ESTIMATES AND ASSOCIATED VALUE

Table 6 summarizes our estimates of the total yearly delay that will be averted through WSP deployment at the 34 airports currently targeted to receive the system. Projected aircraft operations for calendar year 2000 are from [11] and projections for 2000 are from [11]. Thunderstorm day counts are 30-year climatological means as tabulated in [12].

Table 6
WSP Yearly Delay Benefit Estimates

2000 Dollar Benefit	$21.3 Million
2000 Delay Hours Saved	8924

Airport-specific benefits for each of the 34 WSP airports are listed in Table 7 for year 2000 operations counts. Data on aircraft operations and thunderstorm day counts at these airports are listed in the table.

Table 7
Delay Dollars Saved Based on Estimate of 2000 Commercial Operations

Code	Airport	Days	Air Carrier Operations	Air Taxi Operations	Benefit (Delay Hrs)	Benefit (Delay $)
ABQ	Albuquerque,NM	42	125583	71253	627	1,456,993
AUS	Austin,TX	41	109675	51647	502	1,221,313
SAT	SanAntonio,TX	37	123483	31944	436	1,194,381
JAX	Jacksonville,FL	65	66645	28930	471	1,168,911
BUF	Buffalo,NY	31	133803	47165	426	1,103,007
LAX	LosAngeles,CA	4	538765	194383	341	1,030,645
SRQ	Sarasota,FL	86	38677	17097	364	898,806
TUS	Tuscon,AZ	42	82250	14184	307	888,765
ELP	ElPaso,TX	36	94569	6596	276	859,114
BHM	Birmingham,AL	58	53912	26163	352	851,435
HNL	Honolulu,HI	7	245585	72041	259	809,856
BDL	Hartford,CT	21	118067	111439	366	729,703
GSO	Greensboro,NC	45	59860	20491	274	714,992
ORF	Norfolk,VA	36	74698	14909	245	695,356
DSM	DesMoines,IA	49	48373	34025	306	670,226
SYR	Syracuse,NY	28	69477	79477	316	591,211
ROC	Rochester,NY	29	73331	36187	241	579,895
CHS	Charleston,SC	56	37203	2495	169	525,465
RIC	Richmond,VA	37	48184	30527	221	498,135
GRR	GrandRapids,MI	35	44481	43332	233	460,450
HSV	Huntsville,AL	57	28864	16155	195	453,867
FWA	FortWayne,IN	39	37029	22915	177	402,485
TYS	Knoxville,TN	47	27320	35426	224	399,647
ALB	Albany,NY	26	39851	110203	296	395,529
LBB	Lubbock,TX	47	31093	11051	150	388,812
DAB	DaytonaBeach,FL	77	18921	5852	145	384,401
MSN	Madison,WI	40	29435	22234	157	335,862
CID	CedarRapids,IA	41	28172	24311	163	335,452
MDT	Harrisburg,PA	32	23770	61234	206	283,455
PVD	Providence,RI	20	40806	32199	111	234,125
GNV	Gainesville,FL	79	8683	16203	149	232,245
ONT	Ontario,CA	4	184483	51078	71	193,552
HRL	Harlingen,TX	26	21748	2929	49	144,452
ISP	Islip,NY	25	16091	34814	97	141,943
				Total	**8,924**	**$21,274,487**

4.3 INDEPENDENT CHECKS ON DELAY BENEFITS ESTIMATES

4.3.1 WSP 1995 Demonstration at Albuquerque

As discussed, the benefit coefficients derived above were based on demonstration "exit interviews" with users of ITWS products similar to (but not identical to) those provided by the WSP. To confirm that the ITWS-based benefit methodology can be applied at the smaller airports slated to receive a WSP, we conducted post-demonstration interviews following the 1995 operational demonstration of the FAA/Lincoln Laboratory WSP prototype at Albuquerque. Controllers and supervisors at the Albuquerque terminal control facility and the Albuquerque ARTCC were questioned to ascertain:

1. Whether the identified benefit categories were applicable;
2. Whether the frequency of benefit realization estimated based on thunderstorm day and operations counts was reasonable;
3. Whether the delay savings estimated per incident were reasonable.

Overall, the controllers and supervisors that were interviewed indicated that the estimates that were extrapolated from the ITWS demonstration airports were consistent with their experiences during the summer demonstration at Albuquerque.

4.3.2 Measured Air Carrier Delay at WSP Airports

The DOT's Airline Service Quality Performance (ASQP) database tallies delay sustained by the air carrier (FAR Part 121) operators. This database includes delays from all causes (weather, mechanical problems, etc.). It does not include delay to air taxi (FAR Part 135) operators and some smaller Part 121 operators. As discussed in Section 3.2.3, these operators handle a sizable portion of passengers at WSP airports.

As a check on the reasonableness of our delay aversion estimates, we compared our estimated delay hour savings with ASQP delay tabulated at the WSP airports. Overall, the estimated total (Part 121 and 135) yearly delay aversion attributed to WSP at the 34 WSP airports is about five percent of the Part 121 yearly delay tabulated for these same airports by the ASQP. Our benefit estimate includes a "downstream" multiplier of 1.8 (see Appendix A). Thus, the actual "own airport" delay aversion claimed is in fact less than three percent of the tabulated Part 121 delay pool. Our delay aversion estimates, therefore, seem quite conservative given that most sources cite weather as a major contributor (50 percent or more) to total aviation system delay, and that the contribution to total delay from Part 135 operators was not tabulated in the ASQP data base.

5.0 DISCUSSION

Current FAA policy on deployment of ground-based wind shear detection systems is based on the previously referenced Integrated Wind Shear Systems cost-benefit analysis (IWS). The IWS estimate of WSP deployment benefit considered safety benefits associated with wind shear accident prevention and one category of delay benefit–gust front induced airport wind shift prediction. Twenty-year WSP life-cycle aggregate benefits were estimated as $71 million, or $3.6 million per year on average. (The IWS assumed the WSP would be deployed in the year 2000. IWS-computed yearly benefits actually decrease with time, owing to application of an OMB-specified seven percent yearly "discount factor" to account for the decreased value of future benefits in current-year dollars. In addition, the IWS assumed that the air carrier fleet would increasingly equip with forward-looking on-board wind shear detection radars, thus decreasing the available safety benefits pool.)

Our assessment indicates that delay-related benefits that will be realized through WSP deployment are, in fact, many times larger than the total benefits ascribed in the IWS. Our year 2000 delay benefits estimate exceeds the IWS average yearly benefit by a factor of five. Addition of the accident aversion benefits assessed in the IWS to our delay benefits estimate increases estimated year 2000 benefits from WSP deployment to approximately $25 million, or six times the average IWS benefit. Estimated yearly dollar delay aversion benefits per WSP-equipped airport vary, depending on airport operations count and thunderstorm exposure, from approximately $100 thousand to well over $1 million.

We believe that our benefits estimate errs, if anything, on the conservative side. We ascribed no benefits to delay aversion associated with military and General Aviation operations at WSP airports, a significant fraction of total activity at these terminals. We did not assess a benefit for the WSP's capability to remove AP-related false weather echoes from approach control and tower DEDS and BRITE displays, a significant source of Unsatisfactory Condition Reports (UCRs) for the existing ASR-9 weather channel.

Implications of our assessment are as follows:

1. The overall benefit-cost ratio for the WSP program has been significantly underestimated by previous FAA-sponsored studies. The IWS ascribes a benefit-cost ratio of slightly greater than unity. Our assessment indicates that the actual ratio is five or greater. (For example, extension of our methodology to general aviation (GA) and military traffic would increase the benefit-cost ratio to approximately eight.)

2. A significant number of additional ASR-equipped airports qualify for the WSP enhancement based on economic rationale. Established deployment justification is that the incremental costs of deployment be less than accrued life-cycle benefits. A five- to eight-fold increase in the estimate of the benefits of WSP justifies deployment at essentially all of the 54 ASR-9 equipped airports that will not receive the dedicated TDWR.

3. The IWS's determination that deployment of WSP is more cost effective than procurement of additional TDWRs is strengthened. Delay benefits associated with WSP deployment likely exceed those of TDWR owing to the accuracy and timeliness of WSP's vertically integrated precipitation reflectivity measurements and inclusion of a storm movement/extrapolation product.

Overall, this delay benefits assessment further supports the current FAA policy to develop and deploy ASR Weather Systems Processor enhancements at airports not slated to receive the dedicated TDWR/ITWS. Cost-benefit ratio and "net present value" estimates for WSP deployment are very favorable when these benefits are considered. An FAA update of the 1994 IWS will be accomplished by September 1996 to serve as the basis for ongoing FAA decision making with respect to ground-based wind shear protection systems. Incorporation of the results from this report will be an important element in this update.

APPENDIX A
BENEFIT CATEGORIES AND RATIONALE FOR WSP "EFFECTIVITIES" RELATIVE TO ITWS

This Appendix briefly describes the delay benefit categories considered in our assessment and the rationale we used to assign a relative effectivity for the WSP *vis a vis* ITWS. Our considerations draw heavily on the technical overlaps and differences between the two systems that are discussed in Section 2.3.

A.1 Departure Transition Area (DTA) Closure Anticipation

This benefit is realized through the ability of TRACON and ARTCC supervisors to anticipate that a departure transition area (i.e., "gate") will be closed within the next twenty minutes by thunderstorm activity. Aircraft are directed earlier towards an alternate DTA, thereby reducing flight distance to the alternate gate.

We estimate the WSP's relative effectivity for this benefit category as 0.75. Assumed degradations relative to ITWS are due to lack of the Storm Cell Information (SCI) product (0.20) which may refine a user's estimate of the severity of a displayed thunderstorm cell, and possible impact of storms beyond the WSP's 60 nmi maximum range (0.05) within the planning time horizon.

A.2 DTA Traffic Balance

Anticipation of DTA closings and re-openings allows terminal and en route supervisors to more efficiently distribute traffic flow out of terminal airspace amongst available DTAs. This benefit applies primarily to larger air terminals where traffic densities are high. Using the same rationale as in A.1, we estimate the WSP's relative effectivity for this category to be 0.75.

A.3 Runway Shift Anticipation (Thunderstorm)

ITWS and WSP products allow terminal ATC supervisors to anticipate that airport runways will close or re-open due to heavy precipitation and/or wind shear. Benefits to approaching aircraft in flight accrue from reductions in go-arounds and earlier re-direction of aircraft to the appropriate runway. Instances where ground control initially directs departing aircraft to an inappropriate runway will be reduced, thereby reducing taxi out time. This particular benefit category excludes runway shifts necessitated by gust front wind shifts. These are treated in A.5.

We estimate that 60 percent of such runway shifts are due primarily to the heavy precipitation associated with thunderstorms. Relative WSP effectivity for anticipation of these shifts is taken as 0.8 due to the absence of the SCI product. We assume that the remaining 40 percent of such runway shifts are caused by the movement or development of wind shear onto the runways. WSP effectivity in anticipating these impacts is taken as 75 percent of that achieved by ITWS. A 15 percent reduction is ascribed to the lesser detection capability of the ASR-9 sensor versus the TDWR, and a further 10 percent reduction accrues from the WSP's lack of a microburst prediction product.

Composite WSP relative effectivity for non-gust front related runway shift anticipation is therefore:

$$0.6 \times 0.80 + 0.4 \times 0.75 = 0.78$$

A.4 Shorter Distances in TRACON

This benefit accrues through improved vectoring of aircraft in terminal airspace, made possible through anticipation of thunderstorm impacts on terminal flight routes and thunderstorm-induced runway shifts.

We assume that one half of the benefit is accrued through anticipation of flight route impacts and that one half results from runway shift anticipations. WSP relative effectivity for anticipating flight route impacts is taken as 0.8 (no SCI). Effectivity for runway shift anticipation was estimated above. Composite effectivity for this benefit category is:

$$0.5 \times 0.8 + 0.5 \times 0.78 = 0.79$$

A.5 Runway Shift Anticipation (GF)

Anticipation of gust front induced runway wind shifts was the one delay-related benefit area accounted for in the 1994 IWS. Our estimate of the relative effectiveness of the WSP wind shift product, 0.6, is simply the ratio of the WSP and ITWS P_d estimates cited in Section 2.3. To be conservative, we used the lower WSP P_d measurement obtained in Albuquerque.

A.6 One Runway Opens

This benefit is realized by anticipating that hazardous weather will clear one runway, thereby allowing ground and approach controllers to position aircraft for earlier resumptions of takeoffs and landings, respectively.

We assume as in A.3 that 60 percent of the runway re-openings occur because of ATC awareness that heavy precipitation has cleared the runway; the other 40 percent occur when wind shear and microbursts are observed to clear the runway. Reasoning as in A.3 leads to a relative effectivity for the WSP of:

$$0.6 \times 0.8 + 0.4 \times 0.85 = 0.82$$

Note that we did not invoke A.3's 10 percent WSP wind shear detection degradation caused by lack of a microburst prediction product. This product does not facilitate anticipation of a runway's re-opening.

A.7 ATA Re-openings Anticipation

This benefit is realized through the ability of TRACON and ARTCC supervisors to anticipate that an arrival transition area will open as thunderstorms move off the gate. Unnecessary aircraft re-routings are avoided.

We estimate the WSP's relative effectivity for this benefit category as 0.8. Assumed degradation relative to ITWS is due to lack of the SCI product.

A.8 ATAs Remain Clear

Anticipation that an ATA will remain clear again avoids unnecessary aircraft re-routings. We assign the WSP a relative effectivity of 0.75 for this benefit category, using the arguments of A.1.

A.9 ATA Closures Anticipation

Anticipation that an ATA will close facilitates earlier re-routings of aircraft, thereby reducing flight time to a usable ATA. We again invoke the argument of A.1 to assign the WSP a relative effectivity of 0.75 for this benefit category.

A.10 Land More Before Shutdown

Anticipation that thunderstorms with associated heavy precipitation and wind shear will reach the airport and suspend operations allows ATC to give priority to landing aircraft (over departures). This reduces airborne delays at the expense of somewhat greater, but less costly, ground delay. We use the arguments of A.3 to assign a WSP relative effectivity of 0.78 for this benefit area.

A.11 ARTCC Anticipation of Arrival

ARTCC traffic planners with access to ITWS or WSP information are better able to anticipate when airports will "reopen" after having been closed by heavy precipitation or wind shear. Given the ability to anticipate airport reopenings, the ARTCC can lift traffic flow restrictions and resume normal operations rates as soon as the weather clears the airport. Using the argument of A.6, we assign a relative effectivity of 0.82 to the WSP for this benefit category.

A.12 Better Airborne Holds

Better terminal weather information helps ARTCC planners forego unnecessary holding patterns. We assume that 60 percent of airborne holds occur because thunderstorms impact a route or ATA. WSP effectivity for these impacts is taken as 0.75, as in A.9. The remaining 40 percent of airborne holds are assumed to occur due to inability to use the airports runways. As argued in A.10 we ascribe an relative effectivity of 0.78 for this circumstance. The composite effectivity for this benefit area is then:

$$0.6 \times 0.75 + 0.4 \times 0.78 = 0.76$$

A.13 More Arrivals before AAR Reduction

This benefit is realized when terminal and en route supervisors recognize that thunderstorm activity will necessitate a future reduction in airport acceptance rate (AAR). Giving priority to arriving (versus departing) aircraft minimizes airborne delay. We ascribe a relative effectivity of 0.76 to the WSP for this benefit category, using the arguments of A.12.

A.14 Hold Jets Higher

Earlier anticipation of the need for airborne holds allows these to be implemented at higher altitude, thereby reducing fuel consumption. As in the preceding two benefit categories, we estimate the WSP's effectivity relative to ITWS as 0.76.

A.15 Fewer First Tier Ground Stops

Unnecessary ground stops imposed on flights scheduled to be dispatched to the affected airport occur because of inaccurate anticipation of the start and duration of runway closings (70 percent of time) or terminal route closings (30 percent of time). Respective WSP relative effectivities are 0.82 (from A.11) and 0.80 (no SCI). The composite effectivity for this benefit category is:

$$0.82 \times 0.7 + 0.80 \times 0.3 = 0.81$$

A.16 Better Ground Stops

Improved ability to anticipate the start and duration of reduced AAR conditions facilitates effective use of ground stops for traffic management. The arguments of A.15 lead us to assign a relative effectivity of 0.81 to the WSP in this benefit area.

A.17 Fewer Diversions before Airport Shutdown

The ITWS and WSP product suite reduce occurrence of unnecessary diversions to alternate airports through providing more precision as to when thunderstorms and wind shear will reach the airport. We use the arguments of A.10 to assign a relative effectivity of 0.78 to the WSP for this benefit category.

A.18 Downstream Delay

"Downstream" delay occurs when the initial delay incurred by an aircraft and/or flight-crew is compounded as they are unable to complete subsequent flight legs on schedule.

Reference 10 describes the basis for our assumption of a downstream delay factor of 1.8. This factor applies equally to ITWS and WSP.

A.19 Fewer Diversions (Runways reopen)

Unnecessary diversions are avoided when flight crews can be advised that airport runways will re-open before their allowed holding periods have expired. Using the arguments of A.11, we assign a relative effectivity of 0.82 to the WSP for this benefit category.

A.20 Early Diversions

Early recognition that diversion of aircraft to alternates is inevitable reduces airborne holds and flight time to the alternate. The arguments of A.10 lead us to assign a relative effectivity of 0.78 for this category.

A.21 Fewer Missed Connections

Net reduction of delay for aircraft inbound to an airport reduces the occurrence of missed connections and associated costs to the airlines and to passengers. The relative effectivity for this benefit category is derived from effectivities assigned to the delay-reducing benefit categories.

A.22 Shorter Ground Stops

Improved ability to anticipate the end of reduced AAR conditions allows for earlier lifting of ground stop programs. The arguments of A.15 lead us to assign a relative effectivity of 0.81 to the WSP in this benefit area.

A.23 Don't Need an Alternate

Airline dispatchers for regional airlines may use real-time weather information to influence a decision whether or not to specify an alternate destination for aircraft scheduled to arrive at the ITWS or WSP airport. Flights that do not specify an alternate destination carry less fuel than those that do.

The relative effectivity for this benefit category is derived from effectivities assigned to the delay-reducing benefit categories.

A.24 Better Fuel Estimation

Airline dispatchers may use real-time weather information to recognize situations when they do not need to carry excess holding fuel.

The relative effectivity for this benefit category is derived from effectivities assigned to the delay-reducing benefit categories.

A.25 Less Wind Damage to Equipment

Anticipation of the arrival of damaging winds at an airport allows ATC facilities personnel and airline operators to shelter or secure ground equipment. WSP benefits in this area would be derived from the gust front product. ITWS provides additional relevant information through its tornado and SCI products. We degrade the previously assumed WSP gust front relative effectivity an additional 0.2 owing to absence of these products. The effectivity for this benefit category is therefore 0.4.

A.26 Better Handling of Priority Aircraft

Airline dispatchers may use ITWS or WSP information to recognize deteriorating terminal weather conditions and choose to give departure or arrival priority to full flights or flights with international connections rather than relatively empty flights.

The arguments applying to improved terminal flight routing (A.4) are used here to assign a relative effectivity of 0.79.

A.27 Less Ramp Gridlock

Net reduction of the duration and extent of ground delays during thunderstorm episodes alleviates the compensating increases in gate push-back requests following the clearing of the airport. Mitigation of associated "traffic jams" further reduces net delay associated with the thunderstorm episode.

The relative effectivity for this benefit category is derived from effectivities assigned to the delay-reducing benefit categories.

GLOSSARY

AAR	Airport Acceptance Rate
ABQ	Albuquerque International Airport
AP	Anomalous Propagation
ARTCC	Air Route Traffic Control Center
ASQP	Airline Service Quality Performance
ASR-9	Airport Surveillance Radar
ATA	Arrival Transition Area
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
BRITE	Bright Radar Indicator Tower Equipment
DEDS	Data Entry and Display System
DFW	Dallas/Ft. Worth International Airport
DTA	Departure Transition Area
FAA	Federal Aviation Administration
GA	General Aviation
GSD	Geographic Situation Display
HNL	Honolulu International Airport
IOC	Initial Operating Capability
ITWS	Integrated Terminal Weather System
IWS	Integrated Wind Shear Systems Cost-Benefit and Deployment Study
LAX	Los Angeles International Airport
MCO	Orlando International Airport
MEM	Memphis International Airport
MSP	Minneapolis International Airport
NEXRAD	NEXt generation weather RADar
OMB	Office of Management and Budget
ORD	Chicago-O'Hare International Airport
PHL	Philadelphia International Airport
RDT	Ribbon Display Terminal
SCI	Storm Cell Information
TDWR	Terminal Doppler Weather Radar
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control facility
UCR	Unsatisfactory Condition Report
WSP	Weather Systems Processor

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