Seattle-Tacoma International Airport
Airport Capacity Enhancement Plan
June 1991

PREPARED JOINTLY BY THE U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL AVIATION ADMINISTRATION, PORT OF SEATTLE, AND AIRLINES SERVING SEATTLE–TACOMA.

Figure 1 Seattle–Tacoma International Airport

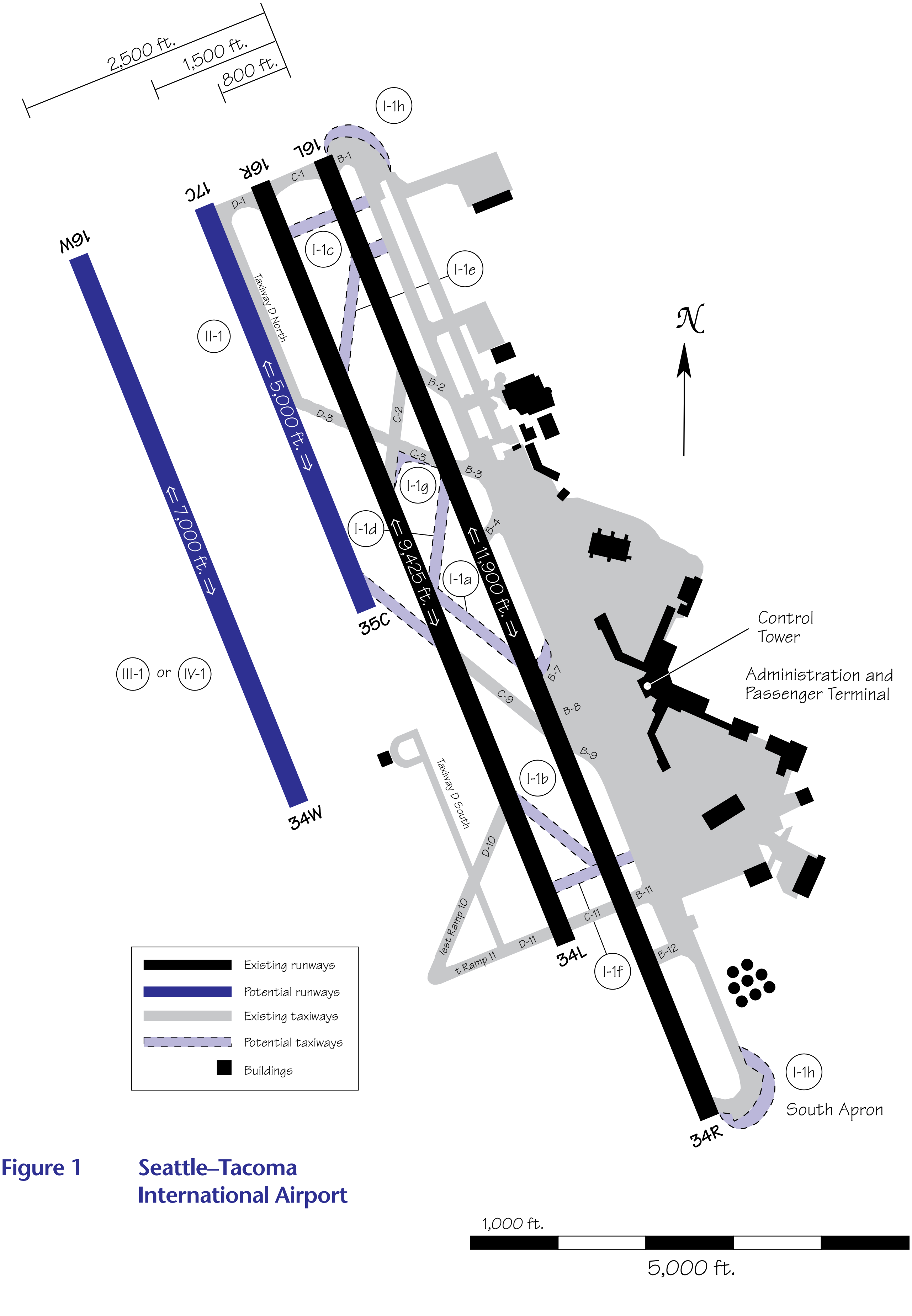

Figure 1 **Seattle–Tacoma International Airport**


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Summary

The air transportation industry faces a continuing challenge to meet the needs of future air traffic by enhancing existing airport and airspace capacity and developing new facilities. To meet this challenge, the FAA, airport operators, and aviation industry groups have initiated Airport Capacity Design Teams at major airports throughout the country.

In 1989, more than 15 million passengers flew into and out of Seattle-Tacoma International Airport (Sea-Tac). Almost 335,000 aircraft took off or landed. Aircraft experienced 48,000 hours of delay, which cost aircraft operators about $69 million (based on 1989 dollars). At a time in the future when the level of aircraft operations at Sea-Tac reaches 390,000, and with no improvements in capacity, 168,000 hours of delay are forecast. Similarly, 241,000 hours of annual flight delay, with an associated delay cost of $347 million, are forecast when Sea-Tac reaches 425,000 operations. It is important to note that these costs represent only those borne by the operators of aircraft and do not include the costs incurred by passengers.

The Seattle-Tacoma Airport Capacity Design Team considered measures that could increase capacity and reduce delays solely on a technical basis. Environmental, economic, social, or political issues were beyond the scope of this study. These issues will be addressed in current and future airport planning studies in the Puget Sound region, and the data generated during the Capacity Team study can be used in such studies.

The Capacity Team explored the implications of numerous capacity improvements. The Capacity Team's technical evaluation identified a total of 21 individual actions as

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The major recommendations in terms of timing to achieve implementation were:

	Future 2 Delay Savings	
• Construct improved exits and taxiways to achieve improved ground efficiency.	6,230 hours	$8.97 million
• Reduce in-trail spacing between like-type aircraft to 2.5 nautical miles.	42,790 hours	$61.61 million
• Realign an existing taxiway for use as a new parallel commuter runway for VFR 1 and VFR 2 capability.	66,190 hours	$95.31 million
• Construct a new parallel air carrier runway and taxiway system with precision instrumentation (PRM, ILS) to achieve all weather parallel runway capability for:		
– Dependent operations.	167,390 hours	$241.04 million
– Independent operations.	196,570 hours	$283.06 million
• Implement a wake vortex advisory system.	46,330 hours	$66.71 million

potential means of reducing delays and increasing capacity.

Each alternative was tested using sophisticated computer modeling developed by the FAA to quantify benefits. In conducting the tests, it was necessary to establish different levels of airport activity to compare the merits of each plan. These activity levels are referred to throughout this report as: *Baseline*, which equals 320,000 aircraft operations (takeoffs or landings); *Future 1*, or 390,000 operations; and, *Future 2*, or 425,000 operations. This report uses these aircraft traffic levels in its forecasts without reference to a specific date. In this way, the report should retain its validity until the highest traffic level is reached. These traffic levels correspond to activity levels developed for a planning study being conducted by the Puget Sound Air Transportation Committee.

Of all the alternatives, constructing a new parallel runway (16W/34W) capable of accommodating large air carrier transport aircraft would provide the greatest savings. This new air carrier runway represents more than three times the savings of a potential new commuter aircraft runway (17C/35C). See Figures 2 and 3.

Figure 2 Annual Delay Costs — Existing Airfield Improvements

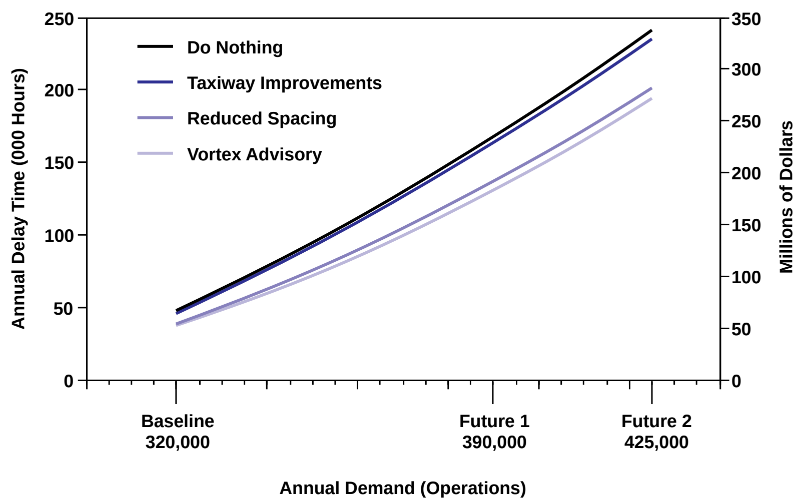

Figure 3 Annual Delay Costs — New Runway Improvements

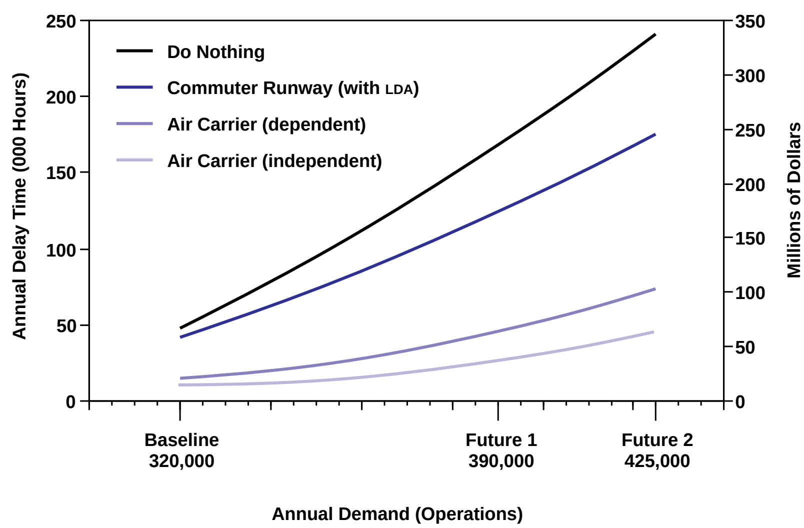

Figure 4 illustrates the capacity and delay curve under IFR conditions for the existing two–runway configuration. Under IFR conditions, delays begin to escalate rapidly as demand exceeds 55 operations per hour.

Figure 5 illustrates that, while demand exceeds 55 operations only during a few hours of the day at Baseline demand levels, 55 operations per hour is frequently exceeded at the demand levels forecast for Future 2.

Figure 4 Flow Rate vs. Average Delay, IFR 1 Conditions

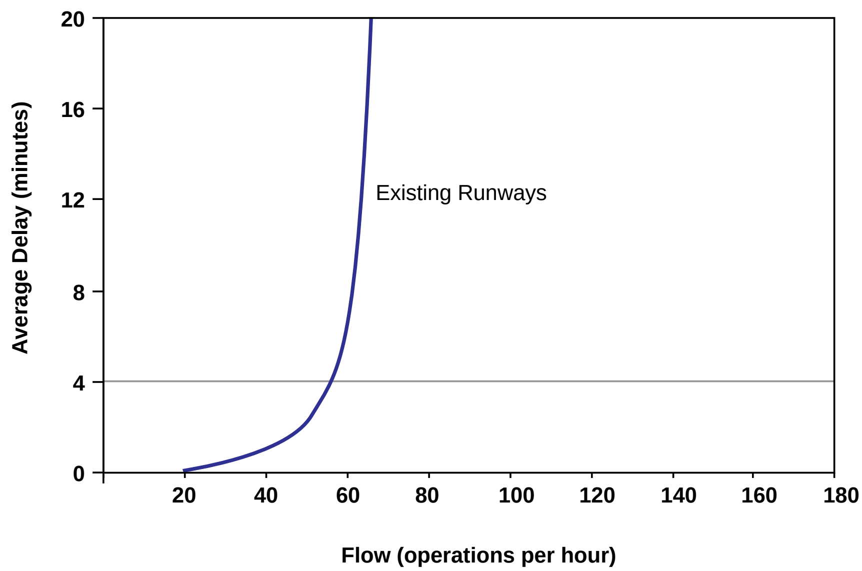

Figure 5 Profile of Daily Demand

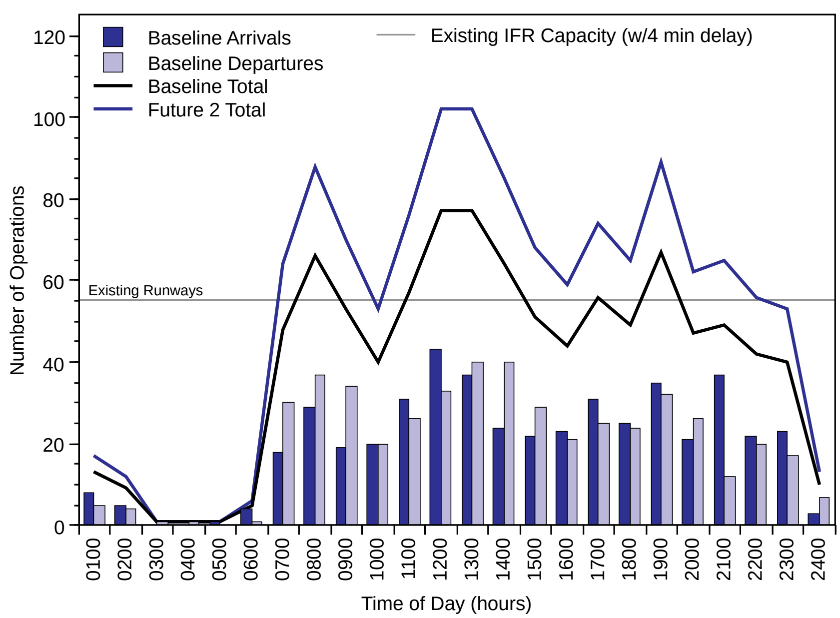

FIGURE 6 Studied Options

	Existing Configuration		
	Do Nothing Total Delay Costs		

Item No.	Improvements	Time Frame	Responsible Agency
	Improvements to Existing Airfield		
I-1	Improved Exit and Taxiway Construction	Near-term	Port of Seattle
I-2	Reduce In-trail Spacing to 2.5 Nautical Miles	Near-term	FAA
I-3	CAT I ILS on 16L (IFR 1)	Near-term	FAA
I-4	LDA Approach to Runway 16L/34R (with ILS to 16R/34L)	Near-term	FAA
I-5	Noise Abatement Effect on Departures	Near-term	FAA/Airlines
I-6	Wake Vortex Advisory System	Near-term	FAA
	New Runway Improvements		
	Commuter Runway		
II-1	Commuter Runway 17C/35C (converted Taxiway D) (VFR)	Near-term	Port of Seattle
II-2	LDA to Runways 17C/35C and ILS to 16L/34R	Near-term	FAA
II-3	Wake Vortex Advisory System	Near-term	FAA
	Dependent Runway		
III-1	Air-carrier (dependent) Runway 16W/34W	Intermediate	Port of Seattle
III-2	LDA Approaches to Runway 16W/34W	Intermediate	FAA
III-3	CAT I on 16W (IFR 1)	Intermediate	FAA
III-4	CAT II on 16W (over CAT I)	Intermediate	FAA
III-5	CAT I on 34W (IFR 1)	Intermediate	FAA
III-6	Staggered Approaches to Runways 16L/16W & 34R/34W to 2.0 NM	Intermediate	FAA
III-7	Staggered Approaches to Runways 16L/16W & 34R/34W to 1.5 NM	Intermediate	FAA
III-8	Operate Runways 16R/34L as Primary Runways vs. 16L/34R with 16W/34W	Intermediate	FAA
III-9	Wake Vortex Advisory System	Intermediate	FAA
	Independent Runway*		
IV-1	Air-carrier (independent) Runway 16W/34W	Intermediate	Port of Seattle
IV-2	CAT II on 16W (only)	Intermediate	FAA
	Demand Management		
V-1	Uniformly Distribute Scheduled Commercial Operations	Near-term	Airlines

Comments: Savings in the two-runway case are based on dual-stream arrivals in VFR 1 and single-stream in VFR 2 and IFR.
Commuter runway arrivals are dual-stream in VFR 1 and VFR 2.
Air-carrier runway arrivals are dual-stream in VFR 1, VFR 2, and IFR.
Airfield/runway operational use is considered to be 56% in VFR 1, 19% in VFR 2, 18% in IFR 1, 5% in IFR 2, and 2% in IFR 3. (See weather definitions on page 19.)
* Independent parallel operations will depend on the minimum runway separation distance approved by the FAA.

	Baseline		Future 1		Future 2	
	000s Hours	Millions of $	000s Hours	Millions of $	000s Hours	Millions of $
	47.99	69.16	167.83	241.67	241.04	347.09

Est. Construction Costs (1989 dollars)	Annual Savings (in 1989 dollars)					
	Baseline		Future 1		Future 2	
Millions of $	000s Hours	Millions of $	000s Hours	Millions of $	000s Hours	Millions of $
8.000	2.26	3.25	4.34	6.25	6.23	8.97
	11.74	16.91	34.63	49.88	42.79	61.61
0.769	2.19	3.15	5.06	7.28	8.36	12.04
	3.48	5.01	31.96	46.02	43.06	62.01
	0.62	0.90	0.93	1.34	1.58	2.28
	10.26	14.77	37.19	53.55	46.33	66.71
10.000	6.03	8.69	43.65	62.84	66.19	95.31
1.467	5.59	8.06	40.16	57.81	60.72	87.43
	0.36	0.51	0.79	1.14	1.11	1.60
250.000	32.86	47.30	121.81	175.41	167.39	241.04
1.467	5.51	7.93	40.41	58.19	61.22	88.16
1.271	11.28	16.24	42.88	61.74	58.57	84.34
0.706	3.72	5.35	12.54	18.06	14.11	20.32
1.271	1.94	2.80	7.96	11.47	10.77	15.50
	11.29	16.25	47.10	67.83	61.21	88.15
	12.27	17.67	53.45	76.96	69.44	99.99
	-(6.91)	-(9.94)	-(43.30)	-(62.36)	-(54.12)	-(77.95)
	1.02	1.46	5.98	8.61	11.75	16.91
250.000	37.49	53.98	141.93	204.39	196.57	283.06
0.706	3.82	5.49	15.58	22.43	18.77	27.03
	4.87	7.02	10.97	15.77	10.99	15.83

Note: Savings are not necessarily additive.

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SEA-TAC
INTERNATIONAL
AIRPORT

Section 1 — Introduction

Background

Seattle-Tacoma International Airport (Sea-Tac) is one of the busiest airports in the United States. In 1989, the airport processed 15.2 million inbound and outbound passengers, ranking it among the top 25 U.S. airports. A total of 334,924 aircraft operations (takeoff and landings) were conducted at the airport by air carriers, general aviation, and the military.

Aircraft delays increase dramatically when the number of aircraft needing to land and takeoff (demand) from Sea-Tac approaches the capacity of the airport. Additionally, aircraft delays increase when weather conditions deteriorate. Reduced visibility greatly diminishes the traffic handling ability (capacity) at Sea-Tac because the separation between the two parallel runways is insufficient to permit the use of both runways simultaneously for instrument approaches.

The term capacity refers to the processing capability of the airport, or its components, over a period of time. In airport planning and design, capacity has been defined in two ways. The first, practical capacity, is the number of aircraft operations that can be accommodated in a given period that corresponds to a level of delay deemed acceptable. The second definition refers to ultimate capacity, or the maximum number of aircraft that can be accommodated in a given period, assuming a constant demand, or queue, for service. The latter definition, commonly referred to as throughput, is not concerned with delay. The Capacity Team used the former, practical capacity, as its capacity measure.

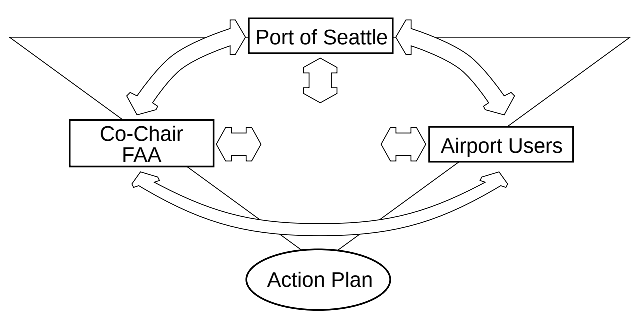
Aircraft delay is the difference between constrained and unconstrained operating time. Weather, the physical characteristics of the airfield, air traffic control procedures, and other aircraft competing for the use of the same facilities all contribute to aircraft delay.

The Seattle-Tacoma Airport Capacity Design Team was formed to evaluate means of increasing capacity and efficiency at Sea-Tac and reducing costly aircraft delays. The Capacity Team was composed of representatives from the Port of Seattle, FAA, airlines, Puget Sound Council of Governments, and others, who studied several proposals for increasing capacity at the airport. The basic organization of the Capacity Team is shown in Figure 7, and individual participants are listed in Appendix B. The different proposals studied are the main subject of this report.

Objectives

The prime objective of the Capacity Team was to identify and assess various actions at Sea-Tac which would increase airport capacity, improve efficiency of operations, and reduce aircraft delays. The purpose of the process was to ascertain the technical merits of each alternative action and its impact on capacity.

Figure 7 Capacity Team Organization



In addition to identifying and evaluating capacity enhancement measures for the airport, the Capacity Team:

- Determined current airport capacity and the causes of aircraft delays associated with the airspace, airfield, and passenger terminal.
- Evaluated capacity and delay benefits of alternative ATC procedures and navigational, airfield, and airport user improvements.
- Examined the relationship between air traffic demand and delay so that the delay associated with different traffic levels could be identified.

Scope

The Capacity Team limited its analyses to air traffic within the terminal area and the airfield. Terminal area is a general term that describes the airspace where air traffic control services are provided for aircraft arriving or departing an airport (approach control) and for aircraft operating on or in the immediate vicinity of an airport (airport traffic control).

The Capacity Team considered measures that could increase capacity and reduce delays solely on a technical basis. Environmental, economic, social, or political issues were beyond the scope of this study. These issues will be addressed in current and future airport planning studies in the Puget Sound region, and the data generated during the Capacity Team study can be used in such studies.

Methodology

The Capacity Team followed a structured and logical sequence of analytical tasks while conducting the study. Periodic coordination meetings were held to review interim results and determine the information needed for the next steps. Experts from the FAA Technical Center performed computer airport simulations using two separate models, the Airfield Delay Simulation Model (ADSIM) and the Runway Delay Simulation Model (RDSIM).

ADSIM simulates the movement of aircraft on the airport and the effects of delay in the adjacent airspace. RDSIM simulates aircraft traffic on the runways and does not consider the taxiway system or movements into or out of the passenger terminal. Appendix A contains more details on the computer simulations used.

The simulation models tested the various capacity enhancement alternatives by estimat-

ing annual delays. These simulations were conducted for present and future scenarios that were based upon different assumptions and three different demand levels. A *Baseline* benchmark of 320,000 aircraft operations reflects 1989 airport activity, the base year for the study. Traffic levels of 390,000 (named *Future 1*) and 425,000 (*Future 2*) operations were also selected as benchmarks to analyze the effects of future levels of demand on the alternatives. These future activity levels were purposely not associated with a time frame, to allow conclusions to be tied to activity levels rather than specific dates.

The Capacity Team also tested the alternatives under different weather conditions, since capacity varies during different visibility conditions. The categories of weather conditions used were:

- VFR 1 – Ceiling (the height of clouds, smog, etc. above ground) is at least 5,000 feet, and visibility at least 5 miles. These conditions prevail about 56% of the time on an annual basis.
- VFR 2 – Ceiling is between 2,500 and 4,999 feet, and visibility more than 3 miles. These weather conditions occur about 19% of the time.
- IFR 1 – Ceiling is between 650 and 2,499 feet, and visibility more than 1,800 feet Runway Visual Range (RVR). IFR 1 conditions occur about 18% of the time.
- IFR 2 – Ceiling is below 650 feet, and visibility is more than 1,200 feet RVR. IFR 2 conditions occur about 5% of the time.
- IFR 3 – Ceiling is zero, visibility is less than 1,200 feet RVR. IFR 3 conditions occur about 2% of the time.

Section 2 — Existing Conditions

Present Airport

Seattle-Tacoma International Airport (Sea-Tac) presently consists of two parallel north-south runways. They are designated 16L/34R and 16R/34L. Runway 16L/34R is 11,900 feet long, and Runway 16R/34L is 9,425 feet long. Both are 150 feet wide. The centerlines of the runways are separated by 800 feet. Runways 16R, 34R, and 34L are equipped with Instrument Landing Systems (ILS) that allow for aircraft landings during periods of inclement weather and reduced visibility. The Runway 34R and 34L ILS are classified as Category I (CAT I) systems which allow aircraft to descend to a height of 200 feet above ground before visual contact is made with the runway. The ILS on Runway 16R is a CAT II/III system which permits descents to a height of 100 feet above ground before visual contact with the runway must be established. Since the CAT II ILS permits operations during more periods of reduced visibility, overall airport capacity is increased.

The 800-foot separation between the parallel runways is important in the Capacity Team analysis. In good weather (VFR 1), both runways can be used simultaneously for takeoffs and landings. In bad weather (VFR 2 and IFR), however, FAA standards require at least a 2,500 foot separation between parallel runways in order to use both runways simultaneously (dependent, staggered approaches). Thus, during periods of marginal or bad weather, Sea-Tac is limited to the use of one runway for landing, which greatly reduces its capacity.

The taxiway system also affects an airport's ability to handle traffic. Capacity benefits can be obtained if aircraft can exit the runway quicker and taxi to and from the terminal efficiently. At Sea-Tac, the existing taxiway system includes a number of parallel and exit taxiways which facilitate the movement of aircraft while on the ground.

FIGURE 1 shows the existing layout of runways, taxiways, and major buildings at Sea-Tac, as well as potential capacity improvements.

Existing Operations

Air traffic is controlled at airports to provide safe and efficient access for aircraft operators and also to relieve, whenever possible, intrusive aircraft noise on airport neighbors. With more than one runway, the FAA air traffic controllers at Sea-Tac are afforded some flexibility, and thus certain runways have been assigned specific functions.

Aircraft operations are conducted into the prevailing wind. At Sea-Tac this results in a south flow of aircraft traffic about 71% of the time, and a north flow 29%. When winds are blowing from the south, the airport is in a south flow, and Runway 16R is the primary arrival runway, and Runway 16L is mainly used for takeoffs. In a north flow, Runway 34R is used for arrivals, and 34L for departures. With the recent installation of the 34L ILS, this may change, however.

The flow of traffic around Sea-Tac is based upon a four-cornerpost concept of air traffic control. Simply described, there are four points, or corners, of the surrounding airspace over which all arriving aircraft will pass and be sequenced for landing at the airport. All computer simulations and capacity and delay analyses were based on the cornerpost system and assumed two streams of traffic for arrivals in both the north and south traffic flows in acceptable weather conditions.

Existing Capacity

There are many factors that affect airport capacity, but, in general terms, capacity is dependent upon the airfield configuration, the airspace environment and the types of aircraft operating in it, the navigational aids serving an airport, and the air traffic control facilities. The most significant factors are the spacing between successive aircraft on final approach and the number of and distance separating runways. The closer the spacing between aircraft, the greater the number of operations. Spacing is dependent upon air traffic rules, which in turn are dependent upon weather conditions and the mix of aircraft types operating at the airport. For parallel runways, the greater the distance separating them, the greater their independence and thus the greater their capacity.

Figure 8 presents the different capacities for Sea-Tac for three weather conditions — VFR 1, VFR 2, and IFR. Capacities are expressed as the number of arrival paths and total operations that can be handled in an hour.

In bad weather (IFR), capacity is reduced from a total of 98 to a total of 55 operations.

Figure 8 — Existing Hourly Capacities of Sea-Tac

Weather Condition	Nº Arrival Paths	Total Operations[1]
VFR 1	2	98
VFR 2	1	65
IFR	1	55

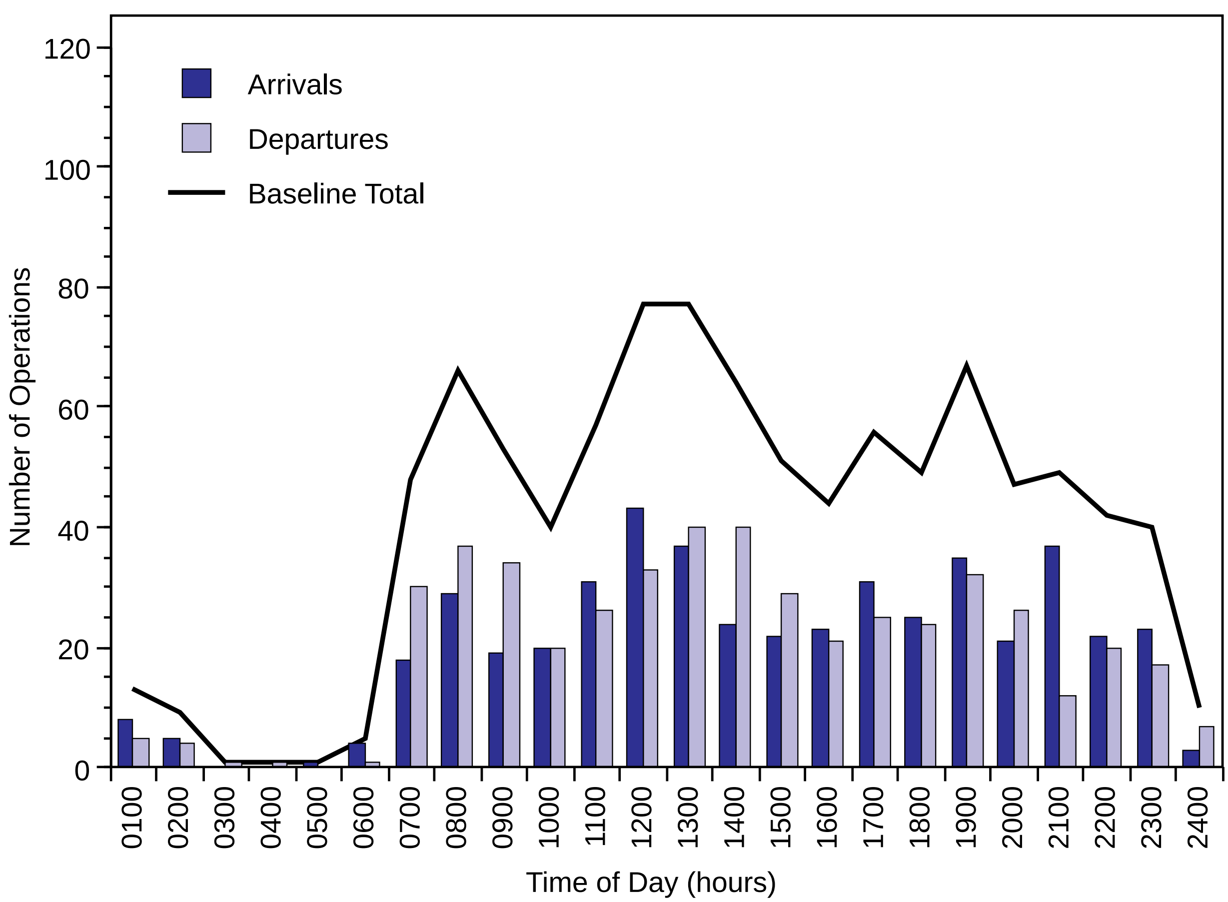
1. Assumes 4 minute arrival delay and 50/50 split of arrivals and departures.

Air Traffic Demand

Traffic at major airports like Sea-Tac occurs around the clock, with distinct peak and off-peak periods. The Baseline demand at Sea-Tac is 320,000 operations (takeoffs and landings). During an average day of the peak traffic month, this translates into 966 daily operations, with a peak of 77 operations per hour.

Figure 9 presents the hourly distribution of aircraft operations throughout an average day, based on the Baseline demand of 320,000 operations per year. By comparing the daily demand peaks in Figure 9 with the hourly capacities in Figure 8, it is possible to anticipate the times during the day when flight levels exceed the existing hourly capacity of 55 operations in IFR weather conditions, provided there are no improvements in airfield capacity.

Figure 9 — Baseline Demand for Sea-Tac (1989 data)

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Section 3 — Capacity Enhancement Alternatives

Introduction

The Sea-Tac Airport Capacity Design Team derived and tested a series of alternative measures that, if implemented, would increase capacity at Sea-Tac. The goal was to identify the option(s) that best meet the overall objectives of the project, given that there could be a number of possible solutions to the problem.

The Capacity Team considered a wide range of capacity enhancement measures. These measures can be categorized as follows:

- Improvements to Existing Airfield
- Commuter Runway
- Dependent Air Carrier Runway
- Independent Air Carrier Runway
- Demand Management

The simulation models computed the reduction in annual delay (in hours) provided by each alternative. These reductions were then translated into a monetary figure by applying a factor of $1,440 per hour, which represents an average hourly aircraft operating cost (in 1989 dollars) for the mix of aircraft using Sea-Tac. This equated to the costs for operating the aircraft and included such items as fuel, maintenance, and crew costs.

Improvements to Existing Airfield

This group includes options such as the construction of taxiway and other airfield improvements, installation of new navigational aids, and implementation of new operating procedures for the existing airfield configuration.

I-1. Improved Exit and Taxiway Construction

The total benefits provided by the following individual improvements would be a reduction in delay by 6,230 hours per year under Future 2 demand levels, which translates into an annual dollar value of $8.97 million.

a. Construct Midpoint Improved Exit and Taxiway on Runway 16R.

This project would add an improved, or smaller-angle, exit at a midfield location along Runway 16R, the primary arrival runway in south traffic flows. It would provide an earlier exit from the runway and reduce runway occupancy time.

b. Construct Improved Exit and Associated Exit Taxiway for Runway 16L.

This would add an improved exit midway between the existing Taxiway C-9 and the end of Runway 16R that would connect to a new right-angle exit for Runway 34L.

c. Construct Additional Entrance Taxiways for Runways 16R and 16L.

The construction of taxiways parallel to the existing entrance taxiways for Runway 16 thresholds to provide a dual-entrance capability would improve efficiency in queuing departing aircraft.

d. Construct Midpoint Improved Exit Taxiway on Runway 34L.

This project would permit an earlier exit from the runway for some aircraft that presently exit on Taxiway C-2.

e. Construct Improved Exit and Crossover Taxiway Near the End of Runway 34L.

This would provide a new shallow-angle turnoff near the end of Runway 34L and a right-angle exit with appropriate separation from the present entrance taxiway to 34L. This second entrance taxiway would provide greater flexibility in sequencing departures.

f. Construct Crossover Taxiway Near the End of Runway 34R.

This project would provide a dual-entrance capability for departures to the north on Runway 34R. It would reduce potential departure bottlenecks by permitting the flow of traffic onto the runway at two points.

g. Improve Intersection of Taxiways C-2 and C-3 by Widening the Pavement Fillet.

During the study of airport operations, it was determined that almost all aircraft arriving on Runway 34L that exit on Taxiway C-2 turn onto Taxiway C-3 to reduce the taxi distance to the terminal building. Widening the pavement fillet at the intersection of the two taxiways would provide more maneuvering room and permit higher taxi speeds. Planned for construction in 1991.

h. Construct Wider Runup Pads at the End of Runways 34R and 16L.

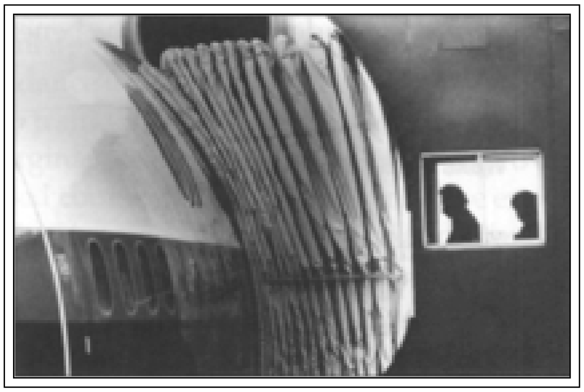
Runup pads would function as holding bays for aircraft awaiting final ATC clearance and permit those airplanes already cleared to taxi onto the runway. This would increase the flexibility of departure operations and reduce departure delays. Planned for construction in 1991.

I-2. Reduce In-trail Spacing to 2.5 NM for Aircraft of the Same Class.

Item I-1 would provide sufficient exit taxiways to reduce average runway occupancy time to 50 seconds. Therefore, reducing longitudinal spacing on final approach, from the present 3.0 NM to 2.5 NM for aircraft of similar class and less than 300,000 pounds, could be implemented. This would increase arrival rates and decrease arrival delays. With two runways, arrival delays would further decrease. However, departure delays could increase if longer departure queues block critical taxiways. Annual delays would be reduced by 42,790 hours under Future 2 demand. This translates into an annual savings of $61.6 million.

I-3. Install Category I ILS on Runway 16L.

This would improve airport reliability by providing an additional ILS runway and enhance airport flexibility by allowing the alternate use of Runway 16L as the primary arrival runway. However, with the present parallel runway configuration (only 800 foot separation), the benefits would be nominal. The primary benefit of this option would be in a three-runway scenario providing dual-stream, parallel IFR approaches on the outboard runways. However, even under a two-runway scenario in IFR 1 with Future 2 demand, the reduction in annual delay would be 8,360 hours, or $12.0 million.



I-4. LDA approach to Runway 16L/34R and ILS to 16R/34L.

Operations on Runway 16L/34R would be feasible in VFR 2 weather conditions if an LDA were available on 16L/34R approaches, in addition to the ILS system already available on Runway 16R/34L. An LDA is a NAVAID used for an instrument approach that provides directional guidance to the runway. If acceptable to aircraft crews, it would provide for two-stream operations for both north and south flows, and would result in delay reductions of 43,060 hours per year, for an annual savings of $62.0 million at Future 2 traffic levels. The minimums for the LDA would be relatively high — 1,400 to 2,500 foot ceiling and three miles visibility.

I-5. Effect of Noise Abatement Procedures on Departures.

Procedures involve fanning, or spreading, departures over a greater area in order to avoid concentration of noise over one area. The ability to fan all departures would improve departure capacity since in-trail spacing between successive departures could be reduced. Fanning departures would reduce annual delay costs by about $2.3 million in a Future 2 scenario.

I-6. Wake Vortex Advisory System for Close Spacing.

Since the turbulence created by heavy aircraft at landing and take-off speeds (wake vortices) can be hazardous to trailing aircraft, the FAA has established minimum separations to eliminate the hazards of wake vortices. Installation of a wake vortex advisory system allows for reduced separation, provided the safety of operations is not compromised. Implementation of this system would reduce delays by 46,330 hours and save $66.7 million in aircraft operating costs annually for the existing airfield configuration at Future 2 traffic volumes. This equipment is under development and is expected to be available by Future 2.

New Runway Improvements

Commuter Runway

The term commuter refers to regional airlines that usually operate smaller, turbo-prop aircraft seating from 15 to 40 passengers. Because of their size and performance characteristics, commuter aircraft can operate on shorter runways. Commuter aircraft accounted for about 42 percent of the takeoffs and landings at Sea-Tac in 1989.

II-1. Realign Taxiway D as 5,000' Commuter Runway 17C/35C.

This project would convert the existing Taxiway D into a Runway 17C/35C for commuter aircraft. It would be separated from Runway 16R/34L by 700 feet and Runway 16L/34R by 1,500 feet, which would permit dual arrival streams in VFR 1 and VFR 2 . Runway 17C/35C was assumed to serve primarily as a commuter arrival runway equipped with an LDA, with most commuter departures on Runway 16R. Large, air carrier aircraft would operate on Runway 16L/34R which is the longest runway. Because of the runway separations, benefits would be limited to VFR since simultaneous IFR operations could not be conducted because of wake vortex hazards even with the projected reduction by the FAA in separation standards. The annual reduction in delay would be 6,030 hours for Baseline demand. The reductions would grow to nearly 66,190 hours a year, or $95.3 million, for Future 2 demand.

II-2. LDA to Runway 17C/35c and ILS to 16L/34R.

Operations on the commuter runway would be feasible in VFR 2 weather conditions if an LDA were available on 17C/35C for approaches, in addition to the ILS system already available on runway 16L/34R. This would provide for a two-stream operation and would result in delay reductions of 60,720 hours per year, or $87.4 million with Future 2 demand. The benefits estimated in Alternative II-1 assumed the commuter runway would be LDA equipped, and thus the benefits shown here are included as part of the benefits shown in II-1.

II-3 Wake Vortex Advisory System.

Implementation of a wake vortex advisory system would result in additional user benefits of $1.6 million at Future 2 demand levels.

Dependent Runway

Alternatives in this category relate to the construction of a third parallel runway, 16W/34W, 7,000 feet long and capable of accommodating large commercial airliners. The new runway would be separated by 2,500 feet from Runway 16L/34R. This would eliminate the need for wake vortex turbulence restrictions and result in two streams during both VFR and IFR.

III-1. Construct Dependent 7,000' Runway 16W/34W.

Construction of a new parallel runway 7,000 feet long, capable of handling commercial airliners, would allow dual arrival streams during IFR, increasing the arrival acceptance rate. It would allow use of one of three runways as a departure runway, also improving the departure capacity. During IFR, the hourly capacity would increase from 50 to 64 operations. Annual savings in delay costs would reach $241 million from a reduction in delay of 167,390 hours at Future 2 traffic levels. Items III-2 through III-5 were included in calculating the above savings.

III-2. LDA Approach to Runway 16W/34W and ILS to 16L/34R.

These runway improvements would also include an LDA to Runway 16W/34W and an ILS to 16L/34R to create two streams of air traffic. An LDA is a NAVAID used for an instrument approach that provides directional guidance to the runway. It would provide for two traffic streams during south flows in marginal weather. Aircraft would be provided course guidance to a point close enough to the airport so the pilot could land visually. This would enhance capacity and also reduce air traffic controller workload.

This alternative would allow for dual-stream operations during VFR 2 weather conditions to both 16w/34w and 16L/34R. It would provide an annual benefit of $88.2 million at Future 2 demand levels.

III-3 Install Category I ILS on Runway 16W.

A Category I (CAT I) ILS permits descents to a height of 200 feet above ground before a pilot must execute a missed approach if the runway is not in sight. Installation of a CAT I ILS on the new Runway 16W would reduce annual delays by 58,570 hours, or $84.3 million, at Future 2 demand levels.

III-4. Install Category II ILS on Runway 16W.

A Category II (CAT II) ILS permits descents to a height of 100 feet above ground before a pilot must execute a missed approach. Installation of a CAT II ILS on the new Runway 16W would reduce annual delays by an additional 14,110 hours over CAT I capability, for an additional savings of $20.3 million in aircraft operating costs at Future 2 demand levels.

III-5 Install Category I ILS on Runway 34W.

Installation of a CAT I ILS on Runway 34W would reduce annual delays by 10,770 hours, or $15.5 million in annual aircraft operating costs at Future 2 demand levels.

III-6. Staggered Approaches During IFR to Runways 16L/16W and 34R/34W with 2.0 NM Stagger.

Currently, the standard that allows for dual streams with runways separated by 2,500 to 4,300 feet places a stagger of 2.0 nautical miles between adjacent streams. The benefit over a single stream at Future 2 is $88.2 million.

III-7. Staggered Approaches During IFR to Runways 16L/16W and 34R/34W with 1.5 NM Stagger.

Reducing the stagger during final approaches would reduce the in-trail spacing between successive arrivals. Improved arrival acceptance rates lower arrival demand that could extend into peak departure periods. Thus, both arrival and departure capacities are enhanced. For Future 2 demand levels, the annual reduction in delay would be 69,440 hours or $100 million. This is a net benefit of $11.8 million over the 2.0 NM stagger.

III-8. Operate Runways 16R and 34L as Primary Arrival Runways with Runway 16W/34W (Rather Than 16L and 34R with 16W/34W).

This option would result in more flexibility in air traffic by alternating arrivals and departures on a runway according to operational needs (e.g., noise constraints, etc.). But with the three-runway configuration, it would be preferable to operate the outboard runways

(16L and 16W, and 34R and 34W) for arrivals. Using 16R and 34L for arrivals would result in a disbenefit of $78 million at Future 2 demand levels.

III-9 Wake Vortex Advisory System

Implementation of a wake vortex advisory system would yield an additional $16.9 million at Future 2 demand levels.

Independent Runway

The greatest capacity enhancement benefit at Sea-Tac would be the addition of a third parallel runway which permits independent parallel approaches in all weather conditions.

Options in this group are all keyed to the development of a third parallel runway, capable of handling all air carrier aircraft and operating independently of Runway 16L/34R. The exact separation of a new runway from Runway 16L/34R to permit closely spaced independent IFR arrivals on both runways is under evaluation by the FAA. Currently, this requires 4,300 feet between parallel runway centerlines.

A development 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 and a new air traffic controller display system.

IV-1. Construct Independent 7,000' Runway.

A third air carrier runway with sufficient separation to provide totally independent, simultaneous, instrument (ILS) approaches would maximize the benefits of dual arrival streams. Improved arrival capacity would provide for efficient management of arrival demand and avoid the overlap of delayed arrivals into peak departure periods. Sea-Tac's IFR capacity would increase from 55 to 86 operations per hour, and the estimated savings in delay costs would be $283.1 million a year for the Future 2 demand level. The annual reduction in delay would be 196,570 hours.

IV-2. Install Category II ILS on Runway 16W.

This would provide a CAT II ILS on Runway 16W to improve operations at the airport in bad weather. The annual reduction in delay would be 18,770 hours, or $27.0 million in annual aircraft operating costs.

Demand Management

V-1. Uniformly Distribute Scheduled Commercial Operations within the Hour.

A more even distribution of airline flights during peak periods would promote an orderly flow of traffic near the terminal and on the taxiway system. With the existing airfield and current ATC procedures, annual delay savings would be $15.8 million at Future 2 demand levels.

However, Sea-Tac is a connecting hub for passengers, and a uniform distribution of traffic may not be consistent with such an operation. Hubbing creates efficiencies that can't be measured in a delay study. The hub and spoke system provides frequent service between city pairs that could not support direct service.

Section 4 — Summary of Technical Studies

Overview

The Sea-Tac Capacity Team evaluated the operation of the existing airfield and the potential benefits of the capacity enhancement alternatives in terms of airfield capacity, airport demand, and average aircraft delays.

Sophisticated computer models were applied to determine aircraft delays during peak periods for current and future traffic levels. The models used were the Runway Delay Simulation Model (RDSIM) and the Airfield Delay Simulation Model (ADSIM). More details on these models can be found in Appendix A of this report.

"Daily Operations" for this study corresponded to an average day in the peak traffic month for each of the future traffic levels. Three traffic levels were defined for the study: 320,000 annual aircraft operations, representative of 1989 activity and referred to as the *Baseline* benchmark; 390,000 operations to reflect future activity in the near term and called *Future 1*; and 425,000 annual operations to reflect an intermediate-term traffic level and identified as *Future 2*. The future activity levels were purposely not associated with a time frame to allow conclusions to be geared to activity levels rather than specific dates.

Daily delays were annualized to determine the potential economic benefits of the proposed improvements. Annualization is based on the frequency of weather occurrences, percent of the time each runway is utilized, and 331 equivalent days. Figure 10 illustrates the runway utilizations and airport weather occurrences used in the analysis. The annualized delays provide a means for comparing the benefits of the different alternatives.

To quantify delays in monetary values, an average direct operating cost of $1,440 per hour (in 1989 dollars) for the mix of aircraft operating at Sea-Tac was applied to the computed delays. This provided the delay costs incurred by the aircraft operators. The costs of delays associated with lost passenger time, disruption of airline service, or other intangible factors were not considered since the derivation of these costs can be highly subjective.

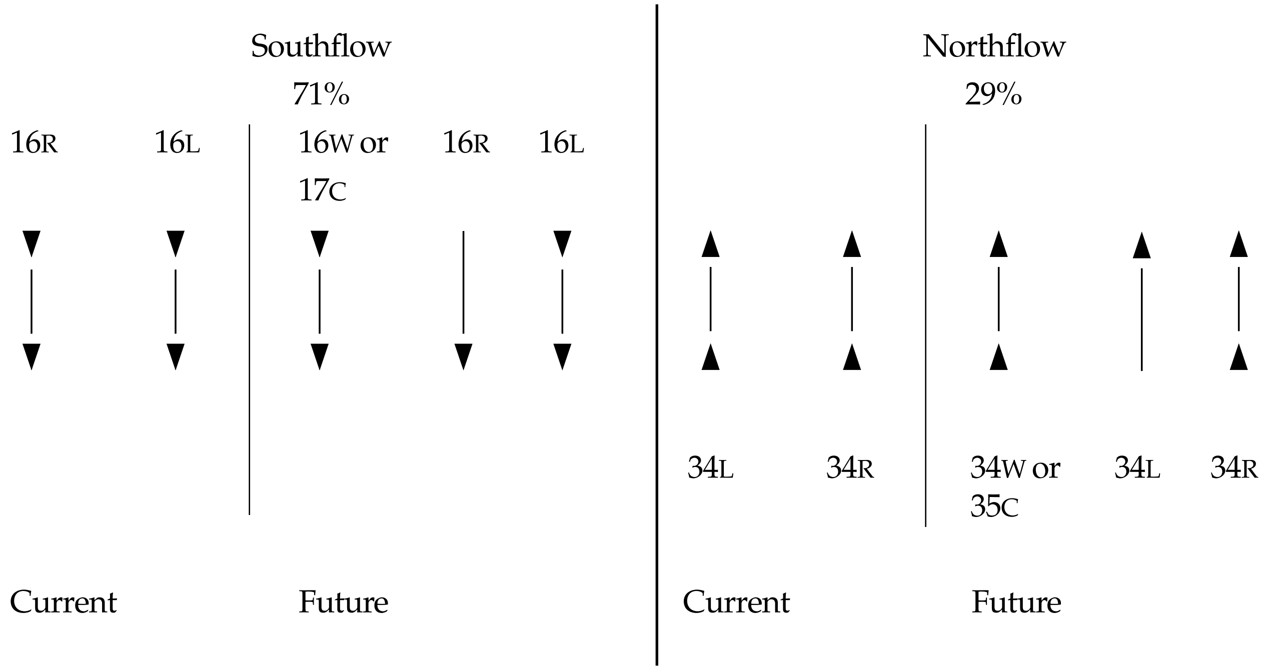
A comparison of the costs of a particular improvement and the delay reductions associated with that improvement would indicate the effectiveness of each alternative.

For an anticipated increase in demand, an optimum combination of improvements can be implemented so that airfield capacity is increased while aircraft delays are kept within acceptable limits.

Figure 10
Airfield Weather and Runway Utilization
Seattle-Tacoma International Airport

Annual Percent Used

Annual runway/configuration operational use is based on weather conditions at Sea-Tac.



Ceiling/Visibility *		Operational Use %		
		Southflow	Northflow	Total
VFR 1	5000 feet/5 miles or above	34	22	56
VFR 2	Between 4999 and 2500 feet/more than 3 miles	15	4	19
IFR 1	Between 650 and 2499 feet/more than 1800 ft. RVR	15	3	18
IFR 2	Below 650 feet/more than 1200 ft. RVR	5	0	5
IFR 3	Zero/less than 1200 ft. RVR	2	0	2
	Total	71	29	100

VFR — Visual Flight Rules in VMC (Visual Meteorological Conditions)
IFR — Instrument Flight Rules in IMC (Instrument Meteorological Conditions)
RVR — Runway Visual Range
* — Based upon 10 years of Sea-Tac weather data

Airfield Capacity

The Sea-Tac Capacity Team defined capacity as the maximum number of aircraft operations (landings and takeoffs) that can take place in a given amount of time. The following conditions were considered:

- Weather (ceiling and visibility conditions)
- Acceptable level of delay
- Airspace constraints
- Runway layout and use
- Aircraft mix
- Percent arrival demand

Capacity was calculated for both an average four-minute arrival delay and for maximum throughput (see Figure 11). The maximum throughput capacities were based on unlimited arrival and departure queues and produced very large delays. Figure 11 illustrates the severe penalty associated with the maximum throughput. The average arrival delay per aircraft is plotted against the arrival capacity for one of the VFR runway configurations. Capacity with a delay of four minutes per aircraft is 61 arrivals per hour. A maximum throughput of 78 arrivals per hour represents a delay of 55 minutes per aircraft.

As the traffic flow, or the number of aircraft operations per hour, increases, delay increases moderately until it reaches about four minutes per aircraft. Once the amount of delay reaches this point, any increase in the number of take-offs or landings increases the amount of delay significantly. Therefore, even when the airport is operating at an acceptable level of delay, a small increase in aircraft operations can cause a significant increase in the average delay per aircraft.

Capacity in hourly operations and average delay in minutes per operation were generated by the Runway Delay Simulation Model (RDSIM). A description of this model is included in Appendix B.

Figure 11 — Airport Delay Curve, Current Runway Configuration

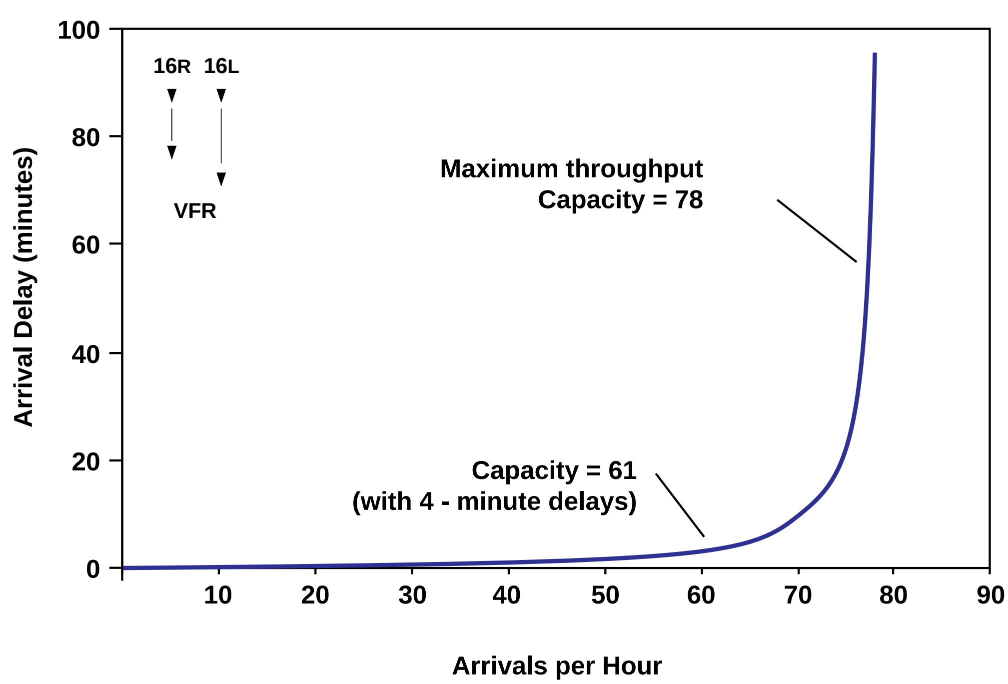
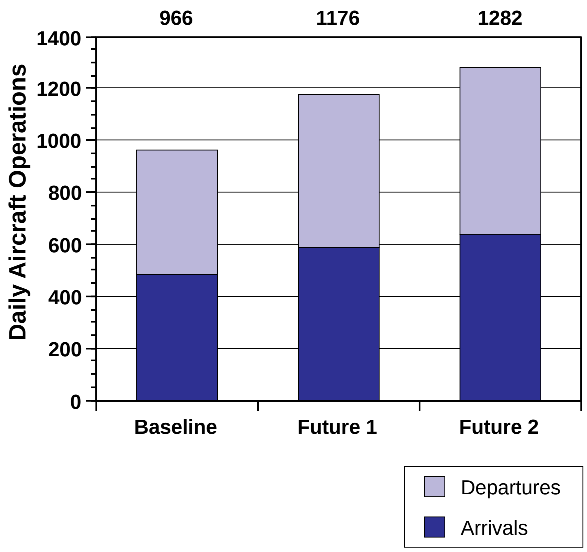


Figure 12
Airfield Demand
Seattle-Tacoma International Airport



Aircraft Operations

Annual	24-hour Day (average day, peak month)	Peak Hour
Baseline, 320,000 (1989)	966	77
Future 1, 390,000	1176	94
Future 2, 425,000	1282	102

Figure 12 (above) illustrates the average-day, peak-month demand levels for Sea-Tac for each of the three annual activity levels used in the study, Baseline, Future 1, and Future 2.

The airport capacity analysis curves shown in Figure 13, Flow versus Delay, compare the capacity and delay characteristics of the existing two-runway configuration and of the proposed dependent and independent air carrier runway alternatives under IFR 1 weather conditions. These curves assume a balanced flow with equal priority for arrivals and departures and a traffic demand of 50 percent arrivals and 50 percent departures randomly distributed within the hour. Other patterns of demand can alter the capacity/delay relationship.

Since capacity is significantly less during IFR conditions, and delay disproportionately greater, airfield capacity and delay characteristics under IFR provide a much more useful demonstration of the relationship between capacity and delay.

Figure 14 (right) illustrates the hourly profile of daily demand for the Baseline activity level of 320,000 aircraft operations per year. It also includes a curve that depicts the profile of daily operations for the Future 2 activity level of 425,000 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 55 operations per hour with the existing runway configuration, and,
- while hourly demand exceeds 55 operations only during a few hours of the day at the Baseline demand levels, 55 operations per hour is frequently exceeded at the demand levels forecast for Future 2, if there are no improvements in airport capacity.

Figure 13 Flow Rate vs. Average Delay, IFR 1 Conditions

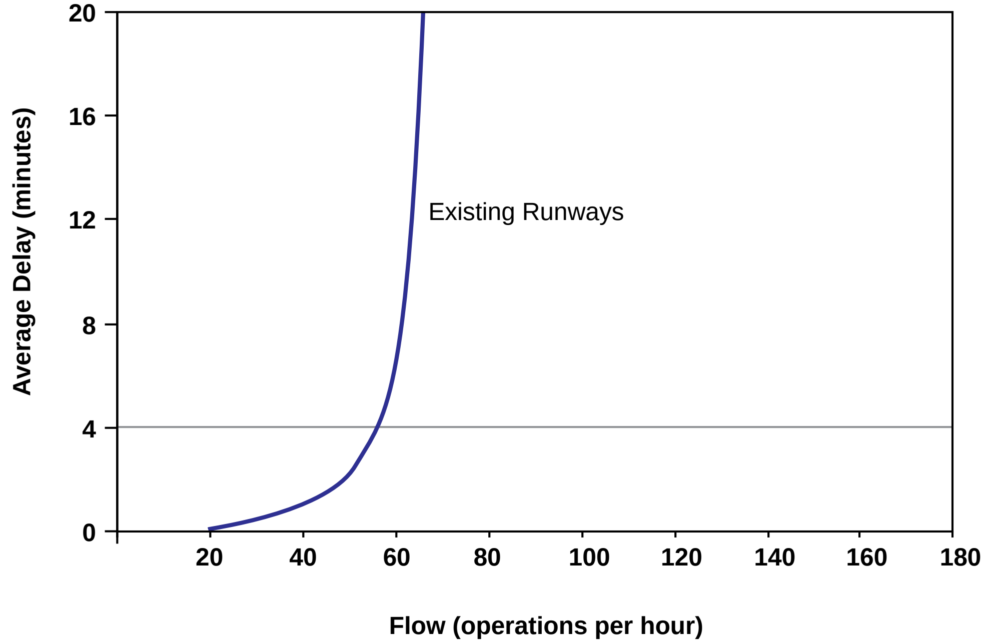


Figure 14 Profile of Daily Demand for Sea-Tac

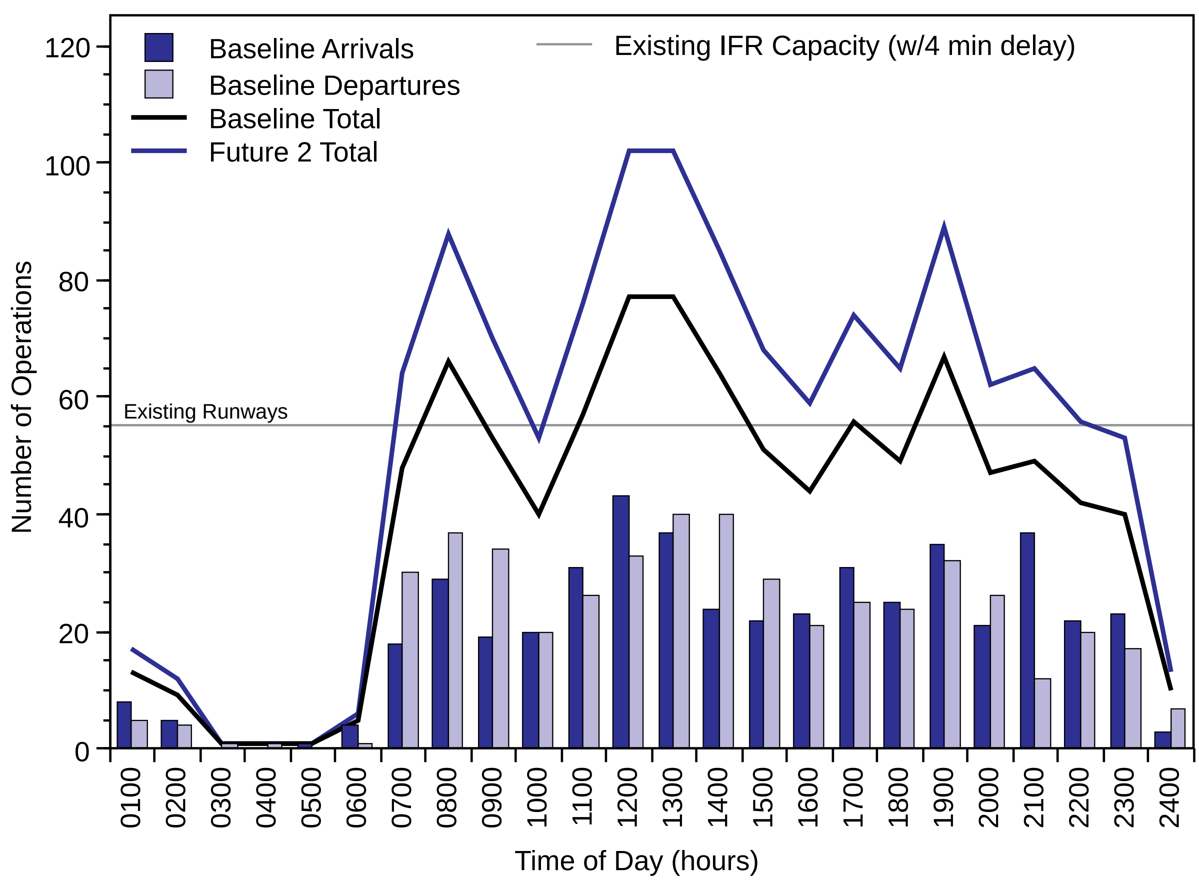


Figure 15 Annual Delay Costs — Existing Airfield Improvements

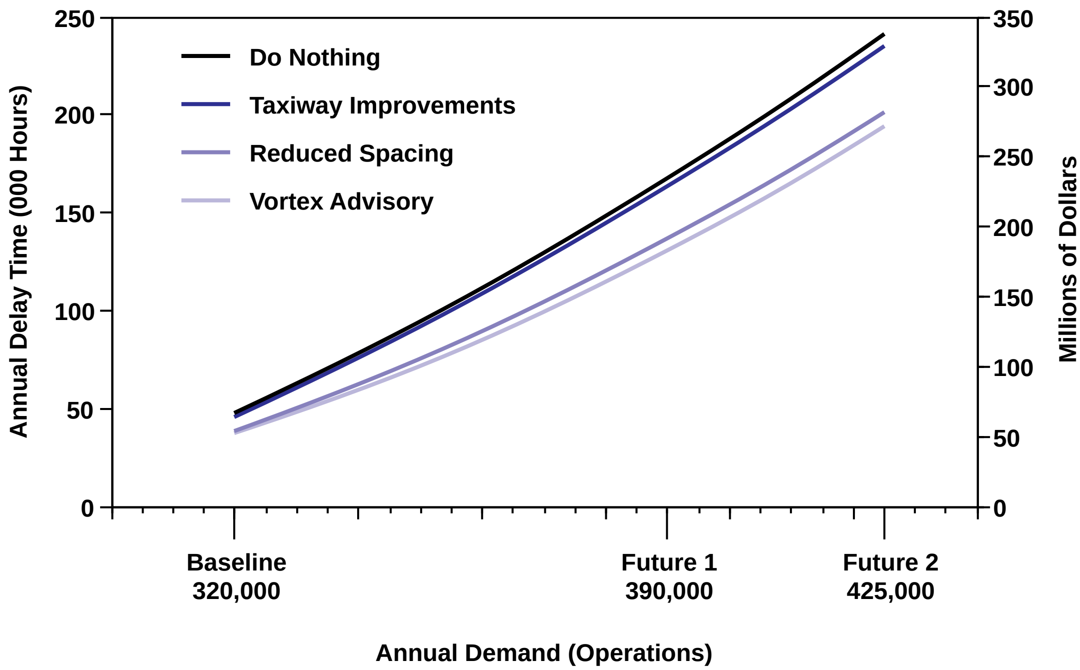
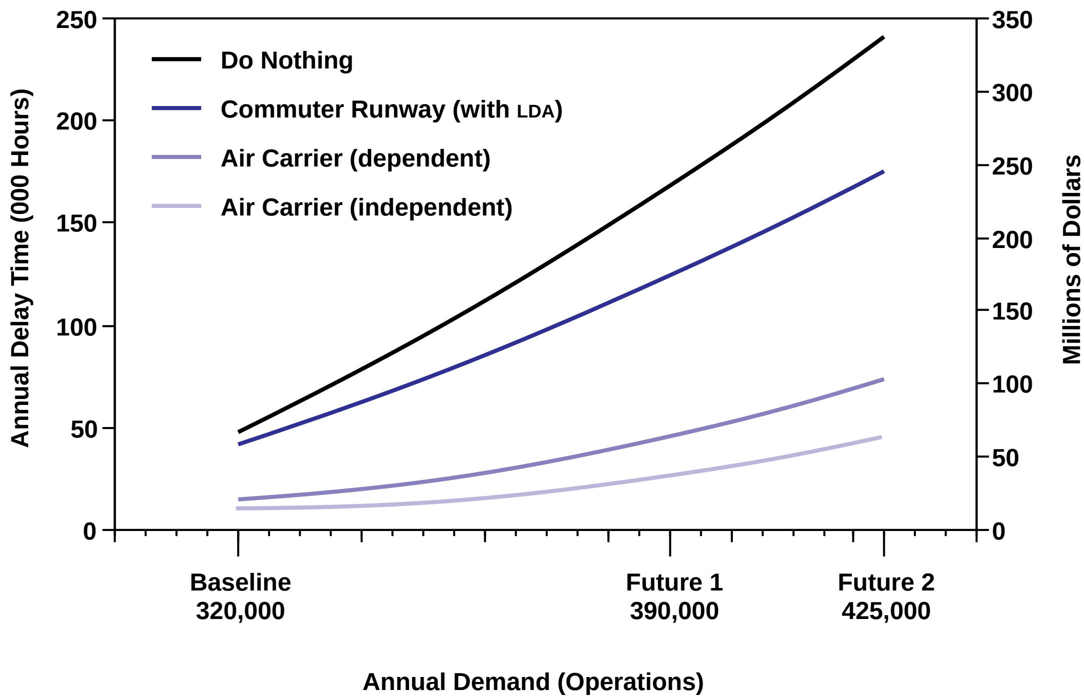


Figure 16 Annual Delay Costs — New Runway Improvements



Aircraft Delays

Aircraft delay is the time over and above unimpeded travel time that an aircraft must take to move from its origin to destination as a result of interference from other aircraft in the system that are competing for the use of the same facilities.

The major factors that influence aircraft delay are:

- Weather
- Airport demand
- Airfield physical characteristics
- Air traffic control procedures
- Aircraft operational characteristics

Figures 15 and 16 present the annual delay costs in millions of 1989 dollars for the three demand levels studied. These figures compare the "Do Nothing" case with…

…two runway improvements (Figure 15)

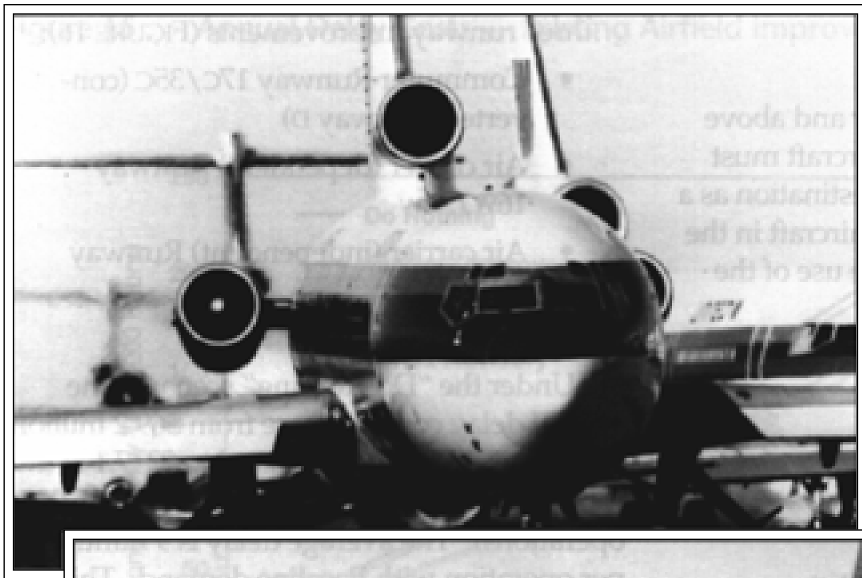
- Improved exit and taxiway construction
- Reduced in-trail spacing to 2.5 nautical miles
- Wake vortex advisory system

…three runway improvements (FIGURE 16):

- Commuter Runway 17C/35C (converted Taxiway D)
- Air carrier (dependent) Runway 16W/34W
- Air carrier (independent) Runway 16W/34W

Under the "Do Nothing" scenario, the annual delay costs increase from $69.2 million under Baseline (1989) demand to $347.1 million with Future 2 demand levels (425,000 operations). The average delay is 9 minutes per operation with Baseline demand. This will increase to 34 minutes per operation at Future 2 activity levels. And, these represent average delay levels; some aircraft would incur much greater delays.

Review of Figures 15 and 16 shows that the greatest savings would be provided by constructing a third parallel runway (16W/34W) capable of accommodating large air carrier transport aircraft. This new independent air-carrier runway will provide more than three times the savings of a new commuter aircraft runway (17C/35C).



Appendix A — Computer Models and Methodology

The Seattle-Tacoma International Airport Capacity Design Team studied the effects of proposed delay-reduction and capacity increase options on the anticipated increase in demands at Sea-Tac using computer modeling.

Model simulations involved present and future air traffic control procedures and various airfield improvements for different traffic demands. To assess projected 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, FAA specialists developed traffic demands based on the Official Airline Guide, historical data, and Capacity Team forecasts. Aircraft volume, mix, and peaking characteristics were developed for three demand periods (Baseline, Future 1, and Future 2) based on the changing nature of the airport. Annual delays estimated for the proposed improvement options were calculated from the experimental results. These estimates took into account the yearly variations in runway configurations, weather, and demand based on historical data.

The Capacity Team then compared the annual delay estimates and assessed the potential delay reductions for each capacity enhancement improvement.

The different computer models used are described in the following paragraphs. These models were developed by the FAA and have been used to evaluate delays at major airports around the country.

Airfield Delay Simulation Model (ADSIM)

A fast-time, discrete-event model that employs stochastic processes and Monte Carlo sampling techniques. It describes significant movements by 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. For each application, the model is calibrated against field data to insure it is site specific.

Inputs for the simulation model were empirically derived from the collected 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 for total and hourly aircraft delays, travel times, and flow rates for the airport and for individual runways.

Runway Delay Simulation Model (RDSIM)

There are two forms of the RDSIM. The first is a short form of the ADSIM that simulates only the runways and runway exits while it ignores the taxiway and gate complexes for a user-specified daily traffic demand. In the second form, the model still only simulates the runway and runway exits, but creates its own demand based on user-specified parameters with randomly assigned arrival and departure times. This form of the model is suitable for capacity analysis.

The RDSIM model, in its delay analysis mode, was used to compute, for a given demand, hourly flow and associated delay for various improvements during the full period of airport operations. The experiments were repeated 40 times using Monte Carlo sampling techniques to introduce system variability into each run. The results were then averaged to produce the delay outputs for a given demand level. Different demand levels were simulated for each run to generate demand versus delay relationships.

The RDSIM model, in its capacity mode, was used in performing the capacity analysis for Sea-Tac. A schedule of ever increasing levels of demand was applied to the three runway cases. The model then computed the number of operations occurring in a one-hour period and the average delay incurred by each of those aircraft. The capacity model assumes that there is no traffic at the airport at the start of the hour, and that demand is randomly distributed throughout the hour. Other inputs, such as the mix of aircraft types, runway exit usage, and the occupancy times were the same as in the detailed ADSIM and RDSIM experiments.

Appendix B — Capacity Team Participants

Federal Aviation Administration Members

David Field	Seattle ADO, Chairman, Sea-Tac Capacity Team
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Sarah Dalton	Seattle ADO
Eric Harrell	Sea-Tac ATCT
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David Cain	Seattle AFS
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Jennifer Barresi	FAA Technical Center
Albert Schwartz	FAA Technical Center
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Port of Seattle Members

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Alan Yazdani	Bob Wells
Michael Cheyne	

Other Members

John McNamara	Air Transport Association
Mike Oswald	Air Line Pilots Association
Don Smith	Boeing Field/King County International Airport
Daniel Scott	Horizon Air
Ron Ahlfeldt	P&D Technologies
Jim Billing	Puget Sound CoG
Jess Marker	United Airlines
William Hamilton	Washington DoT
Jerry Lenzi	Washington DoT

Appendix C — Glossary and Abbreviations

ADO	Airport District Office
ADSIM	Airfield Delay Simulation Model
ANM	FAA Northwest Mountain Region
AOPA	Aircraft Owners & Pilots Association
ARR	arrival
ARTCC	Air Route Traffic Control Center
ASC	Aviation System Capacity and Requirements Office
ATA	Air Transport Association of America
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
Baseline	1989 activity level at Sea-Tac of 320,000 operations
COG	Council of Governments
DEP	departure
Future 1	A future projected activity level at Sea-Tac, representing a near-term milestone representing 390,000 operations
Future 2	A future projected activity level at Sea-Tac, representing an intermediate-term milestone representing 425,000 operations
FSDO	Flight Standards District Office
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LDA	Localizer Type Directional Aid
MLS	Microwave Landing System
NAVAID	Navigational Aids
RDSIM	Runway Delay Simulation Model
RVR	Runway Visual Range
Sea-Tac	Seattle-Tacoma International Airport
Stochastic	random variable or random process
TCA	Terminal Control Area
TRACON	Terminal Radar Approach Control Facility
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WA DOT	Washington State Department of Transportation

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