PHILADELPHIA INTERNATIONAL AIRPORT

Airport Capacity Enhancement Plan
September 1991

Philadelphia International Airport

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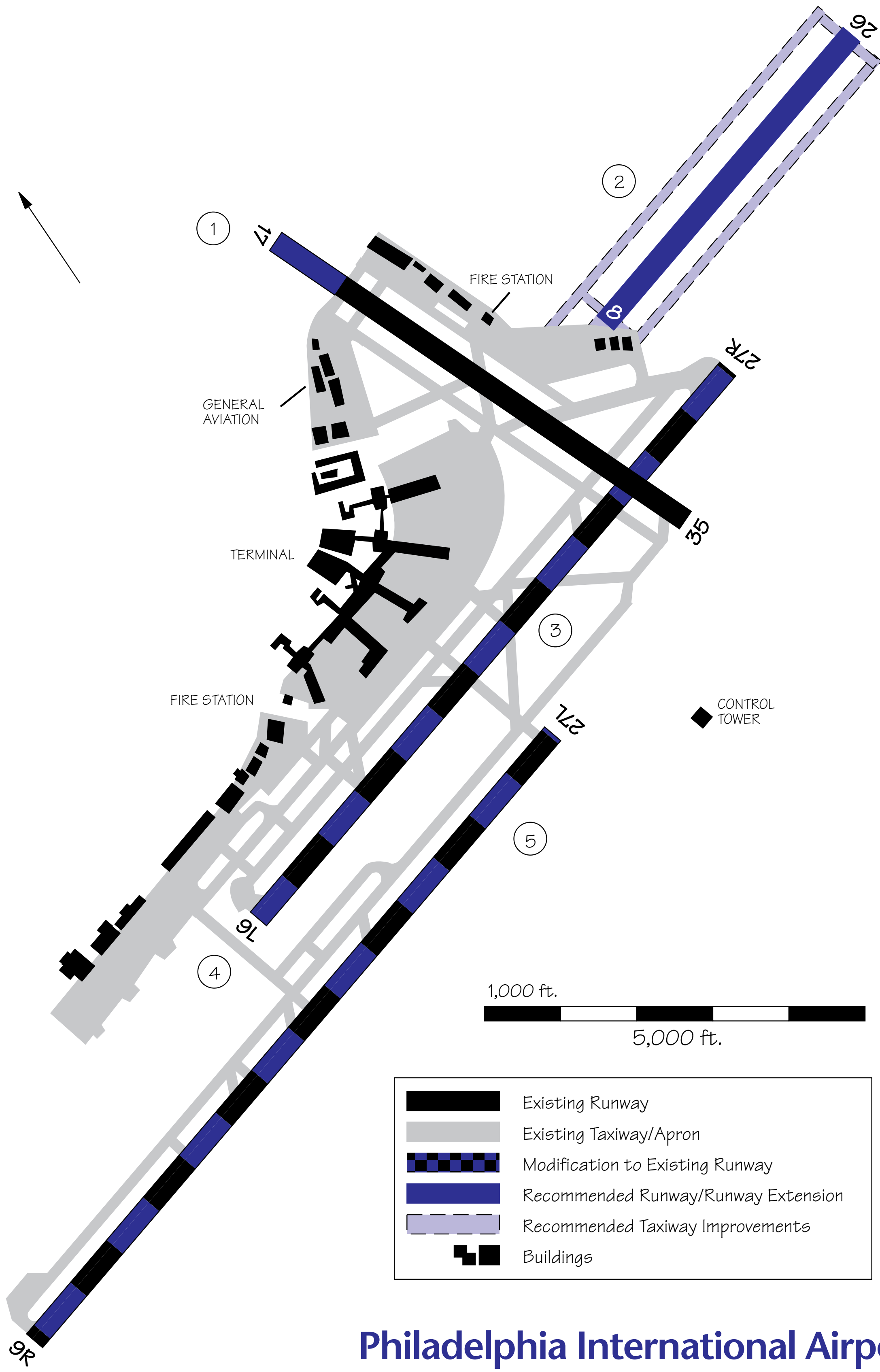
Prepared jointly by the U.S. Department of Transportation, Federal Aviation Administration, the City of Philadelphia, Department of Aviation, and the airlines and general aviation serving Philadelphia.

FEDERAL AVIATION ADMINISTRATION

Figure 1 Philadelphia International Airport



Philadelphia International Airport

Summary

The Federal Aviation Administration (FAA), airport operators, and aviation industry groups have initiated Airport Capacity Design Teams at various major air carrier airports throughout the United States to identify and evaluate alternative means to enhance existing airport and airspace capacity to handle future demand. A Capacity Team for Philadelphia International Airport (PHL) was formed in 1990.

Steady growth at PHL has made it one of the busiest airports in the country. Activity at the airport has increased from 4,544,000 passenger enplanements in 1983 to 7,743,000 in 1988, a 70 percent increase. In 1990, the airport handled 410,000 aircraft operations (takeoffs and landings).

The primary objective of the Capacity Team at PHL was to identify and assess various actions which, if implemented, would increase PHL's capacity, improve operational efficiency, and reduce aircraft delays. The purpose of the process was to determine the technical merits of each alternative action and its impact on capacity. Additional studies will be needed to assess environmental, socioeconomic, or political issues associated with these actions.

Alternatives identified by the Capacity Team were tested using computer models developed by the FAA to quantify the benefits provided. Different levels of activity were chosen to represent growth in aircraft operations in order to compare the merits of each action. These annual activity levels are referred to throughout this report as:

Baseline – 410,000 operations;
Future 1 – 500,000 operations; and
Future 2 – 565,000 operations.

If no improvements are made at PHL (the "Do Nothing" scenario), the annual delay cost will increase from 40,370 hours or $56.2 million at the Baseline level of operations to 501,690 hours or $698.9 million by Future 2.

The major recommendations resulting from the Philadelphia study include:

	Future 2 Annual Delay Savings	
	Hours	**Millions of 1990 $**
• Construct new commuter Runway 8/26	142,504	$198.5
• Conduct dependent approaches to Runways 9R and 17	13,243	$18.4
• Remove departure fix restrictions	9,258	$12.9
• Install Localizer Directional Aid (LDA) on Runway 9L	7,908	$11.0
• Relocate Runway 9L/27R (includes benefits of new commuter Runway 8/26)	154,624	$215.4

Figure 2 — Capacity Enhancement Alternatives and Annual Delay Savings

Alternatives		Action	Time Frame[Δ]
Airfield Improvements			
1.	Extend Runway 17/35 600 ft to the north	Recommended	Baseline–Future 1
2.	Construct new 5,000-ft commuter Runway 8/26 3,000 ft north of Runway 9R/27L	Recommended	Baseline
3.	Relocate Runway 9L/27R (laterally) 400 ft to the south with associated parallel and apron taxiways**	Recommended	Baseline–Future 1
4.	Shift Runway 9L/27R (longitudinally) 2,735 ft to the west**	Recommended	Baseline–Future 1
5.	Shift Runway 9R/27L (longitudinally) 1,000 ft to the east**	Recommended	Baseline–Future 1
Facilities and Equipment Improvements			
6.	Install Localizer Directional Aid (LDA) on Runways 9L and 27L	Recommended	Baseline
6a.	LDA approach Runway 27L with ILS arrivals Runway 27R	Recommended	Baseline
6b.	LDA approach Runway 9L with ILS arrivals Runway 9R	Recommended	Baseline
7.	Install Precision Runway Monitor (PRM)	Recommended	Baseline
Operational Improvements			
8.	Allow air carrier use Runway 17/35 (Stage III aircraft)	Not Recommended	—
9.	Allow restricted air carrier use Runway 17/35 with arrivals on Runway 35 and departures on Runway 17	Study*	Baseline–Future 1
10.	Implement preferential taxiway routing	Recommended	Baseline
11.	Conduct dependent approaches Runways 9R & 17	Recommended	Baseline
12.	Conduct dependent approaches Runways 27R & 17	Recommended	Baseline
13.	Implement a steep-angle MLS approach to Runway 27L	Recommended	Future 2
14.	Conduct an airspace capacity design project and re-structure terminal airspace	Study*	Baseline
14a.	Remove departure fix restrictions	—	—
14b.	Install Terminal ATC Automation (TATCA) enhancements	—	—

Δ Refers to time the project is recommended to be in place.

* The term "Study" suggests that a specific study be conducted or that it become part of a larger planning effort, such as a Master Plan update or a FAR Part 150 Airport Noise Compatibility Study. These individual proposals require further investigation at a level of detail that is beyond the scope of this effort.

† These improvements were not simulated. Therefore, no dollar figures are available. There is a description of each of these items in Section 2 — Capacity Enhancement Alternatives.

** The savings shown represent the combined benefits of alternatives 2, 3, 4, and 5.

Estimated Construction Cost (in millions of 1990 dollars)	Estimated Annual Delay Savings (in hours and millions of 1990 dollars) Baseline (410,000)	Future 1 (500,000)	Future 2 (565,000)	
$16.6	—	—	—	(1)
$169.2	20,097/$28.0	84,875/$118.2	142,504/$198.5	(2)
$108.7	**	**	**	(3)
$54.9	20,402/$28.4**	88,171/$122.8**	154,624/$215.4**	(4)
$30.6	**	**	**	(5)
$1.0	—	—	—	(6)
—	198/$0.3	1,724/$2.4	3,648/$5.1	(6a)
—	2,606/$3.6	4,168/$5.8	7,908/$11.0	(6b)
—		†		(7)
—	3,126/$4.4	—	—	(8)
—	2,290/$3.2	—	—	(9)
—		†		(10)
—	555/$0.8	5,816/$8.1	13,243/$18.4	(11)
—	74/$0.1	672/$0.9	1,244/$1.7	(12)
—		†		(13)
—	—	—	—	(14)
—	1,898/$2.6	4,105/$5.7	9,258/$12.9	(14a)
—		†		(14b)

Figure 3 IFR Flow Rate Versus Average Delay

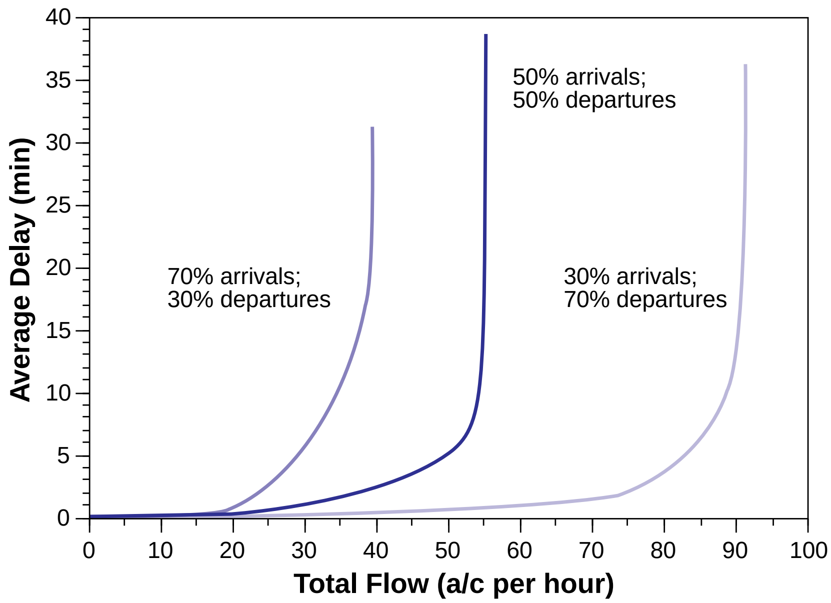


Figure 4 Profile of Daily Demand — Hourly Distribution

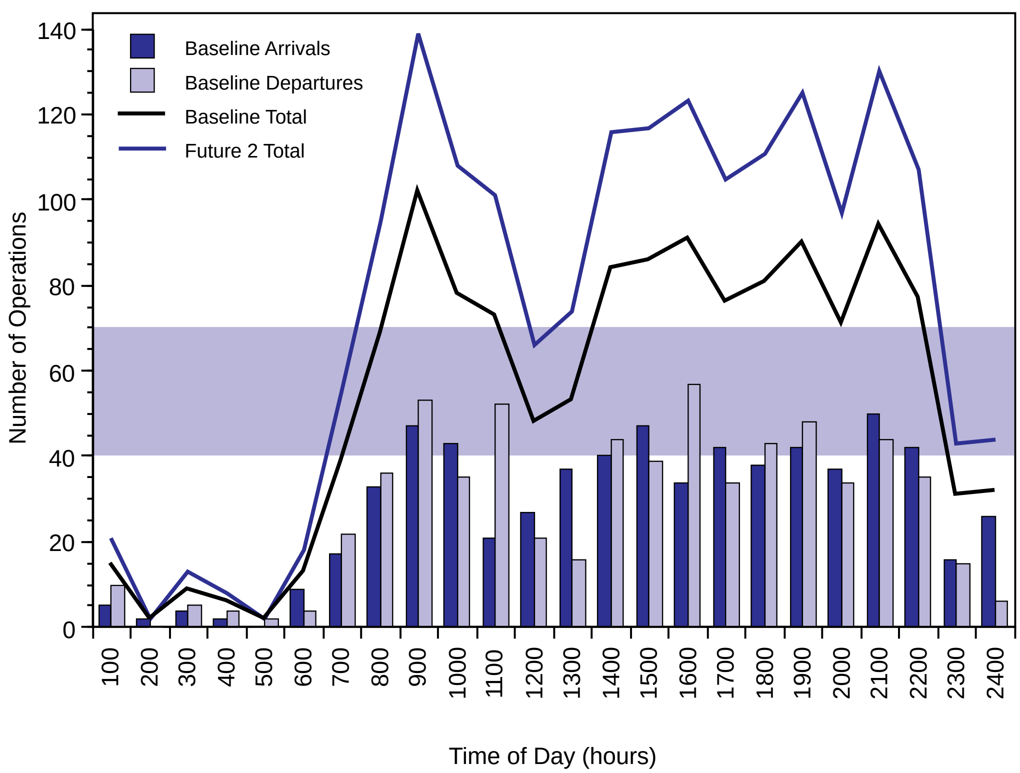
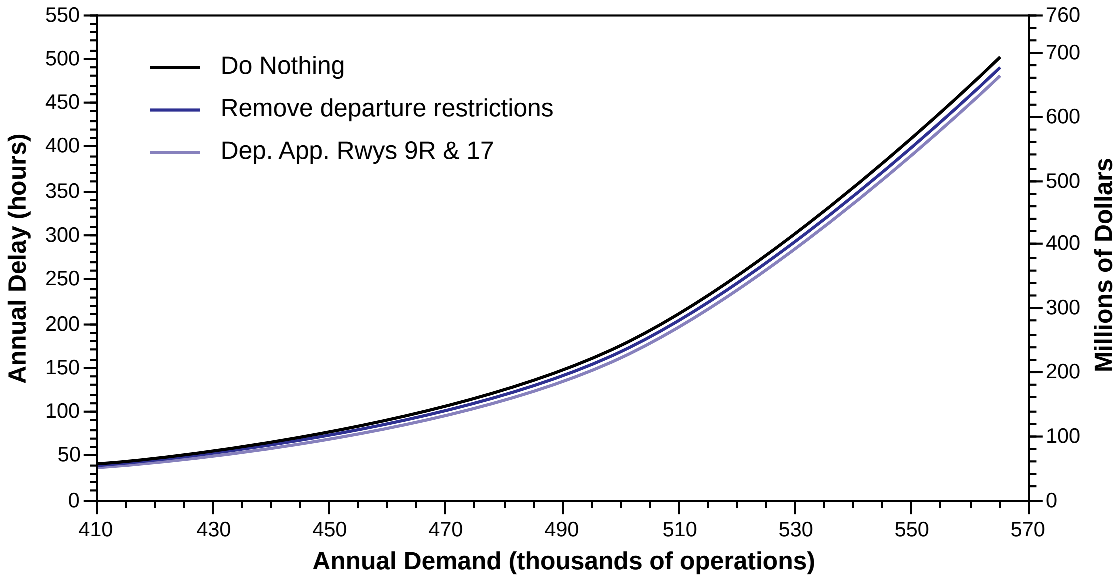


Figure 3 illustrates the capacity curves for the current airfield configuration at PHL under Instrument Flight Rules (IFR) conditions. They show that aircraft delays will begin to escalate rapidly as hourly demand exceeds 40 to 70 operations per hour. Figure 4 shows that, while hourly demand exceeds 40 to 70 operations during certain hours of the day at Baseline demand levels, 40 to 70 operations per hour is frequently exceeded at the demand levels forecast for Future 2.

Figure 5 Annual Delay Costs — Capacity Enhancement Alternatives



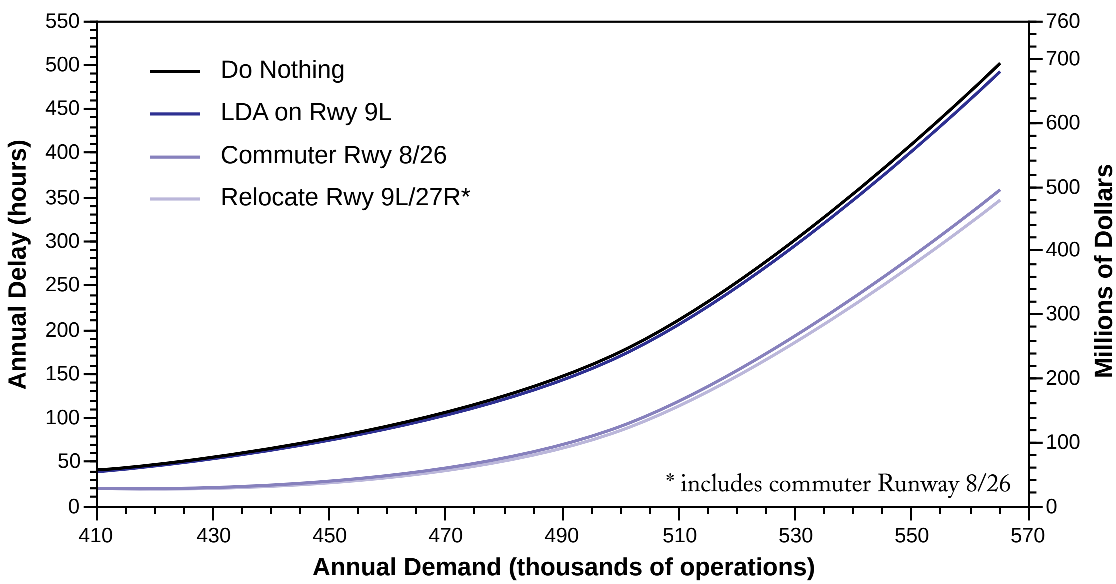


Figure 5 shows how delay will continue to grow at a substantial rate as demand increases if there are no improvements in airfield capacity, i.e., the "Do Nothing" scenario. Annual delay costs will increase from 40,370 hours or $56.2 million at the Baseline level of operations to 501,690 hours or $698.9 million by Future 2. The chart also illustrates that the greatest savings in delay costs would be provided by:

- Constructing new commuter Runway 8/26
- Conducting dependent approaches to Runways 9R and 17
- Removing departure fix restrictions
- Installing Localizer Directional Aid (LDA) on Runway 9L
- Relocating Runway 9L/27R (includes commuter Runway 8/26)

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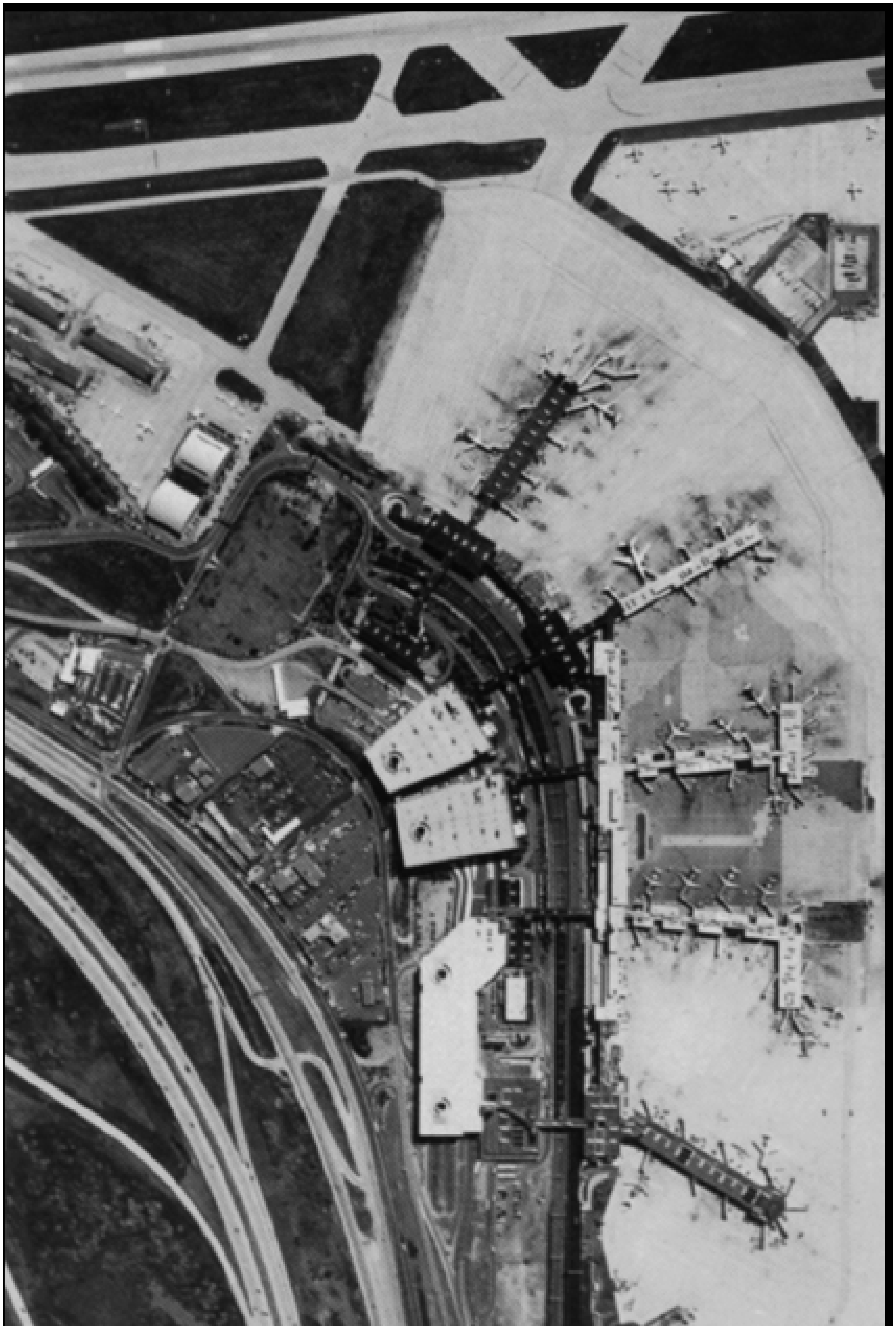
Section 1

Introduction



Background

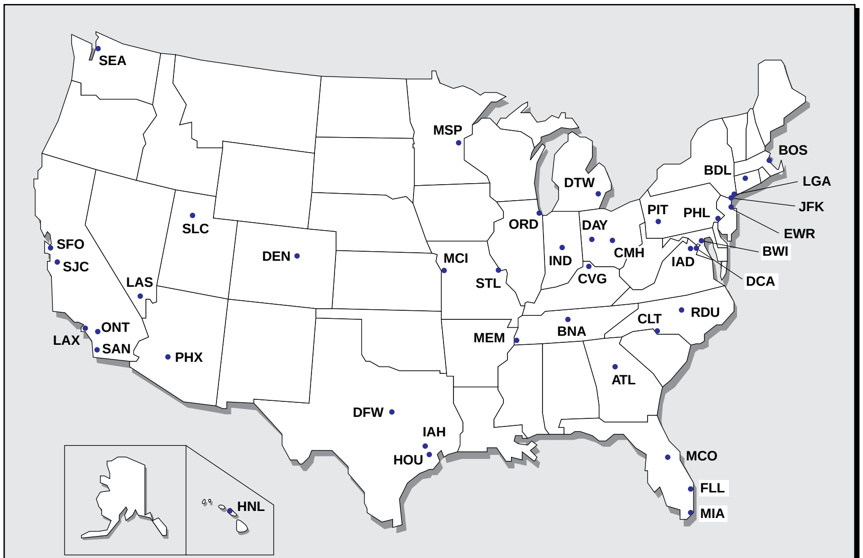
Aircraft delays are often interrelated, in that problems at one airport are reflected throughout the airspace system and create delays and late flights at other airports. Figure 6 shows the airports projected to exceed 20,000 hours of annual aircraft delay in 1998, assuming no capacity improvements.

The challenge for the air transportation industry in the nineties is to enhance existing airport and airspace capacity and to develop new facilities to handle future demand. As environmental, financial, and other constraints continue to restrict the development of new airport facilities in the U.S., an increased emphasis has been placed on the redevelopment and expansion of existing airport facilities.

To begin to meet this challenge, the FAA, along with airport operators and aviation industry groups throughout the country, have initiated joint industry and government airport Capacity Teams to study airport capacity enhancement at the major air carrier airports in the U.S. The objectives of these studies are to identify various alternatives for increasing capacity and to evaluate their potential to reduce delays.

Over the past decade, steady growth at Philadelphia International Airport (PHL) has made it one of the nation's busiest airports. Enplanements at PHL rose from 4,544,000 in 1983 to 7,743,000 in 1988, a 70 percent increase, and placed PHL 23rd in passenger enplanements among U.S. airports. PHL's total aircraft operations reached 410,000 in 1990.

Figure 6 **Forecast of Airports Exceeding 20,000 Hours of Annual Aircraft Delay in 1998, Assuming No Capacity Improvements**



Source: FAA Office of Policy and Plans

This report has established benchmarks for development based upon traffic levels and not upon any definitive time schedule, since growth parameters can vary year to year from projections. As a result, the report should retain its validity until the highest traffic level is attained, regardless of the actual dates paralleling the development.

A *Baseline* benchmark of 410,000 aircraft operations (takeoffs and landings) was established based on the annual traffic level for 1990, the base year for the study. Two future traffic levels, *Future 1* and *Future 2*, were established at 500,000 and 565,000 annual aircraft operations respectively, based on Capacity Team consensus of potential traffic growth at Philadelphia. If no improvements are made at PHL, annual delay levels and delay costs are expected to increase from an estimated 40,370 hours and $56.2 million at the Baseline activity level to 501,690 hours and $698.9 million by the Future 2 demand level.

The Capacity Team studied various proposals with the potential for increasing capacity and reducing delays at PHL. The improvements evaluated as a part of the Capacity Team's efforts are delineated in Figure 2 and described in detail in Section 2 — Capacity Enhancement Alternatives.

Objectives

The major goal of the Capacity Team at PHL was to develop an action plan of options to increase airport capacity, improve airport efficiency, and reduce aircraft delays. In achieving this objective, the Capacity Team:

- Assessed the current airport capacity and the causes of delay associated with the airfield, the immediate airspace, and the apron and gate-area operations.
- Identified and evaluated capacity and delay-reduction benefits of alternative air traffic control (ATC) procedures, navigational improvements, and airfield development.

Scope

The Philadelphia International Airport Capacity Team limited its analyses to aircraft activity within the terminal area airspace and on the airfield. They considered the technical and operational feasibility of the proposed improvements, but did not address environmental, socioeconomic, or political issues regarding airport development. These issues need to be addressed in future airport system planning studies, and the data generated by the Capacity Team can be used in such studies.

Methodology

The Capacity Team proceeded along a logical sequence of events, with periodic meetings for review and coordination. The FAA Technical Center's Aviation Capacity Branch provided expertise in airport simulation modeling. Other Capacity Team members contributed suggested improvement options, data, text, and capital cost estimates.

Initial work consisted of gathering data and formulating assumptions required for the capacity and delay analysis and modeling. Where possible, assumptions were based on actual field observations at PHL. Proposed improvements were analyzed in relation to current and future demands with the help of the Runway Delay Simulation Model (RDSIM) and the Airport and Airspace Simulation Model (SIMMOD). Appendix B briefly explains the models.

The simulation model considered air traffic control procedures, airfield improvements, and traffic demands. Air traffic control procedures and system improvements determined the aircraft separations to be used for the simulations under both VFR and IFR. Alternative airfield configurations were prepared from present and proposed airport layout plans. Various configurations were evaluated to assess the benefits of projected improvements.

Air traffic demand levels were derived from *Official Airline Guide* data, historical data, and Capacity Team forecasts. Aircraft volume, mix, and peaking characteristics were considered for each of the three different demand forecast levels (Baseline, Future 1, and Future 2). From this, annual delay estimates were determined based on implementing various improvements. These estimates took into account historic variations in runway configuration, weather, and demand. The annual delay estimates for each configuration were then compared to identify delay reductions resulting from the improvements.

Following the evaluation, the Capacity Team developed a plan of "Recommended Alternatives" for consideration, which is shown in Figure 2.

Section 2

Capacity Enhancement Alternatives

Figure 1 shows the current layout of the airport, plus the recommended airfield improvements. The PHL Capacity Team selected the capacity enhancement alternatives listed in Figure 2 for evaluation.

Figure 2 presents the recommended action and suggested time frame for each improvement evaluated for the activity levels Baseline, Future 1, and Future 2, which correspond to annual aircraft operations of 410,000, 500,000, and 565,000 respectively. Benefits of the improvements are not necessarily additive.

These selected alternatives are categorized and discussed under the following headings:

- Airfield Improvements.
- Facilities and Equipment Improvements.
- Operational Improvements.

Airfield Improvements

1. Extend Runway 17/35 600 feet to the north.

Runway 17/35 crosses, or intersects, Runway 9L/27R. Air traffic control procedures for operations conducted on intersecting runways are more restrictive than for operations conducted on non-intersecting, or parallel, runways.

The 600-foot extension of Runway 17/35 in conjunction with the relocation of Runway 9L/27R 400 feet to the south (Alternative 3) would effectively eliminate the intersection of the two runways and increase their respective capacities during most conditions of wind and weather. Air traffic controllers would also benefit from the elimination of the requirement to deal with the intersection of the two runways during conditions that permit commuter and general aviation (GA) arrivals on Runway 17 holding short of Runway 9L/27R and commuter and GA taxiway-intersection departures on Runway 35.

The estimated cost in 1990 dollars is $16.6 million.

2. Construct new 5,000-foot commuter Runway 8/26 3,000 feet north of Runway 9R/27L.

Construction of this additional runway would provide capacity to meet the demands of Future 1 and Future 2 aircraft activity levels. Commuter aircraft now account for about 44 percent of the take-offs and landings at PHL. If commuter aircraft were to operate primarily on Runway 8/26 in addition to the lengthened Runway 17/35 (Alternative 1), additional capacity would be available on the main runways for larger air carrier turbojet aircraft.

If the new commuter Runway 8/26 were constructed 3,000 feet from the existing Runway 9R/27L, it could potentially support independent parallel instrument flight rules (IFR) operations, which would add significantly to capacity at PHL during instrument meteorological conditions (IMC). The exact lateral separation needed to permit closely spaced independent IFR arrivals is under evaluation by the FAA. Currently, this requires 4,300 feet between parallel runway centerlines. A developmental program known as the Precision Runway Monitor (PRM) has demonstrated the potential for reducing parallel runway spacing (see alternative 7).

The estimated cost in 1990 dollars is $169.2 million.

Annual savings at the Baseline activity level would be 20,097 hours or $28.0 million, and, at Future 2 activity levels, 142,504 hours or $198.5 million.

3. Relocate Runway 9L/27R (laterally) 400 feet to the south with associated parallel and apron taxiways.

Runway 9L/27R crosses, or intersects, Runway 17/35. Air traffic control procedures for operations conducted on intersecting runways are more restrictive than for operations conducted on non-intersecting, or parallel, runways.

The 400-foot lateral relocation of Runway 9L/27R in conjunction with the extension of Runway 17/35 to the north would effectively eliminate the operational intersection of the two runways and increase their respective capacities during most conditions of wind and weather. Air traffic controllers would benefit from the elimination of the requirement to deal with the intersection of the two runways during conditions that permit commuter and general aviation (GA) arrivals on Runway 17 holding short of Runway 9L/27R and commuter and GA taxiway-intersection departures on Runway 35.

The associated parallel and apron taxiways created by the relocation of Runway 9L/27R will provide additional ground movement capacity to reduce taxiway and apron congestion delay for arrivals and departures.

The estimated cost in 1990 dollars is $108.7 million.

4. Shift Runway 9L/27R (longitudinally) 2,735 feet to the west.

Shifting Runway 9L/27R 2,735 feet to the west on its existing centerline would eliminate the physical intersection with Runway 17/35 and provide for the increase in capacity that would result from operations on non-intersecting runways.

The estimated cost in 1990 dollars is $54.9 million.

In the simulations, alternatives 3, 4, and 5 were modeled together under the assumption that the new commuter runway, Runway 8/26, was already in place. The combined annual savings for alternatives 2, 3, 4, and 5 at the Baseline activity level would be 20,402 hours or $28.4 million, and, at Future 2 activity levels, 154,624 hours or $215.4 million.

5. Shift Runway 9R/27L (longitudinally) 1,000 feet to the east.

Shifting Runway 9R/27L 1,000 feet to the east would provide nearly balanced thresholds between Runways 27R and 27L. This would eliminate the wake vortex dependency between departures from Runway 27R and arrivals to Runway 27L and would provide air traffic controllers with the flexibility to use either Runway 27R or 27L for departures depending on traffic demand and departure route clearances.

The estimated cost in 1990 dollars is $30.6 million.

Facilities and Equipment Improvements

6. Install localizer directional aid (LDA) on Runways 9L and 27L.

The use of LDA approaches on Runways 9L and 27L would require the installation of two instrument landing system (ILS) localizer antennas with their beams radiating parallel to the localizer beams for each runway. Under certain conditions of VFR and IFR weather, aircraft would approach the airport using the offset localizer beam until they break out under the cloud cover and then proceed visually to land on the runway with a banking maneuver. The LDA approach would provide for dual-stream operations and significantly increase airport capacity under these VFR and IFR weather conditions. The minimums for an LDA approach would be relatively high — plus or minus 1,000-foot ceiling and 3 miles visibility.

The estimated cost in 1990 dollars is $1.0 million.

6a. LDA approach to Runway 27L with ILS arrivals on Runway 27R.

With an LDA approach to Runway 27L and ILS arrivals on Runway 27R annual savings at the Baseline activity level would be 198 hours or $0.3 million, and, at Future 2 activity levels, 3,648 hours or $5.1 million.

6b. LDA approach to Runway 9L with ILS arrivals on Runway 9R.

With an LDA approach to Runway 9L and ILS arrivals on Runway 9R annual savings at the Baseline activity level would be 2,606 hours or $3.6 million, and, at Future 2 activity levels, 7,908 hours or $11.0 million.

7. Install Precision Runway Monitor (PRM).

The ability to conduct simultaneous independent parallel approaches in all weather conditions would add significantly to capacity at PHL. If the new commuter Runway 8/26 were constructed 3,000 feet from the existing Runway 9R/27L, it could potentially support independent parallel operations. The exact lateral separation needed to permit closely spaced independent IFR arrivals is under evaluation by the FAA. Currently, this requires 4,300 feet between parallel runway centerlines.

A developmental program known as the Precision Runway Monitor (PRM) has demonstrated the potential for reducing parallel runway spacing. This program relies upon improved radar surveillance with higher update rates of aircraft locations and a new air traffic controller display system. If PRM equipment becomes available, changes allowing simultaneous independent parallel ILS approaches could be implemented.

Operational Improvements

8. Allow air carrier use of Runway 17/35 (Stage III aircraft).

Although there are immediate delay savings that could be realized through the unrestricted use of Runway 17/35 by Stage III air carrier aircraft, the City of Philadelphia Department of Aviation has a longstanding policy which discourages air carrier take-offs on Runway 35 and arrivals on Runway 17.

Annual savings at the Baseline activity level would be 3,126 hours or $4.4 million.

9. Allow restricted air carrier use of Runway 17/35.

With arrivals on Runway 35 and departures on Runway 17, annual savings at the Baseline activity level would be 2,290 hours or $3.2 million.

10. Implement preferential taxiway routing.

Developing and implementing preferential taxiway routes for use during periods of increased traffic volume would result in a more uniform ground traffic flow on the airport. Optimum ground traffic flows, which depend on the runway configuration in use at a given time, can be designed to keep aircraft moving between the gates and runways as efficiently as possible. The actual routes will depend on the completion of airfield improvements such as additional runways and taxiways.

11. Conduct dependent approaches to Runway 9R and Runway 17.

Under visual flight rules (VFR) conditions, it is common to use non-intersecting converging runways for independent streams of arriving aircraft. Because of the reduced visibility and ceilings associated with instrument flight rules (IFR) conditions, simultaneous (independent) use of runways is currently permitted for aircraft arrivals only during relatively high weather minimums. However, a program is under development that would allow dependent (alternating) arrivals on non-parallel runways through the use of a converging runway display aid for air traffic controllers.

Annual savings at the Baseline activity level would be 555 hours or $0.8 million, and, at Future 2 activity levels, 13,243 hours or $18.4 million.

12. Conduct dependent approaches to Runways 27R and Runway 17.

If dependent arrivals (as described above) were allowed on Runways 27R and 17, the annual savings at the Baseline activity level would be 74 hours or $0.1 million, and, at Future 2 activity levels, 1,244 hours or $1.7 million.

13. Implement a steep angle MLS approach to Runway 27L.

Developing and implementing the operational procedures to support the steep-angle-approach glide slope available with MLS would provide a second approach stream in the west flow during lower ceiling and visibility conditions to support the DASH-7 aircraft in the fleet serving PHL.

14. Conduct an airspace capacity design project and re-structure terminal airspace.

The Capacity Team highly recommends a complete analysis of all of the en route airspace that interconnects with PHL. This analysis should include concepts of airspace restructuring that offer the potential for improving arrival and departure air route capacity in conjunction with airport improvements. New technology and operating concepts need to be reviewed in an effort to improve flow-control procedures and reduce or eliminate miles-in-trail restrictions that are in excess of optimum aircraft spacing. The end result should be airspace capacity that takes advantage of the airport's surface capacity.

14a. Remove departure fix restrictions.

Departure restrictions attributable to limitations in the en route airspace environment are apparent in the spacings imposed on aircraft departing from PHL that are beyond the optimum allowable spacing. If all aircraft presently operating at PHL were allowed to operate free of miles-in-trail departure fix restrictions beyond optimal aircraft spacing, there could be a reduction in annual delays.

Annual savings at the Baseline activity level would be 1,898 hours or $2.6 million, and, at Future 2 activity levels, 9,258 hours or $12.9 million.

14b. Install Terminal Air Traffic Control Automation (TATCA) enhancements.

The development and implementation of new technologies offer significant promise to improve capacity. TATCA is a research and development program that is developing air traffic control (ATC) automation aids. TATCA automation aids will help controllers use the available capacity of terminal airspace more fully and increase the safety and efficiency of aircraft operations into and out of terminal areas, particularly under instrument meteorological conditions (IMC).

The TATCA program includes the dynamic traffic planner (DTP), a comprehensive traffic planning and coordination aid, that will automatically derive current traffic demand information from surveillance, flight plan, and manual input data. It will use this information to suggest acceptance rates and other important planning measures and to calculate efficient landing sequences. It will provide a final approach spacing aid, a converging approach delivery aid, speed control and holding advisories, and descent advisories. The DTP will present its products to individual members of the terminal controller team via a customized local display of the landing plan in the form of coordinated displays of aircraft arrival times and landing sequences.

A related TATCA activity is the accelerated development of a final approach spacing aid, specifically for airports with converging approaches. The converging-approach delivery aid will assist controllers in feeding staggered approach streams to converging runways.

The TATCA program was initiated in FY 1989. Evaluation of the initial arrival planning functions is planned for FY 1993, with evaluation of the integrated arrival and departure planning function and controller advisories to begin in the following year. The results of these evaluations will provide the basis for the preparation of specifications for operational implementation.

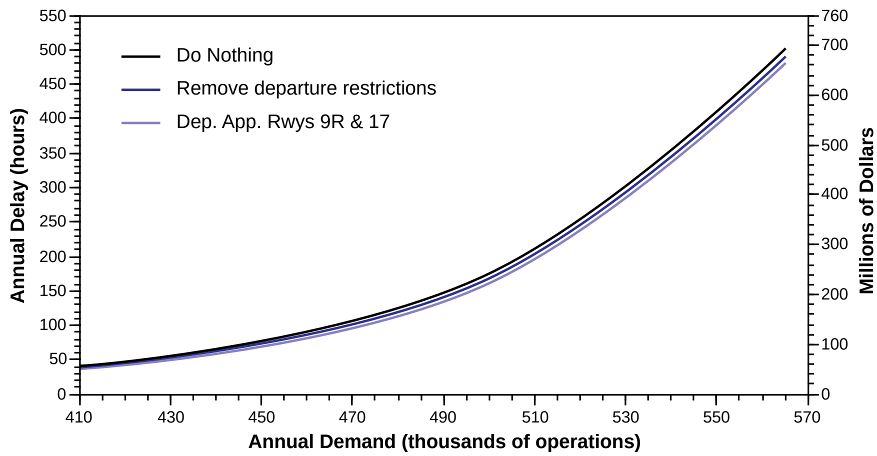
Section 3

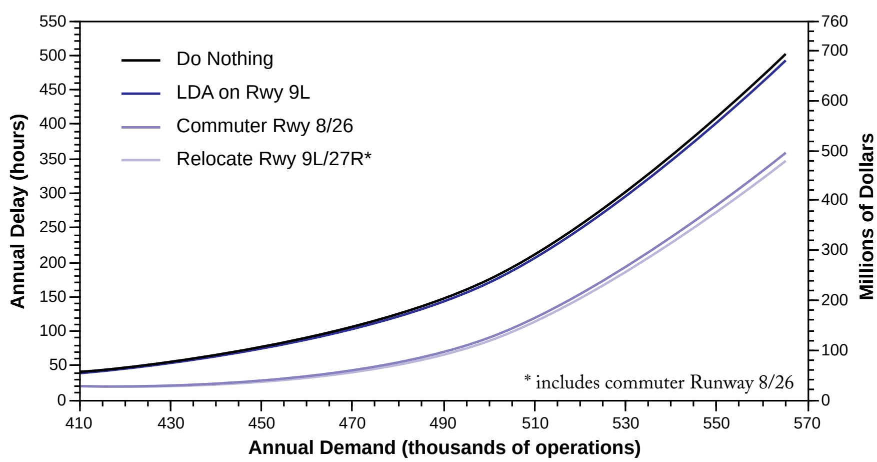
Conclusions

Figure 7 illustrates the impact of delays at Philadelphia International Airport. The chart shows how delay will continue to grow at a substantial rate as demand increases if there are no improvements made in airfield capacity, i.e., the "Do Nothing" scenario. The chart also shows that the greatest savings in delay costs would be provided by:

- Constructing new commuter Runway 8/26
- Conducting dependent instruments approaches to Runways 9R and 17
- Removing departure fix restrictions
- Installing Localizer Directional Aid (LDA) on Runway 9L
- Relocating Runway 9L/27R (includes new commuter Runway 8/26)

Figure 7 Annual Delay Costs — Capacity Enhancement Alternatives





Section 4

Summary of Technical Studies

Overview

The Philadelphia International Airport Capacity Team evaluated the efficiency of the existing airfield and the proposed future configuration. Figure 8 illustrates airfield weather conditions, and Figures 9 and 10, airfield weather and runway utilization. Figure 11 illustrates the traffic percentages by fix for air carrier and air taxi aircraft arriving at and departing from PHL. The potential benefits of various improvements were determined by examining airfield capacity, airfield demand, and average aircraft delays.

The Capacity Team used the Airport and Airspace Simulation Model (SIMMOD) to determine aircraft delays during peak periods. Delays were calculated for current and future conditions.

For the short-term demand level (Future 1 or 500,000 aircraft operations per year), it was assumed that a new terminal (designated "Terminal A Prime") had been constructed on the east side of the present Terminal A. For the simulation runs, gates at that "new" terminal handled the additional future traffic that supplemented the present-day schedule.

For the long-term demand level (Future 2 or 565,000 operations per year), it was assumed that a terminal (designated "Terminal F") had been constructed to the north of the present Terminal E. For the simulation runs, gates at this terminal handled the additional traffic that supplemented the short-term schedule.

Daily operations corresponding to an average day in the peak month were used for each of the forecast periods. Daily delays were annualized to measure the potential economic benefits of the proposed improvements. The annualized delays provide a basis for comparing the benefits of the proposed changes. The benefits associated with various runway use strategies were also identified.

The fleet mix at Philadelphia International Airport (PHL) has an average direct operating cost of $1,393 per hour. This figure represents the costs for operating the aircraft and includes such items as fuel, maintenance, and crew costs, but it does not consider lost passenger time, disruption to airline schedules, or any other intangible factors.

The cost of a particular improvement is measured against its annual delay savings. This comparison indicates which improvement will be the most effective.

For expected increases in demand, a combination of improvements can be implemented to allow airfield capacity to increase while aircraft delays are minimized.

Figure 8 Airfield Weather

Ceiling	Visibility	Occurrence (%)
VFR1	3,000 feet / 5 SM or above	80.6
VFR2	Between 3,000 and 1,000 feet / 5 to 3 SM	8.7
IFR	Between 1,000 and 200 feet / 3 to 0.5 SM	10.7
	Total	100.0

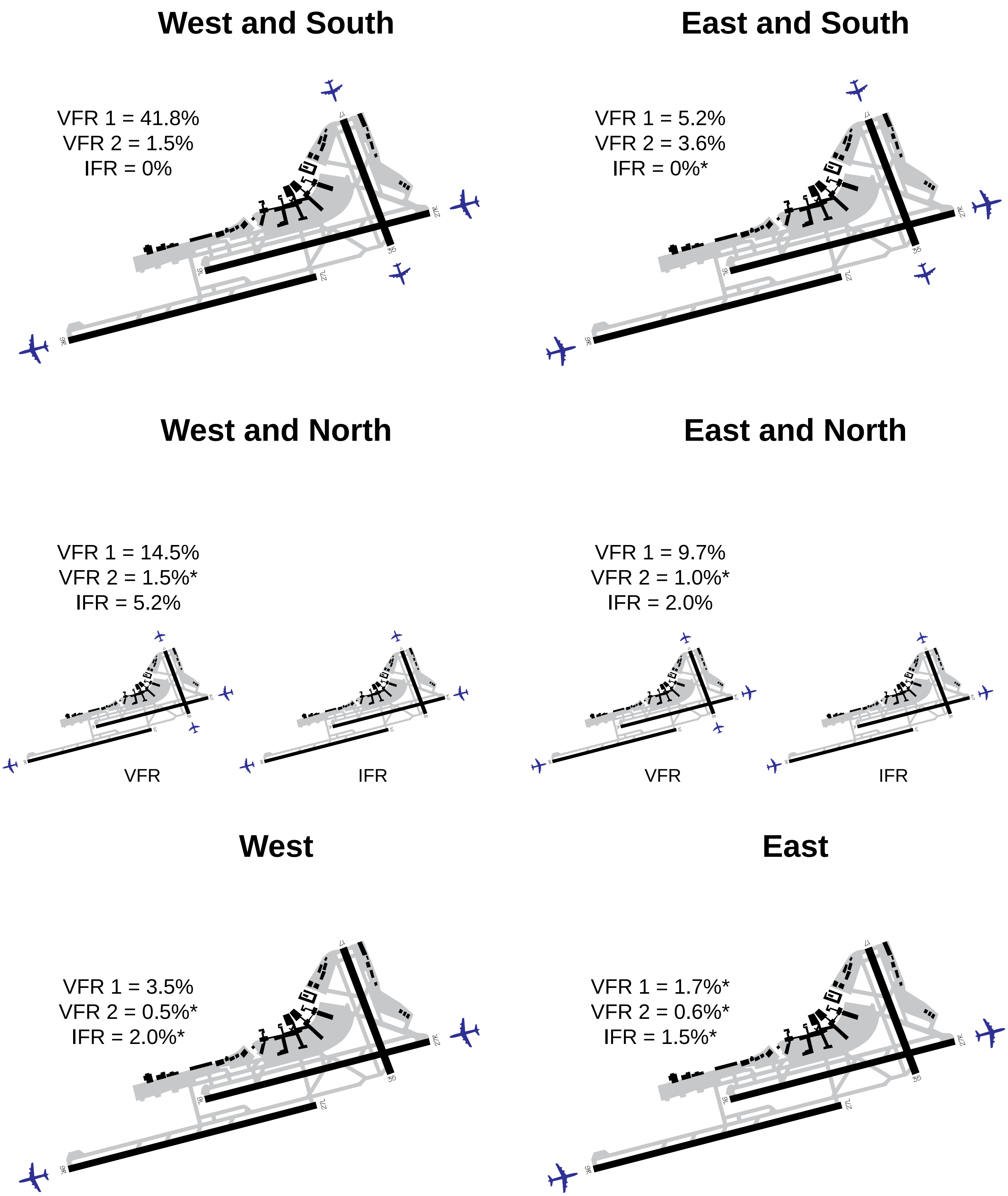
VFR - Visual Flight Rules
IFR - Instrument Flight Rules
SM - Statute Miles

Figure 9 Airfield Weather and Runway Utilization (%)

Flow	VFR 1	VFR 2	IFR	All Weather
West and South	41.8	1.5	0.0	43.3
West and North	14.5	1.5*	5.2	21.2
East and North	9.7	1.0*	2.0	12.7
East and South	5.2	3.6	0.0*	8.8
West	3.5	0.5*	2.0*	6.0
East	1.7*	0.6*	1.5*	3.8
Other	4.2*			4.2
			Total	100.0

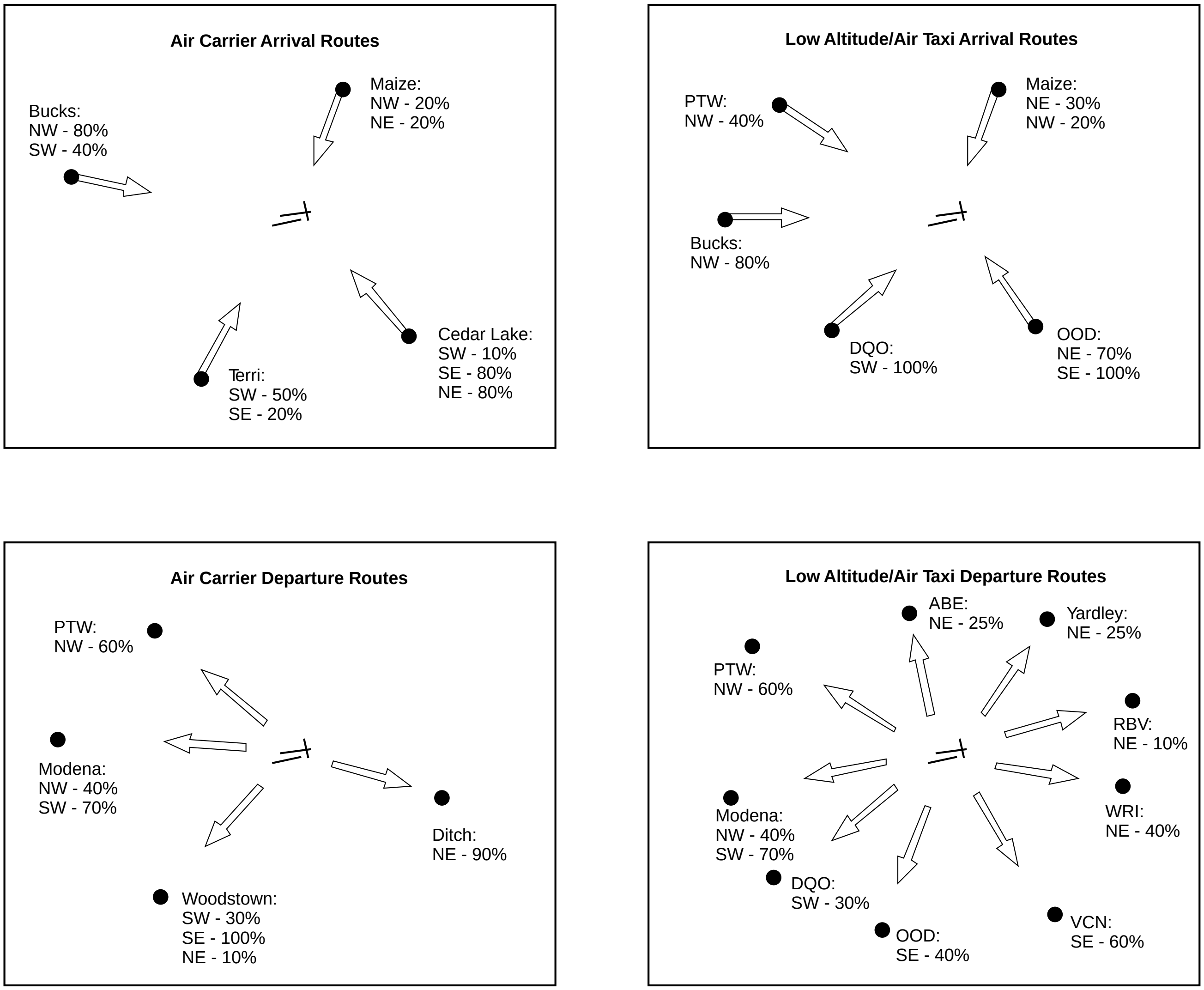
* Note: These particular flow/weather configurations were not simulated.

Figure 10 Airfield Weather and Runway Utilization



Other: VFR 1 = 4.2%*, Combined Total = 100
* = These particular flow/weather configurations were not simulated.

Figure 11 Traffic Percentages by Fix for Arriving and Departing Aircraft (1990)



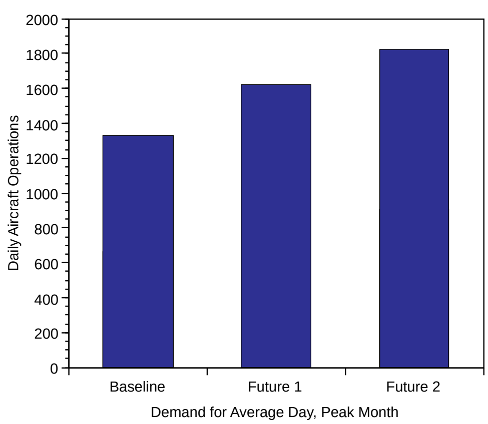
Airfield Capacity

The PHL Capacity Team defined airfield capacity to be the maximum number of aircraft operations (landings or takeoffs) that can take place in a given time considering the following conditions:

- Level of delay
- Airspace constraints
- Ceiling and visibility conditions
- Runway layout and use
- Aircraft mix
- Percent arrival demand

Figure 12 illustrates the average-day, peak-month arrival and departure demand levels for PHL for each of the three annual activity levels used in the study, Baseline, Future 1, and Future 2.

Figure 12 Airfield Demand Levels — Aircraft Operations and Average Day of Peak Month



	Annual	24-Hour Day (Average Day, Peak Month)	Peak Hour
Baseline	410,000	1,322	102
Future 1	500,000	1,612	124
Future 2	565,000	1,820	139

Figure 13 presents the airport capacity curves for PHL. The curves were developed for the most prevalent runway configuration, under instrument flight rules (IFR) conditions. These curves are based on the assumption that arrival and departure demand is randomly distributed within the hour.

The curves in Figure 13 illustrate the relationship between airfield capacity, stated in the number of operations per hour, and the average delay per aircraft. They show that, as the number of aircraft operations per hour increases, the average delay per operation increases exponentially.

Figure 14 illustrates the hourly profile of daily demand for the Baseline activity level of 410,000 aircraft operations per year. It also includes a curve that depicts the profile of daily operations for the Future 2 activity level of 565,000 aircraft operations per year.

Comparing the information in Figures 13 and 14 shows that

- aircraft delays will begin to escalate rapidly as hourly demand exceeds 40 to 70 operations per hour with 50 percent arrivals and 50 percent departures, and,
- while hourly demand exceeds 40 to 70 operations during certain hours of the day at Baseline demand levels, 40 to 70 operations per hour is frequently exceeded at the demand levels forecast for Future 2.

Figure 13 IFR Flow Rate Versus Average Delay

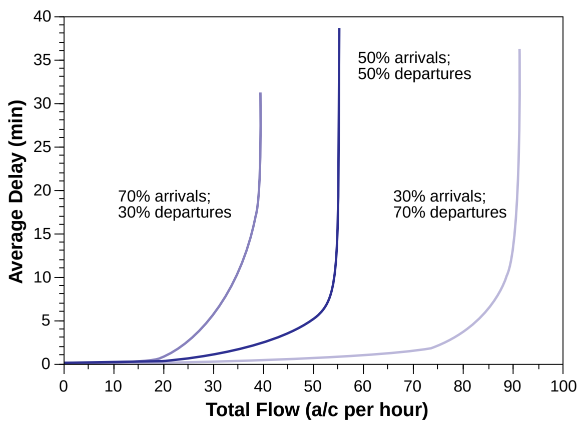
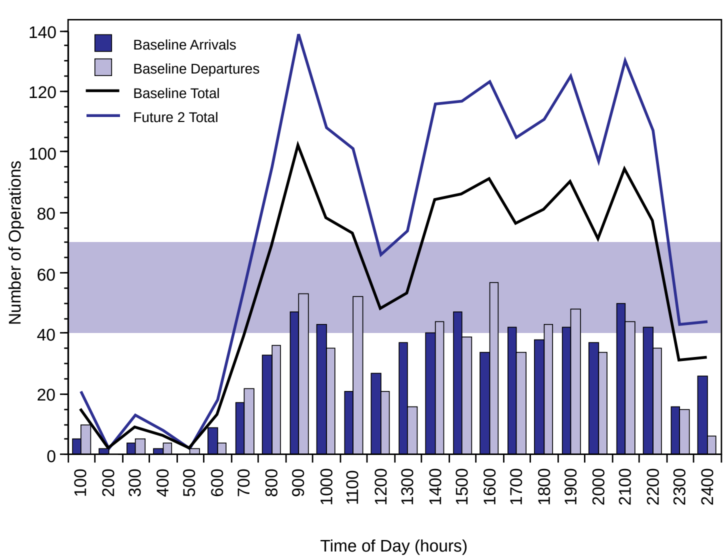


Figure 14 Profile of Daily Demand — Hourly Distribution



Aircraft Delays

Aircraft delay is defined as the time above the unimpeded travel time for an aircraft to move from its origin to its destination. Aircraft delay results from interference from other aircraft in the system competing for the use of the same facilities.

The major factors influencing aircraft delays are:

- Weather
- Airfield and ATC System Demand
- Airfield physical characteristics
- Air traffic control procedures
- Aircraft operational characteristics

Average delay in minutes per operation were determined by use of the Airport and Airspace Simulation Model (SIMMOD). A description of this model is included in Appendix B. If no improvements are made in airport capacity, the average delay per operation of 5.9 minutes in Baseline will increase to 53.3 minutes per operation by Future 2.

Under the "Do Nothing" situation, if there are no improvements in airfield capacity, the annual delay cost could increase as follows:

		Annual Delay Costs	
	Operations	Hours	Millions of 1990 $
Baseline	410,000	40,370	$56.2
Future 1	500,000	174,791	$243.5
Future 2	565,000	501,690	$698.9

Appendix A

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Appendix B

Computer Models and Methodology

The PHL Capacity Team studied the effects of various improvements proposed to reduce delay and enhance capacity. The options were evaluated considering the anticipated increase in demand. The analysis was performed using computer modeling techniques. A brief description of the models and the methodology employed follows.

Computer Models

Runway Delay Simulation Model (RDSIM)

RDSIM is a short form of the Airport Delay Simulation Model (ADSIM), which is a fast-time, discrete-event model that employs stochastic processes and Monte Carlo sampling techniques. There are two forms of the RDSIM model. The first simulates only the runways and runway exits, ignoring the taxiway and gate complexes, for a user-specified daily traffic demand. The second version also simulates only the runway and runway exits, but it creates its own demand using randomly assigned arrival and departure times. The demand created is based upon user-specified parameters. This second form of the model is suitable for capacity analysis.

The model was calibrated for this study against field data collected at PHL to ensure it was site specific. For a given demand, the model calculates the hourly flow rate and average delay per aircraft during the full period of airport operations. Using the same aircraft mix, computer specialists simulated different demand levels for each run to generate demand versus delay relationships.

Airport and Airspace Simulation Model (SIMMOD)

SIMMOD is a fast-time, event-step model that simulates the real-world processes by which aircraft fly through air-traffic-controlled en route and terminal airspace and arrive and depart at airports. SIMMOD traces the movement of individual aircraft as they travel through the gate, taxiway, runway, and airspace system and detects potential violations of separations and operating procedures. It simulates the air-traffic-control actions required to resolve potential conflicts to insure that aircraft operate within procedural rules. Aircraft travel time, delay, and traffic statistics are computed and provided as model outputs. The model was calibrated for this study against field data collected at PHL to ensure it was site specific. Inputs for the simulation model were also derived from empirical field data. The model repeated each experiment 10 times using Monte Carlo sampling techniques to introduce system variability. The results were then averaged to produce output statistics.

Methodology

Model simulations included present and future air traffic control procedures, various airfield improvements, and traffic demands for different times. To assess the benefits of proposed airfield improvements, the FAA used different airfield configurations derived from present and projected airport layouts. The projected implementation time for air traffic control procedures and system improvements determined the aircraft separations used for IFR and VFR weather simulations.

For the delay analysis, agency specialists developed traffic demands based on the *Official Airline Guide*, historical data, and various forecasts. Aircraft volume, mix and peaking characteristics were developed for three demand periods (Baseline, Future 1 and Future 2). The estimated annual delays for the proposed improvement options were calculated from the experimental results by determining differences in total system time. These estimates took into account the yearly variations in runway configurations, weather, and demand based on historical data.

The potential delay reductions for each improvement were assessed by comparing the annual delay estimates.

Appendix C

Glossary

ADSIM	Airport Delay Simulation Model
AOPA	Aircraft Owners and Pilots Association
ATA	Air Transport Association of America
ATC	Air Traffic Control
DTP	Dynamic Traffic Planner
FAA	Federal Aviation Administration
GA	General Aviation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LDA	Localizer Directional Aid
MLS	Microwave Landing System
NM	Nautical Miles
NAVAID	Navigation Aid
PHL	Philadelphia International Airport
PRM	Precision Runway Monitor
RDSIM	Runway Delay Simulation Model
RVR	Runway Visual Range
SIMMOD	Airport and Airspace Simulation Model
SM	Statute Miles
TATCA	Terminal Air Traffic Control Automation
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

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