MTR 00W0000053

MITRE TECHNICAL REPORT

Time and Cost Impacts of Offshore Routing of LAX Departures

June 2000

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Sponsor:	Federal Aviation Administration	**Contract No.:**	DTFA01-C-93-00001
Dept. No.:	F046	**Project No.:**	02001206-PW

MITRE

Center for Advanced Aviation System Development
McLean, Virginia

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Abstract

Recent proposals to modify the turboprop departure routes from Los Angeles International Airport (LAX) to the south and east are evaluated in terms of their impact on the efficiency of air traffic operations. The evaluation uses the Sector Design Analysis Tool and the Total Airport and Airspace Modeler. The new routes will require greater spacing of aircraft, which is shown to lead to large ground delays on the airport surface. Costs to users of the airspace are estimated to total tens of millions of dollars per year, depending on the details of the routing chosen.

KEYWORDS: Aircraft Noise, Air Traffic Control, Departure Procedures, LAX, Southern California TRACON, TAAM

Acknowledgments

The authors would like to thank the dozens of personnel from Southern California TRACON, Los Angeles Tower, Los Angeles Air Route Traffic Control Center, Los Angeles World Airports, and the Western Pacific Regional Office, without whose expertise and patience this work would not have been possible. We would also like to thank Phil LaRocca of the Office of Airspace Planning and Analysis for coordinating the efforts, and Angela Signore for preparing the document for publication.

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Section 1

Background and Study Overview

Aircraft departing Los Angeles International Airport (LAX) for the eastern, southern, and midwestern United States take off west over water, turn south as they climb, and then turn east toward their destinations. This is done to reduce aircraft noise experienced in Los Angeles and surrounding cities. By the time the aircraft are once again over land, they have climbed at least 5000 feet above ground. Traffic to San Diego follows much the same route, but keeps going south instead of turning east.

The Palos Verdes Peninsula extends into the Pacific Ocean, just south of Los Angeles. When turboprop aircraft make their turn back over land, they are over Palos Verdes. Residents of the communities on or near Palos Verdes, most notably Rancho Palos Verdes, Palos Verdes Estates, Rolling Hills Estates, Hermosa Beach, Redondo Beach, Manhattan Beach and Torrance, have formed an organization called the Peninsula Aircraft Noise/safety Information Committee (PANIC)[1] as a clearinghouse for information on aircraft noise. They have also formed a lobbying group called the South Bay Task Force to encourage the Federal Aviation Administration (FAA) to review the noise caused by turboprop aircraft, and investigate what rerouting of aircraft can be implemented to alleviate it. The community preference is that all aircraft be kept five miles offshore of the peninsula, after which they will make landfall to the south, near Huntington Beach. Since the issue was brought to the attention of the FAA, they have made what changes can be done without a major restructuring of the airspace. Most significantly, when traffic and controller workload permit it, turboprops are sent one mile offshore before turning.

1.1 Anticipated Impacts of a Reroute

Turboprop aircraft have a wide variety of performance characteristics: rates of climb, airspeed during climb, and cruising speed. Air traffic naturally moves most efficiently when faster aircraft can pass slower ones on the same track. The current departure route enables this: the faster an aircraft can climb, the sooner it can turn east. The slower or heavier aircraft fly further south before turning. As a result, the departures fan out over a wide area of coastline. (See Figure 3-3.) When they re-converge at the Seal Beach navigation aid, the fast aircraft are in front.

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1 http://www.palosverdes.com/panic/

If the proposal of the South Bay Task Force is implemented, air traffic controllers will no longer have a "passing lane" to put faster aircraft in front of slow ones. This loss of flexibility implies that departures may be less efficient. Departures from LAX could be significantly less efficient, possibly leading to decreased capacity at the airport and long delays for passengers. In the worst case, given that LAX is a relatively small airport with cramped terminals and taxiways, it is possible that the backups of departures can block arrivals from reaching their gates. LAX already operates near capacity, so any new obstruction of arrivals will require traffic flow management programs such as ground delays at connecting airports. Closer analysis was needed to determine the magnitude of the effect.

1.2 Study History

An assessment of the noise caused by aircraft using the current routing was completed in 1999 by ATAC Corporation, under contract to Los Angeles World Airports[2]. Their study, using the air traffic control simulator SIMMOD and the FAA's Integrated Noise Model, showed that current noise levels are significantly below the threshold at which the FAA must act to alleviate noise, but that offshore routing would reduce them. The study investigated alternate routes in which aircraft are kept 1, 3, or 5 miles offshore. The cost to aviation of the offshore routing was estimated to be about $3 million per year, primarily due to extra airborne time. Ground delay was not found to be as significant.

The Air Transport Association, an industry group representing commercial air carriers, disagreed with this cost estimate. Their own study, estimating a departure delay of three minutes per flight, concluded that the annual cost to its members would be closer to $30 million per year.

To better understand the discrepancy, the FAA (Air Traffic Airspace Management Office and Western Pacific Regional Office) asked CAASD in September 1999 to investigate the impact on airline delays of this proposal and some other compromise routings. CAASD brought the Sector Design Analysis Tool (SDAT) and the Total Airport and Airspace Modeler (TAAM) to the task. This paper presents a description of the study (Section 2), the data that went into the modeling (Section 3), and time and cost estimates of the impact on aviation (Section 4).

2 http://www.awp.faa.gov/so_cal/pdf/pv6_30.pdf

1.3 Summary of Findings

This study found significantly larger cost impacts than either the ATAC or Air Transport Association studies. The difference between these results and the ATAC results is due to two causes. First, and most important, the description of current operations in this study more closely reflects the flexibility that controllers have to sequence aircraft for maximum efficiency. Second, traffic at LAX increased in the year between the two studies, so more flights are affected.

According to sources familiar with the Air Transport Association study, this simulation shows the same qualitative result. This simulation agrees that ground delay is the major source of cost penalties to users, but the simulation shows six to seven minutes of ground delay per flight instead of the Air Transport Association's estimate of three minutes.

Table 1-1 shows the bottom line cost figures than the CAASD study, using Air Transport Association's estimates of cost per minute of delay on the ground and in the air for a representative mix of aircraft.

Table 1-1. Cost of Offshore Routing ($M per year)

	Ground	Airborne	Total Penalty
1 mile offshore	$34.8	$1.1	$35.8
2 miles offshore	$46.4	$5.8	$52.2
3 miles offshore	$58.0	$10.6	$68.5
5 miles offshore	$71.5	$14.2	$85.7
Hybrid	$29.0	$8.8	$37.8

The Air Transport Association estimate of delay is lower than this simulation would indicate, so the cost penalties of all of these scenarios are higher than the Air Transport Association figure. The "hybrid" scenario is a combination: aircraft headed south along the coast to San Diego would be routed three miles offshore, but eastbound turboprops that have the most need of the passing lane would continue over Palos Verdes. Since the San Diego flights constitute more than two thirds of the traffic, this scenario improves the impact only slightly.

Section 2

Approach

To answer questions about the likely impact of the rerouting, a straightforward airport simulation of LAX using TAAM was conducted. Since some simulation scenarios would affect operations at John Wayne Orange County (SNA) and Long Beach (LGB), these airports were simulated as well, but at a very coarse level. The simulation was conducted in conformance with the guidelines for airspace studies developed by RTCA[3] and the FAA Office of Airspace Planning and Analysis.[4]

The simulation was based on:

- ARTS data from the Southern California TRACON
- Flight plans from the Enhanced Traffic Management System
- Schedules from the Official Airline Guide (OAG)
- Traffic counts from the Air Traffic Service Operations Management System
- Airport layout information from Los Angeles World Airports
- Interviews with specialists from SCT and LAX tower

Extensive processing of these data was required to obtain the parameters needed to run the simulation. First, essential traffic parameters were obtained from the Automated Radar Terminal System (ARTS). Then, traffic schedules for the simulation day was obtained from the OAG. For non-scheduled traffic, which is a small but significant part of LAX traffic and a major portion of LGB and SNA demand, ETMS trajectories were used. ETMS flight plans were also used to assign arrival fixes to LAX flights on the basis of departure airport, and departure fixes based on destination.

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3 RTCA SC-192, *Government and Industry Guidelines and Concepts for NAS Analysis and Redesign*, RTCA/DO-224, Washington DC,1998.

4 Federal Aviation Administration, *Airspace Management Handbook*, Department of Transportation, Washington, DC, 1999.

Trajectory information was obtained from the ARTS at the southern California TRACON, adapted by parsing and database programs developed specially for this project, and imported into SDAT. This visualization tool, developed at the FAA, shows traffic in three dimensions and calculates entry and exit times for any specified volume of airspace. Information extracted was the climb rates for various types of aircraft, inter-departure times from LAX runways, and the general pattern of departure routes taken on a day of clear weather and heavy traffic around LAX.

2.1 TAAM Simulation

TAAM is a fast-time gate-to-gate simulation of any air traffic management system. It has the ability to model virtually every part of the airport or the airspace.

> "Its purpose is to represent or simulate the essential features of the airspace and airport being studied. That representation may be used to better understand, analyze, and evaluate a specific concept,… at a fraction of the cost of real-time operational studies…. It is a free-flow model. The aircraft move in four dimensions (latitude, longitude, altitude, time) according to their performance characteristics, the flight plan, the stipulated procedures, and sometimes, following control actions such as radar vectoring. Additional realism is provided by randomizing aircraft performance"[5] within specifiable bounds.

Its particular applicability to this problem is a result of its ability to respond automatically to changing conditions. The analyst does not have to specify the details of how each aircraft will move, what taxiways to take, what runway to use, what departure route to fly. TAAM chooses these on the basis of hundreds of parameters and switches in the model of an airport, and by an extensive rule base, developed by the analyst, which provides the correct action for an aircraft in specific circumstances.

LAX was simulated in detail from gate to departure fix, and from arrival fix to gate.

Assessment of traffic at SNA and LGB shows users of those airports will suffer airborne effects, but no great schedule disruptions. Since so much of their traffic is unscheduled, the gaps between scheduled flights are not due to airborne separation, so the simulation would show no difference. When a rerouting scenario required moving an arrival or departure route, the increased airborne time was calculated. Otherwise, no impact is expected, so for these airports, only one runway and the complete set of terminal routes were modeled.

No attempt was made to simulate the effect of overflight traffic in the vicinity of LAX. With the exception of a few helicopters, overflight traffic is procedurally separated from the modeled flows. That is, overflights do not use the same airspace.

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5 *TAAM Capabilities and Applications*, The Preston Group, Melbourne, Australia, 1996.

2.2 Simulated Scenarios

The original request from the communities on Palos Verdes was for a five-mile offshore route. This route would have several repercussions on other air traffic flows. Currently, jet departures from LAX use the airspace west of the fan. These would have to be routed further out. Departures from SNA via Pomona to Dagget, which currently make right turns after takeoff and pass east of LAX, would be flying in the face of the turboprop departures, so they would have to be moved south, and then merged into the Los Angeles "loop" departure route. Tandy arrivals into LGB and SNA, which arrive from Central and Northern California over the ocean west of the current turning points, would be pushed even further out, up to the limits of airspace available for civil aviation.

This is a fairly extreme set of impacts, so the SCT treated the five-mile request as an adjustable parameter, to see if there is a point at which some benefit can be obtained at reasonable cost to airspace users. Simulations were conducted of routings 1,2,3, and 5 miles offshore, and one hybrid scenario in which turboprop traffic to San Diego and Palomar was put five miles offshore, with the jets moved out correspondingly further, but turboprop traffic over Seal Beach was permitted to continue as today[6].

Several traffic levels were simulated to identify the sensitivity of the results to demand. A low traffic day, about 10th percentile, a heavy traffic day, about 90th percentile, and an extreme day, 99th percentile were chosen. Only the 90th percentile day will be described in detail below. "90^{th} percentile" means that traffic of this level or higher occurred on 37 days in the previous year.

2.3 Metrics

User impacts of the proposed new departure procedure will be confined to increased airborne time and possible arrival and departure delays. The metrics needed for this study are simple differences in airborne and ground movement time.

Ultimately, the cost to implement the proposed procedure will be an important factor in the decision whether to implement it. The last phase of this study was a conversion of the time penalties faced by airspace users, into economic impact. This was done in two ways: First, using cost figures from the Air Transport Association, which may be considered the industry standard; second, cost figures from the FAA's Office of Policy and Plans, which are frequently used in FAA decision making.

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6 The 1, 3, and 5 mile offshore scenarios are the same routing as used in the ATAC study.

Section 3

Simulation Development

The process of developing the simulation contained three major parts: creation of the traffic file, simulation of the departure routes in the SCT, and simulation of ground operations at LAX.

3.1 Traffic

The first task in developing traffic is to get the right number of flights. Figure 3-1 shows the OPSNET traffic counts at LAX for one year preceding 1 November 1999. Note that the traffic is steadily growing, but that the heaviest traffic of the week seems to be leveling off. The 90th percentile traffic day would be 2265 flights; the 99th percentile day had 2327. Both occurred between August and October 1999.

The 90th percentile day was Thursday, August 26; this day was used as the starting point. The 99th percentile day was obtained by adding flights to this base, which minimizes the effects of changes other than total number of flights.

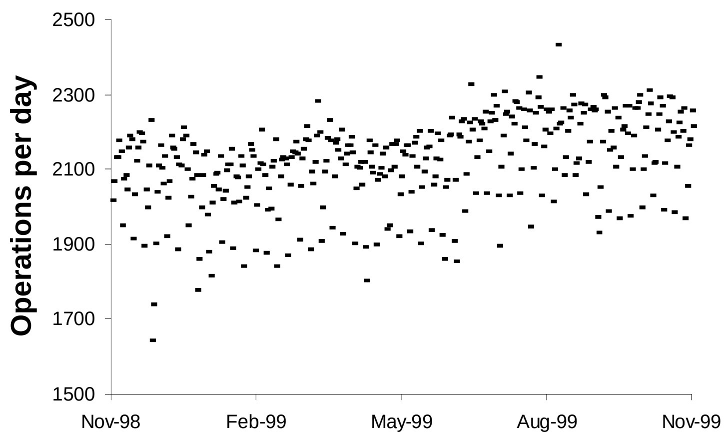

Figure 3-1. OPSNET Traffic at LAX (for the year preceding the study)

To calculate delay correctly for this task, the traffic at LAX must try to make scheduled times of arrival and departure. Therefore, the OAG was used as the primary source of LAX traffic. There are also unscheduled flights at LAX (mostly charters and cargo flights, but a few general aviation); these were obtained by removing the scheduled flights from a day of ETMS traffic, and appending the remainder to the OAG file. SNA and LGB traffic is predominantly non-scheduled. For these airports, ETMS flight plans were used directly.

The air traffic control system outside the arrival and departure fixes for LAX, SNA, and LGB was omitted from this study. Therefore, a flight plan of the scheduled traffic consisted of just a departure airport, one fix, and an arrival airport. The fix determined the approach or departure procedure. For departures, the OAG times were used (See Figure 3-2). For arrivals, the scheduled arrival time at LAX was used as a constraint, and the TAAM preprocessor calculated the time at which the flight should arrive at the arrival fix in order to place the correct load on the airspace around LAX.

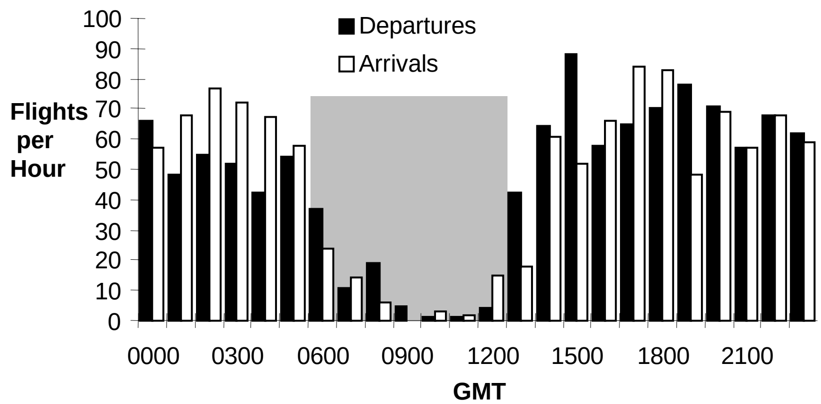

Figure 3-2. OAG Traffic at LAX (grey period is not simulated)

Only 19 hours of the day were simulated. At night, LAX typically goes into “over-ocean” operations for noise abatement. When the airport is in this configuration, the departures over Palos Verdes are much fewer, much higher, and much quieter.

3.2 Departure Fan

Departure routes in TAAM are not defined by point-to-point trajectories, which makes it particularly well suited for simulating the departures out of LAX. The departure procedures currently in use in the SCT are expressed in terms of headings to which aircraft must turn upon reaching a particular altitude. Given the differences in aircraft weights, this means that, in effect, a new departure path is created for each flight (See Figure 3-3). All departure routes were restricted to be above 5000 ft as they pass over the coastline, headed east.

Most of the eastbound flights were going to the Seal Beach VOR. In a point-to-point model (like the ATAC study), they would be obliged to depart at least three miles in trail. In this model, however, the simulation launched departures based on whether they would have three miles lateral separation or 1000 ft separation at Seal Beach, not along the whole route. Only if the aircraft would not be separated by their different performance characteristics, was a flight delayed at the runway end.

This is a very good approximation to what controllers actually do, as long as aircraft performance data are used that are appropriate to Southern California weather. Data from ARTS were used to extract minimum and maximum climb rates for each type of aircraft seen in the sample. Manufacturers' data were used as a check.

Figure 3-4 shows the simulation of the departure fan. As in all simulations, the widest-deviating flights are not represented, but the core of the fan is essentially correct. Figures 3-4 through 3-7 show the planned departure routes in the various simulated scenarios. The sharp corners will not be flown by the aircraft; aircraft will turn at the corners according to their preferred bank angles and speeds, derived from manufacturers' data.

Figure 3-3. ARTS Trajectories of Turboprop Departures to SLI and SAN/CRQ

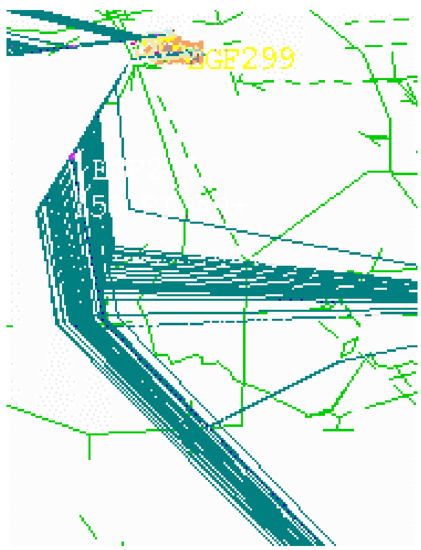

Figure 3-4. Baseline Simulation of the Same Departure

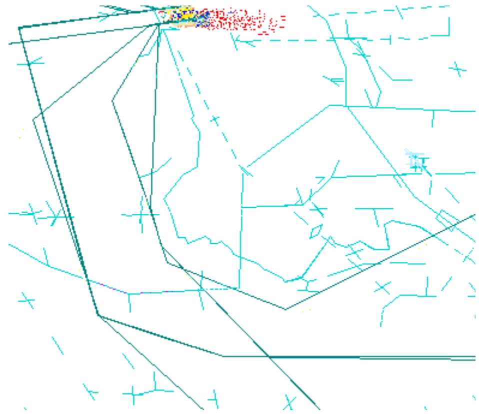

Figure 3-5. Simulation of 1-Mile Offshore Routing

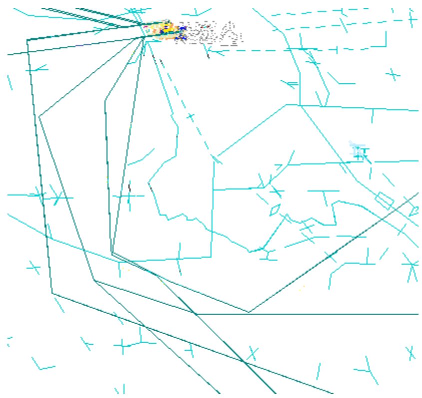

Figure 3-6. Simulation of the 3-Mile Offshore Routing

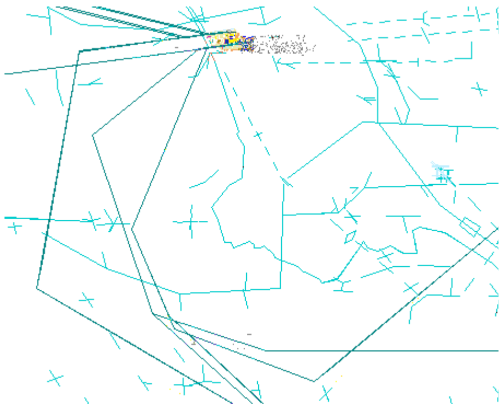

Figure 3-7. Simulation of the 5-Mile Offshore Routing

3.3 Ground Movement

The airport surface at LAX, as modeled in this study, is shown in Figure 3-8. Buildings are in gold, taxiway centerlines are in red, and runways are in black. The green lines are radials off the LAX VOR navigation aid. True North is toward the top of the figure.

The runways, reading down from the top of the figure, are 24R, 24L, 25R, and 25L. The outer runways are primarily for arrivals; the inner runways are primarily for departures. When demand permits and visual approaches can be used, some arrivals come to the inner runways as well. The details of runway use, in TAAM jargon, are in Appendix A.

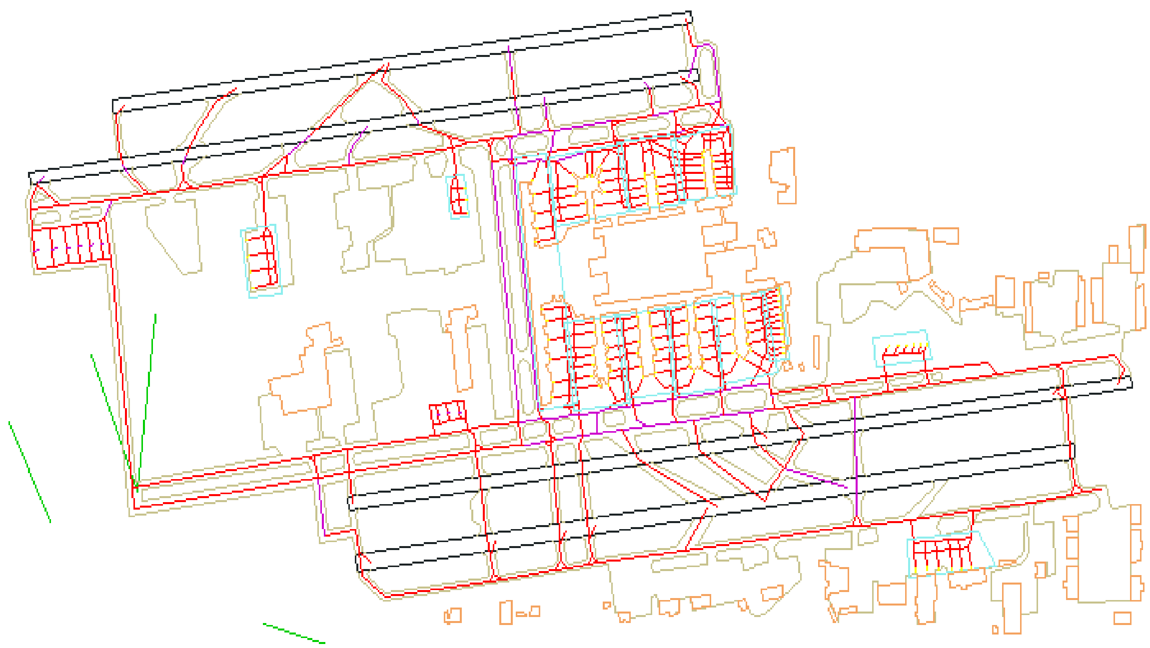

Figure 3-8. Simulation Layout of LAX

3.3.1 Runway Choice

The most important principle in modeling LAX ground movement is called “taxi-correct”. This means that departing flights are directed to the departure runway on the side of the airport that corresponds to their departure fix, not to the runway that is easiest to reach. A great deal of traffic crosses from one side of the airport to the other on the ground (taxiways Q and S, running north-south in the middle of the field), so the aircraft do not have to cross in the air. In effect, the ground controller accepts extra workload, increasing efficiency by simplifying the job of the approach control. This procedure was modeled by default in TAAM.

There are several exceptions to this rule. Loop departures, in which jets fly out over the ocean to gain altitude, then turn around and pass over the airport again on their way to Dagget, can depart from either runway. The heaviest aircraft, including all trans-pacific flights, prefer to use 25R, the longest runway, even when they are departing over Ventura to the northwest. All of these exceptions were modeled to correspond to the Standard Operating Procedures of the SCT and radar tracks in the ARTS data. When traffic to San Diego is very heavy, some departures use the north complex at LAX. This was simulated by permitting them to use runway when the queue of aircraft waiting to depart runway 25R is ten aircraft longer than the queue waiting to depart runway 24L (See Appendix A).

Under instrument flight rules, arrivals use the two outer runways, 25L and 24R. Arriving flights under visual approaches can use any of the four runways, though they use the inner ones only during times of low departure demand. When arrival demand is highest, arrivals are accepted by LAX to the inner runways at 10 miles in trail. When arrival and departure demand are both high, arrival traffic to the inner runways is greatly reduced. Such flexibility of configuration was simulated by placing arrivals to the inner runways 40 miles in trail when departure demand was high. When TAAM encountered this requirement, its sequencing logic directed virtually all arrivals to the outer runways.

Arrivals from the north are preferentially sent to runway 24R, arrivals from the east and south are preferentially sent to 25L. If heavy, unbalanced demand requires it, there is a “teardrop” approach to get flights from Ventura or Fillmore over the airport to land on the southern complex. Likewise, there is an approach from the south that takes flights on the Paradise approach to any of the four runways. Turboprop traffic from the south passes over the Seal Beach VOR, and, in accordance with trajectories in the ARTS data, was turned on to the final approach to the south complex close to the airport.

3.3.2 Same-Runway Separations

Generally, under Visual Flight Rules, a departure can be cleared behind another departure when the first flight is 6000 ft away (just over halfway down Runway 25R, which is 11,000 ft from end to end). A turboprop behind a jet is not more restricted, except for heavy or B757, because the jet's greater speed means that its lead is constantly increasing. The largest separations occur when a jet is behind a turboprop, because the speed difference works in the opposite direction, or when wake turbulence is a factor. To maximize departure capacity, air traffic control tries to minimize sequences where the faster aircraft is behind. Natural "holes" in the departure lineup are used to taxi arrivals across the departure runway.

When two consecutive departures are going to the same fix, they must be placed at least three miles in trail (more if flow management requires it), so ground controllers try to avoid this situation as well. The great virtue of the turboprop fan over Palos Verdes is that the differing performance characteristics of the aircraft can be used to get separation in the air, without blocking a runway for that long interval.

Arrivals are separated according to wake turbulence rules under instrument flight rules, with minimum allowable separations from three to six nautical miles in trail, depending on the weights of the leading and following aircraft. Under visual flight rules, pilots have leave to follow as closely as they judge to be safe, which is considerably closer. The minimum allowable separations used in this study are closer to 2.5 nmi between large jets, with a bit extra when the trailing aircraft is small. See Table 3-1.

Table 3-1. Wake Turbulence Separations Under VFR

	Following Aircraft			
Leading Aircraft	**Heavy**	**B757**	**Large**	**Small**
Heavy	4	5	5	6
B757	4	4	4	5
Large	2.5	2.5	2.5	2.5
Small	2.5	2.5	2.5	2.5

3.3.3 Turboprop Shotgun

A technique for increasing departure runway throughput, unique to LAX, is called the "shotgun". Taxiing east, toward the east end of Runway 25R, taxiways B and C merge, and then deliver aircraft to the end of the runway (See Figure 3-9). The majority of the traffic is jets, so jets are passed through the merge point until a group of turboprops is collected. Then, the group of turboprops is cleared through in quick succession. Their differing departure fixes, and different climb rates and speeds, permit controllers to send them out in a spray of different headings with very small runway separation.

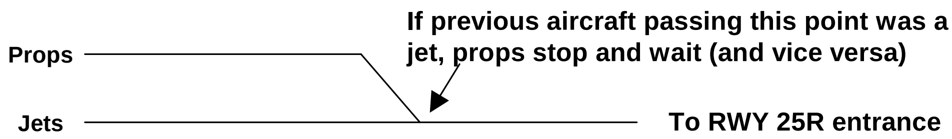

Figure 3-9. Rules for "Shotgun" of Turboprops

Taxiing is optimized continuously, everywhere on the airport's surface. In the simulation, the computation was simplified by condensing the optimization to a point. The simulated shotgun is implemented with the parallel taxiways B and C. Turboprops are lined up on taxiway C, jets on taxiway B. The turboprop shotgun is implemented by a quartet of taxiway rules. When a taxiing aircraft arrives at the merge point, TAAM is instructed to re-evaluate the taxipath. While re-evaluating, it stops and waits unless the previous aircraft through the point is of the same engine type. If there is no contending flight on the other taxiway, of course, the flight proceeds. In this way, groups of three to five turboprops were observed to collect on taxiway C and depart together.

3.4 Separation Times

3.4.1 Validation Against ARTS Data

ARTS does not contain wheels-up times, but its record of aircraft position and time is very accurate, so a simple trick was used to estimate departure intervals. SDAT can count entry times into any volume of airspace, so a small region was defined just to the west of each departure runway. Entry times into this region were used as proxies for the wheels-up time. Figures 3-10 and 3-11 show the relationship between the ARTS and TAAM departure intervals. Qualitative agreement is good, but there is a slight bias in TAAM toward longer intervals. Note particularly the fact that the most frequent separation from the south complex is between 1 and 2 minutes, where the most frequent separation from the north complex is less than one minute. This reflects the fact that the south complex has the longest runway, which is preferred for the heaviest jets, which have the largest separation requirements behind them.

The slight bias between simulated and actual intervals is due to variable performance of aircraft. In reality, controllers use their knowledge of the properties of specific flights to depart them with the closest possible spacing. This simulation, by contrast, was made without detailed information on aircraft weights or pilot preferences, since this information is not available from FAA sources. Weights and performance of each aircraft were assigned randomly, which reproduces the observed behavior of the traffic, but is slightly less efficient.

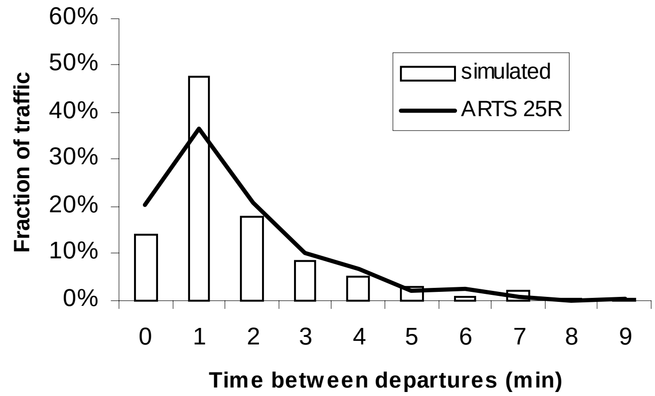

Figure 3-10. Histogram of Inter-Departure Separations from the LAX South Complex

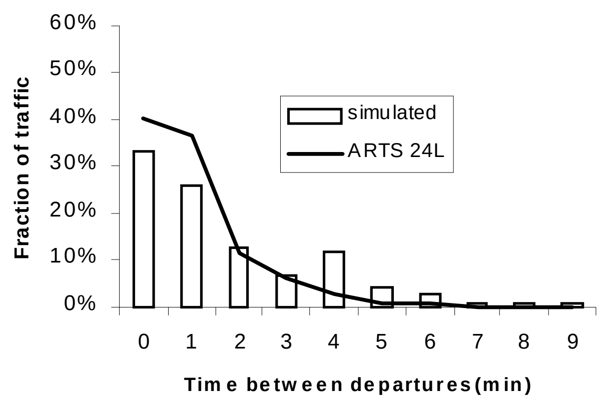

Figure 3-11. Histogram of Departure Separations from the LAX North Complex

Arrival separations are not so easy to evaluate from ARTS, because the traffic sample contained arrivals to all four runways. The resolution of the ARTS is not sufficient to separate arrivals to 25R from 25L, or 24L from 24R. However, since this study is only indirectly concerned with arrivals, exact matching of the arrival intervals was not necessary. As long as simulated arrivals were pushed as close to departures as procedures allow, the model of arrivals was sufficient.

Other Airports

Due to the presence of significant amounts of VFR traffic at SNA and LGB, which does not appear in any of our data sources, no delay measurements or separation validation was undertaken for these airports. TAAM airport parameters were set so that there was no large delay in the baseline scenario. The parameters were not changed for the offshore rerouting. Only the SIDs (standard departure routes) and STARS (arrival routes) in TAAM were altered between the simulation scenarios.

In the simulated traffic, there were 311 itinerant IFR operations at SNA, and 73 itinerant IFR operations at LGB. Local operations and VFR operations were not included.

Section 4
Results

A few general observations show the immediate impact of the changed departure routes.

- At this level of traffic, 2265 flights per day, there was no significant increase of arrival delays in the offshore scenarios. Currently, the inner runways handle departures, but can accept arrivals if departures are quiet during a period of heavy arrival demand. In the offshore scenarios, departure queues were lined up for more of the day, so the inners were less available for arrivals. The number of arrivals to the inner runways decreased by about 30 percent.
- When departures lined up for runway 25R, the queue seldom reached back to Terminal 8 in the baseline, but this happened at least once per day in each offshore scenario. This is significant because a queue that blocks the taxiways between the terminals can lead to irresolvable conflicts, which may lead to ground stops of incoming traffic. This never happened in the 90th percentile day, as long as visual approaches were used all day.
- When instrument meteorological conditions (IMC) were assumed for the whole simulation day, the current ground configuration was just barely feasible in the baseline scenario, infeasible in the offshore-routing scenarios. This is not surprising, since even short periods of IMC cause disruptions from which it is difficult to recover. A whole day of IMC would doubtless lead to flight cancellations. Cancelled flights mean the day would not finish at the 90th percentile of traffic.

4.1 Airborne Time

Excess airborne time in a TAAM simulation comes from flying a longer distance, from speed control for spacing enroute, and from holding to sequence arriving aircraft to a runway. Table 4-1 shows the impacts of the various reroutings. LAX has over a thousand departures during the simulated period, which means that the extra departure time is less than a minute per flight. SNA is affected most per flight. Any impact on LGB is too small to measure here.

Arrival capacity at LAX is not directly affected by the offshore rerouting, which can be seen from the “LAX arrivals” row of the table. Even in the most-penalizing offshore routing, essentially zero minutes of arrival delay are added. Eventually, of course, when the departure queues get long enough, arrival delays will mount up. This is beginning to happen in the five-mile scenario.

The excess arrival time at SNA is due to the longer routes, not to holding. Excess departure time, for both LAX and SNA, is due to longer routes.

Table 4-1. Excess Airborne Time (minutes per day)

		Offshore Routing Scenario				
		Hybrid	**1 Mile**	**2 Mile**	**3 Mile**	**5 Mile**
LAX	Departures	436	71	317	563	765
	Arrivals	0	0	0	0	2
SNA	Departures	93	3	48	93	93
	Arrivals	78	20	49	78	103
LGB	Departures	0	0	0	0	0
	Arrivals	0	0	0	0	0
Total		**601**	**72**	**395**	**718**	**963**

Excess airborne time increases linearly with traffic. That is, if there were half as much traffic, the cost per day would be half as much. In the 10^{th} percentile day, this was the only source of penalties to users. For the 99^{th} percentile day, the baseline arrival delays were higher, as were the delays in all scenarios. The impact of the reroute was about the same.

4.2 Ground Movement Time

The ground movement time of departures from LAX is by far the dominant source of penalties due to the offshore routing[7]. Figure 4-1 shows graphically how the taxi-out time per flight is affected by the various routings. Note that, whereas Table 4-1 shows airborne time penalties less than a minute per flight, Figure 4-1 shows penalties of three to seven minutes per flight.

The most important thing to notice is the sharp jump from the baseline to any of the rerouted scenarios. The details of the rerouting are less important than the fact that the "passing lane" is gone. As the reroute is pushed further offshore, the taxi-out time increases. This is because the time to reach the fix (usually SLI) is increased, which means that when a slow aircraft departs, it needs more space behind it to prevent it being overtaken by a faster aircraft. When there is a queue waiting to depart from that runway, each aircraft experiences the same delay (a half-minute or so), and a large impact on the average is the result.

7 Ground movement at SNA and LGB was not modeled, so no comparable number is available there, but the total impact is estimated to be insignificant compared to LAX.

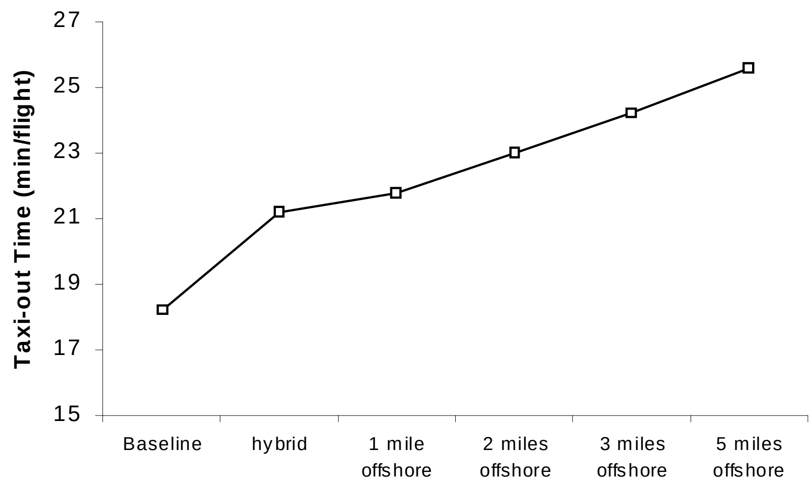

Figure 4-1. Increase in Ground Movement Times at LAX

Ground movement time is highly nonlinear. In the 10th percentile day, there was very little increase in mean taxi-out time. This is because there was seldom a long line of departures, so when a fast turboprop was behind a slow one, its ground delay did not spread to other flights. In the 99th percentile day, the problem was much worse. Not only did a longer queue suffer the delays due to the lack of a passing lane for turboprops, but occasionally the queue for runway 25R would grow long enough to block access to Terminals 7 and 8. The penalties due to the reroute were slightly more severe than those in Figure 4-1.

4.2.1 Annualizing Penalties

To derive the annual impact of a change in ground delays, we return to OPSNET traffic counts. Over the year from 1 November 1998 to 31 October 1999, there were 711796 operations at LAX. On the day simulated here, there were 2265 operations in OPSNET. Therefore, annual numbers can be estimated by dividing the daily delay totals by the fraction of the year's traffic that was handled that day, that is, multiplying by 314.25. The result is shown in Table 4-2. (The "per flight" column of the table is the numbers plotted in Figure 4-1.)

Table 4-2. Annualized Ground Movement Penalties at LAX (minutes)

	Per Flight	Penalty	Per Day	Per Year
Baseline	18.2	—	—	—
1 mile offshore	21.8	3.6	3717	1,168,100
2 miles offshore	23	4.8	4956	1,557,466
3 miles offshore	24.2	6	6195	1,946,833
5 miles offshore	25.6	7.4	7641	2,401,094
Hybrid	21.2	3	3098	973,416

As mentioned above, the impact of the reroute on ground delay is not linear, since there is little ground delay on a low traffic day, and extreme delays on the busiest days, so the simple multiplication would be an overestimate for 1999. However, traffic is growing. As Figure 1 shows, the 90th percentile day for the year collected here is a fairly typical day since August 1999. Therefore, the overestimate is not serious, if it is still an overestimate at all.

4.3 Economic Impact

Converting airborne and ground times into costs is properly the job of an airline's own accountants, since each company has their own costs, many of which are proprietary information. Nevertheless, a cost-benefit calculation for new air traffic control procedures, systems, or infrastructure requires an industry-wide number on which decisions can be based. Recognizing this, several organizations have developed models based on direct operating costs that are in some sense an industry average. This approach, which yields figures in terms of dollars per minute of delay, is appropriate for small changes in the airspace system. For larger changes, those that induce a response from the users of the system in terms of schedule changes or entry/exit from a particular market, a different model is needed[8].

We assume that no such schedule changes will be made to accommodate the changes in departure capacity at LAX from these reroutes, and calculate the resulting impacts based on two different cost models: one from the Air Transport Association, one from the FAA.

Air Transport Association Model

The ATA model is the industry standard. It assigns different costs to different phases of flight. Table 4-3 shows the details. All figures are in 1998 dollars per minute of delay.

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8 Homan, A., *A New Paradigm for Measuring the Benefits of Air Traffic Control Improvements,* McLean, VA, The MITRE Corporation, MP99W154, July 1999.

Table 4-3. Air Transport Association Cost Parameters

Gate	Taxi-out	Airborne	Taxi-in
$23.32	$23.79	$46.76	$29.10

Applying these cost figures to the delays in Table 4-2, we find the costs in Table 4-4.

Table 4-4. Annual Costs Using the Air Transport Association Model ($M per year)

	Ground	Airborne	Total Penalty
1 mile offshore	$34.8	$1.1	$35.8
2 miles offshore	$46.4	$5.8	$52.2
3 miles offshore	$58.0	$10.6	$68.5
5 miles offshore	$71.5	$14.2	$85.7
Hybrid	$29.0	$8.8	$37.8

The FAA model[9] is monitored by at the Office of Policy and Plans[10] (APO) in FAA Headquarters. It describes costs differently; in terms of the type of aircraft experiencing the delay. For air carrier aircraft, the delay cost is $27.13 per minute. For air taxi aircraft (those with less than 30 seats), the delay cost is $4.83 per minute, and for general aviation, the delay cost is $1.87 per minute. For this model, the total delays were apportioned to the different classes of users according to their overall presence at the airport. General aviation was an insignificant portion of the LAX delay costs. General aviation was the majority of the traffic at SNA and LGB. Applying these cost figures to the delays in Table 4-2, we find the costs in Table 4-5.

9 *Economic Values for Evaluation of FAA Investment and Regulatory Programs*, FAA-APO-98-8, June 1998

10 http://api.hq.faa.gov/

Table 4-5. Annual Costs Using the APO Model ($M per year)

	Ground	Airborne	Total Penalty
1 mile offshore	$24.3	$0.5	$24.7
2 miles offshore	$32.4	$2.6	$34.9
3 miles offshore	$40.5	$4.7	$45.1
5 miles offshore	$49.9	$6.3	$56.2
Hybrid	$20.2	$3.9	$24.2

The APO numbers are considerably smaller than the Air Transport Association numbers. Even for the air carrier costs alone, which would most closely correspond to the Air Transport Association member airlines that provided the data, the FAA numbers are only higher than the Air Transport Association estimate of the cost of delay taken at the gate. Note that the two ways of estimating costs to users lead to different rankings of the hybrid and 1-mile-offshore routing plans — according to the industry standard, the 1-mile-offshore routing is less expensive overall; according to APO, the hybrid is slightly less expensive. This is a result of the fact that the Air Transport Association's cost model includes a difference between time on the ground and time in the air, and APO's model does not.

Section 5

Conclusion

This simulation of Los Angeles International Airport and its surrounding airspace has shown that considerable penalties to users will likely result from any attempt to route turboprops over a single route offshore of Palos Verdes. The penalties, in time and operating costs, are primarily suffered by departures from LAX. A secondary impact is suffered by arrivals to SNA, in those scenarios that moved the turboprops more than one mile offshore. No direct disruption of arrivals was seen, as long as traffic stays at this level and the weather stayed good. However, any increase in traffic will mean increases in impact, as will significant periods of IFR. Indirect disruption of arrivals is possible, and will certainly occur unless airlines adjust their schedules to compensate, but identifying aircraft itineraries to link a given departure with an arrival later in the day was outside the scope of this study. These delays at other airports, which also represent a cost to users, were not included in the totals.

This is the third study of this particular reroute. The first, by ATAC Corporation, was perceived by the airlines as underestimating the cost of the reroute. The second, by the Air Transport Association themselves, showed costs ten times as high. This study, because of its more precise representation of the flexibility of current operations, showed costs one to two times as high as the Air Transport Association study.

The question of routing flexibility in the current operation is particularly interesting. ATAC's study used SIMMOD, which is a node-and-link model of air traffic. It can not directly model a near-continuous fan of departures directly. Instead, a SIMMOD analyst must approximate a fan with a finite number of links and nodes. In the ATAC Palos Verdes study, a fan of six routes was used. Since SIMMOD did not show a great difference in ground delay between their six-route set and a single offshore route, it may be surmised that even confining the flights to a few roughly parallel routes would still fall short of current performance. The TAAM simulation, whose results are presented here, had a baseline that more closely reflected current operations, which are more efficient than even a network of six point-to-point routes, so the estimated penalties of changing procedures to a single route were higher.

Appendix

TAAM Usage File for LAX

This is an English-language version of the TAAM input file describing how the various parts of the airport surface are used in the simulation. Words and numbers in **boldface** are parameters that have been set in accordance with observations and facility input. Several parts that deal with the details of the graphical layout have been omitted. Some parameters have been set to zero, to force TAAM's logic to obtain a particular observed result.

Runways

Runway 06L : CLOSED

Runway 06R : CLOSED

Runway 07L : CLOSED

Runway 07R : CLOSED

Runway 24L

70.0 meters wide

Open for: All
Arrival queue is dependent on parallel runways.
Departure queue is dependent on all ops on parallel runways.

All market segments permitted to use this runway.
All weight classes permitted to use this runway.

Max Taxi	Capture Distance (m)	Touchdown distance from threshold (m)	Capture distance for crossing vs. arrivals	Trombone inwards (nmi)	Trombone outwards (nmi)	Base leg minimum (nmi)	Base leg maximum (nmi)
unl.	1800	300	1800	0.00	0.00	3.00	13.01

Runway Dependencies

Runway	Departure Waiting for Arrival	Departure – Departure Separation	Arrival – Arrival Separation	Departure – Arrival Separation
06L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
06R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
24R	Independent	Independent	Independent	Independent
25L	Independent	Independent	Independent	Pass crossing before other aircraft reaches capture distance.
25R	Independent	Independent	Independent	Independent

Pairwise Runway Capture Distance (m)

	Turbojet	Turboprop	Piston
Turbojet	1800	0	0
Turboprop	0	0	0
Piston	0	0	0

Runway 24R

70.0 meters wide

Open for: Arrivals only
Arrival queue is dependent on parallel runways.
Departure queue is dependent on all ops on parallel runways.

All market segments permitted to use this runway.
All weight classes permitted to use this runway.

Max Taxi	Capture Distance (m)	Touchdown distance from threshold (m)	Capture distance for crossing vs. arrivals	Trombone inwards (nmi)	Trombone outwards (nmi)	Base leg minimum (nmi)	Base leg maximum (nmi)
unl.	1800	300	1800	0.00	0.00	3.00	13.01

Runway Dependencies

Runway	Departure Waiting for Arrival	Departure/Departure Separation	Arrival/Arrival Separation	Departure/Arrival Separation
06L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.		Become airborne before other aircraft reaches capture distance.
06R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
24L	Commence after landing aircraft touches down.[11]	Independent	Independent	Independent
25L	Independent	Independent	Independent	Independent
25R	Independent	Independent	Independent	Independent

11 This cell should read "independent", if current operations were taken literally. This setting, however, made the inter-arrival and inter-departure intervals match the observed behavior of flights at the airport.

Pairwise Runway Capture Distance (m)

	Turbojet	Turboprop	Piston
Turbojet	1800	0	0
Turboprop	0	0	0
Piston	0	0	0

Runway 25L

70.0 meters wide

Open for: Arrivals only
Arrival queue is dependent on parallel runways.
Departure queue is dependent on all ops on parallel runways.

All market segments permitted to use this runway.
All weight classes permitted to use this runway.

Max Taxi	Capture Distance (m)	Touchdown distance from threshold (m)	Capture distance for crossing vs. arrivals	Trombone inwards (nmi)	Trombone outwards (nmi)	Base leg minimum (nmi)	Base leg maximum (nmi)
unl.	1800	300	1800	0.00	0.00	3.00	13.01

Runway Dependencies

Runway	Departure Waiting for Arrival	Departure – Departure Separation	Arrival – Arrival Separation	Departure – Arrival Separation
06L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
06R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
24L	Independent	Independent	Independent	Independent
24R	Independent	Independent	Independent	Independent
25R	Commence after landing aircraft touches down.	Independent	Independent	Independent

Pairwise Runway Capture Distance (m)

	Turbojet	Turboprop	Piston
Turbojet	1800	0	0
Turboprop	0	0	0
Piston	0	0	0

Runway 25R

53.0 meters wide

Open for: All
Arrival queue is dependent on parallel runways.
Departure queue is dependent on all ops on parallel runways.

All market segments permitted to use this runway.
All weight classes permitted to use this runway.

Max Taxi	Capture Distance (m)	Touchdown distance from threshold (m)	Capture distance for crossing vs. arrivals	Trombone inwards (nmi)	Trombone outwards (nmi)	Base leg minimum (nmi)	Base leg maximum (nmi)
unl.	1800	300	1800	0.00	0.00	3.00	13.01

Runway Dependencies

Runway	Departure Waiting for Arrival	Departure – Departure Separation	Arrival – Arrival Separation	Departure – Arrival Separation
06L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
06R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
07R	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Become airborne before other aircraft reaches capture distance.
24L	Independent	Independent	Independent	Independent
24R	Independent	Independent	Independent	Independent
25L	Commence after landing aircraft touches down.	Fully dependent on departures on other runway.	Independent	Independent

Pairwise Runway Capture Distance (m)

	Turbojet	Turboprop	Piston
Turbojet	1800	0	0
Turboprop	0	0	0
Piston	0	0	0

Gates

Gate Occupancy Times: (All times are in minutes)

	Before Departure	After Arrival	Wait for Link	Min. Turnaround
Med/heavy	20	20	40	20
Light	1	1	1	1

Taxi

'Previous Aircraft' means the last aircraft to use this **segment**.
The capture distance is calculated for aircraft crossing a **runway when the aircraft clears the runway**.
Aircraft start and end **at the gate**

Default Ground Movement Speeds (kt):

Default Taxi Speed **15** kts
Default Apron Taxi Speed **7** kts
Default Towing Speed **5** kts

Sequencing Intervals

Default Interval	Rwy Capture Distance (m)	Crossing Clearance	Seq Distance for Parallels (m)	Ground Delay Threshold	Runway Holding Preference	Airborne Separation Check (nmi)
0	1853	1853	1852	1920	0%	20.0

Arrival Sequencing and Landing Queue Thresholds

Queues & Sequencing on the basis of **distance**:

Enter landing queue **139** nmi from airport.
Begin sequencing actions **98** nmi from airport.
Sequence fixed **48** nmi from airport.

Departure Sequencing

The sequencing strategy is in order of **Flow ETA**
Partial departure sequence optimization
Departures **are** radar separated, beginning **3** nmi from airport.
Conflict look-ahead time is **360** seconds.

Max crosswind/tailwind, dry runway: **5 / 25** kts.
Max crosswind/tailwind, wet runway: **0 / 20** kts.

Miles in Trail and Flow Management

Do not use intrail separation with overflights.
Do not use intrail separation past top of descent.
No limit on flow into airport.
Reassess flow every 0 minutes.
No speed control on cruise.
Use ground delay instead of airborne if the departure airport is within 0 nmi.
The desired IAS on final approach is **150** kts.
If the ground delay is greater than **3** hours, **let the flight depart**.
Line up departures **early**.

Miscellaneous Parameters

Flights **may not** overtake on STARS.
Simultaneous operations **are** permitted on crossing runways.
Link flights by **callsign, flight number, or carrier**.
Delay flights **at gate** to minimize overall delay.
Select a sid or star if the route is within **35** miles and **60** degrees of the arrival fix (measured from airport).
Airborne conflict checking is **on**.
Safe taxi mode is **off**.
Calculate runway length needed from **acceleration of aircraft**
Gates **are** used.
Max delay at gate is 5.0 minutes.
Taxipath changing **is** permitted
Taxipath changing **is** permitted, even after waiting.
Doglegs for short air delays **will** be used.

Taxiway Penalties

No change from defaults. Extra distance added to taxi path for each:

	distance (m)
degree of turn	5
aircraft coming in opposite direction	1000
open-runway crossing	100
aircraft going to different runway	100
deicing station	1000

Runway Selection Strategies

Departures

Choose the runway closest to the departure fix.
If no suitable runway is found, **use the runway closest to suitable**.
Override the default selection if the difference in
 queue length is greater than **10**,
 crosswind (kt) is greater than **20**,
 tailwind (kt) is greater than **5**,
 gate/runway distance (m) is greater than **5000**,

Arrivals

If no suitable runway is found, **use the runway closest to suitable**.
Override the default selection if the difference in
 queue length is greater than **10**,
 crosswind (kt) is greater than **20**,
 tailwind (kt) is greater than **5,**
 gate/runway distance (m) is greater than **5000**,

Flights stay in the runway list for **2.0** minutes.
Time between checks for pushback is **1.0** minutes.
No limit on number of taxiing aircraft.

Glossary

APO	Office of Policy and Plans
ARTS	Automated Radar Terminal System
ATA	Air Transport Association
AWP	Western Pacific Region of the FAA
CAASD	Center for Advanced Aviation System Development
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
IMC	Instrument Meteorological Conditions
LAX	Los Angeles International Airport
OAG	Official Airline Guide
OPSNET	Operations Network
PANIC	Peninsula Aircraft Noise/safety Information Committee
SDAT	Sector Design Analysis Tool
SIDS	Standard Instrument Departures
STARS	Standard Terminal Automation Replacement System
TAAM	Total Airport and Airspace Modeler
TRACON	Terminal Radar Approach Control Facility
VFR	Visual Flight Rules