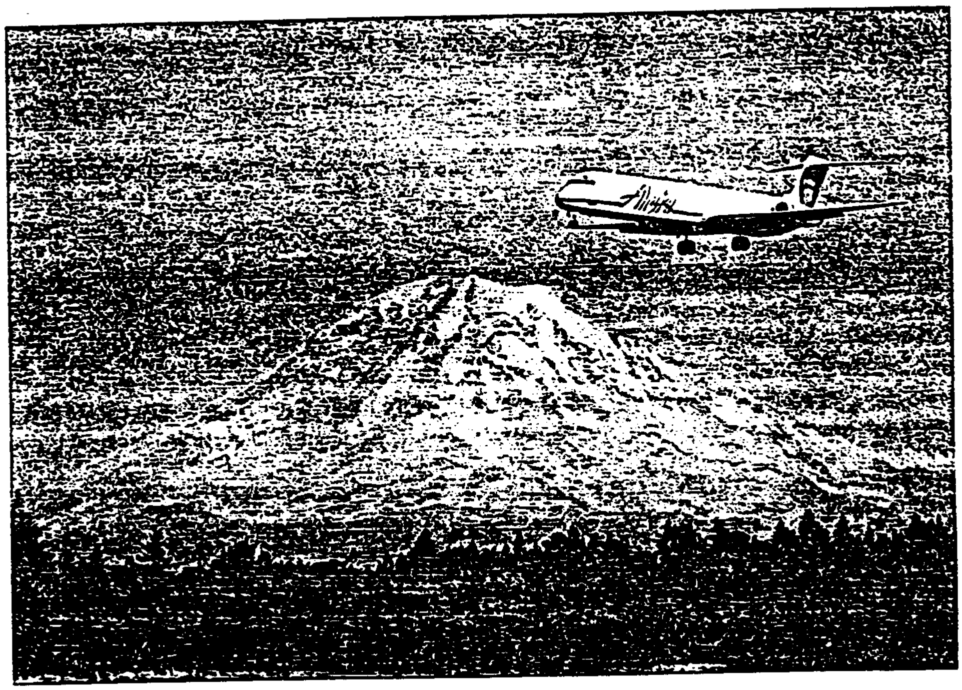
# Seattle-Tacoma International Airport



# Capacity Enhancement Plan Update

AR 038694

# Seattle-Tacoma International Airport

# Capacity Enhancement Plan Update

# July 1995

Prepared jointly by the U.S. Department of Transportation, Federal Aviation Administration, Port of Seattle and the airlines and general aviation community serving Seattle-Tacoma International Airport.

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# Executive Summary

Figure 1. Annual Delay Costs — Capacity Enhancement Alternatives

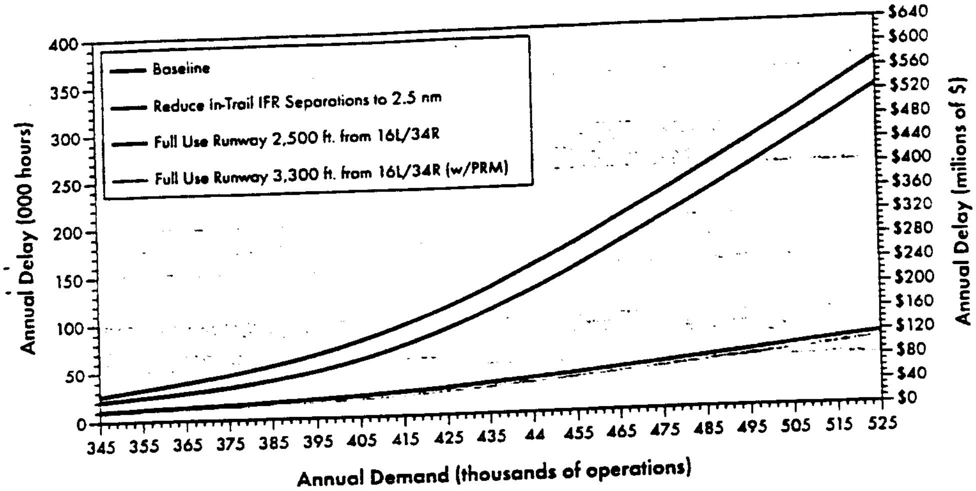
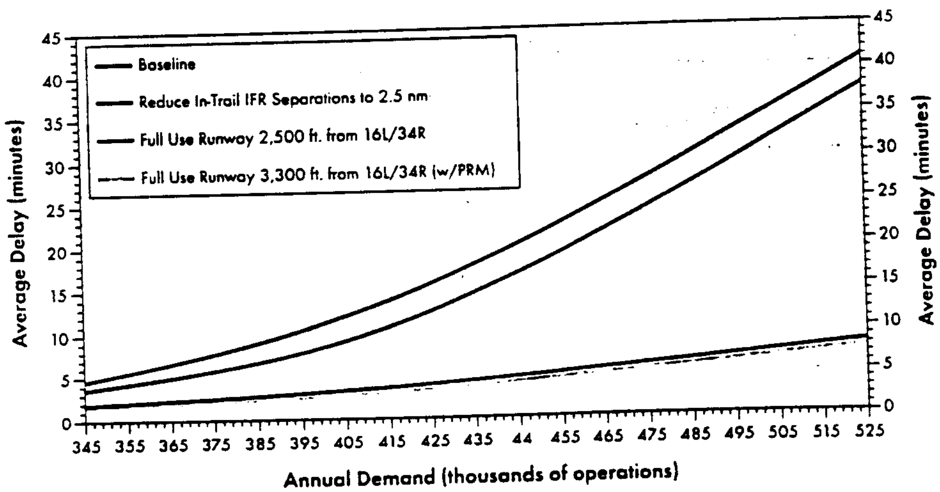



Figure 2. Average Delay per Operation — Capacity Enhancement Alternatives



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Recognizing the problems posed by congestion and delay within the National Airspace System, the Federal Aviation Administration (FAA), airport operators, and aviation industry groups have initiated joint Airport Capacity Design Teams at various major air carrier airports throughout the U.S. Each Capacity Design Team identifies and evaluates the technical merits of alternative means to enhance existing airport and airspace capacity to handle future demand, decrease delays, and improve airport efficiency. Over 35 Airport Capacity Design Teams have either completed their studies or have work in progress.

The need for this program continues. In addition, the need to update individual studies has become apparent due to the incremental improvements made to existing airports and improvements in procedures and new technologies which have not been previously studied at specific airports. In 1993, 23 airports, including Seattle-Tacoma International Airport (SEA), exceeded 20,000 hours of airline flight delay. If no improvements in capacity are made, the number of airports that could exceed 20,000 hours of annual aircraft delay is projected to grow from 23 to 32 airports by the year 2003.

A capacity enhancement plan was initiated in late 1989 for Seattle-Tacoma International Airport. A report containing capacity enhancement recommendations was published in June of 1991. Seattle-Tacoma International Airport is one of the 23 airports identified in the 1994 Aviation Capacity Enhancement (ACE) Plan as exceeding 20,000 hours of delay annually. Steady growth at SEA has made it one of the busiest airports in the country. Passenger enplanements at SEA rose from 5,167,185 in 1984 to 10,471,150 in 1994, an increase of over 100 percent. In 1984, the airport handled 224,000 aircraft operations (takeoffs and landings), and in 1994, 353,052 aircraft operations, an increase of 58 percent. This growth, along with the period of time since the last study and the need to reassess and further analyze capacity enhancement alternatives, combined with the availability of more advanced modeling tools, resulted in the initiation of this update to examine, in more detail, certain capacity enhancement alternatives.

In October 1993, the second Airport Capacity Design Team for SEA was formed to reassess and again identify various potential improvements which, if implemented, would increase SEA's capacity, improve operational efficiency, and reduce aircraft delays. A major benefit of this effort was its contribution to the Port of Seattle's Master Plan Update as well as its ongoing studies for SEA expansion.

Selected 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:

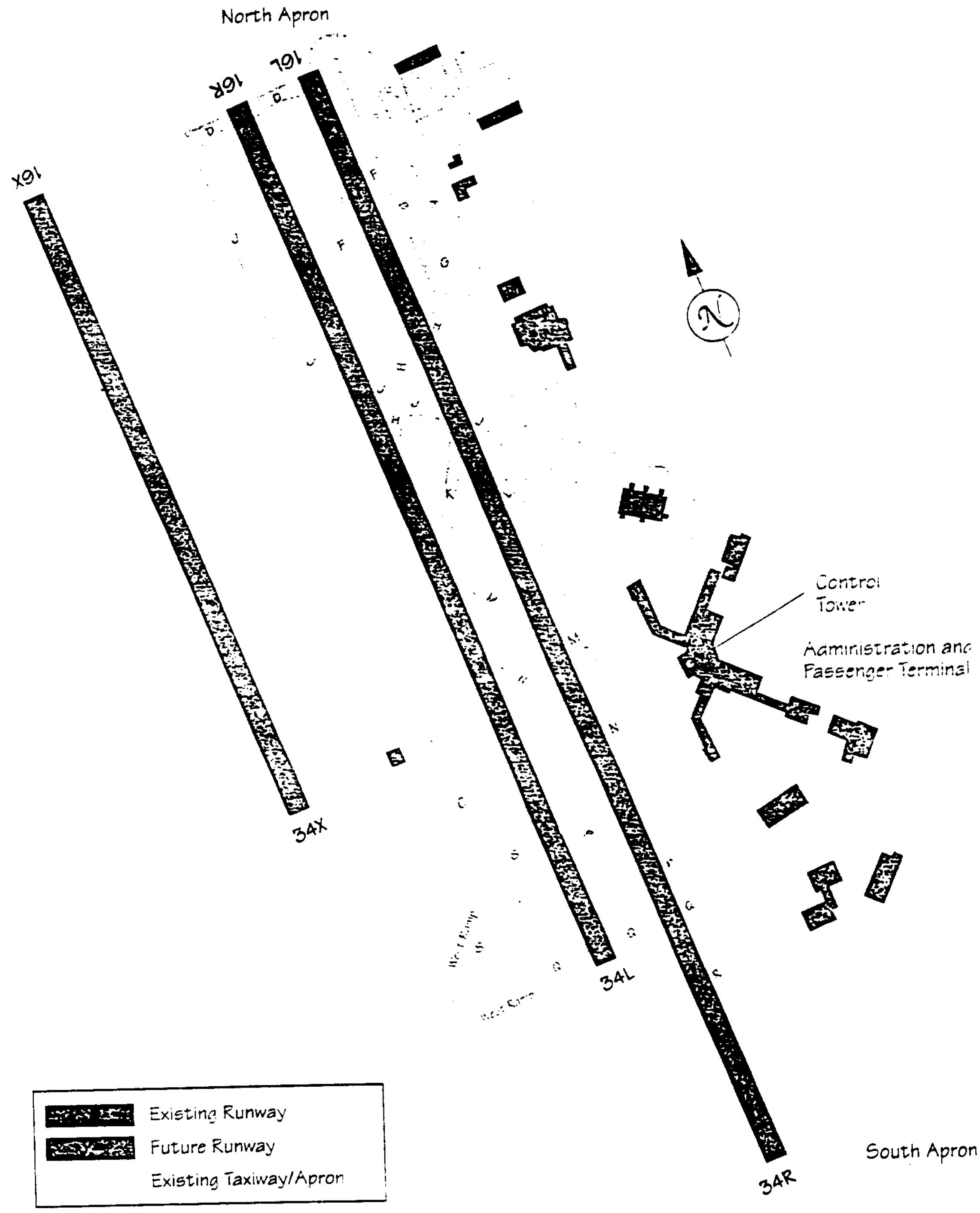
- Baseline — 345,000 operations;
- Future 1 — 425,000 operations
- Future 2 — 525,000 operations

The study results, as depicted in Figure 4, show that all of the improvements listed result in annual delay savings for all three activity levels, Baseline, Future 1, and Future 2. At the Baseline level, indications are that the maximum delay savings would be realized from the construction of a third parallel runway 3,300 feet west of Runway 16L/34R, while the minimum in delay savings would occur as a result of the installation and use of a wake vortex detection system on the present airfield. Through the Future 2 level of 525,000 annual operations, the maximum delay savings would be obtained by the construction of a full-use runway 2,500 feet west of Runway 16L/34R with no King County International Airport (BFI) interaction and glide slope interference.

Figure 1 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 Baseline scenario. Annual delay costs will increase from 25,867 hours or $41.49 million at the Baseline level of operations to 110,490 hours or $177.2 million by Future 1 and 357,976 hours or $574.19 million by Future 2.

Figure 2 illustrates the average delay in minutes per aircraft operation for these alternatives. Under the Baseline alternative, if there are no improvements made in airfield capacity, the average delay per operation of 4.5 minutes at the Baseline level of activity will increase to 15.6 minutes per operation by Future 1 and 40.92 minutes per operation by Future 2.

**Figure 3. Seattle-Tacoma International Airport Seattle, Washington**



## Figure 4. Study Results Summary

| | Estimated Annual Delay Savings[1] (in hours and millions of dollars) | | |
|---|---|---|---|
| | Baseline (345,000) | Future 1 (425,000) | Future 2 (525,000) |
| **Operational Improvements** | | | |
| 1. Reduce In-trail Separations in IFR to 2.5 NM | 5,658/$9.1 | 22,759/$36.5 | 28,646/$45.9 |
| 2. Wake Vortex Detection Avoidance System | 4,725/$7.6[2] | 14,089/$22.6[2] | 47,793/$76.7[2] |
| **New Runway Improvements** | | | |
| 3. Parallel runway 16X/34X, 1,500 feet west of runway 16L/34R (Class 3 and 4) | 5,531/$8.9 | 32,775/$52.6 | 137,629/$220.8 |
| 4. Parallel runway 16X/34X, 2,500 feet west of runway 16L/34R | | | |
| A. Class 3 and 4 | 12,418/$19.9 | 68,145/$109.3 | 224,488/$360.1 |
| B. Full-use, CAT III capability on 16X and 16L | 14,988/$24.0 | 82,479/$132.3 | 283,080/$454.1 |
| 1. No BFI Interaction | 15,395/$24.7 | 84,732/$135.9 | 286,367/$459.3 |
| 2. FMS and GPS | 17,350/$27.8 | 91,122/$146.2 | 312,690/$501.6 |
| 3. No BFI Interaction nor Glide Slope Interference | 17,493/$28.1 | 91,405/$146.6 | 315,657/$506.3 |
| C. CAT I Capability on 16X and 16L, CAT III on 16R | 12,452/$20.0 | 75,259/$120.7 | 271,106/$434.9 |
| D. Modified Full-use, No Heavy Aircraft on 16X/34X | 14,186/$22.8 | 81,542/$130.8 | 275,181/$441.4 |
| 5. Parallel Runway 16X/34X, 3,300 feet west of runway 16L/34R | | | |
| A. Without PRM | 17,790/$28.5 | 91,871/$147.4 | 309,331/$496.2 |
| B. With PRM | 16,322/$26.2 | 86,199/$138.3 | 287,399/$461.0 |
| **Marketplace Solutions** | | | |
| 6. Peaking | | | |
| A. Peak Hour Pricing | 5,840/$9.4[3] | 22,234/$35.7[3] | 49,518/$79.4[3] |
| B. Peak Spreading | 7,359/$11.8 | 9,867/$15.8 | 50,746/$81.4 |

1. The delay savings benefits of these alternatives are not necessarily additive.
2. Savings shown are possible if all wake vortex turbulence dependencies among aircraft are eliminated. Therefore, this is the maximum possible savings and the actual savings would be less.
3. Delay savings are due to fewer flights and flight rescheduling. Annual operations were 335,048 (Baseline), 413,047 (Future 1), and 507,725 (Future 2).

# Section 1

## Introduction

## Background

Recognizing the problems posed by congestion and delay within the National Airspace System, the Federal Aviation Administration (FAA) asked the aviation community to study the problem of airport congestion through the Industry Task Force on Airport Capacity Improvement and Delay Reduction chaired by the Airport Operators Council International.

By 1984, aircraft delays recorded throughout the system highlighted the need for more centralized management and coordination of activities to relieve airport congestion. In response, the FAA established the Airport Capacity Program Office, now the Office of System Capacity and Requirements (ASC). The goal of the office and its capacity enhancement program is to identify and evaluate initiatives that have the potential to increase capacity, so that current and projected levels of demand can be accommodated within the system with a minimum of delay and without compromising safety or the environment.

In 1985, the FAA initiated a renewed program of Airport Capacity Design Teams at various major air carrier airports throughout the U.S. Each Capacity Team identifies and evaluates alternative means to enhance existing airport and airspace capacity to handle future demand, and works to develop a coordinated action plan for reducing airport delay. Over 35 Capacity Design Teams have either completed their studies or have work in progress.

The need for this program continues. In 1993, 23 airports, including Seattle-Tacoma International Airport (SEA), exceeded 20,000 hours of airline flight delays. If no improvements in capacity are made, the number of airports that could exceed 20,000 hours of annual aircraft delay is projected to grow from 23 to 32 by 2003.

In a September, 1994 address, the FAA Administrator stated that "the most serious potential problem in meeting the demands on aviation in the coming years will be inadequate capacity of our major airports." He predicted that air travel in the U.S. will increase 60 percent in the next 10 years, and in 20 years, as many as 1 billion passengers annually will pass through our airports. He noted that unless we find a way to add airport capacity, our industry could be forced into distorted patterns of growth... stunted by the unyielding confines of an infrastructure we are unable or unwilling to expand.

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.

## Seattle-Tacoma International Airport

Seattle-Tacoma International Airport is one of the 23 airports identified in the 1994 Aviation Capacity Enhancement (ACE) Plan as exceeding 20,000 hours of aircraft delay annually. In the past decade, Seattle-Tacoma has been one of the Nation's busiest airports. Passenger enplanements at SEA rose from 5,167,185 in 1984 to 10,471,150 in 1994, an increase of over 100 percent. SEA's total aircraft operations (one takeoff or one landing equals one operation) reached 353,052 in 1994, an increase of 58 percent over the 224,000 aircraft operations the airport handled in 1984.

Seattle-Tacoma International Airport is owned and operated by the Port of Seattle. The airport is currently situated on about 2,500 acres and is at an elevation of 429 feet above mean sea level. The airfield has two parallel runways, 16L/34R and 16R/34L, separated by 800 feet.

## Seattle-Tacoma Airport Capacity Design Team

A Seattle-Tacoma International Airport Capacity Enhancement Design Team was established in late 1989, and an Airport Capacity Enhancement Plan containing Design Team recommendations for capacity enhancement was published in 1991. Since the publication of the original enhancement plan, changes in FAA operational procedures and standards have been approved and implemented and advancements have been made in capacity analysis and modeling. This, combined with the fact that the 1991 study did not include consideration of the interaction of SEA and King County International Airport (BFI) operations, dictated a reexamination of SEA.

In October 1993, the second Airport Capacity Design Team for SEA was formed to reassess potential improvements which, if implemented, would increase SEA's capacity, improve operational efficiency, and reduce aircraft delays. This study update was undertaken to determine the technical merits of alternatives and the associated impact on capacity. A major benefit of this effort was its positive contribution to the Port of Seattle's Master Plan Update and its ongoing studies for constructing a third runway at SEA. Additional studies will be needed to assess associated environmental, socioeconomic, or political issues.

The 1991 study was completed using the Airfield Delay Simulation Model (ADSIM) and the Runway Delay Simulation Model (RDSIM). This Update Study utilized the Airport and Airspace Simulation Model (SIMMOD), which is capable of analyzing additional airspace assumptions and, therefore, produces a more complete simulation. Additional attention was given to weather analysis in the 1995 study. A ten year weather history was used to determine how often and when each weather condition occurred. This technique more accurately depicts the changes from one weather condition to another.

This report has established benchmarks for airport development based upon traffic levels and not upon any definitive time schedule, since actual growth 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 of 345,000 aircraft operations (takeoffs and landings) was established based on the annual traffic level for 1993. Two future traffic levels, Future 1 and Future 2, were established at 425,000 and 525,000 annual aircraft operations respectively. If no improvements are made at SEA, annual delay levels and delay costs are expected to increase from an estimated 25,867 hours and $41.49 million at the Baseline activity level to 110,490 hours and $177.2 million by the Future 1 demand level and 357,976 hours and $574.19 million by Future 2.

The Capacity Team studied various proposals with the potential for increasing capacity and reducing delays at SEA. The improvements evaluated by the Capacity Team are delineated in Figure 4 and described in some detail in Section 3, Study Results.

## Objectives

The major goal of the Capacity Team was to identify and evaluate proposals to increase airport capacity, improve airport efficiency, and reduce aircraft delays. In achieving this objective, the Capacity Team:

- Examined the causes of delay associated with BFI interaction.
- Evaluated delay benefits of alternative air traffic control (ATC) procedures, navigational improvements, airfield development, and operational improvements.

## Scope

The Capacity Design Team limited its analyses to aircraft activity within the terminal area airspace of SEA; the airfield at SEA, excluding the taxiways adjacent to and surrounding the gate areas; and the interaction between SEA and BFI. The existing relationship between SEA and BFI is depicted in Figure 5. The capacity impact manifests itself in the following way: any IFR (instrument flight rules) arrival to BFI runway 13 will require a gap in the arrival stream to any new runway 2,500 feet or 3,300 feet to the west of 16L/34R. This will occur in both Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC). This effectively means that each IFR arrival to BFI Runway 13 is substituted for an arrival at SEA Runway 16X. The impact of BFI on SEA capacity while SEA was in north flow was not felt to be frequent and consistent enough to warrant detailed analysis. The Capacity Design Team did not address environmental, socioeconomic, or political issues regarding airport development. These issues are addressed in separate airport planning studies. The data generated by the Capacity Design Team may be used in such studies.

# Methodology

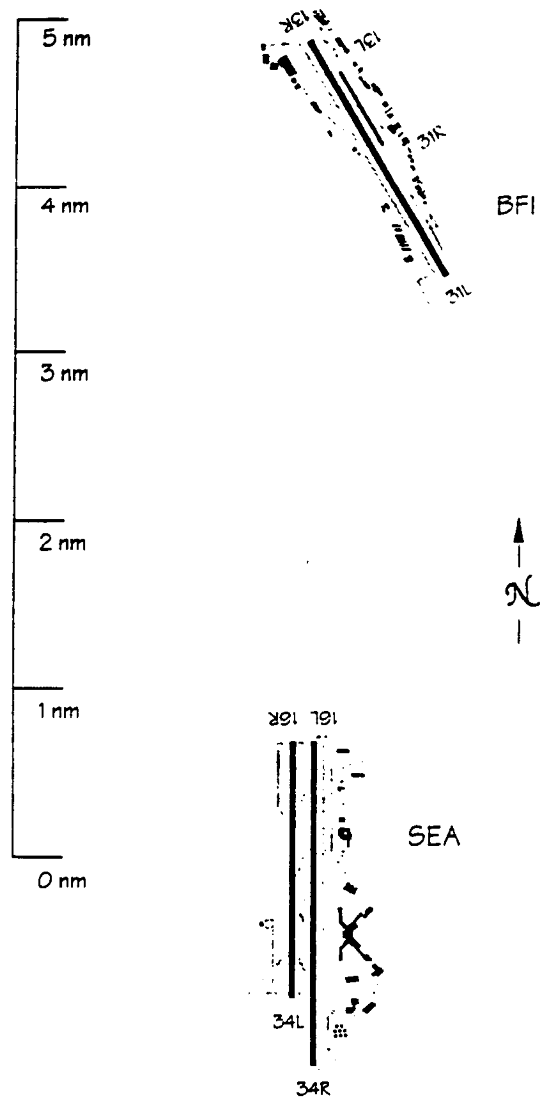
The Capacity Team, which included representatives from the FAA, the Port of Seattle, and various aviation industry groups (see Appendix A), met periodically for review and coordination. The Capacity Team members considered suggested capacity improvement alternatives proposed by the FAA's Office of System Capacity and Requirements, FAA Technical Center, and Regional Aviation Capacity Program Manager, and by other members of the Team. Alternatives that were considered practicable were developed into experiments that could be tested by simulation modeling. The FAA Technical Center's Aviation Capacity Branch provided expertise in airport simulation modeling. The Capacity Team validated the data used as input for the simulation modeling and analysis and reviewed the interpretation of the simulation results. The data, assumptions, alternatives, and experiments were continually reevaluated, and modified where necessary, as the study progressed.

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 SEA. Proposed improvements were analyzed in relation to current and future demands with the help of FAA computer models, the Airport and Airspace Simulation Model (SIMMOD) and the Runway Delay Simulation Model (RDSIM). Appendix B briefly explains the models.

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

Air traffic demand levels were derived from *Official Airline Guide* data, historical data, and Capacity Team and other 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 runway configuration, weather, and demand. The annual delay estimates for each configuration were then compared to identify delay reductions resulting from the improvements.

**Figure 5. Existing Relationship of SEA to BFI**



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# Section 2

## Comparison of the 1991 and 1995 Studies

Work on the Capacity Enhancement Plan, published in 1991, began in 1989. Delay data used in the 1995 update differs from that projected in the 1991 plan based on initial data gathered in 1989.

## Improvements Since 1991

Since the issuance of the 1991 report, a number of airfield and operational improvements have been completed, are in the construction phase, or planned to be completed by the year 2000. These include: additional high speed exits on Runway 16R/34L; expansion and improvement of the southside cargo maintenance area; expansion of Concourse A; installation of Microwave Landing System (MLS) equipment; and utilization of Runway 34L as the primary arrival runway in north flow.

Several other changes have occurred at the airport since 1989 which have contributed to delay reduction at SEA. The following list summarizes these changes, all of which have increased the efficiency of the air traffic flow at SEA:

- Implementation of the 4-post plan resulted in a more consistent separation between arriving aircraft and a more balanced use of the runways as reflected in Figure 8.
- The ILS hold line for runway 16R located east of runway 16L was moved to a point between runways 16R and 16L. Now, aircraft holding for departure on runway 16R are 800 feet closer and do not have to cross an active runway prior to departure. The end result has been a reduction in departure intervals on runway 16R.
- The installation of runway centerline lights on runway 16L allowed the increased use of runway 16L for departures during some IFR conditions. This resulted in a reduction, from 7 percent to 0.3 percent, in the amount of time that the sole use of runway 16R was required for IFR arrivals and departures.
- Air Traffic Control personnel have concentrated on reducing departure delays and have been more aggressive in monitoring flows.
- The aircraft fleet is more homogeneous, which results in the average longitudinal separation between aircraft being reduced. The change in the fleet mix is noted in Figure 7.
- The aircraft fleet has modernized, which has resulted in higher average approach speeds and a reduction in the arrival interval. The change in approach speeds is detailed in Figure 7, while the impact on capacity is shown in Figure 6.
- The airfield is easier to use due to the installation of improved airfield lighting and signage.



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## Data Comparisons

It should be noted that the single greatest factor influencing the calculation of delay for the 1995 report update is the change in airspeeds used for analysis and modeling by the Team.

The following figures provide a comparison of 1991 and 1995 data.

As shown in Figure 6, data for the 1991 and 1995 studies indicates an increase in arrival capacity due to the decrease in IFR arrival separation distance and an increase in arrival speeds.

Figure 7 depicts approach speeds by aircraft class and aircraft class distribution for both the 1991 and 1995 studies. Airspeeds have increased from 10 to 20 knots for all aircraft classes. For the purposes of this report, aircraft class definitions have been modified from those used for the 1991 study. Class 2, as used in the 1995 study, includes Class 2 and 3 from the 1991 study, while the 1991 study Classes 3 and 4 were combined to make the 1995 study Class 4. Approach speeds were increased for this study based on a recommendation of the Design Team which was confirmed by review of the Automated Radar Terminal System (ARTS) data.

As depicted in Figure 8, data gathered for the 1991 study reveals that, for VFR traffic, Runway 16R was the primary VFR approach runway and Runway 16L was utilized almost exclusively as the VFR departure runway. 1995 data indicates that while Runway 16R is still the predominate VFR arrival runway, VFR departures now utilize Runway 16R almost 20% of the time.

A comparison of the 1991 and 1995 baseline daily demand level, depicted in Figures 9 and 10, shows that hourly demand levels have generally increased for all time periods. Demand increases, contrary to the 1991 study projections, have tended to equalize hourly demand levels rather than increase peak periods of demand.

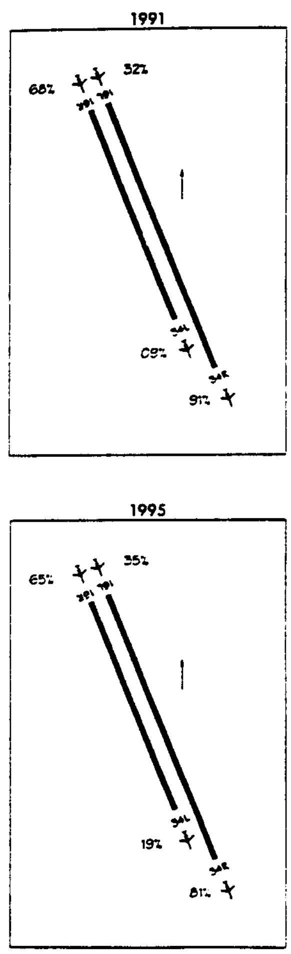
**Figure 6. IFR Arrival Capacity — Comparison**

| | 1991 | 1995 |
|---|---|---|
| Expected Value, Separation between Arrival Aircraft | 4.41 nm | 4.35 nm |
| Expected Value Arrival Speed | 129 knots | 137 knots |
| Arrival Capacity | 29.3 aircraft/hour | 31.5 aircraft/hour |

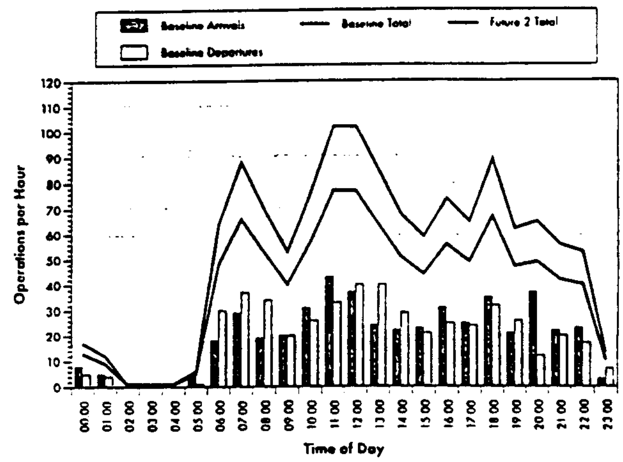
## Figure 7. Aircraft Class Mix — Comparison

| | Class 1 | | Class 2 | | Class 3 | | Class 4 | |
|---|---|---|---|---|---|---|---|---|
| | 1991 | 1995 | 1991 | 1995 | 1991 | 1995 | 1991 | 1995 |
| Approach Speed | 140 knots | 155 knots | 130 knots | 140 knots | 120 knots | 130 knots | 100 knots | 120 knots |
| Distribution | 11.0% | 8.6% | 73.0% | 54.2% | 14.0% | 31.1% | 2.0% | 5.9% |

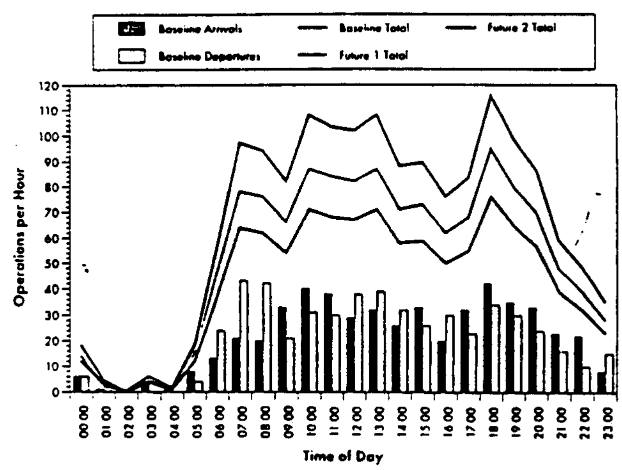
## Figure 8. VFR Runway Use Comparison




## Figure 9. 1991 Profile of Daily Demand — Hourly Distribution




## Figure 10. 1995 Profile of Daily Demand — Hourly Distribution



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# Section 3

## Study Results

The capacity enhancement alternatives are categorized and discussed under the following headings:

- Operational Improvements
- New Runway Improvements
- Marketplace Solutions

Figure 3 shows the current layout of the airport, plus the airfield improvements considered by the Capacity Team.

Figure 4 lists the study results and presents the estimated annual delay savings benefits for selected improvements. The annual delay savings are given for the activity levels Baseline, Future 1, and Future 2, which correspond to annual aircraft operations of 345,000, 425,000, and 525,000 respectively. The delay savings benefits of the improvements are not necessarily additive.

# Operational Improvements

### 1. Reduce In-trail Separations in IFR to 2.5 NM.

Existing procedures for IFR require that arriving aircraft be separated by 3 NM or more. Reducing longitudinal separation minimums to 2.5 NM would increase arrival rates and runway capacity. The reduced separation procedure requires that the leading aircraft weight class be the same or less than the trailing aircraft. When a heavy jet or B757 is the leading aircraft, the standard IFR wake vortex separation cannot be reduced to 2.5 NM. To implement reduced in-trail separations, the average runway occupancy time (ROT) must be 50 seconds or less, in addition, the runway exits must be visible from the tower, therefore, the separation can only be reduced in IFR 1 conditions.

The reduced in-trail separation procedure is currently in use at SEA for south flow operations to Runway 16R. Implementation of this procedure for north flow operations is dependent on the construction of interconnecting taxiways and compliance with the ROT requirement. The Port of Seattle forecast report dated April 12, 1994, predicts an increased percentage of heavy aircraft and Boeing 757s and a decrease in all other classes. The benefits shown below are based on the fleet mix as depicted in Figure 7, however, it should be noted that, if the forecast report prediction holds true, the result would be smaller benefits at the Future 1 and 2 demand levels because of the fact that the separation distance from heavy aircraft cannot be reduced.

Annual delay savings at the Baseline activity level would be 5,658 hours or $9.1 million; at Future 1, 22,759 hours or $36.5 million; and, at Future 2 activity levels, 28,646 hours or $45.9 million.

### 2. Wake Vortex Detection Avoidance System.

Under current conditions, controllers cannot detect the presence of wake vortices. Therefore, to guard against these potential hazards, increased separations between aircraft are maintained. The Wake Vortex Avoidance System (WVAS) increases capacity by permitting reduced spacing between aircraft when wake vortices present no hazards to following aircraft. It is anticipated that joint FAA and National Aeronautics and Space Administration (Langley) efforts, utilizing a radar type sensing technology named the Automated Vortex Sensing System (AVSS), will yield an operational system by 1998.

The results of this experiment indicate the benefit that could be obtained if all wake vortex separations were eliminated all of the time. Savings shown below are possible if all wake vortex turbulence dependencies among aircraft are eliminated. Therefore, this is the maximum possible savings and the actual savings would be less.

Estimated project cost is unknown at this time.

Annual delay savings at the Baseline activity level would be 4,725 hours or $7.6 million; at Future 1, 14,089 hours or $22.6 million; and, at Future 2 activity levels, 47,793 hours or $76.7 million.

## New Runway Improvements

### 3. Parallel Runway 16X/34X, 1,500 feet West of Runway 16L/34R (Class 3 & 4)

Construction of a new Class 3 & 4 runway would provide a secondary landing runway for propeller aircraft in both north and south flow VFR conditions.

Estimated construction cost is $43 million, based on a 5,000 ft. runway.

Annual delay savings at the Baseline activity level would be 5,531 hours or $8.9 million; at Future 1, 32,775 hours or $52.6 million; and, at Future 2 activity levels, 137,629 hours or $220.8 million.

### 4. Parallel Runway 16X/34X, 2,500 feet West of Runway 16L/34R.

#### A. Class 3 & 4

A new Class 3 & 4 runway constructed 2,500 ft. from runway 16L/34R would provide a secondary landing runway for propeller aircraft during VFR and IFR 1 conditions for both north and south flow. Under IFR 1 conditions, the new runway would be a secondary landing runway in both north and south flow for propeller aircraft while maintaining a 1.5 NM stagger from aircraft landing on 16L/34R. This improvement assumes that there is a CAT I capability on Runways 16L and 16X for south flow and all the Runway 34 ends. The current CAT III capability would remain on Runway 16R.

Estimated property acquisition and construction cost is $261 million, based on a 5,000 ft. runway.

Annual delay savings at the Baseline activity level would be 12,418 hours or $19.9 million; at Future 1, 68,145 hours or $109.3 million; and, at Future 2 activity levels, 224,488 hours or $360.1 million.

### B. Full-use, CAT III Capability on 16X and 16L

A new full-use runway 2,500 ft. from 16L/34R will provide a secondary landing runway for all aircraft under both north and south flow VFR conditions. During south flow IFR 1/2/3 conditions, the new runway would be utilized as a secondary arrival runway while maintaining a 1.5 NM stagger. For IFR 4 conditions, the new runway would be the primary landing runway under south flow conditions only. For north flow conditions, during IFR 1/2 operations, the new runway will be utilized as the secondary arrival runway with a 1.5 NM stagger separation from aircraft landing on Runway 34R. This improvement assumes that there is a CAT III capability on Runways 16X and 16L and that all other runway ends have CAT I capability. The glide slope critical areas are protected in the IFR 2/3/4 conditions. BFI arrivals are assumed to interact with arrivals to Runway 16X.

Estimated property acquisition and construction cost is $409 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 14,988 hours or $24.0 million; at Future 1, 82,479 hours or $132.3 million; and, at Future 2 activity levels, 283,080 hours or $454.1 million.

#### 1. No BFI Interaction

A new full-use runway 2,500 ft. from 16L/34R will provide a secondary landing runway for all aircraft under both north and south flow VFR conditions. During south flow IFR 1/2/3 conditions, the new runway would be utilized as a secondary arrival runway while maintaining a 1.5 NM stagger. For IFR 4 conditions, the new runway would be the primary landing runway under south flow conditions only. For north flow conditions, during IFR 1/2 operations, the new runway will be utilized as the secondary arrival runway with a 1.5 NM stagger separation from aircraft landing on Runway 34R. This improvement assumes that: there is a CAT III capability on Runways 16X and 16L and that all other runway ends have CAT I capability; the glide slope critical areas are protected in IFR 2/3/4 conditions; and BFI and Runway 16X arrivals operate independently. It is unknown if this is feasible at this time.

Estimated property acquisition and construction cost is $409 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 15,395 hours or $24.7 million; at Future 1, 84,732 hours or $135.9 million; and, at Future 2 activity levels, 286,367 hours or $459.3 million.

#### 2. FMS and GPS

A new full-use runway 2,500 ft. from 16L/34R will provide a secondary landing runway for all aircraft under both north and south flow VFR conditions. During south flow IFR 1/2/3 conditions, the new runway would be utilized as a secondary arrival runway while maintaining a 1.5 NM stagger. For IFR 4 conditions, the new runway would be the primary landing runway under south flow conditions only. For north



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flow conditions, during IFR 1/2 operations, the new runway will be utilized as the secondary arrival runway with a 1.5 NM stagger separation from aircraft landing on Runway 34R. This improvement assumes that there is a CAT III capability on Runways 16X and 16L and that all other runway ends have CAT I capability. With the implementation of GPS/FMS procedures in CAT II and III conditions, no glide slope critical area protection is needed in IFR 2/3/4 conditions. There are no other known capacity improvements which will result from the implementation of FMS or GPS.

Estimated property acquisition and construction cost is $409 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 17,350 hours or $27.8 million; at Future 1, 91,122 hours or $146.2 million; and, at Future 2 activity levels, 312,690 hours or $501.6 million.

### 3. No BFI Interaction nor Glide Slope Interference

A new full-use runway 2,500 ft. from 16L/34R will provide a secondary landing runway for all aircraft under both north and south flow VFR conditions. During south flow IFR 1/2/3 conditions, the new runway would be utilized as a secondary arrival runway while maintaining a 1.5 NM stagger. For IFR 4 conditions, the new runway would be the primary landing runway under south flow conditions only. For north flow conditions, during IFR 1/2 operations, the new runway will be utilized as the secondary arrival runway with a 1.5 NM stagger separation from aircraft landing on Runway 34R. This improvement assumes that there is a CAT III capability on Runways 16X and 16L and that all other runway ends have CAT I capability. This improvement assumes that BFI and Runway 16X arrivals operate independently. With the implementation of GPS/FMS procedures in CAT II and III conditions, no glide slope critical area protection is needed in IFR 2/3/4 conditions. It is unknown if either of these enhancements are, or will be, feasible.

Estimated property acquisition and construction cost is $409 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 17,493 hours or $28.1 million; at Future 1, 91,405 hours or $146.6 million; and, at Future 2 activity levels, 315,657 hours or $506.3 million.

## C. CAT I Capability on 16X and 16L, CAT III on 16R

A new full-use runway 2,500 feet from 16L/34R will provide a secondary landing runway for all aircraft under both north and south flow VFR conditions. Under IFR 1 conditions, the new runway would be a secondary landing runway in both north and south flow for all aircraft while maintaining a 1.5 NM stagger from aircraft landing on 16L/34R. This improvement assumes that there is CAT I capability on Runways 16L and 16X for south flow and all the Runway 34 ends. The current CAT III capability would remain on Runway 16R.

Estimated property acquisition and construction cost is $404 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 12,452 hours or $20.0 million; at Future 1, 75,259 hours or $120.7 million; and, at Future 2 activity levels, 271,106 hours or $434.9 million.

### D. Modified full-use Runway 16X/34 2,500 ft. from 16L/34R, except NO heavy aircraft on 16X/34X.

This option, which excludes utilization of the new runway by heavy aircraft, provides a secondary arrival runway under south flow VFR and IFR 1/2/3 conditions. During south flow IFR 4 operations, the new runway becomes the primary arrival runway. During north flow VFR and IFR 1/2 operations, the new runway will be utilized as the secondary arrival runway. It should be noted that simulation results do not reflect all of the implications of restricting Runway 16X/34X to non-heavy jets. There were considerable complications in controlling traffic to a limited-use runway that were not fully modeled. It is felt that these simulation results underestimate the delays associated with this type of runway.

Estimated property acquisition and construction cost is $361 million, based on a 7,500 ft. runway.

Annual delay savings at the Baseline activity level would be 14,186 hours or $22.8 million; at Future 1, 81,542 hours or $130.8 million; and, at Future 2 activity levels, 275,181 hours or $441.4 million.

## 5. Parallel Runway 16X/34X, 3,300 feet West of Runway 16L/34R.

Currently, during IMC, simultaneous instrument approaches are approved for parallel runways with minimum centerline spacing of 3,400 feet when a Precision Runway Monitor (PRM) is in use. It is anticipated that, during 1995, simulations will be conducted at the FAA Technical Center to determine if runway spacing down to 3,000 feet will be approved for simultaneous instrument approaches using a PRM. Assuming that simultaneous approaches with 3,000 feet separation is authorized, for north flow operations, the new runway would become the secondary arrival runway for aircraft in VFR and IFR 1/2, but not in IFR 3/4 because glide slope critical area protection is needed under those conditions.

### A. Without Precision Runway Monitor (PRM)

The construction of a new full-use runway 3,300 ft. from 16L/34R will provide a secondary arrival runway for all aircraft under VFR conditions with Runway 16R/34L as primary arrival runway and 16L/34R used for departures. For IFR 1/2/3 south flow operations, the additional runway should be utilized as the secondary arrival runway for all aircraft while maintaining a 1.5 NM stagger from aircraft arriving on 16R. For IFR 4 conditions the new runway would be the primary arrival runway. During IFR 1/2 north flow operations only the additional run-



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way would be utilized as the secondary arrival runway for all aircraft while maintaining a 1.5 NM stagger from aircraft arriving on 34L. Although glide slope critical area protection is needed, it is not a consideration due to the runway utilization. BFI arrivals are assumed to interact with arrivals to Runway 16X.

Estimated property acquisition and construction cost is $725 million, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 17,790 hours or $28.5 million; at Future 1, 91,871 hours or $147.4 million; and, at Future 2 activity levels, 309,331 hours or $496.2 million.

### *B. With Precision Runway Monitor (PRM)*

Construction of a new full-use runway 3,300 ft. from Runway 16L/34R with installation of the Precision Runway Monitor equipment would provide a secondary landing runway for all aircraft under south flow VFR and IFR 1/2/3 conditions. The new runway would become the primary arrival runway under IFR 4 conditions. For north flow operations, the new runway would become the secondary arrival runway for all aircraft during VFR and IFR 1/2 conditions only. This improvement assumes the operations on Runway 16X/34X and Runway 16L/34R are independent. Glide slope critical area protection is needed in IFR 2/3/4 conditions. BFI arrivals are assumed to interact with arrivals to Runway 16X.

Estimated property acquisition and construction cost is $725 million plus the cost of the PRM, based on an 8,500 ft. runway.

Annual delay savings at the Baseline activity level would be 16,322 hours or $26.2 million; at Future 1, 86,199 hours or $138.3 million; and, at Future 2 activity levels, 287,399 hours or $461.0 million.

## Marketplace Solutions

### 6. Peaking

### *A. Peak Hour Pricing*

The Port of Seattle has evaluated a range of demand management strategies. The delay savings below were obtained by using a theoretical daily demand schedule that would be caused by a peak hour minimum landing fee of $200 which would result in canceled commuter flights and rescheduling away from peak operating periods. The daily schedule used in this alternative has fewer operations than the daily schedule used in all other alternatives, therefore, the delay savings are due to a reduced number of operations as well as rescheduled flights. Annual operations used for this alternative were 335,048 (Baseline), 413,047 (Future 1), and 507, 725 (Future 2).

Annual delay savings at the Baseline activity level would be 5,840 hours or $9.4 million; at Future 1, 22,234 hours or $35.7 million; and, at Future 2 activity levels, 49,518 hours or $79.4 million.

### B. Peak Spreading

This strategy examines the effect of distributing aircraft operations evenly during the 60 minute peak intervals. This is a theoretical assumption which will be difficult, if not impossible, to consistently achieve in actual practice. It is intended to quantify the upper limit of potential improvements which could occur through cooperative scheduling of airline flight schedules.

Annual delay savings at the Baseline activity level would be 7,359 hours or $11.8 million; at Future 1, 9,867 hours or $15.8 million; and, at Future 2 activity levels, 50,746 hours or $81.4 million.

# Section 4

## Summary of Technical Studies

# Overview

The Seattle-Tacoma International Airport Capacity Design Team evaluated operations and proposed future configurations. A brief description of the computer models and methodology used can be found in Appendix B. Certain standard inputs were used to reflect the operating environment at SEA. Details can be found in the data packages produced by the FAA Technical Center during the study. The potential benefits of various improvements were determined by examining airfield capacity, airfield demand, and average aircraft delays.

Figure 11 shows current airfield weather conditions. The Airport and Airspace Simulation Model (SIMMOD) experiments were performed for a 24 hour period for each of the pertinent weather conditions. A ten year weather history for SEA was obtained from the National Weather Service. The results of these weather specific SIMMOD experiments were then used as inputs to a queuing model to calculate the delays for this ten year pattern of actual SEA weather. The results, therefore, reflect the specific weather patterns occurring at SEA.

Figure 12 breaks down the traffic demand distribution by aircraft class for each demand level while Figure 13 depicts the actual aircraft types and classes observed during the data collection effort. Figure 14 shows the approach speeds for the aircraft categories used in the study.

Figure 15 illustrates the average-day, peak-month demand levels for SEA for each of the three annual activity levels used in the study, Baseline, Future 1, and Future 2.

Figure 16 shows the hourly profile for daily demand at BFI, under IFR conditions. It also depictes the projected growth for Baseline, Future 1 and Future 2.

The fleet mix at SEA, for the quarter ending September 1994, has a weighted-average direct operating cost of $1,604 per hour or $26.73 per minute. These figures represent the costs for operating the aircraft and include such items as fuel, maintenance, and crew costs, but they do not consider lost passenger time, disruption to airline schedules, or any other intangible factors. Airline financial data was derived from FAA Form 41, Schedule P-5.2 (Item # 70989, Total Aircraft Operating Expenses). Ramp-To-Ramp block hours were derived from FAA Traffic Form 41, Schedule T-2 (Item # Z630, Revenue Aircraft Hours, Ramp-To-Ramp). The dollar per hour costs are calculated as the ratio of these two figures.

Daily operations corresponding to an average day in the peak month were used for each of the forecast periods. SIMMOD and the Runway Delay Simulation Model (RDSIM) were used to determine aircraft delays during peak periods. Delays were calculated for current and future conditions. Daily delays were annualized to measure the potential economic benefits of the proposed improvements. The annualized delays provided a basis for comparing the benefits of the proposed changes. The benefits associated with various runway use strategies were also identified. The cost of a particular improvement was measured against its annual delay savings. This comparison indicated which improvements would 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.

Annual aircraft delays were calculated based on the results of SIMMOD and RDSIM computer simulations that utilized runway use, weather, and operating cost data generated during the Capacity Team study.

# Airfield Operations

## Figure 11. Airfield Weather

| | Ceiling/Visibility | Runway Operating Configuration | % of Occurrence |
|---|---|---|---|
| VFR 1 | 5,000 feet and above/ 5 sm and above | Independent Arrivals & Departures with dual approach streams | 56.1% |
| → VFR 2 | 2,500 to 4,999 feet/ 3 to 5 sm | Single arrival stream with additional aircraft under ceiling | 19.7% |
| → IFR 1 | 800 feet to 2,499 feet/ 2 sm and above | Single Approach Stream | 17.0% |
| → IFR 2 | Not Applicable/ 1,800 RVR to 2 sm | One Approach Stream - Protect Glideslope | 5.4% |
| IFR 3 | Not Applicable/ 600 RVR to 1,799 RVR | Same as IFR 2 - No Arrivals to the North | 1.5% |
| IFR 4 | Not Applicable/ 600 RVR and below | Low visibility plan - one runway | 0.3% |

## Figure 12. Daily Traffic Demand Distribution by Aircraft Class

| Aircraft Class | Aircraft Types | Baseline (345,000) | Future 1 (425,000) | Future 2 (525,000) |
|---|---|---|---|---|
| Class 4 | Single-Engine and Small Twin-engine Propeller Aircraft | 5.9% | 5.9% | 5.9% |
| Class 3 | Large Twin-engine Propeller Aircraft | 31.3% | 31.3% | 31.3% |
| Class 2 | Non- Heavy Jets | 54.2% | 54.2% | 54.2% |
| Class 1 | Heavy Jets | 8.6% | 8.6% | 8.6% |

The Design Team decided to use the same fleet mix for all of the demand levels even though the fleet will change in the future. This was done to minimize the number of variables as demand levels changed. Additionally, the team was not able to forecast a fleet mix for the Future 2 demand level. The April 12, 1994, forecast report, prepared for the Port of Seattle, predicts an increased percentage of Class 1 or heavy aircraft and a decrease in all other classes. This change in the fleet mix would result in a smaller benefit at the Future 1 and 2 demand levels for the reduction of in-trail separation distance in IFR to 2.5 NM because separation distance from heavy aircraft cannot be reduced. This change in fleet mix would have a nominal effect on all of the other improvements.

## Figure 13. Aircraft Types Observed at Field Data Collection

| Class 1 — Heavy Jets | | | |
|---|---|---|---|
| B747 | Boeing 747 | DC10 | McDonnell-Douglas DC10 |
| B767 | Boeing 767 | MD11 | McDonnell-Douglas MD-11 |
| L101 | Lockheed L1011 | DC8 | McDonnell-Douglas DC-8 |

| Class 2 — Non-Heavy Jets | | | |
|---|---|---|---|
| A320 | Airbus 320 | DC9 | McDonnell-Douglas DC-9 |
| B727 | Boeing 727 | MD80 | McDonnell-Douglas MD-80 |
| B737 | Boeing 737 | FA28 | Fokker Fellowship |
| B757 | Boeing 757 | G2 | Gulfstream/Amer. Gulfstream II |
| HS25 | Hawker-Siddeley HS/DH/BH125 | LR35 | Gates Learjet 35 |
| WW24 | Westwind 1124 | DA50 | Dassault Falcon |
| N265 | Rockwell Int'l Sabreliner (265) | C650 | Cessna III |

| Class 3 — Large Twin-engine Propeller Aircraft | | | |
|---|---|---|---|
| DH80 | DeHavilland DASH-8 | BA31 | British Aerospace Jetstream 31 |
| BE30 | Beech Super King Air 300 | CV60 | General Dynamics Convair 600 |
| CV64 | General Dynamics Convair 640 | SHD6 | Short 360 |
| SW4 | Swearingen Merlin (IV/Metro III) | BE20 | Beech Super King Air 200 |

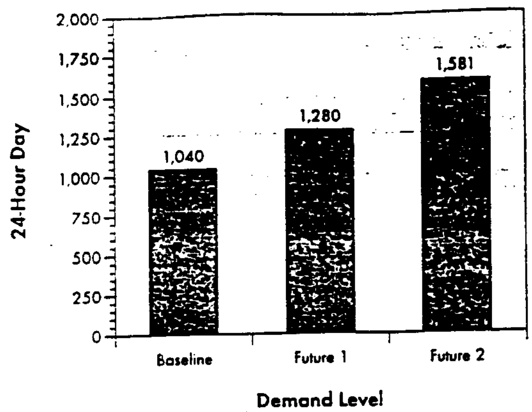
| Class 4 — Single-engine and Small Twin-engine Propeller Aircraft | | | |
|---|---|---|---|
| DC30 | McDonnell-Douglas DC-3 | AC68 | Rockwell Int'l Super Commander |
| BE90 | Beech King 90 | PA31 | Piper Navajo |
| C172 | Cessna Skyhawk 172 | C210 | Cessna 210 |
| C208 | Cessna Caravan i | C310 | Cessna 310 |
| C340 | Cessna 340 | C402 | Cessna 402 |
| C404 | Cessna Titan | | |

## Figure 14. Approach Speeds (Knots)

| Speed | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|
| Knots | 155 | 140 | 130 | 120 |

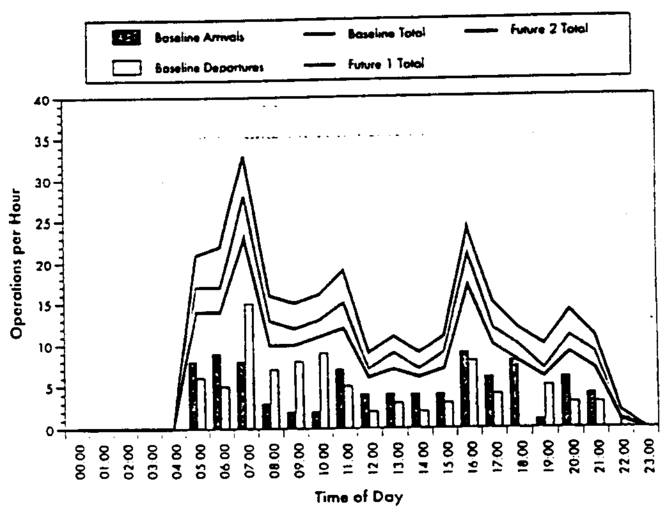
Approach speeds were raised from those previously used in capacity enhancement studies on recommendation of the Design Team, confirmed by review of the Automated Radar Terminal System (ARTS) data.

## Figure 15. SEA Annual and Daily Demand Levels




| Annual Operations | | Daily Operations | Equivalent Days |
|---|---|---|---|
| Baseline | 345,000 | 1,040 | 332 |
| Future 1 | 425,000 | 1,280 | 332 |
| Future 2 | 525,000 | 1,581 | 332 |

## Figure 16 — Demand Profile for BFI (Instrument Operations Only)



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# 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 competing for the use of the same facilities.

The major factors influencing aircraft delays are:

- Ceiling and visibility conditions
- Airfield and ATC system demand
- Airfield physical characteristics
- Air traffic control procedures
- Aircraft operational characteristics

Average delay in minutes per operation was generated by 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 4.50 minutes at the Baseline level of operations will increase to 15.60 minutes per operation by Future 1 and 40.92 minutes per operation by Future 2. Under the Baseline scenario (no improvements in capacity), the annual delay cost could increase as follows:

| | Annual Delay Costs | |
|---|---|---|
| | **Hours** | **Millions of $** |
| Baseline | 25,867 | $41.49 |
| Future 1 | 110,490 | $177.73 |
| Future 2 | 357,976 | $574.19 |

Figure 17 demonstrates the impact of delays at Seattle-Tacoma 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 Baseline scenario.

Figure 18 illustrates the average delay in minutes per aircraft operation for these alternatives. Under the Baseline alternative, if there are no improvements made in airfield capacity, the average delay per operation of 4.5 minutes at the Baseline level of activity will increase to 15.6 minutes per operation by Future 1 and 40.92 minutes per operation by Future 2.

**Figure 17. Annual Delay Costs — Capacity Enhancement Alternatives**

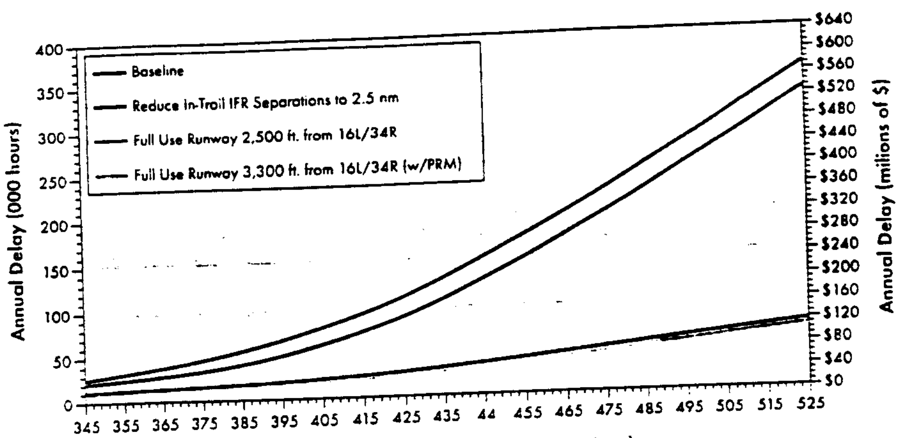
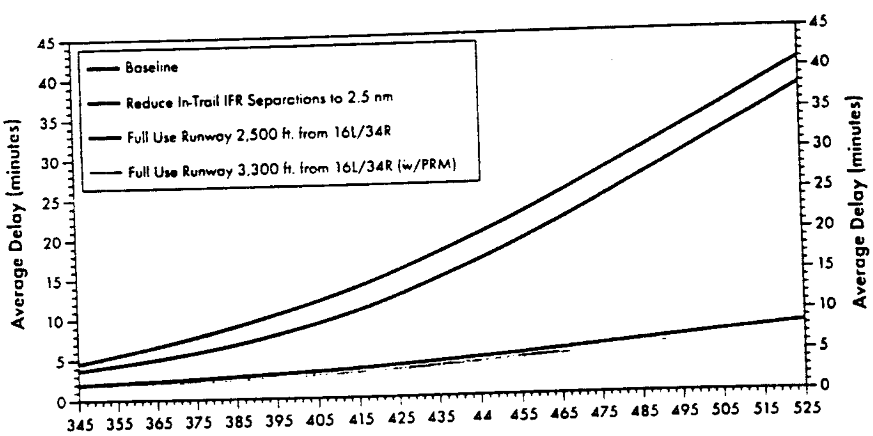



**Figure 18. Average Delay per Operation— Capacity Enhancement Alternatives**



# Appendix A

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# Appendix B

## Computer Models and Methodology

The SEA 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 model and the methodology employed follows.

# Computer Models

## Runway Delay Simulation Model (RDSIM)

RDSIM is a short version of the Airfield Delay Simulation Model (ADSIM). ADSIM is a fast-time, discrete event model that employs stochastic processes and Monte Carlo sampling techniques. It describes significant movements of aircraft on the airport and the effects of delay in the adjacent airspace. The model was validated in 1978 at Chicago O'Hare International Airport against actual flow rates and delay data.

RDSIM, on the other hand, simulates only the runways and runway exits. There are two versions of the model. The first version ignores the taxiway and gate complexes for a user-specified daily traffic demand and is used to calculate daily demand statistics. In this mode, the model replicates each experiment forty times, using Monte Carlo sampling techniques to introduce system variability, which occurs on a daily basis in actual airport operations. The results are averaged to produce output statistics. The second version also simulates the runway and runway exits only, but it creates its own demand using randomly assigned arrival and departure times. The demand created is based upon user-specified parameters. This form of the model is suitable for capacity analysis.

For this study, RDSIM was calibrated against field data collected at SEA to ensure that the model was site specific. For a given demand, the model calculated the hourly flow rate and average delay per aircraft during the full period of airport operations. Using the same aircraft mix, simulation analysts 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 process 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 operation 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 SEA 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 average to produce output statistics.



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## 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, different airfield configurations were 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.

Traffic demands were developed by the Port of Seattle and the Technical Center based on an actual day's traffic at SEA. August 30th was chosen as representative of an average day peak month. The Design Team decided to maintain the same mix and peaking characteristics for the Future 1 and Future 2 demand levels. Therefore, these two future demand levels were developed by simply increasing the Baseline demand by the appropriate percentage.

SIMMOD experiments are performed for a 24 hour period for each of the pertinent weather conditions. A ten year weather history for SEA was obtained from the National Weather Service. The results of these weather specific SIMMOD experiments were then used as inputs to a queuing model to calculate the delays for this ten year pattern of actual SEA weather. The results, therefore, reflect the specific weather patterns occurring at SEA.

The potential delay reductions for each improvement were computed by comparing the annual delay estimates with the Baseline results.

# Appendix C

## List of Abbreviations

| | |
|---|---|
| ADSIM | Airfield Delay Simulation Model |
| ARTCC | Air Route Traffic Control Center |
| ARTS | Automated Radar Terminal System |
| ASC | Office of System Capacity and Requirements, FAA |
| ASDE | Airport Surface Detection Equipment |
| ATC | Air Traffic Control |
| ATCT | Airport Traffic Control Tower |
| AVSS | Automated Vortex Sensing System |
| BFI | King County International Airport |
| CAT | Category — of instrument landing system |
| FAA | Federal Aviation Administration |
| FMS | Flight Management System |
| GA | General Aviation |
| GPS | Global Positioning System |
| IFR | Instrument Flight Rules |
| ILS | Instrument Landing System |
| IMC | Instrument Meteorological Conditions |
| LBS | Pounds |
| MLS | Microwave Landing System |
| NM | Nautical Miles |
| PRM | Precision Runway Monitor |
| RDSIM | Runway Delay Simulation Model |
| ROT | Runway Occupancy Time |
| RVR | Runway Visual Range |
| SEA | Seattle-Tacoma International Airport |
| SIMMOD | Airport and Airspace Simulation Model |
| SM | Statute Miles |
| SOIR | Simultaneous Operations on Intersecting Runways |
| TERPS | Terminal Instrument Procedures |
| TRACON | Terminal Radar Approach Control Facility |
| VFR | Visual Flight Rules |
| VHF | Very High Frequency |
| VMC | Visual Meteorological Conditions |
| VOR | VHF Omnidirectional Range — course information only |
| WVAS | Wake Vortex Avoidance System |

**Credits:**

Editorial and production support provided by JIL Information Systems, Inc.

Cover photo courtesy of Don Conrard.

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