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Airport Surface Delays and Causes

A Preliminary Analysis

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FOREWORD

This study was performed under the auspices of a Memorandum of Agreement between the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) to support advanced aviation technologies and airspace system investment analysis. Specifically, it supports the NASA Terminal Area Productivity (TAP) Program.

This report was produced under the supervision of Dr. David K. Chin, currently with MCA Research Corporation and formerly with Lockheed Martin. The principal analysts and authors were Jay Goldberg and Tammy Tang, both of Lockheed Martin. The authors take full responsibility for all analyses, conclusions, viewpoints, and interpretations expressed in this report.

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1.0 Overview

This report summarizes FAA Program Analysis and Operations Research Service (ASD-400)/ Lockheed Martin activities and findings related to airport surface delays and causes, in support of NASA Langley Research Center's Terminal Area Productivity (TAP) Program.

The activities described in this report were initiated in June 1995. A preliminary report was published on September 30, 1995. The final report incorporates data collection forms filled out by traffic managers, other FAA staff, and an airline for the New York City area, some updates, data previously requested from various sources to support this analysis, and further quantification and documentation than in the preliminary report. This final report is based on data available as of April 12, 1996.

This report incorporates data obtained from review and analysis of databases and literature, discussions/interviews with engineers, air traffic staff, other FAA technical personnel, and airline staff, site visits, and a survey on surface delays and causes. It includes analysis of delay statistics; preliminary findings and conclusions on surface movement, surface delay sources and causes, runway occupancy time (ROT), and airport characteristics impacting surface operations and delays; and site-specific data on the New York City area airports, which are the focus airports for this report.

Some key findings relating to surface delays and causes, and specifics of the New York airports:

* According to airline reports to the Air Transport Association (ATA), in 1994, airlines incurred 786,000 hours of delays; 586,000 hours, or 74.5 percent of the total, were on the surface in the form of gateholds, taxi-out, or taxi-in delays. Over 1/3 of the surface delays reported to the ATA, 197,000 hours, were incurred at the 10 TAP focus airfields.

* The vast majority of surface delays are incurred waiting in the departure queue, and to a lesser extent, arrivals waiting for gates. At some airports, ramp congestion causes taxi-out and taxi-in delays. Surface congestion varies depending on traffic volume, airport layout, runway configuration being used, and local weather.

* A key determinant for surface movement is ground visibility; most of the time when instrument flight rules are in effect, surface visibility is adequate for normal aircraft movement.

* Weather frequently impacts surface movement even when it does not impact the airport; surface delays are often caused by groundhold or severe weather avoidance programs.

* In the New York City area, airspace congestion and restrictions intensify the severity of ground delays; with local or en route weather, arrivals are heavily favored over departures, since there is virtually no flexibility to divert.

* Runway occupancy time is not generally viewed as a capacity constraint, given current procedures; with new technology and procedures it could be a capacity constraint.

2.0 Background and Scope of Study

2.1 Background and Context

While many of the inefficiencies and delays in today's National Airspace System (NAS) can be ascribed to lack of capacity, it is clear that these problems cannot be resolved simply by building more airports or runways - there are constraints of physical space, airspace, money, and the environment. As such, the FAA and NASA are focusing attention on increasing capacity and efficiency within these constraints.

Weather has always been a primary obstacle to the smooth flow of aviation. Although weather media events such as hurricanes and snowstorms are obvious impediments to aviation activity, thunderstorms and low ceiling/visibility cause temporary shutdowns of airports, runways, and airspace, slow down airport arrival rates and surface movement, and increase the risk of accidents on a daily basis. According to the FAA's Air Traffic Activity and Delay Reports, 65 percent of delays of greater than 15 minutes in the 1984-1994 period were attributable to weather[1]. ASD-400/Lockheed Martin estimates that over 40 percent of all delay costs (including delays of less than 15 minutes) are caused by weather[2]. In 1994, this equated to over $1.2 billion in direct aircraft operating costs (fuel, crew, and maintenance), and $2.8 billion in passenger time lost (using FAA Critical Economic Values for passenger time[3]). Even at an airport with clear weather, delays are often incurred due to weather at destination terminals or in the en route airspace. Furthermore, according to National Transportation Safety Board (NTSB) statistics, about 40 percent of aviation accident casualties (fatalities, injuries, aircraft damage) are incurred due to weather, and low visibility significantly increases the incidence of runway incursions.

The FAA is currently implementing or planning several programs which will enable improved weather data acquisition, displays to controllers, analysis, and dissemination; and improved guidance on the airport surface. These programs are listed and described in FAA's Capital Improvement Plan (CIP), which contains all acquisition programs, and in the Research, Engineering, and Development (R,E&D) Plan, which covers FAA initiatives in the pre-acquisition phase. Successful R,E&D projects either support or are transitioned to CIP programs. However, FAA's capability to improve the NAS is subject to budgetary constraints. The present annual CIP budget is $2-2.5 billion, while the R,E&D budget is about $250 million, but both, like other federal programs, face severe austerity measures which could result in programs being postponed, cut, or even canceled. Current projections are for a CIP budget of $1.7-1.8 billion, and an R,E&D budget of less than $200 million for the rest of the decade.

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[1] Produced by FAA Air Traffic Management Service (ATM-300); this is an average of annual figures 1984-94. These reports list the number of delay events of greater than 15 minutes.

[2] This is a global estimate for delays of all durations, used in several Cost-Benefit Analyses of FAA weather programs; delays of less than 15 minutes are more likely to be caused by congestion.

[3] These are policy values used by the FAA for passenger time, fatalities, and injuries. The methodology used to derive these values is explained in "Economic Values for Evaluation of FAA Investment and Regulatory Programs" (FAA-APO-89-10). The values, which also include industry average values for aircraft operating costs, replacement and repair of aircraft, are updated regularly.

NASA is engaged in advanced aviation research, looking beyond the FAA's R,E&D Plan, on a number of levels. The NASA Langley Research Center's Terminal Area Productivity (TAP) Program is focused on improving airport and terminal airspace operations, and includes several research initiatives with the aim of achieving clear weather capacities in instrument meteorological conditions (IMC) without compromising safety. IMC is distinguished from visual meteorological conditions (VMC), in which aircraft navigation, landing, and separation can be accomplished visually. The four key elements of the TAP Program are: Reduced Spacing Operations, Air Traffic Management, Aircraft-air traffic control (ATC) Systems Integration, and low visibility landing and surface operations (LVLASO). The first two elements deal with the terminal airspace, LVLASO with ground movement, and Aircraft-ATC Integration with both.

In order to better evaluate the potential impact of TAP technologies, NASA decided to focus its analyses on 10 major airports. These airports were selected on the basis of high level of aviation activity, significant occurrence of IMC, and significant levels of delays. The 10 airports selected, with location identifiers (used hereafter) are:

Atlanta Hartsfield International (**ATL**)
Boston Logan International (**BOS**)
Chicago O'Hare International (**ORD**)
Dallas-Fort Worth (**DFW**)
Detroit Metropolitan Wayne County (**DTW**)
Los Angeles International (**LAX**)
New York Kennedy International (**JFK**)
New York LaGuardia (**LGA**)
Newark International (**EWR**)
San Francisco International (**SFO**)

2.2 Scope of Study

This analysis was conducted to support the LVLASO element of TAP. LVLASO's stated goal is to "improve the efficiency of airport surface operations for commercial aircraft operating in weather conditions to Category IIIB {i.e., runway visual range, or RVR, down to 150'} while maintaining a high degree of safety"[4]. LVLASO is concerned with aircraft operations on the runway, taxiways, and gate area, and the integration of various elements of the air traffic system, including the aircraft cockpit. To support surface operations, the specific deliverables envisioned are: surface guidance, navigation, and surveillance technology; steering and braking guidance and control for roll-out turnoff and integration guidelines for safe landing, roll-out, turn-off, and taxi; a dynamic runway occupancy measurement (DROM) system; and recommended procedures for aircrew and air traffic management during surface operations.

NASA's Advanced Subsonic Technology Program, which includes the TAP Program, and the FAA's Program Analysis and Operations Research Service (ASD-400) have entered into a memorandum of agreement under which ASD-400, with its contractor, Lockheed Martin, will provide operations research and economic analysis support to the TAP Program. In order to assist the TAP Program, and specifically the LVLASO element to better focus its research efforts in a tight budgetary environment, ASD-400/Lockheed Martin are tasked to evaluate surface delays and causes, under both VMC and IMC, to determine the extent of the surface movement problems, and to identify the loss of capacity/efficiency associated with IMC conditions. Further,

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[4] Quoted from LVLASO Level III Plan Update, 1995 Briefing

since TAP is evaluating terminal airspace as well as the surface, the LVLASO element requires understanding of the extent to which runway occupancy time (ROT) is a constraint to capacity, and whether reducing ROT, particularly under IMC, would be a useful research objective.

The goal of this analysis is to present both general and airport-specific analyses of surface movement, the impact of IMC on surface movement, the sources of surface delays, and bottlenecks. Although a number of delay reports and databases exist, these do not identify the sources or specific causes of delays. The FAA's monthly Air Traffic Activity and Delay Report attributes delays of greater than 15 minutes to 'weather', 'terminal volume', 'center volume', etc., but only lists the number of delay incidents of greater than 15 minutes. Delays are broken out in several databases by phase of flight: gate, taxi-out, airborne, and taxi-in; but these merely note the phase in which the delay occurs. For example, taxi-out delay includes any delay between push back from the gate and wheels off; there is no indication whether a taxi-out delay occurs due to ramp congestion, surface movement delays, or waiting in the queue. Similarly, the causes of these delays are not provided beyond the categories in the Air Traffic Activity and Delay Reports.

On a macro level, this report attempts to address these issues in general, noting general issues, global trends, airport characteristics and other factors impacting surface movement and delays. On a micro level, it also includes airport-specific analyses. The 10 TAP airports were evaluated to identify a 'focus airport' to analyze in detail. The choice was to evaluate the three New York City area airports, JFK, EWR, and LGA. The proximity of the airports to each other renders them largely interdependent, and air traffic controllers at the New York en route center and TRACON, and air traffic managers in the FAA's Eastern Region have to in many ways treat the three airports as one. Key factors in the selection of the New York Metroplex were:

- All three suffer very high levels of surface delays.
- All three have significant levels of IMC and weather delays.
- All are high volume airports, near their physical capacities, with minimal room to expand - and thus are highly dependent on capacity enhancement measures not involving pavement.
- The three airports provide interesting contrasts: JFK is the nation's primary international airport; LGA is a physically small airport with heavy shuttle traffic and a constant heavy flow of activity; EWR is a major hub.

A subsequent study will evaluate airport surface delays and causes at all 10 TAP airports, with input from traffic managers, airlines, and pilots.

3.0 Current and Planned Capabilities

3.1 Current IMC Surface Movement Capabilities and Deficiencies

Low ceilings and visibility conditions present many obstacles to the smooth flow of aviation, reducing airport and airspace capacities, and increasing the risk of accidents. The impact on a specific airport depends on the configuration, but arrival acceptance rates are reduced, and many airports lose the use of runways. Surface movement slows, even if many aircraft (particularly general aviation, GA) are not operating. Runway/taxiway crossings require considerably more caution, and the rate of runway incursions increases. Further, current weather processing and prediction capabilities do not provide controllers data on when IMC will occur or lift. This often increases delays, since controllers may not be able to plan adequately for IMC procedures, and may not be able to restore the airport to full capacity in a timely manner when the IMC lifts.

Visual flight rule (VFR) separations are presently maintained by pilots visually on final approach, both for single and parallel runways. On closely spaced parallel runways (<2,500') wake vortex is a factor, but the additional lateral separation requirement has only a minimal impact on capacity; about 5 percent. Figure 3.1-1 displays nominal representative VFR capacities for single and parallel runways[5]. These are 'typical' capacities; actual capacities may vary depending on the airport and airspace environment, local restrictions, fleet mix, ROT, and controllers.

Under instrument flight rules (IFR), controller-maintained radar separations are enforced on final approach, and multiple runway configurations can lose much of their capacity. Parallel runways may be too closely spaced to allow for simultaneous operations, so what are independent runways under VMC are reduced to dependent (typically, where runways are 2,500'- 4,300' apart), and dual runways are rendered virtual single runways (runways are <2,500' apart) in IMC. With separations greater than 4,300', runways remain independent, and are subject only to single-runway reduced arrival and departure rates. Figure 3.1-2 displays representative IFR capacities for single and parallel runway configurations, with capacity reductions. Again, these are typical figures only, and can vary. Note that departure capacity is reduced much less dramatically than arrival capacity: 5-6 percent vs. 27 percent for a single-use single runway. In most cases, departures may be reduced much more, since a runway or parallels may be used for both arrivals and departures.

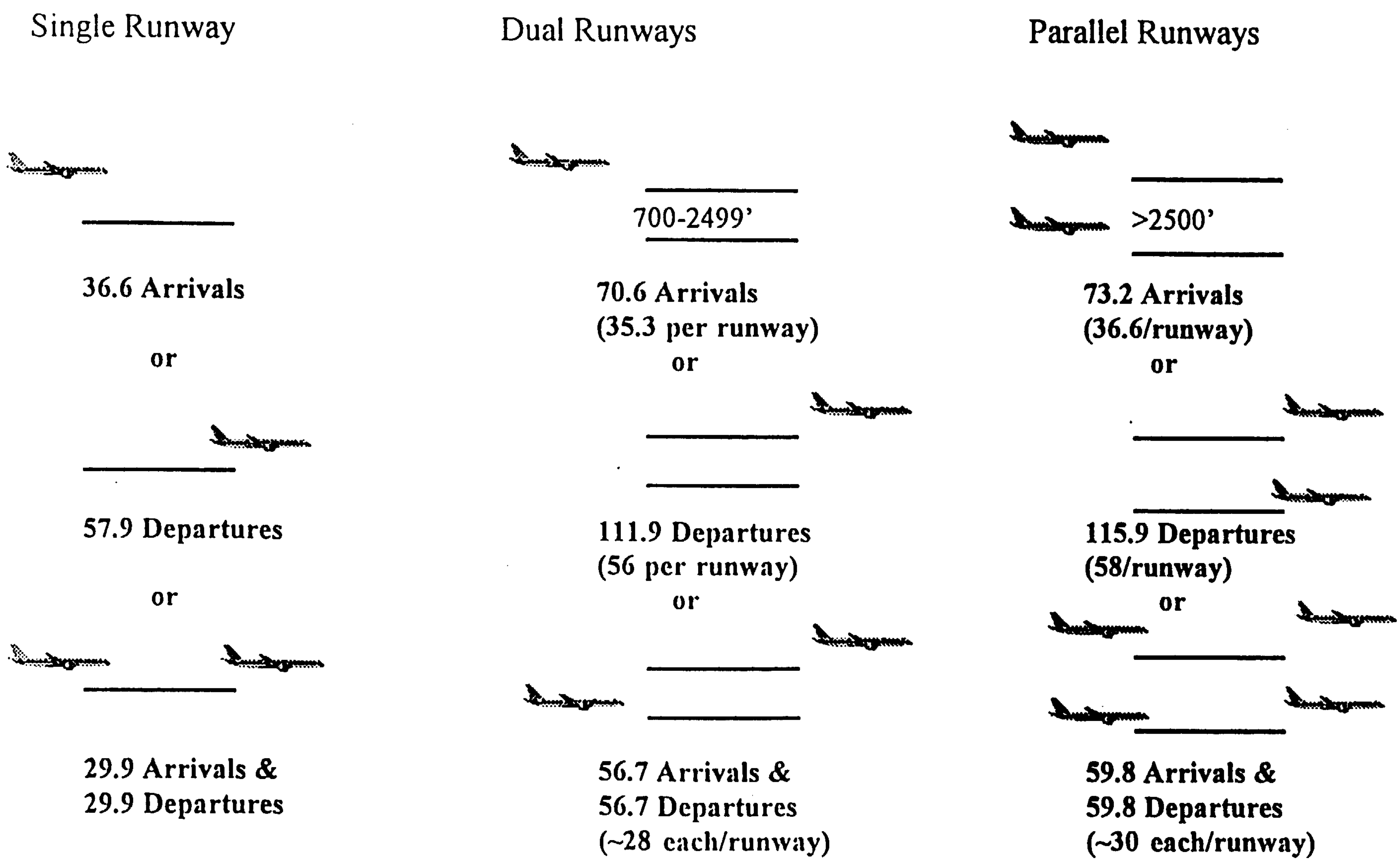
The IFR approach procedures for the 10 TAP airfields are:

- Independent Parallels: ATL, DFW, DTW, LAX, ORD
- Dependent Parallels: JFK
- Single Runways: BOS, EWR, LGA, SFO

Where runways intersect (of the 10 TAP airports, all but ATL, DFW, and LAX have intersecting runways), one of the intersecting runways is shut down, or the two runways operate dependently.

[5] VFR and IFR capacity estimates from FAA-DL5-87-1, "Estimates of Potential Increases in Airport Capacity Through ATC System Improvements in the Airport and Terminal Areas"

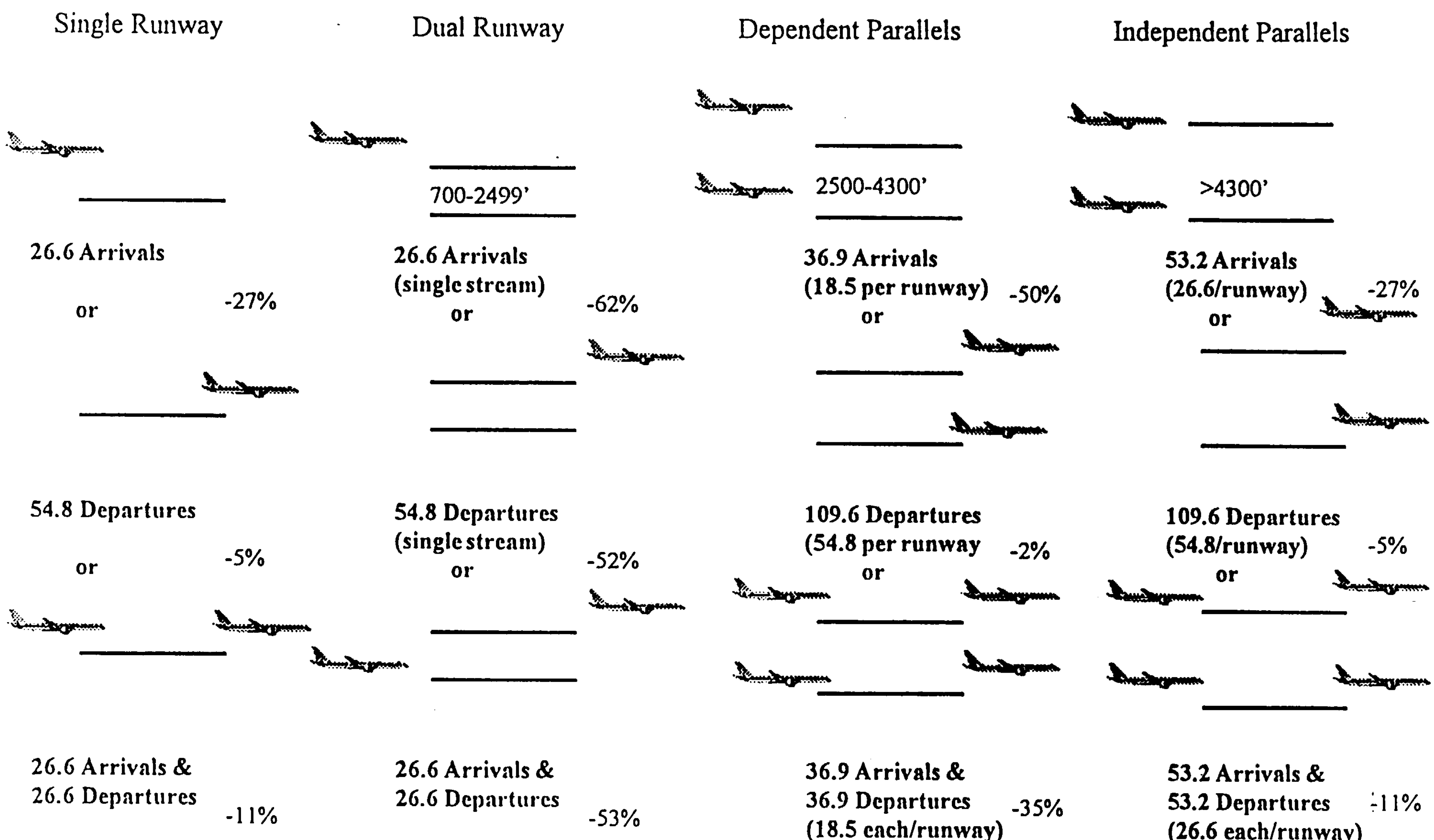
Figure 3.1-1: Typical VFR Capacities Today *



* *Average arrival acceptance and departure rates; numbers will vary by airport.*

Figure 3.1-2: Typical IFR Capacities Today *

With Reductions from Corresponding VFR Capacities



* *Average arrival acceptance and departure rates; numbers will vary by airport.*

Taxiing operations are also slowed down where taxiways cross runways, since aircraft must be cleared. Where controllers do not have adequate radars and display systems, a clearance may require position reports and confirmations over highly crowded communications channels.

The Airport Surface Detection Equipment (ASDE), version 2, was installed at 12 major airports to assist controllers viewing the airport, but ASDE-2 is an analog radar built on vacuum-tube technology. It has experienced high failure rates and is of limited use to controllers during low visibility conditions. The FAA is currently replacing the ASDE-2s with ASDE-3 radars and is installing ASDE-3s at an additional 23 sites (in total, 35 major airports, including all 10 TAP airports). ASDE-3, a more reliable, real-time, solid state system, which displays aircraft and ground vehicle positions accurately to controllers in IMC, has thus far been commissioned at 20 sites, including 8 TAP airports (EWR and LGA are scheduled to be commissioned in 1997).

ASDE-3 presents the controller a relatively 'clutter-free' display over an airport map underlay, and can help reduce the amount of communication required for clearances. However, even ASDE-3 does not improve the pilot's situational awareness.

Weather reporting and prediction are also problems. Current equipment does not successfully indicate the onset and lifting of IMC, and is only beginning to accurately report thunderstorms. Airports without the Terminal Doppler Weather Radar often have poor warning or reporting of thunderstorms (TDWRs are scheduled for 45 airports, including 8 TAP airports - see Figure 3.2-1 - but the program has suffered numerous problems with land acquisition). At some airports, individual airlines have implemented their own weather systems, which may provide them with data that the controllers do not have.

A further problem is the integration of systems on several levels; often FAA ATC systems are not fully integrated, preventing the optimal dissemination of data. Additionally, tower controllers and ramp controllers may not have the same information. Ramp controllers often have little data on aircraft positions or which aircraft are ready to arrive or depart. Some airlines have purchased for their hubs a passive radar system, called PASAR, which provides real-time position feeds to enable ramp controllers to more effectively sequence departures and position arrivals, but PASAR is most useful for hubbing operations, since it does not provide data on the flight plans of the target aircraft (which the ramp controllers would have for their own aircraft)[6].

3.2 FAA Terminal Surface and IMC Operations Programs

In evaluating the operational impact and potential benefits of TAP/LVLASO technologies, their effectiveness must be evaluated not against the current environment, but against the aviation environment which will be in place when such technologies will be implemented. With rapidly advancing technology in a number of key fields, major enhancements in several areas are expected. The FAA's Strategic Plan (March 8, 1994) includes as one of its airport surface movement goals "Ground taxi-in and taxi-out average delays should be reduced by a minimum

[6] PASAR is a monopulse radar, which basically reads data from the ASR-9, Mode S, or Beacons; the FAA's Surface Movement Advisor provides flight data, and will be for general use.

of 15 percent from the 1990 level, and further improvements should allow for growth in operations without increases in ground delay."

Despite the current inefficiencies in airport surface movement and IMC operations, the FAA has a number of CIP programs to be implemented over the next decade which will provide significant improvements in the areas of surveillance and traffic management; lighting and guidance; and weather display, reporting, and forecasting. In addition, the FAA is cooperating with industry to promote and develop standards for aircraft movement and procedures, cockpit displays, and aircraft lighting in order to make IMC surface movement more efficient and safer. These efforts are summarized in Figure 3.2-1. This chart notes FAA programs in these areas, briefly describes their functionality, notes implementation dates, and where appropriate, notes which of the 10 TAP airfields will be covered by systems. In addition, relevant R,E&D programs are included in italics.

In the area of surveillance and traffic management, two key enhancements to ASDE-3 are planned, the Airport Movement Area Safety System (AMASS), and Airport Surface Target Identification System (ATIDS, formerly, Airport Surface Traffic Automation, ASTA). AMASS will be the first level of automation for ASDE-3; it will provide automated conflict alerts to controllers when aircraft are getting too close to other aircraft, ground vehicles, or obstacles. It also improves the effectiveness of ASDE-3 by distinguishing between radar signal reflections from stationary objects and real targets. A full-scale development model will be deployed at SFO for operational testing by June 1996.

ATIDS is a longer term program to develop surface surveillance, communication, and automation techniques to provide an effective all-weather runway incursion alert and prevention system. ATIDS is expected to include software enhancements to share data with the departure sequencing program (DSP) and terminal air traffic control automation (TATCA) to create an inter-related arrival-departure sequencing system. It will link ASDE-3, Mode S, and airport surface radar (ASR-9) surveillance sensors to provide continuous target coverage throughout the terminal surface and airspace areas. One element of this is to provide target identification data tags for aircraft (air carrier and GA) and airport vehicles.

Two other surface movement programs of note are the surface movement advisor (SMA), and the Center-TRACON Automation System (CTAS) Final Approach Spacing Tool (FAST). SMA will be an element of the Tower Automation Platform, and will probably be integrated with the Terminal Control Computer Complex (TCCC)[7]. Originally part of the ASTA program, it will probably be linked with ATIDS. SMA will provide ramp controllers with aircraft position and routing data for both arrivals and departing aircraft, which will enable improved sequencing of aircraft; for example, ramp controllers could line up departures to avoid having consecutive aircraft heading on the same departure path. SMA is projected to reduce taxi delays by 5 to 15

[7] The means of implementing SMA are currently not clear. The concept originated as an enhancement to ASTA called Traffic Planner/Conformance Monitor, TPCM. ATIDS may be placed under SMA.

Figure 3.2-1: FAA Programs Impacting Terminal Surface/IMC Operations

Program	Description/Functionality	Op Date	ATL	BOS	DFW	DTW	EWR	JFK	LAX	LGA	ORD	SFO	Comments
			TAP Airports (X Indicates Installation at airport)										
Surveillance/Traffic Management													
Airport Surface Detection Equipment (ASDE-3)	Ground movement radar: Detects acft, vehicles moving on surface, displays positions to controllers	1993-96	X	X	X	X	X	X	X	X	X	X	Sited for 37 aflds; 20 commissioned, inc. 8 TAP (not yet at EWR, LGA)
Airport Movement Area Safety System (AMASS)	Warns of, displays surface conflicts on ASDE-3; provides safety logic, aural, visual alerts	1997-99	X	X	X	X	X	X	X	X	X	X	At ASDE-3 aflds, testing at SFO, BOS
Data Link for GPS/ADS on Airport Surface	*ID of data links for all aircraft, ground vehicles for GPS-Automated Dependent Surveillance Integration*	*1996-97*											*Establish standards for aircraft, ground vehicles*
Airport Surface Target Identification System (ATIDS)	Target IDs for air carriers on ASDE-3; tags for GA; Integrates GPS, ADS on surface	2001-03	X	X	X	X	X	X	X	X	X	X	Planned at ASDE-3 aflds, but studying cost-effectiveness by site; testing at ATL
Surface Movement Advisor (SMA)	Provides runway use data to ramp controllers for optimal sequencing of arrivals, departures	1998-2000	X	X	X	X	X	X	X	X	X	X	To be part of Tower Automation Platform, integrated with TCCC
CTAS/Passive Final Approach Spacing Tool (FAST)	Provides efficient landing sequencing for runway load balancing	2000-01			X		X	X	X	X	X		CTAS Build 2; ARTS III-E sites to get prototype "passive FAST"; testing at DFW
CTAS/FAST, Build 3	Descent Advisor, conflict probe for optimal arrival and landing	2002-03	X	X	X	X	X	X	X	X	X	X	Will include enhanced Build 2 functionality; program scope in flux
Lighting/Guidance													
Runway Status Lights	"Traffic signals" for intersecting runways/ taxiways; 'red light' activated by radar	1996-1998	X	X	X	X	X	X	X	X	X	X	At ASDE-3 sites, interface with ASDE-3, ATIDS; being tested at BOS; NASA-LaRC participating
Automated Airfield Lighting Control	Standards and specifications for automated control of airfield lighting, CHI for system	1996-97											Standards being developed by VNTSC, emphasizing COTS products
Weather													
Terminal Doppler Weather Radar (TDWR)	Detects microbursts, gust fronts, wind shifts, precipitation in terminal area	1994-97	X	X	X	X	X	X		X *	X		At 45 aflds with high convective activity; LGA covered by JFK radar
Icing Forecasts (R,E&D Project)	*Will ID icing areas, severity, duration; forecast onset, intensity, cessation of icing conditions*	*~2000*											*Will transition to ITWS, WARP*
Airport Ceiling and Visibility Forecasts (R,E&D)	*Develop short (<30 min), longer-term (to ~4 hr) c/v forecasts*	*~2000*											*Will transition to ITWS, WARP*
Weather and Radar Processor (WARP)	En route weather data processor, but will show storm position and motion	1999	X	X	X	X	X	X	X	X	X	X	At ARTCCs, but covers airports; P3I will include ceiling/vis. algorithms
Integrated Terminal Weather System (ITWS)	Provides controllers at towers, TRACONs, ARTCCs detailed, integrated terminal area weather display	2000-01	X	X	X	X	X	X		X	X		At TDWR airports; much of IMC impact may come from P3I, ~2003-06
Aircraft/Cockpit Technologies													
Cockpit Moving Maps	4 Layers: (1) afld diagram, (2) GPS map, (3) taxi route, (4) other traffic	1996											All 4 layers demo'd; RTCA developing standards
Cockpit Procedures for Surface Movement	FAA-Industry effort to define cockpit coordination, special precautions in IMC	1996-97											Report on 'best practices'; to serve as training/education aid
Improved Aircraft Conspicuity	Establish recommended practices for acft lighting during low visibility surface operations	1996											Recommended practices for acft lighting during night, low visibility
Land and Hold Short Operations (LAHSO)	Add capacity by allowing landing on intersecting runways or designated short hold points	1996											Need visual aids, procedural changes, for both wet, dry conditions

Standard type indicates FAA Capital Investment Plan Program or FAA/Industry initiative with product results

Italics indicate Research, Engineering and Development (R,E&D) Program or research support to CIP Program percent[8]. Further, SMA will provide a surface safety system, including automatic alerting to aircraft and controllers, automatic runway status lights, active taxi route guidance, delivery of surface traffic data to the cockpit, and direct cockpit alerts.

FAST will essentially provide TRACON controllers with analogous capability for landing aircraft; enabling more efficient use of runways by sequencing to balance runway usage. A prototype, sometimes called 'passive FAST', will be provided to sites supported by the ARTS III-E radar (New York, Chicago, Southern California, Dallas, and Denver TRACONs). CTAS Build 3, which will include a 'Descent Advisor' and conflict probe, to provide aircraft optimal arrival trajectories and landings, as well as passive FAST capabilities, will be deployed at up to 25 TRACONs, probably including all 10 TAP airports.

Lighting/guidance programs and standards are being developed to automate runway lighting to provide useful guidance data to pilots. Runway status lights would essentially serve as traffic signals at intersections of runways and/or taxiways. These would be integrated with the ASDE-3 system, and may receive data from ATIDS. Software upgrades to enable the status lights to better guide aircraft are likely. Currently status lights are being developed and tested at BOS, with NASA-Langley and Lincoln Laboratory participating in the testing.

Weather detection, analysis, display, and prediction capabilities will all be significantly upgraded. With completion of the TDWR installation (scheduled by 1997), 45 major airports with high levels of convective activity will have a system to detect microbursts, gust fronts, wind shifts, and precipitation. Multiple R,E&D efforts are aimed at detection and short-term prediction of IMC phenomena and icing conditions.

However the availability of real-time weather data and short-term predictability will come largely with the implementation of the FAA's primary weather processing programs, the Weather and Radar Processor (WARP), and the Integrated Terminal Weather System (ITWS). WARP, to be installed in 1999, will be an en route system, but will provide en route traffic managers real-time weather data with airport boundary underlays, so that traffic managers can determine storm location and motion around airfields. Pre-planned product improvements (P^3I) to be implemented in 2000-2003 include ceiling/visibility algorithms, which could provide display and warning of IMC conditions. ITWS, to be installed in 2000-2001 at airports covered by TDWR, will integrate weather data from a variety of sensors to present controllers with a real-time, unified meteorological picture of the terminal area. ITWS displays will be in the towers, TRACONs, and en route centers, thus providing shared situational awareness and improved coordination between the three levels of control (processors to be located at TRACONs). ITWS P^3I features, to be implemented in the 2002-06 time frame include short term (30 minute) predictions of meteorological conditions, notably ceiling and visibility, runway wind, and

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[8] This figure is cited in the FAA Capital Investment Plan, based on an estimate by the Office of Aviation Policy and Plans (APO). It is also the range of benefits in a preliminary estimate by ASD-400.

convective weather growth and decay forecasts[9].

In addition to these CIP programs, the FAA is cooperating with industry to improve aircraft/ cockpit technologies and human performance issues. In MITRE's 1992 study "Report by Airline Pilots on Airport Surface Operations", numerous experienced airline pilots reported surface movement difficulties at major airfields, including unfamiliarity with airports; inadequate signs, markings and lighting; and inadequate airport charts. Furthermore, the survey found a lack of consistency in cockpit crew procedures during taxiing. In response to this, FAA's System Architecture and Integration Service (ASD-100) is working with industry to establish by 1997 standards for cockpit moving maps, cockpit procedures for surface movement, and improved aircraft conspiquity during night and low visibility conditions[10]. Cockpit moving map concepts are being tested; it is expected that standards will include depictions of runways, taxiways, and aircraft position derived from differential global positioning system (GPS), display of standard and low visibility taxi routes, and compliance with route clearances. Cockpit procedures for surface movement, particularly under IMC, will be evaluated, and a joint FAA-industry report, with material for crew training and GA pilot education, is to be published by late 1996.

Finally, the Air Traffic Procedures Service, ATP-120, is evaluating land and hold short operations (LAHSO) to enable landing on intersecting runways. This could increase capacity during IMC by enabling intersecting runways and taxiways to remain open. Major airports which often lose significant capacity during IMC due to intersecting runways include ORD, BOS, LGA, Cleveland (CLE), Minneapolis (MSP), and Baltimore-Washington International (BWI). At LGA, currently controllers attempt to have most arrivals exit before the runway intersection.

4.0 Approach

NASA's objectives for this study were to understand the causes of surface delays in order to be able to better focus the LVLASO research. Additionally, NASA wanted an airport-specific analysis of at least one of the TAP airfields.

In order to accomplish NASA's objectives, ASD-400/Lockheed Martin undertook to (a) determine the scope of the problem by analyzing aviation statistics, delay statistics, and meteorological data, and estimating surface delays {particularly at the 10 TAP airfields}, (b) through analysis of literature and databases; interviews with engineers, program/technical staff, and other experts; and site visits, evaluate surface delays, and to the extent possible, describe the sources and causes, with as much quantification as possible, (c) to provide some general findings and conclusions about surface delays and to identify the impact of different airport/aviation/ external characteristics impacting surface delays, and (d) focus on the New York City area airports {JFK, LGA, EWR}, to provide site-specific analysis.

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[9] See "Cost-Benefit Analysis of the Integrated Terminal Weather System", or the Operational Requirements Document for a more detailed description of ITWS functionality.

[10] These initiatives are described in the "Runway Incursion Action Plan", report DOT/FAA/ASD-100/95-01, April 1995, issued by the FAA Office of System Architecture and Program Evaluation.

Any estimation of delays is order of magnitude only, since there are different definitions of what constitutes a delay, and accounting procedures are various, inconsistent, and often incomplete. Airline schedules mask delays and inefficiencies, since they incorporate 'expected' delay times into schedules to ensure 'on-time' performance; for example, in the Official Airline Guide (OAG), flights between BOS and Washington DC (IAD or DCA) show an average of 1 hour and 40 minutes between departure and arrival times, though the actual flying time may be less than 1 hour, depending on the aircraft model, route, and winds. Thus, a variety of databases were reviewed, with much of the focus on identifying trends in delays by airport, and extracting useful background data to support this analysis. In addition, an attempt was made to determine the extent to which delays at the 10 TAP airports are attributable to weather.

Using a model to evaluate surface delays was determined not to be optimal at this point, since a more detailed understanding of surface operations was required to provide accurate inputs to any model. Thus, this effort focuses on understanding surface operations and identifying bottlenecks and sources of delays. This effort will enable more effective use of a model (i.e., more accurate, realistic inputs) to support a cost-benefit analysis of LVLASO or other TAP elements.

To obtain these data, discussions were held with engineers, ATC staff, and other operational and aviation specialists, both at the FAA, and at operational sites. System capacity simulation modelers at the FAA Technical Center in Atlantic City were consulted, since the FAA Office of System Capacity has commissioned studies on capacity and surface movement at major airports. In order to collect and quantify data on the sources and causes of surface delays, data collection forms were developed for distribution to FAA air traffic managers/controllers and airline traffic managers. For this analysis, forms were distributed through the FAA Eastern Region to traffic managers and controllers at the three New York airports, and to Continental Airlines, which has a hub at EWR (the only airline hubbing operation in the New York City area). Data collection forms were also developed for pilots, though data collection from pilots will require further coordination through a union. A subsequent study will present complete survey results, with data collection forms from ATC staff at the 10 TAP airports, several airlines, and pilots. In addition to the survey forms, Lockheed Martin staff talked with traffic management supervisors and visited airport control towers.

Four data collection forms were generated, focusing on distinct areas to be evaluated: gatehold, taxi-out, ROT, and taxi-in. The key data elements requested on the forms were:

(a) Gatehold Delays

- Sources/causes of ATC (i.e., not airline/aircraft problems) gateholds, such as destination or en route weather, or surface congestion
- Impact of local weather (at the airport)

(b) Taxi-out Delays

- Sources of VMC delays: ramp, taxi, intersections, queue, ROT
- Causes of delays

- Impact of night and different weather/IMC phenomena: low ceiling/visibility (how low to impact delays and how), wet pavement, snow/ice, sub-freezing temperatures, thunderstorms

(c) Taxi-in Delays
- Sources of VMC delays: ROT, taxi, intersections, ramp, waiting for gate
- Causes of delays
- Impact of night and different weather phenomena (as with taxi-out delays)

(d) ROT
- Factors impacting ROT, and relative importance
- Impact of different weather phenomena (as with taxi-out delays)
- Differences between air carrier/commuter/GA, domestic vs. international

For taxi-out, taxi-in, and gatehold delays, respondents were asked to estimate the percentage of such delays caused by the listed (or other) factors; or if this was not possible, to rate the factors as major, moderate, minor, or not a factor. On each form, respondents were asked first for the situation under VMC, and then for how different weather phenomena change the VMC scenario. This provides for a 'baseline' case, describing surface delays in clear, dry weather, and then allows an evaluation of the incremental impact of weather. In addition, respondents were asked to estimate taxi-out times (wheels off to queue) under VMC, nighttime, and various weather conditions. The FAA Eastern Region Office (AEA) assisted in this effort, selecting personnel at each airport to fill out the forms and coordinating throughout. In addition, Continental Airlines, which has a hub at EWR, participated in the effort. A total of 13 surveys were received; AEA provided 4 each from EWR and LGA, and 3 from JFK (a JFK Traffic Management Supervisor, an EWR controller, the rest traffic managers); Continental submitted one survey for EWR; and a traffic management officer at the Leesburg en route center with New York TRACON and en route center experience was interviewed, covering all 3 airports.

5.0 Data Sources

A primary objective in data collection for this report was to obtain a broad range of data, which is both as authoritative as possible, and representative of various interests and viewpoints. Key topics targeted for data acquisition included:

- Aviation data, such as projected activity at TAP airfields
- Capacity data for airports, including acceptance rates, restrictions, procedures
- Delay data, as aggregated as possible, nationally, and for TAP airfields
- Weather data, especially ceiling and visibility data, for the TAP airfields
- Surface movement data, on taxiing, ROT, pilot motivation, airline operations
- ATC operations, procedures, and techniques for surface traffic management
- Differences between VMC and IMC landing and surface operations
- FAA surface programs and initiatives
- Airport-specific data for JFK, EWR, and LGA

In addition, data was collected on airport/airspace models to determine the possible uses, advantages, and disadvantages of various models, and to identify the optimal model for use in a future cost-benefit analysis of LVLASO and/or other TAP programs.

A summary of key data sources, noting how data was used, is described below.

Databases -- FAA databases were used as the most authoritative sources for data on aviation activity and airport capacity. The FAA Terminal Area Forecasts (TAF), updated annually, includes historical and projected operations and passenger enplanements by class (air carrier, air taxi, commuter, GA, military) for every United States airport.

Engineering Performance Standards (EPSs), produced by FAA Air Traffic Flow Management, provide airport capacity figures for each airport. The EPSs consist of a matrix showing arrival and departure capacities per hour for each airport configuration (i.e., runway use and flow directions) at four levels of ceiling/visibility conditions[11]; (1) visual approaches; typically, ceilings >= 3,000', visibility >= 5 miles, (2) basic VFR; below visual approaches, but ceilings >= 1,000', visibility >3 miles, (3) highest circling minimum IFR; below basic VFR, but ceilings >= 500', visibility >= 1 mile, and (4) precision landing IFR; Category (CAT) I or worse.

Two FAA databases were utilized for delay data, the Air Traffic Activity and Delay Reports, and the Consolidated Operations and Delay Analysis System (CODAS). The Air Traffic Activity and Delay Report, issued monthly by FAA's Air Traffic Management Service, lists the number of delay incidences of greater than 15 minutes. It aggregates delays by cause (weather, terminal volume, en route volume, runway closure, equipment failure, other), and number of delays by airport, though not by airport by cause (however, these numbers are tracked and can be obtained). This database, however, has several deficiencies. It only counts incidences of delays, not delay times. It appears to be a poor indicator of system delays; although the number of reported delays greater than 15 minutes has gone down significantly in recent years, other data bases measuring delays of all durations do not show a corresponding drop in delay minutes per operation[12].

CODAS was developed by the FAA Office of Aviation Policy and Plans (APO) to provide "a government and industry agreed upon methodology and procedure for computing delay by flight." CODAS computes delays attributable to only air traffic and weather (i.e., not airline or aircraft problems), and provides delays by phase of flight. CODAS thus far includes only large air carrier activity, about 58 percent of scheduled flights. CODAS has been upgraded to include actual wheels on, wheels off, and actual taxi times (previously, one had to estimate these using ASR-9 data). Though CODAS will be a monthly report, unfortunately, at present there is only

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[11] The EPS numbers are more guidelines than hard numbers; a number may reflect a theoretical maximum, a restriction (e.g., no more than X departures per hour allowed), or an ATC estimate. Depending on demand and the skill of the controllers involved, hourly 'capacity' numbers can be exceeded.

[12] For example, the Airline Service Quality Performance (ASQP) database, maintained by the Department of Transportation shows the average delay per operation to be unchanged from 1991-1993, and the drop in delays from 1990-1991 to be far less than the numbers in the Air Traffic Activity and Delay Reports suggest.

one month of the revised CODAS data available (January 1995), and even this month of data is being recalibrated and validated.

A third delay reporting database used is the Air Transport Association (ATA) Air Carrier Delay Reports, a monthly publication which provides delays reported by participating airlines. This report covers all air carrier airports, but provides detailed delays by airport for 38 major airports, by phase of flight, and notes both average delay time per operation and average delay time per delay incident for each phase of flight. Data is collected from ATA member airlines. At major airports, the ATA data typically covers 55-60 percent of operations, but this varies greatly depending on the mix of traffic.

In addition, delays caused by weather, and specifically by IMC, were estimated for the 10 TAP airports using an aviation weather delay model developed by MIT Lincoln Laboratory[13]. The Lincoln Laboratory model is based on climatological and aviation activity data.

This analysis also utilized meteorological data from the National Climate Data Center (NCDC) for each of the 10 TAP airports. The NCDC's International Station Meteorological Climate Summaries provide 30-45 years of detailed weather data by airport, including the ceiling and visibility charts found in Appendix B.

Literature -- A variety of government documents and reports, as well as non-government reports and articles were consulted for this effort. The most important documents are listed in the Bibliography at the end of the report.

Several Department of Transportation and FAA publications were used for general reference, notably the Capital Investment Plan (CIP), the Research, Engineering and Development (R,E&D) Plan, Airport Capacity Enhancement Plan, and FAA Aviation Forecasts. A variety of DOT/FAA documents, including documents produced under contract to the FAA, were used for background information and to support analysis on airport/airspace capacity, surface movement, surface operations programs, and modeling. ASD-400/Lockheed Martin Cost-Benefit Analyses of CIP surface, terminal, and weather programs were used to evaluate the current aviation environment and enhancements to it over the next 10 years.

Finally, research articles and reports on weather, ROT, and surface movement were reviewed; providing additional data on these topics, as well as non-FAA and non-government perspectives.

Engineering/ATC/Technical Staff -- Differing perspectives of surface movement, delays, ATC, and the New York area were sought in selecting subjects for interviews and technical discussions. A list of people consulted is at the end of the Bibliography section of this report.

FAA engineers in the Systems Architecture and Integration Office (ASD-100) and the Systems Capacity Office (ASC) were consulted to discuss, respectively, surface movement, and system/

[13] See Weber, Wolfson, Clark, and Troxel, "Weather Information Requirements for Terminal Air Traffic Control Automation", 1992

airport capacity issues. Engineers at the FAA Technical Center provided data on capacity, surface delays, and airport/airspace models. Several levels of air traffic management/control specialists were interviewed; air traffic managers at the Air Traffic Control System Command Center (ATCSCC, or Central Flow), traffic management officers at the FAA Eastern Region and New York TRACON, and Air Traffic Managers at JFK and LGA.

In addition to FAA staff, Continental Airlines traffic managers at EWR were interviewed about airline operations in the New York area. Other technical experts were consulted on a variety of topics, including one of the developers of the Lincoln Laboratory aviation weather delay model on the model and weather/IMC delay issues, and FAA and contractor staff working on surface movement, traffic flow management, and weather programs.

Data collection forms were distributed to traffic managers at JFK, EWR, and LGA, as well as to Continental Airlines traffic managers and an Eastern Region Traffic Management Officer.

Site Visits -- Site visits were utilized to obtain first-hand information on surface operations and delays, and to obtain specialized technical data. Since the New York City metroplex airports were selected as focus airfields, the primary site visits were to New York, with stops at JFK, LGA, EWR, the Eastern Region Office, and the New York TRACON. Airport visits included observations of traffic from control towers, and the TRACON visit included examination of the TRACON's traffic management system, delay databases, and automation tools. Given its proximity, a previous site visit to Washington National (DCA) was conducted to observe and discuss surface operations, delays, and IMC procedures. A Lockheed Martin analyst later visited the DCA TRACON.

Two other FAA sites were visited to obtain technical/operational data, the FAA Technical Center, and Central Flow. At the FAA Technical Center, discussions were held with Aviation System Analysis and Modeling (ACT-520) staff regarding modeling of airport surfaces for Airport Capacity Enhancement Plan analyses. Key data obtained included modeling results relating to surface and terminal area delays, use of airport/airspace models, and capacity issues. At Central Flow, discussions centered on airport acceptance rates, New York airspace procedures, and general data on delays.

6.0 General Findings

6.1 Airport Surface Delay Evaluation

Background --In general, delays occur when the terminal airspace or airport surface operational capacities are unable to accommodate air traffic demand. Delays have always resulted from an insufficient amount of airport runways and terminal airspace. Flights converge from a number of directions onto one or two active runways to arrive at or depart from an airport, overloading the capacity of the airport, and ultimately, the national airspace system.

Delays are usually measured as the time difference between scheduled flight time[14] and actual flight time by a current delay reporting system (ETMS, ATOMS, CODAS, ASQP, ACARS, etc.). Delay statistics have been collected and reported in two formats: by phases of flight (airport specific delays); and by cause. None of the FAA databases provide much detail on airport-specific delays beyond numbers of delay occurrences. Four phases of flight are generally used by the FAA and airlines to break down delays incurred from departure gate to arrival gate: gate delay, taxi-out delay, airborne delay, and taxi-in delay (these phases can be easily delineated and measured by location/area). Total system delay by cause is reported monthly by the FAA Air Traffic Activity and Delay reports. Causes of delay used in this FAA official report are weather, volume, closed runway/taxiway, NAS equipment interrupts, and other events. It is extremely difficult to use aggregated delay statistics to attribute delays to both a phase of flight and associated cause because of the complexity of the national airspace system.

Gate, taxi-out, and taxi-in delays comprise airport surface delays in this report. The statistics used herein are largely taken from airline reports to the Air Transport Association (ATA). According to the ATA statistics, in 1994, surface delays accounted for 74.5 percent, or 586,000 of the reported 786,000 hours of delays, with an estimated cost of $1.2 billion to the airlines. The 10 TAP airfields accounted for over 1/3 of these surface delays, 197,000 hours. Appendix A provides yearly statistics by phase of flight for the 10 TAP airfields for the years 1990-1994 and statistics for the 10 TAP airfields. In this section, causes of surface delays are described, and delays associated with each cause are roughly estimated by analyzing simulation results, previous studies, and delay statistics. Also, an order of magnitude estimate of weather delays was calculated, based on the MIT Lincoln Laboratory Aviation Weather Delay Model. These data and analyses will help identify the level of delays caused by surface congestion and point to possible means to reduce the delays.

A. Gate Delay -- ATC-related gate delays may be issued by:

- Central Flow: Gatehold programs issued by the Air Traffic Control System Command Center (ATCSCC, or Central Flow) due to severe weather at destination airports, or NAS system failures. According to airline reports for a special 1993 "Sources and Value of Losses" estimate by the ATA, about 60 percent of the ATC-related gate delays in 1993 were issued by central flow[15]. The cost of these delays to the airlines was estimated at $95 million (*this does not imply that the delays or costs were the 'fault' of the FAA, it is only a valuation of the delay time vs. optimal time claimed by the airlines; this number does NOT include the cost of passenger time lost*).
- Local ATC: Gate delay issued by local controllers due to local airspace and airport surface congestion. These delays result from terminal area traffic volume (mainly caused by in-trail spacing requirements in IFR), severe weather avoidance programs (SWAPs), and

[14] Flight times are scheduled by airlines to meet the on time performance requirement by the Department of Transportation (DOT). Thus, arrival times incorporate 'expected' delays. Therefore, delays measured based on scheduled flight time do not capture a portion of delays caused by current system inefficiencies.

[15] Although this data set has not been fully validated, and accounting methods varied slightly by airline, this was the only such breakout available. It is probably roughly representative in its breakdown of sources of gatehold.

runway/taxiway usage restrictions under IMC. Airlines reported that about 40 percent of the gate delays in 1993, with a delay cost of $74 million, were issued by local ATC.

Sources of non-ATC related gate delays can be:

- Airport: Delays caused by aircraft de-icing requirements, snow removal, and other problems at the airport. Airlines reported that less than 1 percent of 1993 gate delays (with an estimated cost to airlines of $7 million) were caused by airport problems.

- Airline: Gate-hold resulting from airline problems, such as passenger boarding delays, bags and cargo loading, mechanical repair and inspection, etc. These delays are not reported in the ATA database.

Gatehold delays reported to the ATA for its 1994 annual report - based on delays beyond the 'expected' (i.e., time included in the airline schedules to ensure on-time performance) totaled $129 million[16]. The 10 TAP airfields accounted for over 25 percent of this total.

Figure 6.1-1 displays the average gate delay per gate delay event for the 10 TAP airfields in 1994, and Figure 6.1-2 notes the percentage of departures from the TAP airfields experiencing gate delays. Multiplying the average gate delay per delay event by the percentage of departures experiencing gate delay yields average gate delay per operation. The average gate delay per operation is in the 0.4 - 2.1 minute range for all airports. Airport or local ATC policy can have a large impact; note that DFW has the greatest delay per event, but the lowest percentage of departures delayed, while LGA has the most flights experiencing delays, but the shortest delay time per event.

Figure 6.1-1

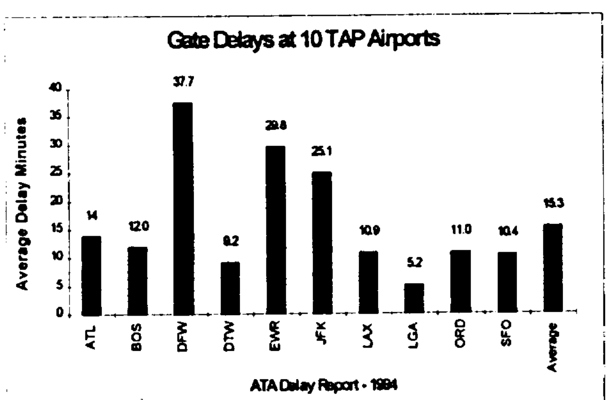
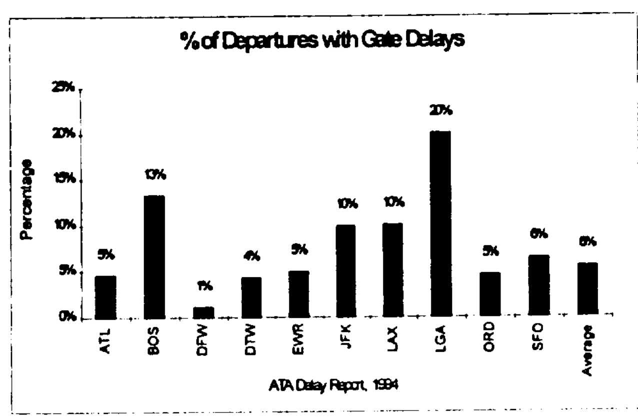


Figure 6.1-2



B. Taxi-out Delay -- Taxi-out delays are widely defined as the time difference between actual and nominal taxi time. Actual taxi time is defined as the time from when the aircraft was electronically logged off at the gate until it was airborne (also called "out-to-off" time). Nominal taxi time is based on an 'average', often an airline's average historical taxi time, and is used as the 'expected' taxi time. Different airlines have different taxi time estimation methods based on their perspective of taxi delays. For example, Northwest Airlines uses a 5 year running average

[16] From December 1994 ATA Air Carrier Delay Report; the ATA data represents about 58 percent of all operations.

out-to-off time as nominal taxi-out time. Taxi-out delays which were calculated against these nominal taxi-out times already compensate for the airline hubbing operations, where several aircraft may have the same nominal departure time. CODAS uses unimpeded taxi time when queue size = 1, characterized by airport, carrier, and equipment. This method provides an 'ideal' taxi time, and measures the absolute level of inefficiency.

Based on air carrier reports to ATA, taxi-out delays cost airlines $813 million in 1994, using the ATA standard aircraft operating costs of $35 per minute. This total is for delays beyond 'expected' delays (e.g., multiple aircraft scheduled for departure at the same time). Taxi-out delays account for nearly half of all delay time (see first chart in Appendix A; page A-2). The 10 TAP airfields account for 36.4 percent of this total.

Modeling results, FAA air traffic personnel, FAA engineers, and Continental staff all agreed that the vast majority of taxi-out delays are incurred waiting in the departure queue, both in VMC and IMC. According to the FAA Technical Center Aviation System Analysis and Modeling Branch (ACT-520), up to 95 percent of total taxi-out delay time occurs in the departure queues, though this varies by airport, airport runway use configuration, and other airport-specific factors. This percentage changes little during IMC, since any increase in taxi time tends to be more than matched by additional time in the queue, due to miles-in-trail restrictions, and frequently, closure of runways during IMC. Additionally, during IMC, there are fewer aircraft operating, since most GA and many air taxi/commuter aircraft are not properly equipped for IFR conditions. Where visibility is low enough to slow surface movement significantly (typically CAT II/III), many air carrier aircraft are not operating.

Analysis of delay databases which aggregate delays by phase of flight supports these conclusions. In all databases which distinguish gate, taxi-out, airborne, and taxi-in delays, taxi-out delays tend to be 3-4 times the level of taxi-in delays (typically, taxi-out delays account for 45-50 percent of delay time, airborne 25-30 percent, taxi-in delays 12-15 percent, and gatehold 8-12 percent[17]). The second and third charts in Appendix A (pages A-3 and A-4) note airports with the highest taxi-out and taxi-in delays. TAP airfields occupy 9 of the top 15 positions for taxi-out delays per operation, but only 6 of the top 15 in taxi-in delays. Taxi-out delays per operation are on average almost 3.5 times taxi-in delays per operation (ramp congestion tends to produce taxi-in and taxi-out delays of similar magnitude; however, the 'arrival queue' is in the airborne phase. Thus, the difference between taxi-out and taxi-in delay times generally approximates the departure queue). Furthermore, at EWR, Continental reported that from January through June 1995, average taxi-out times were 27 minutes per departure, compared to an average taxi-in time of 8 minutes - with most arrivals on the outside runway. This statistic alone implies that the overwhelming majority of departure delays (at EWR) are incurred in the queue or in departure sequencing (the taxi out average is somewhat skewed by extreme delays during SWAPs).

Additionally, several air traffic personnel and engineers interviewed stated that they "believe the 95 percent." Survey responses in the data collection forms do not support the 95 percent figure,

[17] ATA data, a 1989 study by FAA/APO, and Airline Service Quality Performance (ASQP) data all show the distribution of delay time within these ranges.

but do support the conclusion that though surface congestion can be a problem under certain conditions, departure queue delays are routine and far more prevalent under VMC and IMC. During thunderstorms, survey respondents noted that departure queues can be much greater due to SWAPs and the associated in trail restrictions (up to 50 miles at times) and/or favoring of arrivals. One EWR traffic manager noted that departure delays can be sometimes measured in hours during SWAPs. Waiting in departure queues is also made more severe by IFR or storm conditions which shut down runways. IFR conditions can also cause taxiway congestion and delays, but time in the queue is multiplied by in trail restrictions and wake vortex considerations especially when heavy and GA/Commuter aircraft are forced to depart on the same runway.

Departure queue delays in VMC are generally caused by runway capacity (i.e., more aircraft wanting to depart than runways available), often aggravated by the airspace structure and/or local regulations, such as noise restrictions. Airline scheduling often creates demand far greater than the supply of runways. Hubbing operations frequently have banks of departures, often with several departures scheduled for the same time; gateway airports (i.e., with significant international traffic) may have numerous aircraft scheduled for trans-oceanic flights at the same time; and airports hosting shuttle operations between popular city pairs may face numerous "on-the-hour" departures. In the New York area, departure queues are attributed to airline scheduling, airspace congestion, and frequent use of suboptimal runway configurations (i.e., with lower capacity than preferred configurations).

The other significant source of taxi-out delay reported is congestion at ramp accesses, though this varies greatly by airport, depending on the airport layout, the size of ramp accesses, the traffic at ramp accesses, the proximity of the ramp access to taxiways (closer often results in traffic blocking the taxiway), and the demand versus the supply of gates. However, ramp congestion tends to cause short delays, particularly compared to those of a long departure queue.

Taxiway congestion (i.e., from ramp to runway) does not appear to be a constant problem, but can slow down traffic during departure pushes. Although the problem is much more severe in the New York area than in other areas, taxiway congestion is often severely aggravated during thunderstorms because departure paths are cut off, and airspace congestion, combined with a policy of heavily favoring arrivals severely limits the release of departures at EWR and LGA (to a much lesser extent at JFK). At LGA and EWR, when arrivals and departures are not balanced, large numbers of aircraft on the surface can cause severe surface congestion.

Another factor in surface delays can be radio frequency congestion. This is typically not a significant problem without weather. However, several traffic managers in the survey noted that there can be severe frequency congestion - which delays clearances and departure releases - under several conditions. The primary conditions noted were SWAPs and groundhold programs because aircraft being held frequently call to determine their status. IFR conditions often require increased communication between controllers and pilots for clearances and other instructions; this problem appears to be significantly reduced with ASDE-3, which provides controllers with a clear, accurate depiction of aircraft locations, but still, pilots may require more instructions when visibility is poor.

The FAA Technical Center (ACT-520) modeled Minneapolis-St. Paul International Airport (MSP) in September, 1993 and Seattle-Tacoma (SEA) in June, 1995 with the simulation model SIMMOD, as elements of Airport Capacity Enhancement Plan studies. Figures 6.1-3 and 6.1-5 show how the runway usage at MSP and SEA were modeled. Figures 6.1-4 and 6.1-6 indicate the percentage of delays caused by taxiway congestion and waiting in the departure queue.

Figure 6.1-3

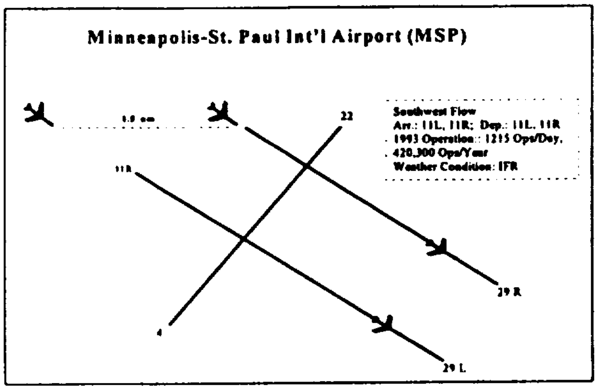


Figure 6.1-4

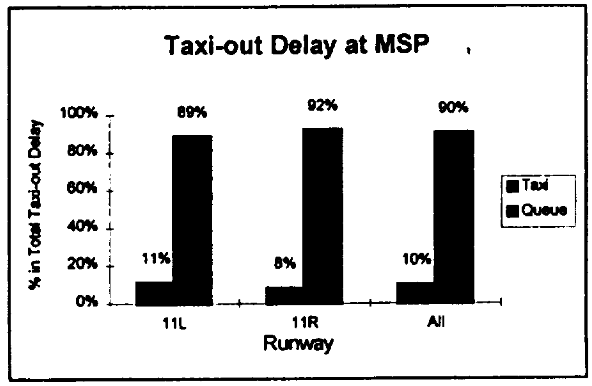


Figure 6.1-5

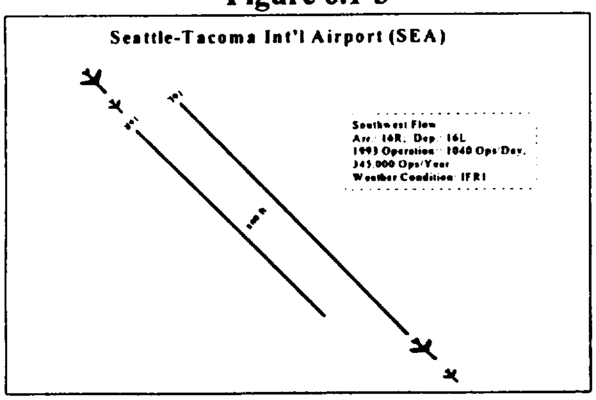
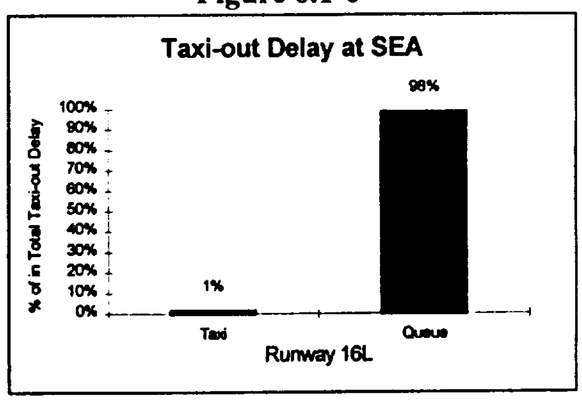


Figure 6.1-6



The MSP and SEA studies did not consider ramp congestion; however, often ramp areas are controlled by airlines, and thus controllers/traffic managers have little data on ramp congestion, and many delays/bottlenecks may be due to airline actions.

Figure 6.1-7 and 6.1-8 show, respectively, the average taxi-out delay time per delay occurrence and the percentage of departures experiencing delays at 10 TAP airports in 1994, as reported to ATA. The second chart in Appendix A (page A-3) shows taxi-out delays per operation, with JFK and EWR the highest in the United States. FAA delay databases (e.g., OPSNET) tend to show EWR with the highest delays, with JFK generally not far behind. It should be noted that since the ATA data does not include international carriers, a large percentage of JFK operations are not reflected in the ATA data.

Figure 6.1-7

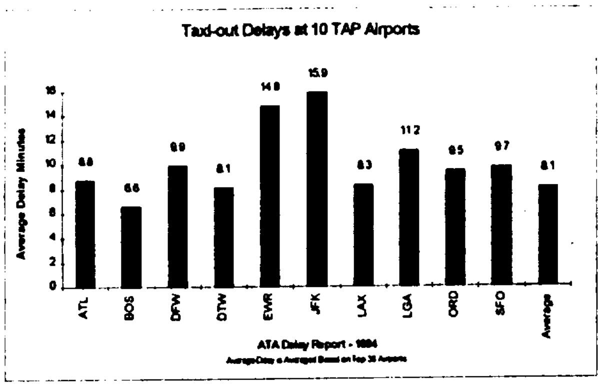
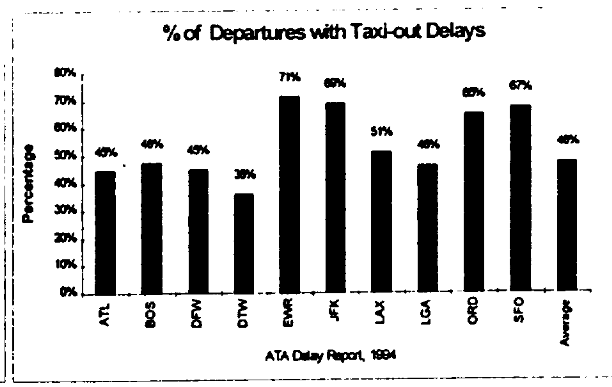


Figure 6.1-8



C. Taxi-in Delays -- Taxi-in delay is widely defined as the time difference between actual taxi time and nominal taxi-in time. Actual taxi-in time is the time from when the aircraft is electronically logged on the ground until it is in the gate (also referred to as 'on-to-in' time). Nominal taxi-in time is airlines' historically averaged taxi-in time (50th percentile - again different airlines use different methods of defining 'average'). CODAS uses unimpeded taxi time when queue size = 1, by airport, carrier, and equipment.

The cost of delays estimated by ATA air carrier reports in 1994 was $238 million, using the ATA standard $35 per minute for taxi time. Again, the 10 TAP airfields were significant contributors, accounting for over 30 percent of this total.

As shown in Figure 6.1-9, taxi-in delays are much less of a problem than taxi-out delays. According to air carrier reports to the ATA, average taxi-in delay nationwide against nominal taxi time is less than 1.1 minutes per operation, and 3.2 minutes per delay occurrence (shown below), compared to taxi-out delays of 4.0 minutes per operation, and 8.3 minutes per delay event above nominal taxi-out time. The ASQP, which does not factor in 'expected' delays, shows for 1991-1993, an average of 2.2 minutes of taxi-in delay per operation, compared to 6.9 minutes of taxi-out delay per operation. Figure 6.1-10 shows the percentage of arrivals experiencing taxi-in delays, also far less than the percentage experiencing taxi-out delays.

Figure 6.1-9

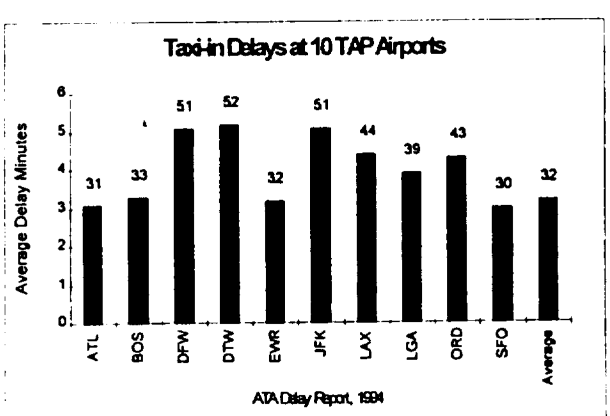
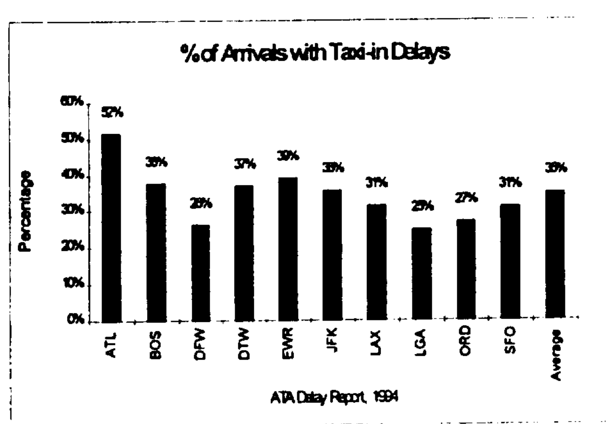


Figure 6.1-10



The third chart in Appendix A (page A-4) shows the top airports in taxi-in delays per operation.

According to the FAA Technical Center airport capacity modeling staff (ACT-520), up to 90-95 percent of taxi-in delay is incurred waiting for gates, again, with the situation varying by airport and runway use configuration (*at this writing, no documentation was available*). Expert opinion from air traffic staff and engineers broadly agreed that waiting for gates is the major source of taxi-in delays. An FAA Eastern Region traffic management officer stated that taxi-in delays "are almost always gate availability." He noted that this can be particularly a problem at hubs, where several aircraft arrive almost simultaneously, bringing passengers to meet connections; though airlines gate management efficiency varies. Waiting for gates can also become a major problem when groundhold programs or SWAPs are in effect, and aircraft are held at gates, preventing arrivals from using the gate. This is especially true when few departures are allowed out of the airport, or when the airport has a limited number of gates. Waiting for gates is virtually always an air carrier problem, since commuters typically do not use gates. Where most of the 'feeders' for connecting flights are commuters, waiting for gates may not be a problem at hubs or gateways.

In the survey forms, the consensus was that the ramp access/exit area is the major source of congestion; this can result from aircraft waiting for gates, aircraft entering and exiting the area, or proximity of the ramp to taxiways. Where the ramp is close to taxiways, this can cause congestion on the taxiways as well. Congestion during VFR often depends on an airline's gate management, though airport layout and number of gates are also key factors. At hub operations, if an arrival push includes numerous jets connecting passengers to flights in an ensuing arrival push, there may be gate shortages. Several survey respondents noted that the major source of gate shortages is aircraft being held by groundhold programs or SWAPs.

It should also be noted that taxi-in delay also often results from surface congestion. The extent of surface congestion depends on the airport layout and runway use configuration. Often, arrivals land on 'outside' runways, and have to cross runways or taxiways, or travel a circuitous route to gates; this problem is aggravated during IMC, particularly when clearances are required for runway/taxiway crossing (though ASDE-3 reduces the impact of this). Also, where there is little space between gate/ramp areas and taxiways or runways, there may be congestion, particularly when an aircraft has to cross ramp/gate areas to reach its gate.

D. Surface Delay Summary -- Since the ATA data includes only about 58 percent of operations on average, and at some airports (such as JFK) much lower; they do not reflect the total delay costs. In order to estimate total surface delays at TAP airfields, an attempt was made to normalize the ATA data to cover all operations. Using total 1994 operations from the FAA's Air Traffic Activity and Delay Reports; fleet mix, and passenger loading from the FAA Terminal Area Forecasts; and FAA Critical Economic Values for aircraft operating costs and passenger time, total and surface delay costs were estimated. Since GA and commuter aircraft do not use gates, their ramp area and taxi-in delays are generally minimal, and were thus estimated to be 0. Figure 6.1-11 below shows estimated surface delays for the 10 TAP airports in 1994. The total is $1.33 billion, of which about $400 million is in aircraft operating costs (fuel, crew, and maintenance only) and $930 million in passenger costs.

Figure 6.1-11: Surface Delay Cost Estimate at TAP Airports

				Est. 1994 Surface Delays (000 Minutes)					
TAP Airports	1994 Operations	1994 Delays (000 Minutes)	Est Delay Cost ($ M)	Gate Hold	Taxi-Out	Taxi-In	Total Surface	% Delay Time on Surface	Est Surface Del. Costs
ATL	714,181	3,820	$261.4	168	1409	418	1994	52.2%	**$128.0**
BOS	471,074	1,880	$89.2	252	869	194	1315	70.0%	**$59.9**
DFW	841,375	3,608	$265.0	142	1887	364	2393	66.3%	**$167.9**
DTW	485,033	1,603	$84.3	72	706	343	1121	69.9%	**$56.6**
EWR	440,490	3,206	$187.3	223	2332	186	2741	85.5%	**$157.0**
JFK	350,107	2,946	$229.5	266	1918	193	2378	80.7%	**$180.4**
LAX	674,937	2,524	$180.7	241	1435	300	1976	78.3%	**$137.4**
LGA	338,047	1,768	$114.2	129	874	120	1123	63.5%	**$69.1**
ORD	881,994	4,211	$326.4	182	2731	422	3335	79.2%	**$251.2**
SFO	431,990	2,105	$166.8	103	1410	142	1655	78.6%	**$127.4**
TOTAL	**5,629,228**	**27,671**	**$1,904.8**	**1,778**	**15,571**	**2,682**	**20,031**	**72.4%**	**$1,334.9**
		Percent of total delay time:		*6.42%*	*56.28%*	*9.69%*			

Operations -- From FAA Air Traffic Activity and Delay Reports, December 1994
1994 Delays, Surface Delays (000 Minutes) -- Derived from ATA December 1994 Air Carrier Delay Report, with extrapolation to cover all operations (assumes no gatehold or taxi-in delays for commuter and GA)
Estimated Delay Costs, Surface Delay Costs -- Based on fleet mixes, passenger loading, using FAA Critical Economic Values for Passenger Time, industry aircraft operating costs for fuel, crew, and maintenance costs
Note: Airborne delay costs per minute are greater than ground (fuel) delay costs, so surface delay costs are less than 72.4% of Total

At the TAP airports, an estimated 56 percent of delay time is in the taxi out phase. The hubbing and international pushes at these airports contribute significantly to this, and in the New York area, the airspace congestion and favoring arrivals over departures during weather are major factors.

E. Weather Delays -- Departure delays are usually caused by runway capacity and terminal airspace congestion, and taxi-in delays are usually caused by inadequate gate or ramp congestion. A relatively small amount of surface delays accrue in taxiing. Discussions with different levels of ATC staff and pilots indicated that taxiing slows significantly when ground visibility is at the CAT II level or worse (< .5 miles) or when there is snow or ice on the surface, but during these times, there tends to be considerably less traffic. Today, many aircraft, including older air carrier models, and most air taxi/commuter and GA (except for high performance business jets) are not equipped to fly in CAT II/III conditions; and neither are many airports equipped to handle traffic in CAT II/III visibility. Over the next 10 years, instrument equipage of aircraft and improved ATC technologies will allow increasing numbers of aircraft to fly in low ceiling/visibility conditions to an increased number of airports. Consequently it would increase the demand for IFR, down to CAT III operational capability.

Quantification of the impact of weather on air traffic operations is key to assessing the potential operational impact and benefits of LVLASO. However, quantification of the weather impact is very difficult because weather is only one of many factors influencing the operation of the air traffic system. Consequently there are problems in isolating weather-related delays from other causes. In some cases the weather is the immediate and obvious cause, as when a snowstorm or fog closes an airport. In other cases, the cause is more ambiguous, as when a flight is late departing because it waits for a delayed incoming flight which may itself have been delayed by bad weather at the origin or en route. ATC staff at all three New York airports indicated that the worst delay problems were caused not so much by weather *on* the airports, as by weather en route - severe weather avoidance programs (SWAPs) or storms impacting the airports' departure or arrival paths - or at popular destination airports, causing groundholds of multiple aircraft.

The FAA's Air Traffic Activity and Delay Report (using OPSNET) counts delay occurrences of greater than 15 minutes, and breaks these events out by cause. From 1984-1994, about 65 percent of delays greater than 15 minutes were caused by weather. In 1994, the percentage of delays caused by weather was even higher, almost 75 percent. Most of the remaining delays; almost 30 percent from 1984-1994, but 19 percent in 1994, are due to "terminal volume", with the rest divided almost equally between closed runways/taxiways (this category does **not** include closures due to IFR procedures), NAS equipment failures, and 'other events'. Center volume accounts for a minuscule number of OPSNET-recorded delays (~0.1 percent).

However, the Air Traffic Activity and Delay Report is not an accurate measure of the impact of weather, since delays of less than 15 minutes - which constitute the majority of delay time - are less likely to be caused by weather, and more likely to be caused by volume (for example, departure queues or ramp congestion, which are not long enough to keep aircraft waiting more than 15 minutes). In previous analyses, Lockheed Martin estimated that weather most likely accounts for about 30 percent of delays of less than 15 minutes, and about 41 percent of total delay time (all durations). However, this estimate was based on statistical analysis, rather than on field observations, and was a global, rather than an airport-specific analysis.

MIT Lincoln Laboratory developed an Aviation Weather Delay Model to estimate the delays attributable to various weather conditions at major airports[18], based on daily weather conditions extracted from the National Climatic Data Center Local Climatological Data summaries. 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. Airport delay statistics were extrapolated for the 20 busiest US airports in order to derive a rough estimate of the contribution of the weather categories (thunderstorms, heavy fog, low visibility). These weather data reflect long-term means of each airport[19]. Lockheed Martin, in consultation with Lincoln Laboratory, extended the analysis to cover the 45 ITWS airports[20].

Figure 6.1-12 shows estimates of current total delays and weather delays at the 10 TAP airfields. Total delays are estimated by using delays reported to ATA in 1994, and extrapolating from these to cover all operations at the airfield. Weather delay statistics are from the Lincoln Laboratory model, with calculations based on 1994 operations. Interestingly, the overall percentage of delays due to weather almost exactly matches the Lockheed Martin estimate.

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[18] Weber, Wolfson, Clark, and Troxel, "Weather Information Requirements for Terminal Air Traffic Control Automation". "Heavy Fog" is defined as CAT II/III conditions; Low Ceiling/Visibility is IFR conditions with minima above CAT II. Conditions such as rain or snow are categorized by the concurrent ceiling/visibility.

[19] The delay 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 airports.

[20] ASD-400/Lockheed Martin, "Cost-Benefit Analysis of the Integrated Terminal Weather System", March 1995

Figure 6.1-12: Weather Delay Cost Estimate at TAP Airports

TAP Airports	1994 Operations	1994 Delays (000 Minutes)	Est. Delay Cost ($ M)	Est. 1994 Weather Delay (000 Minutes): Thunder-Storms	Heavy Fog	Low Ceiling/ Visibility	Total Weather	% Delay Time Due to WX	Est. Wx Delay Cost ($ M)
ATL	714,181	3,820	$261.4	532.7	569.9	959.3	2061.8	54.0%	$133.1
BOS	471,074	1,880	$89.2	133.5	288.2	581.6	1003.2	53.4%	$50.7
DFW	841,375	3,608	$265.0	564.8	246.2	714.6	1525.6	42.3%	$105.9
DTW	485,033	1,603	$84.3	238.8	283.8	579.6	1102.2	68.8%	$54.7
EWR	440,490	3,206	$187.3	170.8	234.3	487.2	892.4	27.8%	$53.0
JFK	350,107	2,946	$229.5	130.6	130.4	408.0	668.9	22.7%	$52.5
LAX	674,937	2,524	$180.7	30.2	789.9	806.6	1626.6	64.5%	$117.0
LGA	338,047	1,768	$114.2	121.0	125.9	394.0	640.9	36.3%	$41.7
ORD	881,994	4,211	$326.4	500.0	375.3	949.5	1824.8	43.3%	$138.4
SFO	431,990	2,105	$166.8	12.9	195.3	430.9	639.1	30.4%	$49.9
TOTAL	**5,629,228**	**27,670**	**$1,904.8**	**2,435.3**	**3,239.1**	**6,311.2**	**11,985.6**	**43.3%**	**$796.8**
				20.32%	*27.02%*	*52.66%*			

Operations - From FAA Air Traffic Activity and Delay Reports, Dec. 1994

1994 Delays Minutes -ATA 1994 Delays, with extrapolation to cover all departures (assumes no gate or taxi-in delays for commuter and GA)

Est. Delay Cost - Based on Fleet Mix, Passenger loading, using FAA Critical Economic Values for Passenger time, industry aircraft operating costs

Weather Delays - Based on MIT Lincoln Laboratory Aviation Weather Delay Model; 'Heavy Fog' indicates CAT II/III ceiling/visibility, whereas "Ceiling/Visibility" refers to IFR ceiling/visibility above CAT II conditions

*Weather Delay Cost - % Delays caused by Weather * Est. Delay Cost for airport*

The data indicate that LAX has the highest percentage of delays due to weather; this is not unexpected, since LAX has the highest occurrence of low ceiling and visibility. The SFO weather delays are underestimated; Lincoln Laboratory model developers noted that a 2,500' ceiling is more appropriate for SFO, as "it better represents the true threshold for operational impact resulting from marine stratus which commonly interferes with local area traffic management"[21]. Additionally, the New York area airports show a relatively low percentage of delays due to weather. This can be explained in large part by the facts that (a) the Lincoln Laboratory model refers to weather *at* the airport; much delay at the New York airports is due to local storms which do not actually impact the airports directly, but cut off flight paths, or to SWAPs; and (b) airspace congestion in the New York area aggravates capacity problems. A much higher percentage of delays at the New York airports is probably due to weather, though it does not directly impact the airports (see details in Section 7).

6.2 Surface Delays - General Analytical Findings

Surface movement in IMC -- Surface movement in IMC was compared by many interviewees to driving a car; one slows down significantly when short range vision is poor (most respondents defined this as CAT II/III), or when the surface is slippery. Wet (non-slippery) pavement by

[21] From Clark, "Characterizing the Causes of Low Ceiling and Visibility at U.S. Airports", 1995

itself requires extra caution when landing and slowing after landing, but interviewees did not believe that it slows taxiing, which is normally done at slow speeds (~7-10 miles per hour). Even when visibility becomes very poor, this impact is balanced by the fact that there are fewer aircraft operating. It is expected, however, that over the next 10 years, most air carrier, and many commuter aircraft are likely to equip for lower ceiling/visibility conditions. CAT II/III conditions are most prevalent in the hours before and after sunrise, particularly in areas near oceans (airports nearest the coasts have the greatest prevalence of CAT II/III conditions), but CAT II/III conditions are relatively scarce; less than 2 percent of the time at all TAP airfields.

Survey respondents indicated that snow and ice slow traffic down the most; with average taxi times stated as 50-100 percent longer than daytime VMC by all who filled in the section on taxi times under different conditions.

With low visibility, crossing runways or taxiways is often a bottleneck, since the aircraft must be cleared (under VMC, runway crossings were described as similar to a stop sign). Where ASDE-3 is operational (currently EWR and LGA are the only TAP airfields without ASDE-3[22]; both are scheduled to receive them in 1996-97), controllers can see aircraft positions on their displays in real-time, and can clear aircraft with much less communication and more confidence, but pilots may not be helped significantly. Several interviewees stated that for pilots to move as in VMC, they must be able to see or visualize any nearby aircraft, and be able to determine their movement. Map or symbolic displays showing other aircraft do not provide this visualization. Survey respondents indicated that IFR conditions slow taxi times by 25-50 percent.

Low ceilings (with reasonable ground visibility) impact surface operations primarily at runway crossings, since controllers must determine that no aircraft are about to descend through the clouds.

Other weather conditions were given mixed responses. Half of the respondents indicated that wet pavement slows taxi times, from 20-50 percent, though the other half reported wet taxi times to be the same as with dry pavement. Some traffic managers indicated that high temperatures slow taxiing somewhat (~10-15 percent), though others reported no change for temperature extremes. Temperature extremes were also reported by some respondents to slow ROT somewhat.

Thunderstorms at the airport or in the terminal area were not considered to be a significant factor in out-to-off times, with the big exception of when SWAPs are in effect. Many respondents cited taxi times during thunderstorms as the same as under VMC, but most indicated that SWAP delays can be enormous. Some respondents just wrote an 'average' taxi time during thunderstorms as 50-90 percent longer than in VMC; but indicated elsewhere in the survey that thunderstorms had a major impact on departure queue time (and sometimes ramp congestion time), but not on actual taxi times.

It should be noted that night time often creates the equivalent of IMC conditions. Particularly where there are intersecting runways/taxiways, surface lighting may be confusing (BOS is an

[22] EWR and LGA have the analog ASDE-2; traffic managers and controllers at both airports stated or wrote in survey forms that ASDE-2 is of little help in IFR conditions; an EWR controller called the display "inferior".

example of this), and pilots may miss exits. Most cockpits currently do not provide airport maps or vision enhancements to pilots. The "Report by Airline Pilots on Airport Surface Operations" revealed that pilots consider lighting at many major airports to be inadequate. A JFK traffic manager stated that at night-time under VMC conditions, a pilot familiar with the airport would be only minimally slowed down, but that night-time IMC conditions often slow down taxiing considerably due to glare. Virtually all survey respondents indicated that night-time VMC does not or only minimally slows traffic (particularly for pilots familiar with the airport), but that night-time IMC conditions slow traffic somewhat more than day-time IMC.

Surface movement at any airport can not be divorced from the system -- Surface movement and delays are not just functions of conditions at the airport; they are impacted by conditions throughout the NAS. Virtually every person consulted and all respondents cited factors external to the airport as major causes of delay. Weather at another airport may result in a groundhold program, in which aircraft destined for that airport are held on the ground; when multiple aircraft are scheduled for the weather-impacted airport, surface congestion may result. At DCA, controllers noted that the small physical size of the airport meant that groundhold programs for a major city pair are a major source of surface congestion and delays. An FAA Eastern Region (AEA) traffic management officer stated that this can also be a major problem at LGA.

A related problem is severe weather avoidance programs (SWAPs). These are procedures taken so that aircraft are routed around thunderstorms and other weather hazards, and impact en route airspace. Often, where high volume airspace is involved, this means extra travel funneled into already crowded tracks - this is particularly severe when arrival or departure gates near a major airfield are impacted. Traffic managers (tower, Continental, and AEA) representing all three New York City airports called SWAPs a major source of delay, since typically, they result in departures paths being shut down and more crowded arrival tracks. Both Continental and EWR traffic managers noted that delays caused by SWAPs are often measured in hours for individual departures.

Airspace being shut down implies more severe airborne congestion, but also frequently severe surface congestion. If departing aircraft are held on the ground, surface movement becomes more difficult, particularly where airports are space-constrained, or where there is a lack of holding aprons (sometimes referred to as 'penalty boxes').

6.3 Runway Occupancy Time (ROT) Analysis Findings

Analysis of ROT comprised:

- A literature review covering ROT under different runway conditions, pilot motivation, and the impact of high speed exits;
- Statistical analysis of ROT under different runway and weather conditions;
- Modeling results from the FAA Technical Center; and
- Data collection from air traffic managers, airlines, and pilots.

The key finding from all these sources is that under the present aviation environment and procedures, ROT is generally not an issue for either VMC or IMC surface operations, but could become a factor impacting surface delays when separation standards are reduced. ROT in this report is the time that an aircraft is occupying the runway - both above and on the runway, or from crossing the threshold to exit. Though the times can vary with aircraft size and airport characteristics, for a commercial jet aircraft at a major airfield, arrival ROT for a large commercial jet (e.g., B-727, B-737, B-757, DC-9/MD-80, A-320) is typically about 50 seconds, of which about 26-27 seconds are on the ground. Heavy jets (B747, DC-10/MD-11, L-1011) typically take somewhat longer (by most accounts, 5-10 seconds), often depending on exit location. Current wake vortex separation standards for arrivals are 3-6 miles, depending on the sequence of aircraft. Using typical airspeeds and basic mathematical queuing algorithms, the FAA Technical Center determined that ROT becomes a factor impacting delays only when wake vortex (arrival) separations are reduced to less than 2 miles. This may be plausible with the implementation of the CTAS Final Approach Spacing Tool, reduced spacing operations, and some degree of CTAS-aircraft flight management system (FMS) integration, all of which is likely by the time LVLASO technologies will be ready for implementation. On commuter/GA runways, the implementation of multiple glide-slope approaches would preclude the requirement for in-trail separations, and thus render ROT a major determinant of arrival rates (though airspace restrictions or track limitations may prevent this in certain locations, notably around New York City).

A second key finding is that, for the most part, weather does not impact ROT; in fact, under moderate IMC, ROT may be slightly reduced due to increased operational awareness. The literature search revealed studies of ROT under different weather conditions at BOS, LGA (both 1984), Memphis (MEM, 1986), IAD (1988), ATL and DFW (1988). In addition, ROT was assessed in the evaluation of wake vortex data by the FAA Technical Center for 10 airports (1984-1992), and by Dr. Antoni Trani, of Virginia Polytechnic Institute, for 4 airports in 1992.

At BOS, LGA, MEM, and IAD, ROTs were gathered under VMC with dry pavement, and IMC and/or wet pavement. Lockheed Martin ran a statistical analysis, using analysis of variance (ANOVA), a procedure used to determine whether means from different samples are drawn from populations with the same mean. In each case, the analysis showed that ROT under IMC/wet pavement was not significantly different than ROT under VMC/dry pavement. A MITRE study of ATL and DFW evaluated ROT under dry and wet runway conditions, and performed t-tests indicating no statistically significance between dry and wet ROT (not enough data was included to perform the ANOVA test). The average ROTs for each airport are noted in Figure 6.3-1 (p. 31). Further statistical analysis using data from these airports and the Technical Center indicated that there are statistically significant differences between classes of aircraft and between airports.

It should be noted that IMC or wet pavement does not necessarily indicate conditions that would slow down aircraft movement. IMC is typically defined as ceiling below 1,500' (different sources cite anywhere from 1,000' to 2,000'; but ceilings <1,500' typically require initiation of an instrument approach) and/or visibility below 3 miles. Though individual pilot thresholds may vary, conditions have to be far worse than borderline IMC for pilots to use runway procedures and speeds more cautious than under VMC; generally, non-precision instrument approaches (ceiling >500' and visibility > 1 mile) do not result in increased ROT. Traffic managers and

Figure 6.3-1: ROT Under Different Weather Conditions

Airport	Mean ROT	
La Guardia	VMC/Dry	IMC/Wet
	46.8 Sec.	45.3 Sec.
Boston Logan	VMC/Dry	IMC/Wet
	49.3 Sec.	52.7 Sec.
Memphis	VFR/Dry	IFR/Wet
	55.9 Sec.	49.6 Sec.
Dulles	Dry	Wet
	55.1 Sec.	54.2 Sec.
Atlanta	Dry	Wet
	50.1 Sec.	48.8 Sec.
Dallas-Ft. Worth	Dry	Wet
	52.2 Sec.	51.1 Sec.

pilots interviewed noted that if ground visibility is greater than the perceived stopping distance, there is no tendency to slow down runway taxiing or exiting. Controllers do not slow aircraft on runways or from exiting runways if they can see the aircraft and its surroundings.

An analysis of meteorological data from the National Climate Data Center indicated that at the 10 TAP airfields, an average of only 7 percent of IMC was severe enough to require CAT II/III landings (i.e., ceiling <200' or visibility < 1/2 mile); with a range of 4 percent (SFO) to 12 percent (ATL) of IMC time at CAT II/III level. Several interviewees noted that even at CAT II/III conditions, mean ROT may not be significantly slower than under VMC, since GA and most commuter aircraft would not be flying. Ceiling and visibility charts for the TAP airfields are found in Appendix B.

Traffic managers from the FAA and Continental stated that with wet pavement, slowing/stopping and turning distances are longer (one traffic manager officer noted that stopping distances for a heavy aircraft can be 2,000' longer), but they were not sure what the impact on average ROT was. An FAA engineer noted that with wet pavement, pilots use better breaking techniques, and often touch down closer to the head of the runway to be able to exit at the desired location. During observations by the authors from the LGA tower, ROT was timed with a wristwatch for about 40 aircraft arriving, about half with dry pavement and half with wet pavement. Consistent with what the all of these interviewees stated, when the pavement was wet, aircraft took longer slowing and turning distances, but touched down closer to the runway threshold. ROTs for both groups were consistently about 45 seconds, but whereas arrivals on dry pavement generally were in the air for 15-18 seconds past the runway threshold, and about 27-30 seconds on the ground, arrivals on wet pavement typically touched down about 5-7 seconds past the runway threshold, and were on the surface for about 38-40 seconds before exiting (the aircraft timed were all B-727, B-737, B-757, or DC-9/MD-80s, which together comprise over 80 percent of LGA air carrier traffic).

There is some question about possible differences of pilot motivation to exit the runway quickly under IMC and VMC. The literature indicates that under IMC or wet pavement conditions, pilots may have increased operational awareness. Controllers may hurry arrival aircraft off the runway to ensure that the aircraft is off the runway before the next arrival lands. However, traffic managers for the New York City airports indicated that due to the constant high volume of traffic, controllers always try to minimize ROT.

Factors impacting ROT and Runway Exiting -- Studies on ROT in the literature review and talks with traffic managers identified several factors impacting ROT, including:

- Aircraft Type	- Exit Design	- Pilot Technique
- Aircraft Weight	- Exit Location	- Runway Condition
- Airline Policy	- Exit Speed	- Touchdown Point
- Controller Direction	- Gate Location	- Wind Velocity

Terry Ruhl of the University of California found that the dominant factor in runway exit selection is the terminal gate location[23]. The pilot is concerned less with ROT than with 'on-to-in' time, and thus uses the runway like a highway going to the exit nearest the destination. Generally pilots exit earlier only when directed by controllers or airline policy (this generally means an airline, usually at a hub, attempting to land its own aircraft more quickly where consecutive arrivals are with the same airline).

Other studies and interviewees indicated that pilots are concerned with passenger comfort when landing, taxiing, or selecting an exit. A JFK traffic manager stated that certain airlines which put more emphasis on passenger comfort take off more slowly and ascend at a lower angle of attack, and try to avoid relatively sharp or fast turns.

High speed exits could be located to reduce ROT, but their impact on system capacity and delays is not clear, since (a) airlines and pilots are more concerned with reaching the gate than exiting the runway; an earlier runway exit may increase taxi time, (b) pilots may avoid risk or passenger discomfort and thus bypass a high speed exit, (c) building high speed exits may entail significant redesign of the airfield surface. Further, high speed exits, where they exist, are not always usable. They are often not far enough down the runway for larger aircraft to be able to use them. At JFK, one high speed exit has an almost 90 degree turn very shortly after the exit point, thus rendering it unusable for most large or heavy aircraft.

Respondents to the survey provided varying answers to what they believed most influences ROT (choices equated to the factors listed above). The most common answers for primary factors were: exit design, aircraft type/weight, and gate location. EWR respondents rated pilot motivation as a major factor. Several respondents noted that international aircraft have longer ROT or take longer to exit, though this is due in part to the size of the aircraft. Many respondents noted that GA pilots unfamiliar with the airport also frequently take longer to exit (At JFK and EWR, most international pilots are said to be familiar with the airports).

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[23] See "Empirical Analysis of Runway Occupancy Time with Applications to Exit Taxiway Location and Automated Exit Guidance", 1989

6.4 Airport Characteristics and Surface Operations

The surface operations, IMC procedures, and delay situations differ at every airport because every airport has a different configuration, use pattern, airspace, weather, and environment (e.g., noise and other local restrictions). This report has attempted to identify airport characteristics which impact surface operations and delays to assist NASA and the FAA in identifying leading candidate sites for new systems. Some key characteristics and their impacts are listed below:

Airport Layout -- There are some clear distinctions between older and more modern airports. Older major airports were often designed with runways aligned to accommodate prevailing winds, or to provide most aircraft a launch in the right direction to their primary destinations. Since there were usually two or three primary routes (e.g., air traffic from the northeast tended to go south or west), or wind patterns, there were often intersecting or converging runways. Further, when parallel runways were constructed, particularly if prior to the first large commercial jets (Lockheed Electra, B-707, DC-8) in the mid-1950s, they were often closely spaced. At the time such airfields were constructed, neither volume nor weather was much of an issue; there was not enough demand to cause serious surface congestion, and aircraft generally did not fly in bad weather. Today, airports with closely spaced, intersecting, or converging runways, for example, BOS, SFO, LGA, or EWR suffer greater capacity losses under IMC, because runways are lost, or are rendered dependent.

Modern airport design, as exemplified by ATL or DFW, is characterized by widely spaced parallel runways (though there may be intersecting or converging runways, often for commuters or GA), allowing for multiple simultaneous operations. If arrivals and departures are not as direct for more aircraft, the impact of IMC is less severe, since runways are generally not lost or rendered dependent, and capacity loss is defined by the lower arrival acceptance rate. However, since such airports tend to be much larger than those with older designs, taxi distances are often greater, and there may be more taxiing bottlenecks (e.g., taxiing from an outer runway to the gate area, sometimes requiring a runway crossing).

Runway Configuration/Usage -- Most airports can operate using a number of runway configurations. Airport capacities, surface movement issues, and local restrictions can vary greatly depending on the configuration in use. Use of the same number of runways does not yield the same capacity, since the environment in the air or on the ground may change. There may be restrictions on departures or arrivals from a certain direction or sharing of or crossing flight paths for other airports. At JFK (see airport map in Section 7.2), the 13/31 runways provide greater capacity and fewer surface movement problems than the 4/22 runways since (a) they are further apart, and thus can remain independent in IFR, whereas the 4/22s are too close to be used in parallel in IFR; and (b) the 13/31s are on opposite sides of the terminal area, so activity on one does not impact activity on the other; when the 4/22s are in use, arrivals on 4R/22L must cross 4L/22R to reach the terminal, thus limiting departures or causing taxi delays. Even 'turning an airport around' (i.e., arriving/departing on the same runways in opposite directions) can have a significant impact on capacity; since it may result in different arrival paths, or departures taking off over a city, crossing another flight path, or having to remain on the same fix for a longer distance (where aircraft can 'fan out' after take off, another aircraft can depart sooner; if all aircraft depart on the same fix, aircraft speed or wake vortex considerations require greater separations).

Controllers and traffic managers generally have a preferred configuration, typically the one with the greatest capacity. The extent to which the preferred configuration is used may be limited by weather, winds, or, in areas with multiple airports, by the configuration of other airports. IFR weather may render parallel runways dependent or effectively one runway depending on the separation between them, and may eliminate the use of a converging runway or one of crossing runways. Winds can cause runway shifts when a cross-wind (i.e., perpendicular to a departure) is too strong, or when arrivals and/or departures have too strong a tailwind. In the New York City area, the proximity of the airfields and the perpendicular runways of all three require that configurations be coordinated, and limit the use of preferred configurations. For example, use of EWR's Runway 11/29 is often curtailed or not permitted (by the New York TRACON) because of the configurations in use at LGA or Teterboro (TEB).

Where runways are utilized by all classes of aircraft, delays may be increased due to wake vortex separation requirements. A GA aircraft departing behind a B-747 on the same fix may be held at a 6-mile or greater separation in VFR. If air carriers and commuters/GA use separate runways, wake vortex becomes less of an issue, and arrival or departure rates become more constant. When one runway is used for departures, during a departure push, the controller can improve capacity by efficient sequencing of aircraft; separating aircraft using the same departure fix or bunching heavy or small aircraft together. This task can be rendered very difficult if there is not a holding area near the queue, or if the controller has a limited view of aircraft taxiing out for departure.

For hubs in particular, the flexibility of runway use patterns is a key issue. Controllers often keep a runway open for departures or arrivals only, even when there is a push in the opposite direction. Where controllers are more aggressive about adjusting the airfield configuration to meet demand, delays are reduced (controllers were said by multiple sources to maintain runway use patterns for convenience, or 'because it is easier').

The airspace configuration or nearby airports may also dictate runway usage. For example, if nearby airports share fixes or have runways with crossing arrival/departure paths, there may be a need to coordinate airport configurations to optimize capacity and minimize area delays. This is particularly true of the New York area, where airports are closely spaced with runways of the same (crossing) orientations. Thus, operations at EWR, JFK, and LGA are most often essentially parallel. Where airports are closely spaced - such as JFK and LGA - IFR conditions may render the two airports essentially parallel runways, requiring the same runway use patterns at each airport (e.g., both landing on 31s). EWR's 11/29 (primarily GA/commuter) runway is often not usable due to the configurations in use at LGA, or even TEB.

Hubs/Gateways -- Since airline deregulation, many airlines have set up hub and spoke systems for carrying the majority of their passengers. Typically, a major airline controls over half, and sometimes up to 90 percent of the traffic at its hubs, with the primary exception being where two airlines have collocated hubs. Six TAP airfields host hubbing operations, with two - ORD and

DFW - serving as dual hubs. The level of local dominance at the hubs, using 1994 passenger statistics, is shown in Figure 6.4-1:

Figure 6.4-1: Hubs at TAP Airfields

Passenger Share of Dominant Airline(s), 1994

Dual Hubs			Single Hubs		
ORD	United	47.2%	ATL	Delta	78.7%
	American	34.3%	DTW	Northwest	73.9%
			EWR	Continental	51.5%
DFW	American	60.5%	SFO	United	55.0%
	Delta	25.6%			

Source: Avitas Aviation, based on carrier filings with the DOT

Additionally, JFK, LAX, and BOS serve as gateway airports; multiple airlines use these airports as base points for international operations. Several foreign airlines have major operations at TAP airports, most notably: British Airways, Air France, and Lufthansa at JFK; and Japan Air Lines at SFO.

The primary impact of hubs or gateways on surface operations, IMC procedures, and delays, is in terms of traffic flows. Hubbing operations are characterized by 'banks': numerous aircraft feeding major flights arrive at approximately the same time; since passengers on these flights have multiple destinations, the numerous connecting flights depart at approximately the same time. Thus hubs will typically have morning and afternoon peak periods, where first, there is a very heavy stream of arrivals (often with low demand for departures), followed about 45-60 minutes later by a very heavy stream of departures (often with little demand for arrivals). If airlines are not careful with their planning, they can experience taxi-in delays, as several closely spaced arrivals may overwhelm the supply of available gates. Airlines usually build delays into their schedules, and in their own accounting, may consider a 20 minute wait in a departure queue the norm, not counting it as a 'delay'. Other periods of the day tend to have significantly lower levels of traffic. With dual hubs, the two operations tend to cooperate and have separate peak periods. At hubs in the geographic center of the country, the peaks tend to be less severe, since traffic headed to the east coast and that towards the west coast tend to be at different times. Predictably, the impact of IMC will depend largely on whether the incidence is during a peak or off-peak time. Since IMC often occurs in the morning, the morning peak hour is often slowed down, which may disrupt traffic for the rest of the day.

At gateways, though there does not tend to be a dominant airline, there are distinct peak times for departures to Europe or Asia, and similar patterns of arrival and departure banks are observed - notably at JFK, where over 1/3 of the operations are international. Departure banks for international flights tend to be 1-1.5 hours after arrival banks, but may be as heavy as at hubs. JFK often has up to 30 aircraft in the departure queue at 7-7:30 PM, virtually all going across the Atlantic, as observed by Lockheed Martin, as well as by the FAA Technical Center in a previous analysis of the airport.

At airfields which are neither hubs nor gateways, traffic patterns are usually more evenly spread throughout the day, and peak hours are more evenly balanced between arrivals and departures. At LGA, there is a constant heavy flow of traffic in and out of the airport from about 8 AM to 10 PM, with little variation from hour to hour. However, like other airports with shuttle service, there tends to be a large demand for departures on the hour. At DCA, also not a hub, there are peak hours in the morning and afternoon, often business or political travelers traveling in or out of Washington DC for the day, though the balance between arrivals and departures is not skewed as in hubs. DCA also hosts several East Coast shuttle operations, though to a lesser extent than LGA, which has several shuttles to the midwest.

During IMC, despite the heavier volume, hubs operations may be easier for controllers. Whereas a non-hub may have to balance arrivals and departures - often keeping arrivals separated by 4 miles to allow departures to leave, at hubs, the traffic may be largely in one direction. However, IMC is particularly problematic when runways are lost during a push. During an arrival push, a groundhold program is likely to be put in effect, while during a departure push, there is likely to be increased delays, particularly in the queue. This problem is aggravated when a runway used for commuter and GA is closed, and the commuter and GA aircraft have to depart off the same runway as heavy aircraft; this situation, which often occurs at EWR, often results in longer in-trail separations due to wake vortex considerations.

7.0 Airport Specific Findings: JFK, EWR, LGA

7.1 The New York City Metroplex Area -- Background and Context

In aviation terms, the New York City Metroplex is the most congested area in the world. Three of the United States' busiest airports serve New York City, and several significant satellite airports (some of which are relievers for the majors) are in the immediate area. Although rankings vary from year to year, in 1993, JFK ranked 8th nationally in passenger enplanements, EWR 9th, and LGA 18th (and, respectively, 11th, 12th, and 27th in the world; JFK, and to a lesser extent, EWR and LGA slumped in 1991-93 due to the Gulf War and its aftermath, and to the recession; in 1985, they were ranked 6th, 7th, and 11th in the world), while all three were in the top 25 in terms of operations (some GA airports had more operations; but London Heathrow and Frankfurt are the only non-U.S. airport with as many). Nowhere in the world are three airports of these volumes so close together: LGA and JFK are only 9 miles apart, and by air, both are 15-18 miles from EWR (see Figure 7.1-1).

The first airport serving the nation's largest city was EWR, constructed in 1917, less than 10 miles from Manhattan. EWR was busy enough (given constraints of the day) that in 1935, airlines established the first 'Air Traffic Control Center', a somewhat primitive en route center, near the airport. The center, along with two others established soon after (Cleveland and Chicago) were taken over by the Department of Commerce the next year. In the early 1930s, New York's Mayor Fiorello LaGuardia, on his first flight to his city, noted that the airport was not in the city, or even in New York state. Thus, LaGuardia Airport was built in Queens in the late 1930s, with some pressure on the federal government to create jobs. Though slightly larger, it is similar in design to another airport built at the same time, Washington's DCA. LaGuardia was soon the primary airport serving the city.

After World War II, a new airport, called Idlewild, was built on the south side of Queens, about 9 miles from LGA, to handle the new demand for international traffic (which had been virtually non-existent before the war). In the immediate post-war period, international traffic was almost entirely to Europe, and Idlewild, by the 1950s was the primary international airport in the United States. This became a more important role in the late 1950s with the introduction of the Lockheed Electra, Boeing 707, and DC-8, the first generation of large passenger jets, which made international aviation much cheaper, safer, and accessible. The airport was expanded and modernized regularly from the 1950s through the early 1970s, as larger jets were introduced and the demand for international travel steadily increased. After the assassination of President John F. Kennedy, Idlewild was renamed in his honor, and given the location identifier JFK.

By the late 1960s, the New York City airports were two of the nation's busiest in terms of both operations (each over 300,000 annually) and passenger enplanements, and the airspace was becoming congested. EWR was a busy regional airport, and significant general aviation activity was increasing at nearby Teterboro (TEB, 7 miles NNE of EWR) and Westchester (HPN, about 15 miles north of LGA), but control of the airspace favored LGA and JFK. EWR was expanded and modernized in the 1970s, though airspace control procedures in the area remained the same.

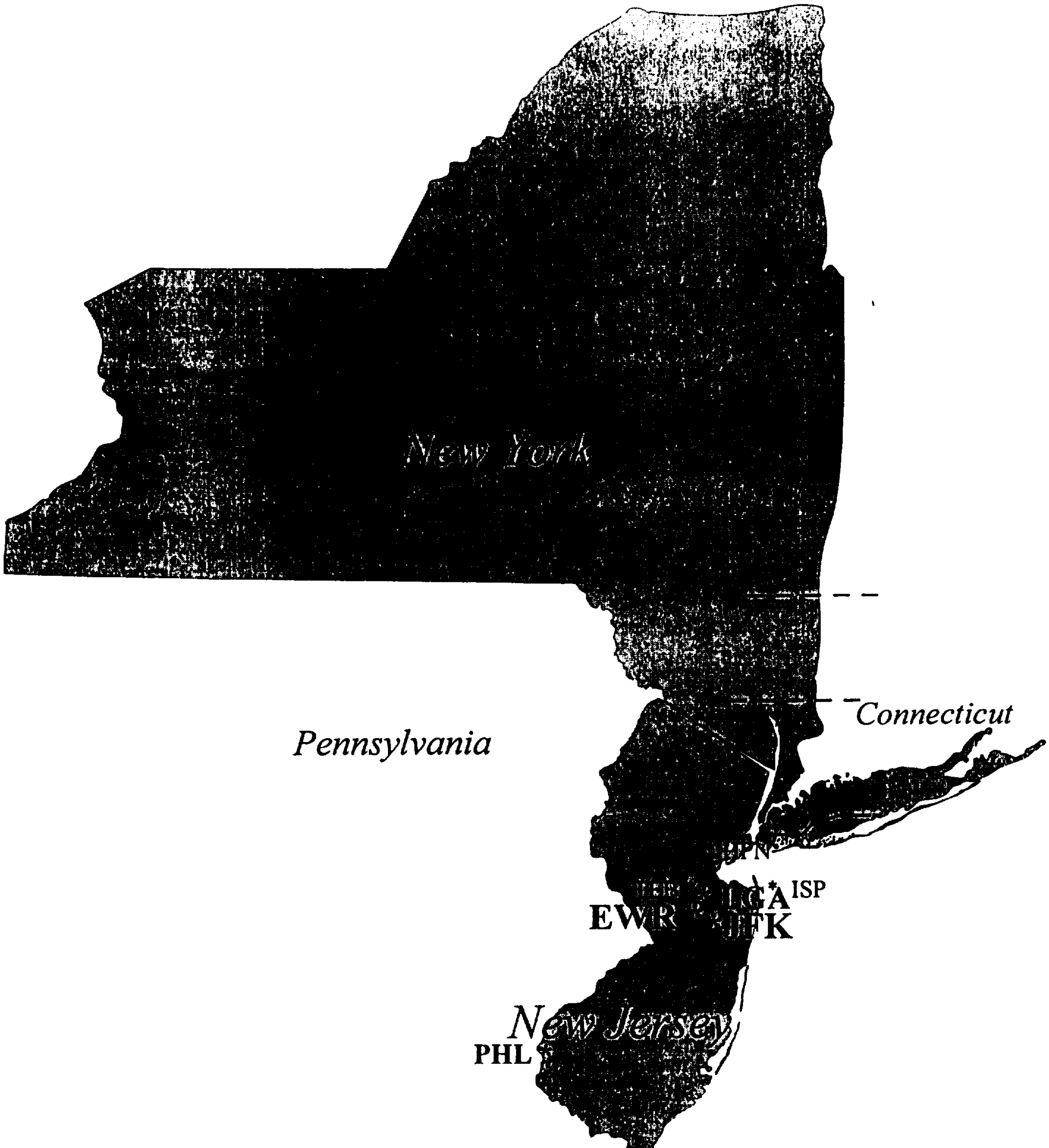

Figure 7.1-1: The New York City area has 3 major and several significant reliever airports, resulting in severe airspace congestion.

This became a significant problem in the early to mid 1980s, as aviation activity at EWR increased dramatically. In the wake of deregulation, People's Express established a hub in Newark, and New York Air and Eastern expanded significantly (though Eastern scaled back after 1986). Between 1982 and 1985, annual operations at EWR almost doubled from 215,000 to 400,000, while passenger enplanements soared from 5.5 million to over 14 million. By 1985, Newark ranked 5th in the nation in passenger enplanements, ahead of JFK, LGA, and even Denver[24]. In addition, with ground transportation becoming increasingly congested around LGA and JFK, EWR was promoted as being the fastest entry into Manhattan. In 1987, international traffic began to flow into Newark, and Continental Airlines became the primary airline at the airport, as it (through Texas Air) acquired People's Express.

By the early 1980s, aircraft routes in the northeast corridor could no longer accommodate increased aircraft operations, thereby severely restricting the movement of air traffic in and out of the New York area. Air traffic congestion increased to the extent that arrivals to and departures from New York City area airports accounted for over 25 percent of the national total of reported delays. In October 1981, the FAA initiated the process of realigning the airspace over 19 eastern states and the District of Columbia which became known as the East Coast Plan (later, the Expanded East Coast Plan, EECP). In July 1985, representatives of the FAA regions and headquarters reached agreement on traffic flows and high altitude route alignments, which were implemented in February 1987. Arrival and departure paths were narrowed, but the number of departure paths from JFK, LGA and EWR was increased from 17 to 28, and arrival paths increased from 9 to 12. An attempt was made to segregate EWR flights from traffic in and out of busy New Jersey satellite airports such as Teterboro and Morristown. Additionally, the airspace was resectored to reduce the amount of coordination required between controllers.

Although the EECP implementation led to a significant drop in reported delays in the New York area airspace, several problems quickly emerged. From 1982 to 1986, the number of instrument operations handled by the New York TRACON increased by 57 percent, from 1.03 million to 1.61 million. Since much of the analysis for EECP was conducted in the early 1980s, EWR was still treated as the third airport, and the recommended realignment still favored traffic in and out of LGA and JFK (though EWR overtook both in operations and, for 1985-86, in enplanements). A 'fast track' and 'slow track' were implemented for arrival and departure corridors, with jets allowed to fly at higher altitudes and speed, while propeller aircraft are kept at lower altitudes and speeds. This resulted in nearly all commuter aircraft being kept on the 'slow track', though newer or larger commuter aircraft fly more efficiently at higher altitudes and speeds. Additionally, there were numerous complaints from northern New Jersey residents about aircraft noise and overflights. By the end of the decade, delays in the area were again rising sharply. The EECP was modified in January 1990, with a departure corridor added for EWR.

The New York area is the first area in the country to have a single TRACON for multiple airports, however, there was minimal integration of airspace or coordination between the airports at first, and the airspace is not yet fully integrated. The implementation of the ARTS IIIE,

[24] TAF and FAA Aviation Forecast Statistics in the mid-late 1980s showed JFK with more enplanements in 1985, but the JFK numbers were later revised downward. At this writing, we have not found an explanation for this.

completed in 1994, will enable tying radars from JFK, EWR, LGA, Islip (ISP), and Westchester (HPN) together, but additional software development is required to attain full integration.

Today, as evident from air traffic activity and delay statistics, the New York area airports and airspace remain highly congested. JFK and LGA are believed to be operating at about their annual capacities (each at ~1000 operations per day), while expanded capacity at EWR probably depends highly on restructured airspace. Despite these constraints, air cargo operations (an increasingly profitable sector) are rapidly expanding at JFK and EWR; the North American Free Trade Agreement (NAFTA) has led to new routes between LGA and Canada; TEB is expanding its role as a hub for the Federal Reserve Board[25]; and TEB and HPN are major centers for high performance business jet operations. Currently the Eastern Region is scheduled to begin work to restructure the New York area airspace after completion of the Potomac project, currently ongoing, to create a metroplex control facility (MCF) for the Washington DC-Baltimore area.

Aircraft Operations at New York City Airports, 1994

Level 5 Airports	Operations	Satellite Airports	Itinerant Operations	Instrument Operations
EWR	440,490	Teterboro (TEB)	191,247	95,000
JFK	350,107	Westchester (HPN)	198,890	89,000
LGA	338,047	Islip (ISP)	130,000	58,000
		Morristown (MMU)	140,000	20,000
		Caldwell (CDW)	111,000	5,000
Totals:	**1,128,644**		**771,137**	**267,000**

Sources: FAA/ATM-300, Air Traffic Activity and Delay Report, Dec. 1994 (exact numbers). FAA Terminal Area Forecasts (TAF), Sept. 1994 (numbers ending with 000)

The airspace congestion has several major impacts on surface movement, IMC operations, and delays at all three primary airports:

* En route weather can cause severe delays at each airport - even when the airport itself is not directly impacted. Thunderstorms moving west or south of the New York area cut off departure gates and interfere with arrival patterns. Due to the large number of arrival and departure paths to/from the various airports, there is minimal room to divert, so aircraft are forced to share common flight paths. Thus:
* Departures can be almost cut off altogether. With inclement weather, arrivals are heavily favored over departures. Due to the density of arrival and departure tracks, arrivals are always allowed to land, since there is virtually no means for them to divert other than to overfly and try to get back into the arrival path. When arrivals strongly outnumber departures (at times when departure demand is significant), major surface delays result.

[25] The Federal Reserve Board maintains a fleet of business jets which shuttles 20 billion checks (about $10 billion worth per day) annually between banks. This system is described in the *Washington Post*, Jan. 17, 1996, pp. F1-2

* The three major airports all have perpendicular runways with the same orientations. Each has 4-22 runways (EWR and JFK have parallels), JFK and LGA both have 13-31 runways, while EWR has an 11-29. This requires coordination between the airports so that configurations do not clash (for example, a runway 11 departure from EWR would cross paths with an LGA arrival on runway 13 or departure off 31). Because flight paths of perpendicular runways cross, the configuration at one airport may dictate the configuration or limit the capacity at another. In IFR weather, JFK and LGA are often treated as one airfield with parallel runways.

7.2 JFK

JFK is the United States' premier international airport, particularly for trans-Atlantic operations. Although Miami (MIA) recently surpassed JFK in the number of international operations, in 1989, JFK had almost twice the number of international passengers as MIA and LAX, its nearest American rivals (this margin had narrowed to 25-30 percent by 1993). Approximately 1/3 of the operations and 55-60 percent of passengers at JFK are international (by contrast, about 40 percent of passengers at MIA and 25 percent at LAX are international). According to International Civil Aviation Authority (ICAO) statistics, in 1989, JFK ranked 7th in the world in total passengers, 5th in international passengers, 2nd in commercial freight volume, and 10th in number of international operations[26].

JFK is on the southern end of Queens, about 11 miles east by road from Manhattan, and 9 miles south-southwest of LGA. Transatlantic flights can exit easily by heading south, then east over the ocean. The airport has two sets of parallel runways, 13R-31L and 13L-31R, separated by 6,698', and 4L-22R/4R-22L, about 3,000' apart. 4L-22R intersects the two 13-31 runways. A 3,000' runway (14-32), formerly for GA, is no longer in use. The JFK control tower is located near the physical center of the airfield, immediately north of the international air terminal. The control tower is 321' high (controllers' view above the airport surface; the top of the tower is 338'), and approximately 2 miles from the 13R heading. A detailed map of JFK is shown in Figure 7.2-1.

Aviation Activity -- JFK is a major gateway airport for American, TWA, and Delta; and several international airlines, notably British Airways, Air France, and Lufthansa have major operations there. Over 100 international airlines are represented with regular flights, and about 1/3 of the operations and passengers transiting JFK are accounted for by non-United States airlines. In terms of number of operations, JFK's peak year was in 1984, with 360,550. The number dipped as low as 304,000 in 1991, from the Gulf War and recession, but recovered to 350,000 in 1993 and 1994. The number of passengers peaked in the mid-to-late 1980s (15-17 million enplanements), fell to 12.6 million by 1991, and had recovered to 13.5 million in 1993. Some international traffic has been lost to EWR, and probably to IAD.

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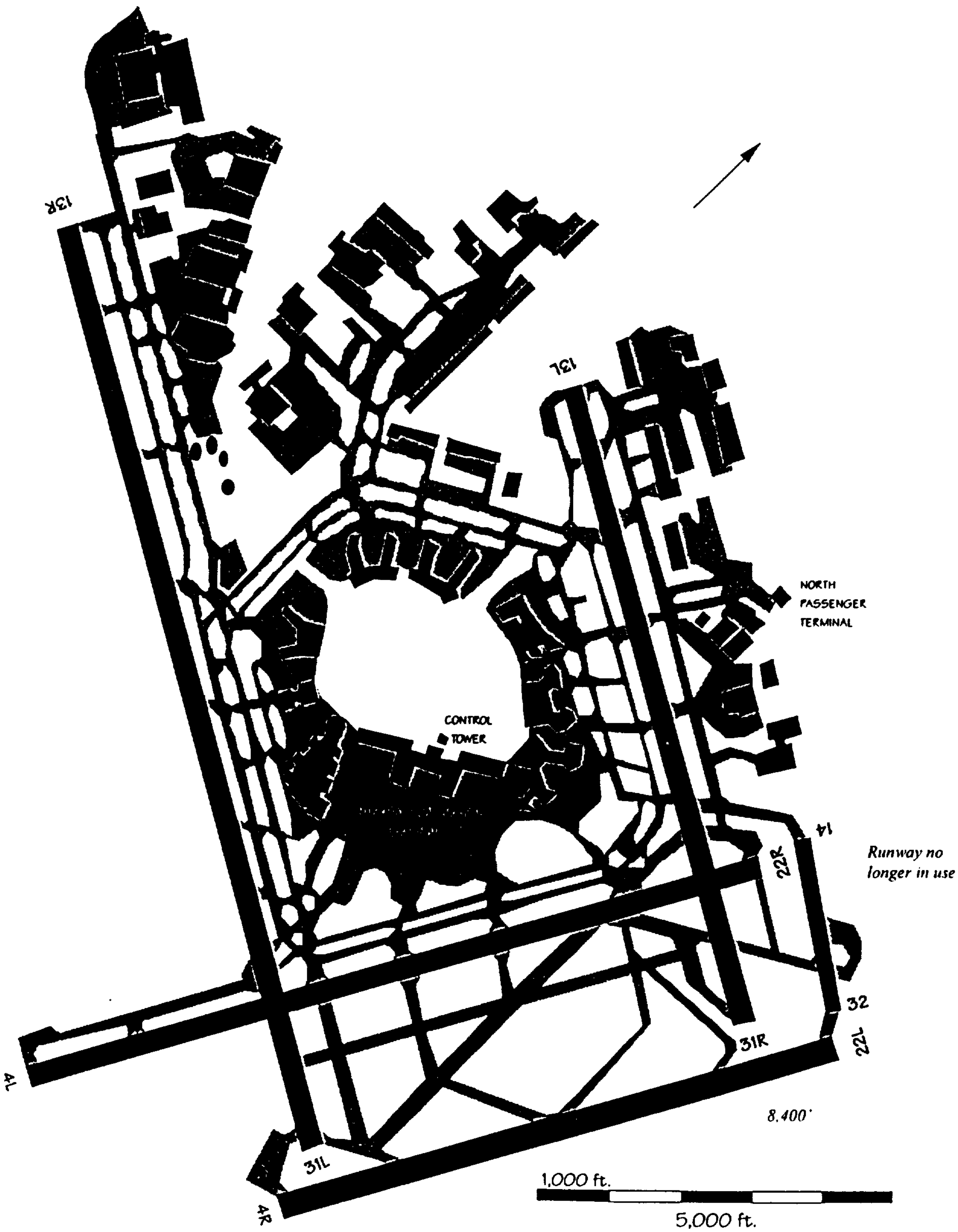
[26] Statistics from ICAO Digest of Statistics, No. 371, "Airport Traffic", 1989. The latest available update, for 1993, shows JFK well behind MIA in international operations, and about 20-30% ahead of MIA and LAX in international passengers, but 1991-mid 1993 were slow years at JFK. Traffic at JFK has picked up considerably since late 1993, but international statistics and rankings are not yet available.

Figure 7.2-1: John F. Kennedy International Airport (JFK)



JFK is busy throughout the day. Typically, there is an early arrival push, about 7:30-8:30 AM (local time), followed by a departure push from about 9-10:30 AM. In the afternoon, there is an arrival push from about 4-5:30 PM, followed by a departure push from 6-8:30 PM, with traffic generally heavy until at least 10 PM. The afternoon push peaks at 7-7:30 PM, the most favorable time for departures to Europe and the Middle East. The authors noted 20-30 aircraft in the departure queue during this time while observing from the JFK tower. Runway 13R, about 14,500' long, is used for departures of heavy/high performance international traffic - including B-747-400s, Airbus 340s (often at maximum flying weight), and Concordes. During a typical VMC arrival push, runways 13L and 22L are used for arrivals, while 13R is used for both; during a departure push, typically, 22R and 13R are used for departures, with 13L or 22L used for both. According to the JFK tower Air Traffic Manager and the EPS, VMC capacity at JFK, using one of these preferred configurations, is about 95 operations per hour[27]. In 1994, JFK's traffic was just over 60 percent air carrier operations, over half of which are heavy aircraft, 36 percent commuters, many feeding international flights, and 4 percent GA.

Weather -- A summary ceiling and visibility chart for JFK is provided in Figure 7.2-2 to show the prevalence of levels of VFR and IFR conditions at the airport. Ceiling and visibility charts for JFK and the other TAP airfields, based on 33-45 years of data from the National Climactic Data Center, are presented in Appendix B (the data in Figure 7.2-2 is extracted from the JFK chart in Appendix B, page B-7). The definitions for different ceiling/visibility categories and the basis for these definitions, are provided at the beginning of Appendix B.

Figure 7.2-2: Ceiling and Visibility Conditions at JFK

Category Name	Ceiling	Visibility	Percent of Time	
VFR	>=3000'	>=5 miles	75.1%	**VFR: 85.3%**
Marginal VFR	>=1500'	>=3 miles	10.2%	
IFR: Non-Precision	>= 500'	>=1 mile	10.2%	**IFR: 14.7%**
IFR: CAT I	>= 200'	>=1/2 mile	3.0%	
IFR: CAT II	>= 100'	>=1/4 mile	0.8%	
IFR: CAT III	>= 0'	>=0	0.7%	

JFK is under IFR conditions just under 15 percent of the time, using a rule-of-thumb that ceilings of less than 1,500' or visibility of less than 3 miles requires the initiation of an instrument approach by arrivals. About 10 percent of this IFR time (or 1.5 percent of total time) conditions are Category II/III; enough to significantly slow surface movement. Fog is more prevalent in the winter and spring, occurring on about 12 percent of days (versus 5-7 percent of days in the summer), typically impacting operations in the early morning hours (6-8 AM). Haze occurs frequently in the summer (about 25 percent of days; compared to about 10-15 percent of non-summer days), often until as late as 10 AM. CAT II/III conditions are most prevalent (up to 4 percent of the time) in January to June in the hours just before and after sunrise. Rain is most prevalent in April-May, thunderstorms in June-August.

[27] This figure is based on the EPS capacity figure for the listed configurations; depending on winds and configurations of other airports, an optimal configuration may not be allowed.

Surface Movement Issues --

* The tower air traffic manager and survey respondents at JFK stated that the biggest problem for surface movement is SWAPs, particularly when there is little warning about weather. This is typically caused by thunderstorms from the west, which move north and close off departure gates. Interestingly, JFK itself (not on the 'mainland') is not often directly hit by thunderstorms.

* VMC surface delays are largely incurred waiting in the queue; typically large numbers of aircraft are scheduled to depart across the Atlantic in the late afternoon; as many as 30 aircraft can be in the queue for departure at 7-7:30 PM.

* A traffic management supervisor provided the following average out-to-off taxi times for JFK on a follow-up telephone call:

– VMC, day:	12 minutes
– VMC, night:	12-13 min. (if pilot reasonably familiar with airfield)
– IMC, day	15-17 min. (CAT II or worse; not much impact if better)
– IMC, night	19 min. (CAT I or worse)
– Snow/Ice/Sleet	20+ min.
– Wet Pavement	15 min.
– Temperature Extremes	12 min.
– Thunderstorm	20+ min. (with heavy rain; with SWAPs, worse)

He also noted that radio frequency congestion is a problem during low visibility, since more instructions, sometimes repeated are required. Snow/ice/sleet was seen by the three JFK respondents as having the biggest impact on taxi speed, though IFR, thunderstorms, and wet pavement were also cited. Snow/ice was identified as having a severe impact on ramp congestion; IFR on runway/taxiway crossing; and IFR and snow/ice on taxiway congestion.

* According to the traffic management officer interviewed in Washington and the JFK traffic management supervisor, the "vast majority" of taxi-in delays are incurred waiting for gates. SWAPs often cause ramp congestion when departures are held. Ramp congestion was noted by all survey respondents as being severely impacted by snow/ice and IFR.

* ROT is not considered a problem. Due to the almost constant volume of heavy traffic, controllers try to move aircraft off the runways as quickly as possible. International aircraft are not a problem, as most international flights are regular, and pilots are familiar with JFK's procedures (though heavy jets typically have somewhat longer ROTs than large jets). There are sometimes language problems. While observing at JFK, with wet pavement and borderline IFR/VFR conditions, the authors timed ROTs with a wristwatch. Aircraft were timed from crossing the runway threshold until completely off the runway. Large aircraft (B-727, B-737, B-757, DC-9/MD-80, Airbus-320) ROTs were generally 45-55 seconds, typically about 50 seconds; while heavy aircraft (B-747s, A-340) had ROTs in the 55-60 second range. Snow/ice/sleet was seen as having the biggest slowing impact on ROT, though the traffic management supervisor also cited CAT II/III conditions.

* Generally, air carrier and commuter/GA aircraft are segregated, using different runways for arrivals and departures. This reduces wake vortex separations and the variability quotient.

* Low ceiling and visibility is more of a problem at JFK than at EWR or LGA, since conditions are more severe more often. Further, due to the size of the airfield and the height of the tower (controllers at 321' above surface), controllers are unable to see the entire airfield much more frequently than at EWR or LGA.
* ASDE-3 has significantly helped controllers in IMC. The tower air traffic manager noted that ASDE-3 reduced the communications requirements (iterations per aircraft), and thus reduced hold times. His comment on the impact on controllers was "the picture is worth 1,000 words."

7.3 EWR

EWR has the largest number of operations of the NYC airports, and since 1985 has been jockeying with JFK and LGA for the lead in passengers. It has been consistently among the top 15 airports in both operations and passengers since 1984. People's Express established a hub at EWR in the early 1980s; it was subsequently, in 1987, purchased by Continental (through the now defunct Texas Air). Continental has maintained a major hub at EWR since 1987, and currently controls just over half the operations and enplanements at EWR.

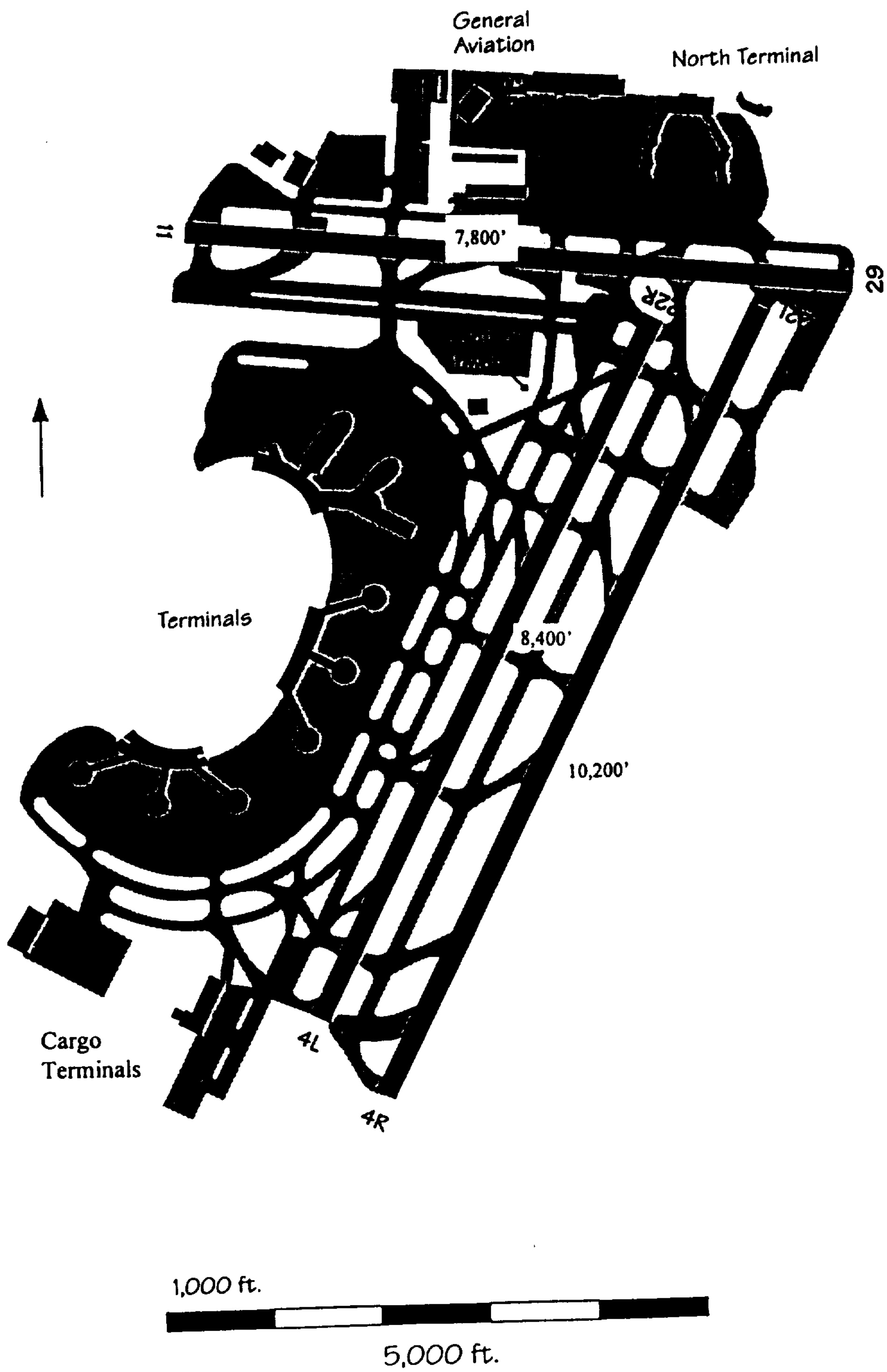
EWR is on the east side of Newark, just across Newark Bay from Staten Island; about an 8 mile drive from Manhattan. It has parallel 4-22 runways, 948' apart, and a third runway, 11-29, north of the parallels. Runway 4R-22L, the far runway from the terminal area, is the longest runway, 10,200', while 4L-22R is 8,400' long. Typically 4R-22L is used for air carrier arrivals and 22R for air carrier departures, though heavy aircraft (passenger and cargo) often use the longer runway for departures. EWR users hope to be able to lengthen 22L, which is about the only extension physically possible. Runway 11-29, 7,800' long is used for commuter and GA operations, though its use is sometimes limited due to its heading directly towards the New York City airports and shared departure and arrival tracks. The control tower is located near the center of the runway area; it is approximately 150' high, and about 1.3 miles from the furthest runway point, the heading of 4R. An airport map of EWR is shown in Figure 7.3-1.

Aviation Activity -- Aviation activity at EWR dropped after 1986 when Eastern Airlines scaled back and eventually left - 1988 operations were down 10 percent, and enplanements down 27 percent from 1986 - but the number of operations topped the 1986 level in 1993, and in 1992 EWR returned to the top 10 nationally in passengers (though the 12 million enplanements were still 20 percent below the peak in 1986). However, EWR has increased its role in freight traffic; ranking 7th in the United States and 16th in the world in freight traffic in 1993[28]. Although EWR has increased international traffic since international service began in 1987, over 3/4 of the traffic to and from EWR is south or west.

EWR has heavy traffic throughout most of the day. There are largely domestic departure pushes from about 8-9 AM and 4-5 PM, and an international departure push from about 7:30-8:30 PM.

[28] From ICAO Digest of Statistics, Airport Traffic, 1993; in 1989 EWR ranked 18th in the world, but in 1993, cargo tonnage loaded and unloaded was 55 percent higher than in 1989

Figure 7.3-1: Newark International Airport (EWR)



Arrival pushes are not as pronounced; there are periods of heavy arrivals in the afternoon, about 3-3:30 PM, and 5:30-6:30 PM, much of the latter connecting to international flights. Air carriers comprise about 67 percent of EWR traffic, commuters 28 percent, and GA 5 percent. EWR controllers and users prefer to use runway 11/29 for commuters and GA aircraft, and the 4/22s for air carrier traffic. Since departures off the runway 4s intersect LGA and JFK flight paths, controllers prefer to depart from the 22 side of the runway. A Continental Airlines ramp manager estimated that departing from the 4 side of the runway increases departure delays (primarily in the queue) by up to 25 percent. Additionally, since departures from 4 head over runway 11/29, this severely limits its use.

Using the preferred configuration of departing air carriers from runway 22R and landing on 22L, while using 11/29 for commuter and GA aircraft, the hourly capacity of EWR (according to the EPS) is 108 operations. Continental estimated that the 22s are used in aggregate, about 60 percent of the time; more in the summer, less in the winter; while the 4s are used the remainder of the time (no breakdown was available on the use and non-use of 11/29).

Weather -- Figure 7.3-2 presents a summary of ceiling/visibility conditions at EWR. As at JFK, EWR experiences IFR conditions on average 14.7 percent of the time, based on 1948-1992 data. However, EWR incurs less Category II/III conditions; only about 0.7 percent of the time; or just 5 percent of IFR time. The IFR profile is similar to that at JFK, with fog somewhat more prevalent in the winter and spring, and haze in the summer months, though both tend to be somewhat less severe, and burn off faster than at JFK. As at JFK, EWR has the most rain in April-May; thunderstorms occur primarily in May-August, but at almost twice the frequency as at JFK or LGA. Like JFK, EWR is often more severely impacted by thunderstorms which are to the west or south, but often do not actually hit the airport. Severe IFR (CAT II/III) is very rare in the summer, and is most prevalent in the winter in the hours before and after sunrise.

Figure 7.3-2: Ceiling and Visibility Conditions at EWR

Category Name	Ceiling	Visibility	Percent of Time	
VFR	>=3000'	>=5 miles	74.1%	**VFR: 85.3%**
Marginal VFR	>=1500'	>=3 miles	11.2%	
IFR: Non-Precision	>= 500'	>=1 mile	11.6%	**IFR: 14.7%**
IFR: CAT I	>= 200'	>=1/2 mile	2.4%	
IFR: CAT II	>= 100'	>=1/4 mile	0.4%	
IFR: CAT III	>= 0'	>=0	0.3%	

Surface Movement Issues --

* EWR is virtually 'boxed in', with JFK and LGA to the east and northeast, and several large reliever airfields to the north, west, and southwest. Teterboro (TEB) - with almost 200,000 operations per year, and heavy activity from the Federal Reserve fleet and high performance business jets, even in IFR - is 7 miles to the north. In terms of airspace, LGA and JFK have the 'outside' tracks, to the east and north of EWR. About 3/4 of EWR's traffic is to the west (midwestern states) and south. When storms come from the west, EWR's tracks are shut down first. Since JFK's and LGA's routes are more 'fanned' (much of JFK traffic is

transatlantic, LGA's is more dispersed), they are not as impacted by single departure paths being cut off. One Continental traffic manager added that the military is inflexible about the use of oceanic fixes (where there are 'warning areas'); he noted that using oceanic routes for traffic to Florida would save a lot of delays.

* Because of the airspace problems noted, and the strong favoring of arrivals, EWR is often unable to release departures. During SWAPs, arrivals can outnumber departures by 2.5-1[29], even with restricted flows into the area. Continental traffic managers claimed that the FAA needs to be more flexible about alternating usage of fixes (i.e., using arrival fixes for departures when there are few arrivals), but the current host computer is not capable of handling this. During an August 4, 1995 thunderstorm occurrence, out-to-off (i.e., push back from gate to wheels off) times averaged 40 minutes at LGA and JFK, and 185 minutes at EWR[30]. One EWR traffic manager noted in the survey that during SWAPs, departures have been delayed for up to 5 hours, and all survey respondents mentioned SWAPs as the leading cause of gateholds and departure delays.

* During IFR, EWR is a one-runway airfield, as runway 11/29 is generally closed, and since the parallel runways are less than 1,000' apart, they can not be used for simultaneous operations. This means that any commuters departing must use runway 4L/22R, along with the air carriers; the result is longer in trail separations when a commuter aircraft follows a large or heavy aircraft.

* Because of the hubbing operation, thunderstorms can impact an entire day's traffic, whether they directly hit the airport, or just shut down a departure fix. Continental reported that with a high number of thunderstorms this June, only 38 percent of flights in and out of EWR for the month were on time.

* Continental's January-July 1995 surface movement (all-weather) statistics at EWR: Average out-to-off time - 27 minutes; average on-to-in time - 8 minutes. Since average taxi time was said to be 7 minutes, allowing for 2 minute intervals between departures (i.e., 9 minutes total), this implies that taxi out delay consists of a maximum of 2 minutes per departure of ramp/surface congestion, and 16 minutes (~90 percent) of waiting in the queue.

* Taxi times, gate-to-queue, from three survey respondents, all EWR traffic managers:
  - VMC, day: 7 minutes
  - VMC, night: 7 min. (if pilot reasonably familiar with airfield)
  - IMC, day 10 min.
  - IMC, night 11+ min.; one respondent noted that with night-time IFR conditions, a ground-hold program is normally in effect
  - Snow/Ice/Sleet 12+ min.; secondary de-icing can increase this
  - Wet Pavement 7 min.
  - Temperature Extremes 7 min. (in mid-summer, may be somewhat slower)
  - Thunderstorm 7+ min. without SWAPs, with SWAPs, up to 300 minutes; all three respondents noted that thunderstorms result in a 'major' increase in departure queue time

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[29] According to Continental Airlines Air Traffic Managers; figure confirmed by an AEA Traffic Manager.
[30] According to Continental Airlines Air Traffic Managers.

* Continental reported that "the vast majority" of departure delays are incurred in the queue; the primary reasons being: suboptimal runway configuration; airspace conflicts; and departure sequencing, particularly since the departure sequencing is often performed by the TRACON to avoid airspace conflicts. One traffic manager quantified VMC day-time delays; the source of VMC delays (calibrated) was: departure queue - 55 percent, departure sequencing - 22 percent, runway/taxiway crossing - 10 percent, taxiway congestion - 6.5 percent, ramp congestion - 6.5 percent. Radio frequency interference was noted to be a factor in taxi-out delays by all ATC respondents. One respondent noted that it is a major problem during SWAPs and groundhold programs because pilots being held frequently call to determine their situation.
* Continental noted that weather reporting at EWR is poor. This often results in controllers being unprepared for weather. EWR does not yet have a TDWR.
* Snow/ice/sleet and thunderstorms have the greatest impact on surface delays, particularly when SWAPs are involved. According to Continental and two ATC survey respondents, thunderstorms have a 'major' impact on ramp and taxiway congestion when arrivals greatly outnumber departures. Although 'temperature extremes' was not considered a major delay factor, it was noted that during the summer, most heavy aircraft prefer to use the outer (longer) runway 4R/22L, which increases runway crossings.
* Continental reports that for the taxi-in phase, the ramp entrance is the major bottleneck. This may cause taxiway congestion as well. The major cause of ramp congestion is aircraft waiting for gates. During winter weather, this situation is severely aggravated by de-icing, which typically takes place at the ramp area (though secondary de-icing takes place in the departure queue or at holding areas). Ramp congestion is also aggravated by SWAPs or thunderstorms when aircraft are held at the gate.
* EWR is one of two TAP airfields without ASDE-3 (the other being LGA). Three of the EWR ATC staff survey respondents commented that the ASDE-2 display is poor, and provides little assistance in IFR.
* Survey respondents differed on the primary factors impacting ROT, but exit design/speed, pilot motivation, and pilot technique averaged out to be key factors. Snow/ice was rated the weather condition with the biggest impact, but one traffic manager noted that with these conditions, there are increased separations for final approach.
* Runway use configuration can impact surface movement. When aircraft are departing from 22R (out off 4L), there is often surface congestion near the control tower. Arrivals coming from the 4R runway may incur surface congestion if they are headed to the north (Continental) terminal (see map, Figure 7.3-1). Continental also noted that taxiway congestion also increases significantly when 11/29 is not in use, since all departures and all arrivals use the same runway.
* One traffic manager noted that 'VIP's can cause major disruptions. EWR is often the staging point for figures such as the President or Pope entering/exiting the country. When this occurs, all other aircraft are held at the gate.

7.4 LGA

LGA is New York City's 'domestic' airport, largely handling air carrier traffic between New York City and other major U.S. cities, as far as Denver. LGA is a major hub for shuttle traffic between New York and several cities in the northeast corridor and midwest, and with the North American Free Trade Agreement, shuttle service to Montreal and Toronto is increasing. LGA is in many ways similar to Washington DC's DCA, though traffic is much heavier. Although LGA is not a hub, USAir and Delta run major shuttle operations here, and each accounts for over 1/4 of the passenger traffic[31]. American handles another 15-20 percent of LGA passengers (all according to carrier filings with the DOT).

LGA is at the north end of Queens, just south of Riker's Island, and about an 8 mile drive from Manhattan. Like DCA, it is a physically small, close-in-to-the-city airport. It consists of two intersecting 7,000' runways, 4-22, and 13-31 (identical to the orientation of JFK's runways). The control tower is near the intersection of the runways, about 1 mile from the farthest runway point. Controllers are about 150' above the runway surface. An airport map of LGA is displayed in Figure 7.4-1.

Aviation Activity -- Virtually since its opening, LGA has remained one of the nation's busiest airports. The number of annual operations topped 300,000 in the 1960s, but due to airspace congestion, has not risen by more than 25 percent since. The peak year was in 1990, at almost 375,000. It has remained at 335-340,000 since. Enplanements peaked at 11.8 million in 1988. In 1991, enplanements dropped 15 percent, from 11.4 million in 1990, to 9.8 million, knocking LGA out of the top 10 U.S. airports for the first time. The runway length prevents LGA from handling the largest aircraft, but it does serve DC-10s, B-767s, and L-1011s. LGA traffic is about 70 percent air carrier (about 5 percent of which is heavy aircraft), 25 percent commuter, and 5 percent GA. The percentage of commuter aircraft has been steadily increasing, according to LGA tower personnel.

LGA's traffic is steady and very heavy all day, with typically 60-70 operations per hour from about 7:30 AM to 10 PM. The hourly traffic tends to be balanced between arrivals and departures, though there are numerous shuttles scheduled to leave on the hour. Arrivals are often very heavy at 30-45 minutes past the hour. One traffic manager referred to LGA as an 'anti-hub', with air carriers bringing in planeloads of people, who disperse onto commuter aircraft. The level of traffic at LGA is all the more remarkable due to the configuration of two short, crossing runways. Departures must frequently hold due to wake vortex considerations. Further, local noise (high density) restrictions limit the traffic level to an average 66 operations per hour.

The preferred configuration at LGA is departing from runway 13, and landing on 22; this results in the minimum of airspace conflicts, and, according to the EPS, enables up to 78 operations per hour. The configuration used depends, more than anything, on prevailing winds.

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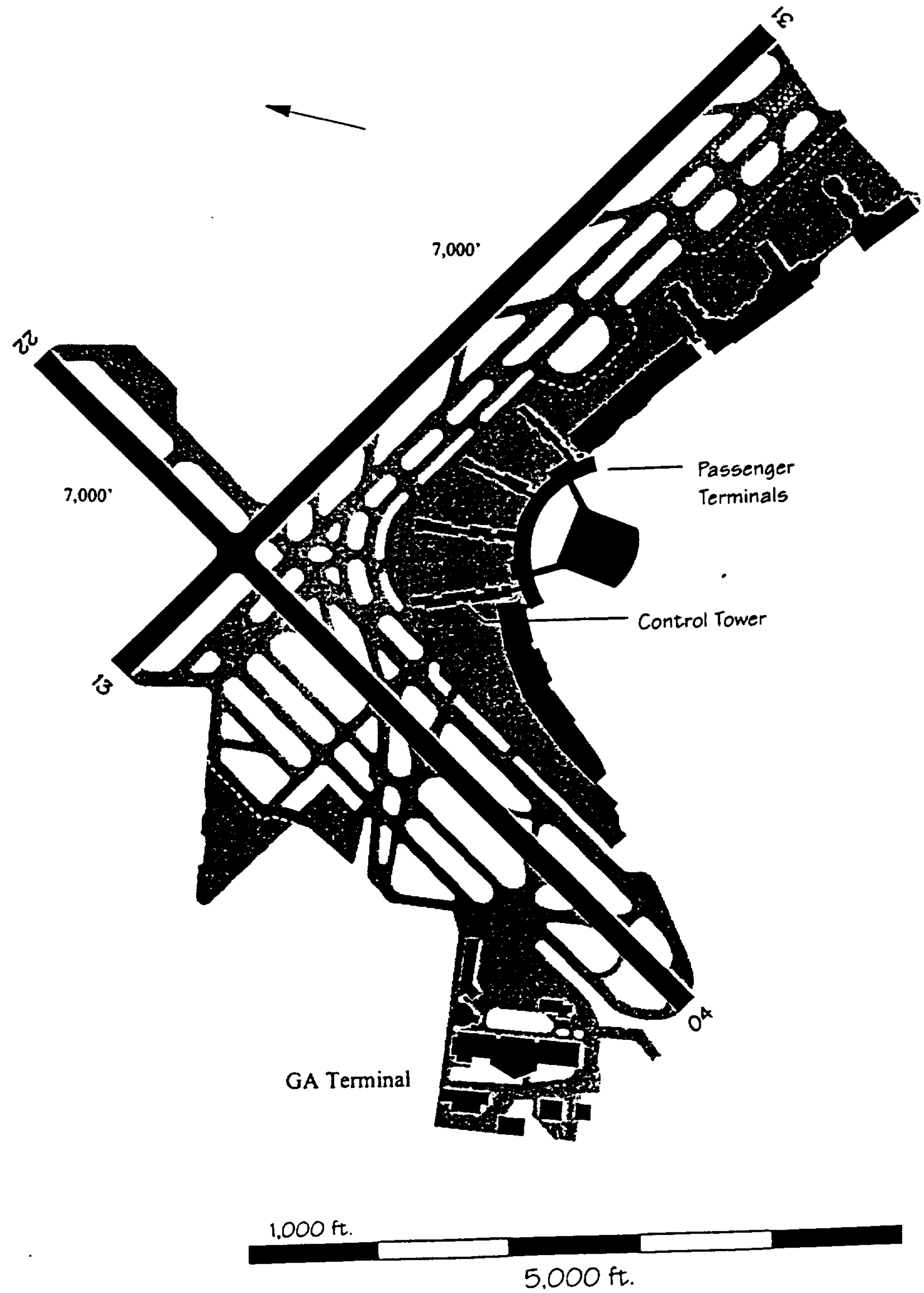
[31] According to 1994 DOT statistics

Figure 7.4-1: New York LaGuardia Airport (LGA)



Weather -- A ceiling/visibility condition summary for LGA is displayed in Figure 7.4-2. The profile is similar to those at JFK and EWR, with severe IFR at EWR levels (0.7 percent of the time, less than 5 percent of all IFR). In general, LGA's weather is very similar to that at JFK, except in the area of severe IFR weather, in which the profile closely resembles EWR's.

Figure 7.4-2: Ceiling and Visibility Conditions at LGA

Category Name	Ceiling	Visibility	Percent of Time	
VFR	>=3000'	>=5 miles	73.6%	**VFR: 84.8%**
Marginal VFR	>=1500'	>=3 miles	11.2%	
IFR: Non-Precision	>= 500'	>=1 mile	11.6%	**IFR: 15.2%**
IFR: CAT I	>= 200'	>=1/2 mile	2.9%	
IFR: CAT II	>= 100'	>=1/4 mile	0.4%	
IFR: CAT III	>= 0'	>=0	0.3%	

Surface Movement Issues --

* LGA is not a hub, and thus does not have major arrival or departure pushes, but has a steady flow of traffic all day. The most severe queuing is caused by large numbers of shuttle flights scheduled to leave on the hour. The authors observed a long queue of aircraft lining up in the first 10 minutes of an hour, but just after the half hour, there was no queue at all.

* Although LGA is generally able to release departures more easily than EWR, SWAPs and groundhold programs can cause severe surface congestion. When arrivals greatly outnumber departures - and this almost always happens during SWAPs, since LGA has a fairly steady flow of both arrivals and departures - LGA can quickly become congested due to its small size. Additionally, there is often severe ramp congestion, since LGA does not have enough gates. While EWR and JFK have a lot of commuter flights feeding into connecting flights, LGA has a much higher proportion of direct flights (i.e., passengers with NYC as a destination) by air carriers, which require gates.

* Two traffic managers provided the following average out-to-off taxi times for LGA:

– VMC, day:	7-15 minutes	10 minutes
– VMC, night:	8-16 min.	10
– IMC, day	10-18 min.	15
– IMC, night	11-19 min.	~18
– Snow/Ice/Sleet	11-19 min.	20
– Wet Pavement	9-17 min.	15
– Temperature Extremes	8-16 min.	15
– Thunderstorm	10-18 min.	10 (if no SWAP)

* Respondents did not view thunderstorms as slowing travel to the queue, but all rated thunderstorms as having a major impact on departure queue delays. Snow/ice and IFR conditions were rated as having the most severe impact on surface movement. Traffic managers noted that the ASDE-2 is of little help, and that controllers' vision can be severely impaired in IFR conditions, particularly at night. This aggravates radio frequency congestion, since more contacts are needed than if the controller has a better view of the aircraft's location (as with ASDE-3).

* One traffic manager provided a breakdown of VMC taxi-out delays as follows: Ramp - 15 percent, taxiway congestion - 20 percent, runway/taxiway crossing - 5 percent, departure sequencing - 15 percent, departure queue - 25 percent, radio frequency congestion - 5 percent, pilot not ready - 15 percent. Since 'pilot not ready' occurs in the departure queue, and RFC was stated to be pilots checking on status (generally in departure queue or awaiting sequencing, during VMC); the location of delays would be: Ramp - 15 percent, taxiway congestion - 20 percent, crossings - 5 percent, departure sequencing/ queue - 60 percent.

* Departure queuing can be longer at LGA than at other airports, since (a) all aircraft depart from the same runway, (b) departures are all straight out, with no 'fanning' until several miles out; this means that any in-trail restrictions always apply.

* The one respondent who gave a quantitative answer for VMC taxi-in delays, responded as follows: waiting for gate, ramp congestion, taxiway congestion - 25 percent each, radio frequency congestion - 15 percent, runway crossings - 10 percent. During VMC, radio frequency congestion is likely to occur between landing and the ramp, since at the ramp, the aircraft is controlled by the airline. Because of LGA's small physical size, waiting for gates or congestion at ramp entrances tends to spill over onto taxiways.

* Aircraft type/weight and exit design were listed as primary factors influencing ROT. Generally, at LGA, large air carrier aircraft have ROTs of 45 seconds, with little observed variability (see p. 31). The authors observed that pilot technique can be a significant factor; some pilots moved slower and came to almost a complete stop before turning off the runway, while others moved smoothly off; at the extremes, this made a difference of about 6-10 seconds (~40-42 seconds versus ~48-50 seconds).

* As at DCA, with no part of either runway more than about .9 miles from the tower, and the tower controllers at a height of 150', it is very rare that controllers can not see the entire field of operations.

* Generally, if aircraft are landing on 4/22 or from 31/13, controllers try to have the aircraft exit before the runway intersection. This usually enables usage of both runways during IFR.

8.0 Conclusions

Key conclusions, based on research, site visits, survey results, observations, and talks with engineers and ATC staff are as follows:

* The vast majority of surface delays are incurred waiting in the departure queue, and to a lesser extent, arrivals waiting for gates (taxi-out delays are, on average, three times taxi-in delays). Queuing delays result from lack of capacity, airline scheduling, some degree of ATC inefficiency, and frequently, from problems external to the airport, such as en route weather or airspace congestion.

* Surface congestion varies depending on traffic volume, airport layout, and local weather. Severe congestion appears to be most often caused by airspace problems - en route weather, SWAPs, departure paths shut down, etc.

* Snow/ice/sleet cause the most severe surface movement problems, but thunderstorms, particularly if accompanied by SWAPs, cause the lengthiest departure queues. IFR slows traffic severely if at the CAT II/III level, where pilots can not see the position and movement of other aircraft well; however, in these conditions, most aircraft are not flying.

* A key determinant for the slowing of surface movement is ground visibility; most of the time when 'instrument flight rules' are in effect, surface visibility is adequate for normal aircraft movement. Surface movement generally does not slow significantly except when pilots' short range visibility is impaired, or when surfaces are slippery.

* ROT does not appear to be a factor in surface delays under the current environment and procedures. Wake vortex separations are large enough that typical ROTs at major airports (~50 seconds or less) do not slow arrivals. When separations are reduced to less than 2 miles, or if multiple glide slope approaches are implemented, ROT would be a limiting factor.

* Weather frequently impacts surface movement even when it does not impact the airport; surface delays are often caused by groundhold or severe weather avoidance programs.

* In the New York City area, airspace congestion and restrictions intensify the severity of ground delays; with local or en route weather, arrivals are heavily favored over departures, since there is virtually no flexibility to divert. This increases departure delays and surface congestion. Anything beyond nominal growth at the NYC area airports would probably require realignment of the airspace.

* For airports to operate in IMC as in VMC, the most critical improvements necessary (under current conditions) would be: keep runways open, keep runways independent, optimize departure and arrival sequencing (at the airport, and metroplex level, as necessary), and improve pilots' view of the airfield, through improved maps and/or displays.

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Glossary of Acronyms

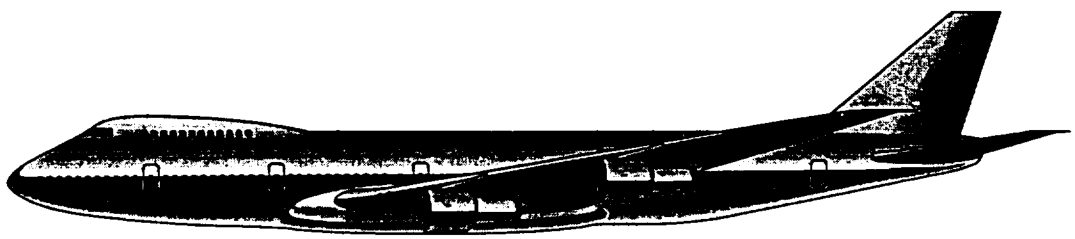
AMASS	Airport Movement Area Safety System (ASDE-3 enhancement)
ASD-400	FAA's Program Analysis and Operations Research Service
ASDE-3	Airport Surface Detection Equipment (ground movement radar)
ASQP	Airline Service Quality Performance (Dept. of Transportation operations and delay database; has 10 participating airlines)
ATA	Air Transport Association
ATC	Air Traffic Control
ATIDS	Airport Surface Target Identification System (enhancement to ASDE-3)
CAT I/II/III	Precision landing system categories (3 is for lowest ceiling/visibility)
CIP	Capital Investment Plan (FAA acquisition projects)
CODAS	Consolidated Operations and Delay Analysis System (FAA database)
CTAS	Center TRACON Automation System
EECP	Expanded East Coast Plan
EPS	Engineering Performance Standard (for airport capacity)
FAST	Final Approach Spacing Tool (an element of CTAS)
FMS	Flight Management System
GA	General Aviation
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ITWS	Integrated Terminal Weather System (FAA weather processor/display)

LaRC	NASA's Langley Research Center
LVLASO	Low Visibility Landing and Surface Operations (NASA TAP Program)
NAS	National Airspace System
P^3I	Pre-Planned Product Improvement (i.e., planned system enhancements)
R,E&D	FAA's Research, Engineering and Development program
ROT	Runway Occupancy Time
RVR	Runway Visual Range
SWAP	Severe Weather Avoidance Program
TDWR	Terminal Doppler Weather Radar
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

Airport Location Identifiers *(TAP Airports in Bold)*

ATL	Atlanta Hartsfield International
BOS	Boston Logan International
BWI	Baltimore-Washington International
DCA	Washington National
DFW	Dallas-Fort Worth International
DTW	Detroit Metropolitan Wayne County
EWR	Newark International
HPN	Westchester County (White Plains, NY)
IAD	Washington Dulles International
ISP	Islip, Long Island MacArthur
JFK	New York John F. Kennedy International
LAX	Los Angeles International
LGA	New York LaGuardia
MIA	Miami International
MSP	Minneapolis-St. Paul International
ORD	Chicago O'Hare International
SEA	Seattle-Tacoma International
SFO	San Francisco International
TEB	Teterboro (New Jersey)

APPENDIX A:
ATA Delay Statistics, 1990-1994



This Appendix shows delay statistics for the 10 TAP Airfields, based on air carrier submissions to the Air Transport Association (ATA).

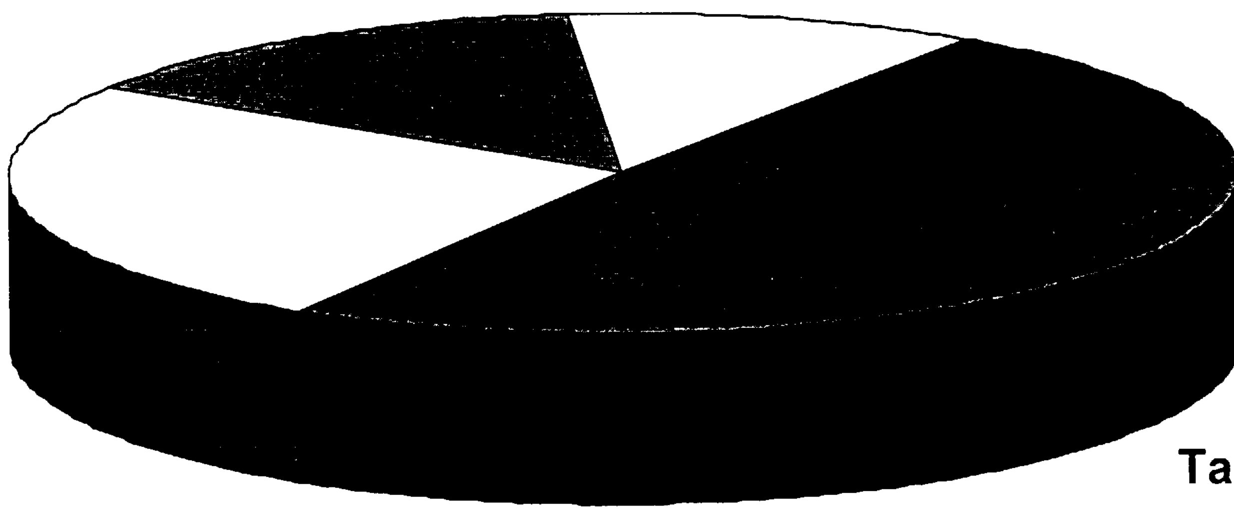
The first page (A-1) shows the breakdown of delays by phase. This breakdown is largely consistent with FAA statistics on delay by phase. The next 2 pages (A-2, A-3) show 1994 statistics for airports with, respectively, the most taxi-out and most taxi-in delay. Each chart shows for the leading airports (a) average delay minutes per operation, and (b) average delay minutes per delay occurrence. Comparing the two lines for each airport indicates the percentage of operations incurring delays - if the 2 bars are approximately equal, most operations incur delays; if the delays per delay event bar is much higher, fewer operations are delayed.

The next 5 charts (A-4 through A-9) show delays by phase of flight at the 10 TAP airfields, as reported to the ATA. There is one chart for each year, 1990-1994. Each chart shows average delays per delay event for:

- Gate Delays
- Taxi-Out Delays
- Airborne Delays
- Taxi-in Delays
- Average Delay minutes per delay event.

Since these are statistics only for airlines reporting to the ATA, they are not complete, but appear to be broadly consistent with other databases.

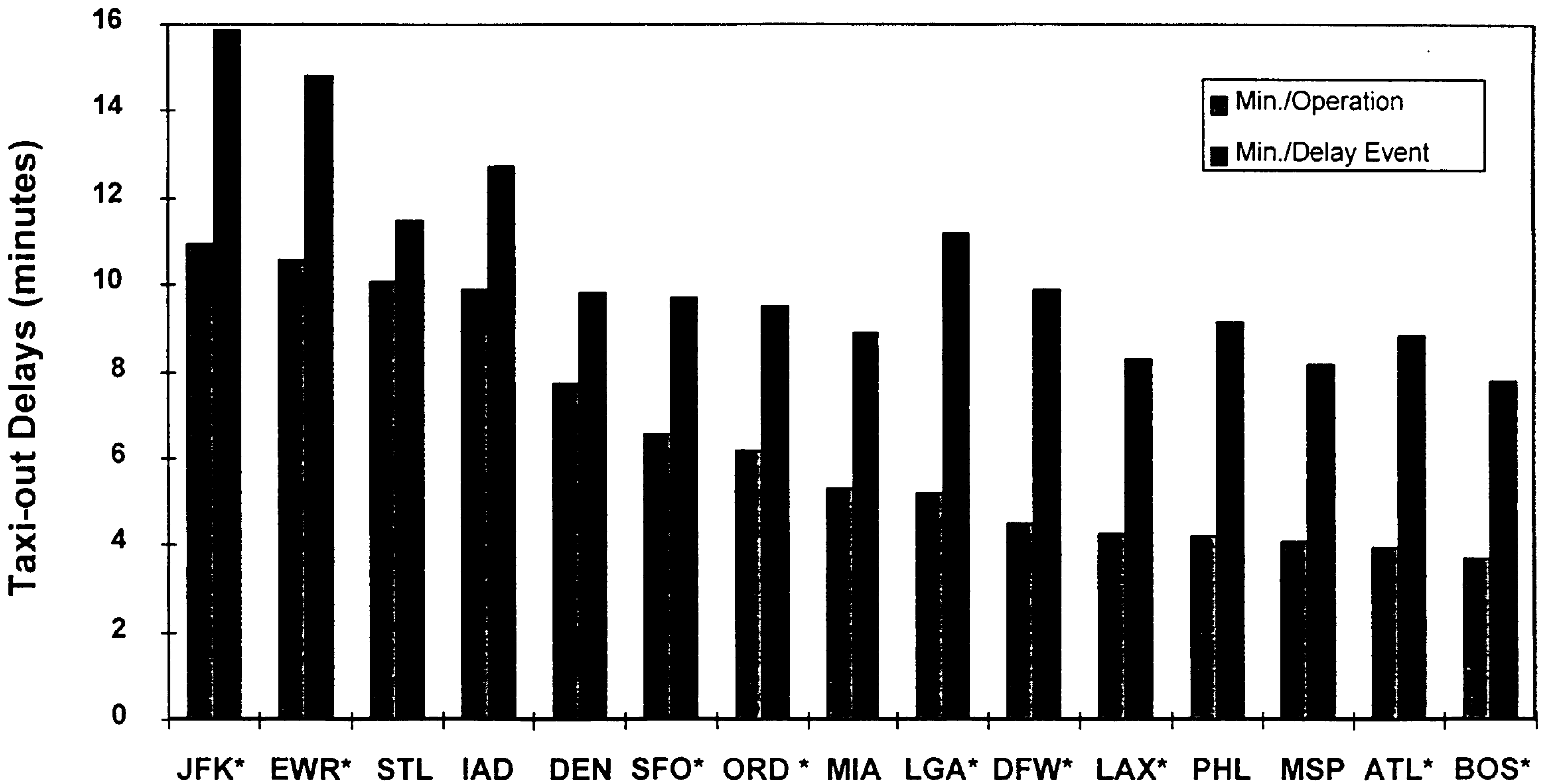
1994 Delay Time by Phase of Flight



Source: Air Transport Association Air Carrier Delay Report, Dec 1994

Taxi-Out Delays: Leading Airports

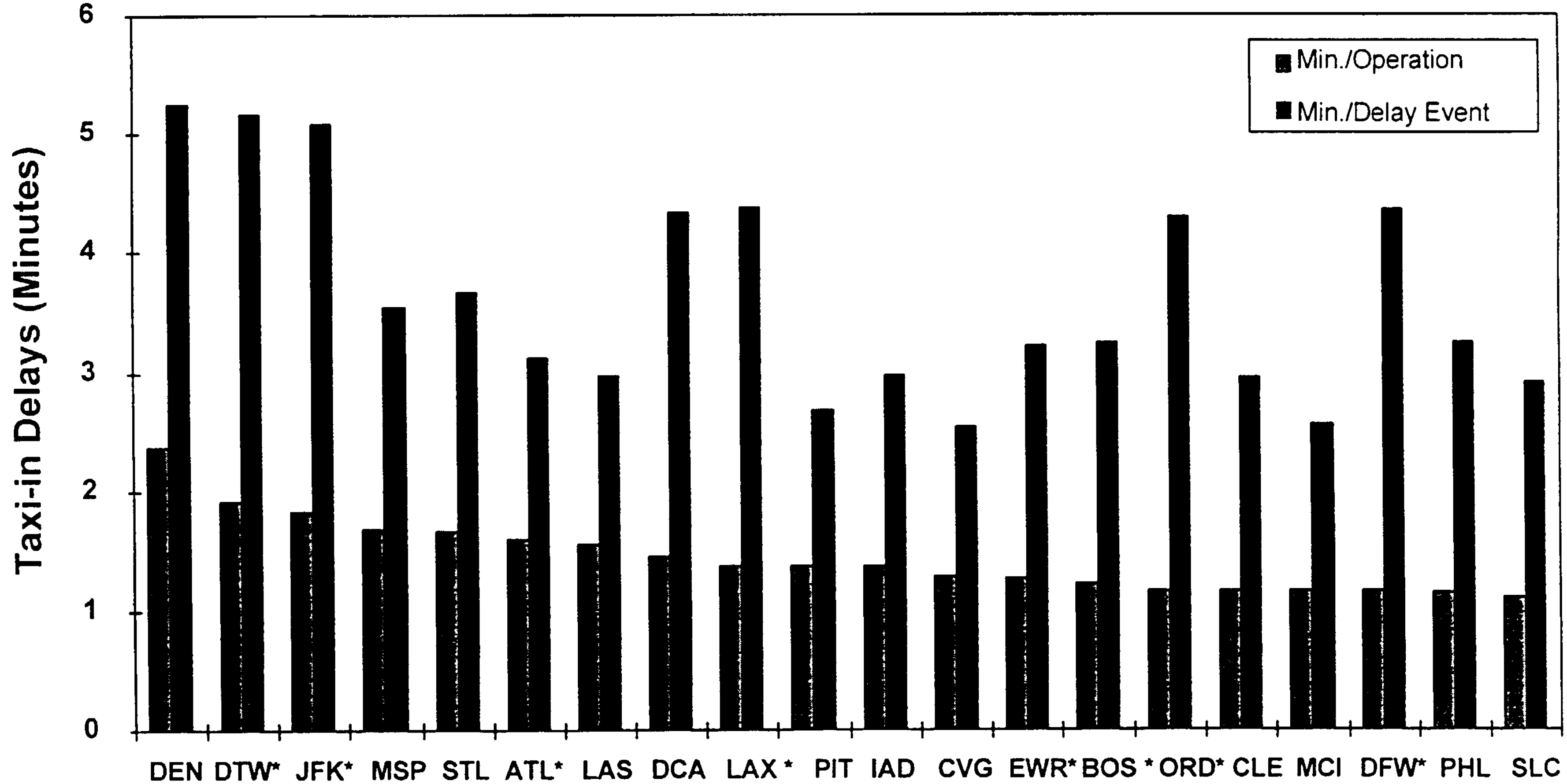
ATA Air Carrier Delay Report, 12/94



*Top 15 Airports in Taxi-out delays, 1994 ATA data, ranked by delay minutes per operation. * TAP airport*

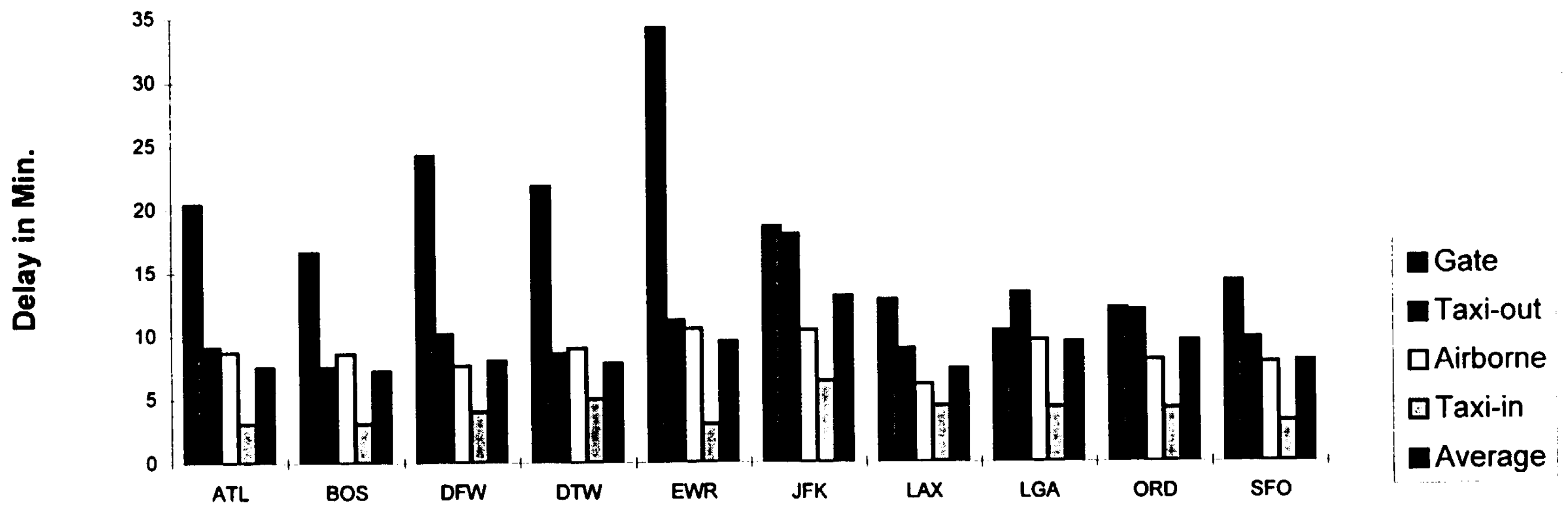
Taxi-In Delays: Leading Airports

ATA Air Carrier Delay Report, 12/94



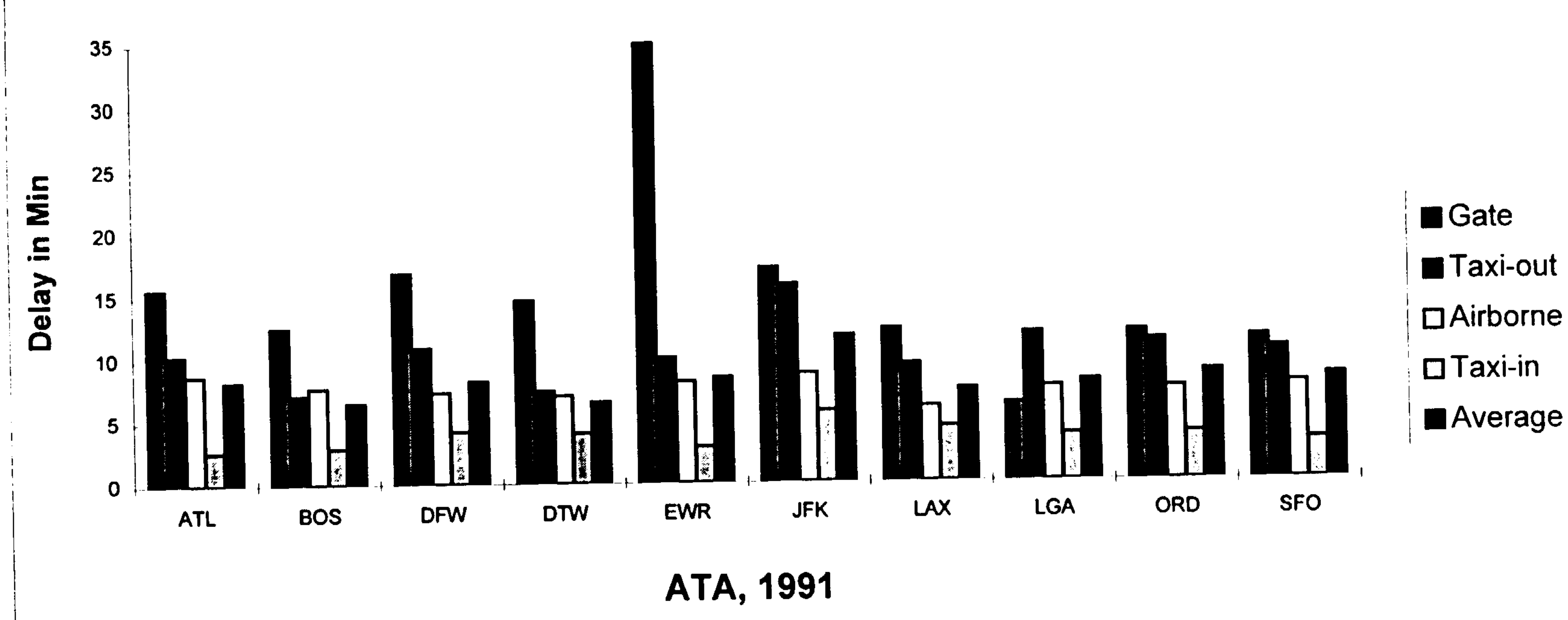
*Top 20 Airports in Taxi-in delays, 1994 ATA data, ranked by delay minutes per operation. * TAP airport*

Delay Statistics of the 10 TAP Airports

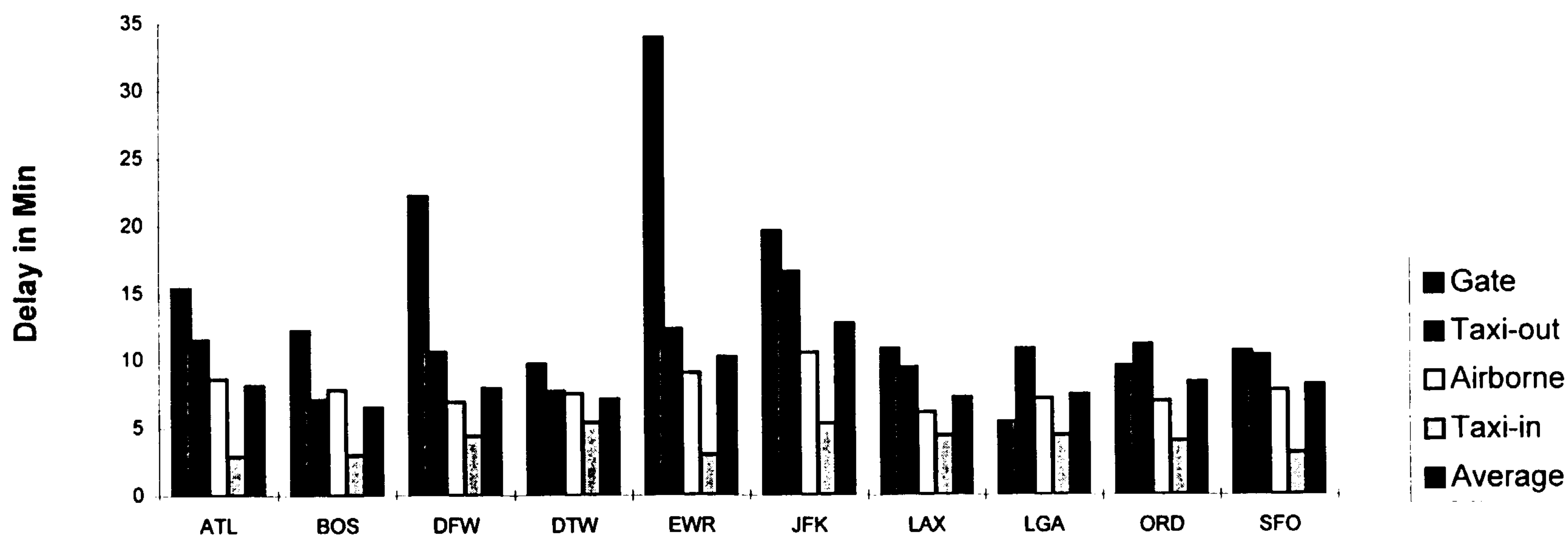


ATA,1990

Delay Statistics of the 10 TAP Airports

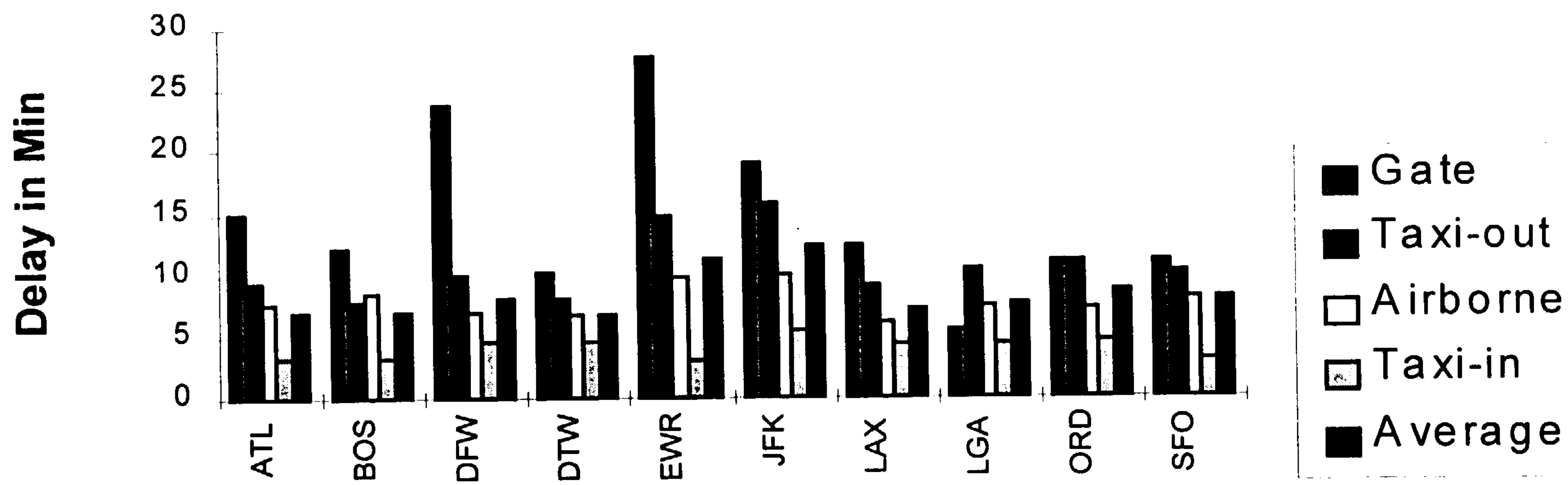


Delay Statistics of the 10 TAP Airports



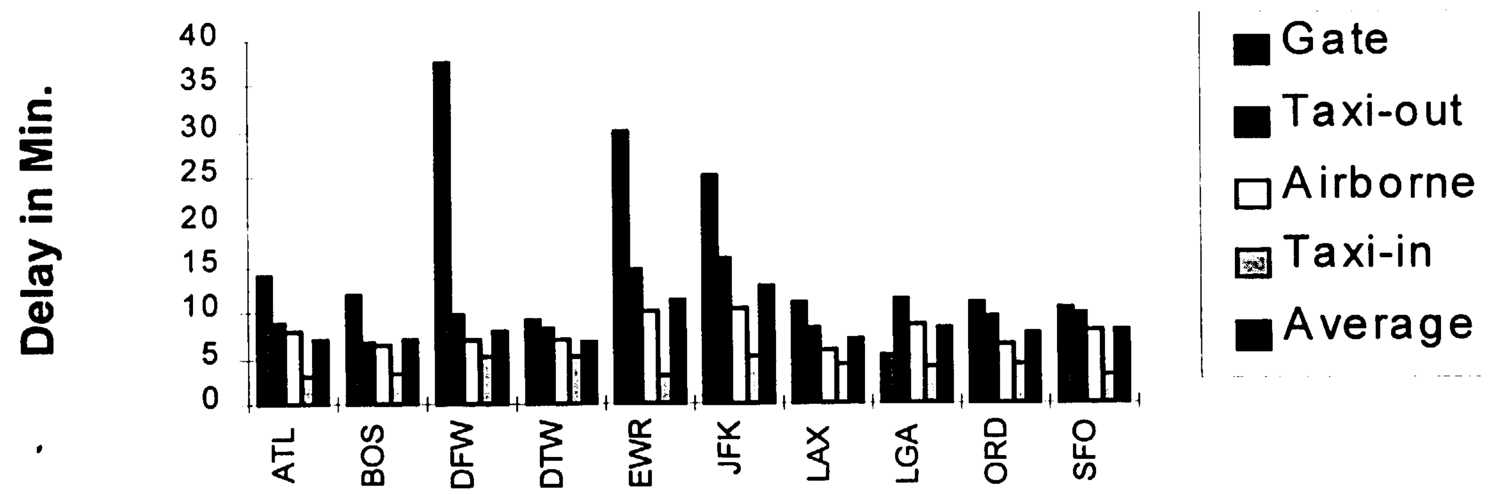
ATA, 1992

Delay Statistics of the 10 TAP Airports



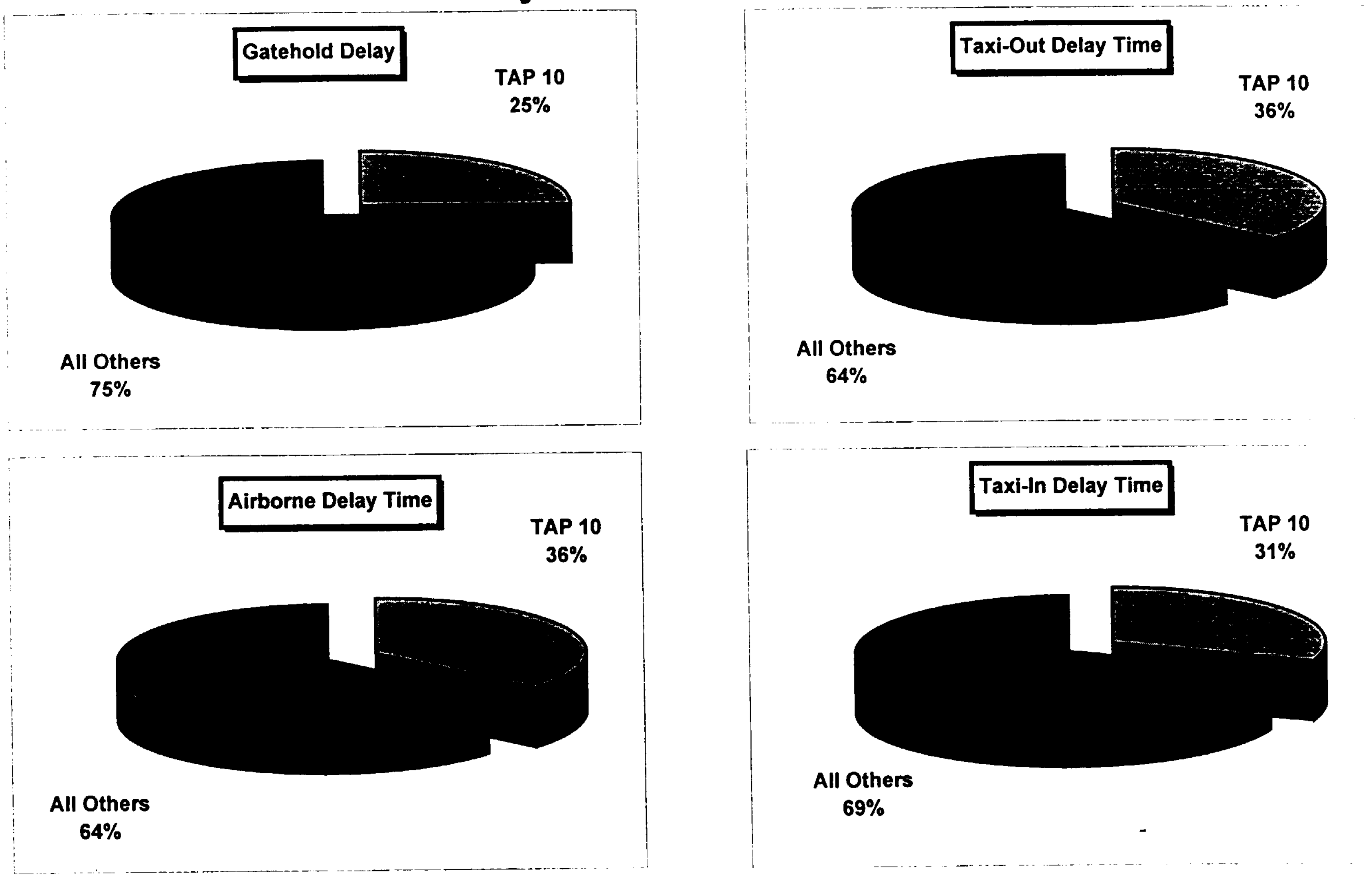
ATA, 1993

Delay Statistics of the 10 TAP Airports



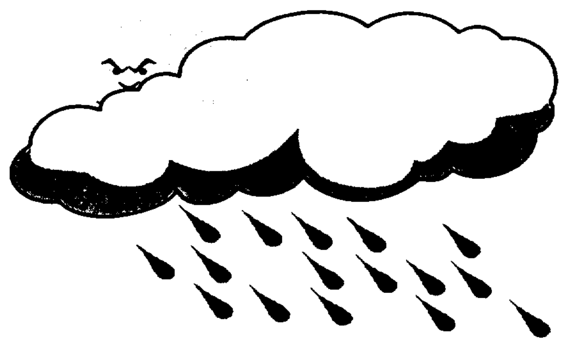
ATA, 1994

Delays at TAP 10 Airfields



Source: Air Transport Assn. Air Carrier Delay Report, Dec. 1994

APPENDIX B:
Ceiling and Visibility Profiles of the TAP Airfields



The charts in this Appendix show ceiling and visibility profiles for the 10 TAP Airfields, in alphabetical order, by location identifier (ATL, BOS, DFW, DTW, EWR, JFK, LAX, LGA, ORD, SFO). The data is annual averages from 33-45 years of observations from the National Climate Data Center's International Station Meteorological Climate Summaries - thus the data is ***specific to the airport***, not to the city or nearby data collection point.

The chart shows percentage of the time that conditions are equal to or better than the ceilings (in feet) and visibilities (in miles) noted. The chart is divided into conditions that parallel arrival approach procedures. The boldened figures indicate the percentage of the time that this procedure or better is present.

VFR -- defined as ceilings above 1,500' and visibility above 3 miles; this is because, typically, with minima below this, initiation of an instrument approach is required. Conditions vary from airport to airport, but these figures are used as typical. The bold figure at the lower right of the VFR box indicates the percentage of time the airport experiences VFR (e.g., for ATL, 84.6 percent).

Non-Precision -- Non-precision instrument approach required. Typically, the minima for this category are ceiling >= 500', visibility >= 1 mile. The bold figure in the lower right of non-precision indicates the percentage of time the airport is at non-precision or better conditions (at ATL, 93.4 percent). Subtracting the non-precision number from the VFR number provides the percentage of the time non-precision approaches are required (93.4-84.6 percent = 8.8 percent).

CAT I - A Category I precision landing; standard minima are 200' ceiling, and 1/2 mile visibility.

CAT II - Category II precision landing; standard minima are 100' ceiling, and 1/4 mile visibility.

CAT III -- Category III; below CAT II.

International Station Meteorological Climate Summary

Atlanta Hartsfield International Airport (ATL)

LAT 33 39N LONG 084 26W — ELEV 1010ft=308m

Percent Frequency Ceiling and Visibility (from hourly observations, 1945-1990)

CEILING	VISIBILITY IN STATUTE MILES >=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	44.9	53.8	55.1	55.9	56.2	56.3	56.5	56.6	56.7	56.7	56.7	56.7	56.7
>=20000	48.7	58.8	60.2	61.0	61.5	61.6	61.8	61.9	61.9	61.9	62.0	62.0	62.0
>=18000	48.8	58.9	60.4	61.2	61.6	61.7	61.9	62.0	62.1	62.1	62.1	62.2	62.2
>=16000	49.0	59.1	60.6	61.4	61.9	62.0	62.2	62.2	62.3	62.3	62.3	62.4	62.4
>=14000	50.0	60.3	61.8	62.7	63.1	63.2	63.4	63.5	63.5	63.6	63.6	63.6	63.6
>=12000	51.4	62.3	63.8	64.7	65.2	65.3	65.5	65.6	65.6	65.6	65.7	65.7	65.7
>=10000	53.0	64.5	66.2	67.1	67.6	67.7	67.9	68.0	68.1	68.1	68.1	68.2	68.2
>=9000	53.6	65.4	67.1	68.1	68.5	68.7	68.9	69.0	69.0	69.1	69.1	69.1	69.2
>=8000	54.5	66.7	68.4	69.4	69.9	70.0	70.3	70.4	70.4	70.4	70.5	70.5	70.5
>=7000	55.1	67.5	69.3	70.3	70.9	71.0	71.3	71.3	71.4	71.4	71.5	71.5	71.5
>=6000	55.8	68.4	70.2	71.3	71.8	72.0	72.2	72.3	72.4	72.4	72.4	72.5	72.5
>=5000	56.7	69.7	71.6	72.7	73.3	73.4	73.7	73.8	73.8	73.9	73.9	73.9	73.9
>=4500	57.4	70.6	72.6	73.7	74.3	74.4	74.7	74.8	74.8	74.9	74.9	74.9	75.0
>=4000	58.3	71.9	73.9	75.1	75.7	75.8	76.1	76.2	76.3	76.3	76.3	76.4	76.4
>=3500	59.1	73.2	75.2	76.4	77.0	77.2	77.4	77.5	77.6	77.6	77.7	77.7	77.7
>=3000	60.2	74.6	76.7	78.0	78.6	78.8	79.1	79.2	79.3	79.3	79.3	79.4	79.4
>=2500	61.4	76.3	78.5	79.8	80.5	80.7	81.0	81.1	81.2	81.2	81.3	81.3	81.3
>=2000	62.5	78.0	80.3	81.7	82.4	82.6	82.9	83.1	83.2	83.2	83.2	83.3	83.3
>=1800	62.9	78.7	81.0	82.4	83.2	83.3	83.7	83.8	83.9	84.0	84.0	84.0	84.1
>=1500	63.6	79.9	82.3	83.8	84.6	84.8	85.1	85.3	85.4	85.4	85.5	85.5	85.5
>=1200	64.4	81.3	83.9	85.4	86.2	86.5	86.9	87.1	87.2	87.2	87.3	87.3	87.3
>=1000	64.8	82.2	84.9	86.5	87.5	87.7	88.2	88.4	88.5	88.5	88.6	88.6	88.6
>=900	65.0	82.8	85.5	87.2	88.2	88.4	88.9	89.1	89.3	89.3	89.3	89.4	89.4
>=800	65.1	83.2	86.1	87.9	88.9	89.2	89.7	89.9	90.1	90.1	90.2	90.2	90.2
>=700	65.3	83.7	86.7	88.6	89.7	90.0	90.6	90.9	91.0	91.1	91.1	91.2	91.2
>=600	65.4	84.2	87.4	89.4	90.6	91.0	91.6	91.9	92.1	92.1	92.2	92.2	92.3
>=500	65.5	84.6	88.0	90.2	91.6	92.0	92.9	93.2	93.4	93.5	93.5	93.6	93.6
>=400	65.5	85.0	88.6	91.0	92.7	93.2	94.3	94.8	95.1	95.2	95.3	95.3	95.4
>=300	65.6	85.2	88.8	91.5	93.4	94.0	95.4	96.1	96.7	96.8	97.0	97.0	97.1
>=200	65.6	85.2	88.9	91.6	93.6	94.2	95.8	96.7	97.6	97.9	98.2	98.3	98.4
>=100	65.6	85.2	88.9	91.6	93.6	94.2	95.8	96.8	97.7	98.1	98.6	99.1	99.4
>=0	65.6	85.2	88.9	91.6	93.6	94.2	95.8	96.8	97.7	98.1	98.7	99.2	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Boston Logan International Airport (BOS)

LAT 42 22N LONG 071 02W — ELEV 20 ft = 6 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1945-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	42.8	49.2	50.8	52.2	52.9	53.2	53.4	53.4	53.5	53.5	53.5	53.5	53.5
>=20000	45.2	52.0	53.7	55.1	55.9	56.2	56.4	56.5	56.5	56.5	56.6	56.6	56.6
>=18000	45.4	52.3	54.1	55.5	56.2	56.6	56.8	56.9	56.9	56.9	56.9	56.9	56.9
>=16000	45.8	52.8	54.6	56.0	56.7	57.1	57.3	57.4	57.4	57.4	57.4	57.5	57.5
>=14000	46.7	53.9	55.7	57.2	57.9	58.3	58.5	58.6	58.6	58.6	58.7	58.7	58.7
>=12000	48.2	55.8	57.7	59.3	60.1	60.4	60.7	60.8	60.8	60.8	60.8	60.8	60.9
>=10000	50.2	58.2	60.3	62.0	62.8	63.2	63.4	63.5	63.6	63.6	63.6	63.6	63.6
>=9000	51.0	59.3	61.5	63.1	64.0	64.4	64.7	64.8	64.8	64.8	64.8	64.8	64.9
>=8000	52.5	61.2	63.4	65.2	66.1	66.5	66.8	66.9	67.0	67.0	67.0	67.0	67.0
>=7000	53.5	62.5	64.8	66.6	67.6	68.0	68.2	68.4	68.4	68.4	68.4	68.5	68.5
>=6000	55.0	64.4	66.8	68.7	69.7	70.1	70.4	70.5	70.6	70.6	70.6	70.6	70.6
>=5000	56.8	66.6	69.1	71.1	72.2	72.6	72.9	73.0	73.1	73.1	73.1	73.1	73.1
>=4500	57.8	67.9	70.5	72.5	73.6	74.0	74.3	74.4	74.5	74.5	74.5	74.6	74.6
>=4000	58.9	69.3	71.9	74.0	75.1	75.6	75.9	76.0	76.1	76.1	76.1	76.1	76.1
>=3500	60.2	70.9	73.6	75.7	76.9	77.3	77.7	77.8	77.9	77.9	77.9	77.9	77.9
>=3000	61.3	72.3	75.1	77.4	78.5	79.0	79.4	79.5	79.6	79.6	79.6	79.7	79.7
>=2500	62.3	73.7	76.6	78.9	80.2	80.7	81.0	81.2	81.3	81.3	81.3	81.3	81.3
>=2000	63.5	75.3	78.3	80.7	82.0	82.6	83.0	83.1	83.2	83.3	83.3	83.3	83.3
>=1800	63.8	75.8	78.9	81.4	82.7	83.2	83.7	83.8	83.9	84.0	84.0	84.0	84.0
>=1500	64.4	76.9	80.1	82.7	84.1	84.7	85.2	85.4	85.5	85.6	85.6	85.6	85.6
>=1200	65.1	78.1	81.5	84.3	85.9	86.5	87.1	87.4	87.5	87.6	87.6	87.6	87.6
>=1000	65.5	79.0	82.6	85.6	87.3	88.0	88.7	89.0	89.2	89.2	89.3	89.3	89.3
>=900	65.7	79.4	83.2	86.3	88.1	88.9	89.6	89.9	90.2	90.2	90.3	90.3	90.3
>=800	65.8	79.9	83.8	87.2	89.1	89.9	90.7	91.1	91.4	91.5	91.5	91.6	91.6
>=700	65.9	80.3	84.4	87.9	90.0	91.0	91.8	92.3	92.6	92.7	92.8	92.8	92.9
>=600	66.0	80.7	84.8	88.6	90.9	91.9	92.9	93.4	93.8	94.0	94.1	94.1	94.1
>=500	66.0	80.9	85.2	89.2	91.7	92.9	94.0	94.7	95.2	95.4	95.6	95.6	95.6
>=400	66.1	81.0	85.4	89.5	92.2	93.5	94.9	95.8	96.4	96.7	96.9	97.0	97.0
>=300	66.1	81.0	85.4	89.6	92.5	93.9	95.4	96.5	97.4	97.7	98.1	98.3	98.4
>=200	66.1	81.0	85.4	89.6	92.5	93.9	95.6	96.8	97.7	98.2	98.8	99.2	99.3
>=100	66.1	81.0	85.4	89.6	92.5	93.9	95.6	96.8	97.8	98.3	99.0	99.5	99.9
>=0	66.1	81.0	85.4	89.6	92.5	93.9	95.6	96.8	97.8	98.3	99.0	99.6	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Dallas-Fort Worth International Airport (DFW)

LAT 32 54N LONG 097 02W | ELEV 551 ft = 168 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1953-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
·			VFR				NON-PRECISION			CAT I		CAT II	CAT III
Unlimited	58.5	62.0	62.4	62.6	62.7	62.8	62.8	62.8	62.8	62.8	62.8	62.9	62.9
>=20000	62.3	66.3	66.8	67.0	67.1	67.1	67.2	67.2	67.2	67.2	67.2	67.2	67.3
>=18000	62.5	66.4	66.9	67.2	67.3	67.3	67.3	67.4	67.4	67.4	67.4	67.4	67.4
>=16000	62.6	66.6	67.1	67.3	67.4	67.5	67.5	67.5	67.5	67.5	67.6	67.6	67.6
>=14000	63.4	67.4	68.0	68.2	68.3	68.3	68.4	68.4	68.4	68.4	68.4	68.4	68.5
>=12000	65.4	69.6	70.1	70.4	70.5	70.5	70.5	70.6	70.6	70.6	70.6	70.6	70.6
>=10000	68.3	72.8	73.4	73.7	73.8	73.8	73.9	73.9	73.9	73.9	73.9	73.9	74.0
>=9000	68.7	73.3	73.9	74.2	74.3	74.3	74.4	74.4	74.4	74.4	74.4	74.4	74.5
>=8000	70.0	74.8	75.4	75.7	75.8	75.8	75.8	75.9	75.9	75.9	75.9	75.9	76.0
>=7000	70.6	75.5	76.2	76.5	76.6	76.6	76.7	76.7	76.7	76.7	76.7	76.7	76.8
>=6000	71.5	76.5	77.2	77.5	77.6	77.7	77.7	77.7	77.8	77.8	77.8	77.8	77.8
>=5000	72.8	78.1	78.8	79.1	79.2	79.3	79.3	79.3	79.4	79.4	79.4	79.4	79.4
>=4500	73.6	79.0	79.7	80.1	80.2	80.2	80.3	80.3	80.4	80.4	80.4	80.4	80.4
>=4000	74.5	80.0	80.7	81.1	81.2	81.3	81.3	81.3	81.4	81.4	81.4	81.4	81.4
>=3500	75.5	81.1	81.9	82.3	82.4	82.5	82.5	82.6	82.6	82.6	82.6	82.6	82.7
>=3000	76.6	82.5	83.3	83.6	83.8	83.9	83.9	84.0	84.0	84.0	84.0	84.0	84.1
>=2500	78.1	84.2	85.1	85.5	85.7	85.7	85.8	85.8	85.9	85.9	85.9	85.9	86.0
>=2000	79.8	86.4	87.3	87.7	87.9	88.0	88.1	88.1	88.2	88.2	88.2	88.2	88.2
>=1800	80.7	87.4	88.3	88.8	89.0	89.1	89.2	89.2	89.3	89.3	89.3	89.3	89.4
>=1500	82.0	89.3	90.3	90.8	91.1	91.1	91.2	91.3	91.3	91.4	91.4	91.4	91.4
>=1200	83.1	90.8	91.9	92.5	92.8	92.9	93.0	93.1	93.1	93.1	93.2	93.2	93.2
>=1000	83.7	91.8	93.1	93.7	94.0	94.1	94.3	94.3	94.4	94.4	94.4	94.5	94.5
>=900	84.0	92.3	93.6	94.3	94.7	94.7	94.9	95.0	95.1	95.1	95.1	95.1	95.2
>=800	84.2	92.8	94.1	94.9	95.3	95.4	95.6	95.7	95.8	95.8	95.8	95.8	95.9
>=700	84.4	93.2	94.7	95.5	96.0	96.1	96.3	96.4	96.5	96.6	96.6	96.6	96.6
>=600	84.5	93.5	95.1	96.0	96.5	96.7	97.0	97.1	97.2	97.2	97.3	97.3	97.3
>=500	84.6	93.7	95.4	96.4	97.0	97.2	97.6	97.8	97.9	97.9	98.0	98.0	98.0
>=400	84.7	93.9	95.6	96.7	97.4	97.7	98.1	98.4	98.6	98.6	98.6	98.7	98.7
>=300	84.7	93.9	95.7	96.8	97.6	97.9	98.4	98.8	99.0	99.1	99.1	99.2	99.2
>=200	84.7	93.9	95.7	96.9	97.6	97.9	98.5	98.9	99.2	99.3	99.5	99.5	99.6
>=100	84.7	93.9	95.7	96.9	97.7	98.0	98.5	98.9	99.3	99.4	99.6	99.7	99.8
>=0	84.7	93.9	95.7	96.9	97.7	98.0	98.5	98.9	99.3	99.4	99.6	99.8	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Detroit Metropolitan Wayne County Airport (DTW)

LAT 42 14N LONG 083 20W — ELEV 633 ft = 193 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1958-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	32.2	41.0	43.2	44.9	45.8	46.2	46.6	46.9	47.0	47.1	47.1	47.1	47.2
>=20000	33.7	43.2	45.6	47.4	48.4	48.8	49.2	49.5	49.7	49.7	49.8	49.8	49.9
>=18000	33.7	43.3	45.7	47.5	48.4	48.9	49.3	49.6	49.7	49.8	49.8	49.9	49.9
>=16000	33.7	43.3	45.7	47.6	48.5	48.9	49.4	49.6	49.8	49.9	49.9	49.9	50.0
>=14000	34.2	44.0	46.4	48.2	49.2	49.7	50.1	50.4	50.5	50.6	50.6	50.7	50.7
>=12000	35.4	45.7	48.3	50.3	51.3	51.8	52.3	52.5	52.7	52.8	52.8	52.8	52.9
>=10000	37.3	48.7	51.5	53.6	54.8	55.3	55.8	56.1	56.3	56.3	56.4	56.4	56.5
>=9000	37.8	49.5	52.3	54.5	55.7	56.3	56.8	57.1	57.3	57.3	57.4	57.4	57.5
>=8000	39.2	51.5	54.6	57.0	58.2	58.8	59.4	59.7	59.9	59.9	60.0	60.0	60.1
>=7000	40.0	52.9	56.1	58.6	59.9	60.5	61.1	61.4	61.6	61.7	61.8	61.8	61.9
>=6000	41.1	54.4	57.7	60.3	61.6	62.3	62.9	63.3	63.5	63.6	63.6	63.6	63.7
>=5000	42.6	56.7	60.2	62.9	64.3	65.1	65.7	66.1	66.3	66.4	66.4	66.5	66.5
>=4500	43.9	58.5	62.2	65.0	66.5	67.2	67.9	68.3	68.5	68.6	68.7	68.7	68.8
>=4000	44.9	59.9	63.7	66.7	68.2	69.0	69.7	70.1	70.4	70.4	70.5	70.5	70.6
>=3500	46.2	62.0	65.9	68.9	70.5	71.4	72.1	72.6	72.8	72.9	72.9	73.0	73.0
>=3000	48.0	64.6	68.7	72.0	73.7	74.6	75.4	75.8	76.1	76.2	76.2	76.3	76.3
>=2500	50.3	68.0	72.4	75.9	77.8	78.8	79.7	80.2	80.5	80.5	80.6	80.6	80.7
>=2000	51.9	70.8	75.5	79.3	81.3	82.4	83.4	84.0	84.3	84.4	84.4	84.5	84.5
>=1800	52.4	71.7	76.5	80.4	82.5	83.6	84.7	85.2	85.6	85.6	85.7	85.8	85.8
>=1500	53.2	73.4	78.5	82.7	84.9	86.1	87.4	88.0	88.4	88.5	88.6	88.7	88.7
>=1200	53.7	74.6	79.9	84.4	86.8	88.1	89.5	90.3	90.7	90.9	90.9	91.0	91.1
>=1000	53.9	75.1	80.6	85.3	87.8	89.3	90.8	91.7	92.3	92.5	92.6	92.6	92.7
>=900	53.9	75.4	81.0	85.8	88.5	90.0	91.6	92.6	93.2	93.4	93.5	93.5	93.6
>=800	54.0	75.6	81.3	86.2	89.0	90.6	92.3	93.4	94.0	94.2	94.4	94.4	94.5
>=700	54.0	75.7	81.5	86.5	89.4	91.1	92.9	94.0	94.7	95.0	95.1	95.2	95.2
>=600	54.0	75.7	81.6	86.9	89.8	91.6	93.5	94.8	95.6	95.9	96.0	96.1	96.2
>=500	54.0	75.8	81.7	87.1	90.1	91.9	94.0	95.5	96.4	96.7	96.9	97.0	97.1
>=400	54.0	75.8	81.7	87.2	90.3	92.2	94.5	96.1	97.1	97.5	97.8	97.9	98.0
>=300	54.0	75.8	81.8	87.2	90.3	92.3	94.6	96.4	97.6	98.1	98.5	98.6	98.6
>=200	54.0	75.8	81.8	87.2	90.3	92.3	94.7	96.5	97.9	98.5	98.9	99.1	99.3
>=100	54.0	75.8	81.8	87.2	90.3	92.3	94.7	96.5	97.9	98.6	99.1	99.4	99.7
>=0	54.0	75.8	81.8	87.2	90.3	92.3	94.7	96.5	97.9	98.6	99.1	99.5	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Newark International Airport (EWR)

LAT 40 42N LONG 074 10W | ELEV 30 ft = 9 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1948-1990)

CEILING	VISIBILITY IN STATUTE MILES >=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	36.4	45.0	46.8	48.5	49.5	50.0	50.4	50.6	50.7	50.8	50.8	50.8	50.8
>=20000	38.9	48.2	50.2	52.1	53.2	53.7	54.1	54.3	54.5	54.5	54.6	54.6	54.6
>=18000	39.0	48.4	50.4	52.3	53.4	54.0	54.4	54.6	54.8	54.8	54.9	54.9	54.9
>=16000	39.1	48.6	50.6	52.5	53.7	54.2	54.6	54.8	55.0	55.0	55.1	55.1	55.1
>=14000	40.0	49.8	51.9	53.9	55.1	55.6	56.0	56.3	56.4	56.5	56.5	56.6	56.6
>=12000	41.4	51.9	54.1	56.3	57.5	58.1	58.6	58.8	59.0	59.1	59.1	59.1	59.2
>=10000	43.0	54.3	56.7	59.0	60.3	60.9	61.5	61.7	61.9	62.0	62.0	62.1	62.1
>=9000	43.7	55.3	57.8	60.2	61.6	62.2	62.7	63.0	63.2	63.3	63.3	63.4	63.4
>=8000	45.0	57.2	59.8	62.2	63.7	64.4	64.9	65.2	65.4	65.5	65.6	65.6	65.6
>=7000	46.4	59.2	61.9	64.5	66.0	66.7	67.3	67.6	67.8	67.9	68.0	68.0	68.0
>=6000	47.7	61.1	63.9	66.5	68.2	68.9	69.5	69.8	70.0	70.1	70.2	70.2	70.2
>=5000	49.7	63.7	66.7	69.5	71.2	71.9	72.6	72.9	73.1	73.2	73.3	73.3	73.3
>=4500	50.9	65.4	68.5	71.4	73.2	74.0	74.6	75.0	75.2	75.3	75.3	75.3	75.4
>=4000	52.3	67.3	70.5	73.5	75.3	76.2	76.8	77.2	77.4	77.5	77.6	77.6	77.6
>=3500	53.6	69.1	72.4	75.6	77.5	78.4	79.1	79.4	79.7	79.8	79.8	79.8	79.9
>=3000	54.5	70.6	74.1	77.4	79.3	80.3	81.0	81.4	81.6	81.7	81.8	81.8	81.8
>=2500	55.4	72.1	75.7	79.2	81.2	82.2	83.0	83.4	83.7	83.8	83.9	83.9	83.9
>=2000	56.0	73.5	77.2	80.9	83.0	84.1	84.9	85.3	85.6	85.8	85.8	85.9	85.9
>=1800	56.3	74.1	77.9	81.6	83.8	84.9	85.8	86.2	86.5	86.6	86.7	86.7	86.8
>=1500	56.7	75.0	79.0	82.9	85.3	86.5	87.4	88.0	88.3	88.4	88.5	88.5	88.5
>=1200	56.9	75.9	80.2	84.4	87.0	88.3	89.4	89.9	90.3	90.4	90.5	90.6	90.6
>=1000	57.0	76.4	80.9	85.4	88.2	89.6	90.7	91.4	91.8	91.9	92.0	92.1	92.1
>=900	57.0	76.7	81.3	86.0	89.0	90.5	91.7	92.4	92.9	93.1	93.1	93.2	93.2
>=800	57.0	76.9	81.7	86.5	89.6	91.3	92.6	93.4	93.9	94.1	94.2	94.3	94.3
>=700	57.0	77.0	81.9	86.9	90.2	91.9	93.4	94.3	94.9	95.1	95.2	95.3	95.3
>=600	57.1	77.1	82.1	87.2	90.7	92.6	94.3	95.3	96.0	96.3	96.5	96.5	96.5
>=500	57.1	77.2	82.2	87.4	91.0	93.1	94.9	96.1	96.9	97.2	97.4	97.5	97.5
>=400	57.1	77.2	82.2	87.5	91.2	93.4	95.4	96.7	97.7	98.1	98.4	98.4	98.5
>=300	57.1	77.2	82.2	87.6	91.3	93.5	95.6	97.0	98.2	98.7	99.0	99.1	99.2
>=200	57.1	77.2	82.2	87.6	91.3	93.5	95.6	97.1	98.3	98.9	99.3	99.5	99.6
>=100	57.1	77.2	82.2	87.6	91.3	93.5	95.6	97.1	98.3	99.0	99.4	99.7	99.8
>=0	57.1	77.2	82.2	87.6	91.3	93.5	95.6	97.1	98.3	99.0	99.4	99.7	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

John F. Kennedy International Airport (JFK)

LAT 40 39N LONG 073 47W ELEV 16 ft = 5 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1948-1990)

CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VISIBILITY IN STATUTE MILES												
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	36.5	45.4	47.3	48.9	49.9	50.3	50.6	50.8	50.9	50.9	50.9	50.9	51.0
>=20000	39.7	49.6	51.7	53.6	54.7	55.1	55.5	55.7	55.7	55.8	55.8	55.8	55.8
>=18000	39.8	49.8	52.0	53.8	54.9	55.4	55.7	55.9	56.0	56.1	56.1	56.1	56.1
>=16000	40.0	50.0	52.2	54.0	55.2	55.6	56.0	56.2	56.2	56.3	56.3	56.3	56.3
>=14000	40.8	51.1	53.4	55.3	56.4	56.9	57.3	57.5	57.6	57.6	57.6	57.6	57.7
>=12000	42.3	53.4	55.7	57.8	59.0	59.5	59.9	60.1	60.2	60.3	60.3	60.3	60.3
>=10000	44.2	56.2	58.8	61.0	62.3	62.8	63.2	63.5	63.6	63.6	63.6	63.6	63.7
>=9000	45.0	57.4	60.1	62.4	63.7	64.2	64.7	64.9	65.0	65.1	65.1	65.1	65.1
>=8000	46.3	59.3	62.1	64.5	65.9	66.4	66.9	67.1	67.3	67.3	67.3	67.3	67.4
>=7000	47.3	60.8	63.6	66.1	67.6	68.1	68.6	68.8	69.0	69.0	69.0	69.1	69.1
>=6000	48.5	62.6	65.6	68.1	69.6	70.2	70.7	70.9	71.1	71.1	71.2	71.2	71.2
>=5000	50.1	64.8	67.9	70.5	72.1	72.7	73.2	73.5	73.6	73.7	73.7	73.7	73.7
>=4500	51.3	66.5	69.7	72.4	74.0	74.6	75.1	75.4	75.6	75.6	75.6	75.6	75.7
>=4000	52.7	68.4	71.8	74.6	76.3	76.9	77.4	77.7	77.9	77.9	78.0	78.0	78.0
>=3500	53.7	69.9	73.3	76.3	78.0	78.6	79.2	79.5	79.6	79.7	79.7	79.7	79.7
>=3000	54.8	71.6	75.1	78.2	79.9	80.6	81.2	81.5	81.7	81.7	81.7	81.8	81.8
>=2500	55.6	72.9	76.6	79.8	81.6	82.3	82.9	83.2	83.4	83.4	83.5	83.5	83.5
>=2000	56.4	74.3	78.1	81.4	83.3	84.1	84.7	85.0	85.2	85.3	85.3	85.3	85.3
>=1800	56.6	74.8	78.7	82.0	84.0	84.7	85.3	85.7	85.9	85.9	86.0	86.0	86.0
>=1500	57.1	75.8	79.8	83.2	85.3	86.1	86.7	87.1	87.3	87.4	87.4	87.4	87.5
>=1200	57.4	76.8	81.0	84.6	86.8	87.7	88.4	88.8	89.0	89.1	89.1	89.1	89.1
>=1000	57.6	77.5	81.9	85.6	87.9	88.9	89.6	90.1	90.3	90.4	90.5	90.5	90.5
>=900	57.7	78.0	82.4	86.3	88.7	89.7	90.5	91.0	91.3	91.4	91.4	91.5	91.5
>=800	57.8	78.3	82.9	86.9	89.5	90.5	91.4	91.9	92.2	92.3	92.4	92.4	92.4
>=700	57.8	78.7	83.4	87.6	90.3	91.4	92.4	92.9	93.3	93.4	93.5	93.5	93.6
>=600	57.9	78.9	83.8	88.3	91.1	92.3	93.4	94.0	94.4	94.6	94.7	94.7	94.7
>=500	57.9	79.1	84.1	88.8	91.8	93.1	94.3	95.0	95.5	95.7	95.8	95.9	95.9
>=400	57.9	79.2	84.3	89.2	92.3	93.8	95.1	95.9	96.5	96.8	96.9	97.0	97.0
>=300	57.9	79.3	84.4	89.3	92.6	94.1	95.5	96.5	97.3	97.6	97.9	98.0	98.1
>=200	57.9	79.3	84.4	89.3	92.6	94.2	95.7	96.7	97.6	98.1	98.5	98.9	99.1
>=100	57.9	79.3	84.4	89.3	92.6	94.2	95.7	96.7	97.7	98.1	98.7	99.3	99.7
>=0	57.9	79.3	84.4	89.3	92.6	94.2	95.7	96.7	97.7	98.2	98.7	99.3	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Los Angeles International Airport (LAX)

LAT 33 56N LONG 118 23W — ELEV 100 ft = 30 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1947-1990)

CEILING	VISIBILITY IN STATUTE MILES >=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	36.9	48.9	52.5	56.0	58.5	59.5	60.6	61.3	61.8	62.0	62.1	62.2	62.3
>=20000	38.4	50.9	54.7	58.3	61.0	62.0	63.1	63.9	64.4	64.6	64.7	64.8	64.9
>=18000	38.6	51.1	54.9	58.5	61.2	62.3	63.4	64.2	64.7	64.9	65.0	65.1	65.2
>=16000	38.8	51.4	55.2	58.9	61.6	62.7	63.8	64.6	65.1	65.3	65.4	65.5	65.6
>=14000	39.4	52.2	56.1	59.8	62.6	63.7	64.8	65.6	66.2	66.4	66.5	66.6	66.7
>=12000	39.9	52.9	56.9	60.6	63.4	64.5	65.7	66.5	67.1	67.3	67.4	67.5	67.6
>=10000	40.2	53.3	57.3	61.1	64.0	65.1	66.3	67.1	67.6	67.8	67.9	68.0	68.2
>=9000	40.3	53.5	57.5	61.3	64.2	65.3	66.5	67.3	67.9	68.1	68.2	68.3	68.4
>=8000	40.6	53.8	57.9	61.7	64.5	65.7	66.8	67.7	68.2	68.4	68.6	68.6	68.8
>=7000	40.8	54.1	58.2	62.0	64.9	66.0	67.2	68.0	68.6	68.8	68.9	69.0	69.1
>=6000	41.2	54.6	58.7	62.5	65.4	66.5	67.7	68.5	69.1	69.3	69.4	69.5	69.6
>=5000	41.9	55.4	59.5	63.3	66.2	67.3	68.6	69.4	69.9	70.1	70.3	70.4	70.5
>=4500	42.3	55.9	60.0	63.9	66.8	67.9	69.1	69.9	70.5	70.7	70.8	70.9	71.0
>=4000	43.0	56.8	60.9	64.8	67.7	68.9	70.1	70.9	71.5	71.7	71.8	71.9	72.0
>=3500	43.8	57.8	62.0	65.9	68.9	70.0	71.3	72.1	72.7	72.9	73.0	73.1	73.2
>=3000	44.8	59.1	63.4	67.4	70.4	71.5	72.8	73.6	74.2	74.4	74.5	74.6	74.7
>=2500	45.8	60.9	65.3	69.4	72.4	73.6	74.9	75.7	76.3	76.5	76.6	76.7	76.8
>=2000	46.8	62.8	67.4	71.8	75.0	76.2	77.5	78.4	79.0	79.2	79.3	79.4	79.5
>=1800	47.2	63.6	68.4	72.9	76.2	77.5	78.8	79.7	80.3	80.5	80.6	80.7	80.8
>=1500	47.8	65.1	70.3	75.1	78.7	80.1	81.5	82.5	83.1	83.3	83.4	83.5	83.7
>=1200	48.3	66.7	72.3	77.7	81.7	83.3	84.9	85.9	86.6	86.9	87.0	87.1	87.2
>=1000	48.6	67.9	74.0	79.9	84.2	86.0	87.8	88.9	89.7	90.0	90.1	90.2	90.3
>=900	48.7	68.4	74.7	80.9	85.4	87.4	89.3	90.6	91.4	91.7	91.8	91.9	92.0
>=800	48.8	68.8	75.3	81.8	86.5	88.5	90.6	91.9	92.8	93.1	93.2	93.3	93.5
>=700	48.9	69.0	75.6	82.4	87.3	89.4	91.7	93.1	94.1	94.4	94.6	94.7	94.8
>=600	48.9	69.2	75.9	82.7	87.8	90.1	92.5	94.1	95.2	95.5	95.7	95.8	95.9
>=500	48.9	69.2	76.0	83.0	88.2	90.5	93.1	94.9	96.1	96.5	96.7	96.8	96.9
>=400	48.9	69.2	76.0	83.1	88.4	90.7	93.5	95.3	96.7	97.2	97.4	97.6	97.7
>=300	48.9	69.2	76.0	83.1	88.4	90.8	93.6	95.6	97.1	97.7	98.1	98.2	98.4
>=200	48.9	69.2	76.0	83.1	88.4	90.8	93.6	95.6	97.2	97.8	98.3	98.7	98.9
>=100	48.9	69.2	76.0	83.1	88.4	90.8	93.6	95.6	97.2	97.9	98.4	98.9	99.3
>=0	48.9	69.2	76.0	83.1	88.4	90.8	93.6	95.6	97.2	97.9	98.4	98.9	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

New York LaGuardia Airport (LGA)

LAT 40 46N LONG 073 54W — ELEV 11 ft = 3 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1948-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	34.3	44.1	46.5	48.2	49.4	49.9	50.3	50.5	50.6	50.6	50.6	50.6	50.6
>=20000	36.7	47.7	50.3	52.2	53.4	54.1	54.5	54.7	54.8	54.8	54.8	54.8	54.8
>=18000	36.9	47.9	50.5	52.4	53.7	54.3	54.7	54.9	55.0	55.0	55.0	55.1	55.1
>=16000	37.0	48.1	50.7	52.7	54.0	54.6	55.0	55.2	55.3	55.3	55.3	55.3	55.3
>=14000	37.6	49.1	51.9	53.9	55.2	55.9	56.3	56.5	56.6	56.6	56.6	56.6	56.6
>=12000	38.9	51.2	54.1	56.3	57.7	58.4	58.9	59.1	59.2	59.2	59.2	59.2	59.2
>=10000	40.5	53.9	57.1	59.5	61.0	61.8	62.3	62.5	62.6	62.7	62.7	62.7	62.7
>=9000	41.1	54.8	58.1	60.5	62.1	62.9	63.4	63.7	63.8	63.8	63.8	63.8	63.9
>=8000	42.1	56.5	59.9	62.5	64.2	65.0	65.6	65.8	66.0	66.0	66.0	66.0	66.0
>=7000	43.1	58.0	61.6	64.3	66.0	66.9	67.5	67.7	67.8	67.9	67.9	67.9	67.9
>=6000	44.2	59.6	63.2	66.0	67.8	68.7	69.3	69.6	69.7	69.7	69.7	69.8	69.8
>=5000	45.9	62.2	66.0	68.9	70.8	71.7	72.4	72.6	72.8	72.8	72.8	72.8	72.8
>=4500	46.9	63.6	67.5	70.5	72.4	73.4	74.0	74.3	74.4	74.5	74.5	74.5	74.5
>=4000	48.3	65.6	69.7	72.8	74.8	75.8	76.5	76.8	76.9	77.0	77.0	77.0	77.0
>=3500	49.5	67.5	71.7	74.9	76.9	78.0	78.7	79.0	79.1	79.2	79.2	79.2	79.2
>=3000	50.6	69.2	73.6	76.9	79.1	80.2	80.9	81.2	81.3	81.4	81.4	81.4	81.4
>=2500	51.3	70.6	75.1	78.6	80.8	82.0	82.7	83.0	83.2	83.2	83.3	83.3	83.3
>=2000	52.1	72.0	76.7	80.3	82.6	83.9	84.6	85.0	85.1	85.2	85.2	85.2	85.2
>=1800	52.3	72.5	77.2	80.9	83.3	84.5	85.3	85.7	85.8	85.9	85.9	85.9	85.9
>=1500	52.7	73.4	78.4	82.2	84.8	86.1	86.9	87.3	87.5	87.5	87.6	87.6	87.6
>=1200	53.0	74.5	79.7	83.8	86.5	88.0	88.9	89.3	89.5	89.6	89.6	89.6	89.6
>=1000	53.1	75.1	80.5	84.8	87.8	89.3	90.4	90.8	91.1	91.2	91.2	91.2	91.2
>=900	53.2	75.3	80.8	85.3	88.3	90.0	91.1	91.6	91.9	92.0	92.0	92.0	92.0
>=800	53.2	75.6	81.3	86.0	89.2	91.0	92.2	92.7	93.1	93.2	93.2	93.2	93.2
>=700	53.3	75.9	81.7	86.6	90.0	91.8	93.2	93.8	94.2	94.3	94.4	94.4	94.4
>=600	53.3	76.0	82.0	87.1	90.7	92.6	94.1	94.8	95.3	95.4	95.5	95.5	95.5
>=500	53.3	76.1	82.2	87.5	91.2	93.4	95.1	95.9	96.4	96.6	96.7	96.7	96.7
>=400	53.3	76.2	82.3	87.7	91.6	93.9	95.8	96.8	97.4	97.6	97.8	97.8	97.8
>=300	53.3	76.2	82.3	87.8	91.8	94.1	96.3	97.4	98.2	98.5	98.7	98.8	98.8
>=200	53.3	76.2	82.3	87.8	91.8	94.2	96.3	97.6	98.6	99.0	99.3	99.4	99.5
>=100	53.3	76.2	82.3	87.8	91.8	94.2	96.4	97.7	98.6	99.1	99.5	99.7	99.9
>=0	53.3	76.2	82.3	87.8	91.8	94.2	96.4	97.7	98.6	99.1	99.5	99.7	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

Chicago O'Hare International Airport (ORD)

LAT 41 59N LONG 087 54W | ELEV 674 ft = 205 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1958-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
			VFR				NON-PRECISION			CAT I		CAT II	CAT III
Unlimited	37.0	45.4	47.1	48.5	49.1	49.3	49.5	49.6	49.7	49.7	49.7	49.7	49.7
>=20000	39.5	48.7	50.6	52.1	52.8	53.0	53.2	53.3	53.4	53.4	53.4	53.4	53.4
>=18000	39.5	48.8	50.6	52.2	52.8	53.0	53.2	53.4	53.4	53.4	53.4	53.4	53.5
>=16000	39.6	48.8	50.7	52.2	52.8	53.0	53.3	53.4	53.4	53.4	53.4	53.5	53.5
>=14000	39.7	49.1	50.9	52.5	53.1	53.3	53.6	53.7	53.7	53.7	53.8	53.8	53.8
>=12000	40.9	50.6	52.6	54.2	54.9	55.1	55.3	55.4	55.5	55.5	55.5	55.5	55.5
>=10000	43.2	53.9	56.0	57.8	58.6	58.8	59.1	59.2	59.3	59.3	59.3	59.3	59.3
>=9000	44.0	55.1	57.3	59.2	59.9	60.2	60.5	60.6	60.7	60.7	60.7	60.7	60.7
>=8000	45.9	57.8	60.2	62.2	63.1	63.3	63.6	63.8	63.9	63.9	63.9	63.9	63.9
>=7000	46.8	59.2	61.6	63.8	64.6	64.9	65.2	65.4	65.5	65.5	65.5	65.5	65.5
>=6000	47.5	60.2	62.7	64.9	65.8	66.1	66.4	66.6	66.7	66.7	66.7	66.7	66.7
>=5000	48.9	62.2	64.9	67.2	68.1	68.4	68.8	69.0	69.0	69.1	69.1	69.1	69.1
>=4500	49.9	63.7	66.5	68.8	69.8	70.1	70.5	70.7	70.8	70.8	70.8	70.8	70.8
>=4000	50.6	64.6	67.4	69.9	70.9	71.2	71.6	71.8	71.9	71.9	71.9	72.0	72.0
>=3500	51.8	66.4	69.3	71.8	72.9	73.3	73.7	73.9	74.0	74.0	74.0	74.0	74.1
>=3000	53.4	68.6	71.7	74.3	75.5	75.9	76.3	76.5	76.7	76.7	76.7	76.7	76.7
>=2500	55.4	71.4	74.7	77.6	78.8	79.2	79.7	80.0	80.1	80.1	80.1	80.2	80.2
>=2000	56.8	73.6	77.1	80.1	81.5	81.9	82.5	82.8	82.9	83.0	83.0	83.0	83.0
>=1800	57.4	74.4	78.0	81.1	82.5	83.0	83.6	83.9	84.0	84.1	84.1	84.1	84.1
>=1500	58.5	76.5	80.3	83.7	85.3	85.8	86.5	86.9	87.1	87.1	87.1	87.1	87.1
>=1200	59.2	78.0	82.0	85.7	87.4	88.0	88.8	89.3	89.5	89.5	89.5	89.5	89.5
>=1000	59.5	78.9	83.2	87.2	89.1	89.7	90.7	91.2	91.5	91.5	91.6	91.6	91.6
>=900	59.6	79.3	83.7	87.9	89.9	90.6	91.7	92.2	92.5	92.6	92.6	92.7	92.7
>=800	59.7	79.6	84.2	88.6	90.7	91.5	92.6	93.3	93.6	93.7	93.7	93.8	93.8
>=700	59.7	79.8	84.6	89.2	91.5	92.3	93.6	94.3	94.7	94.8	94.9	94.9	94.9
>=600	59.7	80.0	84.9	89.7	92.2	93.2	94.6	95.5	95.9	96.1	96.2	96.2	96.2
>=500	59.8	80.0	85.0	90.1	92.7	93.7	95.3	96.3	96.9	97.0	97.2	97.2	97.2
>=400	59.8	80.1	85.1	90.3	93.0	94.1	95.9	97.1	97.8	98.0	98.2	98.3	98.3
>=300	59.8	80.1	85.1	90.3	93.2	94.3	96.2	97.4	98.3	98.6	98.9	99.0	99.0
>=200	59.8	80.1	85.1	90.3	93.2	94.3	96.2	97.5	98.5	98.9	99.3	99.5	99.5
>=100	59.8	80.1	85.1	90.4	93.2	94.3	96.3	97.5	98.5	98.9	99.4	99.7	99.8
>=0	59.8	80.1	85.1	90.4	93.2	94.3	96.3	97.5	98.5	98.9	99.4	99.7	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

International Station Meteorological Climate Summary

San Francisco International Airport (SFO)

LAT 37 37N LONG 122 23W | ELEV 8 ft = 2.5 m

Percent Frequency Ceiling and Visibility (from hourly observations, 1948-1990)

	VISIBILITY IN STATUTE MILES												
CEILING	>=10	>=6	>=5	>=4	>=3	>=2.5	>=2	>=1.5	>=1	>=.75	>=.5	>=.25	>=0
	VFR					NON-PRECISION				CAT I		CAT II	CAT III
Unlimited	48.6	59.2	60.7	61.9	62.9	63.2	63.5	63.6	63.7	63.7	63.7	63.8	63.8
>=20000	50.7	62.0	63.5	64.8	65.9	66.2	66.5	66.7	66.7	66.8	66.8	66.9	66.9
>=18000	50.9	62.2	63.8	65.1	66.3	66.5	66.9	67.0	67.1	67.1	67.2	67.2	67.2
>=16000	51.2	62.6	64.2	65.5	66.7	67.0	67.3	67.5	67.5	67.6	67.6	67.6	67.7
>=14000	52.0	63.6	65.3	66.6	67.8	68.1	68.4	68.6	68.7	68.7	68.8	68.8	68.8
>=12000	52.9	64.7	66.4	67.7	69.0	69.3	69.6	69.8	69.8	69.9	69.9	70.0	70.0
>=10000	53.6	65.6	67.3	68.7	69.9	70.2	70.6	70.7	70.8	70.8	70.9	70.9	71.0
>=9000	53.9	65.9	67.6	69.0	70.2	70.5	70.9	71.1	71.1	71.2	71.2	71.3	71.3
>=8000	54.3	66.4	68.2	69.6	70.9	71.2	71.5	71.7	71.8	71.8	71.8	71.9	71.9
>=7000	54.7	66.8	68.6	70.0	71.3	71.6	72.0	72.1	72.2	72.3	72.3	72.3	72.4
>=6000	55.2	67.5	69.2	70.7	71.9	72.3	72.6	72.8	72.9	72.9	73.0	73.0	73.0
>=5000	56.0	68.4	70.2	71.7	73.0	73.3	73.6	73.8	73.9	73.9	74.0	74.0	74.1
>=4500	56.6	69.1	70.9	72.4	73.7	74.0	74.4	74.5	74.6	74.7	74.7	74.7	74.8
>=4000	57.2	69.8	71.6	73.1	74.4	74.7	75.1	75.3	75.4	75.4	75.4	75.5	75.5
>=3500	58.1	70.8	72.7	74.2	75.5	75.8	76.2	76.4	76.5	76.5	76.6	76.6	76.6
>=3000	59.4	72.3	74.1	75.7	77.0	77.4	77.8	77.9	78.0	78.1	78.1	78.1	78.2
>=2500	61.0	74.2	76.2	77.7	79.2	79.5	79.9	80.1	80.2	80.2	80.3	80.3	80.4
>=2000	62.8	76.5	78.5	80.1	81.6	82.0	82.4	82.6	82.7	82.7	82.8	82.8	82.9
>=1800	63.7	77.6	79.6	81.3	82.8	83.2	83.6	83.8	83.9	84.0	84.0	84.0	84.1
>=1500	65.8	80.2	82.3	84.0	85.6	86.1	86.5	86.8	86.9	86.9	87.0	87.0	87.1
>=1200	68.0	83.0	85.2	87.0	88.7	89.2	89.7	90.0	90.1	90.1	90.2	90.2	90.3
>=1000	69.9	85.4	87.7	89.6	91.3	91.8	92.4	92.7	92.8	92.8	92.9	92.9	93.0
>=900	70.6	86.4	88.7	90.6	92.5	92.9	93.5	93.8	94.0	94.0	94.1	94.1	94.1
>=800	71.5	87.7	90.0	92.0	93.9	94.4	95.0	95.3	95.5	95.5	95.6	95.6	95.7
>=700	72.2	88.7	91.1	93.1	95.1	95.6	96.3	96.6	96.8	96.8	96.9	96.9	97.0
>=600	72.6	89.4	91.9	94.0	96.0	96.6	97.3	97.7	97.8	97.9	97.9	98.0	98.0
>=500	72.7	89.8	92.2	94.3	96.4	97.0	97.8	98.2	98.4	98.5	98.5	98.6	98.6
>=400	72.8	90.0	92.4	94.6	96.7	97.3	98.2	98.6	98.8	98.9	99.0	99.0	99.1
>=300	72.8	90.0	92.5	94.6	96.8	97.4	98.3	98.8	99.1	99.2	99.3	99.3	99.4
>=200	72.8	90.0	92.5	94.7	96.8	97.5	98.4	98.9	99.2	99.3	99.4	99.6	99.7
>=100	72.8	90.0	92.5	94.7	96.8	97.5	98.4	98.9	99.2	99.3	99.5	99.6	99.8
>=0	72.8	90.0	92.5	94.7	96.8	97.5	98.4	98.9	99.2	99.3	99.5	99.6	100.0

Minima can vary depending on local conditions; separations here are typical figures, intended to show approximate prevalence of each condition at airport

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13. ABSTRACT (*Maximum 200 words*)

This report summarizes FAA Program Analysis and Operations Research Service (ASD-400)/Lockheed Martin activities and findings related to airport surface delays and causes, in support of NASA Langley Research Center's Terminal Area Productivity (TAP) Program. The activities described in this report were initiated in June 1995. A preliminary report was published on September 30, 1995. The final report incorporates data collection forms filled out by traffic managers, other FAA staff, and an airline for the New York City area, some updates, data previously requested from various sources to support this analysis, and further quantification and documentation than in the preliminary report. This final report is based on data available as of April 12, 1996. This report incorporates data obtained from review and analysis of data bases and literature, discussions/ interviews with engineers, air-traffic staff, other FAA technical personnel, and airline staff, site visits, and a survey on surface delays and causes. It includes analysis of delay statistics; preliminary findings and conclusions on surface movement, surface delay sources and causes, runway occupancy time (ROT), and airport characteristics impacting surface operations and delays; and site-specific data on the New York City area airports, which are the focus airports for this report.

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