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Influence of Capacity Constraints on Airline Fleet Mix

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Executive Summary

The continuing increase in the demand for air transportation has resulted in volumes of air traffic that are approaching the capacity of the airport infrastructure at many major airports in the United States and elsewhere in the world, leading to the prospect of significantly greater levels of air traffic delay in the future unless capacity can be expanded. At the same time, environmental and other concerns are limiting the ability of airports to construct additional runways to increase their airside capacity. However, the passenger throughput of the runway system at major airports is dependent on the fleet mix, and an increase in average aircraft size will allow an airport to serve more passengers with the same number of aircraft movements. Thus there is growing interest at many congested airports in policy options that could influence airlines to accommodate traffic growth through the use of larger aircraft rather than adding flights. This report documents the findings of research sponsored by the Los Angeles World Airports to examine the influence of airport capacity constraints on airline fleet mix and to explore the potential effects of policy options to encourage airlines to utilize larger aircraft in congested markets.

Changes in average aircraft size do not result from a steady increase in the size of each aircraft, but instead from a change in the composition of the traffic being handled by an airport and the discrete changes in aircraft size in particular markets when different aircraft types are deployed in those markets. Thus in order to understand the likely future trends in average aircraft size, as well as the effect of strategies that the airport might pursue to encourage favorable trends, it is necessary to understand the competitive dynamics of the various markets served by the airports, and the factors that determine the type of equipment that airlines use in those markets. These factors are likely to differ significantly between short haul and long haul markets, while both the volume of traffic in a market and the number of carriers serving the market will affect the size of aircraft that can be economically operated in the market.

At major hub airports, such as Los Angeles International (LAX), a significant proportion of the runway capacity is utilized by regional airline operations using relatively small turboprop aircraft. While these operations account for a large proportion of the total aircraft movements, they handle a relatively small proportion of the passenger traffic. At LAX these operations account for about 30 percent of the aircraft movements, but only about 5 percent of the passengers. Thus the competitive dynamics of air service in these markets, as well as the type of equipment used, can have a dramatic effect on total aircraft operations at the larger airports. The mix of large and small aircraft can also affect the runway capacity due to both speed differences and the need to provide greater separation when small aircraft follow heavy aircraft. However, these flights form an important link to the smaller communities in the surrounding region, providing them with access to longer haul flights, as well as feeding the airline hub operations at the major airport. Therefore consideration needs to be given to the political implications of policy options that affect air service for these communities.

Until recently, airport authorities have given relatively little attention to policies that might influence the type of aircraft that airlines use at their airports. The High Density Rule that the FAA imposed on Chicago O'Hare, New York Kennedy, New York LaGuardia, and Washington National airports in 1985 established slot limitations that restricted the ability of airlines to add flights, and in the case of New York LaGuardia and Washington National airports also established a perimeter rule that prohibited nonstop service to and from airports more than 600 miles from the two airports. In the case of Washington National, there was also an explicit limitation on the size of the aircraft, due in part to the length of the runways. More recently, the Massachusetts Port Authority (Massport) attempted to implement a change in the structure of the landing fees charged to airlines at Boston Logan Airport. Termed the Program for Airport Capacity Enhancement (PACE), the proposed fee structure would have replaced the existing price structure that was proportional to the certificated landing weight of the aircraft with one that charged smaller aircraft more per unit weight than larger aircraft. However, the proposed program was challenged in court by the airlines and the FAA, the courts ruled in favor of the challengers, and Massport withdrew its proposal.

In spite of this limited and somewhat inauspicious experience with such policies, it is clear that a range of policy options is possible. These options fall into five broad classes:

1. Limitations on the use of specific aircraft types or markets that can be served;
2. Limitations on the frequency of service, either on a market-specific basis or by limiting the number of operations for each airline (slot controls);
3. Pricing structures that favor the use of larger aircraft;

4. Negotiated agreements with airlines that limit the size of aircraft that are used or the frequency with which certain markets are served;
5. Changes in the priority rules by which aircraft are handled by the air traffic management system during congested conditions.

Some of these options are actions that an airport authority could take on its own, some would require the support of the FAA, and some could require legislation. However, the need for legislation need not be an insuperable barrier. Airport delays are clearly a matter of great public concern, and airport authorities are in a strong position to lobby for legislative change if it can be shown to be in the best interests of the traveling public. Since reducing the costs of airport delay is also in the financial interests of the airlines, it may even be possible to craft proposals that will obtain the support of the airline industry.

Even if no explicit actions are taken to encourage the use of larger aircraft, growing delays may cause airlines to begin to utilize larger aircraft. Airlines are only too well aware of the disruption that their operations experience when traffic demand exceeds capacity at busy airports. However, their ability to utilize larger aircraft is constrained by their overall fleet and how aircraft are routed across their network, as well as the competitive situation that they face in each market. Thus a critical question addressed by the current research is how much increase in average aircraft size can be expected to result from growing levels of congestion, absent policies to encourage the use of larger aircraft.

Traffic Trends at Los Angeles International Airport

An analysis of the growth in passenger traffic in different market segments at LAX since 1970 shows that while all market segments have experienced traffic growth, international traffic has grown faster than domestic traffic and regional airline passenger traffic has also grown faster than the domestic traffic of the large airlines, although the regional airline traffic growth appears to have slackened in the last few years. While the number of aircraft operations has not grown as much as passenger traffic over the past three decades, the growth in operations since 1982 has generally kept pace with the growth in passenger traffic. The resulting ratio of average passengers per operation grew steadily from 1970 to the mid 1980's, then declined slightly over the following decade and has been showing an upward trend since 1995 to approach the level it was at 15 years ago.

However, the trends in average number of passengers per operation and average aircraft size differ across the market segments. The growth in average passengers per operation for domestic air carrier traffic over the past decade has been due entirely to an increase in average load factor, and the average number of seats per departure has actually declined slightly. In contrast, the regional airlines have shown a significant and steady growth in both the average number of passengers per operation as well as the average aircraft size, due to the replacement of aircraft with 19 or fewer seats by aircraft in the 30 to 35 seat range. The average number of passengers per operation for international traffic peaked in 1988 and has been relatively stable since 1994 at a level somewhat less that in 1988, although considerably higher than for domestic traffic.

Between 1988 and 1998 there were significant changes in the size and number of markets served by regional airlines from LAX. Two trends stand out over this ten year period: first the dramatic growth in regional airline traffic in most of the larger markets, and second the loss of regional airline service from LAX in many of the smaller markets. The number of markets with direct service declined from 33 to 21, while the number of markets with more than 100,000 enplaned passengers per year in each direction increased from one to five. At the same time, the number of markets with less than 50,000 enplaned passengers per year declined from 30 to 10, while the number of markets with less than 1,000 enplaned passengers per year went from 10 to one. One factor in the growth of regional airline traffic was the replacement of air carrier service in three of the larger markets by regional airlines as a result of the development of code-sharing relationships between the regional airlines and the major airlines.

Short and medium haul markets in the western states, including the California Corridor between Southern California and the San Francisco Bay Area, accounted for ten of the twenty densest domestic markets from LAX in 1999, with Las Vegas and San Francisco the largest and second largest market respectively. The majority of these markets involve both frequent service and use of relatively small aircraft. Therefore examination of the recent tends in these markets provides a useful perspective on the factors that appear to be influencing the size of equipment used in such markets and the prospects for increasing average aircraft size.

Passenger traffic grew significantly in most of the ten markets from 1988 to 1999, with the exception of San Francisco, where it declined by 13 percent. However, traffic growth to the two other Bay Area airports (Oakland and San Jose) more than offset the decline in traffic to San

Francisco, with traffic to Oakland growing more than threefold. The average aircraft size in these markets increased over the period in all but two markets (San Francisco and Seattle), although the changes appear to be unrelated to the amount by which the traffic has increased in each market. Overall in the ten markets, the average aircraft size increased from 136 seats to 139 seats over the period, an increase of about 2 percent over a period when the total traffic in these markets grew by 36 percent.

Closer examination of the traffic and aircraft size data for individual markets showed that the changes were by no means uniform over the period, and aggregate data at the market level conceal significant changes in market share and concentration. Several markets became significantly more concentrated by 1999, with United Airlines carrying almost 80 percent of the traffic in the LAX-San Francisco market, Southwest Airlines carrying over 75 percent of the traffic in the LAX-Oakland market, and Alaska Airlines carrying 70 percent of the traffic in the LAX-Seattle market. In other markets the changes were more complex, with Southwest and United Airlines generally increasing their market share at the expense of the incumbent carriers in 1988. However, in spite of this increase in market concentration, there was very little, if any, increase in average aircraft size by the dominant carriers over the period. Almost all the markets showed an increase in load factor over the period, which resulted in an increase in passengers per departure, even if the average aircraft size did not increase.

The analysis of traffic patterns at LAX over the past ten years has shown that in spite of the significant growth in passenger traffic, there has been no corresponding increase in average aircraft size by the large domestic and international airlines. There has been a significant increase in average aircraft size by the regional airlines, although the associated increase in capacity has been partly the result of the large airlines discontinuing service in several of the larger regional airline markets, and it is unclear whether further growth in the regional airline markets will be served through an increase in frequency or the introduction of larger aircraft. While the growth in total aircraft operations appears to have leveled out over the past three years, this is largely the result of shifts in traffic composition, and further growth in passenger traffic is likely to result in a resumption of the growth in aircraft operations. A related issue of concern is the general increase in load factors over the past ten years in many markets that has allowed aircraft operations to grow more slowly than passenger traffic, with little or no increase in average aircraft size. However, there are obviously limits to how much further load factors can increase, and those limits are probably close to being reached.

It is clear that a significant factor in the decision of what size aircraft to use in a given market is the effect on each airline's competitive position in the market. Although the larger West Coast markets have seen a significant increase in market concentration, with different markets dominated by Alaska, Southwest and United Airlines, this has not resulted in a corresponding increase in average aircraft size. Rather, what appears to have happened is that those three airlines have tended to operate the same size aircraft in all markets and to add frequency as their market share increased. On balance, the examination of the trends over the past ten years suggests that prospects for a significant increase in average aircraft size over the next decade at airports like LAX, if left solely to market forces, are not very encouraging.

Fleet Mix, Delay and Scheduling Externalities at LAX

The fleet mix and flight schedule not only affects the number of aircraft operations to be handled at the airport, but also the runway capacity as a result of the different approach speeds of different aircraft types and the minimum separations that air traffic control rules require between aircraft of different weight classes. An analysis of the flight schedule at LAX for 1998 showed that although nonstop service was provided to LAX from 72 domestic and 54 international origins, the 20 markets with the most service accounted for about 60 percent of the flights, while the next 20 markets in terms of service accounted for about a further 20 percent of all flights. The ten markets with the most nonstop service averaged over 200 flights per week each, or more than 30 flights per day. Thus a high proportion of the total aircraft operations at LAX serve relatively few markets.

During congested periods, when demand approaches or exceeds capacity, each flight not only experiences a delay itself, but its presence in the traffic stream increases the delays experienced by all the subsequent flights in the queue of aircraft waiting to use the runway to land or take off. Of course, these queues may not be fully, or even partially, visible, since departing aircraft may be held at their gate or other locations on the airfield rather than in the physical queues at the end of the runways, while arriving aircraft are delayed through various air traffic management strategies, including being held on the ground at their origin airport.

It is therefore appropriate to ask how much delay each flight imposes on other aircraft using the airport. An aircraft at the beginning of a congested period imposes delays on all the subsequent aircraft in the queue until the congestion dissipates. The last aircraft in the queue, on the other hand, only incurs delay itself and imposes no additional delay on other aircraft. If delay is measured in terms of seat-minutes, rather than aircraft-minutes, since a given delay is more costly and inconveniences more passengers when incurred by a large aircraft than by a smaller one, it is clear that the ratio of the delay imposed on other flights by a given flight to that incurred by the flight itself will be much greater for smaller aircraft.

In order to measure how much delay each flight imposes on other flights for a typical day's schedule at LAX, a deterministic queueing model was developed to predict the arrival delay incurred by each arriving flight during the day. For a given run, the arrival time of each flight in the absence of any delay was determined from the flight schedule and varied stochastically to account for variation in flight time or other delays that are not due to runway capacity at LAX. The minimum inter-arrival times (the time interval between each pair of arrivals in the sequence of flights at each runway) were calculated on the basis of aircraft approach speeds and minimum air traffic control separation requirements. When the arrival rate exceeded the resulting runway capacity, arrival queues formed and the delay incurred by each aircraft was calculated from the difference between its planned arrival time based on the adjusted schedule and its actual arrival time due to the arrival queue. Twenty different runs were made to allow for the variation in arrival delays due to the effect of the stochastic adjustment to the scheduled arrival time on the sequence of arriving traffic, and the average delay incurred by each flight was calculated, together with the average total delay imposed by each flight on all the other flights affected by it.

Not surprisingly, it was found that the additional delay imposed on other flights, which we term the Congestion Delay Impact (CDI) varied widely from flight to flight through the day. During the late morning peak, some flights had a CDI in excess of 3 aircraft-hours, while other flights at about the same time had a CDI of only a third as much. However, the arrival delays incurred by each aircraft during this period varied between about 5 and 15 minutes.

Clearly, eliminating flights with high values of CDI would result in significant reductions in delay to other flights. But what of the passengers on those flights? If they were to take the previous flight from the same origin on the same airline (which might have to use a larger aircraft to handle the additional passenger load), in the worst case they would incur the inconvenience of additional travel time equal to the difference in the scheduled departure times of the two flights from the origin, which we term the Schedule Delay Impact (SDI) of the flight being considered for elimination. In order for a meaningful comparison of the values of CDI and SDI for a given flight, they should both be calculated on the basis of seat-minutes (or seat-hours) of delay. We define the Delay Impact Ratio (DIR) for a given flight as the ratio of CDI to SDI for that flight. Values of DIR greater than unity mean that eliminating the flight would reduce the delay to passengers on other flights by more than the additional travel time incurred by those on the eliminated flight, assuming similar load factors on each of the flights. Put another way, adding such a flight to the schedule generates delay costs for other flights that exceed the convenience benefits of adding the flight.

Analysis of the LAX schedule for a typical day showed that a few flights had very high DIR values. The highest DIR was 55, for a USAir Express flight from San Diego, and a further 15 regional airline flights and one domestic air carrier flight had DIR values of 10 or higher. Eliminating five regional airline flights with some of the highest DIR values would produce a cumulative reduction in delay of about 12 aircraft-hours, or 1,570 seat-hours, per day for a cumulative increase in SDI of about 51 seat-hours per day.

Determinants of Aircraft Size

To better understand the factors that influence fleet mix, regression analysis was used to study the relationship between the average size of aircraft flown on U.S. domestic service segments and segment characteristics such as traffic level, segment length, and congestion at the endpoint airports. The models were estimated on a data set consisting of domestic flight segments originating from 18 major U.S. airports that include all of the major airports on the east and west coasts. Interior airports were not included because the larger airports are major hubs, which are dominated by connecting traffic. Such airports are nonetheless represented in the data set since they are the endpoints for many of the segments originating from the 18 study airports.

Data for the number of flights flown, the number of seats, and the number of passengers carried on scheduled service by certificated carriers for each non-stop segment from the study airports in 1998 were obtained from data reported to the U.S. Department of Transportation (DOT) on Schedule T100, using the Onboard dataset from Data Base Products, Inc. Traffic carried by commuter airlines on each of these segments was also estimated by combining data for regional airlines in the T100 dataset with on-line origin-destination data for commuter carriers reporting on Schedule 298C. We discarded those segments where the proportion of traffic carried by commuter airlines exceeded 20 percent, together with those that did not average at least one flight per day by certificated carriers. Altogether, this resulted in 526 segments involving the 18 study airports.

Delay data were obtained from a previous FAA study that had used the U.S. DOT Airline Service Quality Performance (ASQP) database to calculate average arrival delay (the difference between actual arrival time and scheduled arrival time) and flight delay (actual flight time less scheduled flight time) for major U.S. airports.

We used the segment data to estimate regression models that explain the variation in average seats per flight in terms of segment characteristics. We divided our data into two subsets, based on whether the segment density exceeds 300 passengers per day. We term those segments meeting this criterion “high density” segments, the others as “low density” ones. Separate models were estimated for these two subsets. In addition, it proved useful to subdivide the high-density segments into short-haul (length under 500 miles) and medium/long-haul segments (length of 500 miles or more, and termed “long-haul” for brevity).

We found that aircraft size on high density short-haul segments depends largely on density and concentration. The coefficients of these variables in the final model are highly significant statistically, and have similar magnitudes of about 0.13. Since the model is log-linear, this implies that a 10 percent increase in segment density or concentration will result in a 1.3 percent increase in aircraft size. The resulting model explains about half of the observed inter-segment variation in aircraft size, while the model standard error implies that its predictions are accurate to about 10 percent.

The airport constants in the preferred model are mostly insignificant, with the exception of that for Seattle. Most of the estimates are also negative, implying that, relative to the reference airport, LAX, these airports are served by smaller aircraft in their high density short-haul markets, all else equal. While several airports, including Orlando and Tampa, have positive estimates, in no case are these statistically significant. From this we conclude that for high density short-haul segments served by certificated carriers, average aircraft sizes at the other airports in our study are not significantly different from the pattern observed in segments from LAX.

The estimation results for high density long-haul segments are considerably more complex than the short-haul model. The significant factors are density, concentration, stage length, and delay. Market density and delay appear both individually and in interaction with stage length, while for concentration only the stage length interaction is included. Density is positively related to aircraft size, but the effect declines as stage length increases. Delay, however, becomes more important at longer stage lengths. Its individual coefficient is negative, but the overall effect of delay is approximately zero at stage lengths of 500 miles, increasing to about 0.9 for 2,500-mile segments. For similar reasons, increased stage length leads to larger aircraft despite the negative coefficient on the individual stage length term. Aircraft size is more sensitive to stage length when segments have low densities, high delays, and high concentrations.

Several of the airport constants were found to be negative and statistically significant, including those for Boston, Washington National, Newark, Philadelphia, and San Francisco. All else equal, these airports have aircraft sizes 10-20% smaller than LAX. Three airports—Washington Dulles, New York Kennedy, and Miami—have sizes slightly, but not statistically significantly, higher. Thus, for long-haul as well as short-haul segments, we conclude that the majority of other airports considered in this study are similar to LAX in terms of the average size of aircraft used on segments of given characteristics.

The model results for low density segments with under 300 passengers per day served by certificated carriers cover all stage lengths, since there is insufficient data to estimate separate short-haul and long-haul models. In the final model, average aircraft size increases with traffic density, segment length, and segment concentration, with all three relationships significant at the 1 percent level. An increase of 10 percent in each of these variables is associated with aircraft size increases of 2.0, 1.6, and 1.2 percent respectively. The model explains about half of the variation in aircraft size observed in the sample.

Most of the airport constants are positive, in many cases significantly so. This means that, controlling for other factors, low density segments from these airports tend to be served by larger aircraft than at LAX. The magnitude of this difference exceeds 10 percent in several cases, and in the case of New York Kennedy exceeds 60 percent.

Cost Economies of Aircraft Size

An analysis of the relation between aircraft size and airline costs was undertaken as part of the study. Naturally larger aircraft cost more to operate than smaller aircraft, but they also can potentially carry more passengers, resulting in a lower cost per passenger. The analysis departed from a more traditional approach by estimating models of direct and indirect operating cost as a function of the average stage length operated with that equipment, as well as aircraft size and factor prices for fuel and flight crew. It was found that flight crew costs play a significant role in the cost economies of aircraft operation, and that much of the inherent scale economies of larger aircraft have been captured as higher compensation by the flight crew operating that equipment.

In general, direct operating costs show scale economies with respect to both aircraft size and stage length. For a given stage length, direct operating cost per trip declines initially with aircraft size, then increases again with much larger aircraft. The aircraft size that minimizes direct operating cost per seat was found to increase from around 200 seats at 400 miles, to 250 seats at 1.200 miles, and over 300 seats at 2,400 miles. These results change considerably if flight crew cost is treated as endogenous, and scale economies at the sample mean were found to be essentially non-existent.

Policy Interventions

Although airport authorities have generally viewed the airline fleet mix using the airport as a matter beyond their control, there are in fact a number of possible policy options that could be pursued to influence airline decisions affecting the future fleet mix. Consideration of these various policy options needs to consider their legality and likely effectiveness, as well as potential obstacles to implementation.

The legal precedents for airport policy actions to regulate airline decisions on the size of aircraft to use at an airport appear both limited in number and conflicting in direction, in large part reflecting the very limited historical experience with airport interventions in this area. Many of the precedents addressing the rights of airport authorities to regulate aviation activity at their airports have arisen as a result of efforts to control aircraft noise, not air traffic congestion. In a landmark court case in 1973, the U.S. Supreme Court overturned an ordinance by the City of Burbank that banned nighttime jet takeoffs from Burbank Airport, on the grounds that the ban affected operations in federally controlled airspace, and that federal regulation of aircraft noise preempted state and local control. However, the court drew a distinction between the exercise of police authority and the authority of a municipality acting as an airport landlord, a distinction that came to be known as the "proprietor's exemption". Airport congestion has been recognized as an area in which the proprietor's exemption applies, and the courts have upheld the right of the Port Authority of New York and New Jersey to prohibit nonstop flights operating over a specified stage length from LaGuardia Airport, on the grounds that regulating airport congestion is at the core of a proprietor's function as airport manger.

However, the way is which airports exercise these powers are circumscribed by federal law, and any rules, restrictions and user changes must be reasonable and nondiscriminatory. Given the broadness of these principles, their application by the courts has tended to be uneven and inconsistent. In the case of the attempt by the Massachusetts Port Authority to change the landing fee structure at Boston Logan Airport under the Program for Airport Capacity and Efficiency, in order to reduce congestion due to large numbers of small aircraft using the airport, the courts eventually ruled that the program intruded upon federal regulatory responsibility, reversing an earlier Federal court ruling that the proposed fee structure was reasonable in that it reflected the opportunity cost of using the airport.

Subsequently, the federal Airport Noise and Capacity Act has imposed further limitations on the ability of airports to apply their proprietary powers. The implementing regulations specified in Part 161 of the Federal Aviation Regulations (14 CFR 161) establish a set of conditions that must be met for the Secretary of Transportation to approve a restriction on access to an airport that has not gained the agreement of airport users. These include evidence that other remedies are infeasible or would be less cost-effective, and a cost-benefit analysis to show that the proposed restriction would not create an undue burden on interstate or foreign commerce.

Within the framework provided by FAR Part 161, there are several potential rationales to justify the intervention of airport authorities in airline fleet mix and scheduling decisions. The first rationale derives from concepts of welfare economics and represents a logical response to a market failure that causes significant and unnecessary costs to society. Because the delay costs incurred by an additional flight during congested conditions are so much less than the costs imposed on all the other flights using the airport during this period, it can be argued that some regulatory intervention is necessary to prevent excessive use of the airport facilities that imposes greater costs on airport users as a whole than the benefits derived from the additional flights.

The second rationale derives from the well-established responsibility of the airport authority to plan for future development in a deliberate way, through the preparation and updating of airport master plans. This process is designed to evaluate alternative ways of meeting future demand, and selecting the most cost-effective for the airport users. Traditionally, this evaluation has only considered alternative facility configurations. It would appear both consistent and desirable to extend this approach to operational alternatives that include airline decisions that have traditionally been considered exogenous to the facility planning process. Since the airlines pay for a significant part of the airport facilities through landing fees and space rental charges, and their passengers pay the rest through ticket taxes, concession fees, and other charges, the case can be made that an appropriate balance between additional facilities and operational restrictions is in fact in the best interest of the airlines.

The third rationale considers intervention from a public interest perspective that addresses both consumer protection and environmental protection. Air traffic delays reduce the value of the air service that travelers have purchased, and the airport operators have a recognized role in promoting the quality of the air travel experience involved in using the airport, as they currently do by providing high quality terminal facilities and regulating airport concessions. Airport congestion and delay may also have adverse environmental impacts, including an increase in emissions from aircraft delayed in departure queues or waiting for gates to become available, and an increase in noise impacts when excessive delays cause more flights to operate during late evening and night hours.

Apart from the legal and policy justification for intervention, it is also necessary to consider the form that the intervention will take. The easiest is to work with the airlines to implement voluntary programs. The principal difficulty with such an approach is how to prevent other airlines taking advantage of reductions in flight frequency or changes in schedule by a participating carrier to add flights of their own. A second broad approach is through pricing. Peak period surcharges on landing fees would encourage some airlines to schedule their flights at less busy times of day or to utilize larger equipment to increase revenue per flight to cover the higher operating costs. The third approach is through regulations that limit either the size of aircraft that can be operated during congested periods or the frequency in high density markets.

It may be desirable to regulate both size and frequency, as was proposed by San Francisco International Airport, by requiring the use of larger aircraft in markets with higher frequencies. This will tend to limit the ability of airlines to add flights in a market as the traffic grows.

Conclusions

It is clear from an analysis of traffic patterns at LAX over the past ten years that in spite of the significant growth in passenger traffic, there has been very little, if any, increase in average aircraft size by the large domestic and international airlines. There has been a significant increase in average aircraft size by the regional airlines, resulting largely from the replacement of aircraft with 19 or fewer seats by aircraft in the 30 to 35 seat range. However, the regional airlines currently serving LAX have not so far deployed larger aircraft than 35 seats in any of the markets, and it is unclear whether further growth in the regional airline markets will be served through an increase in frequency or the introduction of larger aircraft.

While the growth in aircraft operations over the past ten years appears to have leveled out over the past three years, this is largely the result of shifts in traffic composition, and further growth in passenger traffic is likely to result in the resumption of the growth in aircraft operations. The analysis presented in this paper suggests that airline response to the resulting increase in delays that will inevitably occur appears likely to result in only modest increases in average aircraft size, if left to market forces. In any event, airlines cannot deploy aircraft that they do not have in their fleets, and therefore any significant increase in average aircraft size is likely to be a slow process.

On balance, the prospects for a large enough increase in average aircraft size over the next decade at airports like LAX to accommodate the expected growth in traffic are not very encouraging. Delay costs alone do not appear sufficient to offset the competitive advantages of greater flight frequencies, particularly in short haul and low density markets. Without some intervention by the airport operator, it appears likely that traffic growth will lead to ever greater levels of delay at many airports, including LAX. Although there appears to be weak evidence that the airlines have increased the average aircraft size in many congested markets, this effect is much less pronounced than necessary to offset the growth in traffic. Therefore some form of policy intervention appears to be necessary to encourage the use of larger aircraft if significant future increases in delay levels are to be avoided. A number of approaches are possible, and careful assessment of the pros and cons of each, together with input from the airlines using the airport, will allow the design of appropriate measures that meet the airport objectives within the economic and operational constraints faced by the airlines.

1. Introduction

This report documents the findings of research sponsored by the Los Angeles World Airports to examine the influence of airport capacity constraints on airline fleet mix and to explore the potential effects of policy options to influence airlines to use larger aircraft types and thereby accommodate growth in passenger or cargo demand without a corresponding increase in the number of aircraft operations. This issue is of growing importance at many major airports in the United States and indeed around the world, as a steadily increasing demand for air transportation has resulted in volumes of air traffic that are approaching the capacity of the existing airport infrastructure, resulting in the prospect of significantly greater levels of aircraft delay in the future. At the same time, environmental and other concerns are limiting the ability of airports to construct additional runways to increase their airside capacity.

Background

The productivity of the runway system at major airports is largely dependent on the fleet mix. An increase in average aircraft size will allow an airport to serve more passengers with the same number of aircraft movements, and the peak period capacity of the runway system is itself affected by the mix of larger and smaller aircraft, due to differences in aircraft performance and the differing separation standards resulting from wake vortex considerations. It is common for airport traffic forecasts to assume a continuing increase in average aircraft size in the future, which will allow passenger traffic to continue to grow at a faster rate than aircraft operations. However, changes in average aircraft size do not result from a steady increase in the size of each aircraft. Rather they result from a change in the composition of the traffic being handled by the airport and quantum changes in aircraft size in particular markets when different aircraft types are deployed in those markets. Thus in order to understand the likely future trends in average aircraft size, as well as strategies that the airport might pursue to encourage favorable trends, it is necessary to understand the competitive dynamics of the various markets served by the airport, and the factors that determine the type of equipment that airlines will find economical to use in those markets.

Although fleet mix and load factor are critical determinants of runway system productivity, airports have generally perceived these as beyond their control. Recently, however, there has been growing recognition that, although airlines are the primary decision makers in these domains, airports can exert some leverage through economic incentives, quotas and other operational restrictions, and other means. Moreover, capacity limitations themselves are likely to influence airline service decisions, so that any action taken by an airport to increase capacity may also affect fleet mix and load factor. There is, however, little quantitative information about the impact of airport policies and actions on these variables.

The competitive situation is critical to understanding what size aircraft can be used economically in a given market. If only one airline serves a market, it can deploy the largest aircraft that will provide a reasonable number of daily trips and still achieve a profitable load factor. However, as more carriers enter the market, the airlines will tend to reduce the size of the aircraft that they deploy in the market, both reflecting the fact that the traffic is now divided between several carriers, as well as the desire to retain or obtain as large a market share as possible by offering a more frequent (or at least no less frequent) service that the competition. Where an airline operates only one type of aircraft, the issue of what sized aircraft to operate in a given market is largely predetermined. It is of course possible for an airline to acquire larger aircraft However, there are significant costs involved in doing so, apart from the cost of the aircraft itself, which are likely to discourage an airline from acquiring larger equipment for use in a single market, even if the aircraft could be operated economically in that market. These constraints are somewhat less on long-haul international routes, where a given aircraft may only make one round trip or less per day, and time-zone differences restrict the number of feasible departure times.

At major hub airports, such as Los Angeles International, a significant proportion of the runway capacity is utilized by regional airline operations using relatively small turboprop aircraft. While these operations account for a large proportion of the total aircraft movements, they handle a relatively small proportion of the passenger traffic. However, these flights form an important link to the smaller communities in the state, providing them with access to longer haul flights, as well as feeding the airline hub operations at the major airport. As air traffic generated by the smaller communities grows, these regional airline flights will also increase. If the growth in these markets exceeds that of the major airport as a whole, the proportion of regional airline flights could also increase. On the other hand, the regional airlines might utilize larger aircraft or commence direct service to more distant hubs using regional jet aircraft.

Forecasts of the number of aircraft operations that will be required to serve a projected level of air travel demand is dependent on the assumed changes in both load factor and average aircraft size. These two factors are commonly combined and expressed as the number of enplaned passengers per departure. However, since the proportion of each type of aircraft in the flights serving the airport is required for other reasons (such as capacity and noise analysis) and there is no real basis for predicting changes in enplaned passengers per departure without understanding the associated changes in aircraft mix in different markets, it makes sense to forecast these two factors separately. Since airport capacity is likely to be constrained at most major airports for the foreseeable future, particularly under scenarios of limited airside expansion, it is critical to be able to predict how airline decisions and marketing strategies in response to capacity constraints will affect fleet mix and load factors. These decisions are not independent of airport authority policies and strategies, particularly with regard to such factors as landing fees and the availability of gates. Thus an important aspect of this issue is how airport authority policies can influence these airline decisions in favorable directions.

Policy Options to Influence Fleet Mix

Until recently, airport authorities have given relatively little attention to policies that might influence the type of aircraft that airlines use at their airports. The Airline Deregulation Act of 1978 not only eliminated the regulatory functions of the former Civil Aeronautics Board in favor of allowing a competitive marketplace for airline services, but established a Federal preemption for airline regulation that precluded other levels of government from imposing regulations on the way in which airlines provide service. Even so, airports and the Federal Aviation Administration (FAA) take actions, set fees, and establish operating procedures that influence the cost and efficiency of airlines operations. It would be naïve to imagine that these factors do not influence airline operational decisions. Indeed, the vigor with which airlines respond to proposals to change any of these policies suggests that they are a matter of great concern.

Historically, perhaps the most significant example of a policy that can influence the type of aircraft that airlines deploy at an airport is the High Density Rule that the FAA imposed on four airports (Chicago O'Hare, New York Kennedy, New York LaGuardia, and Washington National) in 1985. This rule established slot limitations that restricted the ability of airlines to add flights, and in the case of New York LaGuardia and Washington National airports also established a perimeter rule that prohibited nonstop service to and from airports more than 600 miles from the two airports. In the case of Washington National, there was also an explicit limitation on the size of the aircraft, due in part to the length of the runways.

More recently, the Massachusetts Port Authority (Massport) attempted to implement a change in the structure of the landing fees charged to airlines at Boston Logan Airport. Termed the Program for Airport Capacity Enhancement (PACE), the proposed fee structure would have replaced the existing price structure that was proportional to the certificated landing weight of the aircraft with one that charged smaller aircraft more per unit weight than larger aircraft. The objective was to provide a financial incentive for airlines to use larger aircraft. However, the airlines claimed the new pricing structure was discriminatory and a violation of the Federal preemption under the Airline Deregulation Act. The FAA sided with the airlines, and in the resulting lawsuit, the courts ruled in favor of the airlines and FAA, and Massport withdrew its proposal.

Clearly, any attempt to change the current situation will be fraught with legal issues. By the very nature of the industry, any change of operating policies or fee structures will produce winners and losers. It can be expected that the losers will challenge the changes in court. Therefore any proposed changes will need to be carefully designed to withstand legal challenge, and may even require legislative authority. However, the current situation is costing the traveling public millions of dollars per year in delay costs and other inconvenience, figures that will only increase in the future. Opportunities to build new runways at many airports are very limited and usually strongly opposed by surrounding communities that will bear the burden of the noise and other impacts of these projects. Even where the airport authority is able to acquire the land and overcome the opposition, these projects are often extremely expensive. It can be expected that even if the airlines and airport authorities are happy with the *status quo*, there will be increasing pressure both from users of the air transportation system and from those affected by proposed airport expansion projects to give serious consideration to potential policy options that could result in the use of larger aircraft.

These options fall into five broad classes:

1. Limitations on the use of specific aircraft types or markets that can be served;

2. Limitations on the frequency of service, either on a market-specific basis or by limiting the number of operations for each airline (slot controls);
3. Pricing structures that favor the use of larger aircraft;
4. Negotiated agreements with airlines that limit the size of aircraft that are used or the frequency with which certain markets are served;
5. Changes in the priority rules by which aircraft are handled by the air traffic management system during congested conditions.

Each of these options is discussed further in chapter 6. Some of these are actions that an airport authority could take on its own, some would require the support of the FAA, and some could require legislation. However, the need for legislative authority need not be an insuperable barrier. The need to address airport delays is clearly a matter of great public concern, and airport authorities are in a strong position to lobby for legislative change if it can be shown to be in the best interests of the traveling public. Since reducing the costs of airport delay is also in the financial interests of the airlines, it may even be possible to craft proposals that will obtain the support of many in the airline industry.

Influence of Capacity Constraints

Even if no explicit actions are taken to encourage the use of larger aircraft, growing delays may cause airlines to begin to utilize larger aircraft. Airlines are only too well aware of the disruption that their operations experience when traffic demand exceeds capacity at busy airports. Scheduling additional flights at congested times clearly exacerbates the situation, leading to greater delays to subsequent flights and disrupting downline operations, and thus it can be expected that at least some airlines will consider using larger aircraft in denser markets rather than adding flights. However, their ability to do this is constrained by two factors. The first is their overall fleet and how aircraft are routed across their network. Obviously, an airline can only use the aircraft that it has in its fleet. Furthermore, aircraft do not simply travel back and forth in a market, but move through the network over the course of the day. While there may be enough traffic in a given market to efficiently utilize a particular aircraft, that may not be true for subsequent flight segments of that aircraft's itinerary. The second constraint is the competitive situation in the market. The more airlines serving the market, the smaller on average the passenger load on each aircraft. Likewise, if one airline increases its service frequency in order to gain market share, its competitors may feel obliged to respond by increasing their frequency as well.

This has two implications. The first is that there are both short-run and longer-run decisions that affect the ability of an airline to utilize larger aircraft. In the short run, the airline is constrained by the aircraft that it has in its fleet. In the longer run, it could add new aircraft to the fleet. The second implication is that understanding how airlines are likely to respond to capacity constraints in any given market requires a careful analysis of the economics of serving the market, including competitive effects. Airlines are in business to make money, and they are likely to behave in an economically rational way. No airline will willingly put itself at a competitive disadvantage, so that other airlines can experience the benefits of reduced congestion!

These issues are explored in more detail in chapter 3. However, there is another aspect to the effect of capacity constraints on airline decisions that is not addressed in any detail in this report. That is whether it is in fact in the airlines' interest to reduce congestion at busy airports. While it is certainly true that airlines incur additional costs from delays, it is also true that those costs are ultimately paid by the traveling public and air cargo shippers, not by the airline shareholders or managers. If the ability of airlines to add flights as demand grows is constrained by airport capacity limitations, it can be expected that the airline yield management systems will reserve a higher proportion of the available seats for passengers willing to pay a higher fare. It is implausible that airlines will continue to sell tickets at heavily discounted fares if this means that they will be turning away full-fare passengers. This will in turn raise the average fare paid by travelers in those markets. If the resulting increases in yield are greater than the increases in delay costs, those markets will become more profitable.

At the same time, rising average fares will tend to dampen the demand for air travel. Thus an equilibrium may be reached in which it appears that the growth in demand for air travel has slowed or even leveled off. While it is beyond the scope of the current study to address these issues, their impact on both airline decision making and the likely future severity of airport capacity constraints should not be ignored.

Regional Airport Issues

Although this study has focused on the situation at Los Angeles International Airport (LAX), it should be recognized that LAX is only one of several airports serving the Southern California region. Thus airlines that find it difficult or costly to add capacity at LAX may decide to expand their service at the other airports in the region. This will divert some traffic from LAX and thus change the distribution of traffic between the airports in the region. However, there are limits to the extent to which this can occur. Many of the smaller secondary commercial service airports in the region are facing their own capacity constraints, and it is unclear how much additional traffic they can handle. Since LAX currently handles some 75 percent of all air carrier enplanements in the region, any significant diversion of traffic to the secondary airports would result in very large growth rates at those airports, quickly consuming any unused capacity.

The region has also been considering the development of a new commercial service airport at the former El Toro Marine Corps Air Station in Orange County, as well as expansion of the use of Palmdale Airport in the high desert and a number of other former military airfields. However, the economic viability of air service from so many airports in the region has yet to be established. There are very few markets with sufficient traffic that they can support frequent service by several airlines serving multiple airports in the region. The economic forces that shape airline decisions on fleet mix at LAX will also affect their decisions on whether to expand or introduce service at other airports in the region.

A detailed consideration of these issues is also beyond the scope of this report. The analysis that was undertaken as part of the study has only considered the traffic levels and fleet mix decisions in markets served from LAX. However, the methodology that is described in this report could equally well be applied to analyze the potential for changes in fleet mix at the other airports in the region. An analysis of which markets could potentially attract additional service from other airports in the region would require a different approach that considers the distribution of trip ends in the region and the factors that cause travelers to choose one airport over another. These issues have been examined in prior research (Lunsford & Gosling, 1994; Hansen, 1995), but have not been addressed in the current study.

Structure of this Report

The remainder of this report is organized as follows. Chapter 2 discusses the trends in airport traffic, aircraft size, and aircraft passenger loads at LAX over the past decade. Chapter 3 examines the recent fleet mix (as of 1998) in more detail, focusing on how flights are distributed among different aircraft types and size classes, and on the operational impact of the existing fleet mix and schedule on airfield capacity and delay. Chapter 4 examines the factors that determine aircraft size and load on individual flight segments, and projects how fleet mix at LAX may change in the future as a result of these factors. Chapter 5 turns to the question of cost economies of aircraft size, analyzing whether airlines would realize cost savings or penalties from upsizing their fleets. Finally, in Chapter 6, we offer policy implications, discussing the appropriate role of airports in airline fleet mix decision-making and alternate means by which they might fulfill that role.

2. Traffic Trends at Los Angeles International Airport

This chapter discusses recent traffic trends at Los Angeles International Airport (LAX) and their implications both for future increases in aircraft operations and the potential for changes in airline fleet mix to accommodate growth in passenger traffic without a corresponding growth in aircraft operations. The chapter first addresses the overall trends in traffic by type of carrier, then examines three specific markets in more detail: markets served predominantly by regional airlines, traffic in the California Corridor between Southern California and the San Francisco Bay Area as well as other major markets in the western United States, and international trans-Pacific markets. These markets have been selected for more detailed examination because of their importance for different types of changes in airline fleet mix.

The regional airlines operate the smallest aircraft, and a relatively small proportion of the total passenger traffic at the airport is carried by a large number of aircraft operations. Clearly a significant change in average aircraft size by regional airlines could have a profound effect on the total number of operations. The California Corridor and other major markets in the western U.S. are notable both for the high volume of traffic and the high frequency of service. At the same time, they are typically operated with relative small aircraft, of the order of 125 seats. Accommodating traffic growth in these markets through increases in average aircraft size would still provide frequent service while reducing the growth in aircraft operations. Finally, there is considerable discussion in the industry about the future prospects for new large aircraft, with seating capacity greater than the current Boeing 747-400 (Sparaco, 2000; Proctor, 2000). Such aircraft are most likely to be deployed on very long haul international services, such as the trans-Pacific markets, where stage lengths favor larger aircraft and time-zone differences create limited time windows for efficient service, which reduces the frequency advantages of using smaller aircraft.

Airport Traffic by Type of Carrier

The growth in passenger traffic at LAX since 1970 is shown in Figure 2-1. It can be clearly seen that while all market segments have experienced traffic growth, international traffic has grown faster than domestic traffic. Less obvious perhaps is the fact that the regional airline passenger traffic has also grown faster than the domestic traffic of the large airlines. For convenience in discussion, and to conform to common industry terminology, the large airlines will be referred to as air carriers, as distinct from the regional airlines, which are also sometimes referred to as commuter airlines, although technically regional airlines are also air carriers. Historically, the regional airlines operated small turboprop aircraft while the air carriers operated larger jet equipment. However, the introduction of smaller jet aircraft such as the Canadair Regional Jet by the regional airlines in some markets (although not so far at LAX), has begun to blur the distinction between the two classes of carrier. This has been exacerbated by the establishment of code-sharing relationships between the regional airlines and major airlines, and in some cases outright ownership of the regional airline by a major carrier. In consequence, the regional airlines have become an integral part of the service network of the major carriers, as discussed further below.

Figure 2-1

Growth in Passenger Traffic at LAX

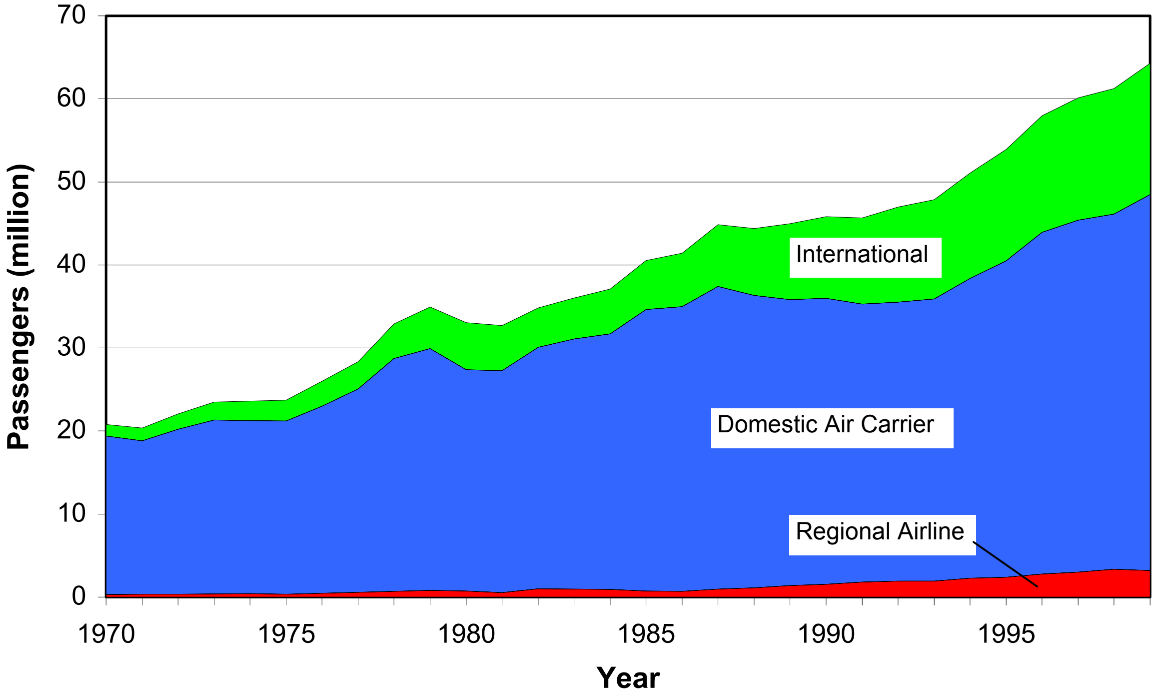
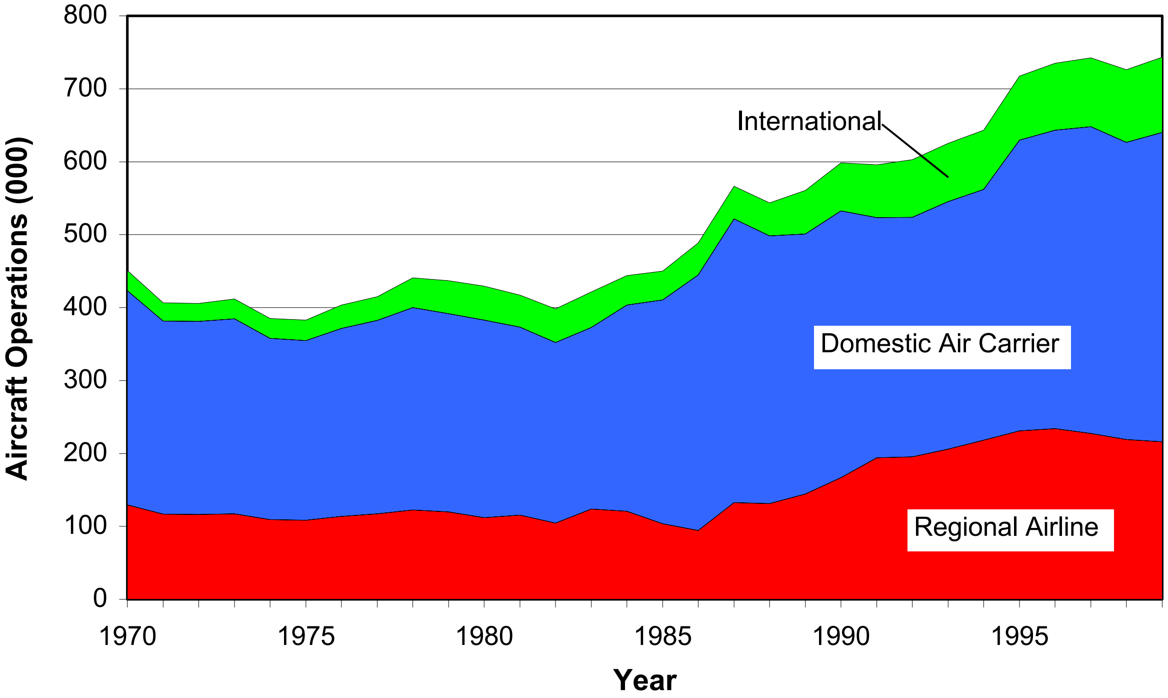


Figure 2-1 also shows the strong growth in domestic traffic since 1993, following a six-year period from 1987, when domestic traffic either declined or experienced only very slow growth. However, the steady growth in regional airline traffic since the mid-1980's appears to have leveled off in the last year.

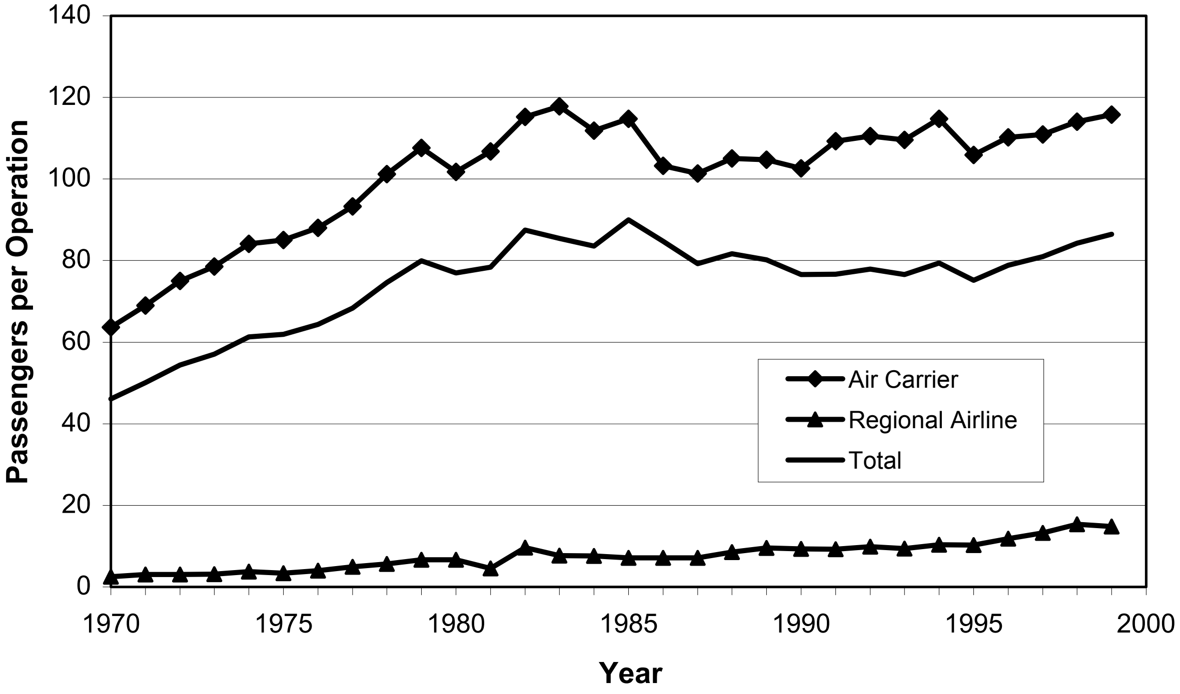
The corresponding growth in operations is shown in Figure 2-2. While it can be seen that operations have not grown as much as passenger traffic over the past three decades, the growth in operations since 1982 has generally kept pace with the growth in passenger traffic. Although the regional airlines account for a relatively small proportion of the total passenger traffic, they account for a significant share of aircraft operations.

Figure 2-2
Growth in Aircraft Operations at LAX



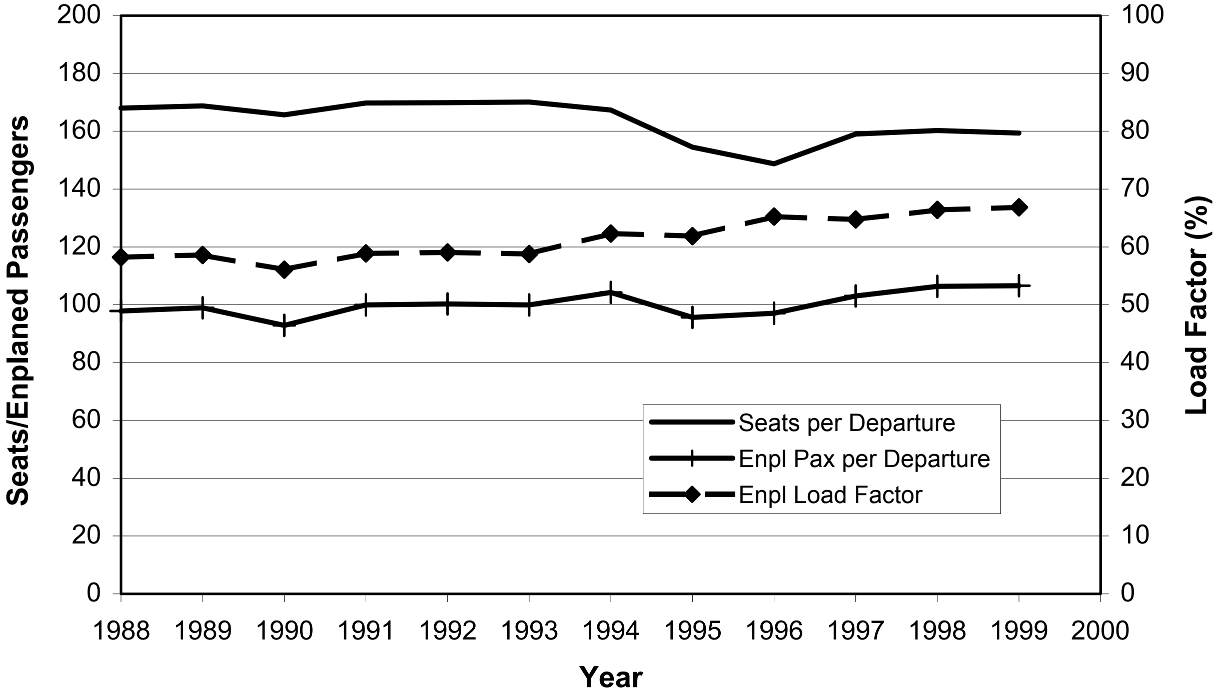
The resulting trends in average passengers per operation are shown in Figure 2-3. After growing steadily from 1970 to the mid 1980's, the overall average number of passengers per operation declined slightly over the following decade and has been showing an upward trend since 1995. The corresponding measure for air carrier operations peaked in the early 1980's, declined over the next four years, and has shown a slow upward trend thereafter, although by 1999 it was still slightly below where it was sixteen years before. Meanwhile the average number of regional airline passengers per operation has shown a fairly steady growth over the entire period, although this appears to have ended in the last year. The apparent paradox in the late 1980's and early 1990's, when the overall average number of passengers per operation declined, while the corresponding measure for both air carrier and regional airline operations increased, was due to the effect of an increasing share of the total traffic being carried by the regional airlines on their much smaller aircraft.

Figure 2-3
Trends in Average Passengers per Operation at LAX



Whether the recent upward trend in overall average number of passengers per operation will continue will thus depend in part on the ability of both the air carriers and the regional airlines to continue increasing their average number of passengers per operation, and in part on the future share of the total traffic handled by the regional airlines. Of course, the average number of passengers per operation results from the combined effect of the average aircraft size and average load factor (proportion of seats occupied). While airline fleet mix decisions directly influence average aircraft size, consideration must also to be given to the effect of changes in load factor. The relative effects of these two factors for domestic air carrier operations over the eleven-year period from 1988 to 1999 is shown in Figure 2-4. It can be seen that the modest growth in passengers per operation is due entirely to increases in load factor rather than aircraft size, which has in fact declined over the period. There are obvious limits to how long an increase in load factor can continue.

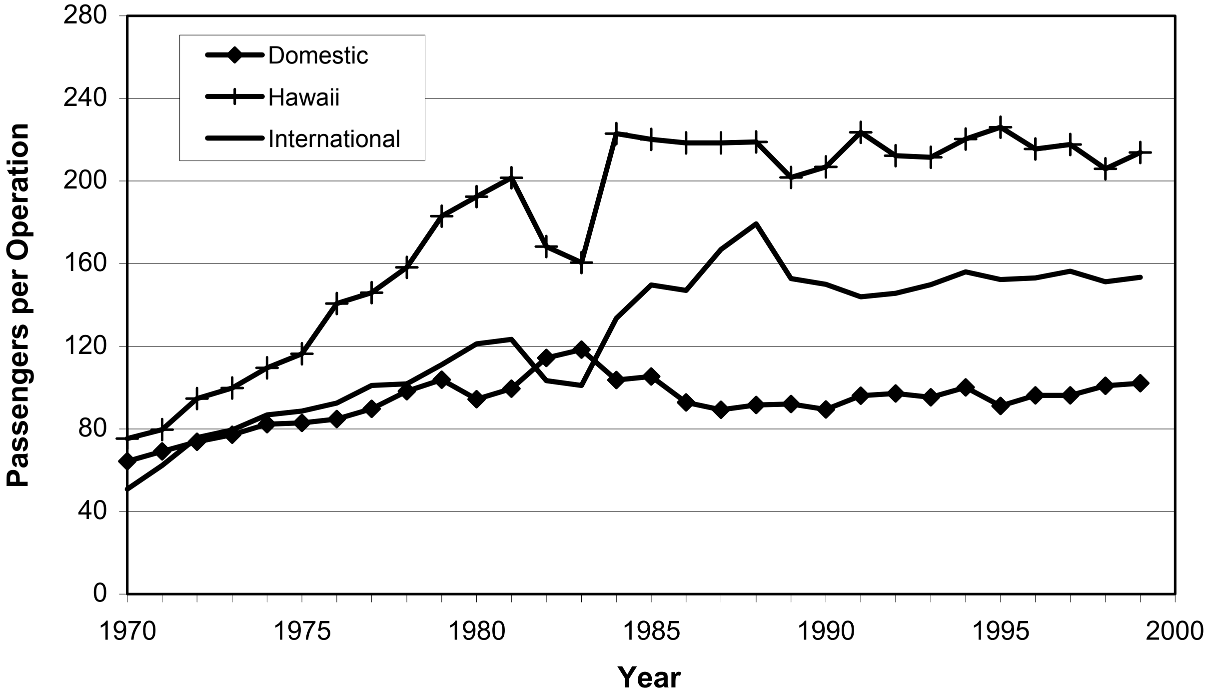
Figure 2-4
Recent Trends in Air Carrier Traffic at LAX
Major and National Airlines, Scheduled Domestic Traffic



As can be expected, the average number of passengers per air carrier operation varies significantly between domestic, domestic trans-Pacific (Hawaii) and international operations, as shown in Figure 2-5. International operations include both long-haul flights and flights to Canada and Latin America, which typically use similar aircraft to those used in domestic operations. In consequence, the average number of passengers per international operation lies between that for domestic and Hawaii operations. The average number of passengers per operation for Hawaii traffic has remained relatively unchanged for the last 15 years, with the recent decline from 1995 to 1998 reversing in the past year. The average number of passengers per operation for other domestic traffic has shown a slight upward trend since the late 1980's, but is still less than its peak in the early 1980's. The average number of passengers per international operation peaked in 1988, declined sharply over the next three years, partially recovered thereafter and has been fairly stable for the past five years.

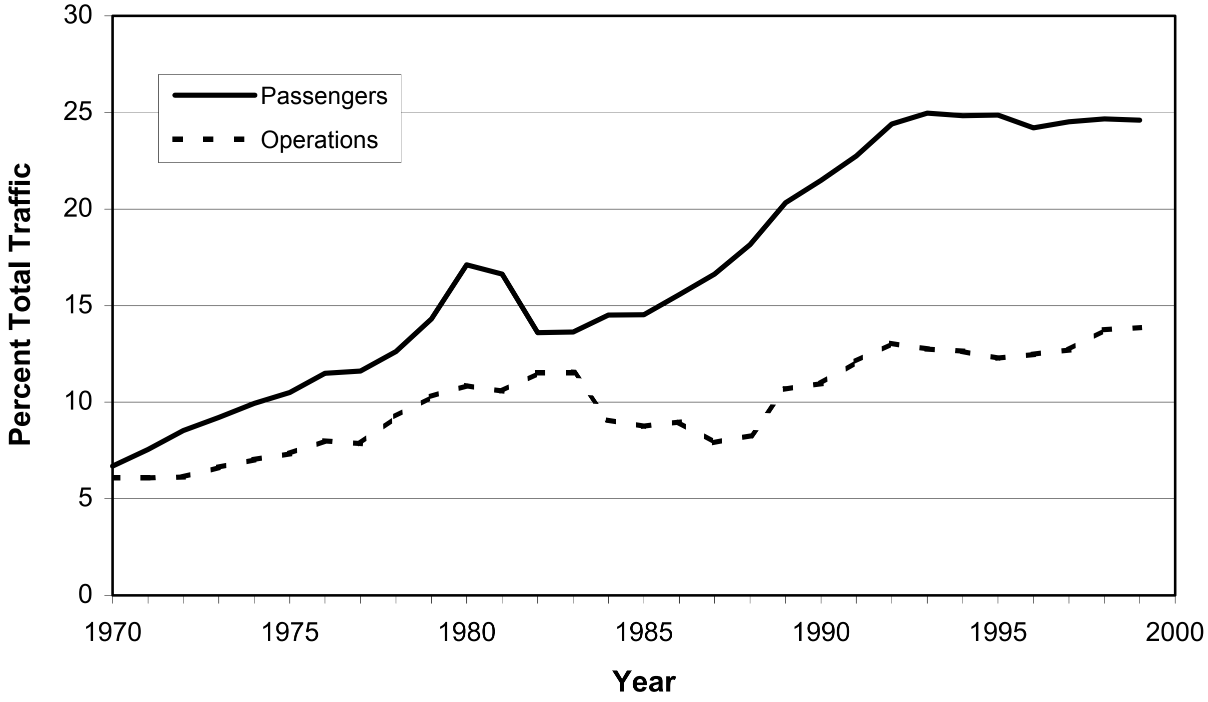
Figure 2-5

Trends in Average Passengers per Operation by LAX Market Segment



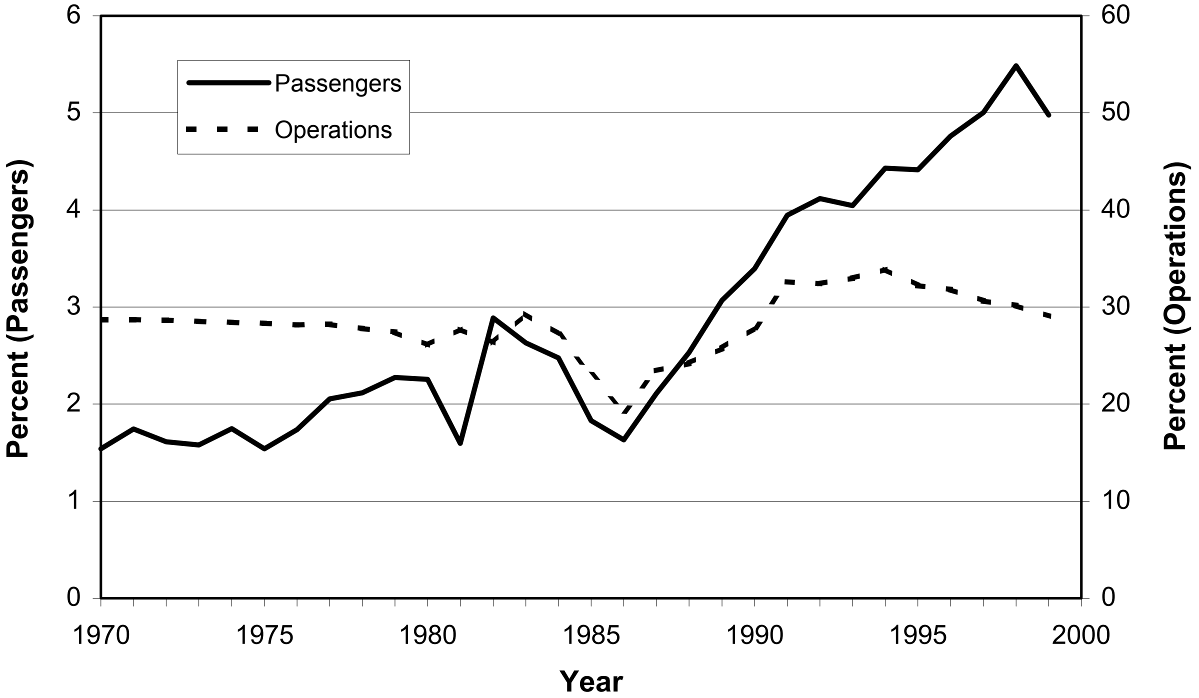
Since 1970, international traffic has accounted for a growing proportion of total passengers using the airport as shown in Figure 2-6, from about 6 percent in 1970 to 25 percent in 1993. However, this proportion has remained fairly constant for the past six years. The corresponding share of aircraft operations has shown a smaller increase, from about 6 percent in 1970 to about 14 percent in 1999.

Figure 2-6
Trends in International Traffic Share at LAX



In contrast, while the share of total passengers accounted for by the regional airlines has experienced a similar growth from about 1.5 percent in 1970 to about 5.5 percent in 1998, as shown in Figure 2-7, most of this growth has occurred since 1986. However, in the last year the regional airline traffic share declined to 5 percent of total traffic. Due to the steady growth in passengers per operation, the corresponding share of aircraft operations has remained relatively unchanged since 1970 at about 30 percent of total operations. This share declined in the mid 1980's, increased during the late 1980's and early 1990's, and reached a peak in 1994 since when it has shown a slight but steady decline.

Figure 2-7
Trend in Regional Airline Market Share at LAX



Clearly, the overall average number of passengers per operation is the result of a complex set of dynamic relationships involving the trends in aircraft size and load factor in the various market segments and the relative share of each of the segments in the total traffic. These factors will be explored in more detail in the following sections.

Regional Airline Markets

The growth in the share of LAX traffic handled by the regional airlines over the ten-year period from 1988 to 1998 suggests that it may be useful to examine the underlying changes in the markets served by these carriers. The changes in the size and number of markets served by regional airlines during this period is summarized in Table 2-1. Between 1988 and 1998 the number of markets with direct service declined from 33 to 21, while the number of markets with more than 100,000 enplaned passengers per year in each direction increased from one to five. At the same time, the number of markets with less than 50,000 enplaned passengers per year declined from 30 to 10, while the number of markets with less than 1,000 enplaned passengers per year went from 10 to one.

Table 2-1

Changes in Regional Airline Markets from LAX

Enplaned Passengers (each way)	Regional Airline Markets 1988	1998
Over 250,000		1
100,000 – 250,000	1	4
50,000 – 100,000	2	5
10,000 – 50,000	9	7
1,000 – 10,000	11	3
100 – 1,000	10	1
Total	**33**	**21**

SOURCE: Data Base Products, *Onboard Database.*

The changes over this period in the traffic in the thirteen largest regional airline markets, with over 40,000 enplaned regional airline passengers in 1998, is shown in Figure 2-8. The ten largest markets, and all but one of the largest thirteen, are California intrastate markets. Table 2-2 shows the total traffic in each market in both 1988 and 1998 and the percentage handled by the regional airlines.

Two trends stand out over this ten year period: first the dramatic growth in regional airline traffic in most of the larger markets, and second the loss of regional airline service from LAX in many of the smaller markets. One factor in the growth of regional airline traffic was the replacement of air carrier service by in three of the larger markets by regional airlines as a result of the development of code-sharing relationships between the regional airlines and the major airlines.

Figure 2-8

Growth in Regional Airline Markets from LAX

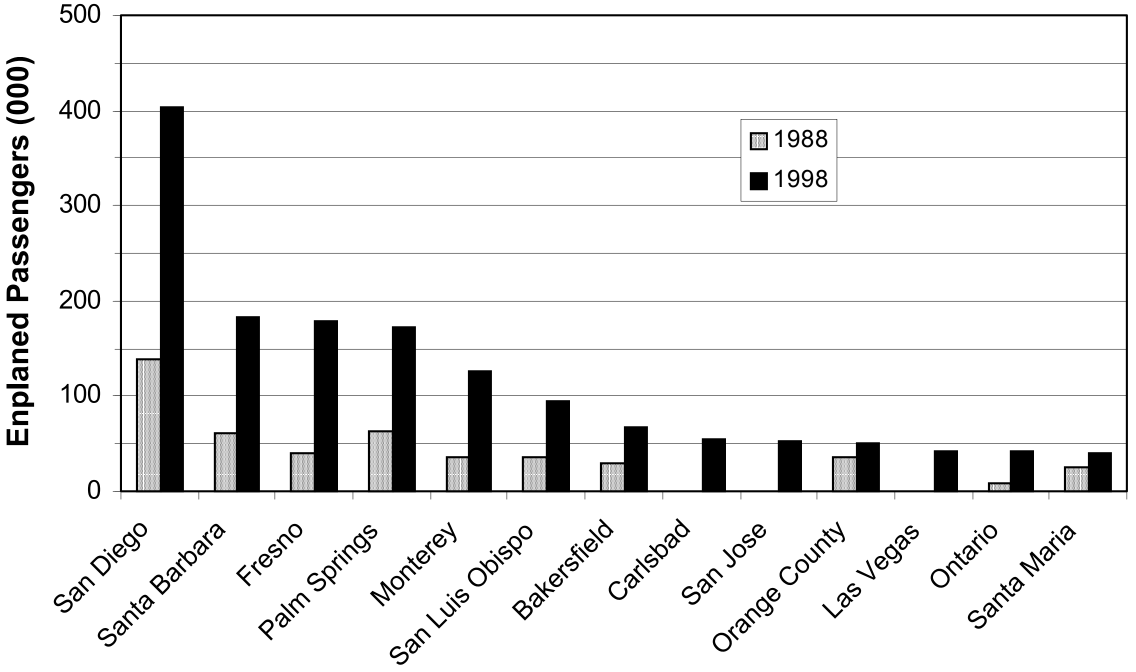


Table 2-2

Changes in Regional Airline Traffic and Market Share in the Largest Regional Airline Markets from LAX

	Total Market Passenger Traffic		Regional Airline Passenger Traffic		Regional Airline Share *(%)*	
Market	1988	1998	1988	1998	1988	1998
San Diego	670,468	456,968	138,593	404,180	21	88
Santa Barbara	61,084	182,286	61,084	182,286	100	100
Fresno	149,723	178,185	38,936	178,185	26	100
Palm Springs	63,355	172,703	63,355	172,703	100	100
Monterey	115,982	126,542	36,582	126,542	32	100
San Luis Obispo	36,736	93,665	36,736	93,665	100	100
Bakersfield	29,396	66,857	29,396	66,857	100	100
Carlsbad	-	54,105	-	54,105		100
San Jose	625,155	710,300	54	53,364	0	8
Orange County	35,226	50,881	34,795	50,623	99	99
Las Vegas	959,702	1,588,445	8	42,887	0	3
Ontario	9,788	43,293	7,801	42,671	80	99
Santa Maria	26,007	40,574	26,007	40,574	100	100

SOURCE: Data Base Products, *Onboard Database*.

Changes in Selected Markets

This section examines the recent changes in four of these markets in more detail. The changes in weekly flight frequency in each of these markets from 1988 to 1998 is shown in Table 2-3.

Table 2-3
Change in Weekly Frequency in Selected Regional Airline Markets

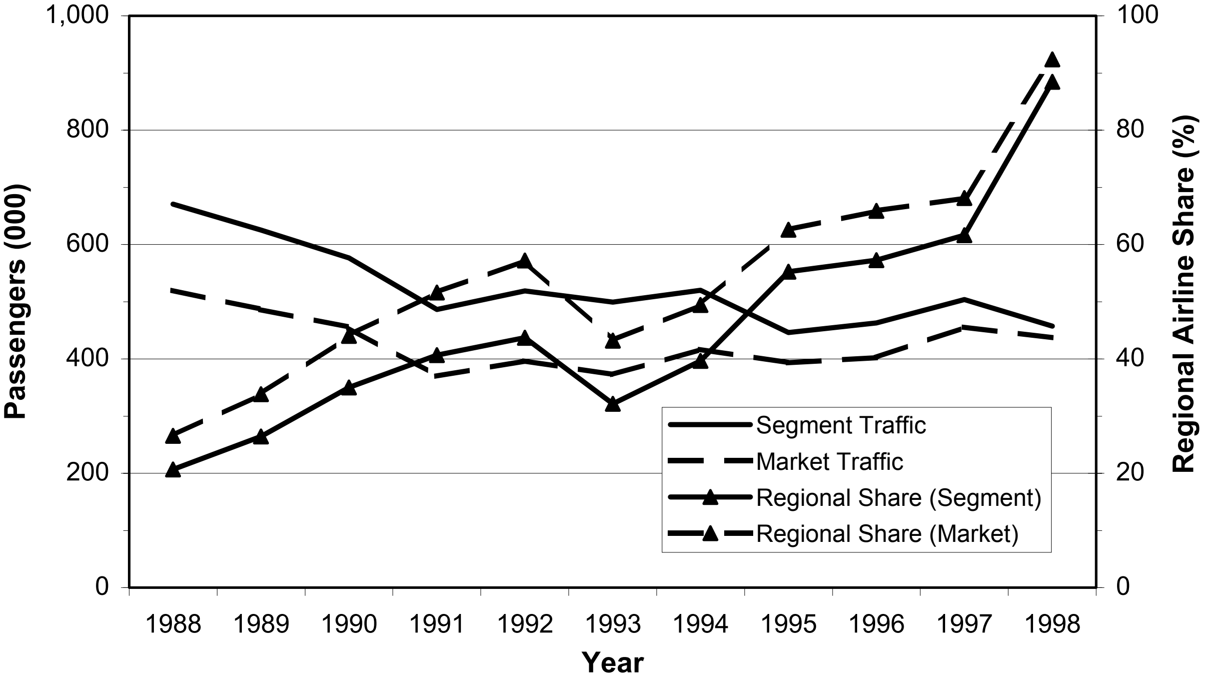
	Carriers		Weekly Frequency		Seats	
Market	July 88	July 98	July 88	July 98	July 88	July 98
San Diego-LAX						
Major Airlines	9	1	237	14	33,955	2,002
Regional Airlines	4	4	321	425	6,379	11,984
			558	**439**	**40,334**	**13,986**
Fresno-LAX						
Major Airlines	2	0	61		6,654	
Regional Airlines	3	4	82	220	1,558	6,198
			143	**220**	**8,212**	**6,198**
Monterey-LAX						
Major Airlines	2	0	41		3,949	
Regional Airlines	2	3	38	126	854	3,864
			79	**126**	**4,803**	**3,864**
Bakersfield-LAX						
Regional Airlines	3	3	**90**	**132**	**1,787**	**4,068**

SOURCE: *Official Airline Guide*, July 1988 and July 1998.

San Diego

It can be seen from Figure 2-8 that the largest single market by far is San Diego. The change in the total traffic in the market and the relative share of the traffic carried by the regional airlines over the ten-year period is shown in Figure 2-9. The distinction between market traffic and segment traffic is important. Market traffic counts passengers that enplane at LAX and deplane at San Diego. Segment traffic counts passengers on board nonstop flights, and includes passengers who are traveling on the same flight into LAX or beyond San Diego. It can be seen that passengers traveling into LAX or beyond San Diego accounted for a significant proportion of the total traffic in the market. However, on the basis of the data reported by each carrier, it appears that very few regional airline passengers travel beyond either airport on the same flight. It should be noted that the caveat *on the same flight* is important. Passengers who change flights at either end of a market are counted as part of the market traffic. A discussion of the limitations of the data sources used for the analysis in this report is contained in Appendix A.

Figure 2-9
Trends in Regional Airline Market Share
LAX to San Diego



While the number of regional airline flights from San Diego to LAX increased from 321 per week to 425 per week, the total number of flights reduced from 558 per week to 439 per week as almost all the air carriers discontinued service in the market. Although the number of weekly seats available in the market decreased dramatically from about 40,300 to about 14,000, the seats available on the regional airline flights almost doubled as a result of the regional airlines using larger equipment.

A significant factor in the increase in the regional airline weekly frequency in the San Diego market between 1988 and 1998 was the entry of USAir Express to replace flights previously offered by USAir (the fourth regional airline in the market in 1988 was Resort Commuter, which only offered 7 flights per week). Of the other regional airlines serving the San Diego market, only United Express increased its frequency, while American Eagle and Delta Connection both reduced their weekly frequency, although both increased their capacity through the use of larger aircraft.

Fresno and Monterey

In the Fresno and Monterey markets, the withdrawal of the major airlines from the markets resulted in both a reduction of capacity and a significant increase in frequency, due to the replacement of large aircraft by much smaller turboprop aircraft. In the Fresno market, USAir Express commenced service to replace the flights discontinued by USAir, while the three existing regional airlines all increased their weekly frequency and significantly increased their capacity through the use of larger aircraft. In the Monterey market, United Express commenced service to replace flights discontinued by United, while both American Eagle and Delta Connection increased both weekly frequency and significantly increased their capacity through the use of larger aircraft. However, USAir Express did not commence service to Monterey to replace the flights offered by USAir, so the number of airlines serving the market declined.

Bakersfield

In the Bakersfield market, which did not have major airline service in 1988, the increase in frequency by all three regional airlines serving the market, combined with the use of larger turboprop aircraft resulted in a significant increase in capacity.

Schedule Considerations at LAX

Since the primary role of the regional airline service between LAX and the smaller communities in the state is to allow passengers traveling to and from those communities to connect with longer haul flights at LAX, the question arises whether the scheduling of the regional airlines flights tends to increase any traffic peaking associated with the scheduling of the longer haul flights of the airlines that are code-sharing with the regional airlines.

An analysis of the distribution of flight arrivals and departures on a typical weekday (a Wednesday) in July 1999 was performed for American Eagle and United Express, the two regional airlines with the majority of the traffic at LAX, in comparison to the flight schedules of their parent carriers. The pattern of flight arrivals and departures throughout the day is shown in Figures C-1 and C-2 of Appendix C. It can be seen that while the flight activity of each airline shows considerable variability during the day, it does not exhibit the distinct cyclical pattern usually associated with airline hubs. Furthermore, there does not appear to be any obvious correlation between the peaking of the regional airline flights and those of their parent carrier. Therefore it does not appear that the impact of the regional airline flights on traffic congestion could be significantly reduced through relatively minor schedule adjustments.

Recent Changes in Regional Airline Service

The drop in regional airline passengers in 1999, shown in Figure 2-1, together with the changes in the percentage of total passengers carried by the regional airlines and the reduction in the number of regional airline operations since 1996 suggests that significant changes may have taken place in the regional airline markets over the past year and a half. An analysis of the regional airline flight schedules for July 1999 and 2000, compared to July 1998, shows that this is indeed the case. The number of weekly departures by each regional airline and the associated seat capacity in each regional airline market from LAX is shown in Table C-1 in Appendix C.

Between July 1998 and July 1999 Delta Connection withdrew from the six markets that they were serving in 1998 and US Airways Express withdrew from the Ontario market. By July 2000, US Airways Express had withdrawn from the remaining four markets that they still served in 1999, leaving American Eagle and United Express as the only regional airlines with any significant presence at LAX. The net effect was a significant reduction in service frequency in several markets. In the case of some of the larger markets, such as Palm Springs, San Diego and Santa Barbara, the regional airline frequency was further reduced by the introduction or restoration of service using large jet aircraft by United Airlines and other air carriers.

California Corridor and Western U.S. Markets

West Coast markets, including the California Corridor between Southern California and the San Francisco Bay Area, accounted for seven of the twenty densest domestic markets from

LAX in 1998, as shown in Table 2-4. Las Vegas and San Francisco were the largest and second largest market respectively. The Southwest and Mountain states of Arizona, Colorado and Utah accounted for a further three of the twenty densest domestic markets. These ten markets are also notable for both relatively frequent service and a relatively low number of passengers per departure. Therefore understanding the dynamics of these markets would appear to provide important information on the prospects for increasing average aircraft size.

Table 2-4

Twenty Largest Nonstop Domestic Markets from LAX

1998 and 1999

1998 Rank	Destination	Passenger Traffic (total on board)		
		1998	1999	Growth *(%)*
1	Las Vegas	1,580,430	1,719,481	9
2	San Francisco	1,348,567	1,325,173	(2)
3	Honolulu	1,346,313	1,339,995	(0)
4	Chicago O'Hare	1,238,380	1,241,111	0
5	Phoenix	1,173,420	1,268,910	8
6	New York Kennedy	1,159,944	1,239,461	7
7	Denver	930,252	874,100	(6)
8	Oakland	911,988	957,725	5
9	Dallas/Fort Worth	811,165	784,685	(3)
10	Seattle-Tacoma	765,049	774,091	1
11	Newark	691,384	667,329	(3)
12	San Jose	663,431	839,185	26
13	Atlanta	594,029	574,459	(3)
14	Salt Lake City	586,805	586,963	0
15	Sacramento Metropolitan	516,245	536,193	4
16	Washington Dulles	512,655	552,402	8
17	Houston Intercontinental	490,836	493,976	1
18	Portland	458,207	480,154	5
19	Kahului, Maui	410,246	526,692	28
20	Minneapolis-St. Paul	329,925	418,891	27

SOURCE: Data Base Products, *Onboard Database*.

As shown in Table 2-4, the change in each market from 1998 to 1999 varied from a growth of 28 percent in the Kahului (Maui) market to a decline of 6 percent in the Denver market. Although the total domestic traffic increased, traffic to several other major hubs, including Altanta, Chicago O'Hare, and Dallas/Fort Worth, either declined or remained flat.

Changes over the past eleven years in both traffic and average aircraft size in these ten markets is shown in Table 2-5. In most cases, traffic grew significantly. The only exception was San Francisco, where traffic on non-stop flights from LAX (termed segment traffic) declined over the eleven-year period by 23 percent. However, traffic growth to the two other Bay Area airports (Oakland and San Jose) more than offset the decline in traffic to San Francisco, with traffic to Oakland growing more than threefold. The changes in average aircraft size in these markets over the period show that those markets that had a smaller average aircraft size in 1988 have seen this size increase, while those West Coast markets that had a larger average aircraft size have tended to see this decline. In contrast, the average aircraft size in the Denver and Salt Lake City markets, which had the largest average aircraft size in 1988, increased further over the period. These changes appear to be unrelated to the amount by which the traffic has increased in each market. Of the ten markets, average aircraft size increased in six and declined in three. Overall in the ten markets, the average aircraft size increased from 136 seats to 139 seats over the period.

In addition to the growth in traffic and average aircraft size, load factors also increased over the ten-year period from an average load factor across all ten markets of 56 percent in 1988 to 66 percent in 1999. Thus while passenger traffic grew by 36.4 percent, departures only increased by 12.7 percent.

Closer examination of the data showed that these changes were by no means uniform over the ten-year period, and aggregate data at the market level conceal significant changes in market share and concentration that are likely to affect the type of equipment that the airlines use in these markets. The changes in traffic, market share, average load factors and aircraft size in each of these markets are shown in the figures in Appendix B. In order to better understand the influence of these factors, the following sections discuss each of these markets in more detail.

Table 2-5

Changes in Ten Densest Western U.S. Markets from LAX

1988-1999

Destination	Segment Traffic 1988	Segment Traffic 1999	Segment Traffic Growth *(%)*	Average Aircraft Size *(seats)* 1988	Average Aircraft Size *(seats)* 1999	Average Aircraft Size *(seats)* Change *(%)*
Las Vegas	959,694	1,719,481	79	131	136	4
San Francisco	1,715,731	1,325,173	(23)	142	130	(8)
Phoenix	1,156,276	1,268,910	10	128	131	2
Oakland	282,335	957,725	239	118	132	12
Denver	782,667	874,100	12	175	187	7
San Jose	625,101	839,185	34	117	130	11
Seattle-Tacoma	556,055	774,091	39	152	144	(5)
Salt Lake City	252,445	586,963	133	166	184	11
Sacramento	302,760	536,193	71	117	132	13
Portland	230,564	480,154	108	135	136	1

SOURCE: Data Base Products, *Onboard Database*.

Las Vegas

Traffic between LAX and Las Vegas grew rapidly from 1991 to a peak in 1996, and then declined over the next two years before recovering in 1999, as shown in Figure B-1. Segment traffic has been higher than the enplaned traffic in the market, reflecting through passengers at either end of the segment, a trend that appears to have increased somewhat in recent years. Average load factors have shown a progressive increase from 1989 to 1996, with a subsequent decline to give a slight increase over the eleven year period. The average aircraft size increased from a low of 128 seats in 1990 to a high of 142 seats in 1994, and has subsequently declined to 136 seats by 1999, giving a 4 percent increase since 1988.

The market shares of the dominant carriers changed dramatically over the eleven-year period, as shown in Figure B-2. In 1988, America West, USAir and Delta together carried 84 percent of the traffic, while Southwest and United had virtually no presence in the market. Over the subsequent eleven years, Southwest and United became the largest and second largest carrier in the market, as USAir withdrew from the market and the market shares of America West and Delta steadily reduced to 20 percent and 10 percent respectively.

San Francisco

Traffic between LAX and San Francisco reached a peak in 1991, as shown in Figure B-3, and has generally declined in subsequent years. Segment traffic has been somewhat higher than the enplaned traffic in the market, reflecting through passengers at either end of the segment. Average load factors have shown a steady increase from 1992 to 1996, but have declined somewhat since then. The average aircraft size has fluctuated from a high of 142 seats in 1988 to a low of 124 seats in 1996, and appears to be increasing again in recent years.

However, the market shares of the four largest carriers in the market have changed dramatically since 1988, as shown in Figure B-4. Between 1988 and 1997, United Airlines increased its market share from just under 30 percent to over 80 percent, although this has declined somewhat in the last two years. In 1988, American Airlines and USAir (which acquired Pacific Southwest Airlines in that year) each had between about 20 and 25 percent of the market, while Delta Airlines had about 5 percent of the market. Over the next three years, Delta increased its market share to about 20 percent as American withdrew from the market. However, United continued to increase its market share, driving Delta's market share back down to below 10 percent by 1999. USAir was able to maintain its market share until 1995, when the introduction of Shuttle by United drove its market share down below 10 percent, and over the next three years it too steadily withdrew from the market, leaving United as the dominant carrier, with about 20 percent of the market divided between Delta and several other carriers.

In spite of its progressively dominant role in the market, United's average aircraft size declined from about 142 seats in 1988 to 115 seats in 1996, although it has begun to increase again in recent years to 125 seats by 1999.

Phoenix

Traffic between LAX and Phoenix has remained relatively constant over the eleven-year period from 1988 to 1999, as shown in Figure B-5. Since 1990, segment traffic has been significantly higher than enplaned traffic, reflecting the dominant role of Southwest in the market and its use of multistop flights. Average load factors have declined slightly over the eleven-year period from 67 percent in 1988 to 64 percent in 1999. The average aircraft size increased steadily over the period from a low of 128 seats in 1988 to a high of 136 seats in 1998, although it decreased to 131 seats in 1999.

The principal changes in the market shares of the dominant carriers over the ten-year period, as shown in Figure B-6, has been the replacement of America West by Southwest as the largest carrier and the growth of United Airlines as a significant presence in the market since 1994. However, in spite of its declining market share, the average aircraft size operated by America West increased from 125 seats in 1989 to 145 seats in 1998, while the average aircraft size operated by Southwest increased from 126 seats in 1988 to 135 seats in 1996, and has remained at that level subsequently. In 1999 the average aircraft size operated by America West reduced to 130 seats, apparently reflecting a strategy to increase frequency and recover some of the market share that had been lost to Southwest and United.

Denver

Traffic between LAX and Denver has fluctuated considerably over the eleven-year period from 1988 to 1999, as shown in Figure B-7, dropping sharply in 1989, remaining fairly constant until 1993 then recovering in 1994, only to drop again in 1995 after Continental discontinued its Denver hub in 1994, before resuming its growth until 1998 and then declining in the last year. Since 1990, segment traffic has been somewhat higher than enplaned traffic, reflecting a modest amount of through traffic, as is typical for a hub (Denver served as a hub for Continental until 1994 and United throughout the period). Average load factors have increased from a low of 60 percent in 1991 to a high of 75 percent in 1994, and have remained fairly steady between 69 and 73 percent subsequently. The average aircraft size has fluctuated between 165 and 189 seats, ending the period somewhat higher than in 1988 at 187 seats.

During the eleven-year period, United Airlines increased its market share from just over 50 percent to over 90 percent in 1995, as shown in Figure B-8, as Continental, which had a market share of just under 50 percent in 1988 withdrew from the market. However, in spite of its steadily increasing market share from 1988 to 1995, the average aircraft size operated by United declined from 196 seats in 1989 to 165 seats in 1992, before increasing to 181 seats in 1995. As its market share declined from 93 percent in 1995 to 86 percent in 1999, the average aircraft size decreased to 170 seats in 1997, before increasing again to 200 seats in 1999.

Oakland

Traffic between LAX and Oakland has grown rapidly over the eleven-year period from 1988 to 1999, as shown in Figure B-9, reaching its highest level in 1995 and declining somewhat thereafter. Since 1994, segment traffic has been significantly higher than enplaned traffic, reflecting the dominant role of Southwest in the market and its use of multistop flights. Average load factors have generally increased over the eleven-year period from 52 percent in 1988 to a high of 74 percent in1992, then declining to 58 percent in 1997 and increasing again to 68 percent in 1999. The average aircraft size increased steadily from 118 seats in 1988 to 135 seats in 1993, then declined to 127 seats in 1996 before increasing again to end the period at 132 seats in 1999.

The market shares have shown dramatic changes over the eleven-year period, as shown in Figure B-10. The period started with PSA as the dominant carrier, with 63 percent of the market. In 1988, PSA was absorbed into USAir and between 1988 and 1991 United Airlines steadily increased its market share. In 1990, Southwest Airlines entered the market and by the following year, the USAir market share had declined to less than 10 percent and it abandoned the market, leaving United with a market share of about 50 percent. However, from 1991 to 1994, Southwest continued to increase its market share until by 1994 Southwest carried 90 percent of the market and United's market share had declined to only 10 percent. The introduction of Shuttle by United resulted in United's market share recovering to 35 percent in 1995, and reducing Southwest's market share to 65 percent. However, United's market share has since declined to 25 percent by 1999, with Southwest's market share growing again to 75 percent. In spite of its growth in both market share and traffic, the average aircraft size operated by Southwest has remained virtually unchanged since 1991 at around 135 seats. The average aircraft size operated by United has shown greater fluctuation, increasing from 113 seats in 1988 to 137 seats in 1993, thereafter declining back to 113 seats in 1996 before increasing to 125 seats in 1999.

Seattle

Traffic between LAX and Seattle has increased relatively slowly over the eleven-year period from 1988 to 1999, as shown in Figure B-11. Since 1990, market traffic has grown faster than segment traffic, and in 1996 even exceeded segment traffic, ending the period only slightly lower than segment traffic. This appears to arise from two offsetting effects. The first is through traffic on Alaska Airlines that continues on to Alaska, while the second is traffic on Southwest Airlines flights that make an intermediate stop at Oakland. Average load factors have increased significantly over the eleven-year period from 49 percent in 1988 to 71 percent in 1998, declining slightly to 70 percent in 1999. The average aircraft size declined from 152 seats in 1988 to a low of 135 seats in 1994, increasing thereafter to end the period at 144 seats in 1999.

The principal change in market shares over the ten-year period has been the steadily increasing dominance of Alaska Airlines, which increased its market share from 24 percent in 1988 to 70 percent in 1999, as shown in Figure B-12. The market share of United Airlines, which in 1988 was the largest carrier with 32 percent of the traffic, declined to a low of 24 percent in 1990, recovered to 32 percent in 1995, and has subsequently fluctuated between 29 and 30 percent. The third largest carrier in 1988, PSA, which was absorbed in to USAir that year, saw its market share steadily decline until it abandoned the market 1991. The fourth largest carrier in 1988, Delta Airlines, remained in the market with a steadily declining market share until it too abandoned the market in 1997. In spite of its increasing traffic and market share, the average aircraft size operated by Alaska only increased slightly from 136 seats in 1988 to 140 seats in 1999. The average aircraft size operated by United declined from 143 seats in 1988 to a low of 118 seats in 1994 and has increased thereafter to 156 seats in 1999.

San Jose

Traffic between LAX and San Jose in 1998 was only slightly greater than in 1988, although it has shown a strong growth in the last year. The market experienced a dramatic drop in traffic between 1988 and 1991, with an equally strong recovery between 1993 and 1996, as shown in Figure B-13. These changes were due to the loss of service by USAir after it absorbed PSA in 1988, followed by the entry of Southwest in 1993. From 1992 to 1997, segment traffic has grown significantly faster than enplaned traffic, reflecting the increasing role of Southwest in the market and its use of multistop flights. Average load factors have increased over the eleven-year period from 48 percent in 1988 to a high of 65 percent in 1991, declining to 58 percent in 1994 before recovering to 65 percent in 1995, and then subsequently declining again to 62 percent in 1999. The average aircraft size increased from 117 seats in 1988 to 142 seats in 1992, then steadily declined to 130 seats in 1999. Part of this decline in average aircraft size in recent years is due to the introduction of service in the market by American Eagle using small turboprop aircraft, as shown earlier in the discussion of regional airline markets.

The changes in the market shares of the principal carriers over the eleven-year period are shown in Figure B-14. The period began with American Airlines as the largest carrier in 1988, with 48 percent of the market, and with PSA/USAir the second largest carrier with 35 percent of the market. By 1992, USAir had withdrawn from the market, leaving American with 99 percent of the market. However, in June 1993 Reno Air replaced American Airlines service in the market and Southwest Airlines entered the market shortly thereafter, resulting in American's market share for the year declining to 44 percent By the following year, Southwest's market share had increased to 54 percent, while that of Reno Air had increased to 40 percent. Thereafter, Southwest's market share increased to 64 percent in 1997, before declining to 50 percent in 1999, while that of Reno Air declined to 16 percent in 1999. The average aircraft size operated by American Airlines increased from 112 seats in 1988 to 142 seats in 1992. With the replacement of service by American Airlines by Reno Air in 1993, the average aircraft size declined to 134 seats by 1998. American purchased Reno Air in December 1998 and resumed serving the market as American in September 1999, resulting in an average aircraft size operated by American and Reno Air during 1999 of 136 seats. The average aircraft size operated by Southwest increased slightly from 135 seats in 1993 to 137 seats in 1999.

Salt Lake City

Traffic between LAX and Salt Lake City has grown significantly over the eleven-year period from 1988 to 1998, as shown in Figure B-15, with most of the growth occurring between 1993 and 1999. The traffic grew slowly from 1988 to 1990, then declined slightly to 1992 before commencing its rapid growth until 1996. It remained fairly constant from 1996 to 1997, then declined somewhat in 1998, with no significant change in 1999. Since 1990, segment traffic has been somewhat higher than enplaned traffic, reflecting a modest amount of through traffic, as is typical for a hub (Salt Lake City has served as a hub for Delta Airlines throughout the period). The strong growth in traffic starting in 1993 coincided with the introduction of service by Morris Air in 1993, followed by its purchase by Southwest in 1994. Average load factors have increased from a low of only 47 percent in 1988 to a high of 74 percent in 1999, with most of the increase occurring after 1992. The average aircraft size has also increased over the eleven-year period, from 166 seats in 1988 to a high of 186 seats in 1997, ending the period slightly lower at 184 seats. However, after increasing to 179 seats by 1991, the average aircraft size then declined to 167 seats in 1994 before resuming its growth to 1997.

The eleven-year period started with Delta Airlines carrying effectively 100 percent of the nonstop market until the entry of Morris Air, as shown in Figure B-16. By 1994, with the absorption of Morris Air into Southwest, Delta's market share had declined to 70 percent. However, from 1995 Delta was able to regain some of its market share, ending the period with 81 percent of the market. From 1988 to 1997, Delta steadily increased its average aircraft size from 166 seats to 209 seats, with a slight decline to 207 seats in 1999. From 1994, the average aircraft size operated by Southwest has remained fairly constant, fluctuating between 135 and 137 seats.

Sacramento

Traffic between LAX and Sacramento generally declined from 1988 to 1994, with a brief recovery from 1990 to 1991, then grew rapidly in 1995 and more slowly thereafter, as shown in Figure B-17, ending the eleven-year period in 1999 considerably higher than in 1988. Segment traffic throughout the period is only slightly higher than market traffic, with a slightly greater increase from 1995 reflecting the increasing role of Southwest in the market and its use of multistop flights. Average load factors have increased over the eleven-year period from 45 percent in 1988 to 55 percent in 1993, then increased sharply to 73 percent the following year and fluctuated between 73 percent and 78 percent thereafter, ending the eleven-year period at 75 percent in 1999. The average aircraft size increased from 117 seats in 1988 to 132 seats in 1992, then steadily declined to 124 seats in 1996 before increasing again to 132 seats in 1999.

However, during the eleven-year period there were significant changes in the carriers serving the market, as shown in Figure B-18. The period began with PSA as the largest carrier in 1988. Following its absorption into USAir that year, it increased its market share the following year to 43 percent of the market, while the second and third largest carriers, Delta and United, also increased their market shares. However, over the next two years both Delta and United continued to increase their market shares while that of USAir declined to 26 percent, leaving United as the largest carrier and Delta as the second largest. From 1991 to 1993, Delta progressively withdrew from the market and the USAir market share recovered to 41 percent, although United remained the largest carrier with 53 percent of the market. The following year, USAir also withdrew from the market and Southwest entered, resulting in United's market share increasing to 72 percent. However, by 1995 Southwest had increased its market share to 48 percent, reducing United's share of the traffic to 52 percent, and these market shares have remained relatively unchanged thereafter. With its increasing market share and traffic from 1988 to 1993, the average aircraft size operated by United increased from 117 seats in 1988 to 124 seats in 1993, before declining to 115 seats in 1996 as Southwest became established in the market. However, since 1996 United's average aircraft size has increased to 127 seats by 1999. The average aircraft size operated by Southwest has remained at about 136 seats since 1994.

Portland

Traffic between LAX and Portland grew significantly from 1988 to 1996, with most of the growth occurring after 1993, and subsequently declined slightly to 1999, as shown in Figure B-19. Segment traffic grew faster than market traffic until 1991, but then market traffic grew faster, until by 1996 market traffic was slightly higher than segment traffic, a situation that has persisted to 1999. This reflects the combination of two effects: the increased use of mutistop flights via Portland by traffic on Alaska Airlines in the early 1990's and the introduction of service to Portland by Reno Air in 1993 and Southwest in 1995 via San Jose and Oakland. Average load factors have increased over the eleven-year period from 51 percent in 1988 to 64 percent in 1999. They remained fairly steady between 1988 to 1993, then increased to a high of 67 percent in 1996, before decreasing thereafter. The average aircraft size increased from 135 seats in 1988 to a high of 147 seats in 1993, then declined to 133 seats in 1996, before ending the period at 136 seats in 1999.

Unlike most other markets examined in this analysis, the three largest carriers in the market have not changed over the eleven-year period, although their relative market shares have, as shown in Figure B-20. The market share of Delta Airlines, which in 1988 was the largest carrier with 39 percent of the traffic, declined to only 13 percent in 1999, dropping it to third place. Alaska Airlines increased its market share from 37 percent in 1988 to 46 percent in 1999, moving up from second to first place, while United Airlines increased its market share from 23 percent to 41 percent. In spite of their increasing traffic and market share, the average aircraft size operated by Alaska only increased from 136 seats in 1988 to 140 seats in 1999, while the average aircraft size operated by United declined from 124 seats in 1988 to 113 seats in 1992, fluctuated between 124 seats and 114 seats over the next two years, then increased steadily to 123 seats in 1999.

Summary

While each market has shown quite different traffic patterns, there are a number of general trends that emerge from the analysis. The first is an increase in market concentration, particularly in favor of Southwest and United. By 1999 either Southwest or United was the largest carrier in seven of the markets, and between them had over 75 percent of the market share in five of these markets. In the two markets for which Alaska was the largest carrier (Portland and Seattle), Alaska and United between them had over 85 percent of the Portland market and almost 100 percent of the Seattle market. In the case of Salt Lake City, where Delta was the largest carrier, Delta and Southwest between them also had 100 percent of the market. The only markets where the third largest carrier had more than 10 percent of the traffic were Las Vegas, where America West, Southwest and United each had between 20 and 30 percent of the market, Phoenix, where Southwest had almost 50 percent of the market, America West had 35 percent and United had 17 percent, and Portland, where Delta had 13 percent.

The second general trend is the shift toward an average aircraft size between about 130 and 140 seats for each of the three dominant carriers in the West Coast markets. The two exceptions to this trend are the services to the mid-continent hubs of Denver and Salt Lake City. However, these markets are dominated by a single carrier and flight frequencies are constrained by the timing of the connecting banks at each hub.

The third important trend is the increase in load factors in most markets. This allowed passenger traffic to grow faster than capacity, whether from the use of larger aircraft or more flights. By 1999, average load factors varied between 60 and 75 percent across the ten markets. While this suggests that some further increase in load factors may be possible in several of the markets, it is generally regarded in the industry that the prospects for achieving average load factors much higher than 75 percent are quite limited.

Trans-Pacific Markets

The trans-Pacific markets account for an increasing share of the international traffic at LAX. In 1990, international departures to Pacific destinations, including foreign flag carrier flights to Honolulu, accounted for 24 percent of all departures to international destinations and 38 percent of all enplaned passengers on international flights. By 1998, these shares had increased to 32 percent and 47 percent respectively. Including domestic services to Hawaii, these are also markets where the introduction of larger aircraft than the Boeing 747-400 are more likely, both due to the longer stage lengths involved and the limitations on the advantages of flight frequency due to time-zone differences. The trends in passenger traffic and aircraft size in the trans-Pacific markets between 1990 and 1998 are shown in Table 2-6.

The number of destinations with more than 50 departures per week increased from 9 in 1990 to 16 in 1998. The largest single market was Tokyo Narita Airport, followed in 1990 by foreign flag carrier flights to Honolulu. However, by 1998 eight trans-Pacific markets had more traffic than these international flights to Honolulu, reflecting both the introduction of direct service to new markets, as well as the increasing range of newer aircraft that allowed nonstop service to more distant destinations and reduced the need for intermediate stops in Honolulu or Tokyo. While total enplaned passengers in the trans-Pacific markets increased by 98 percent from 1990 to 1998, passenger traffic to Tokyo only increased by 10 percent, as the new direct services attracted traffic that previously would have transited through or connected in Tokyo.

In spite of the growth in traffic in all markets except international flights to Honolulu, it can be seen from Table 2-6 that average aircraft size remained fairly constant or declined slightly. The only markets showing an increase in average aircraft size of more than a few seats were Hong Kong and Honolulu, and as noted above, the traffic to Honolulu declined by almost 60 percent.

By 1998, departures to Tokyo averaged almost 10 per day. The next two largest markets, Taipei and Seoul, averaged about 5 departures per day each. However, these markets were served by several airlines. The two airlines with the largest traffic shares in the Tokyo market, Japan Airlines and United Airlines, averaged 2.1 and 1.7 departures per day respectively, while the two airlines with the largest traffic shares in each of the Taipei and Seoul markets averaged between 1.8 and 2.2 departures per day. Whether further growth in these markets will be accommodated by increasing average aircraft size or adding flights will depend in part on whether new airlines enter these markets. Given the congestion at Tokyo Narita Airport and the number of carriers already serving that market, it is likely that airlines will seek to handle traffic growth to and from Japan by adding flights in other Japanese markets, as in fact occurred between 1990 and 1998 with the introduction of service to Nagoya and a sevenfold increase in flights to Osaka.

Table 2-6

Growth of International Trans-Pacific Markets

1990-1998

	Enplaned Passengers		Average Aircraft Size (seats)	
Market	1990	1998	1990	1998
Honolulu	261,604	108,290	344	362
Aukland	106,265	350,457	401	391
Guangzhou		22,408		297
Hong Kong	17,345	249,156	360	380
Kaohsiung		14,874		366
Manila		31,354		392
Nandi	3,282	36,527	368	296
Nagoya		32,262		299
Osaka	57,982	379,401	368	372
Peking		41,304		317
Papeete	61,792	126,913	311	306
Seoul	215,661	419,230	348	346
Shanghai		29,196		260
Sydney	179,370	378,629	387	383
Taipei	123,056	479,312	384	376
Tokyo	763,836	837,432	358	357
Other markets	7,642	887	387	334

SOURCE: Los Angeles Department of Airports.

Summary

It is clear from an analysis of traffic patterns at LAX over the past ten years that in spite of the significant growth in passenger traffic, there has been no corresponding increase in average aircraft size by the large domestic and international airlines. There has been a significant increase in average aircraft size by the regional airlines, resulting largely from the replacement of aircraft with 19 or fewer seats by aircraft in the 30 to 35 seat range. However, this increase in capacity has been partly the result of the large airlines discontinuing service in several of the larger regional airline markets, and it is unclear whether further growth in the regional airline markets will be served through an increase in frequency or the introduction of larger aircraft.

While the growth in aircraft operations over the past ten years appears to have leveled out over the past three years, this is largely the result of shifts in traffic composition, and further growth in passenger traffic is likely to result in the resumption of the growth in aircraft operations. Whether the resulting increase in delays that will inevitably occur will cause the airlines to begin to deploy larger aircraft in the LAX markets is addressed by the analysis in the following chapters. The evidence from the trends of the past ten years is not encouraging. In any event, airlines cannot deploy aircraft that they do not have in their fleets, and therefore any significant increase in average aircraft size is likely to be a slow process.

It is clear that a significant factor in the decision of what size aircraft to use in a given market is the effect on each airline's competitive position in the market. The regional airline markets are being contested by the affiliated or subsidiary regional airlines of four major carriers: American, Delta, United and US Airways. The larger markets are served by all four carriers, while the smaller markets are generally served by two or three carriers. Although the larger West Coast markets have seen a significant increase in market concentration, with different markets dominated by Alaska, Southwest and United Airlines, this has not resulted in a corresponding increase in average aircraft size. Rather, what appears to have happened is that those three airlines have tended to operate the same size aircraft in all markets and to add frequency as their market share increased.

In the trans-Pacific markets, the addition of direct service to new destinations combined with entry of new carriers in existing markets appears likely to continue to offset growth in travel demand in the region, severely limiting the opportunities to introduce larger aircraft than the

Boeing 747. Whether such aircraft can be economically operated in the very densest markets, such as Tokyo and Taipei, will depend on the way that the airline route networks evolve in the region, and whether the growth in traffic to and from those cities is offset by a reduction in the connecting traffic to other destinations, as well as the number of carriers serving each market.

On balance, the examination of the trends over the past ten years suggests that prospects for a significant increase in average aircraft size over the next decade at airports like LAX, if left solely to market forces, are not very encouraging. In a number of markets there has been a slight increase in average aircraft size in the last few years, but whether this indicates a response to increasing congestion or is merely another short-term fluctuation, as has occurred in the past, is unclear. While delay costs are certainly a concern to airlines, recent levels of delay at LAX do not appear to have been sufficient to cause the airlines to forego the competitive advantages of greater flight frequencies.

Another issue of concern is the general increase in load factors over the past ten years in many markets. This has allowed aircraft operations to grow more slowly than passenger traffic, with little or no increase in average aircraft size. However, there are obviously limits to how much further load factors can increase, and those limits are probably close to being reached. Any further growth in passenger traffic will therefore result in the number of flights increasing in proportion to the traffic growth unless the airlines start using larger equipment.

Yet the example of United Airlines in the San Francisco Market suggests that adding flights is the most likely response. Since 1995, United has had about an 80 percent share of the market, giving it the densest airline segment traffic of any of the western U.S. markets by far, and obviously a dominant position in the market. In contrast, the next densest airline segment in 1999 was Southwest in the Phoenix market, with less than 50 percent of that market and less than 60 percent of the traffic carried by United in the San Francisco market. Furthermore, San Francisco experiences some of the worst delays during bad weather of any of the West Coast airports, and these delays tend to impact short-haul flights the most, due to the FAA traffic flow management procedures. Therefore this would appear to be the most promising situation for an airline to deploy larger aircraft. Yet the average aircraft size used by United in this market is one of the smallest of any of the western U.S. markets examined.

3. Fleet Mix, Delay, and Scheduling Externalities at LAX

Introduction

The mix of aircraft using an airport has significant impacts on the airport's operations and facility needs. Besides determining the cargo and passenger throughput that can be served with a given operational capacity, the fleet mix also influences the capacity itself. Through these mechanisms, fleet mix decisions can determine whether an airport has high or low levels of delay, when new runways are needed, and a host of other variables critical to the near term operational efficiency and long-term viability of an airport.

While airport operators recognize that fleet mix is a critical factor in their master planning, they have traditionally viewed it as a demand to be accommodated rather than an object of managerial intervention. This attitude has been reinforced by federal policy, which has discouraged and often forbidden airports from "meddling" in the affairs of airlines. The exceptions have almost generally involved noise impacts rather than operational concerns. With passage of the Airport Noise and Capacity Act of 1991, airport discretion in the noise area was substantially reduced as well. Airports have thus been forced to deal with fleet mix as airlines deal with weather—an important factor to forecast and plan for, but one outside of their control.

Moreover, airports have traditionally employed, and face considerable pressure to maintain, pricing policies that encourage the inefficient use of scarce airport capacity. Fees are rarely differentiated by peak/off-peak period, and commonly discriminate against larger planes by being directly or indirectly tied to aircraft weight. These practices evolved in an era when the primary function of airport pricing was to generate revenue to finance past and future airport expansion, rather than encourage efficient use of existing facilities. For a variety of legal, political, and institutional reasons, they have proven very difficult to change. For example, Massport's PACE program, which sought to restructure landing fees to include a component that is independent of weight, sparked intense opposition from small aircraft operators and was eventually overturned by the FAA (Hardaway, 1991).

Lacking authority to promote efficient airport use either through regulation or pricing, airports have paid little attention to assessing the how efficiently their facilities are used, or even to pondering just what "efficient use" means. If the airport revenue stream is sufficient to cover its costs, and if service decisions are made by airlines subject to the discipline of a competitive marketplace, on what basis can airport proprietors make normative judgments about what the carriers choose to do? Aren't such judgments rendered meaningless by the proprietor's limited information and lack of competence to manage an airline's affairs?

In this chapter, we argue that the above line of thinking, and the hands-off policy toward airline fleet mix and scheduling decisions that derives from it, is rendered obsolete and dysfunctional by current conditions in the U.S. aviation system. These conditions include increased structural barriers and political resistance to airport capacity expansion, and resulting increases in airport congestion and delay. In a setting where runway capacity is scarce, individual airline fleet mix and scheduling decisions can generate large external impacts on other airport users and excessive delays. Without intervention, they are likely to result in significant misallocations of airport services. While airport proprietors may not be perfectly suited to make the necessary interventions, neither is any other agent in the aviation system. The adverse consequences of no action probably outweigh those of imperfect measures chosen with incomplete information.

To support these contentions, we assess the adverse consequences from the current, laissez faire, approach to determining fleet mix and flight schedules at LAX. Using schedule data for the year 1998, and simple, deterministic, models of airport capacity and delay, we investigate the relationships between fleet mix, airport capacity, congestion delay, and service quality. We quantify the difference between the private and collective impacts of individual flights in the 1998 schedule, and propose a systematic procedure for normative analysis that may serve as a basis for regulatory and pricing intervention by the airport proprietor. An appealing feature of this procedure is that it yields an objective, quantitative, and flight-specific measure of delay impact relative to service quality contribution. In these respects, our analytical approach satisfies the requirement that airport policies be fair, reasonable, and non-discriminatory.

The analysis presented here is based on simple, approximate models, which do not fully reflect specific circumstances at LAX. Refinements and validation of the models and data would certainly be required for analytical results and policies based on them to withstand legal and political challenge. These further steps might entail considerable effort and expense, but conceptually they are straightforward.

The remainder of this chapter is organized as follows. First we overview commercial airline schedules into LAX for the 1998 time period, observing basic patterns of airport use in terms of the markets served, the aircraft types used, frequencies of service provided, and so forth. Next, we analyze the impact of fleet mix on capacity and delay at LAX, setting forth the models used and then applying them to the 1998 schedule. Third, we propose and demonstrate our systematic method for identifying flights that generate high delay impacts relative to service benefits, and investigate the consequences of removing such flights from the schedule. A final section offers conclusions and policy implications of our analysis.

Schedule Overview

Our study is based on commercial passenger flight schedules into LAX during the odd-numbered months (January, March, etc) of 1998. The flight schedule data was provided by LA World Airports, which acquired it from Simat, Helliesen & Eichner, Inc. Altogether the data set contains over 14,000 flight records representing over 80,000 scheduled flights. The data set does not contain cargo-only, general aviation, or military flights, which together account for about 10 percent of total LAX operations (Landrum and Brown, 1996). These latter types of activity are therefore not considered in our analysis.

On an average week in 1998, there were approximately 6,800 commercial passenger flights scheduled to arrive at LAX—just under 1,000 per day. The up-line origins for these arriving flights are summarized in Table 3-1. Some 126 airports had non-stop services scheduled into LAX sometime during 1998, while an additional 55 points had direct one-stop service, and six others had direct service of more than one stop. As shown in Figure 3-1, most flights bound for LAX make few stops en route. 78 percent fly non-stop from their ultimate origin, and just 4 percent stop more than once.

The 126 airports with non-stop service to LAX are summarized in Table 3-2. From Table 3-2 it is apparent that LAX is, as proclaimed, a “world airport”, with 54 international non-stop routes along with 72 domestic ones. About half the international services are very long-haul transoceanic routes; the others, many of them fairly short, are within this hemisphere. The domestic routes are distributed fairly evenly among the short-, medium, and long-haul categories.

Table 3-1

Average Weekly Flights to LAX, 1998, by Origin Airport and Number of Stops

Origin Airport	Number of Stops to LAX				
	0	1	2	3	4
SAN	509				
LAS	380		2		
SFO	329	7			
PHX	275	9			
SBA	236				
ORD	235	17	1		
PSP	221				
FAT	219	5			
OAK	214				
SJC	211				
JFK	172	7			
DFW	149	6			
SEA	146	68	2		
DEN	143	10			
MRY	141				
BFL	130				
HNL	118				
SBP	104				
YVR	103	4			
EWR	103	27	4		
SMF	102				
PDX	98	64	6		
SLC	95	24			
CLD	94				
SNA	89				
MEX	79	34	20		7
IAH	74	5			
NRT	70				
IAD	70	10			
ONT	66				
TUS	62	6			
RNO	62	32			
OXR	61				
GDL	57	25	7	7	
ATL	56	20	0		
BOS	55	59	2		
STL	53	32	2		
SMX	53				
LHR	50	1			
ABQ	48	2			
PHL	42	23			
MIA	42	12	5		
DTW	39	8	7		
MSP	39	6			
TPE	37				
SJD	36				
MCO	35	38	3	7	
YUM	34	7			
PIT	34	1			
ELP	34	20	2		
IYK	31				
BNA	30	8			2
SEL	30	10			
KIX	30				
YYZ	30	8			
OGG	29	7			
IPL	28	5			
CVG	28				
CLE	28	11		7	
SYD	28				
CLT	27				
PVR	26				
VIS	25				
AKL	23	4	5	1	
MCI	23	9			2
BWI	21	26	6	7	7
MEM	21	1			
GUA	21				
TPA	20	19			
TIJ	20				
MDW	19	35	32	7	
HKG	18				
YYC	16				
MSY	14	11	16		
SAT	14	19	7		
SAL	14	7			
HMO	14				
FRA	13	7			
GRU	13	1			
MKE	13	9			
CMH	12	24	7		
OMA	11	28			
CDG	11				
BJX	10	4			

Table 3-1 (cont.)

Origin Airport (cont.)	Number of Stops to LAX				
	0	1	2	3	4
AMS	10	1			
AUS	10	23	9		
MZT	10	12			
PMD	9				
PPT	9				
CUL	9		7		
SHA	8	2			
FLL	7	16		3	
YUL	7	3			
KOA	7				
LTO	7				
ZLO	7				
MXP	7				
ZRH	6				
LIM	6	5	3	4	
MNL	6	5			
ZIH	6	4			
IND	5	13			
LAP	5	7			
CUN	5		1		
EGE	5				
NAN	4	3	1		
ANC	4	22	5		
ZCL	4	4			
LIH	4				
SGU	4				
TRC	3	3			
ORY	3				
CAN	3				
DGO	3	5			
SVO	3	1			
ASE	2				
COS	2	15			
MBJ	2		1		
BRU	2	7			
PTY	2		4		
NGO	2				
KHH	2				
DUS	1				
GEG	1	39	33		
MLM	1	4			
HDN	0				
DCA		51	3		

Origin Airport (cont.)	Number of Stops to LAX				
	0	1	2	3	4
LGA		34			
BOI		31			
HOU		26	27	14	
SJU		25	0		
OKC		22			
FCO		21			
SIN		17			
MEL		17			
LBB		14			
SJO		14			
SCL		13		3	4
BDL		11			
BKK		11			
PEK		10			
PBI		9			
SDF		7	6		
AMA		7			
LIT		7			
LMM		7			
TPQ		7			
CEN		7			
MFR		7			
MAF		7			
PVD		6		7	
KUL		6			
RSW		5			
SAP		5			
GIG		4	1		
BOG		4			
YEG		4			
EZE		4	6		
CCS		4			
DEL		4			
NCE		4			
TLV		4			
JAX		3			
AGU		3			
RAR		3			
ALB		2			
CGK		2			
CAI		2			
ROC		2			
PIE		2			

Table 3-1 (cont.)

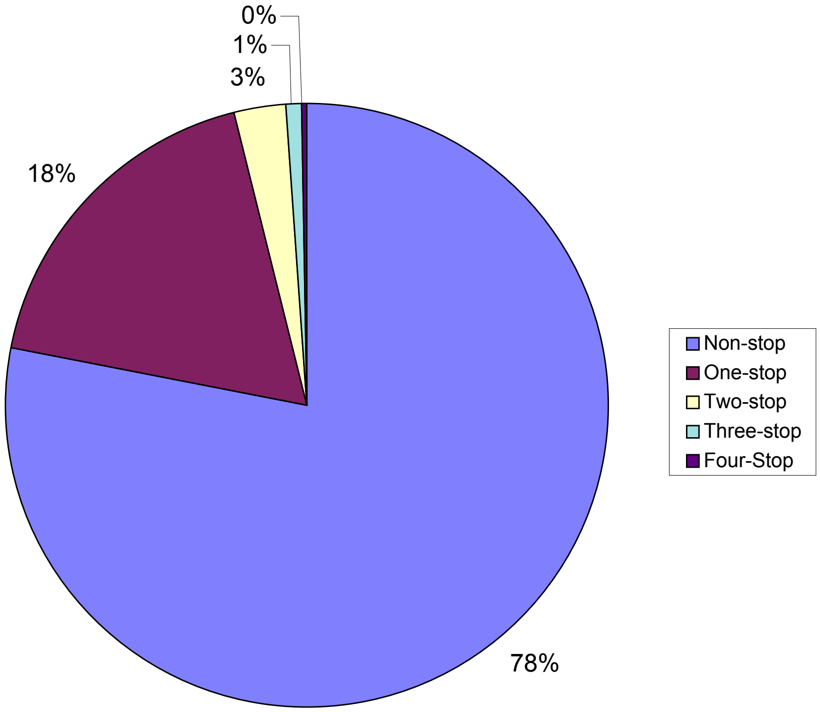
Origin Airport (cont.)	Number of Stops to LAX				
	0	1	2	3	4
FAI		1	2		
BUF		1			
HSV		1			
MFE		1			
CAE		1			
LNK		1			
RDU		1			
ACA		1			
APW		1			
BNE		1			
OAX		0			
JAN			7	4	
MTY			6		
GYE			2		
BOM			1		
TBU			0		
TAM				6	

Table 3-2

Non-stop Origins for LAX, 1998, by Distance Range and Type

Distance Range *(NM)*	Domestic	International	Total
0-500	25	3	28
501-1500	21	17	38
1501-3000	26	8	34
>3000	0	26	26
Total	72	54	126

Figure 3-1
Distribution of Flights to LAX in 1998, by Number of Stops

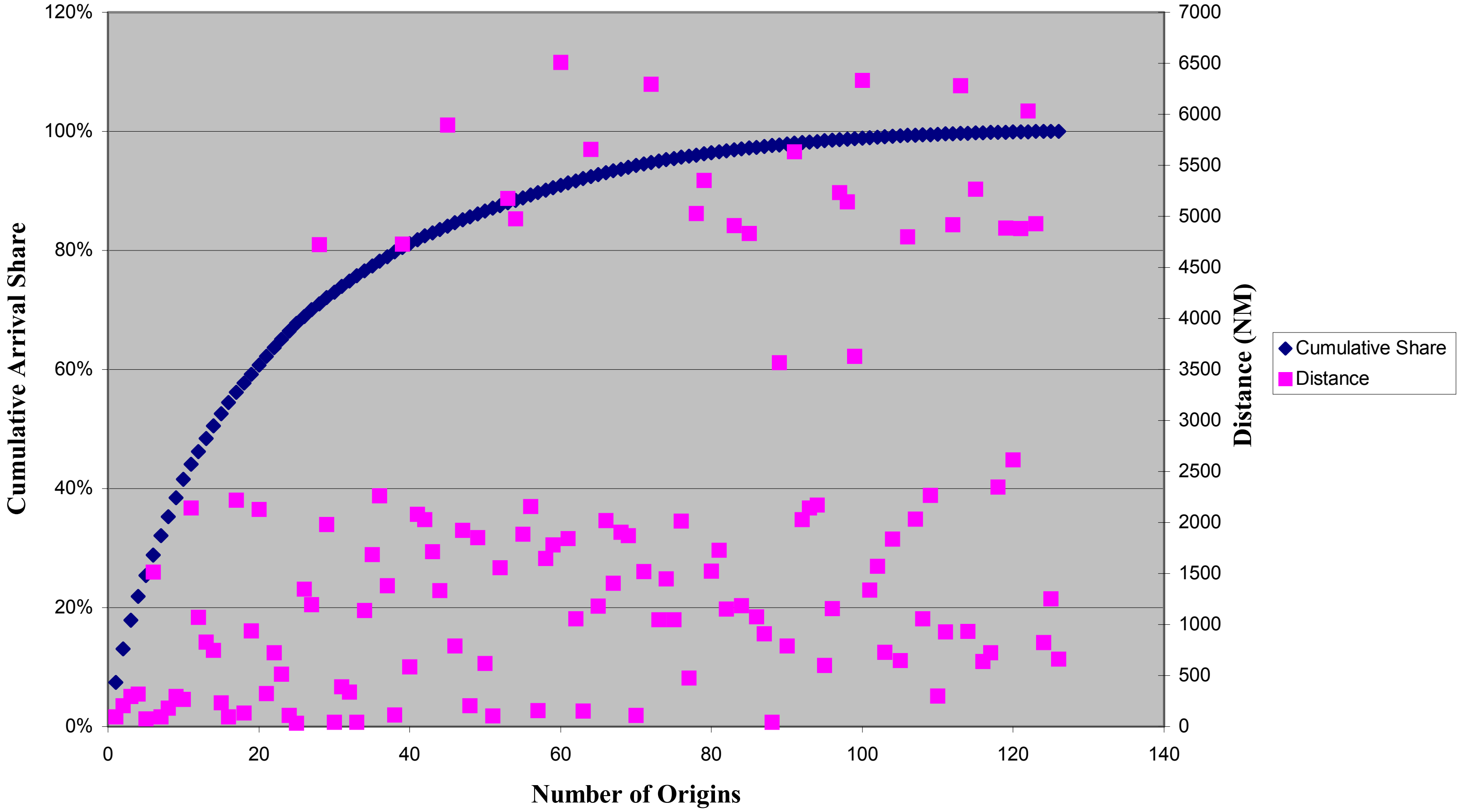


Although LAX had non-stop service to many airports in 1998, a relatively small number of these account for most of the flights. Figure 3-2 depicts this. To construct this figure we ordered the 126 airports with non-stop service to LAX in decreasing order by the number of scheduled non-stop flights to LAX. Then, we plotted the cumulative number of scheduled flights for the top origin airport, the top two origin airports, and so on. From Figure 3-2, we see that 20 non-stop segments generate about 60 percent of all flights to LAX, and 60 airports generate 90 percent of the flights.

As a general rule, the non-stop segments with the most flights to LAX are short-haul. This is also shown in Figure 3-2, where we have also plotted the length of each flight segment (using the axis on the right) on the ordered list. Looking at the lower left corner of Figure 3-2, we see that nine of the top 10 and 12 of the top 20 most-flown segments are less than 500 nm in length. The top 60 routes include 23 of the 28 short-haul ones.

Figure 3-2

Cumulative Arrival Share and Distance of Origins with Non-stop Service to LAX, 1998



The disproportionate contribution of short-haul routes is further demonstrated in Figure 3-3, which plots the cumulative distribution of distance with respect to flights and flight segments. The figure shows that the proportion of non-stop flights originating within a given radius of LAX is higher than the proportion of origin airports within that radius. For example, less that a quarter of non-stop segments are less than 500 miles, as compared to over 50 percent of flights. Thus, for all its “worldliness”, the bulk of LAX capacity is taken up by flights from very close by.

The cumulative flights plot in Figure 3-3 is very closely approximated by three straight lines. The first and steepest line extends from the origin to about 300 nm out. This corresponds to the regional segment of the market. The second line, about half as steep as the first, goes from 300 to about 2500 nm. Included within this range is most of the North American intra-continental market. The third line segment, from 2500 to 6500 nm, corresponds to the intercontinental market segment. It shape is somewhat distorted by the ocean regions from which few flights originate. From the plot, we see that the regional, North American, and intercontinental segments account for 55, 40, and 5 percent of the flights respectively. The rough linearity of the curves means that, within each segment, each increment of radius originates about the same number of flights. This in turn implies that the number of flights per unit area is inversely proportional to distance from Los Angeles.

Figure 3-4 depicts the distribution of flights to LAX by airline in 1998. Four carriers—United, its regional affiliate Mesa (UA3), Southwest, and American—account for about half the total flights. The remainder is divided among several dozen other carriers, most of which have flight shares of less than 1 percent. Altogether, United and Mesa have about a third of the total flights into LAX. Nonetheless, LAX is among the least concentrated of the major airports of the world in terms of airline flight shares. This is a consequence of its limited role as a connecting hub. As a result of this low concentration, most of the delay resulting from a given flight into LAX is incurred by airlines other than the one operating the flight. At more concentrated airports, in contrast, flights affected by congestion are more likely to belong to the same carrier as those causing it.

Figure 3-3

Cumulative Distance Distribution for LAX Non-stop Flights and Markets, 1998

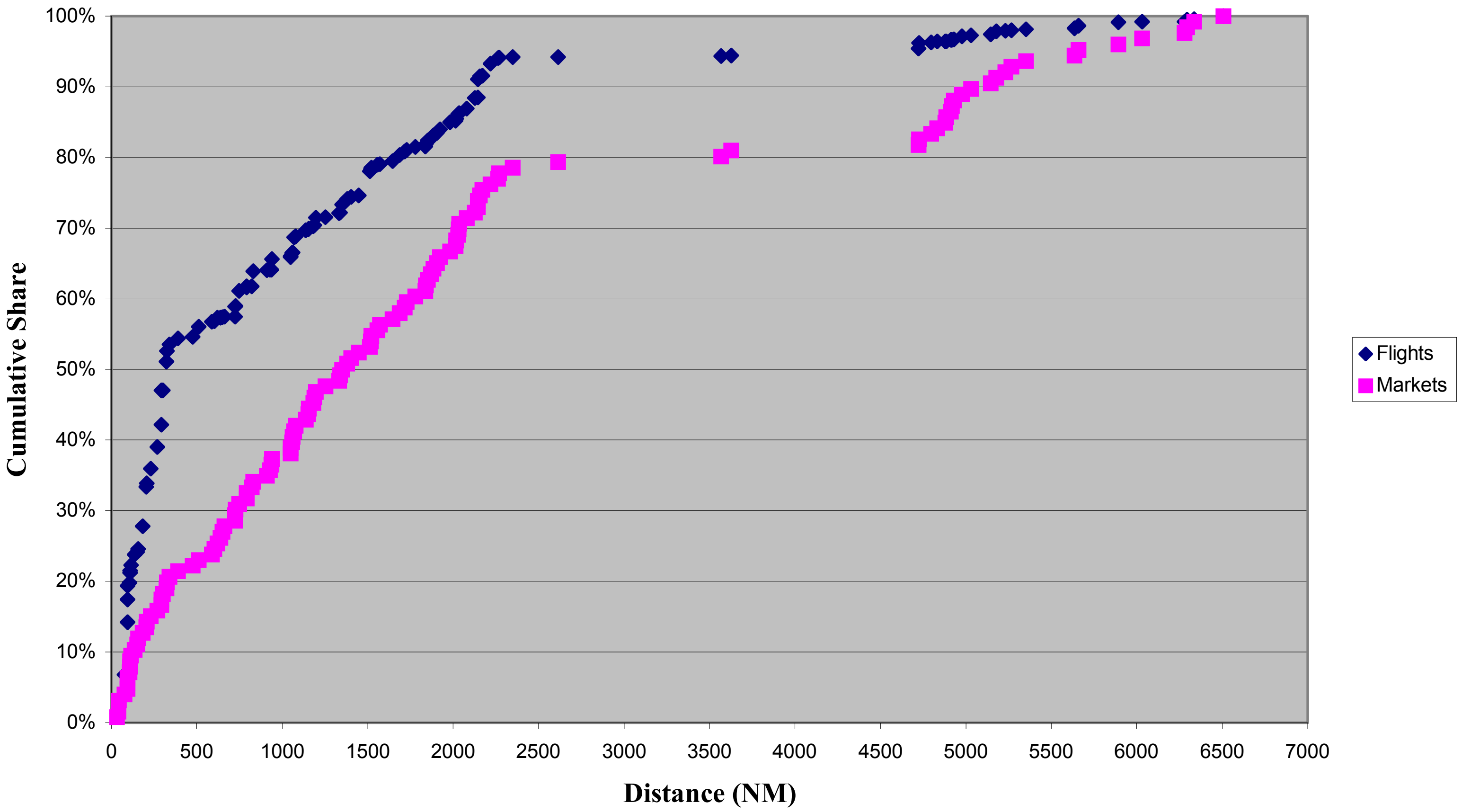
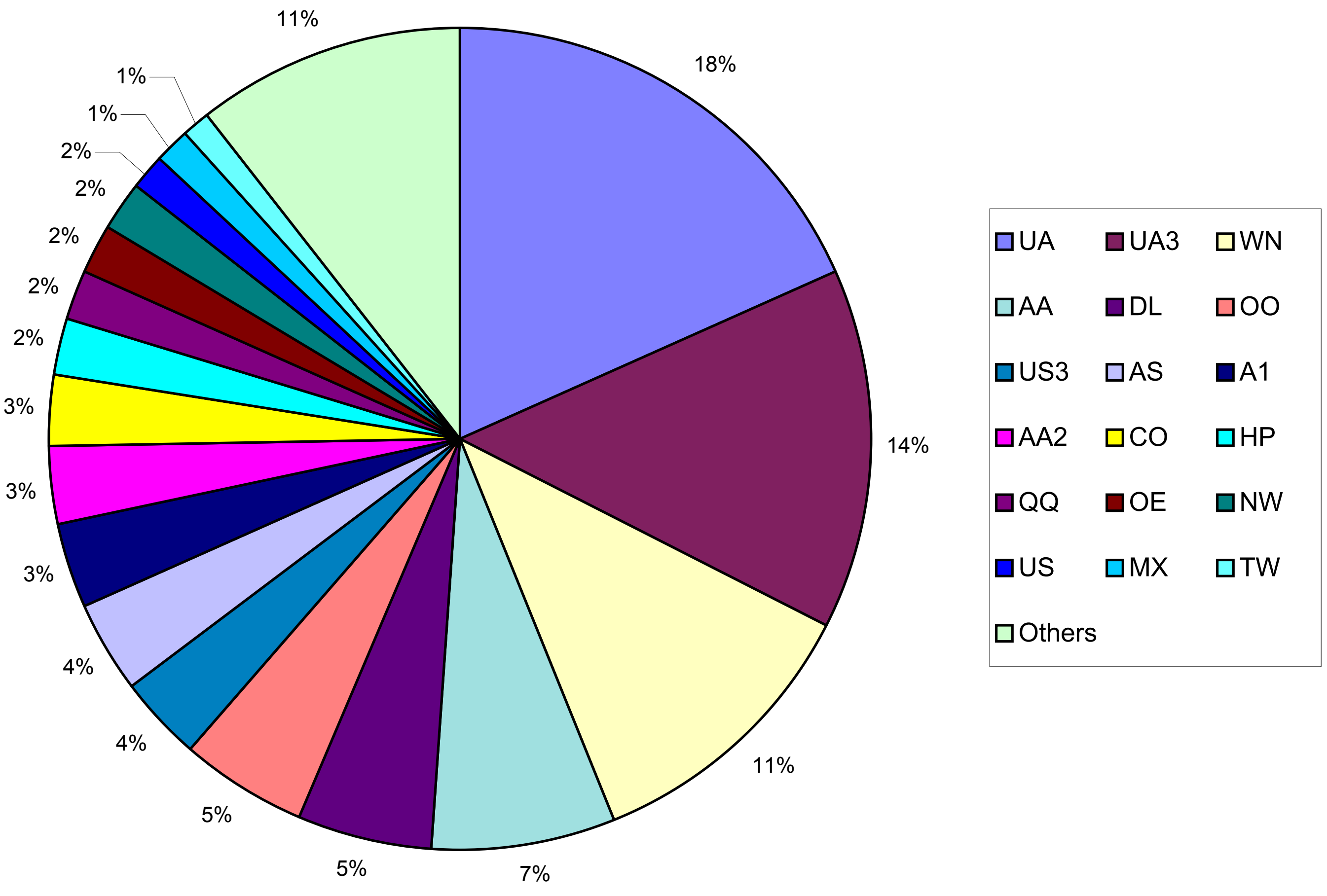


Figure 3-4

Airline Shares of Flights to LAX, 1998



Fleet Mix at LAX

Table 3-3 summarizes the fleet mix at LAX for 1998. The OAG lists services using 44 different aircraft models during this period; in Table 3-3 these are consolidated in 21 types. (For example, the Boeing 737 type includes eight different versions of this aircraft.) Three types—the Boeing 737, Embraer 120, and Boeing 757—account for over half the flights into LAX. The remaining half encompasses a broader mix. Altogether 13 types, ranging from 480-seat 747s to 18-seat Jetsteams, average more than 10 arrivals per day.

Table 3-3

Fleet Mix Summary for LAX, 1998

Aircraft Type	Arrivals per Week	Seats per Flight	Arrival Share	Seat Share	Pct Arrivals International
Boeing 737	1747.8	128	25.7%	25.0%	5.8%
Embraer 120	1357.3	30	19.9%	4.6%	2.5%
Boeing 757	717.5	188	10.5%	15.1%	6.8%
Douglas MD 80	596.7	139	8.8%	9.3%	15.3%
Shorts 360	432.0	33	6.3%	1.6%	0.0%
Boeing 747	337.5	392	5.0%	14.8%	93.5%
Jetstream Super31	326.2	18	4.8%	0.7%	0.0%
Airbus 320	321.8	147	4.7%	5.3%	29.2%
Boeing 767	299.0	202	4.4%	6.8%	19.7%
Douglas DC 10	180.8	292	2.7%	5.9%	4.0%
Boeing 727	172.8	150	2.5%	2.9%	33.3%
Lockheed L1011	99.2	299	1.5%	3.3%	7.1%
Douglas DC 9	71.2	104	1.0%	0.8%	83.4%
Douglas MD 11	53.5	291	0.8%	1.7%	76.9%
Airbus 319	39.0	120	0.6%	0.5%	39.3%
Boeing 777	27.8	302	0.4%	0.9%	37.7%
Douglas MD 90	16.8	152	0.2%	0.3%	0.0%
Airbus 340	7.0	283	0.1%	0.2%	100.0%
BAe 146	4.7	85	0.1%	0.0%	0.0%
Ilyushin II-96	2.2	300	0.0%	0.1%	61.5%
Airbus 310	0.3	205	0.0%	0.0%	100.0%
Total/Overall	6811.2	131	100.0%	100.0%	14.0%

While international flights account for only about 14 percent of the total at LAX, several aircraft types are used predominantly in international services. These include 747s, Douglas MD11s and DC9s, Airbus 340s and 310s, and the Ilyushin II-96. Factors that favor these aircraft for international service include long flight distances, which provide favorable economics for large aircraft, and the preference of some overseas carriers for Airbus aircraft. The DC9s, flown mainly on routes to Mexico, are favored because their low capital cost makes them suitable for tourist travel.

Figure 3-5 shows the distribution of flights by size categories defined in terms of 50-seat increments. The dominant sizes are less than 50 seats, 100-150 seats, and 150-200 seats which together account for 85 percent of the total. Flights with more than 200 seats divide fairly evenly among the categories between 201 and 450 seats. Figure 3-6 reveals that the upper part of this range is dominated by international services, which otherwise make up small (but non-negligible) proportions of the total, except for the DC9s in the 50-100 seat category.

From an operational standpoint, the most important aircraft categories are the weight categories used to define minimum wake vortex separations. These minima, shown in Table 3-4, constrain the arrival capacity of an airport. While directly applicable only under IFR conditions, which occur about 10 percent of the time at LAX (Landrum and Brown, 1996), the separation standards also correlate well with separations observed under VFR. As Table 3-4 shows, required separations are highest when a small aircraft is trailing a heavy one, reflecting both the stronger wakes generated by the latter, and the greater vulnerability to upset of the former.

The distribution of flights by wake vortex weight category is shown in Figure 3-7. About half of all flights are by large aircraft. The remainder is roughly evenly divided between lighter (small) and heavier (B757s and heavies) aircraft. The sizeable fractions of aircraft in these categories means that lead/trail pairs requiring large separations will occur fairly frequently. Implications of this are analyzed in our discussions of capacity and delay impacts below.

Figure 3-5

LAX Arrivals, 1998, by Size Category

(seats)

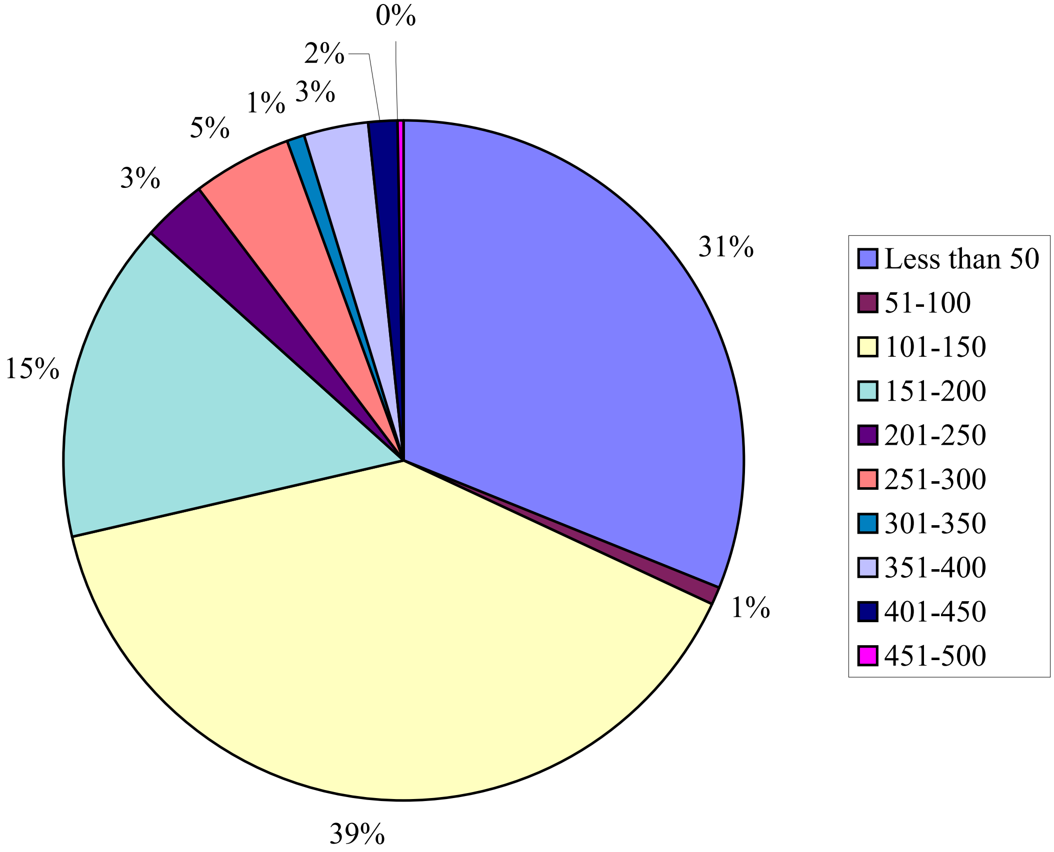


Figure 3-6

LAX Arrivals, 1998, by Size Category and Domestic/International Service Type

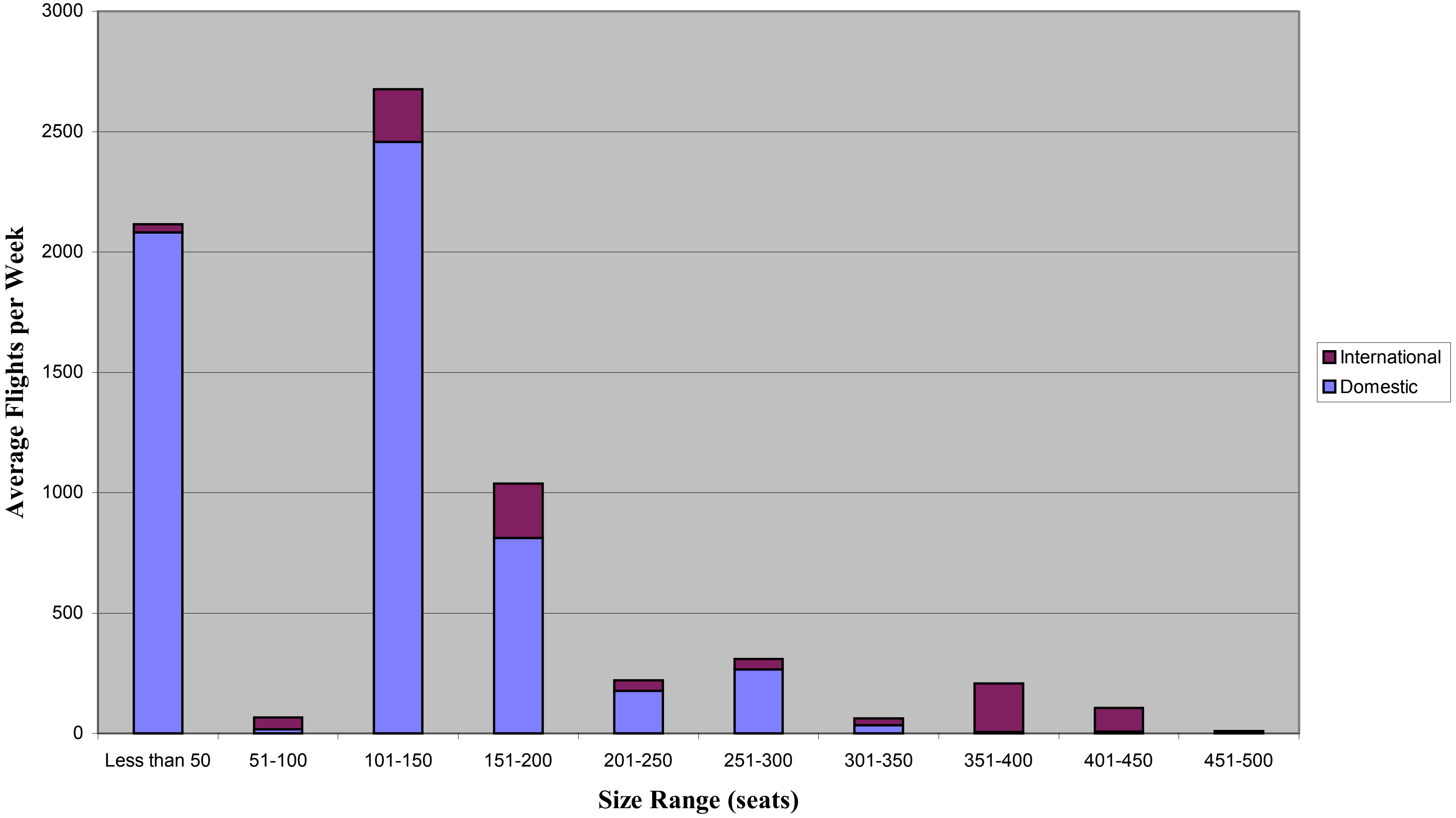


Table 3-4

Wake Vortex Separation Standards

		Trailing Aircraft			
		Small	Large	B757	Heavy
Leading Aircraft	Small (Less than 41,000 lb MTOW*)**	2.5 nm	2.5 nm	2.5 nm	2.5 nm
	Large (41,000-255,000 lb MTOW, except B757)	4	2.5	2.5	2.5
	Boeing 757	5	4	4	4
	Heavy (More than 255,000 lb MTOW)	6	5	5	4

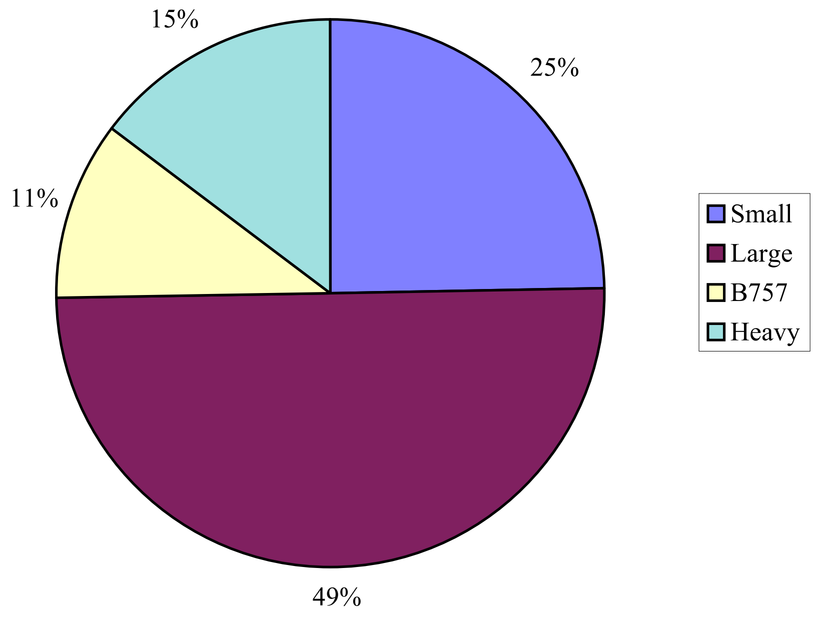
Notes:

* Maximum Take-Off Weight.

** Exceptions for Saab 340 and ATR 42, which are classified as Large.

Figure 3-7

Distribution of LAX Arrivals, by Wake Vortex Category, 1998



As shown in Figure 3-8, the wake vortex mix differs considerably for domestic and international flights. International flights are virtually all flown by aircraft in the large and heavy categories, with roughly equal numbers in each. As a result, international services account for nearly half of the heavy aircraft operations at LAX.

The diverse sizes of aircraft serving LAX means that a large fraction of the total seat capacity comes from a small fraction of the total flights, and vice versa. This is shown in Figure 3-9, which plots the cumulative seat share against cumulative flight share when flights are sorted in decreasing order of the number of seats. Also shown is the number of seats associated with each place on this ordered list. Figure 3-9 reveals that 50 percent of the total seat capacity at LAX is provided by the 26 percent of the flights which have 157 or more seats, and that the 68 percent of the flights with more than 100 seats account for about 93 percent of the seat capacity. Finally, it should be noted that the two points on the furthest right of the graph are the only ones that correspond to aircraft classified as small for wake vortex purposes. (These are the Embraer 120 and the Jetstream Super31; the Saab 340, while having a takeoff weight that would normally be classified as small, is classified as large by exception.) It can be seen that small aircraft account for over 25 percent of passenger flights, but just 5 percent of the seats, at LAX.

Impact of Fleet Mix on Capacity and Delay at LAX

The fleet mix at LAX affects both capacity and delay at the airport. This section employs simple capacity and queuing models to quantify these impacts. Our analysis focuses on arrival capacity and delay, since arrival capacity is typically less than departure capacity, and arrival delay is generally more costly than departure delay.

The methodologies presented in this section are, for the most part, not new. More complete and formal discussions of the them can be found in Horonjeff and McKelvey (1993) and Newell (1979). We have, in the interests of self-containment, attempted to provide enough explanation here to make our arguments accessible to the uninitiated. Others can skim large portions of this section.

Arrival Capacity Impact

The arrival capacity at an airport is directly related to the minimum inter-arrival time between aircraft. As noted earlier this minimum time depends upon the weight classes of the

Figure 3-8

LAX Arriving Flights by Wake Vortex Category and Domestic/International Service Type, 1998

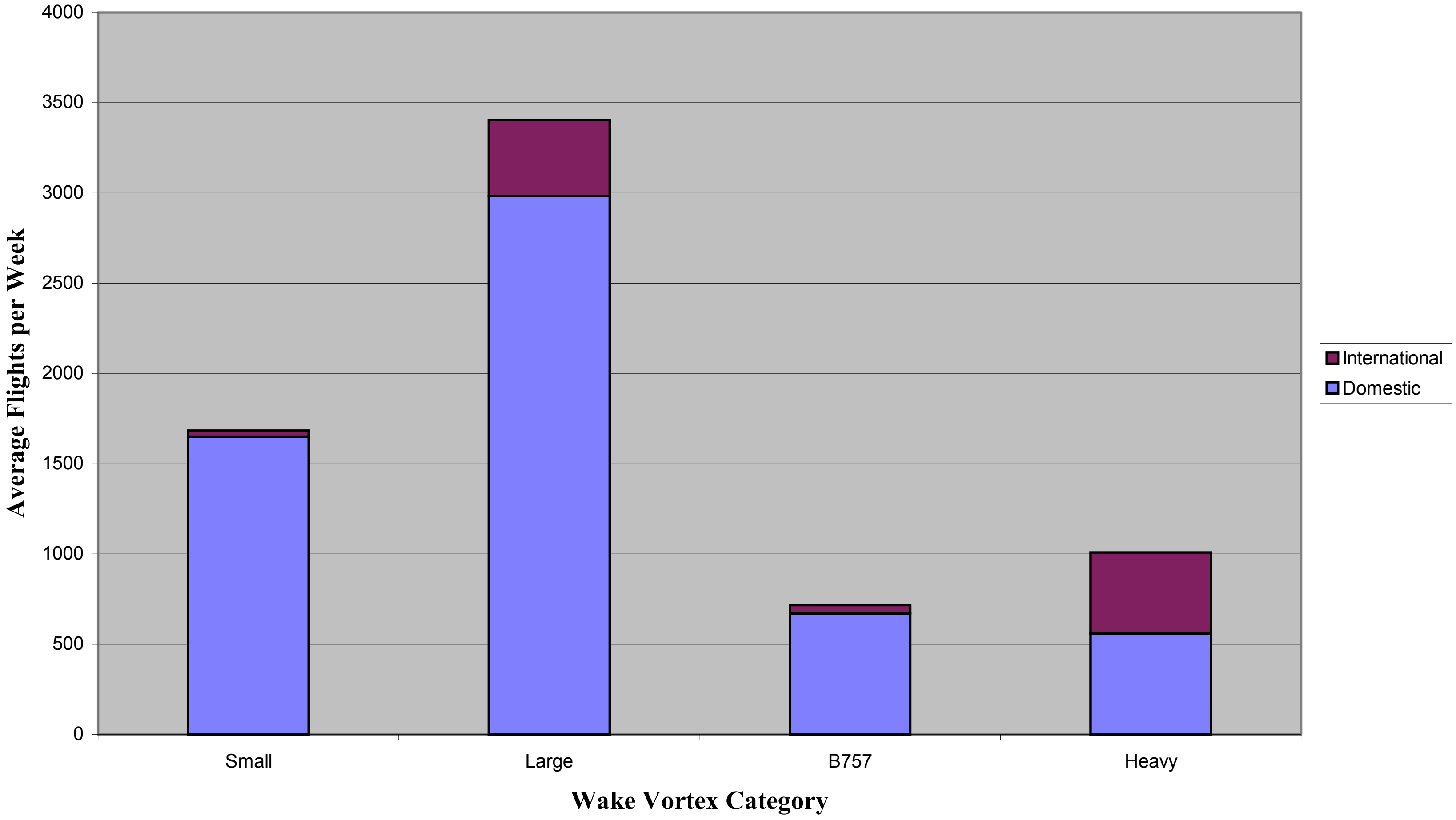
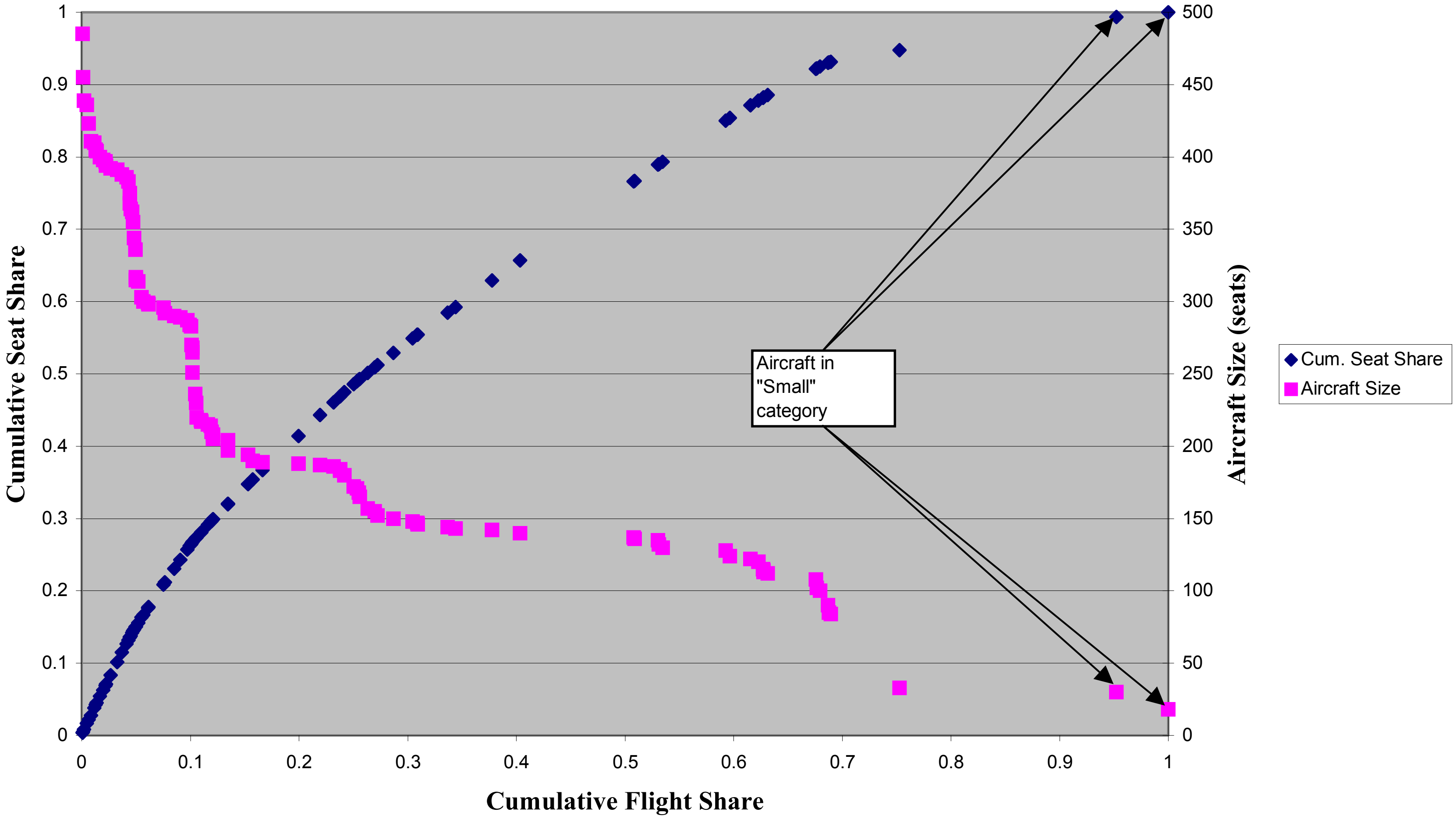


Figure 3-9

Cumulative Aircraft Seat Share and Aircraft Size vs Cumulative Flight Share, LAX Arrivals, 1998



leading and trailing aircraft. In addition, the minimum inter-arrival time depends on the approach speeds of the aircraft. Let δ_{ij} be the minimum allowed separation between a leading aircraft of type i and a trailing aircraft of type j. Let V_i and V_j be the speeds of these aircraft on final approach. When $V_i \leq V_j$ the minimum inter-arrival time is simply $\tau_{ij} = \frac{\delta_{ij}}{V_j}$. This is known as the "closing" case because the separation between the aircraft can decrease (or remain constant) as the aircraft move along the final approach, reaching the prescribed minimum as the leading aircraft touches down. On the other hand, if $V_i > V_j$, we have the "opening" case because separation will increase as aircraft move along the final approach. Suppose the minimum separation δ_{ij} occurs when the lead aircraft is ℓ miles from the runway threshold. The lead aircraft will touch down at a time $\frac{\ell}{V_i}$ later, while for the trail aircraft the time between minimum separation and touchdown will be $\frac{\ell + \delta_{ij}}{V_j}$. The minimum inter-arrival time in the opening case is therefore:

$$\tau_{ij} = \frac{\ell + \delta_{ij}}{V_j} - \frac{\ell}{V_i} = \frac{\delta_{ij}}{V_j} + \ell \cdot (\frac{1}{V_j} - \frac{1}{V_i})$$

Table 3-5 shows the minimum inter-arrival times between each possible combination of leading and trailing aircraft at LAX, using either the closing or the opening case formula as appropriate, assuming that ℓ has a value of 7 nm. The speeds used are approach speeds obtained from Jane's All the World's Aircraft and supplemented from a variety of other sources. They may be somewhat conservative in the case of small planes, which controllers encourage to approach at speeds greater than their nominal values and then slow just before touchdown. The shadings in the table indicate different lead-trail category combinations. The shortest inter-arrival times occur when large, heavy, or B757 aircraft trail small or large aircraft, while the longest times involve a small trailing a heavy. One can see that a fleet mix consisting of only planes in the large size category would be ideal from a flight throughput standpoint, with a plane able to cross the runway threshold almost every minute.

Table 3-5

Minimum IFR Interarrival Times, in Minutes, by Aircraft Type Leading and Trailing

Leading	Trailing																					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1 Embraer 120	1.3	1.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
2 Jetstream Super31	1.3	1.3	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
3 Airbus 319	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
4 Airbus 320	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
5 BAe 146	2.4	2.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
6 Boeing 727	2.8	2.8	1.1	1.1	1.6	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
7 Boeing 737	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
8 Douglas DC 9	2.7	2.8	1.1	1.1	1.6	1.1	1.1	1.1	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
9 Douglas MD 80	2.8	2.8	1.1	1.1	1.6	1.1	1.1	1.1	1.1	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
10 Douglas MD 90	2.8	2.9	1.1	1.1	1.7	1.1	1.1	1.2	1.2	1.1	1.7	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
11 Saab 340	2.3	2.4	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1
12 Airbus 310	3.9	3.9	2.2	2.2	2.9	2.2	2.2	2.3	2.2	2.2	3.0	1.7	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
13 Airbus 340	3.9	4.0	2.2	2.2	2.9	2.2	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
14 Boeing 747 1*	3.9	4.0	2.2	2.2	3.0	2.3	2.3	2.4	2.3	2.2	3.0	1.8	1.8	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
15 Boeing 747 2*	4.2	4.2	2.5	2.5	3.2	2.5	2.5	2.6	2.5	2.4	3.3	2.0	2.0	1.9	1.6	1.9	1.9	2.0	2.0	1.9	1.8	2.5
16 Boeing 767	4.0	4.0	2.3	2.3	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.8	1.8	1.7	1.6	1.7	1.7	1.8	1.8	1.7	1.6	2.3
17 Boeing 777	3.9	4.0	2.2	2.2	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.8	1.8	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
18 Douglas DC 10	3.9	4.0	2.2	2.2	3.0	2.3	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
19 Douglas MD 11	3.9	4.0	2.2	2.2	3.0	2.3	2.2	2.3	2.3	2.2	3.0	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	2.2
20 Ilyushin II-96	4.0	4.0	2.3	2.3	3.0	2.3	2.3	2.4	2.3	2.2	3.1	1.9	1.8	1.7	1.6	1.7	1.7	1.8	1.8	1.7	1.6	2.3
21 Lockheed L1011	4.0	4.1	2.3	2.3	3.1	2.4	2.4	2.5	2.4	2.3	3.1	1.9	1.9	1.8	1.6	1.8	1.8	1.8	1.8	1.7	1.6	2.3
22 Boeing 757	3.3	3.4	1.7	1.7	2.4	1.8	1.8	1.9	1.8	1.7	2.5	1.8	1.7	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.6	1.7

Note:

* Boeing 747 has been subdivided into two types: “747 1” includes earlier models such as 747-200 and 747-300. “747 2” refers to later models such as the 747-400.

In most cases, the arrival capacity at an airport is directly related to the minimum inter-arrival times. Suppose the airport has one runway dedicated to arrivals, and that the first of a sequence of flights, 1, 2, …, N crosses the runway threshold at time $t = 0$. Then the last flight can cross no sooner than $t = \tau_{12} + \tau_{23} + \ldots + \tau_{N-1N}$. Averaging over the sequence, beginning just after the first arrival, the average minimum time per flight is $\bar{\tau} = \frac{\tau_{12} + \tau_{23} + \ldots + \tau_{N-1N}}{N-1}$, and the maximum flights per unit time, or capacity, is $\frac{1}{\bar{\tau}}$. If, as in the case of LAX, there are two independent runways, arrival capacity is $\frac{2}{\bar{\tau}}$.

It is clear from the above discussion that arrival capacity is influenced by the specific sequence of flights landing on a runway. In principle, one can increase capacity by sequencing or segregating operations in order to prevent or limit high inter-arrival time pairs such as a small aircraft trailing a heavy one. For example, when there are two arrival runways, small aircraft could all be assigned to one and heavies to the other. While such strategies increase runway capacity, they may also reduce the efficiency of air traffic flow in the terminal area, and at LAX they are not used.

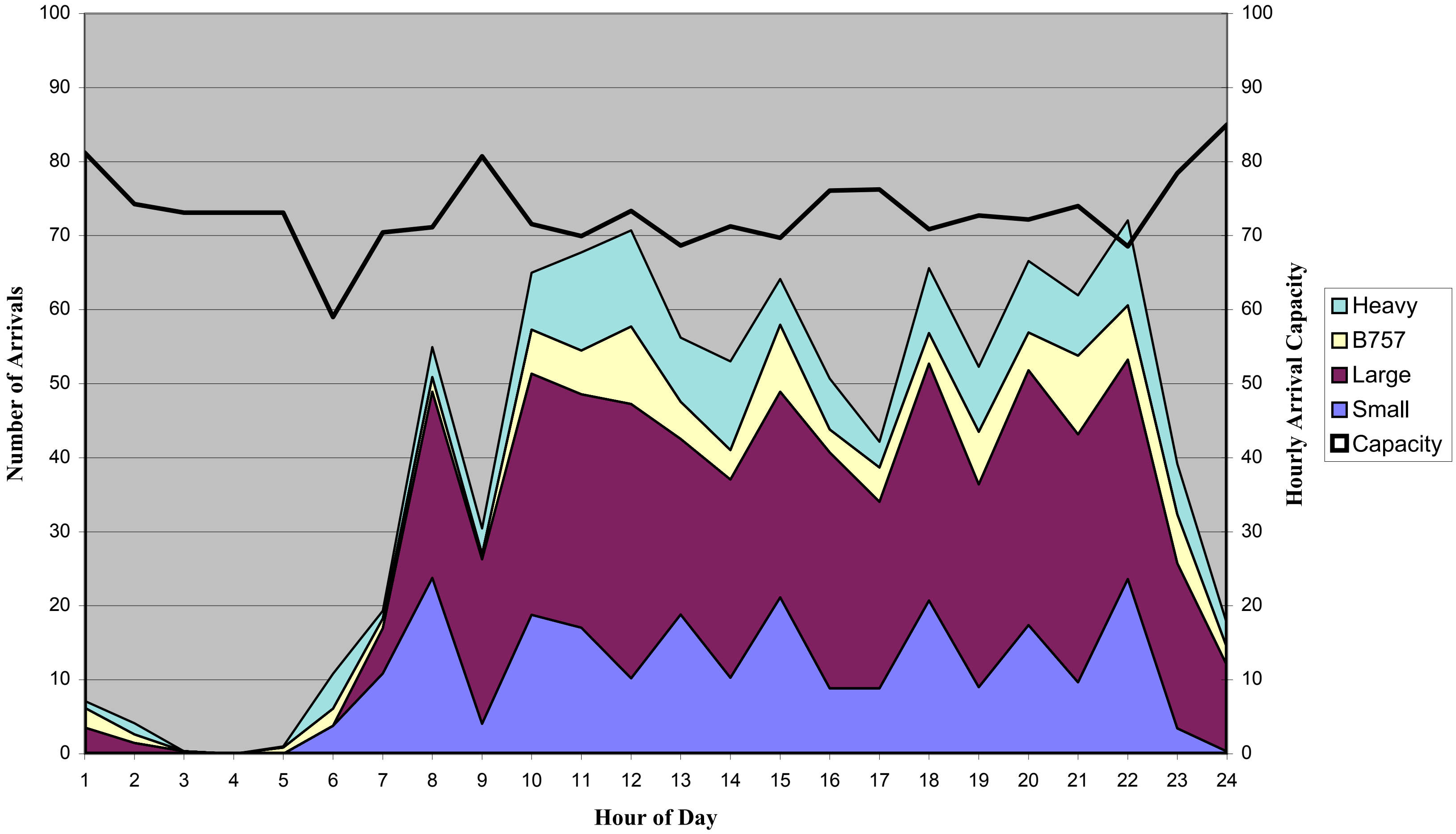
In the absence of measures to strategically sequence or segregate aircraft, the aircraft types leading and trailing in any given pair can be treated as independent variables. If P_i is the proportion of arrivals by aircraft of type *i*, and P_j the proportion of type j arrivals, then the probability that a given lead-trail pair is a type i followed by a type j is $P_{ij} = P_i \cdot P_j$. This leads to the result than the arrival capacity at an airport with two independent runways is:

$$\lambda(\textit{two independent runways}) = \frac{2}{\sum_i \sum_j P_i P_j \tau_{ij}}$$

The proportions of the different types vary throughout the day, as shown by Figure 3-10, which plots the distribution of arriving aircraft by wake vortex size category for each hour. One can see surges of small aircraft arrivals every 2-3 hours, and a major surge in heavy arrivals in the late morning. On the basis of the hourly fleet mix, and the minimum inter-arrival times shown in Table 3-5, the hourly capacity was calculated and is also plotted in Figure 3-10. There is a sharp reduction in arrival capacity from 80 per hour in the 8-9am period, where the fleet is

Figure 3-10

LAX Arrival Fleet Mix and Capacity, by Hour, 1998



dominated by large aircraft, to about 70 during the 9-10am period, when there are more heavy, B757, and small aircraft in the arrival stream. Capacity fluctuates in the low to mid-70s range for the remainder of the day, until the late evening when no more small aircraft arrivals are scheduled, and the capacity goes back up over 80.

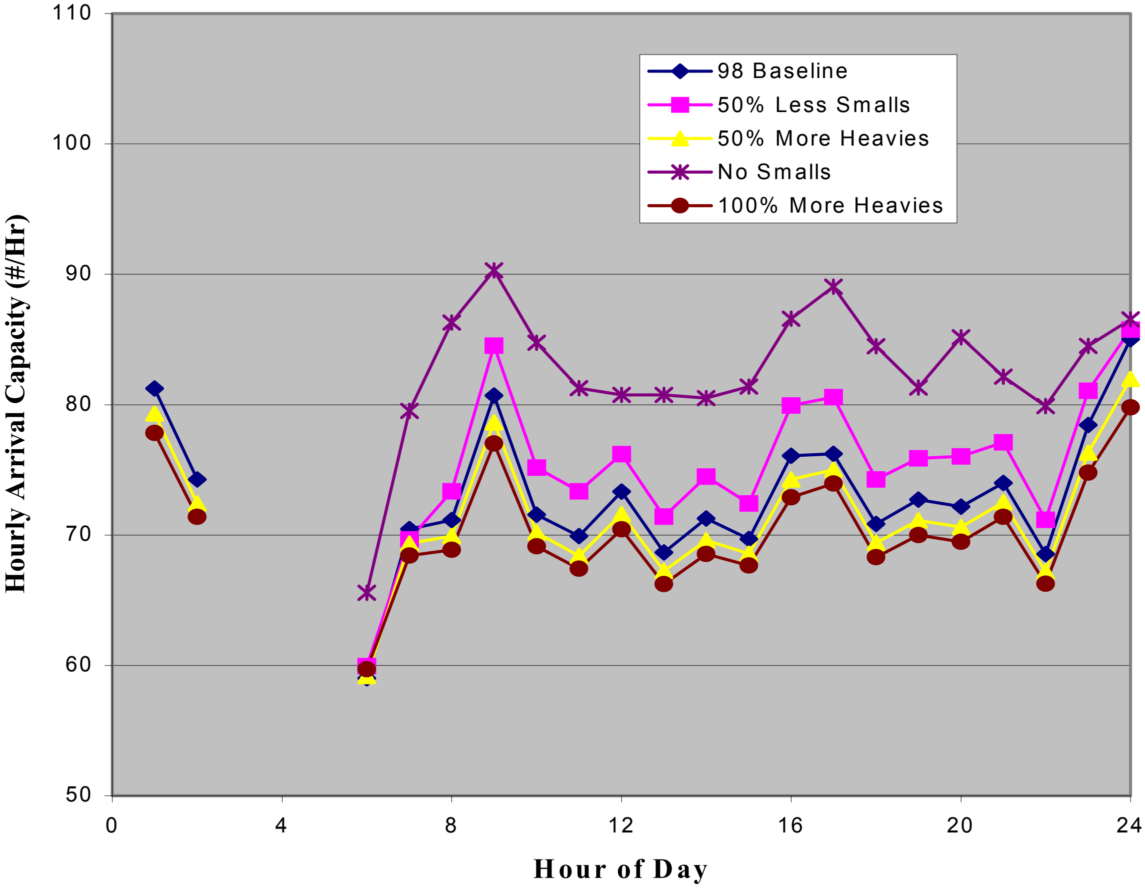
These capacity estimates were compared with those obtained from simulation analyses for the LAX master plan, and airport acceptance rates set by the Southern California TRACON. Simulations for the year 2000 show peak hour arrival throughputs of between 62 and 80 for VFR, depending on the flow direction (west flow higher), and 70 under IFR (with west flow). Acceptance rates reported in Southern California TRACON logs are generally 68 under IFR while ranging from 72 to 84 under VFR (with rates for east and west flow approximately the same). Our IFR capacity estimates are somewhat higher than those obtained from the simulations and TRACON logs, probably because controllers often include some additional buffer to ensure that IFR minima are never violated. On the other hand, our IFR values match quite well with the VFR values obtained from simulation (except for the east flow) and the TRACON acceptance rates. This is somewhat surprising not only because VFR separations are somewhat less, but also because tower controllers often permit a third arrival stream onto an in-board runway under VFR. It appears that limitations in controllers ability to sequence planes to fully use available runway capacity just about offsets the advantages of reduced separations and in-board runway use that our model overlooks. Therefore, our capacity model seems a reasonable tool for the subsequent analysis, given the intent of providing approximate results.

To assess the impact of fleet mix on arrival capacity at LAX, we compared the hourly capacity computed from the 1998 fleet mix (as shown in Figure 3-10) to capacities that would result from four hypothetical alternatives. Two of the alternatives involve reducing the number of small aircraft—in one by 50 percent, and in the other eliminating them altogether. In the other two alternatives, the number of heavy aircraft is increased, first by 50 percent and then by 100 percent. In all scenarios, the changes were assumed to be uniform across the day. For example, if small aircraft are reduced 50 percent, then the number of small aircraft arrivals in each hour of the day is reduced 50 percent. Proportional changes in the different aircraft types belonging to a size category are also assumed to be uniform. In the previous example, both the Embraer 120 and the Jetstream 31 flights are cut 50 percent.

Figure 3-11 compares hourly capacities under the four hypothetical scenarios as well as the 1998 baseline fleet mix. It is evident that arrival capacity is more sensitive to the proportion of small aircraft than the proportion of heavy ones. For most of the day, reducing the number of smalls 50 percent would result in capacity increases of 2-4 arrivals per hour. Eliminating small planes from the fleet mix would increase arrival capacity even more dramatically—in most hours by more than 10. This non-linear relationship reflects the influence of pairing. When the fraction of small aircraft is small, they are almost always forced to trail heavier and faster planes, requiring long inter-arrival times. As more small aircraft are added to the fleet, the likelihood of smalls trailing smalls, which require considerably shorter inter-arrival times, becomes significant.

Figure 3-11

Sensitivity of LAX Hourly Capacity to Fleet Mix



LAX arrival capacity is considerably less sensitive to changes in the number of heavy aircraft. Arrival capacity declines by about 2 per hour under the scenario in which heavy flights increase 50 percent, and about 3 per hour under the 100 percent scenario. The non-linearity has an explanation similar to that for the small aircraft scenarios—as the number of heavy aircraft grows, so does the rate of formation of heavy-heavy pairs, for which inter-arrival times are less than when a heavy is trailed by a non-heavy.

Arrival Delay Impacts

This section analyzes how airline fleet mix and scheduling decisions influence delay at LAX. Although sophisticated simulation models can be used to predict delay, they are not well suited to our goal of assessing the sensitivity of delay to schedule and fleet mix variables, since every question requires a new simulation run. Instead, we employ a simple deterministic queuing model that both predicts delay and clearly reveals the sensitivity of delay to individual flights.

Figures 3-12 to 3-17 depict the main concepts of the deterministic queuing model, as applied using the 1998 fleet mix and a specific arrival schedule from a day in January 1998, which we will term the "sample day schedule." Figure 3-12 is cumulative curve of scheduled arrival times at LAX. On the day represented there were 1001 scheduled arrivals for passenger aircraft—this is the vertical coordinate of the point at the far right of the plot. The horizontal coordinate of that point is the time when the last arrival was scheduled to occur: 5 minutes before midnight. Likewise, the coordinates of every other point on the arrival curve indicate the sequence number of an individual arriving flight (1 for the arrival schedule to occur first, etc.) and the scheduled arrival time for that flight.

The slope of the arrival curve measures the scheduled arrival rate. One can see that the slope is shallow in the early morning hours and then steepens around 7am. After a brief respite beginning at about 8am, there is a sustained high rate extending from 10am into the early afternoon. Other surges are evident between 3 and 4pm, and beginning at about 9pm until about 10:30pm.

As a result of capacity constraints at LAX, not all arrivals can occur when they are scheduled to. The capacity limits the rate at which the cumulative curve for actual (as opposed to scheduled) arrivals can grow. If it is assumed that no arrival can occur before it is scheduled, and that the slope of the actual arrival curve cannot exceed the arrival capacity of the airport, it is

Figure 3-12

Cumulative Curve, Scheduled Arrival Times, LAX Sample Day Schedule

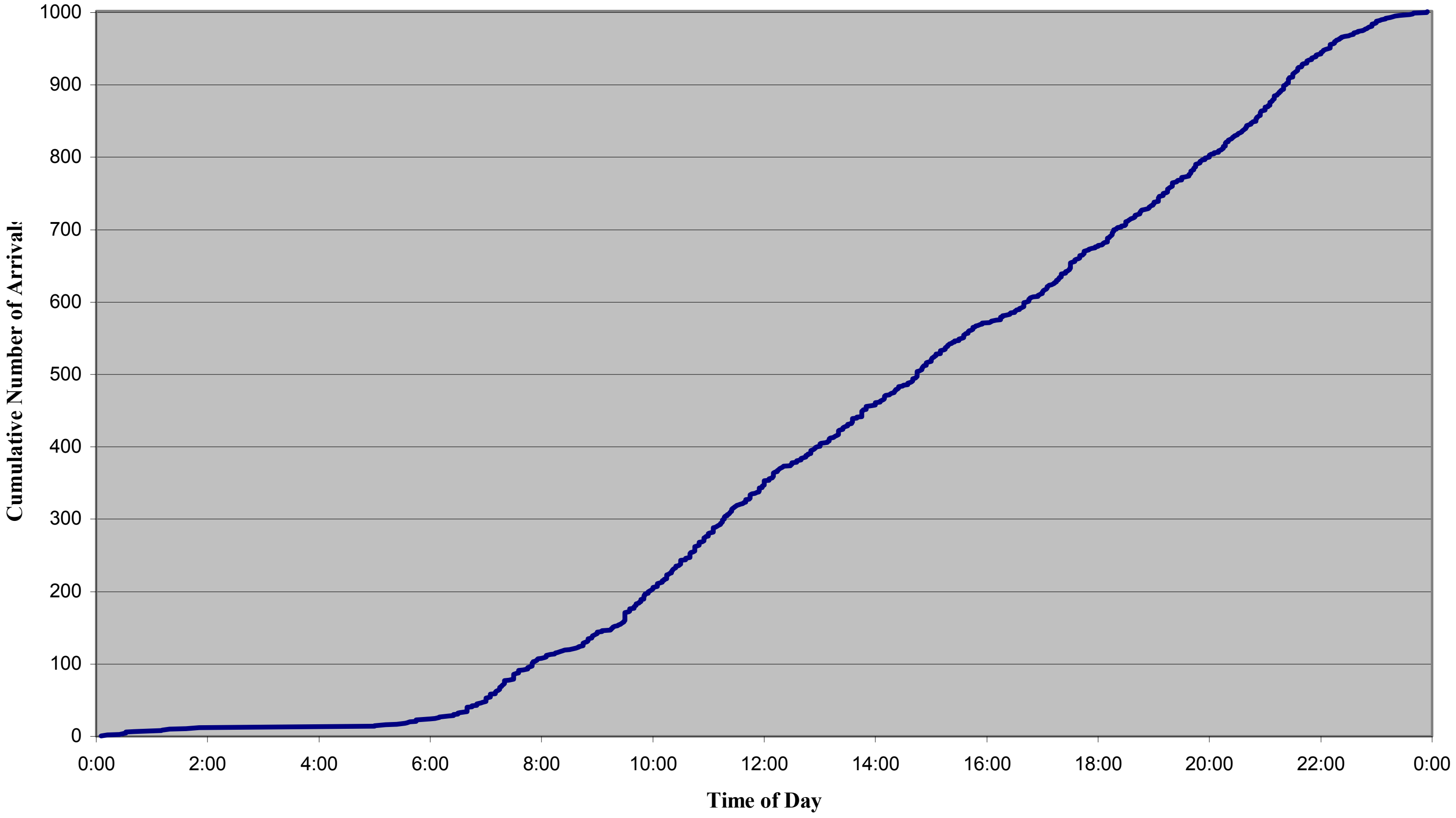


Figure 3-13

Cumulative Curves, Scheduled and Capacity Constrained Arrival Times, Sample Day Schedule

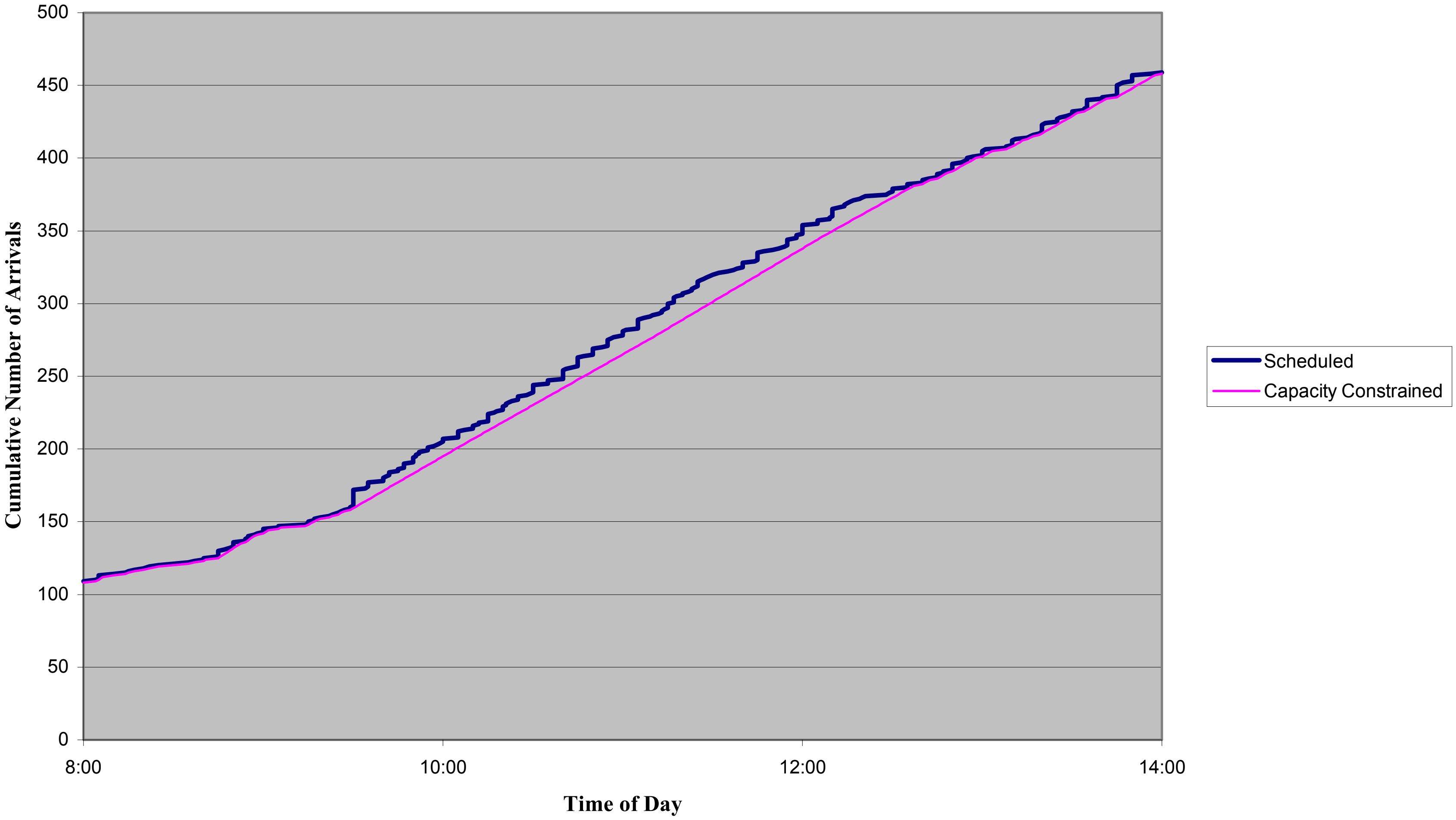


Figure 3-14

Determining Delay and Queue Length from Cumulative Curves

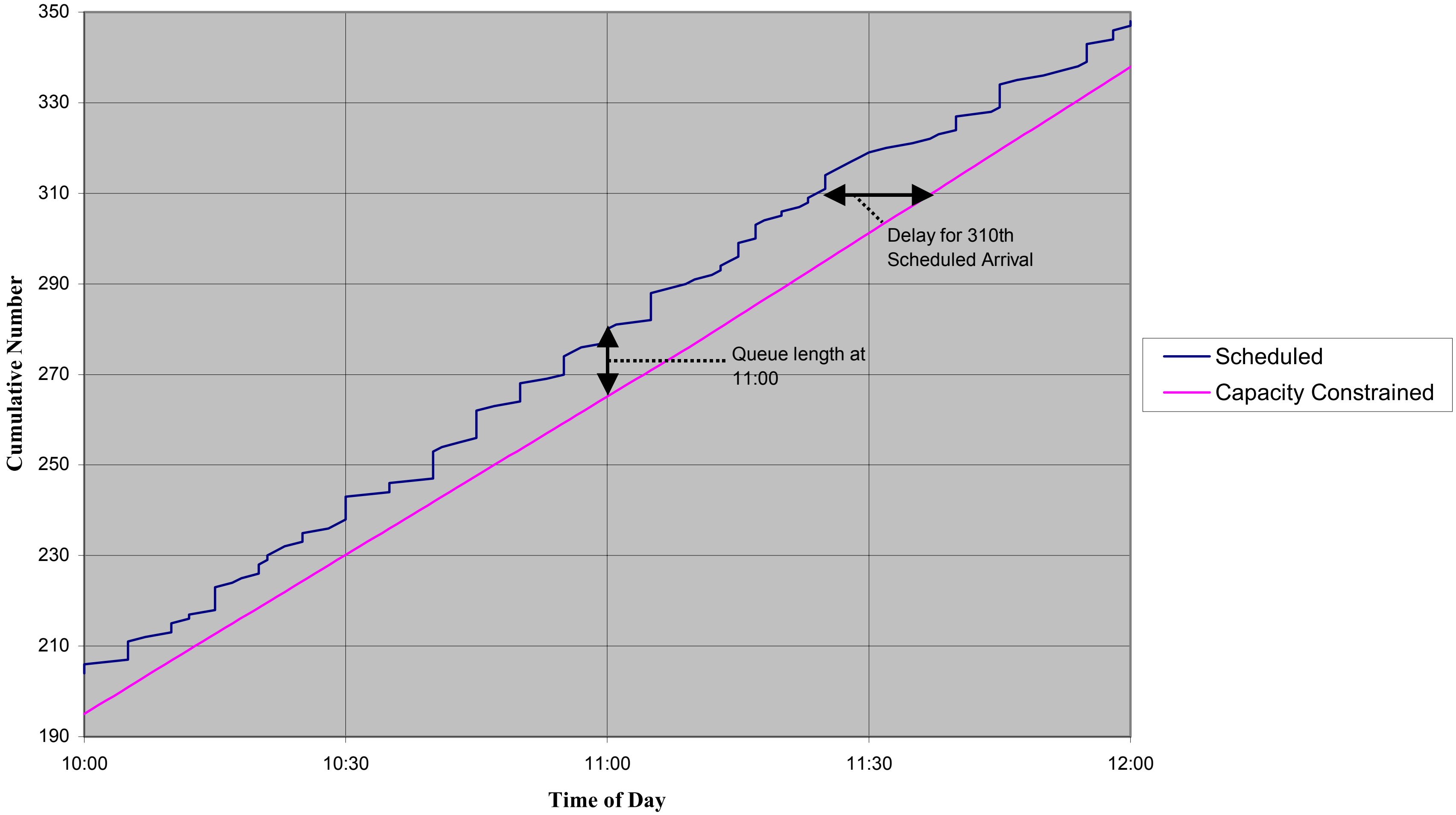


Figure 3-15

Queuing Diagram with Pair Specific Inter-arrival Times

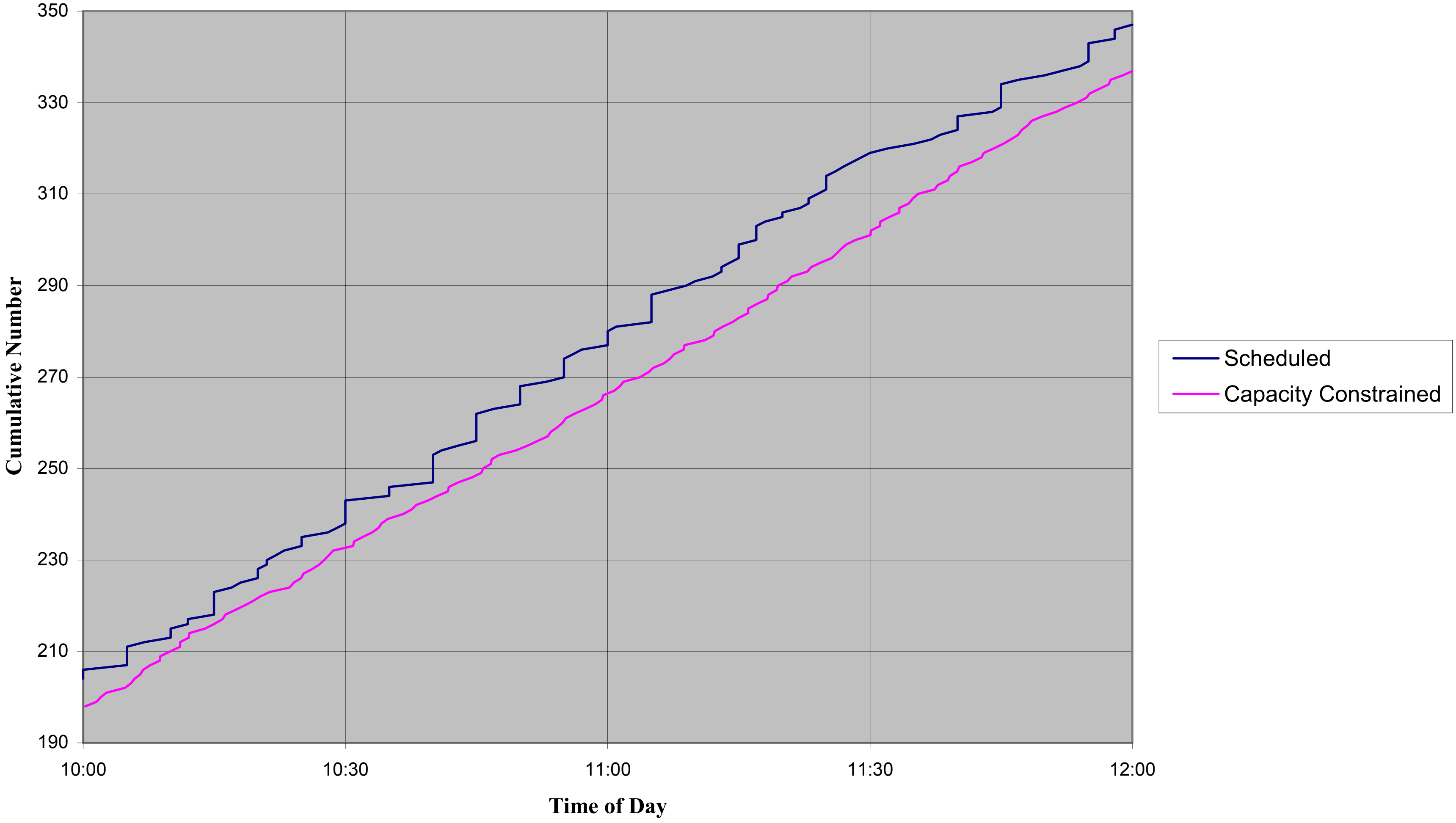


Figure 3-16

Expected Delay vs Schedule Arrival Time, LAX Arrivals, by Growth Scenario

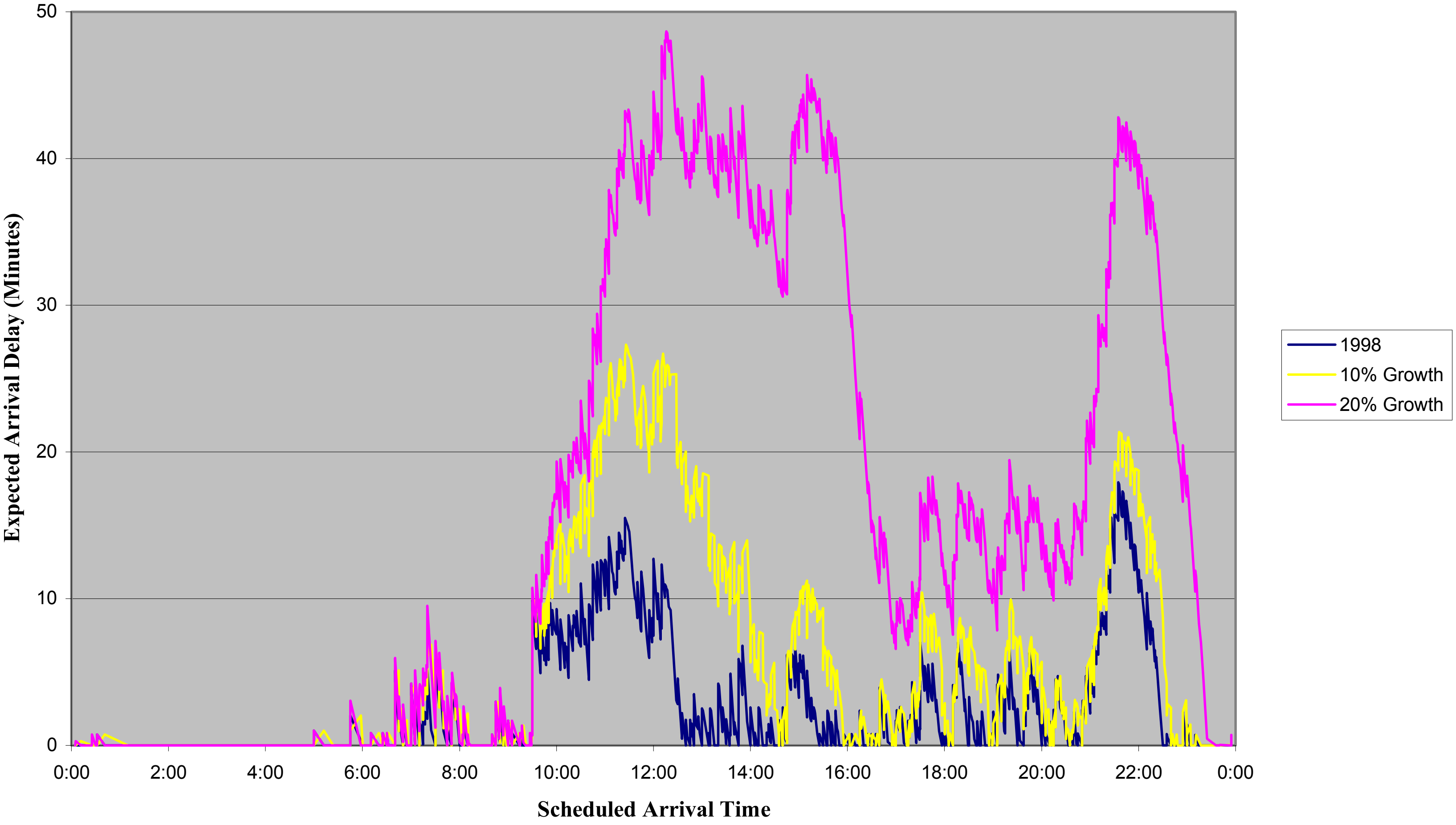
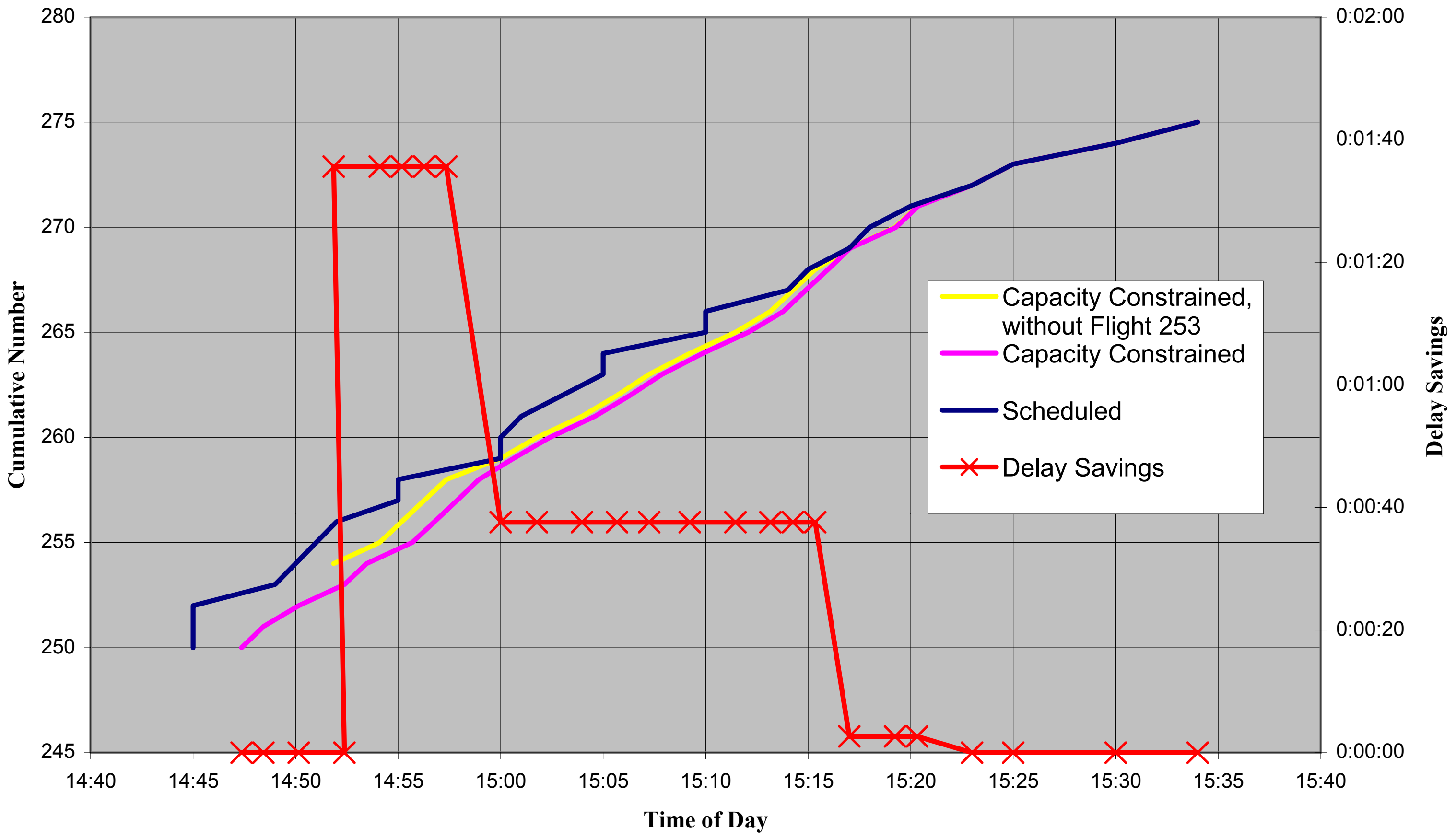


Figure 3-17

The Incremental Delay Impact of a Flight



possible to construct a capacity constrained arrival curve from the scheduled curve and the capacity. This is illustrated for a portion of the scheduled arrival curve in Figure 3-13. Until about 9:30am, the scheduled and constrained curves overlap, since the airport capacity can handle the scheduled demand. Thereafter, until the afternoon, the two curves diverge. During this period, the arrival runways lack the capacity to keep up with the scheduled demand, resulting in delay. Shortly after noon, the scheduled demand slows, enabling the runway system to clear the backlog. The scheduled and constrained curves then nearly overlap except for occasional short demand surges (seen as vertical steps on the scheduled curve) around 1:30pm.

Delays occur when there are gaps between the scheduled and capacity constrained arrival curves. This is shown in Figure 3-14, which narrows in on a portion of the plot shown in Figure 3-13. Consider first the horizontal gap between the two curves at a given cumulative number—310 in the example. By definition, this is the time between when the 310th arrival is scheduled to occur and when it can actually occur. If constrained arrivals occur in the same flight sequence as scheduled ones, then this gap represents the delay to the 310th flight necessitated by arrival capacity constraints at LAX. If the two sequences are different then the 310th flight may have a delay greater than or less than the horizontal gap shown, but this difference must be counter-balanced by one for some other flight. Therefore, whatever the sequence of actual arrivals, the total arrival delay is obtained by summing the horizontal distances between the cumulative curves for scheduled and capacity-constrained arrivals.

The vertical distance between the two curves at a given time also has a simple interpretation. It is the difference between the number of arrivals that have been scheduled to occur by this time and the number that can occur. Thus, the vertical gap reflects the "backlog" of flights or queue length. In the context of flights arriving at an airport this queue includes flights that are holding in the terminal airspace, as well as those that are still en route after being delayed through vectoring or holding at their origin airport.

The capacity-limited portions of the constrained arrival curves in Figures 3-13 and 3-14 have slopes derived from the hourly capacities depicted in Figure 3-10. Within any given hour, therefore, the slope is constant. As explained earlier, these hourly capacities are based on averages of inter-arrival times that vary significantly depending upon the aircraft types. For a given schedule of flights, aircraft types, and runway assignments, the actual arrival curve can be constructed using pair-specific inter-arrival times instead of hourly averages. Figure 3-15 provides an example of this. To construct the constrained arrival curve here, flights were assigned to the two runways on an alternating basis. (While the actual runway assignments are not determined so simply, they are intended to balance demand on the runways during busy periods, and should thus result in comparable levels of delay.) In addition to having a slope that varies as the result of differing inter-arrival times, the curve displays “jiggles” due to arrivals occurring simultaneously at the two runways.

Comparing Figures 3-14 and 3-15, it is evident that the straight line approximates the actual arrival curve quite well. Over the entire day, the average arrival delay based on the straight-line approximation is 4.273 minutes. When the pair-specific curve is used, the average delay is 4.275 minutes. The latter value is, however, sensitive to slight variations in the scheduled arrival curve that change the order of flight arrivals. Such variations are expected as a result of departure delays, winds, en route congestion, and other factors.

The impact of traffic growth at LAX was analyzed by creating hypothetical schedules with 10 percent and 20 percent more arrivals than the 1998 one. The schedules were created by combining the 1998 arriving flights with new ones having the same distributions of scheduled arrival times and aircraft types. The hourly capacities were held constant across the scenarios, reflecting the assumption of constant fleet mix. In Figure 3-16, the daily delay patterns for the three scenarios are compared. The horizontal axis is the scheduled arrival time, while the vertical axis is the expected delay based on the deterministic queuing model. With 10 percent growth, delays associated with the morning rush period extend into the mid-afternoon, and peak delays for the morning rush double. With a growth of 20 percent, delays over 20 minutes persist from 10am until the later afternoon, and again from 9:30-10:30pm. Average delays increase from 4.1 minutes under the 1998 scenario to 8.2 and 22.2 minutes under the 10 percent and 20 percent growth scenarios, respectively. As a comparison, the simulation results obtained for the LAX master plan predict a delay of 10.3 minutes for a demand scenario roughly the same as our 20 percent growth one, but a higher arrival capacity of 80 per hour. When we use 80 as the arrival capacity in our model, we get an average arrival delay of 7.3 minutes.

The Incremental Delay Impact of a Flight

An important advantage of the deterministic queuing model is that it can easily predict the consequences of changes to the arrival schedule or fleet mix. Here we use the model to predict the additional delay that is caused by each flight. If a given flight is eliminated from the schedule during a time when the system is capacity constrained, subsequent flights can be accommodated sooner and thus incur less delay. The resulting reduction in delay is illustrated in Figure 3-17. As the result of the hypothetical elimination of flight number 253, the constrained arrival curve shifts to the left. The magnitude of the initial shift is the minimum of two quantities: (1) the reduction in the minimum inter-arrival times between flights 252 and 254 resulting from eliminating flight 253, and (2) the delay for flight 254 assuming that flight 253 takes place. In other words, the arrival time of flight 254 can move up as early as quantity (1), except that the flight cannot arrive earlier than its scheduled time.

In the case illustrated, the initial shift is determined by the inter-arrival times—quantity (1) above. This initial shift propagates forward in time. Each flight after the eliminated one can move up in the queue as long as the queue exists. However, no flight can have a delay savings greater than the savings of the flight preceding it, or greater than its initial delay. As a result, the delay savings attenuate over time, and then disappear. In the example, delay savings go down beginning with flights scheduled to arrive at 3pm, and again for arrivals after 3:16pm, reaching zero for arrivals at or after 3:23pm.

A similar technique can be used to measure the seat delay caused by a flight. A 1-minute delay to an aircraft with 100 seats causes 100 minutes of seat delay. Measuring delay on a seat basis is useful because many of the costs of delay to an aircraft, including aircraft operating cost and passenger delay cost, are roughly proportional to its number of seats. It is also possible to keep track of whether a delayed flight is operated by the same airline as the flight whose delay impact is being considered, or a different airline. The cases are different because airlines are more likely to take delays to their own flights into account in making scheduling decisions.

Using this approach, we calculated the additional delay resulting from each arrival at LAX in the 1998 sample day schedule. We term this quantity the Congestion Delay Impact, or CDI for short. Rather than using the scheduled arrival time of each flight directly in our calculations, we employed a simulation technique in which each flight is assigned a random quantity of lateness resulting from factors unrelated to capacity constraints at LAX. These factors may include propagation of delay from up-line airports, mechanical problems, and congestion in the en route airspace. It is important to take this randomness into account because the CDI for a flight is highly sensitive to the flight sequence and when the flight enters the arrival queue. In the simulated schedule, the lateness assigned to each flight is drawn from an exponential distribution, with a density function:

$$\rho(t) = \frac{1}{\lambda}\exp(-t/\lambda)$$

The term λ in this formula is equal to the mean value of the distribution. We used a mean value of 5 minutes, and replicated the simulation experiment 20 times.

Simulation results are presented in Tables 3-6 and 3-7. Table 3-6 summarizes delays and delay impacts by aircraft weight class. The first two quantities are the average aircraft delay and seat delay experienced by a flight in a given class. The overall average aircraft delay is 3.9 minutes, slightly less than the 4.3 minutes reported previously because the stochastic lateness smooths some of the peaks in the schedule. There is some variation in the average aircraft delays among the classes, with small aircraft incurring the most delay and large aircraft the least. Seat delay variation, on the other hand, is dominated by interclass differences in aircraft size; the average heavy arrival therefore incurs a seat delay nearly 10 times the average small aircraft arrival. The next four columns in Table 3-6 show the congestion delay impact (CDI) to other flights and other airlines, measured in terms of both aircraft and seats. In calculating delay to other airlines, major airlines and their regional affiliates were assumed to constitute one carrier. The average flight causes about 26 minutes of delay to other flights, 23 minutes of which is incurred by flights of other airlines. Aircraft in the heavy and small weight classes have the largest CDI's, reflecting inter-arrival times required when heavies lead and smalls trail. Seat delay CDI's are roughly proportional to flight delay ones, with the scale factor reflecting the average seats per flight. Finally, the four right hand columns of Table 3-6 present the ratio of the CDI—the delay to *other* flights or airlines that a given flight causes—to the delay that flight *itself* incurs, which we term the Externality Ratio (ER). The average ER's are around 7 for other flights and 6 for other airlines, irrespective of whether delay is measured in terms of seats or aircraft. The seat and aircraft results differ markedly for the individual weight classes however. Heavy aircraft have the highest average ER for aircraft delay—11 for other flights and 10 for

Table 3-6

Congestion Delay Impact, Sample Day Schedule, 1998, by Aircraft Class

			Congestion Delay Impact				Externality Ratio			
	Average Per Flight		Other Flights		Other Airlines		Other Flights		Other Airlines	
Weight Class	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay	Seat Delay	Aircraft Delay	Seat Delay
Small	4.5	121.8	32.5	4214.1	27.3	3680.5	7.2	34.6	6.0	30.2
Large	3.5	425.5	18.1	2323.1	16.1	2083.7	5.1	5.5	4.6	4.9
B757	4.0	739.4	25.3	3187.3	22.0	2769.7	6.4	4.3	5.5	3.7
Heavy	4.0	1121.5	43.2	5525.4	39.6	5048.3	10.8	4.9	9.9	4.5
Overall	*3.9*	*473.6*	*26.2*	*3364.0*	*23.0*	*2995.0*	*6.7*	*7.1*	*5.9*	*6.3*

Table 3-7

Congestion Delay Impact, Sample Day Schedule, 1998, by Airline

				Congestion Delay Impact				Externality Ratio			
		Average Per Flight		Other Flights		Other Airlines		Other Flights		Other Airlines	
Airline	Flights	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay *(min)*	Seat Delay *(min)*	Aircraft Delay	Seat Delay	Aircraft Delay	Seat Delay
UA	178	3.9	626.5	24.2	3077.7	17.0	2254.6	6.3	4.9	4.4	3.6
UA3	120	4.4	131.2	30.5	3939.0	21.3	2854.8	7.0	30.0	4.9	21.8
WN	115	3.7	506.0	18.3	2324.3	16.4	2064.9	4.9	4.6	4.4	4.1
AA	70	3.6	679.1	23.6	3010.9	22.0	2711.9	6.5	4.4	6.0	4.0
A1	65	3.3	109.8	19.6	2469.1	18.5	2433.3	5.9	22.5	5.6	22.2
OE	57	4.2	95.9	34.7	4467.9	32.7	4422.8	8.2	46.6	7.8	46.1
DL	54	3.9	817.0	31.9	4092.8	30.3	3759.2	8.2	5.0	7.8	4.6
OO	54	5.0	150.7	28.5	3723.7	26.7	3671.4	5.7	24.7	5.3	24.4
US3	36	4.9	88.0	41.7	5464.5	39.5	5271.1	8.5	62.1	8.1	59.9
AS	32	3.4	468.9	16.7	2200.8	16.3	2145.3	4.9	4.7	4.8	4.6
CO	26	4.1	599.3	15.1	1883.8	14.8	1844.4	3.6	3.1	3.6	3.1
HP	22	2.1	319.0	15.9	2038.1	15.7	2014.4	7.6	6.4	7.5	6.3
QQ	21	2.5	335.3	19.3	2489.5	19.1	2458.5	7.7	7.4	7.6	7.3
NW	17	3.8	834.3	19.1	2322.9	18.8	2256.7	5.1	2.8	5.0	2.7
US	15	3.7	668.3	21.4	2548.8	20.3	2452.6	5.8	3.8	5.5	3.7
MX	12	3.8	588.0	27.4	3661.6	27.2	3629.4	7.2	6.2	7.2	6.2
TW	10	4.4	751.7	26.5	3277.9	26.4	3250.1	6.1	4.4	6.0	4.3
Others	97	3.9	923.7	36.8	4782.2	36.7	4760.9	9.4	5.2	9.3	5.2
Overall	*1001*	*3.9*	*473.6*	*26.2*	*3364.0*	*23.0*	*2995.0*	*6.7*	*7.1*	*5.9*	*6.3*

other airlines—while small aircraft have by far the highest seat delay ER's, in excess of 30. This is because small aircraft, with few seats, do not incur much seat delay.

Table 3-7 summarizes the CDI results by airline, with the airlines ordered by their number of arriving flights in the sample day schedule. Aircraft CDI's range from 15 minutes (for Continental) to 42 minutes (for Trans States (US3), the USAir regional affiliate). CDI's for other flights and other airlines differ significantly only for United and its regional affiliate—these are the only airlines with a large enough combined share of daily flights to internalize a substantial portion of their delay impact. The regional carriers can easily be identified by their high seat delay ER's, ranging from 22 for A1 (the American affiliate Wings West) to 60 (for Trans States).

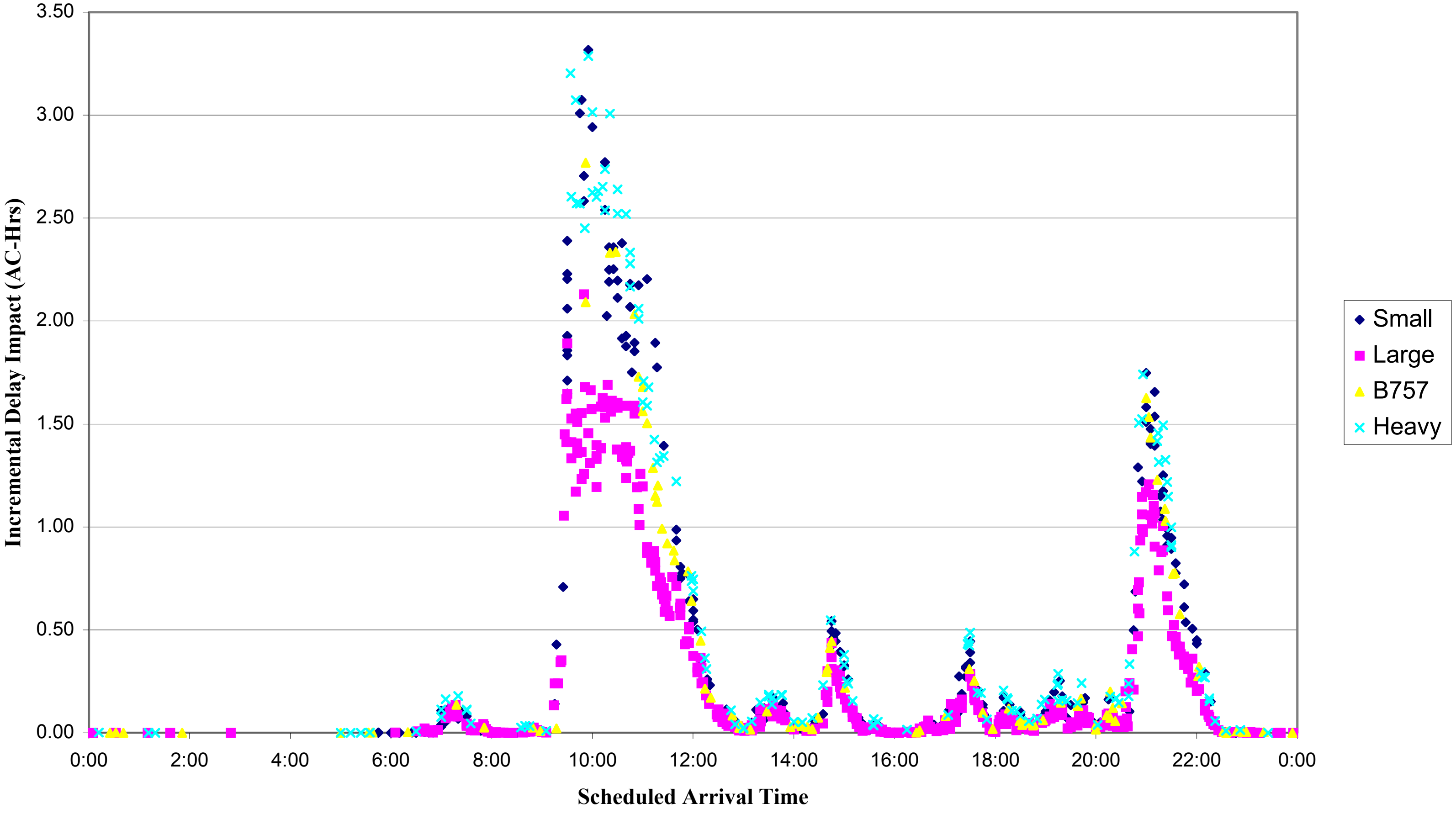
Figure 3-18 depicts the variation in aircraft CDI values for individual flights. Each point in the figure corresponds to one of the 1001 flights scheduled to arrive at LAX on the January 1998 day being analyzed. The symbol used indicates the aircraft size category for the flight. The horizontal axis is the scheduled arrival time, and the vertical axis the CDI (in aircraft-hrs) for the flight averaged over the 20 simulation runs. The figure reveals a strong temporal pattern with the strongest peaks in the morning just before 10am and in the evening around 9pm. During the former period, small and heavy arrivals increase delays to other flights as much as 3 hours, while in the latter period the largest impacts are about 2 hours. Delay impacts of large and B757 aircraft arriving during these periods are somewhat smaller, but consistently in excess of 1 hour.

A striking feature of Figure 3-18 is the suddenness with which CDI values increase at the onset of the peak. The phenomenon derives from the nature of the queuing process. If there is an extended period of queuing delay, the aircraft that arrive at the beginning of this period cause the greatest delay to other flights. They are the "first in line" and thus if they were removed from the queue all others could move up. On the other hand, flights that arrive just before the onset of queuing cause no additional delay. Thus the sharp increased in CDI reflect the difference between being at the front of a queue and altogether avoiding one.

Traffic growth in the absence of new capacity will result in increased CDI's as well as increased delay. To quantify the impact of traffic growth on CDI, we generated a hypothetical schedule with about 20 percent more arrivals than our 1998 one. Simulations of the new schedule resulted in six-fold increases in average delay, to about 24 minutes, and nine-fold increases in average aircraft CDI, to over five hours. Clearly, increased congestion will only increase the already high externality ratios observed in the baseline period.

Figure 3-18

Congestion Delay Impact, by Scheduled Arrival Time and Size Category



These results may provoke the question of how the arrivals at LAX cause more delay (as measured by the CDI) than they incur themselves (as measured by the average delay per flight). This apparent conundrum derives from the fact that the CDI is a *marginal* concept. It measures the additional delay resulting from a flight given the schedule for all the other flights. If we started with no flights at LAX, and added them one at a time, the CDI for each flight as it is added would initially be zero and then (on average) climb gradually and then more steeply. In this scenario, the final delay would equal the sum of the CDI's of each flight at the point it is added to the schedule. In contrast, the CDI's calculated here implicitly treat each flight as if it were the "last one."

In summary, our results show that, on average, arrivals into LAX generate sizable delay externalities, both absolutely and in terms of the ratio of external delay impact to delay incurred. The impacts are highly variable, with major peaks, in which individual flights can cause hours of delay to other flights, in the morning and evening rush periods. The bulk of these impacts are external to the airline operating the flight as well as the flight itself. The magnitude of these market failures, even in an environment where average delays are moderate, points to the need for interventions, either regulatory or economic, to correct for them. To be beneficial, however, such intervention must be guided not just by the delay impacts of flights, but also by their service benefits. To this subject we now turn.

Comparing Delay Impact and Service Impact—The Delay Impact Ratio

In the previous section, we used a deterministic queuing model to assess the delay impact of each flight arriving at LAX on a given day, assuming minimum IFR separations. The results reveal that some flights have very high incremental delay contributions, while others have none at all. In this section, we attempt to weigh the incremental delay impacts of a flight against its contributions to the quality of airline service. A complete analysis of this issue must take into account the role of each flight in an airline's overall scheduling and marketing strategy, and is beyond the scope this study. A rough assessment is possible, however, by making simplifying assumptions about the impacts of removing a given flight from the schedule.

If a flight is removed, passengers who would otherwise use it must choose some other travel alternative. Of course, many such alternatives exist, including taking a different flight to LAX, flying to a different airport, traveling on a different mode, or canceling the trip altogether. For purposes of this analysis, we assume that passengers on the eliminated flight would switch to the previous one to LAX by the same airline from the same origin. This may require that the previous flight employ a larger aircraft so that sufficient capacity can be provided. We assume that in the long run the larger aircraft can be substituted with no effect on airline operating cost. Moreover, by using the earlier flight, passengers would be able to make any connections or appointments in the LA area that they could using the eliminated flight. And by assuming passengers remain on the same airline, we avoid brand loyalty, frequent flier, and connectivity issues that would need to be considered if we assumed that passengers switched to a different carrier.

Thus we reduce the effect of eliminating a given flight to a single consequence: extra, and quite possibly wasted, time in Los Angeles. In the case of connecting passengers, this extra time would take the form of a longer layover at LAX. For others, there is a wide range of possibilities, but as a worst case it could be assumed that they too would spend the time at the airport in an unproductive fashion. In sum, using the terminology of airline economics, eliminating a given flight would cause an increase in "schedule delay," defined as extra trip time resulting from a limited choice of flights.

Therefore, eliminating a given flight to LAX increases one form of delay while reducing another. Passengers displaced from the flight will incur more schedule delay; other flights and the passengers on them will benefit from a reduction in congestion delay. Both of these quantities can be expressed in the same units—say seat-hours—in which case their ratio is a dimensionless quantity, roughly analogous to a cost-benefit ratio, that measures the delay a flight causes relative to the delay it saves. Formally, we define the schedule delay impact, or SDI, of a flight as:

$$SDI_{cpi} = T_{cpi} - T_{cpi-1} \quad i > 1$$

where:

SDI_{cpi} is the schedule delay impact of the ith non-stop flight of the day flown to LAX by carrier c from airport p;

T_{cpi} is the scheduled time of departure of this flight.

The delay impact ratio, DIR, is then calculated as:

$$DIR_{cpi} = \frac{CDI_{cpi}}{SDI_{cpi}}$$

where:

CDI_{cpi} is the congestion delay impact of the ith non-stop flight of the day flown to LAX by carrier c from airport p.

We calculated the DIR for each flight in our 1998 sample day schedule. Figure 3-19 summarizes the results. The ratio is undefined for 227 flights that are the first arrivals of the day for a given airline from a given origin. (We neglect the possibility of night-before travel.) The vast majority of the remaining flights have DIR values of less than 0.5, implying that the congestion delay they cause it less than half of the schedule delay they save. On, the other hand, there are 87 flights which generate more than twice as much congestion delay as they avert in schedule delay. These include 18 flights for which the ratio is over 10. For four arrivals, it is over 30!

Figure 3-20 plots the delay impact ratio against the aircraft seat capacity. A logarithmic scale is used to better differentiate the many flights for which the DIR is less than 1. (Flights with a DIR of zero are assigned the minimum value on the log scale.) Flights with very high DIR's generally involve aircraft under 100 seats. Aircraft over 200 seats almost all have DIR's less than 1—in many cases much less. Although we have seen that these aircraft, being heavies, tend to have large CDI's, their large number of seats and relatively low service frequencies make their SDI's even higher. Most flights with aircraft in the 100-200 seat range also have DIR's less than 1, although there are a number of exceptions.

While the DIR provides a useful scale for comparing the relative value of different flights, it is difficult to set a cut-off point so that "undesirable" flights can be identified. From an economic standpoint, such a cutoff should be based on the relative unit costs of schedule delay and congestion delay. If the ratio of these costs is *r*, then any flight with a DIR greater than *r* is generating more costs than benefits, and, from a social welfare standpoint, should be eliminated. (Again, this assumes that the capacity can be preserved by using a larger aircraft and that the resulting change in aircraft operating cost is zero.) In considering the value of *r*, several factors must be born in mind. First, congestion delay costs are born both by passengers and airlines, while schedule delay is born by passengers only. Government estimates suggest that the costs per seat of congestion delay to passengers and air carriers are approximately equal (Citrenbaum, 1999). Second, schedule delay is predictable and thus can be incorporated into passengers' travel plans, while congestion delay is stochastic and thus more likely to result in wasted time and

Figure 3-19

Delay Impact Ratio Values, Sample Day Schedule, 1998

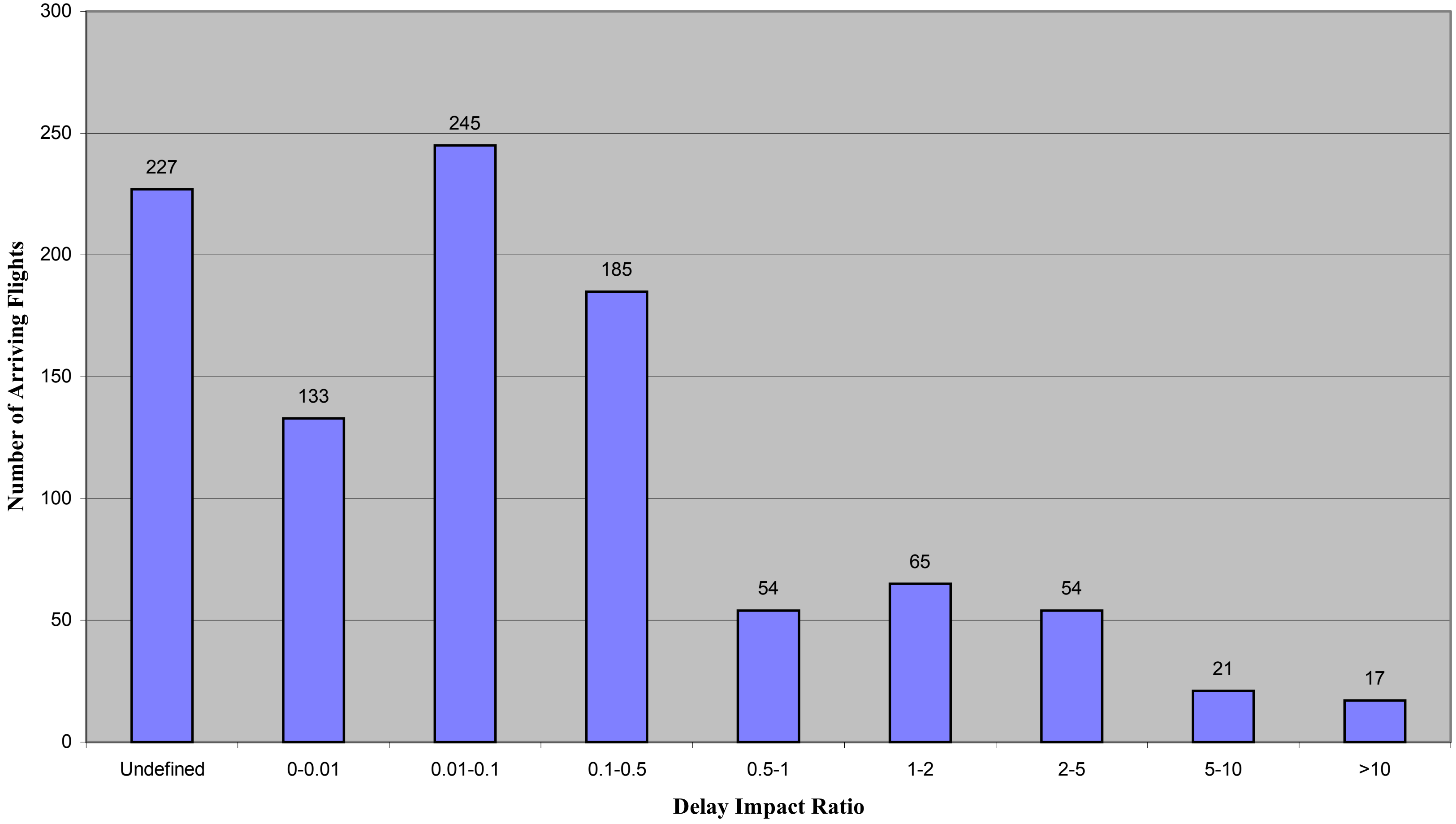
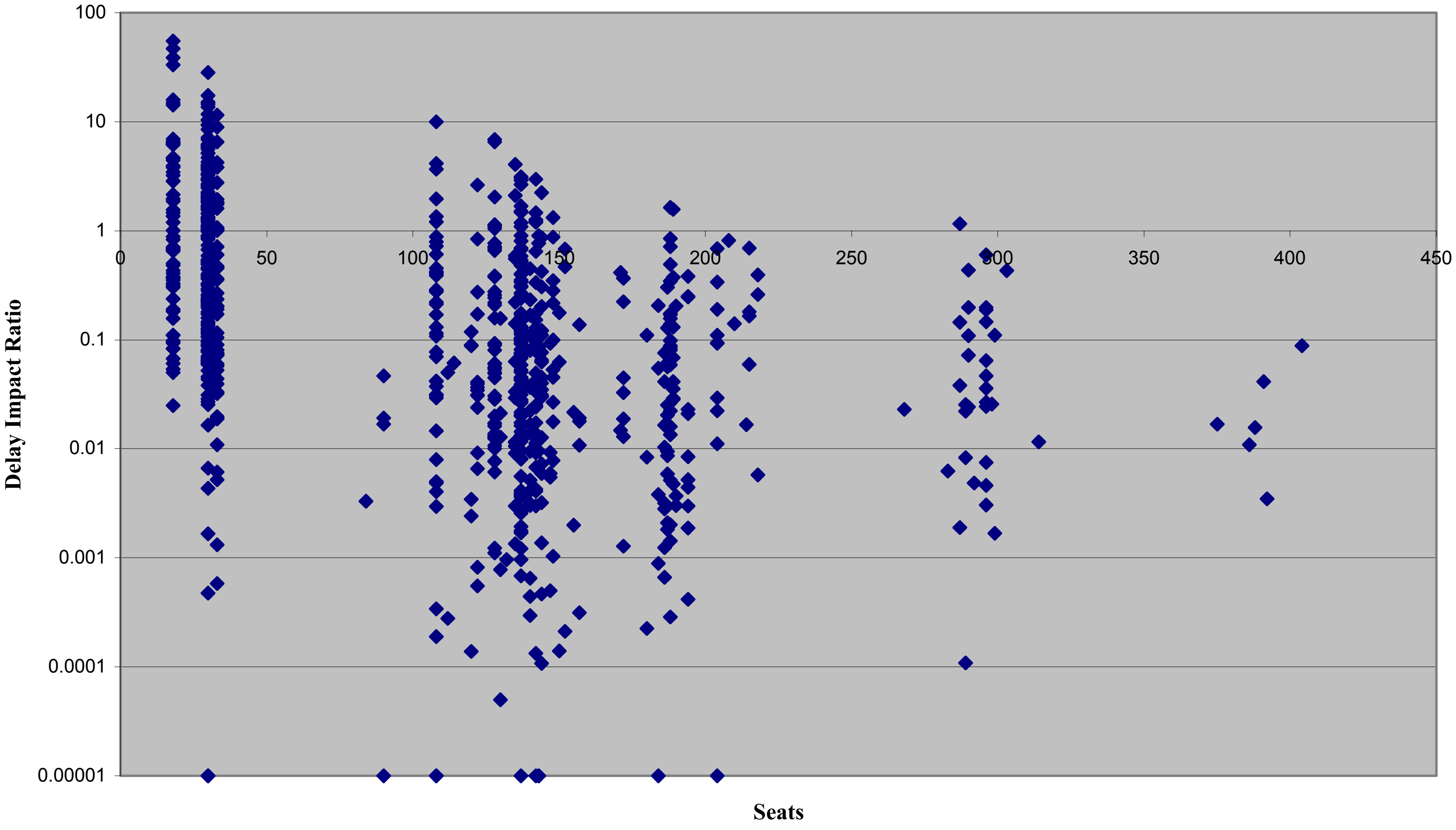


Figure 3-20

Delay Impact Ratio vs Aircraft Seats



disrupted plans, both for travelers and for airlines. Thirdly, the schedule delay impacts of eliminating a flight are concentrated among a small number of individuals, while the congestion delay impacts are dispersed among a much large number of flights and passengers. The first two of these factors suggest that the value of r is greater than 1. The third, while not directly relevant to the question of valuation, is important politically because small groups with concentrated interests can mobilize more easily. This point notwithstanding, it is hard to imagine that the unit value of schedule delay is any more than the unit value of congestion delay. Thus we conclude that $r \leq 1$.

If $r \leq 1$ then flights with DIR's far above 1 generate costs that far exceed their benefits. Table 3-8 lists 18 such flights: those with the highest DIR values for sample day schedule. Also listed in the table are the alternative flights that could be used if the primary flights were eliminated. All the flights are short-haul, and with one exception (US 2015 from SFO) employ commuter aircraft. About half of the flights are from San Diego, and most arrive between 9 and 10am, near the beginning of the morning rush period. The flights at the top of the list usually have alternative flights available within 30 minutes, stretching toward 60 minutes as we move further down.

The DIR can be used to guide a theoretically optimal strategy for drawing down a flight schedule in a manner that maximizes congestion delay reduction benefits while minimizing the resulting increase in schedule delay. For any given schedule, the best flight to remove is the one with the highest DIR. Once this flight is removed, the DIRs can be calculated for the schedule with the remaining flights, and the flight with the highest DIR again removed, and so on until the point is reached where the maximum DIR has an acceptable value. Table 3-9 shows the results of applying this strategy to the sample day schedule through five iterations. Altogether 1570 seat-hrs of congestion delay are eliminated by adding just 51 seat-hours of schedule delay, a ratio of about 30-1. According to our delay model, eliminating just these five flights would reduce congestion at LAX about 20 percent.

Table 3-8

LAX Arriving Flights with Highest Delay Impact Ratios, Sample Day Schedule, January 1998

					Previous Flight				
Flight	Type	Seats	Origin	Time of Departure	Flight Number	Time of Departure	SDI	CDI	DIR
US3 4759	J31	18	SAN	9:50	4707	9:35	5	247	49.4
US3 4734	J31	18	FAT	9:45	4729	9:25	6	282	47.0
US3 4707	J31	18	SAN	9:35	4793	9:10	8	292	38.9
US3 4793	J31	18	SAN	9:10	4768	8:30	12	398	33.2
UA3 5218	EM2	30	SAN	9:00	5216	8:30	15	425	28.4
UA3 5220	EM2	30	SAN	9:30	5218	9:00	15	261	17.4
OE 7338	J31	18	OXR	9:55	7336	8:50	20	308	15.8
UA3 5222	EM2	30	SAN	10:00	5220	9:30	15	228	15.2
OE 7017	J31	18	SNA	9:45	7015	8:30	23	338	15.0
UA3 5224	EM2	30	SAN	10:30	5222	10:00	15	217	14.5
US3 4789	J31	18	SAN	20:10	4741	19:25	14	191	14.2
UA3 5468	EM2	30	PSP	9:05	5466	8:05	30	409	13.6
UA3 5426	EM2	30	MRY	9:35	5424	8:45	25	293	11.7
A1 3206	SF3	33	PSP	8:40	3228	8:00	22	253	11.5
UA3 5128	EM2	30	SBA	10:00	5126	9:10	25	259	10.4
OO 5657	EM2	30	SAN	9:38	5655	8:38	30	313	10.4
UA 2015	735	108	SFO	8:35	2011	8:25	18	180	10.0
UA3 5470	EM2	30	PSP	10:05	5468	9:05	30	282	9.4

Table 3-9

Impacts of Removing High DIR Flights from 1998 Sample Day Schedule

Schedule Modification	Cumulative Increase in Schedule Delay *(seat-hrs)*	Cumulative Decrease in Congestion Delay *(seat-hrs)*	Ratio	Cumulative Decrease in Congestion Delay *(AC-hrs)*
Base	0.0	0	--	0
Eliminate US3 4759	4.5	259	57.6	2
Eliminate US3 4734	10.5	357	34.0	3
Eliminate US3 4793	22.5	439	19.5	4
Eliminate UA3 5218	37.5	930	24.8	7
Eliminate US3 4789	51.0	1570	30.8	12

Conclusions

At a time when adding capacity to the Los Angeles airport system is proving an enormous political and technical challenge, the need to use existing capacity efficiently is undeniable. But encouraging such efficiency has obstacles of its own, including obsolete pricing structures and the limited authority and precedent for intervention by airport authorities. As a consequence, modern airfields, though highly structured in design and closely controlled operationally, remain an untamed frontier economically. Airlines routinely and obliviously make scheduling and fleet mix decisions that generate large amounts of delay for other users. These external effects dwarf the delays taken by individual flights, and in some cases vastly outstrip the value of the flights themselves. Many airlines and passengers suffer as a result.

The analyses presented in this chapter serve to document and quantify these problems as they are experienced at LAX. They reveal that severe externalities can exist even at an airport with comparatively low levels of average delay. This can be seen by juxtaposing several of our quantitative findings: the average flight at LAX incurs an arrival delay of four minutes, but at the margin certain flights generate external aircraft delay impacts approaching three hours, and impose costs congestion delay at least 30 times greater than the service quality benefits they provide.

Problems like these are far easier to identify than to solve. Obstacles to effectively addressing the market failures considered in this chapter have been thumbnailed above. Perhaps by design, these obstacles create an environment in which increasing capacity, whether by operational improvements, new technologies, or new runways, appears to be the only remedy. And, ironically, if adding new capacity is the ultimate goal, then effectively managing existing capacity, and thereby reducing the urgency of the need for expansion, may be viewed as a strategic mistake. In this respect, the biases of the present airport planning and policy environment are self-perpetuating.

For all of these reasons, it is naïve to expect any dramatic near-term change to the present laissez faire approach to schedule and fleet decision making at major airports. But the costs of non-intervention are rising, and may soon reach the point where inertia can be overcome. In preparing for that day, it is important that airport managers recognize that they can play a constructive role in assuaging the rampant externalities that already make delays higher than they ought to be, and will only get worse in the future. A first step in assuming such a role is the development of analytical tools that can enable a manager to roughly but impartially assess how individual users and flights contribute to both congestion and service quality at their airport. That step has been taken in this chapter.

4. The Determinants of Aircraft Size

Introduction

In this chapter, we employ statistical techniques to analyze variation in the type, size, and average loads of aircraft flown on U.S. domestic route segments by commercial airlines. Obviously, the observed variation in these variables is the outcome of a complex process that is influenced by many factors. It can be fully understood only in the context of airlines' overall routing, scheduling, and fleet planning strategies, many aspects of which are proprietary. Nonetheless, casual observation and basic principles of airline economics suggest that a first order understanding can be obtained from analyzing relationships between segment characteristics, such as traffic density and distance, the variables of interest. These segment-level relationships are the focus on this chapter.

In undertaking these analyses, we are motivated by two main questions. First, we would like to predict how traffic growth and capacity constraints may affect the sizes and passenger loads of aircraft in the future. Will the growth of flights be roughly proportional to the growth of traffic, or will much of the growth be accommodated by upsizing the fleet or increasing load factors? And how might airlines' response to traffic growth be influenced by changing levels of congestion and delay in the National Airspace System? Second, we are interested in comparing LAX segments to non-LAX ones in terms of service type, aircraft size, and aircraft load. Are there systematic differences, and if so are they related to observable characteristics of the segments, or more idiosyncratic factors?

Given the empirical orientation of this chapter, our attention must be focused on the past rather than the future. To use our results predictively requires a leap of faith and should be tempered by a healthy dose of skepticism. In particular, the widespread adoption of regional jets is likely to alter the relationships found in this chapter. But such change occurs gradually, and the key structural relationships are likely to preserved in their qualitative essence if not their numerical details.

The remainder of this chapter is organized as follows. The next section provides an overview of received wisdom on the factors that influence average aircraft size and passenger loads. The third section discusses the methodology and data used for our analysis. The fourth section presents our results. In the fifth section, we use the results to assess the impact of changes in passenger traffic and delay on flight activity at LAX. Conclusions are offered in the last section.

Determinants of Aircraft Size

Fundamentally, aircraft size decisions involve trade-offs between cost, convenience, and flexibility. Cost considerations tend to favor larger planes and higher loads, since (up to some limit) these result in lower costs per passenger. Smaller aircraft, on the other hand are generally advantageous in terms of convenience since they allow higher service frequency and less schedule delay. Using smaller aircraft also affords an airline greater flexibility in allocating its fleet among various routes and markets.

While the above factors are almost always at work, their relative importance, and thus the point of optimum trade-off between them, varies with characteristics of the segment being served. These characteristics include: traffic density, segment length, traffic concentration, traffic composition, and characteristics of the airports terminating the segment. Below, we discuss these factors in turn.

Traffic Density

Traffic density is the number of passengers (or, when relevant, freight and cargo) per unit time flowing over a non-stop flight segment. At low traffic densities, small aircraft are required to maintain an acceptable frequency of service. As traffic increases, it becomes possible to serve the segment with larger, more economical aircraft while still offering a reasonable schedule. Therefore we expect aircraft size to increase with traffic density.

Passenger loads are also likely to increase with traffic density. In addition to the effect of aircraft scale economies, passenger loads also increase because as traffic density increases its day-to-day variability declines. This makes it possible to increase average load factors while maintaining a high probability that seats will be available on most flights.

Segment Length

To a good approximation, one can model the cost of a flight as having two components, one proportional to distance and one independent of distance. The cost component that is proportional to distance has scale economies, and thus the cost savings from using larger aircraft increase with the length of the segment. On the other hand, benefits from increasing frequency are likely, if anything, to decrease with segment length because longer segments generally have narrower windows in which both the departure and the arrival are at acceptable times (such as not in the very early morning). Therefore, as segment length increases, the optimum tradeoff between large aircraft and high frequency shifts toward the former. Similarly, for a given aircraft size, the cost advantage of operating full planes increases with segment length. We therefore expect load factors to increase with segment length.

Aircraft length also affects aircraft scale economies. For shorter segments, distance-independent costs dominate, and these are likely to have weaker scale economies than distance-varying costs. Additionally, the speed and high-altitude advantages of large jets are reduced when distances are short. Thus for shorter segments these is a tendency to operate fairly small planes even when densities are very high, while on longer ones high densities are more likely to translate into large aircraft and high traffic loads.

Segment Concentration

Concentration refers to the distribution of segment traffic among the airlines serving the segment. Higher concentration is expected to result in large aircraft size, all else equal. Airlines compete over frequency and load factor, but when concentration is high, there is less pressure to offer high frequency by using smaller or emptier planes. Moreover, for a given overall traffic density, lower concentration means lower traffic density for individual carriers, which, as previously discussed, will result in smaller aircraft and lower load factors.

To measure concentration, it is common to use the Herfindahl-Hirschman index (HHI). Suppose there are N airlines serving a segment and that the traffic share of airline i, in percentage terms, is S_i. The HHI is calculated using the formula:

$$HHI = \sum_{i=1}^{N} S_i^2$$

If the segment is a monopoly, one airline will have a market share of 100%, so the HHI is $100^2 = 10{,}000$. If each of N airlines has a percentage market share of $\frac{100}{N}\%$, the HHI will be $N \cdot \frac{10{,}000}{N^2} = \frac{10{,}000}{N}$. A related concept is the equivalent number of airlines. This is the number of competitors with equal market shares that would yield a given HHI level. From the above, one can see that the number of equivalent airlines is $\frac{10{,}000}{HHI}$.

Traffic Composition

Traffic flowing over a segment can be categorized as local and non-local. Local passengers are flying on that segment only—their true origin and final destination being the origin and destination of the segment. Non-local passengers are flying on the segment as part of a longer itinerary that may include other stops on the same flight or other flights. Among the non-local passengers, one can further distinguish between those whose trips are purely domestic and those who are flying on the segment as part of an international trip.

When a segment carries many non-local passengers, it is likely to be part of a hub-and-spoke route system. Such segments generally feature higher service frequencies and smaller planes than segments serving primarily local traffic. On the other hand, if the segment carries many international passengers, more of its flights are likely to be continuations of international flights, whose long stage lengths call for large aircraft. So average aircraft size is expected to increase with the volume of international traffic it carries, at least in some cases.

Hub Status

The U.S. domestic route system is dominated by hub-and-spoke networks. It is possible that the size of aircraft serving an aircraft will depend upon whether its endpoints are hubs or spokes. As a measure of hub status, we use the ratio between the total traffic on flights leaving an airport, and locally originating traffic on those flights. The ratio exceeds 2 for the largest U.S. hubs, such as Atlanta, Dallas, and Chicago, is around 1 for smaller, "pure spoke" airports. As noted previously, it is widely believed that hub-and-spoke networks tend to employ smaller aircraft, all else equal. Thus, the higher the hub ratios of the endpoint airports, the smaller the aircraft expected to serve a segment, all else equal.

Airport Capacity Constraints

The impact of airport capacity constraints on aircraft size is a major question motivating this research. Constraints may affect aircraft size through various mechanisms. In airports subject to FAA slot control (New York Kennedy, New York LaGuardia, Chicago O'Hare, and

Washington National at the time of this writing) airlines might employ larger planes with higher loads to make the most efficient use of the limited flights that they can operate. At other airports, congestion and delay may induce airlines to consolidate traffic on larger planes. To a first approximation, the effect of congestion is similar to the effect of increasing stage length insofar as it lengthens the flight time, and we have already seen stage length is positively correlated with aircraft size. Moreover, delay is highly variable and airlines can reduce their exposure to such variability by reducing flights on high delay segments. Furthermore, as shown in Chapter 3, when delay is high the marginal delay from operating an additional flight becomes much larger than the average delay. Therefore, if a carrier operates many flights from an airport, it can realize a large aggregate delay saving by reducing the number of flight operations. On the other hand, when an airline operates just a few flights at an airport, its competitors would realize most of the benefit from consolidating traffic onto fewer flights.

Finally, it should be noted that capacity constraints may, in some circumstances, provide airlines with incentives to operate smaller planes. At certain airports, such planes are able to use runways that are too short or otherwise inappropriate for larger aircraft. This becomes more of an advantage if the large aircraft runways are congested. Also, under present air traffic management policies, when demand at airports is projected to exceed capacity, FAA initiates ground hold programs that force some incoming flights to wait at their origins. In these cases, the order of landing at the saturated airport is based on the original schedule, giving airlines with more scheduled flights some advantage. Thus airlines may have a perverse incentive to schedule more flights into airports for which ground delay programs occur often.

Methodology and Data

Two rather different decision processes determine the average size and load of aircraft on a flight segment. First, the segment may feature commuter or certificated (large jet) airline service (or, rarely, a mixture of the two). In effect, this determines whether the aircraft flown will have more or less than 60 seats—the upper limit for commuter airlines. Second, given the type of service, there is the additional choice of about size of commuter or large jet equipment to deploy. Our analysis framework reflects this two-stage decision making approach. First we analyze the binary service-type decision by comparing characteristics of segments with each kind of service. Next, we analyze variation in average aircraft size and loads for certificated segments. (As will be explained below, the data do not allow a similar analysis for commuter segments.)

To study how service type, aircraft size, and aircraft loads are influenced by the various factors discussed in the previous section, we created a data set consisting of characteristics of domestic flight segments originating from 18 major U.S. airports. The airports are listed in Table 4-1. The set includes all of the major airports on the east and west coasts. Interior airports were not chosen because they are either far smaller than LAX or are major hubs which, unlike LAX, are dominated by connecting traffic. Such airports are nonetheless represented in our data set since they are the endpoints for many of the segments involving the 18 study airports.

Data for non-stop service segments were drawn from two main sources. The T100 database provides, for every non-stop domestic segment flown by certificated carriers, the number of flights (scheduled, scheduled and flown, and non-scheduled), the number seats, and the number of passengers carried, by aircraft type and airline. We obtained 1998 T100 data for all flight segments originating from the 18 airports listed in Table 4-1. The Part 298C data base contains on-line origin-destination data for commuter carriers. Again, for the year 1998, we collected Part 298C data for all origin-destination pairs whose origin is among the 18 chosen airports.

The analysis of these data is complicated by the fact that many services that are for all intents and purposes commuter appear in the T100 data base rather than the Part 298C one. If an airline operates even one aircraft with 60 or more seats, it must be certificated and all of its services, included those involving planes with less than 60 seats, are included in T100. To deal with this problem we classified a T100 airline service segment as commuter if the average size of aircraft flown by the airline on the segment is under 60 seats. Passenger traffic on these "quasi-commuter" segments was added to Part 298C passenger data to estimate the total commuter traffic on the segment (this is an estimate because the 298C data is on-line origin-destination, which is different from service segment in cases where there is an intermediate stop). A segment was classified as "commuter" or "certificated" according to the proportion of its total (Part 298 plus T100) traffic in the commuter category. We discarded a handful of segments that were not 80 percent one or the other. Also to avoid segments with very light traffic or sporadic service, we required that all segments average at least 5 passengers per day, and certificated segments average at least one flight per day, in each direction. Altogether, we identified 704 segments involving the 18 study airports, of which 526 are certificated and 179 are commuter.

Table 4-1

Characteristics of Airports Included in Analysis, 1998

Airport	Code	Total On-Board Domestic Passengers (millions)	Pct Commuter Traffic	Hub Ratio[1]	Certificated Seats/Flight	Certificated Pax/Flight	Average Arrival Delay[2]	Average Gate-to-Gate Delay[2]
Boston	BOS	10.1	9.2%	1.06	145	92	15.3	5.3
Baltimore/Washington	BWI	6.8	7.2%	1.11	137	98	11.7	3.0
Washington National	DCA	7.3	6.4%	1.21	133	81	11.1	3.9
Newark	EWR	12.5	9.3%	1.27	139	94	19.8	7.4
Fort Lauderdale	FLL	5.3	2.0%	1.03	147	113	15.0	4.1
Washington Dulles	IAD	4.5	16.6%	1.18	147	95	12.5	3.5
New York Kennedy	JFK	6.6	13.4%	1.43	187	126	18.6	6.1
Los Angeles International	LAX	21.6	6.9%	1.36	160	110	15.2	4.5
New York LaGuardia	LGA	10.0	5.4%	1.06	142	91	12.8	4.6
Orlando	MCO	11.7	4.5%	1.14	148	112	14.1	4.2
Miami	MIA	8.2	11.0%	1.75	169	118	14.7	5.2
Oakland	OAK	4.8	0.0%	1.15	134	85	9.7	2.4
Portland	PDX	6.2	12.4%	1.26	142	91	14.9	4.1
Philadelphia	PHL	9.6	10.4%	1.54	128	84	12.5	3.9
San Diego	SAN	7.0	6.2%	1.07	143	98	12.7	2.9
Seattle-Tacoma	SEA	11.9	7.7%	1.36	144	102	14.5	4.7
San Francisco International	SFO	15.5	3.7%	1.41	159	111	19.1	5.4
Tampa	TPA	6.4	8.2%	1.10	145	110	14.9	4.5

1. Ratio of on-board passengers to originating passengers.
2. Based for ASQP data for 1997.

To determine traffic composition and hub status, data were obtained from the USDOT 10% airline coupon survey. The survey provides the number of true O&D passengers between the origin and destination of each segment (it does not, however, reveal how many passengers were actually flying on the segment itself), and the proportion of these trips that are domestic portions of international itineraries.

Delay data were obtained from a study by Citrenbaum et al (1999) who used the ASQP data base to calculate average arrival delay (actual arrival time – scheduled arrival time) and flight delay (actual flight time – scheduled flight time) for major U.S. airports. In addition, we used dummy (0-1) variables to indicate whether an airport is subject to slot control.

Our analysis of these data involved two main techniques. First, the data were plotted in various ways to help us visualize key relationships. Second, we used regression models in which seats per flight and passengers per flight are treated as dependent variables while the independent variables reflect the various causal factors identified in the previous section. We applied these techniques first to analyze the determinants of service type (commuter vs. certificated), and then the determinants of aircraft size for certificated segments. Since service type is a qualitative variable, we used a special form of regression, known as logistic regression, in this part of the analysis. Also, because aircraft size data are difficult to obtain for commuter segments, we analyzed variation in size and loads only for certificated segments.

Results

Service Type

Graphical Analysis

Figure 4-1 plots, on a logarithmic scale, segment length versus segment density for two sets of service segments: one in which the traffic is more than 80 percent commuter, and the other in which the traffic is more than 80 percent certificated. There is a well-defined frontier separating the two sets of segments, in the form of a negatively sloped line which is also plotted (by eye) on Figure 4-1. Segments whose densities and distances place them between this line and the origin are generally commuter; those whose coordinates are beyond the frontier are typically certificated. Also evident on the plot is a transition area on either side of the frontier where segments may receive either type of service.

Figure 4-1

Segment Distance vs Segment Density, Certificated and Commuter Segments

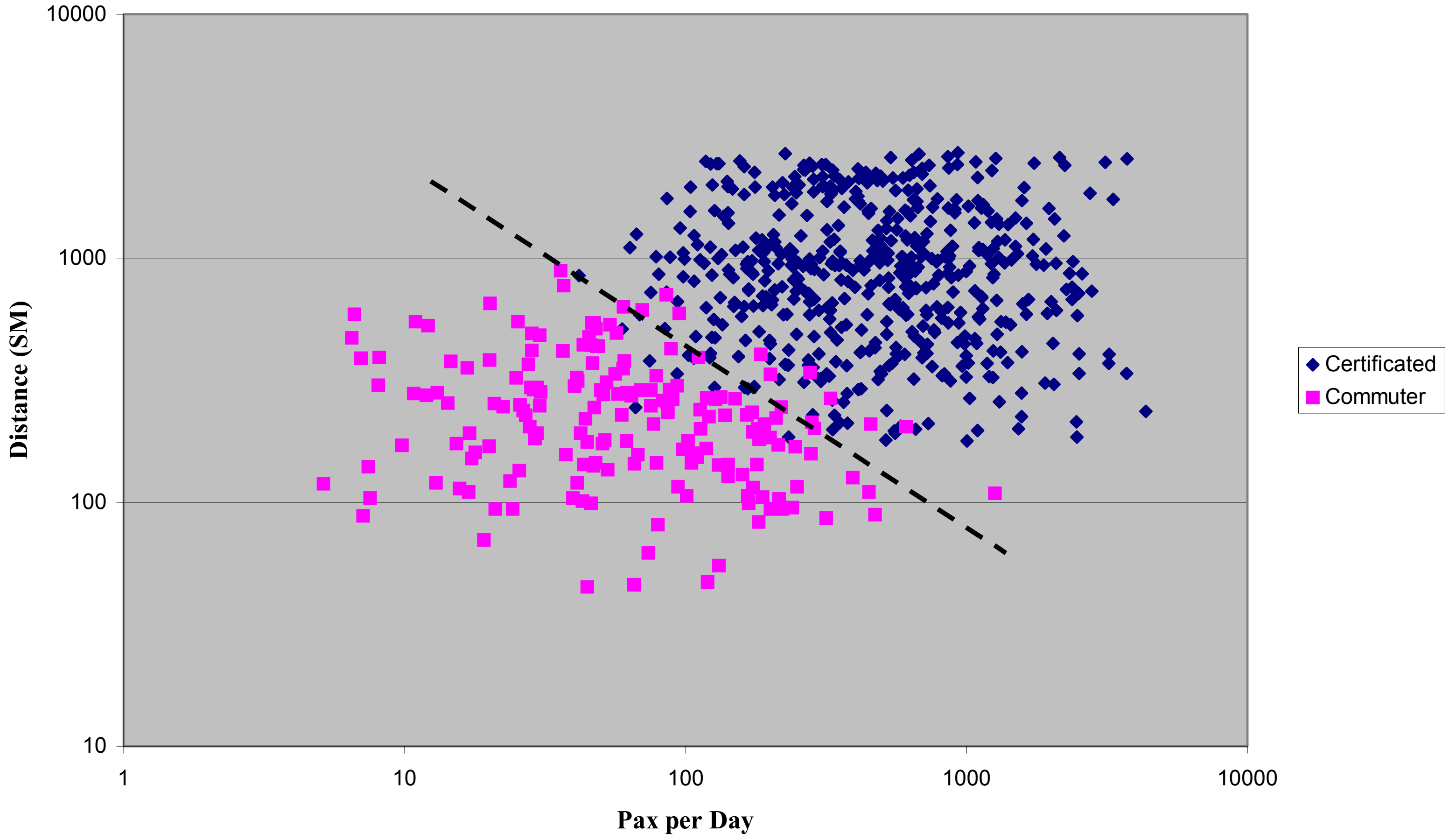


Figure 4-2 is similar to Figure 4-1, but plots LAX commuter and certificated segments using different symbols. From this plot, one can see several differences between the LAX and non-LAX segments. First, LAX certificated segments tend to be more dense and longer. This creates a “gap” between LAX commuter and certificated segments that does not exist for non-LAX ones. Second, LAX commuter segments are all toward the short-distance, high-density end of the spectrum. The longest LAX commuter segment—to MRY—is 267 miles, while a sizable fraction non-LAX segments are over 300 miles. Third, if one scans the plot horizontally, it is apparent that, for any given distance range, the most dense commuter segments involve LAX. Finally, there is some evidence that, controlling for distance and density, LAX segments are more likely to be commuter than non-LAX segments. All of the LAX segments that are near the frontier are commuter, whereas other segments in this region contains roughly equal proportions of commuter and certificated segments.

The high-density, short-distance nature of LAX commuter segments evident in Figure 4-2 reflects the unique geography of the LA region, and points to the appeal of high-speed rail as a solution to regional transportation problems there. As a result of the proximity of Los Angeles to other urban areas of substantial size and affluence, there is an unusually high demand for short-haul, high speed, transport. There would clearly be a benefit from offloading this demand from overstretched airports to a high-speed surface transportation system.

Logistic Regression Analysis of Service Type

To further analyze the factors influencing whether a segment receives commuter or certificated service, we estimated a binary logit model. The model is of the form:

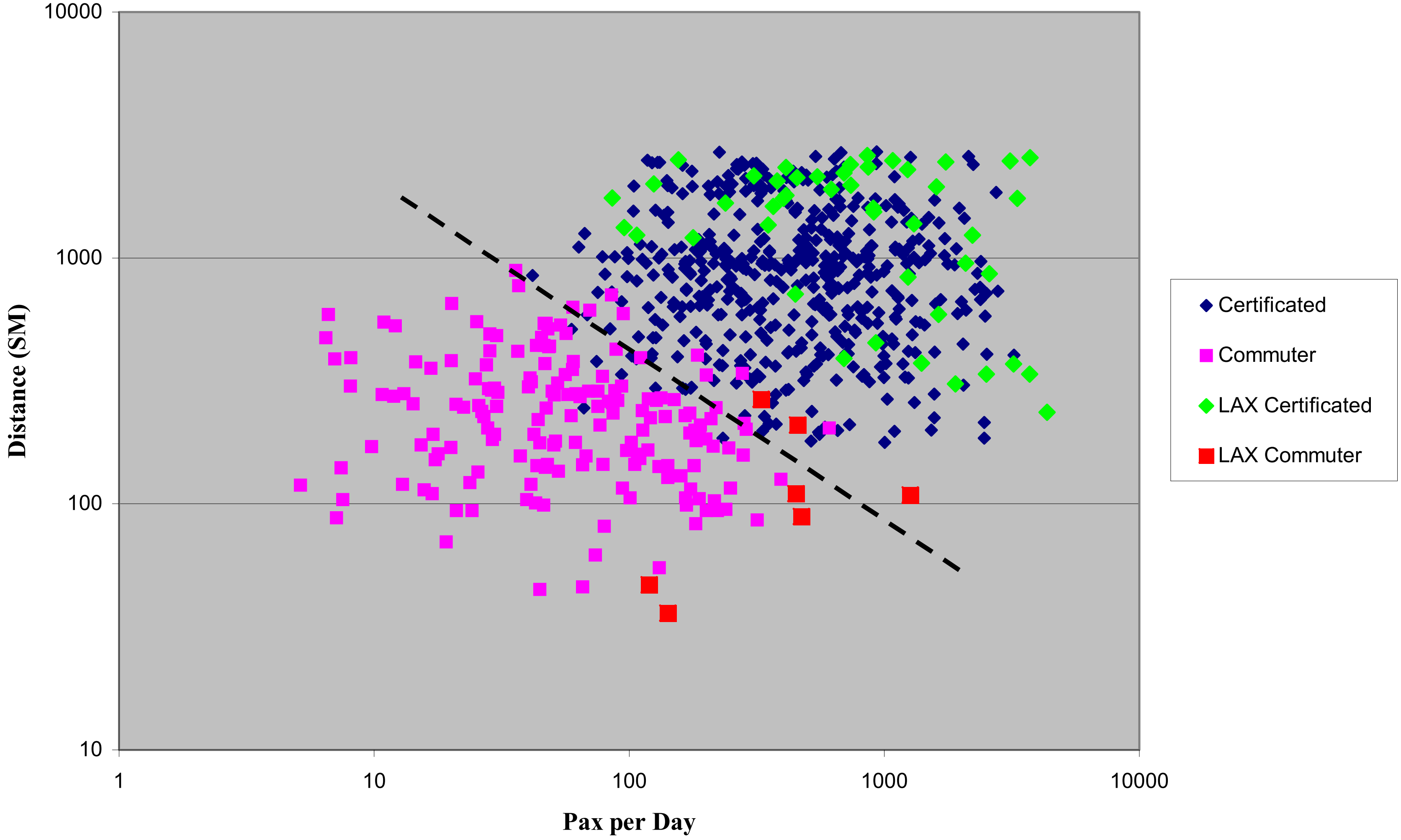
$$P(com_{ij} \mid V_{ij}) = \frac{1}{1 + \exp(V_{ij})}$$

where:

$P(com_{ij} \mid V_{ij})$	is the probability that the segment between origin i and destination j has commuter service, given that its “service potential” is V_{ij}.
V_{ij}	is the segment “service potential”, a function of its density, distance, and other factors whose linear coefficients are estimated from the data.

Figure 4-2

Segment Distance vs Segment Density, Certificated and Commuter, LAX and Non-LAX Segments



For the “service potential” function V_{ij} we employ the specification

$$V_{ij} = \alpha_0 + \alpha_i + \sum_k \beta^k X_{ij}^k$$

where:

α_0	is a constant intercept term, to be estimated in the regression.
α_i	is an origin-specific constant term, to be estimated.
X_{ij}^k	is the value of the kth independent variable for segment with origin i and destination j.
β^k	is the regression coefficient on the kth independent variable, to be estimated.

The independent variables used in the model are shown in Table 4-2. Variables 1 and 2 are the segment density and length. Variable 3 measures the concentration of traffic at the segment end-point airports. Variables 4 and 5 reflect traffic composition on the segment. Variable 6 is a measure of airport congestion and capacity constraint.

Table 4-2

Variable Definitions, Logistic Regression Model of Service Type

k Value	Variable Name	Variable Definition
1	PPD	Natural log of segment traffic density, in passengers per day.
2	SL	Natural log of segment length, in statute miles.
3	WAHHI	Natural log of the weighted average HHI concentration metric for airline traffic shares at the segment origin and destination airports. The average is weighted by passenger traffic at the two airports.
4	ODR	Natural log of ratio of total daily OD traffic between segment origin and destination and segment traffic density (PPD).
5	PDOM	Natural log of proportion of total OD traffic between segment origin and destination that is pure domestic.
6	ARD	Natural log of arrival delay averaged over the segment origin and destination airports.

The full model including all independent variables and airport-specific constants proved impossible to estimate with the available data. In essence, the problem is that it is not possible to statistically distinguish between airport effects, as captured by the constants, and most of the segment characteristic effects, as measured by the *X* variables. We therefore estimated one version of the model which includes all of the characteristics in Table 4-2 but only one airport constant—that for LAX, and a second version which includes as many airport constants as possible, but only two segment characteristics, *PPD* and *SL*. We refer to the former as the "cross-sectional" model and the latter as the "fixed effects" model. The estimation results for both appear in Table 4-3. The cross-sectional results reveal that, in addition to *PPD* and *SL*, *PDOM* is positively associated with certificated service. Factors that appear to discourage certificated service include *ODR*, *WAHHI*, and, most notably, the delay variable, *ARD*.

The latter result implies that, all else equal, segments between airports with higher average delay are more likely to be served by commuters. Various explanations for this apparent anomaly are possible. Inspection of the data reflects that it is based on the high incidence of commuter service at two high delay airports—EWR and JFK. Thus the result may simply be the coincidence of two airports with high delay also having a proclivity toward commuter service. Alternatively, there may be special advantages from operating commuter equipment at these airports as a result of their high delays—namely the ability to land on less congested runways or fly on less congested flight routes available only for commuter planes. Finally, it is possible that the high delays at these airports are the result rather than the cause of the high incidence of commuter service.

The fixed effects model estimates confirm the obvious importance of *PPD* and *SL* as determinants of aircraft type, but suggest that, controlling for these, there are inter-airport differences in propensity toward certificated service. In addition to JFK and EWR, LAX and MIA have high negative coefficients, implying that segments involving these airports are more likely to be served by commuters. None of the airport constants is significant, however, implying that the apparent differences could be nothing more than the result of chance. Figure 4-3 illustrates this by superimposing two lines derived from the model on the plot shown in Figure 4-2. One line indicates the set of points where, according to the fixed effects model, commuter and certificated service are equally likely for non-LAX segments. (These are the

Table 4-3

Estimation Results, Service Type Model (Binary Logit)

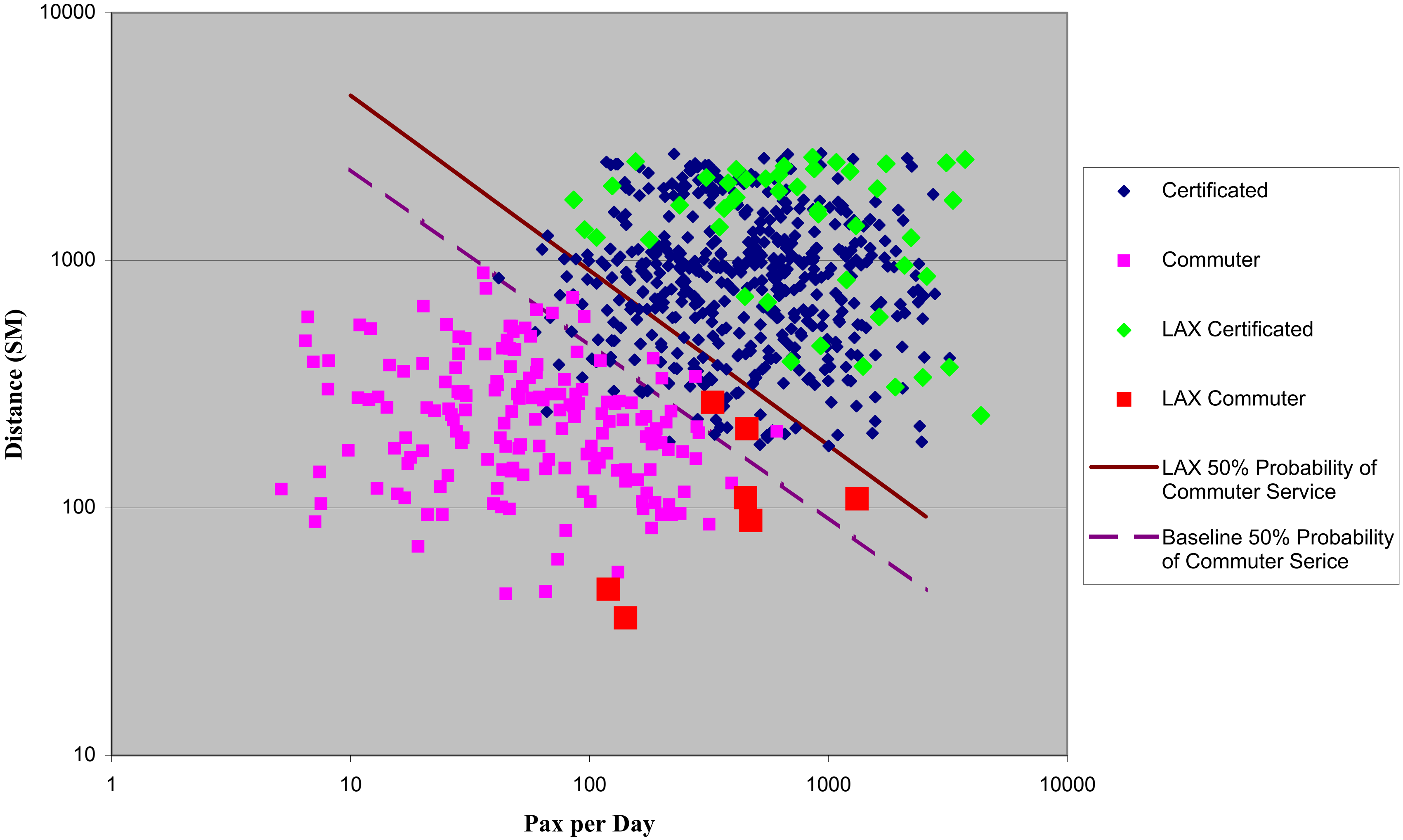
Parameter	Associated Variable	Cross-sectional Model	Fixed Effects Model
β^1	PPD	***6.306***[1]	***16.635***
β^2	SL	***10.451***	***23.567***
β^3	WAHHI	**-3.109**[2]	N/A
β^4	ODR	***-3.042***	N/A
β^5	PDOM	**4.237**	N/A
β^6	ARD	***-9.799***	N/A
α_0	INTERCEPT	***-109.300***	***-319.200***
α_{LAX}	LAX Constant	**-6.548**	-16.149
α_{BOS}	BOS Constant	N/A	-0.885
α_{BWI}	BWI Constant	N/A	12.573
α_{DCA}	DCA Constant	N/A	2.559
α_{EWR}	EWR Constant	N/A	-9.234
α_{FLL}	FLL Constant	N/A	N/A
α_{IAD}	IAD Constant	N/A	-3.422
α_{JFK}	JFK Constant	N/A	-14.431
α_{LGA}	LGA Constant	N/A	6.986
α_{MCO}	MCO Constant	N/A	6.050
α_{MIA}	MIA Constant	N/A	-11.841
α_{OAK}	OAK Constant	N/A	N/A
α_{PDX}	PDX Constant	N/A	N/A
α_{PHL}	PHL Constant	N/A	2.414
α_{SAN}	SAN Constant	N/A	N/A
α_{SEA}	SEA Constant	N/A	7.662
α_{SFO}	SFO Constant	N/A	N/A
α_{TPA}	TPA Constant	N/A	N/A

Notes:

1. Coefficients in ***bold italics*** significant at 1% level, two-tailed test.
2. Coefficients in **bold** significant at 5% level, two-tailed test.

Figure 4-3

Segment Distance vs Segment Density, Commuter and Certificated Segments, with Logit Equal Probability Curves



points where $V = 0$ in the logistic model). The other line is defined similarly, except for LAX segments. The latter is shifted well to the right from the former, reflecting the high negative constant for LAX. But both lines are quite consistent with the observed LAX data—in only three cases does the non-LAX line yield "false" predictions for LAX segments, and even these are quite close to the line of equal probability. In other words, it is hard to conclude from the data whether and how much the LAX line should be shifted from the non-LAX one.

Aircraft Size and Loads

Our analysis of aircraft size focuses on segments served by certificated carriers. Since commuter airlines do not report flights and seats at the segment level, such analysis is not really possible for commuter segments. Moreover, the commuter fleet is rapidly evolving, limiting the insight that can be gleaned from cross-sectional analysis for a given year.

Graphical Analysis

We begin by plotting our two productivity variables, seats per flight and passengers per flight, against segment density (passengers per day), as shown in Figures 4-4 and 4-5. Each point in these figures corresponds to one of the 526 flight segments with certificated service originating from the 18 selected airports. The points are coded by segment length, as shown in the legends included with the figures. Both plots have large amounts of scatter, but also reveal clear patterns. When segment density is low—less than about 300 passengers per day—both productivity measures increase rapidly with it. In this regime, traffic growth is accommodated mainly through increasing plane size and plane loads. This is presumably because the cost savings from doing so outweigh the benefits from increasing service frequency. It may also reflect the effect of the "indivisibility" problem on low density segments, where adding a daily flight entails a large fractional increase in capacity, while upsizing an existing flight permits a smaller and perhaps more appropriate capacity adjustment.

Once market density increases beyond about 300 per day, its effect on flight loads and plane size diminishes. For segments under 400 miles in length, seats per flight levels off at about 130 seats, and passengers per flight at about 80. These values hold even for segments with several thousand passengers per day, which as a result must have daily frequencies of several dozen flights. On longer segments, aircraft size and load also level off, but more gradually, at

Figure 4-4

Average Seats per Flight versus Segment Density, by Segment Distance

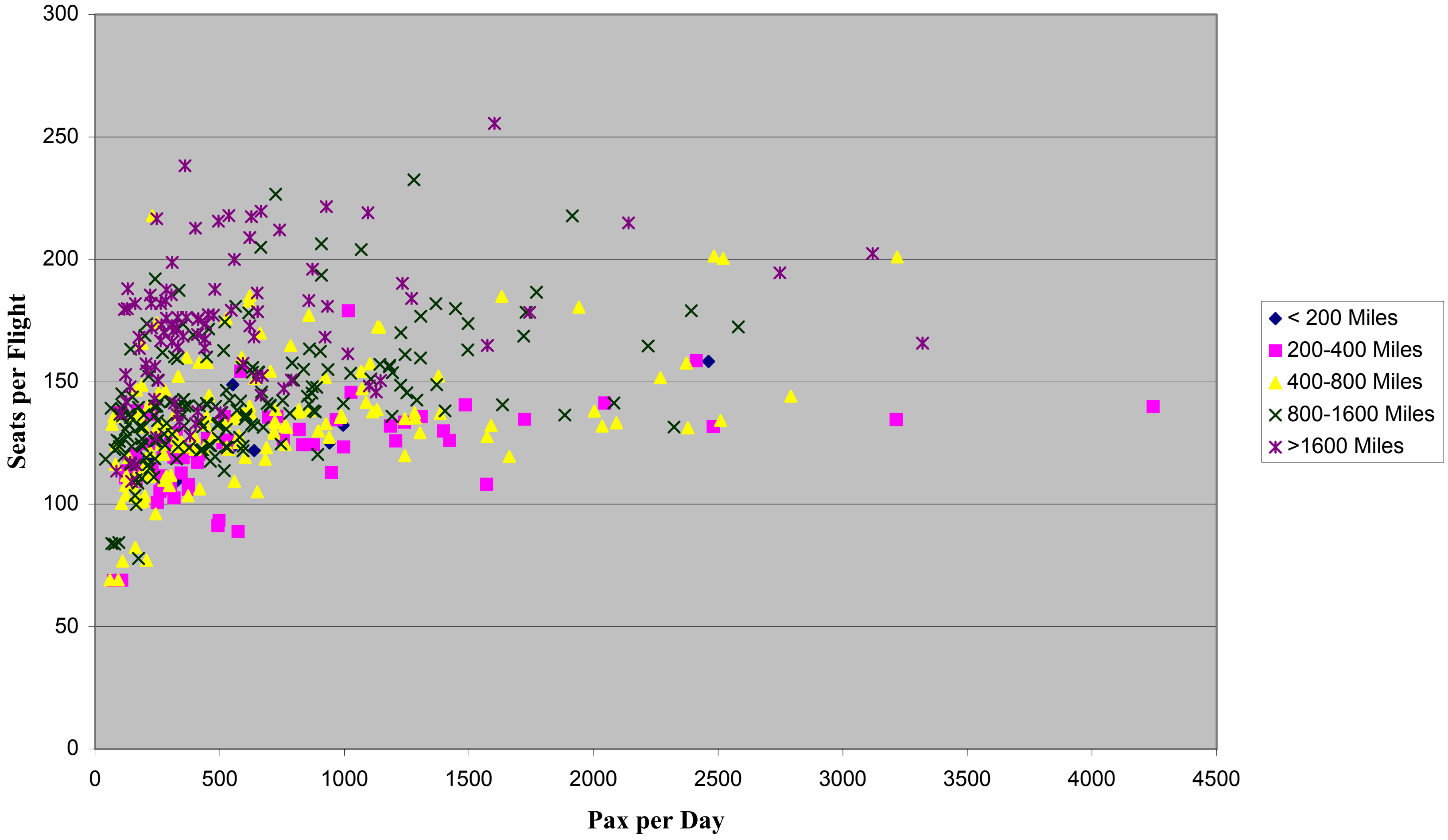
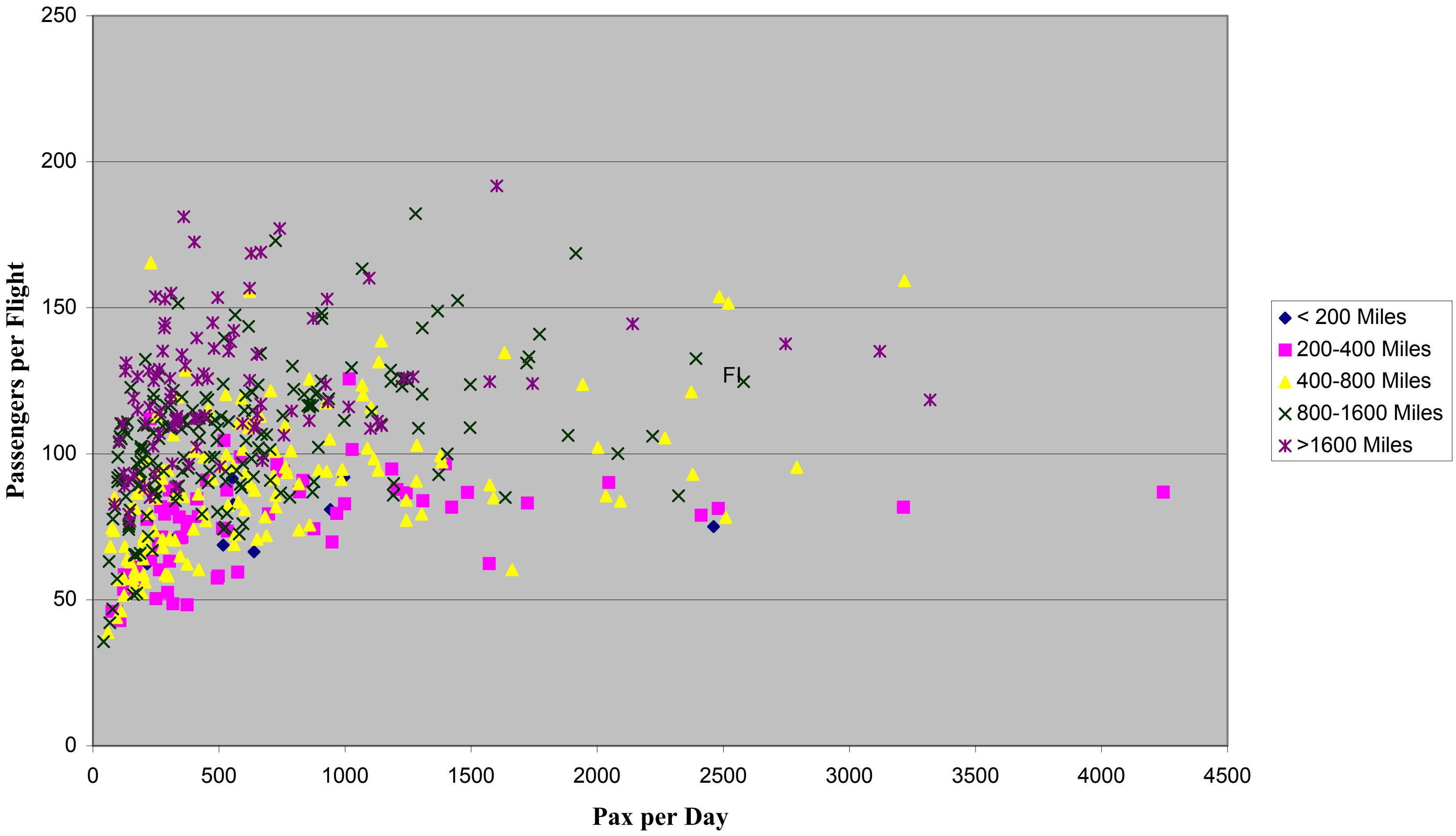


Figure 4-5

Average Passengers per Flight versus Segment Density, by Segment Distance



higher values, and with greater variability. For example, for segments over 1600 miles the average size reaches about 220 seats, but individual segments have values as high as 250 and as low as 170. As will be shown below, much of this variation can be explained by the other factors discussed earlier in this chapter.

Since both density and distance effect aircraft size, it is useful to plot the data using the product of the two—which has units of passenger-miles per day. Further, in light of the non-linear relationships found in Figures 4-4 and 4-5, it is appropriate to plot passenger-miles on a log scale. The resulting plots appear in Figures 4-6 and 4-7. For purposes of comparison, they distinguish segments originating in LAX from those originating from the other 17 airports. Both figures reveal a weak but obvious correlation between flight productivity and passenger miles per day, and suggest that the relationship is approximately linear when the latter is log-transformed. The figures also suggest that while the relationship is roughly the same for LAX and non-LAX segments, LAX flights have slightly higher average seats and loads, when segment passenger-miles are controlled for.

Regression Analysis

We used the segment data to estimate regression models that explain the variation in seats per flight and passengers per flight. The models were of the form:

$$\ln(SPF_{ij})\ or\ \ln(PPF_{ij}) = \alpha_0 + \alpha_i + \sum_k \beta^k X_{ij}^k + \varepsilon_{ij}$$

where:

SPF_{ij}	is the average seats per flight (total seats/total flights) for the segment between origin i and destination j.
PPF_{ij}	is the average on-board passengers per flight (total on-board passengers/total flights between origin i and destination j.
α_0	is a constant intercept term, to be estimated in the regression.
α_i	is an origin-specific constant term, to be estimated, with the constant for LAX forced to zero, making it the “reference” airport.
X_{ij}^k	is the value of the kth independent variable for segment with origin i and destination j.
β^k	is the regression coefficient on the kth independent variable, to be estimated.
ε_{ij}	is a stochastic error term for the segment with origin i and destination j.

Figure 4-6

Average Seats per Flight versus Passenger-miles per Day, LAX and Non-LAX Segments

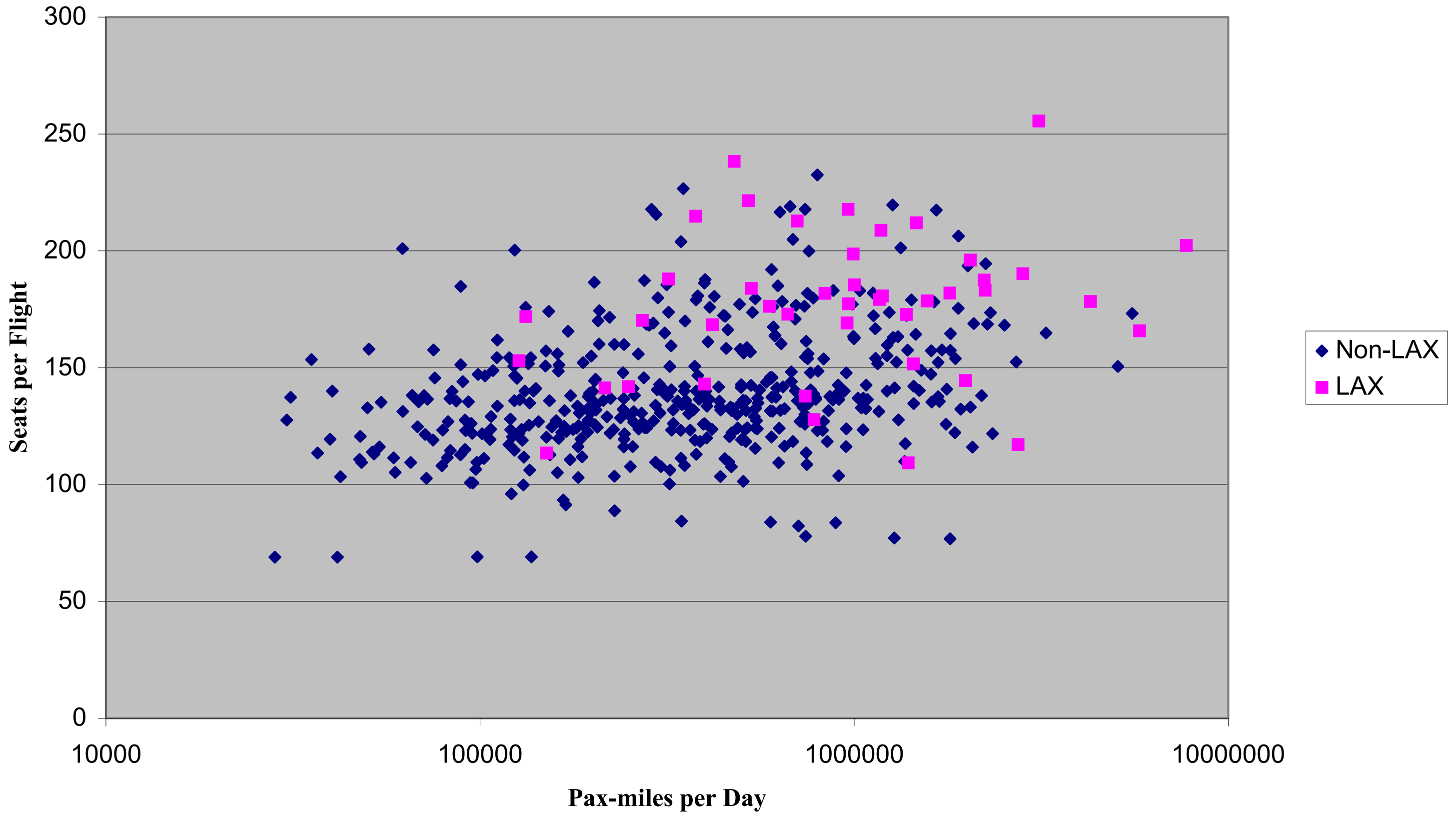
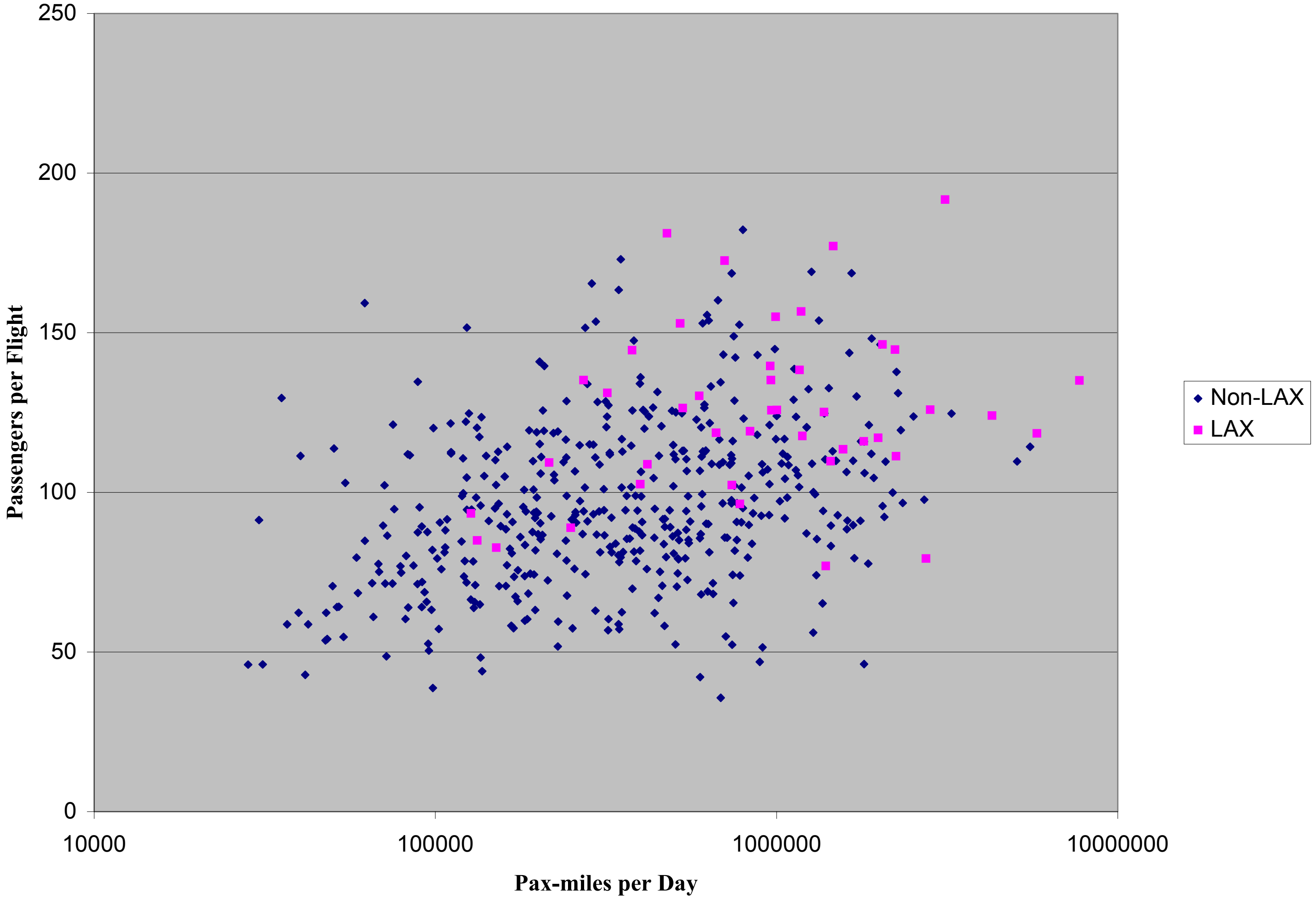


Figure 4-7

Average Passengers per Flight versus Passenger-miles per Day, LAX and Non-LAX Segments



The independent variables used in the model are defined in Table 4-4. Variables 1-3 are the segment length, density, and concentration. Variables 4 and 5 reflect traffic composition on the segment, which variable 6 measures the hub status of the segment endpoint airports. Variables 7 and 8 are measures of airport congestion and capacity constraint. The remaining variables are interactions between stage length and the other independent variables, which are included on the expectation, born out by preliminary analysis, that the sensitivity of size and load to the various independent variables may depend on length of the flight segment.

Table 4-4

Variable Definitions, Regression Models of Average Aircraft Size and Load

k Value	Variable Name	Variable Definition
1	PPD	Natural log of segment traffic density, in passengers per day.
2	SL	Natural log of segment length, in statute miles.
3	HHI	Natural log of the segment HHI concentration metric for airline traffic shares.
4	ODR	Natural log of ratio of total daily OD traffic between segment origin and destination and segment traffic density (PPD).
5	PDOM	Natural log of proportion of total OD traffic between segment origin and destination that is pure domestic.
6	HUBR	Natural log of ratio of total on-board traffic and total originating traffic leaving the segment origin and destination airports.
7	ARD	Natural log of arrival delay averaged over the segment origin and destination airports.
8	SLOT	=0 if neither the origin nor the destination airport is slot controlled; =1 if one of the airports is slot controlled; =2 if both airports are slot controlled.
9	PPD*SL	Product of variables PPD and SL.
10	HHI*SL	Product of variables HHI and SL.
11	ODR*SL	Product of variables ODR and SL.
12	PDOM*SL	Product of variables PDOM and SL.
13	HUBR*SL	Product of variables HUBR and SL.
14	ARD*SL	Product of variables ARD and SL.
15	SLOT*SL	Product of variables SLOT and SL.

In light of the results from the graphical analysis presented above, we divided our data into two subsets, based on whether the segment density exceeds 300 per day. We term those segments meeting this criterion “high density” segments, the others as “low density” ones. Separate analyses were performed on these two subsets. In addition, it proved useful to subdivide the high-density segments into short-haul (length<500 miles) and medium/long-haul ones (length≥500 miles, and termed “long-haul” for brevity). The distance interaction variables (numbers 9-15 in Table 4-4) were considered only for the high density long-haul segments, since only this data set contained sufficient observations and distance variation to make interaction effects estimable.

In estimating the regressions, we began with a model containing all of the independent variables in Table 4-4, and then eliminated variables that proved statistically insignificant until we arrived at a “preferred model”. In the following subsections, we present our preferred models along with several alternative models for each of the segment categories.

High Density Short-Haul Segments

We found that aircraft size on these segments depends largely on density and concentration. In the preferred model, shown in Table 4-5, both of these variables are highly significant statistically, and their coefficients have similar magnitudes of about 0.13. Since the model is log-linear, this implies that a 10 percent increase in segment density or concentration will result in a 1.4 percent increase in aircraft size. The adjusted R^2 of 0.47 implies that this model explains about half of the observed inter-segment variation in aircraft size, while the standard error of 0.10 implies that model predictions are accurate to about 10 percent.

The airport constants in the preferred model are mostly insignificant, with the exception of that for SEA. Most of the estimates are also negative, implying that, relative to the reference airport, LAX, these airports are served by smaller aircraft in their high density short-haul markets, all else equal. While several airports, including MCO and TPA, have positive estimates, in no case are these statistically significant. From this we conclude that for high density short-haul segments served by certificated carriers, average aircraft sizes for LAX are generally on a par with or slightly larger than those for the other airports in our study.

Two other seats-per-flight models are shown for comparison in Table 4-5. The first includes all of the explanatory variables in Table 4-1 except for the stage length interaction

Table 4-5

Estimation Results, Aircraft Size and Load Models, High Density, Short-Haul, Segments

		Seats per Flight Model			Pax per Flight Model
Parameter	Associated Variable	Preferred Model	Full Model	No Fixed Effects	
β^1	PPD	***0.124***[1]	***0.138***	***0.145***	***0.185***
β^2	SL	N/A	0.023	N/A	N/A
β^3	HHI	***0.130***	***0.142***	***0.170***	***0.329***
β^4	ODR	N/A	0.350	N/A	N/A
β^5	PDOM	N/A	-0.023	N/A	N/A
β^6	HUBR	N/A	-0.067	N/A	N/A
β^7	ARD	N/A	0.205	N/A	N/A
α_0	INTERCEPT	***2.910***	**2.081**[2]	***2.382***	0.369
α_{BOS}	BOS Constant	-0.053	-0.087	N/A	**-0.146**
α_{BWI}	BWI Constant	0.020	0.021	N/A	0.009
α_{DCS}	DCA Constant	0.007	0.022	N/A	***-0.168***
α_{EWR}	EWR Constant	-0.053	-0.061	N/A	**-0.145**
α_{FLL}	FLL Constant	-0.124	-0.147	N/A	-0.159
α_{IAD}	IAD Constant	-0.096	-0.078	N/A	-0.126
α_{JFK}	JFK Constant	0.000	0.000	N/A	0.000
α_{LGA}	LGA Constant	-0.027	-0.029	N/A	-0.131
α_{MCO}	MCO Constant	0.122	0.076	N/A	0.160
α_{MIA}	MIA Constant	0.000	0.000	N/A	0.000
α_{OAK}	OAK Constant	-0.045	-0.031	N/A	***-0.181***
α_{PDX}	PDX Constant	-0.110	-0.129	N/A	-0.109
α_{PHL}	PHL Constant	-0.069	-0.043	N/A	**-0.150**
α_{SAN}	SAN Constant	-0.028	-0.054	N/A	-0.086
α_{SEA}	SEA Constant	***-0.262***	***-0.247***	N/A	**-0.274**
α_{SFO}	SFO Constant	-0.048	-0.077	N/A	-0.098
α_{TPA}	TPA Constant	0.120	0.064	N/A	0.135
	Adj. R^2	0.46	0.45	0.37	0.57
	Std. Error	0.10	0.10	0.11	0.13

Notes:

1. Coefficients in ***bold italics*** significant at 1% level, two-tailed test.
2. Coefficients in **bold** significant at 5% level, two-tailed test.

terms. Market density and concentration are the only significant variables in this model; their coefficients are quite similar to those in the preferred model. Average arrival delay, while insignificant, is positive as hypothesized. Because it includes several insignificant variables, this model has a slightly lower adjusted R^2 than the preferred one. In the third model, the airport constants are removed while the specification of the preferred model is otherwise retained. It has a much lower adjusted R^2 and somewhat higher estimates for the density and concentration coefficients.

To help visualize the implications of the preferred seats-per-flight model, we used it to predict average aircraft size for markets with various densities and degrees of concentration. The results are shown in Figure 4-8, which plots predicted aircraft against density under three concentration scenarios: a monopoly (HHI=10,000), a duopoly with equal market shares (HHI=5,000), and a "triopoly" (three airlines with equal market shares, HHI=3,333). Aircraft size grows from 105-120 seats for 300 passengers per day to 155-180 for 4,800 passengers per day. The difference between a monopoly segment and a triopoly one translates into a size difference of about 15 seats for low density segments increasing to around 25 seats for very high density ones.

In estimating the passengers-per-flight model for high density short-haul segments, we retained the specification of the preferred seats-per-flight model. Estimation results appear in the last column of Table 4-5, and are somewhat different from those of the seats-per-flight model. The intercept is lower, while the coefficients of density and concentration are higher, in the latter case by more than two-fold. This implies that the load factor, the ratio of passengers to seats, is higher on segments that are higher density and more concentrated. Several airports have statistically significant, negative, constants in the passengers-per-flight model, implying that flights into these airports have lower average loads than those into LAX, all else equal. Figure 4-8 includes a plot of predicted passengers per flight against market density, for the duopoly case. The load factor increases from 64% to 77% percent as segment density increases from 300 to 4,800 passengers per day.

High Density Long-Haul Segments

Estimation results for long-haul segments appear in Table 4-6. The preferred model has an adjusted R^2 of 0.56 and a standard error of 0.11 (indicating, as in the short-haul model, a

Figure 4-8

Flight Productivity Variables vs Segment Density, High Density, Short-Haul Segments, by Scenario

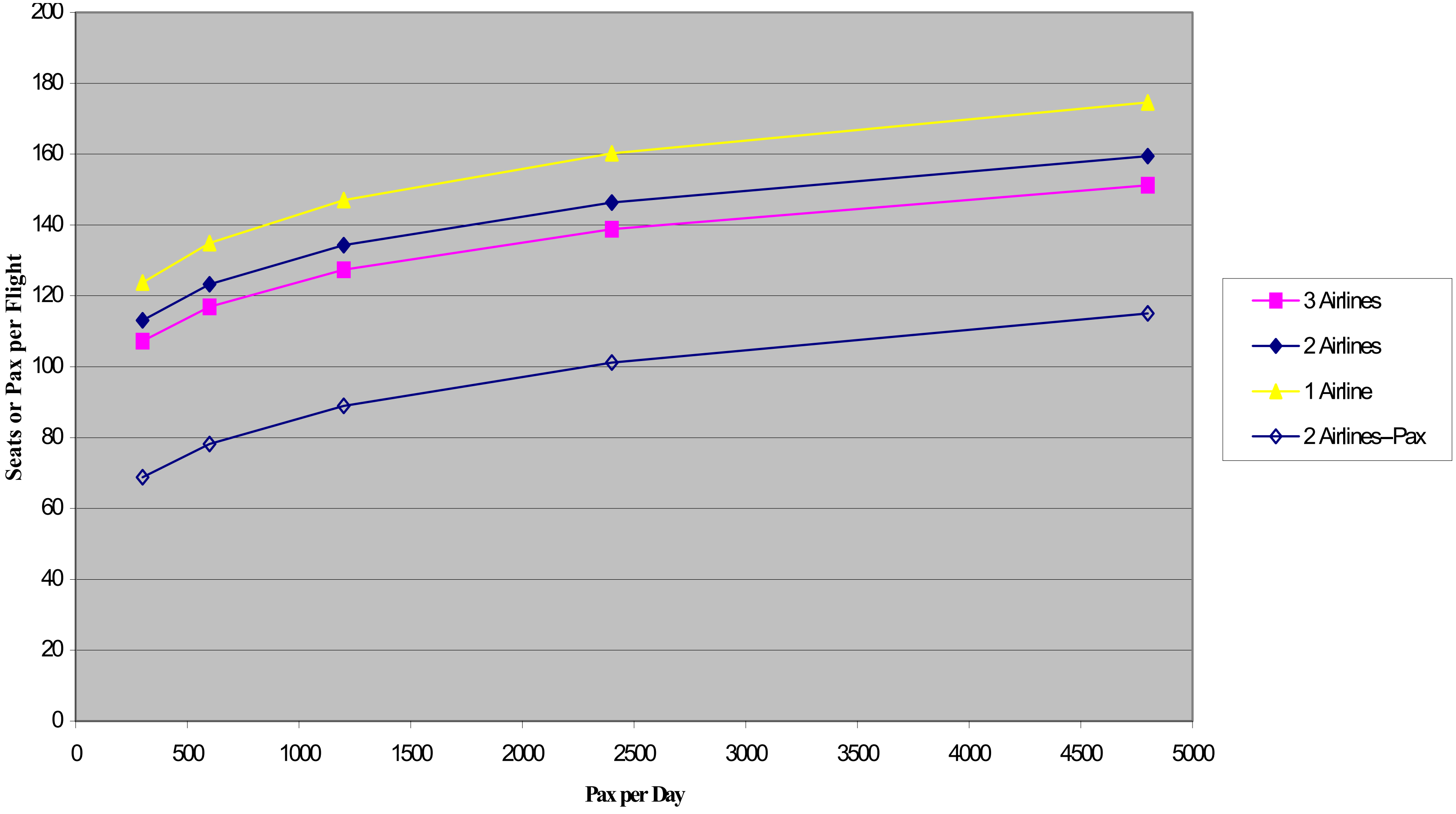


Table 4-6

Estimation Results, Aircraft Size and Load Models, High Density, Long-Haul Segments

		Seats per Flight Model				Pax per Flight Model
Parameter	Associated Variable	Preferred Model	Full Model	No SL Interactions	No Airport Constants	
β^1	PPD	***0.580***[1]	**0.495**[2]	0.422	***0.119***	**0.601**
β^2	SL	***-1.019***	-0.986	**-0.854**	***0.191***	-0.852
β^3	HHI	N/A	-0.149	N/A	N/A	N/A
β^4	ODR	N/A	0.238	N/A	N/A	N/A
β^5	PDOM	N/A	0.267	N/A	N/A	N/A
β^6	HUBR	N/A	-0.229	N/A	N/A	N/A
β^7	ARD	***-3.292***	**-2.679**	***-2.787***	***0.449***	-2.518
β^8	SLOT	N/A	0.582	N/A	N/A	N/A
β^9	PPD*ASL	**-0.066**	-0.054	-0.045	N/A	-0.065
β^{10}	HHI*ASL	***0.027***	0.047	***0.023***	N/A	***0.041***
β^{11}	ODR*ASL	N/A	-0.043	N/A	N/A	N/A
β^{12}	PDOM*ASL	N/A	-0.040	N/A	N/A	N/A
β^{13}	HUBR*ASL	N/A	0.033	N/A	N/A	N/A
β^{14}	ARD*ASL	***0.532***	**0.449**	***0.432***	N/A	**0.436**
β^{15}	SLOT*ASL	N/A	-0.090	N/A	N/A	N/A
α_0	INTERCEPT	***8.615***	8.383	***8.231***	***1.566***	5.755
α_{BOS}	BOS Constant	**-0.080**	***-0.096***	N/A	**-0.076**	***-0.136***
α_{BWI}	BWI Constant	-0.042	-0.046	N/A	-0.017	0.055
α_{DCS}	DCA Constant	***-0.103***	-0.080	N/A	**-0.087**	***-0.149***
α_{EWR}	EWR Constant	***-0.189***	***-0.215***	N/A	***-0.178***	***-0.225***
α_{FLL}	FLL Constant	-0.015	-0.019	N/A	-0.015	***0.123***
α_{IAD}	IAD Constant	0.063	0.032	N/A	0.069	0.011
α_{JFK}	JFK Constant	0.068	0.090	N/A	0.060	0.053
α_{LGA}	LGA Constant	-0.059	-0.031	N/A	-0.047	-0.058
α_{MCO}	MCO Constant	-0.020	-0.025	N/A	-0.012	***0.093***
α_{MIA}	MIA Constant	0.045	0.011	N/A	0.054	0.053
α_{OAK}	OAK Constant	-0.022	-0.005	N/A	0.012	-0.048
α_{PDX}	PDX Constant	-0.008	-0.020	N/A	-0.004	-0.054
α_{PHL}	PHL Constant	***-0.126***	***-0.141***	N/A	***-0.122***	***-0.151***
α_{SAN}	SAN Constant	-0.032	-0.034	N/A	-0.028	-0.018
α_{SEA}	SEA Constant	-0.039	-0.043	N/A	-0.030	0.006
α_{SFO}	SFO Constant	***-0.104***	***-0.122***	N/A	**-0.082**	***-0.150***
α_{TPA}	TPA Constant	-0.050	-0.056	N/A	-0.042	**0.078**
	Adj. R^2	0.56	0.56	0.44	0.53	0.53
	Std. Error	0.11	0.11	0.12	0.11	0.14

Table 4-6 (cont.)

Notes:
1. Coefficients in ***bold italics*** significant at 1% level, two-tailed test.
2. Coefficients in **bold** significant at 5% level, two-tailed test.

predictive accuracy of about 11 percent). The preferred long-haul model, summarized in the first column, is considerably more complex than the short-haul model. The significant factors are density, concentration, stage length, and delay. Market density and delay appear both individually and in interaction with stage length, while for concentration only the stage length interaction is included. Density is positively related to aircraft size, but the effect declines as stage length increases. Delay, however, becomes more important at longer stage lengths. Its individual coefficient is negative, but the overall effect of delay (calculated as $-3.292+0.532*\ln(SL)$) is approximately 0 at stage lengths of 500 miles, increasing to about 0.9 for 2,500-mile segments. For similar reasons, increased stage length leads to larger aircraft despite the negative coefficient on the individual stage length term. Aircraft size is more sensitive to stage length when segments have low densities, high delays, and high concentrations.

Several of the airport constants are negative and statistically significant, including those for BOS, DCA, EWR, PHL, and SFO. All else equal, these airports have aircraft sizes 10-20% smaller than LAX. Three airports—IAD, JFK, and MIA—have sizes slightly, but statistically insignificantly, higher. Thus, for long-haul as well as short-haul segments, we conclude that LAX is in the top tier of airports in terms of aircraft size. But this tier also includes the majority of other airports considered in this study.

Estimates for three other models are included in Table 4-6 for comparison. The full model includes all the variables defined in Table 4-4. It is similar to the preferred model in terms of adjusted R^2, and coefficient estimates of common variables, but the significance level of these variables is somewhat less. None of the other variables is significant at the 0.05 level, but the slot variables are borderline significant at the 0.10 level. Their values imply slot control results in increased aircraft size on segments up to about 600 miles and smaller aircraft on longer segments. It is plausible that slot control would primarily affect short-haul segments, but hard to explain it would also induce shift toward smaller aircraft on longer segments.

The third model summarized in Table 4-6 excludes the segment length interaction terms. This eases interpretation, since the effect of each independent variable is reduced to a single number, but results in a loss of fit (adjusted R^2=0.53 instead of 0.56). From the estimation results we learn that 10 percent increases in segment density, stage length, and delay yield increases in aircraft size of 1.2 percent, 1.9 percent, and 4.4 percent respectively. The fourth seats-per-flight model is the same as the preferred one except that it excludes airport constants. This model has the lowest R^2 of the seats-per-flight models presented, but its coefficient estimates are in essential agreement with the preferred model.

Figure 4-9 depicts the results of the preferred long-haul model graphically. The baseline case assumes a stage length of 1200 miles, an average arrival delay of 15 minutes, and a Herfindahl index of 7000, values close to the averages in our data set. Aircraft size grows from 150 to just over 200 seats as market density increases from 300 to 4800 passengers per day. On a longer route (2400 miles), the predicted size is 40 seats higher when density is low with the difference shrinking to 15 seats when the density if high. Conversely, a high delay segment (average arrival delay of 20 minutes) is expected to have aircraft with about 25 more seats when density is low and 30 more when it is high. Finally, an unusually unconcentrated segment (HHI=3333) would have an average aircraft size 15-20 seats lower than in the baseline case.

The last model summarized in Table 4-6 is for passengers per flight. It is generally consistent with the preferred seats-per-flight model. The delay variables are slightly less significant, with *ARD*, at a significance level of 0.0503, just missing the 5 percent criterion. Most airport constants have the same signs, but two notable exceptions are MCO and TPA, which have negative values in the seat model but positive (and significant) ones in the passenger model. This implies that these Florida destinations have comparatively high load factors, consistent with the tourist-oriented nature of their traffic.

The most interesting and provocative of the above results is the apparent sensitivity of aircraft size to arrival delay. It is natural to question the validity of this result, in particular whether the statistical link found in our analysis reflects a causal link, and whether the effect is can be of the magnitude as we found here. To probe these questions, we performed additional graphical analysis, as shown in Figures 4-10 and 4-11. Figure 4-10 plots average aircraft size against market density for segments over 1500 miles in length, and with the segments divided into two groups. One group, labeled “high delay”, has average arrival delays in

Figure 4-9

Flight Productivity Variables vs Segment Density, High Density, Long-Haul Segments, by Scenario

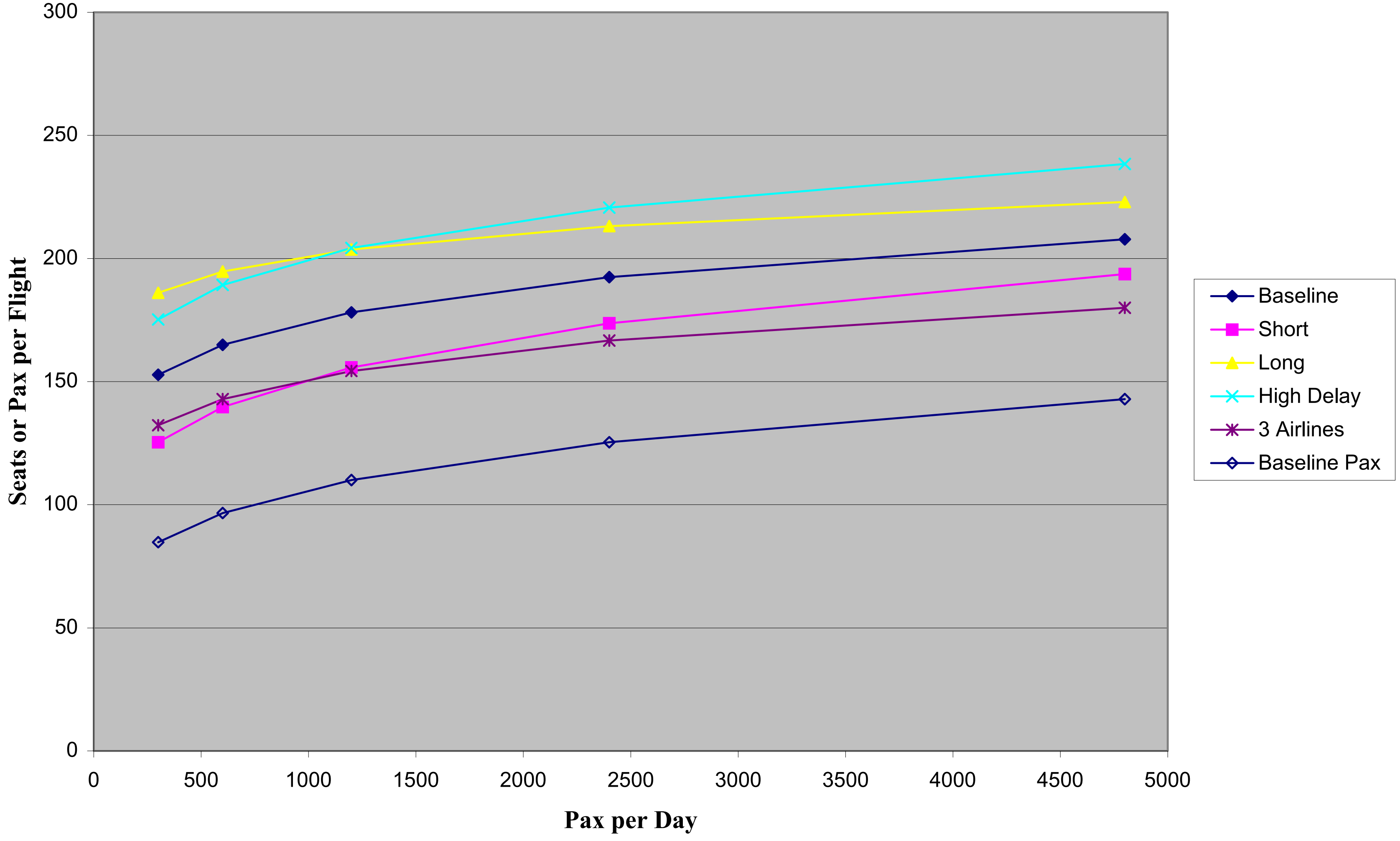


Figure 4-10

Seats per Flight vs Segment Density, Long-Haul Segments, by Delay Category

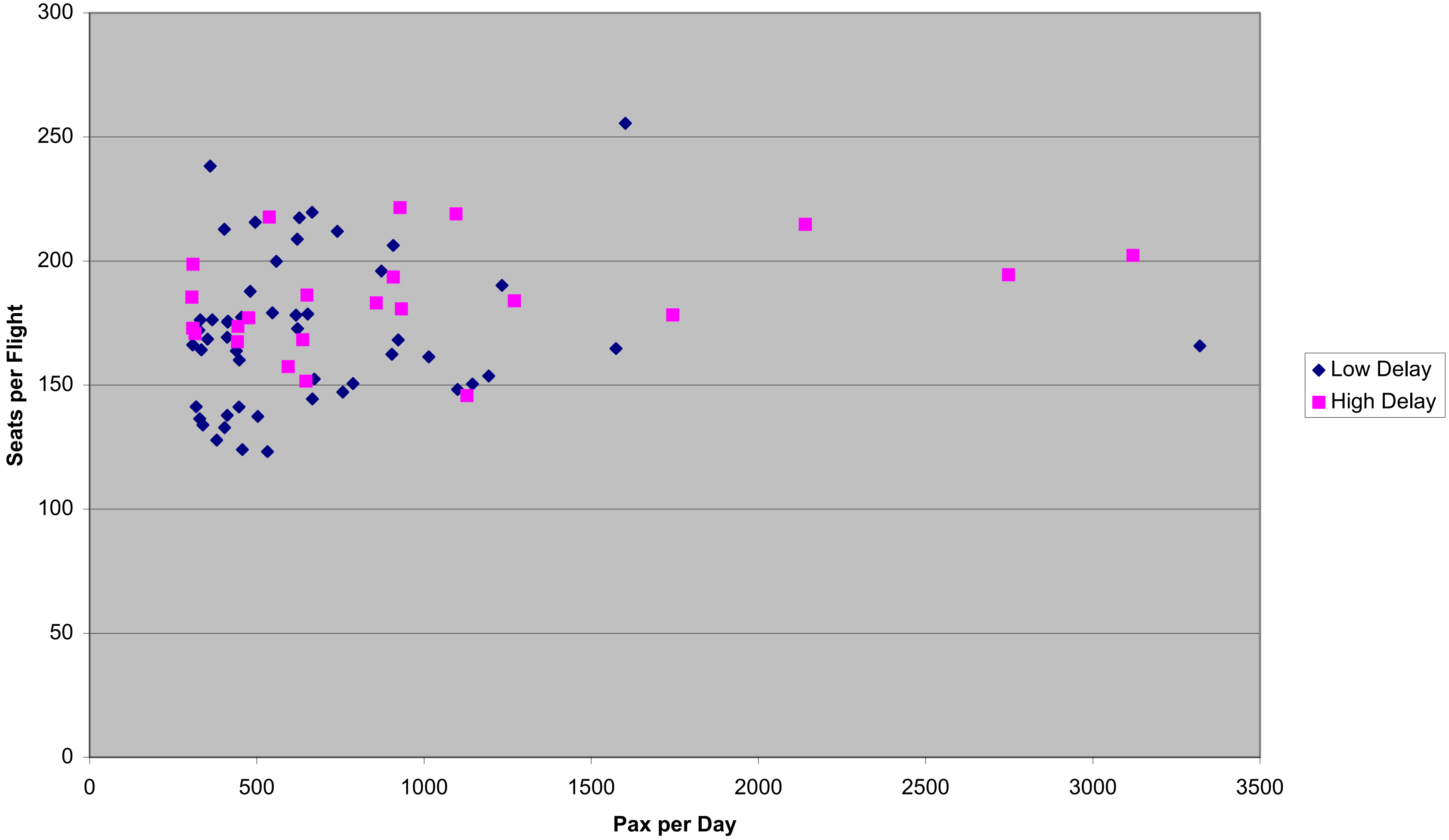
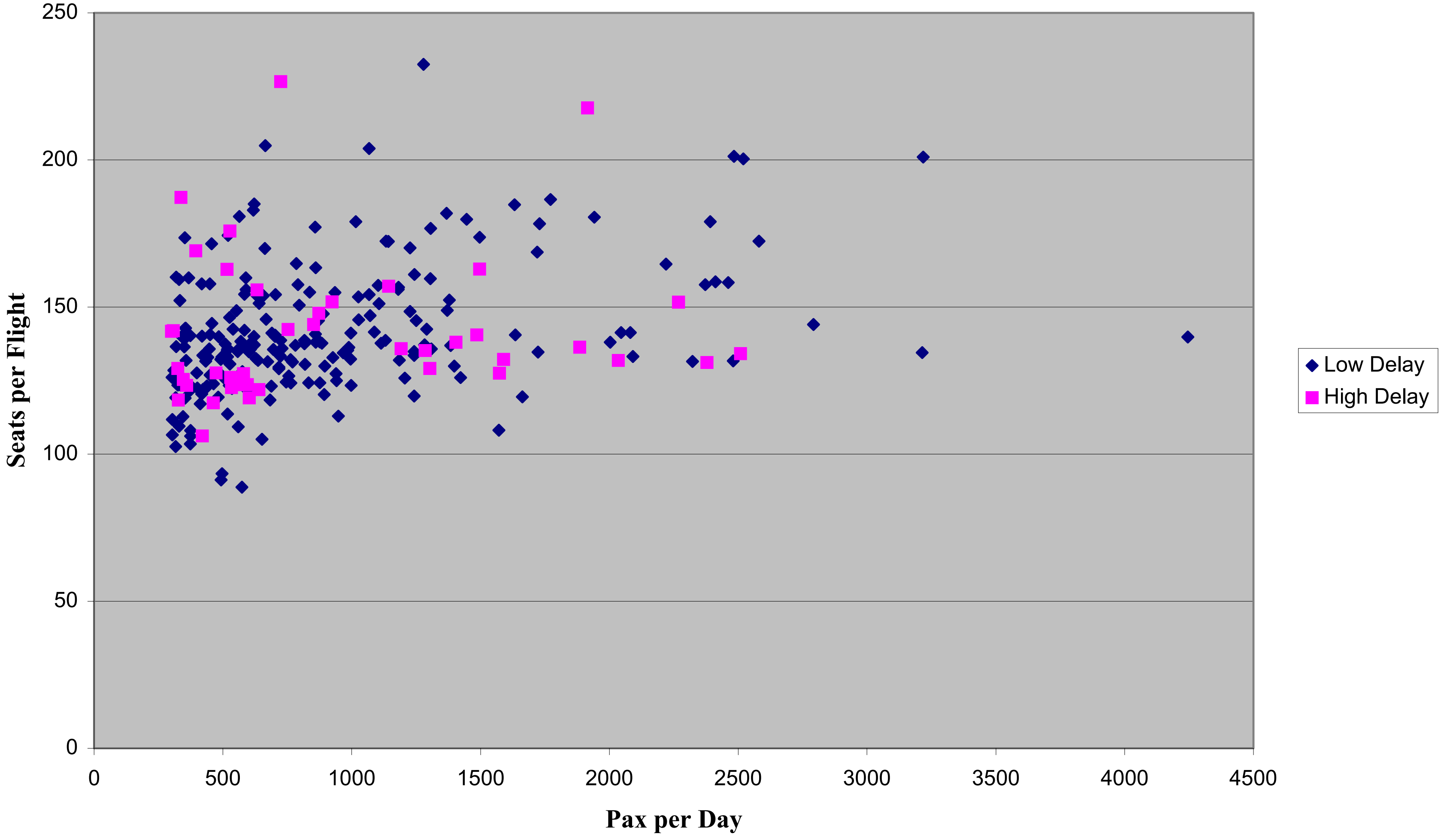


Figure 4-11

Seats per Flight vs Segment Density, Short-Haul Segments, by Delay Category



excess of 15 minutes. The second group, labeled "low delay" includes all other segments over 1500 miles. It is apparent from the plot that high delay segments do on average have higher seats per flight than low delay ones. About 25 percent of these segments have average sizes under 150 seats, as compared to just 1 of 23 high delay segments. Figure 4-11 presents a similar plot for segments shorter than 1500 miles. For these segments, there is no clear association between aircraft size and delay. This is the contrast that is captured by the positive distance-delay interaction coefficient in our model.

Low Density Segments

Table 4-7 summarizes our estimation results for segments with under 300 passengers per day served by certificated carriers. The model covers all stage lengths, since there is insufficient data to estimate separate short-haul and long-haul models. In the preferred model, seats-per-flight is related to traffic density, segment length, and segment concentration, with all three relationships significant at the 1 percent level. An increase of 10 percent in each of these variables is associated with aircraft size increases of 2.0, 1.6, and 1.2 percent respectively. The model explains about half of the variation in aircraft size observed in the sample.

Most of the airport constants are positive, in many cases significantly so. This means that, controlling for other factors, LAX low density segments tend to be served by smaller aircraft. The magnitude of this difference exceeds 10 percent in several cases, and, in the case of JFK, exceeds 60 percent.

The coefficient estimates in the preferred model are rather sensitive to changes in model specification. They all become insignificant when a larger set of explanatory variables is included, as shown in the second column of Table 4-7. When the airport constants are removed, as shown in Figure 4-3, the coefficient on HHI changes dramatically, while the others are affected only slightly.

In the passengers-per-flight model, estimates for which appear in the last column of Table 4-7, coefficients on density, length, and concentration are considerably higher. This implies that load factor increases with each of these variables. This model also has more explanatory power than the seats-per-flight ones, as measured by the adjusted R^2.

Figure 4-12 portrays results for the low-density segment model in graphical form. The baseline in this case assumes a duopoly segment (HHI=5000) of 500 miles in length. Aircraft

Table 4-7

Estimation Results, Aircraft Size and Load Models, Low Density Segments

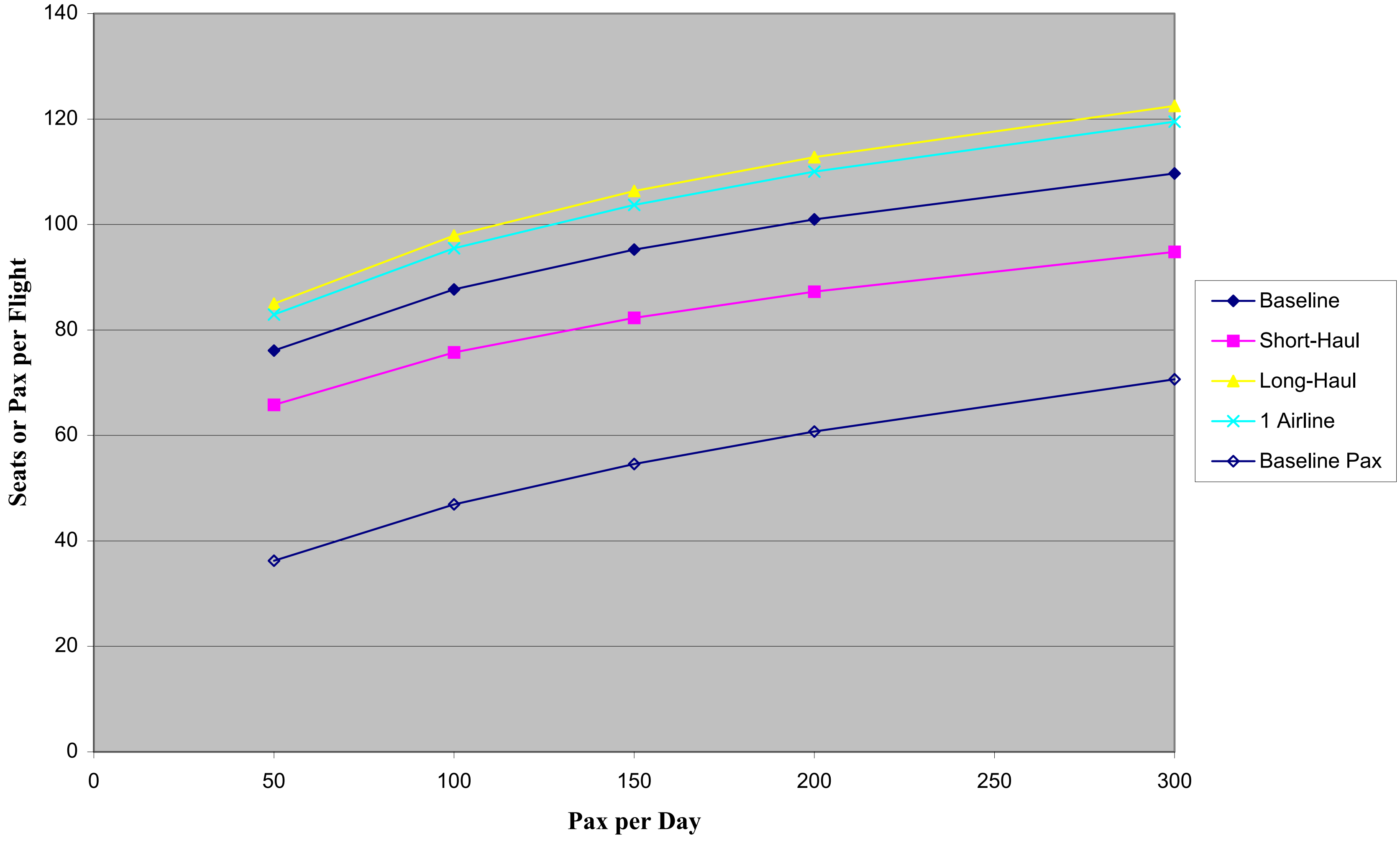
		Seats per Flight Model			Pax per Flight Model
Parameter	Associated Variable	Preferred Model	Full Model	No Fixed Effects	
β^1	PPD	***0.204***[1]	***0.199***	***0.176***	***0.373***
β^2	SL	***0.159***	***0.124***	***0.186***	***0.306***
β^3	HHI	**0.123**[2]	**0.131**	0.021	***0.222***
β^4	ODR	N/A	**-0.233**	N/A	N/A
β^5	PDOM	N/A	-0.040	N/A	N/A
β^6	HUBR	N/A	0.034	N/A	N/A
β^7	ARD	N/A	-0.228	N/A	N/A
β^8	SLOT	N/A	-0.156	N/A	N/A
α_0	INTERCEPT	**1.493**	**2.367**	***2.498***	**-1.657**
α_{BOS}	BOS Constant	0.119	0.105	N/A	-0.043
α_{BWI}	BWI Constant	**0.142**	0.095	N/A	0.128
α_{DCS}	DCA Constant	0.049	0.144	N/A	0.004
α_{EWR}	EWR Constant	0.026	0.044	N/A	-0.097
α_{FLL}	FLL Constant	0.016	0.004	N/A	**0.165**
α_{IAD}	IAD Constant	**0.110**	0.019	N/A	-0.039
α_{JFK}	JFK Constant	***0.387***	0.423	N/A	***0.279***
α_{LGA}	LGA Constant	0.053	0.168	N/A	-0.045
α_{MCO}	MCO Constant	***0.214***	***0.186***	N/A	***0.220***
α_{MIA}	MIA Constant	***0.172***	0.050	N/A	**0.158**
α_{OAK}	OAK Constant	**0.202**	0.126	N/A	**0.258**
α_{PDX}	PDX Constant	0.084	0.029	N/A	0.028
α_{PHL}	PHL Constant	-0.018	-0.063	N/A	-0.046
α_{SAN}	SAN Constant	0.120	0.096	N/A	0.163
α_{SEA}	SEA Constant	0.015	0.053	N/A	0.050
α_{SFO}	SFO Constant	**0.136**	**0.176**	N/A	0.076
α_{TPA}	TPA Constant	**0.135**	0.103	N/A	***0.244***
	Adj. R^2	0.47	0.48	0.35	0.64
	Std. Error	0.16	0.16	0.17	0.19

Notes:

1. Coefficients in ***bold italics*** significant at 1% level, two-tailed test.
2. Coefficients in **bold** significant at 5% level, two-tailed test.

Figure 4-12

Flight Productivity Variables vs Segment Density, Low Density Segments, by Scenario



size increases from just under 80 to 110 seats as market density goes from 50 to 300 passengers per day (the upper limit for which this model applies). The size is about 10 seats less for short-haul (200 mile) segments and 10 seats more for long-haul (1000 mile) ones. A monopoly (HHI=10,000) segment is also expected to have an aircraft size about 10 seats larger on 500-mile segment. Passengers per flight under baseline assumptions increases from under 40 to 75 passengers, implying a load factor increase from 55 to 74 percent, over the range of segment densities considered.

Implications: Impact of Traffic and Delay Growth on Operations at LAX

We used the estimation results from the previous section to assess how increases in passenger traffic and delay would affect flight activity at LAX. This impact could take two forms. First, the service type on certain segments could shift from commuter to certificated. Second, there could be changes in aircraft size and traffic loads without a change in service type. The latter changes could occur on either commuter or certificated segments, but here we will consider only certificated segments because of the aforementioned difficulties in modeling aircraft size on commuter segments.

Our analysis of this section revolves around a set of scenarios defining passenger traffic growth, delay changes, and changes in competition. The scenarios are hypothetical, and intended to explore the sensitivity of flight growth at LAX to these factors rather than to predict the future per se. Each scenario assumes a 40 percent increase in traffic over the baseline year of 1998, which is applied across-the-board to all LAX segments in our data set. Three delay scenarios are considered: increases in average arrival delays at LAX of 0, 5, and 10 minutes per flight. (Baseline average delays are assumed for other airports.) With respect to competition, we assume that segment concentration levels either (i) remain at baseline levels, (ii) decrease slightly in response to traffic growth (based on a regression relating the Herfindahl index to traffic level, we find that a 40 percent increase in traffic results is expected to reduce segment concentration by about 6 percent), or (iii) decrease proportionally to traffic (implying, in effect, that a 40 percent increase in traffic leads to a 40 percent increase in competition). We refer to the latter scenarios as “Increased Competition I” and “Increased Competition II” respectively.

Service Type Impacts

To help assess the probable service-type impacts of a 40 percent growth in traffic, we represented this scenario using Figure 4-13. This figure is similar to Figure 4-3, but eliminates non-LAX commuter segments and depicts current LAX commuter segments assuming the 40 percent traffic increase. From inspection of the figure one can see that the increase pushes three segments, FAT, MRY, and SAN, close to the line representing a 50 percent probability of certificated service for LAX segments. In the case of the former two segments, there are also several non-LAX certificated segments of comparable distance and lower traffic density. On the other hand, LAX segments of comparable length that currently receive certificated service (for example, SMF and SJC) have much higher densities. We conclude that 40 percent traffic growth is unlikely to spark a transition from commuter to certificated service on any LAX segment, although it is a possibility for FAT and MRY.

Aircraft Load Impacts

Although our estimation results can be used to predict changes in both average seats and average passengers per flight, we focus on the latter because the results can be translated directly into the number of additional flights required to accommodate the postulated 40 percent growth in traffic. To make these predictions, we examined each individual LAX certificated flight segment, applying the appropriate model to predict how the assumed changes in traffic level, delay, and competition would affect average flight load and thus flight growth. The results are summarized in Table 4-8. In the absence of delay increases, 33 to 35 percent of the 40 percent growth in traffic would be accommodated by adding flights, and the remainder through increased traffic loads. On the other hand, in the most dire delay scenario, about half of the traffic growth would take the form of increased passengers per flight. The increased loads would all be in high density long-haul markets, where flights could grow as little a 10-12 percent if 40 percent traffic growth were accompanied by high delay.

With regard to competition, the results are similar for the Baseline and Increased Competition I scenarios, reflecting the weak relationship between traffic density and concentration observed in our data set. The second increased competition scenario, in which competition increases proportionally to traffic, leads to substantially smaller average loads and more flights, with flight growth approaching 50 percent if delay remains constant. While there is

Figure 4-13

Segment Distance vs Segment Density, Certificated and Commuter Segments, with LAX Growth Scenario

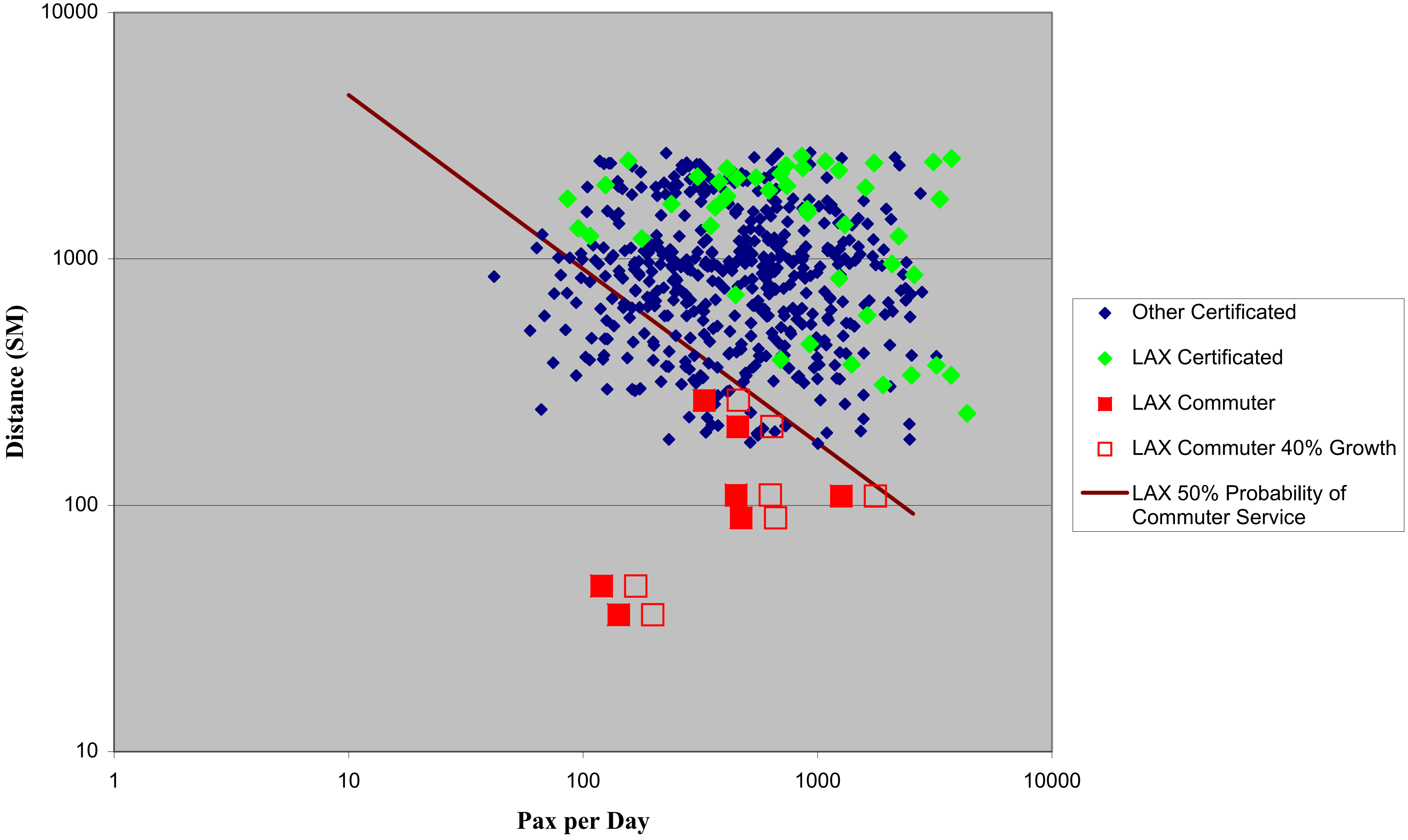


Table 4-8

Impact of Flight Growth at LAX with 40 Percent Traffic Growth, by Delay and Competition Scenario

	Baseline (1998)		Flight Growth: Baseline Concentration			Flight Growth: Increased Competition I			Flight Growth: Increased Competition II		
Destination	Flts/Day	Pax/Flt	Base Delay	Base + 5 min	Base + 10 min	Base Delay	Base + 5 min	Base + 10 min	Base Delay	Base + 5 min	Base + 10 min
High Density Short Haul	216	85	32%	32%	32%	34%	34%	34%	47%	47%	47%
High Density Long Haul	270	122	34%	21%	10%	36%	23%	12%	48%	33%	22%
Low Density	10	87	23%	23%	23%	25%	25%	25%	33%	33%	33%
Overall	*495*	*105*	*33%*	*25%*	*20%*	*35%*	*28%*	*22%*	*47%*	*39%*	*33%*

no particular reason to expect such a change in the competitive environment, its potential to influence flight demand is notable.

Conclusions

In this chapter, we have analyzed relationships between characteristics of domestic flight segments and the type, size, and average loads of equipment serving them. By performing the analysis at the segment level, we obtain statistical tractability and a set of models that are simple to apply. Necessarily, however, the analysis omits network effects, fleet constraints, and other influential factors. These are all treated as statistical noise in the work presented here. Despite these limitations, we are able to reliably predict whether segments receive commuter or large jet ("certificated") service, and to explain about half of the observed variation in aircraft size and load on certificated segments.

Although a variety of explanatory factors were considered, only a few emerge as definitively important. These include segment length, segment traffic density, and the concentration of segment traffic among competing airlines. The high level of statistical significance and inherent plausibility of the relationships involving these variables justifies high confidence in their validity.

Another factor, average arrival delay at the segment endpoint airports, also appears to be important on longer, high density, segments. This intriguing results should, however, be viewed as tentative, given the apparent magnitude of the effect and the possibility of spurious correlation distorting our results. Further analysis and study is called for before this effect can be accepted or used in airport planning decisions. Potentially, however, it is a very important finding.

Otherwise, we find no evidence that delay or capacity constraints result in larger aircraft or larger aircraft loads. If anything, high delay may encourage the substitution of commuter for certificated service. JFK and EWR are examples of high delay airports where there is a propensity toward commuter operations, although it is unclear what, if any, causal mechanism links these two attributes. Slot control also appears unimportant to aircraft size and load. If it has an influence, it must be on what segments are served rather than how they are served.

Our results have a two-fold relevance to LAX. First, they enable us to compare LAX with other airports. In this regard, we have shown that LAX commuter segments are unique in their short length and high density. The large numbers of commuter flights generated by these segments create unique pressures on the airport infrastructure, and help justify and explain the intense interest in high-speed rail for the Southern California region. Otherwise, LAX resembles other airports in terms of the size and loads of the planes serving it, when other factors such as segment length and density are controlled for.

The second implication concerns the likely impact of traffic growth, delay increase, and changes in segment concentration on flight activity at LAX. Applying our calibrated models to LAX segments, we find that, absent changes in delay or concentration, increased traffic will be accommodated mainly through increases in the number of flights. On the other hand, if our estimates of the impact of delay on average flight loads are accepted, future delay increases could substantially change this outcome, cutting certificated flight growth to as little as half of passenger growth under the most dire scenarios. Increased competition would have the opposite effect, causing flight growth in excess of traffic growth under a constant delay scenario.

These results do not imply that airport congestion at LAX can in any way "solve itself." Delay must get considerably worse if it is to significantly retard flight growth. It will be of little consolation to users or the airport operator if such delays are accompanied by increased throughput per flight, just as population declines from mass starvation do little to assuage the severity of a food shortage. This leads us back to the argument in Chapter 3 that rampant delay externalities exist and can be ameliorated only through intervention by some third party. Later, in Chapter 6, we will consider the appropriate role of airports in this regard.

5. Cost Economies of Aircraft Size

In this chapter, we analyze the relation between aircraft size and airline cost. An airline's choice of aircraft interacts with other strategy decisions, and depends on aircraft technology, capital and operating cost, passenger demand, flight distance, airport capacity, competition with other carriers, and other factors. Among these, cost considerations are particularly important. If unit costs decline with aircraft size, airlines will have an incentive to accommodate traffic growth by increasing aircraft size. If unit costs are constant or increase with aircraft size, then increasing frequency will generally be the preferred mode of growth accommodation. Thus, knowledge of the relation between size and cost is critical to forecasting fleet mix.

We first review previous literature on this subject. Next, we analyze the relation between aircraft capital cost and aircraft size. We then turn to aircraft operating cost, considering, in turn, the relation between direct operating, indirect operating, and passenger service cost and the size of aircraft being operated.

Previous Literature

The study on cost economics of aircraft size extends back to the 1970s. Miller and Sawyers (1970) compared both the aircraft capital cost and operation cost for commercial aircraft up to that time, and found that new types of aircraft with larger seat capacity were more cost-efficient (on seat-mile basis) than the older, smaller, planes they replaced. Keeler (1972) compared the total cost for three types of aircraft, and found that the cost per seat-minute for the 251-seat DC8-61 is one-third less than that for Boeing 727-200 (158 seats) and DC9-30 (110 seats). Douglas and Miller (1974) estimated the total airline cost for six types of aircraft, and found that the cost per seat per mile for the Boeing 747 is less than most smaller aircraft, but is almost same as that for DC8-63 and Boeing 727-200, which are only half as large as the Boeing 747. Bailey (1985) provided aircraft operating cost estimates for six types of aircraft—all commercial jets--over different stage lengths, and concluded that for each aircraft type the cost per seat-mile decreases with stage length. She also found that the least-cost aircraft type depends on stage length—on shorter segments smaller aircraft have lower costs; as market distance increases, so does the size of the least-cost aircraft. Meyer and Oster (1984) did similar research and found that the total costs per seat-mile generally decrease with flight distance, but are not clearly related to aircraft size. For example, costs per seat-mile are the same for DC9-30 and DC9-80 over the whole range of flight lengths, while the DC9-80 is a larger, newer, and more fuel-efficient aircraft. One of their explanations for this was that the "technical" operating economies for larger aircraft are largely captured by aircraft manufactures in higher purchasing prices and by pilots in higher salaries.

Besides these comparative studies on the cost economics for specific aircraft types, Keeler (1972), Douglas and Miller (1974), and Morrison and Winston (1986) used econometric models to build aircraft cost functions and explore how average aircraft size influences airlines' total cost. In addition to being quite old, these models do not consider the influences of input factors and flight distance. Since then, there has been very little work on cost economics of aircraft size. Recent work in airline cost analysis, such as Peteraf and Reed (1998), Reed (1999), and Pitt and Norsworthy (1999), focused on the roles of input factor prices and network characteristics in airlines' costs, and did not take aircraft size into consideration.

Given the paucity of recent work on the relation between airline cost and aircraft size, it is clearly appropriate to revisit the subject with more recent data and more rigorous econometric methods. To this task we now turn.

Capital Cost

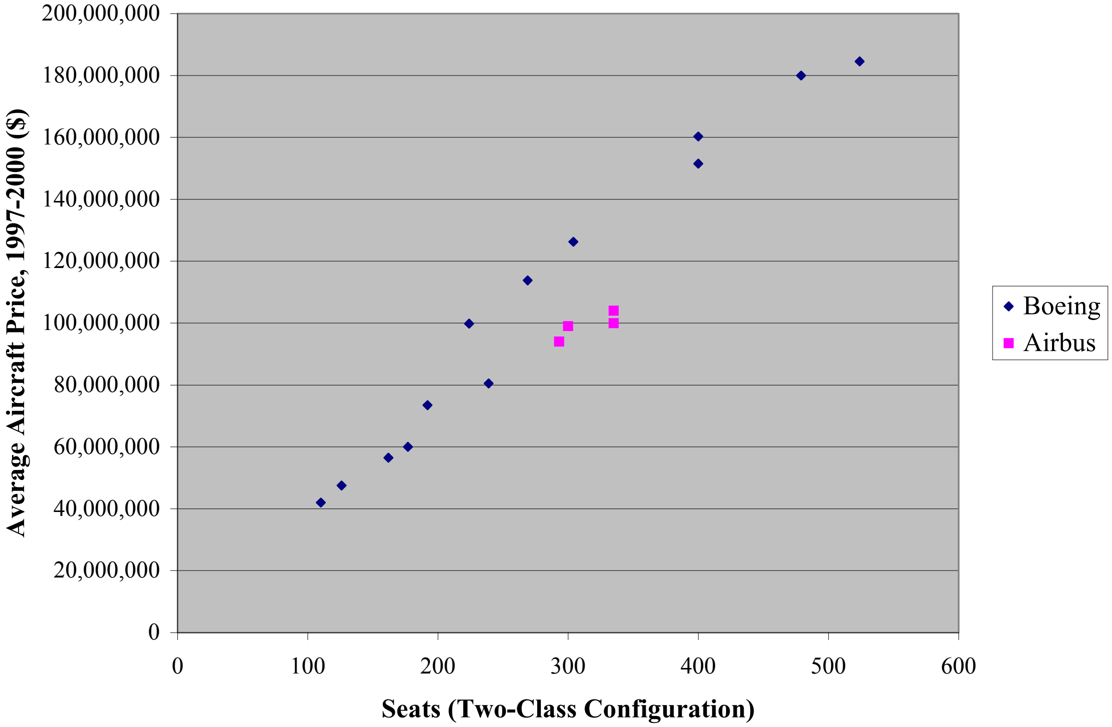
This section considers the relation between aircraft size and capital cost. The dominant form of capital cost that varies with aircraft size is the cost of purchasing aircraft. Commercial aircraft purchases are major transactions and the terms of purchase, including the price, are individually negotiated. Data on these prices is not regularly published. Fortunately, a web site containing average prices for commercial aircraft currently on the market (http://www.pyramid.ch/aircr_prices.htm) was located. The site, maintained by the Pyramid Media Group, gives 1997-2000 "average" prices for 32 models, include four Airbus, 22 Boeing, and 6 Boeing/Douglas. Details on the data sources and averaging methods are not provided.

To obtain information on the attributes of these aircraft, we visited the web sites of Airbus and Boeing. As a size variable, we used the number of seats in typical two-class configuration. As an additional explanator we obtained the aircraft range with full payload. These data were available for 19 of the 32 types with price information. The combined data set is shown in Table 5-1. Purchase price is plotted against size in Figure 5-1. The figure reveals that purchase price is closely correlated with size, that Airbus prices are somewhat less than Boeing prices for similarly sized aircraft, and that there is a jump in prices at around 200 seats, coincident with the transition from narrow-body to wide-body models.

Table 5-1
Aircraft Purchase Price Data

Model	Price *(US$)*	Seating, Two-Class Configuration	Range *(km)*
A330-200	94,000,000	293	11,850
A330-300	100,000,000	335	10,400
A340-200	99,000,000	300	14,800
A340-300	104,000,000	335	13,250
B717-200	35,000,000	106	2,645
B737-600	42,000,000	110	5,649
B737-700	47,500,000	126	6,038
B737-800	56,500,000	162	5,449
B737-900	60,000,000	177	5,084
B747-400	184,500,000	524	13,570
B757-200	73,500,000	192	7,240
B757-300	80,500,000	239	6,426
B767-200ER	99,800,000	224	12,300
B767-300ER	113,800,000	269	11,393
B767-400ER	126,300,000	304	10,440
B777-200	151,500,000	400	9,525
B777-200ER	160,300,000	400	14,260
B777-300	180,000,000	479	11,030

Figure 5-1
Aircraft Purchase Price versus Aircraft Seats, by Manufacturer



Using the data in Table 5-1, we estimated hedonic aircraft price models of the form:

$$\ln(P_i) = \alpha_0 + \alpha_{m(i)} + \sum_j \beta_j \ln(X_{ji}) + \varepsilon \qquad (1)$$

where:

P_i	is the purchase price of aircraft model i;
α_0	is an intercept, to be estimated;
$\alpha_{m(i)}$	is a manufacturer correction factor, set to zero if the manufacturer of aircraft i (*m(i)*) is Boeing, and estimated for Airbus;
X_{ji}	is the value of attribute j for aircraft i;
β_j	is regression coefficient on attribute j, to be estimated;
ε	is a random error term.

Estimation results appear in Table 5-2. All estimates are highly significant statistically. When both size and range are included in the model, the coefficient on seats is 0.83, implying that purchase price increase 0.83 percent for every 1 percent increase in aircraft size. Thus, in this model, there are economies of scale in aircraft size. On the other hand, when range is omitted from the model, the coefficient on seats increases to 1.04, which is not statistically different from 1, implying constant returns to scale. The higher seat coefficient in the second model reflects the fact that larger aircraft also have longer range—the coefficient therefore captures both the scale effect and the range effect.

These results imply that when choosing among aircraft of different sizes but similar ranges, such as those in the B737 family, larger aircraft have a slight advantage in terms of purchase cost per seat. If, however, the size increase is accompanied by a range increase, as it does for planes over 200 seats, then the cost advantage will be fully or partly eliminated. This raises the question of whether manufacturers could produce high capacity, limited-range aircraft whose cost economies are not compromised by range diseconomies, if there were a market for it.

Table 5-2
Estimation Results, Purchase Price Model

Explantory Variable (Associated Coefficient)	Full Model	T-Statistic	Model without Range	T-Statistic
α_0	11.20	46.5	12.61	52.4
α_{airbus}	-0.26	-9.68	-0.19	-3.86
Aircraft Seats(β_{seats})	0.83	21.4	1.04	23.7
Aircraft Range(β_{range})	0.29	6.77	--	--
R^2	0.994		0.987	

Note: All estimates significant at the 1 percent level.

Operating Cost

In this section, we develop cost functions to study the relation between aircraft operating cost and aircraft size, also controlling for other factors, such as flight distance, factor prices, and airline. In addition, we will use the models to investigate how aircraft size interacts with flight distance and factor prices in determining airline operating cost.

We use the same data source, the US Department of Transportation Form 41 (Data Base Products, 1995), used in many previous studies. In Form 41, airline costs are classified into the ten functional groups, as shown in Table 5-3. For purposes of this research, we classify costs into three components: direct aircraft cost, indirect aircraft cost, and passenger service cost. The correspondence between these components and the Form 41 classification is shown in Table 5-3. Direct aircraft cost corresponds exactly to "aircraft operating expense" in Form 41, which includes pilots' and other flight personnel's salary and benefits, aircraft oils, fuels, aircraft rental cost, flight equipment maintenance, flight equipment depreciation, expense of interchange aircraft, and depreciation and amortization related directly to flying. These expense items are given by airline and aircraft type for each quarter. Indirect aircraft cost items include line service expense, control expense, landing fees, ground property maintenance and its depreciation. Data on these expenses are available by airline and quarter, but not by aircraft type. Passenger service costs include all items listed in Form 41's "Passenger Service Expense" functional group: flight attendant expense, food expense, and other in-flight expense. Also included in this category is expense in several other functional groups classified by Form 41 as "directly assignable to passengers." The functional groups "Traffic Servicing Expense", "Reservation and Sales Expense", and "Advertising and Publicity Expense" all include subcategories of this type.

By definition, operating cost does not include the cost of capital that is incurred when an airline owns its own planes or other fixed assets. On the other hand, when an airline leases planes, its rental payments are counted as operating cost. Since the lease rate is set to enable to lessor a fair return on investment, capital cost is accounted for in this case. In the U.S. airline industry, over half the fleet is leased, so our cost models capture a sizable fraction, but not all, of aircraft capital costs.

Table 5-3
Aircraft Cost Categories and Corresponding Functional Groups in Form 41

Form 41 Functional Grouping (Subgrouping)	Direct Aircraft Cost	Indirect Aircraft Cost	Passenger Service Cost
Aircraft Operating Expense	X		
Passenger Service Expense			X
Aircraft Servicing Expense		X	
Traffic Service Expense (Directly Assignable to Passenger)			X
Reservation and Sales Expense (Directly Assignable to Passenger)			X
Advertising and Publicity Expense (Directly Assignable to Passenger)			X
General and Administrative Expense			
Maintenance and Depreciation-Ground Property and Equipment		X	
Depreciation Expense, Maintenance Equipment		X	
Amortization (Other than Flight Equipment)			
Transport Related Expenses			

Because our data set includes a twelve-year period, we converted all dollar quantities into constant dollars by using the airline cost index published by the Air Transport Association.

Direct Aircraft Cost Model

The general direct aircraft cost function is specified as follows, in which each data point is for a specific type aircraft k in a specific airline i during a specific quarter t.

$$DC_{ikt} = f(Seat_{ikt}, ASL_{ikt}, PFuel_{ikt}, PPilot_{ikt}, A_i) \qquad (2)$$

where:

DC_{ikt}	is the average direct operation cost per flight for airline i, aircraft type k, and time t;
$Seat_{ikt}$	is the average seat capacity (available seat-miles per plane-mile) for airline *i,* aircraft type k, and time t;
ASL_{ikt}	is the average stage length (plane-miles per departure) of a flight for airline *i*, aircraft type k, and time t;

$PFuel_{ikt}$	is the unit fuel price per gallon for airline *i*, aircraft type k, and time t;
$PPilot_{ikt}$	is the unit pilot cost per block hour for airline *i*, aircraft type k, and time t;
A_i	is an airline-specific factor capturing characteristics of its individual production technology and efficiency.

Besides $Seat_{ikt}$, which captures the influence of aircraft size in airlines' cost, ASL_{ikt} is used as an independent variable since stage length is also likely to influence direct operation cost. The unit fuel price, $PFuel_{ikt}$, and the unit pilot cost, $PPilot_{ikt}$, are included to capture the effect of input factors prices for oil, fuel and labor directly required for aircraft operation.

The first statistical model we estimated is the Cobb-Douglas model:

$$DC_{ikt} = A_i \cdot Seat_{ikt}{}^{\alpha} \cdot ASL_{ikt}{}^{\beta} \cdot PFuel_{ikt}{}^{\gamma} \cdot PPilot_{ikt}{}^{\lambda} \qquad (3)$$

where the coefficients A_i, α, β, γ, and λ are coefficients to be estimated. This model is linear in logarithms, and thus can be estimated by applying ordinary least squares to its log transformation.

The data for both the dependent and independent variables in the econometric models are obtained either directly or using simple calculation from the Database Products CD-Rom database product, Form 41 (Data Base Products, 1995). The data are available from the 1st quarter of 1987 until the 4th quarter of 1998. We focus on "large" American airlines for which more complete cost data are available. This includes the 10 "Group III" passenger airlines, defined by Form 41 as those with annual operating revenues over $1 billion. The 10 airlines include American Airline (AA), Alaska Airline (AS), Continental Airline (CO), Delta Airline (DL), American West Airline (HP), Northwest Airline (NW), Trans World Airlines (TW), USAir (US), and Southwest Airline (WN). These airlines report their cost and operation data in Form 41 separately for domestic markets and international markets. In this research, we used the domestic data, which includes a wider assortment of aircraft types. With regard to aircraft type, we considered only "stage 3" types of aircraft, which meet the FAA's present requirements for aircraft noise level and will dominate the fleet for at least the next decade. The particular aircraft types considered in our study are listed in Table 5-4.

After we compiled all the data, we conducted a careful cleaning process, with the help and support from Data Base Products, Inc, to exclude the data which are obviously either

Table 5-4

Aircraft Considered in Analysis

Aircraft Type	Average Seats
B-737-300	131
MD-80 & DC-9-80	141
B-737-400	143
B-737-500	164
B-757-200	186
B-767-200/ER	192
DC-8-71	223
B-767-300/ER	228
B-777	290
B-747-200/300	388
B-747-400	420

mistakenly reported by airlines or wrongly input to the database by the product company. The cleaned data set included 1608 quarterly observations from the 10 airlines over 12 years.

Estimation results for the Cobb-Douglas model appear in Table 5-5. The coefficient for aircraft size is 0.77, which implies that, all else equal, a 1 percent increase in aircraft results in a 0.77 percent increase in direct operating cost. This implies economies of scale with respect to aircraft size: as size increases cost per seat decreases, all else equal. We also find economies of distance with respect to stage length: the longer the aircraft fly, the lower the average cost per mile will be.

The Cobb-Douglas model is highly restrictive because it assumes that the elasticity of cost with respect to any particular variable is constant. In order to relax this assumption, we estimated a translog cost function. The general form of this model is:

$$\begin{aligned}[LN(DC_{ikt}) - \overline{LN(DC)}] &= A_i + \sum_{j=1}^{N} \beta_j [LN(X_{ikt}^{j}) - \overline{LN(X^j)}] \\ &+ \sum_{j=1}^{N}\sum_{\ell=1}^{N} \lambda_{j\ell} [LN(X_{ikt}^{j}) - \overline{LN(X^j)}][LN(X_{ikt}^{\ell}) - \overline{LN(X^\ell)}]\end{aligned} \qquad (4)$$

where:

DC_{ikt} is the average direct operation cost per flight for airline i, by aircraft type k at time t;

$\overline{LN(DC)}$ is the sample mean of the log of the direct operating cost;

N is the total number of independent variables in the model;

X_{ikt}^{j} is value of independent variable j for airline i, aircraft type k, and time t;

$\overline{LN(X^{j})}$ is the sample mean of the log of the independent variable j;

$A_i, \beta_j, \lambda_{j\ell}$ are coefficients to be estimated.

Table 5-5

Estimation Results for Aircraft Direct Operating Cost Model

Cobb-Douglas Form

Explanatory Variable (Associated Coefficient)	Estimated Coefficient	T-Statistic
Seat (α)	0.770	23.74
ASL (β)	0.826	34.11
Pfuel (γ)	0.312	7.27
Ppilot (λ)	0.491	22.70
AA Dummy (A_{AA})	-3.706	-22.23
AS Dummy (A_{AS})	-3.711	-23.20
CO Dummy (A_{co})	-3.552	-21.55
DL Dummy (A_{DL})	-3.778	-23.02
HP Dummy (A_{HP})	-3.647	-22.90
NW Dummy (A_{NW})	-3.657	-21.46
TW Dummy (A_{TW})	-3.396	-20.64
UA Dummy (A_{UA})	-3.608	-20.89
US Dummy (A_{US})	-3.730	-22.92
WN Dummy (A_{WN})	-3.849	-25.37

Since all the dependent and independent variables in the model are in deviation form, this model is sometimes called a de-mean translog model. This model can be regarded as a second-order Taylor approximation of a general function about the mean values of the data. Thus, it is far less restrictive than the Cobb-Douglas model.

In estimating this model, we used the same data and the same independent variables as we used for the Cobb-Douglas model. The statistical results are shown in Table 5-6. The T-statistics for all estimated coefficients are significant except the one on the interaction between fuel price and pilot unit cost. Since the hypothesis that this coefficient is zero could not be rejected statistically, the model was re-estimated with this coefficient set to zero. The statistical results are also shown in Table 5-6; we find that the coefficient estimates for the modified model are quite similar to those for the original one.

Due to the interaction terms in the above translog cost models, the elasticity of direct cost with respect to any independent variable depends on the values of all explanatory variables. At the mean values of the data, however, the elasticities are simply the values of the first order coefficients (the $\beta_j's$). The first order coefficient on aircraft size is 0.811, implying that at the mean values, there are economies of scale with respect to aircraft size, with a 1 percent increase in size resulting in a 0.81 percent increase in cost. The second order coefficient on aircraft size is 0.35, which implies that the elasticity of direct operating cost with respect to aircraft size increases with size. On the other hand, the second order coefficient on the interaction between size and stage length is –0.18. This means that as the stage length increases the cost elasticity with respect to aircraft size decreases—i.e. that there are stronger economies of scale at longer distances.

Figure 5-2 depicts the implications of our translog results in terms of representative average cost curves for different stage lengths. Notice that the curves are U-shaped, with the point of minimum cost shifting toward the right as stage length increases—from about 200 seats for a 400 mile stage length to over 300 seats for a 2400 mile route. Strong scale economies with respect to stage length are also evident, with costs for a 600 mile stage 25 percent less than those for a 400 mile stage. Cost is far less sensitive to stage length at longer distances, as evidenced by the near overlap of the cost curves for stages over 1200 mile. Figure 5-3 contrasts the translog with the Cobb-Douglas cost curves, which are, by assumption, parallel to one another and monotonically decreasing in aircraft size.

Table 5-6

Estimation Results for Aircraft Direct Operating Cost Model

Translog Form, Full and Preferred Specifications

	Full Model		Preferred Model	
Explanatory Variable	Estimated Coefficient	T-Statistic	Estimated Coefficient	T-Statistic
Seat	0.811	24.34	0.813	24.51
ASL	0.749	34.45	0.748	34.52
Pfuel	0.240	7.21	0.238	7.18
Ppilot	0.423	18.00	0.424	18.06
Seat*seat	0.348	15.10	0.346	15.16
ASL*ASL	0.320	10.55	0.320	10.57
Pfuel*Pfuel	0.122	1.93	0.123	1.96
Ppilot*Ppilot	0.137	13.83	0.137	13.88
Seat*ASL	-0.184	-3.16	-0.184	-3.16
Seat*Pfuel	-0.632	-5.33	-0.665	-6.14
Seat*Ppilot	-0.158	-3.29	-0.160	-3.23
ASL*Pfuel	0.491	5.96	0.504	6.27
ASL*Ppilot	0.073	1.92	0.078	2.10
Pfuel*Ppilot	-0.050	-0.68	-----	-----
AA Dummy	-0.101	-5.50	-0.100	-5.48
AS Dummy	-0.145	-5.14	-0.145	-5.12
CO Dummy	-0.056	-2.44	-0.054	-2.37
DL Dummy	-0.200	-12.90	-0.200	-12.92
HP Dummy	-0.179	-6.28	-0.177	-6.25
NW Dummy	-0.120	-5.44	-0.120	-5.43
TW Dummy	0.131	5.52	0.132	5.55
UA Dummy	-0.121	-6.65	-0.121	-6.65
US Dummy	-0.154	-8.17	-0.154	-8.19
WN Dummy	-0.544	-13.24	-0.545	-13.28

Note: All variables measure deviations of their logarithms from their sample mean logarithms. For example, "Seat" represents $Log(Seat_{ikt}) - \overline{Log(Seat)}$ in equation (3).

Figure 5-2

Direct Aircraft Cost per Seat-Mile versus Aircraft Size, by Stage Length

Translog Model

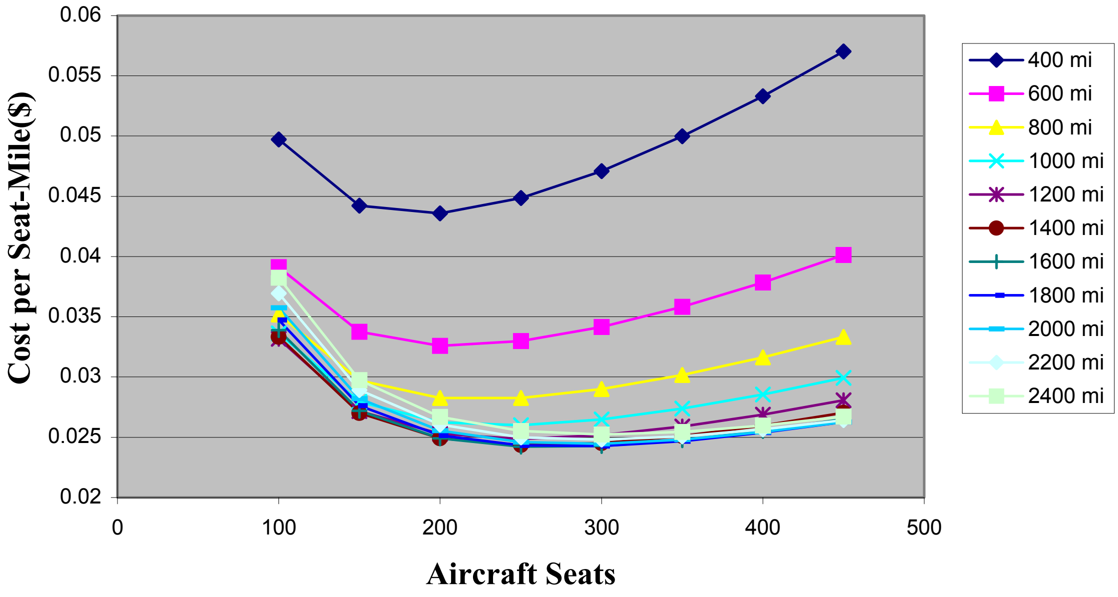
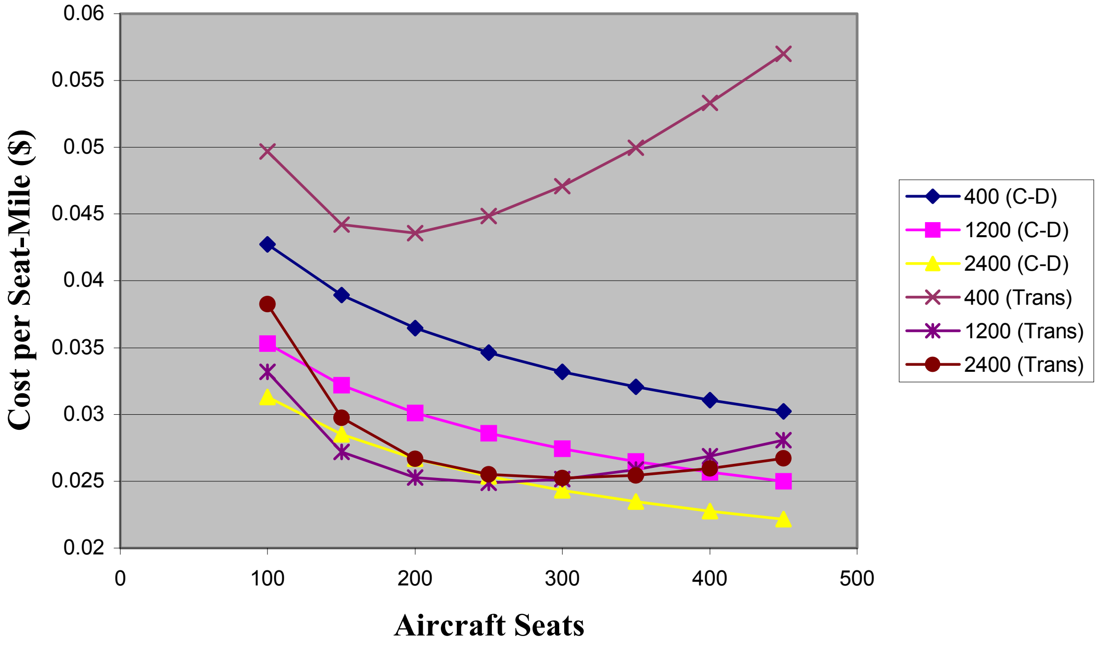


Figure 5-3

Direct Aircraft Cost per Seat-Mile versus Aircraft Size, by Stage Length

Translog and Cobb-Douglas Models



It has been suggested in previous studies of cost economics for aircraft size, such as Meyer and Oster (1984), that pilots flying larger aircraft may be paid more than those flying smaller aircraft, and thus the "technical" economy of scale with respect to aircraft size is offset by the "diseconomies" of pilot cost. To explore whether and how this possible endogeneity of pilot cost may affect aircraft cost economies, we excluded the pilot factor price variable from both the Cobb-Douglas and the translog models, and re-estimated the cost functions. The results are shown in Table 5-7 and Table 5-8 respectively. Instead of economy of scale, slight diseconomy of scale with respect to aircraft size is found in the Cobb-Douglas model, and considerable diseconomy of scale (at the mean values) is found in the translog model. The effect of endogenizing pilot cost is particularly strong on short-haul routes, as shown in Figure 5-4, which compares unit operating costs for the models with endogenous and exogeneous pilot costs. These results suggest that pilot wage structures may discourage airlines from using larger aircraft.

Table 5-7
Estimation Results for Aircraft Direct Operating Cost Model
Cobb-Douglas Form, Taking Pilot Cost Endogenous

Explanatory Variable	Estimated Coefficient	T-Statistic
Seat (α)	1.028	29.43
ASL (β)	0.767	27.72
Pfuel (γ)	0.228	4.63
AA Dummy (A_{AA})	-1.884	-11.22
AS Dummy (A_{AS})	-1.936	-12.06
CO Dummy (A_{co})	-1.880	-11.09
DL Dummy (A_{DL})	-1.916	-11.72
HP Dummy (A_{HP})	-2.142	-12.87
NW Dummy (A_{NW})	-1.673	-9.94
TW Dummy (A_{TW})	-1.792	-10.49
UA Dummy (A_{UA})	-1.707	-9.83
US Dummy (A_{US})	-1.845	-11.46
WN Dummy (A_{WN})	-2.232	-14.50

Table 5-8

Estimation Results for Aircraft Direct Operating Cost Model

Translog Form, Taking Pilot Cost Endogenous

Explanatory Variable	Estimated Coefficient	T-Statistic
Seat	1.093	38.81
ASL	0.727	32.71
Pfuel	0.137	3.40
Seat*Seat	0.563	25.14
ASL*ASL	0.329	9.34
Pfuel*Pfuel	0.250	3.25
Seat*ASL	-0.470	-8.28
Seat*Pfuel	-0.851	-6.43
ASL*Pfuel	0.583	5.91
AA Dummy	-0.072	-3.27
AS Dummy	-0.118	-3.42
CO Dummy	-0.132	-5.40
DL Dummy	-0.129	-6.96
HP Dummy	-0.347	-12.20
NW Dummy	0.039	1.53
TW Dummy	0.009	0.34
UA Dummy	-0.036	-1.71
US Dummy	-0.047	-2.10
WN Dummy	-0.570	-12.30

Indirect Aircraft Cost and Passenger Service Cost Models

As noted above, aircraft-specific data for indirect aircraft cost and passenger service cost are not available. Therefore, we must investigate aircraft scale economies through models that are specified at the airline level.

Indirect Aircraft Cost

The indirect aircraft cost function is specified as follows:

$$IC_{it} = f(ASL_{it}, Dep_{it}, Seats_{it}, PHand_{it}, A_i) \qquad (5)$$

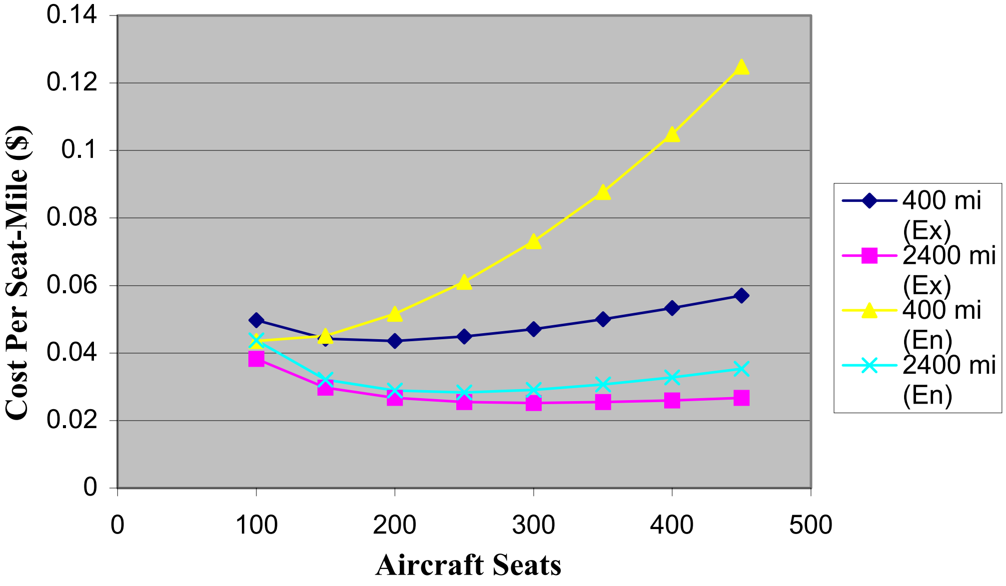
where:

IC_{it}	is the average indirect operation cost per flight for airline i at time t;
ASL_{it}	is the average stage length (plane-miles per departure) of a flight for airline i at time t;
Dep_{it}	is the total number of departures in airline i at time t;
$Seats_{it}$	is the total number of seats available (available seats-miles per plane-mile) in airline i at time t;
$PHand_{it}$	is the handling labor cost per handling employee in airline i at time t.
A_i	is an airline-specific factor capturing characteristics of its individual production technology and efficiency

Figure 5-4

Comparison of Direct Aircraft Cost per Seat-Mile, by Stage Length

Translog Models with Exogenous (Ex) and Endogenous (En) Pilot Cost



$Seats_{it}$, the total number of available seats is used as independent variables to capture the influence of aircraft size on indirect operation cost. ASL_{it}, the average stage length, is used for the same purpose as in the direct operation cost. Dep_{it}, the total number of departures, is used to see whether there is economy of scale in indirect operation cost with respect to the number of operations. $PHand_{it}$, the unit handling labor cost, captures the input factor price for the labor that is most centrally involved in aircraft handling and servicing processes. A_i, the dummy variable for airline i is used to capture airline fixed effects.

In Form 41, indirect aircraft cost and passenger cost data are available from the 3rd quarter of 1987 until 4th quarter of 1998. After a data cleaning process similar to that for the direct aircraft cost data, we had a data set consisting of 433 airline, quarterly, observations. We estimated a Cobb-Douglas (or log-linear) model on this data set. The estimation results are shown in Table 5-9. All the coefficient estimations are statistically significant. The estimated coefficient for *Seats* is 0.684, indicating economies of scale in indirect aircraft cost with respect to aircraft size. The negative sign of *Dep*, airlines' total departures in a quarter, indicates that indirect aircraft cost decreases with the its number of operations. We also find economies with respect to average stage length in indirect operation cost.

Table 5-9

Estimation Results for Aircraft Indirect Operating Cost Model

Explanatory Variable	Estimated Coefficient	T-Statistic
ASL	0.758	11.67
Dep	-0.604	-3.19
Seats	0.684	3.81
PHand	0.215	5.20
AA Dummy	-5.258	-4.08
AS Dummy	-4.636	-4.64
CO Dummy	-4.943	-4.83
DL Dummy	-4.622	-4.41
HP Dummy	-4.964	-4.95
NW Dummy	-4.621	-4.52
TW Dummy	-4.639	-4.54
UA Dummy	-4.486	-4.29
US Dummy	-4.533	-4.49
WN Dummy	-5.041	-5.01

Passenger Service Cost

The general passenger service cost function is specified as follows:

$$PC_{it} = f(ASL_{it}, Pass_{it}, ASM_{it}, PHand_{it}, A_i) \qquad (6)$$

where:

PC_{it}	is the average passenger service cost per revenue passenger mile for airline i at time t;
ASL_{it}	is the average stage length of a flight in airline i at time t;
$Pass_{it}$	is the average number of passengers per flight in airline i at time t;
ASM_{it}	is the average available seat miles per flight in airline i at time t;
$PHand_{it}$	is the unit handling labor cost per handling personnel in airline i at time t;
A_i	is an airline-specific factor capturing characteristics of its individual production technology and efficiency.

In this model, the dependent variable PC_{it} is normalized on a per passenger mile basis. The scale variable ($Pass_{it}$) is based on average passenger load rather than average aircraft size because the costs being considered are related to passengers rather than aircraft. Stage length and aircraft size effects are by ASL_{it} and ASM_{it}, respectively. $PHand_{it}$ is included to control for inter-airline differences in labor cost.

OLS estimation results on our 433-observation data set, again based on a Cobb-Douglas model specification, appear in Table 5-10. We find that the coefficients for both *ASL* and *Pass* are negative, and the coefficient for *ASM* is positive. This implies that the average passenger service cost per revenue passenger mile will decrease with average stage length and the number of passengers served per flight, and increase with the size of aircraft. If we assume that the airlines can keep the same load factor for different sizes of aircraft, then the average passenger service cost per passenger mile decreases with the size of aircraft, since the positive coefficient on “available seat-miles”, 0.314, will be offset by the larger negative coefficient on “number of passengers per flight”, -0.404. This scale economy is fairly weak, however.

Table 5-10

Estimation Results for Passenger Service Cost Model

Explanatory Variable	Estimated Coefficient	T-Statistic
ASL	-0.710	-5.38
Pass	-0.404	-14.80
ASM	0.314	2.40
PHand	0.076	2.22
AA Dummy	8.638	10.40
AS Dummy	7.819	9.76
CO Dummy	8.138	9.56
DL Dummy	8.539	10.30
HP Dummy	7.436	9.26
NW Dummy	8.162	9.99
TW Dummy	8.060	9.76
UA Dummy	8.465	10.10
US Dummy	8.535	10.75
WN Dummy	7.400	9.44

Conclusions

The purpose of this research was to study the cost economics of aircraft size and explore how the sizes of aircraft used by airlines influence their capital and operation cost. Regarding the former, we find some evidence of economies of scale with regard to aircraft purchase price. However, the bundling of long range with high capacity capabilities limits the purchase price savings that can be attained from purchasing large planes to serve short or medium haul routes.

For direct aircraft operation cost, we find economies of scale with respect to both aircraft size and stage length based on a simple Cobb-Douglas model. A translog model confirms that such economies exist at the sample mean of our data set, but vary in a systematic way with both aircraft size and stage length. Specifically, scale economies attenuate as aircraft size increases, but become stronger at longer stage lengths. The aircraft size that minimizes direct operating cost per seat increases from around 200 seats at 400 miles, to 250 seats at 1200, to over 300 seats at 2400 miles. These results change considerably if we treat pilot unit cost as endogenous and thus exclude it from the model specification. Scale economies at the sample mean are then found to be essentially non-existent. This suggests that pilots may “capture” aircraft scale economies through pay scales that depend on the size of aircraft flown, and thus diminish the incentive of airlines to upsize their fleets.

For indirect aircraft cost, we find economies of scale with respect to aircraft size, and also with respect to flight distance and traffic density in terms of number of departures. For passenger service cost, we also find that, controlling for load factor, passenger service cost per revenue passenger mile decreases slightly with the size of aircraft, and also decreases with flight distance and number of passengers per flight.

Based on these results, we can predict how aircraft size influences airline’s cost for any specific airline in any specific market. Then, we can identify the most cost efficient aircraft for this airline in that market, and predict that the airline will choose this aircraft in their operations, if we assume that the demand and revenue in the market is fixed for this airline. But in reality, the airline’s market share, demand and revenue depend on its own aircraft size and operation frequency as well as those of other competitors in the market. There is a need for further research on these relationships, and their implications for the aircraft sizes that profit-maximizing airlines will choose in a competitive market.

6. Policy Interventions

Previous chapters have analyzed trends in fleet mix at LAX and identified key structural factors that influence average aircraft size. These chapters have also touched on—and criticized—the viewpoint of accommodation that characterizes most airport planning, particularly in the United States. Accommodative airport planning treats future demands on airport much as earthquake engineers treat seismic forces on a structure—as "givens" which the system must be engineered to handle. But whereas earthquakes are indeed beyond human control, there are realistic opportunities for intervention to influence the future fleet mix, and hence demand, at an airport. In this chapter, we explore these possibilities from the standpoint of their legality, effectiveness, and obstacles to implementation.

Historical Perspectives

In the early days of aviation, most airports were privately owned, and their owners exercised virtually unlimited authority over their operations (Hardaway, 1991, p. 33). As airports moved from private to public sector enterprises, and as federal jurisdiction over navigable airspace surrounding the airport was established, the authority of airport operators became more circumscribed. A landmark court case in this regard came in 1973, in City of Burbank vs Lockheed Air Terminal. There, the U.S. Supreme Court overturned a city ordinance banning nighttime jet takeoffs from Burbank Airport, on the grounds that the ban had a direct effect on congestion in federally controlled airspace, and that the FAA had "full control over aircraft noise, pre-empting state and local control (Hardaway, 1991, pp. 35-36).

The City of Burbank ruling contained an important caveat whose precise interpretation has been widely discussed ever since. The Supreme Court drew a distinction between the exercise of police authority (as Burbank had done in passing an ordinance) from the authority of a municipality acting as an airport landlord, stating "we do not consider here what limits, if any, apply to a municipality as a proprietor." This distinction came to be known as the "proprietor's exemption."

The origins of the proprietor's exemption may be found in an earlier Supreme Court case concerning airport noise. In the 1961 Griggs decision, the Court ruled that the local authority for building an airport is also responsible for the "taking" of property made uninhabitable by noise from aircraft using the airport. The responsibility derives from the fact that local authorities control the decisions of whether and where to build an airport, and are responsible for the acquisition of land needed to build the facility. The Court ruled that the local authorities had, in the Griggs case, failed to acquire enough property, and that they were liable for this oversight. But, as the inherently local functions of site selection and property acquisition made airports liable for noise impacts, that liability, in turn, entitled airports to prerogatives (other than the usually unrealistic ones of relocating the airport or purchasing all impacted land) in controlling those impacts (Pennington, 1991). Conversely, the federal government was cautious in challenging those prerogatives, for fear of shifting liability to the federal level.

In addition to noise regulation, airport proprietary powers have long been recognized in the area of user charges. As with noise, the underlying logic is to align authority with responsibility. Since airports must cover the bulk of their own expenses, they require the authority to assess fees and charge rents in order to generate the necessary revenue. This is acknowledged in the Airport and Airway Improvement Act, which requires that "rates, rentals, and other charges must be directly and substantially related to providing air transportation" in order to an airport to qualify for federal aid.

Airport congestion has also been recognized as an area in which the proprietor's exemption applies. One of the strongest court decisions supporting the prerogative of airport operators to regulate congestion came in an airline challenge to a prohibition, imposed by the Port Authority of New York and New Jersey, on non-stop flights over a certain distance from operating out of La Guardia. In upholding this restriction, an appeals court stated that "regulating ground congestion at its airports would appear to be at the core of the proprietor's function as airport manager, perhaps more so that the regulation of noise; and the ability of a proprietor…to allocate air traffic…is important to the advancement of that interest (Pennington, 1991, p. 818)." The court based this judgment in part on the fact that the Port Authority operated other airports where long-haul flights were allowed (Hardaway, 1991, p. 43). In a similar vein, U.S. courts have allowed a $25 peak period landing fee surcharge for small (under 25 seat) aircraft, and the temporary denial of an airline's request to initiate service out of a congested airport (Pennington, 1991, p. 830).

Whether applied to noise, fees, or congestion, an airport's proprietary powers are circumscribed by federal law. In broad terms, rules, restrictions, and user charges must be reasonable and non-discriminatory. The former is particularly important in the context of user charges, where courts have held that reasonable charges should, in aggregate, generate revenues sufficient to cover costs and that charges to individual users should approximate the airport costs attributable to them. More generally, to be non-discriminatory an airport proprietor's action must not systematically favor certain classes of users over others—for example general aviation users over commercial ones, or intrastate flights over interstate flights.

Given the broadness of these principles, it is not surprising that their application in various court proceedings has been uneven and inconsistent. The litigation experience with Boston Logan's PACE program provides a telling and salient example. The Program for Airport Capacity and Efficiency was instituted by Massport in 1989, in response to severe congestion at Logan, which was attributed by airport management to large numbers of small aircraft operations. The reduce these, PACE included a landing fee that differed dramatically from the standard, weight-based, one. Under the PACE structure, the landing fee included a fixed component of $91.78 plus an additional $0.54 per thousand pounds of aircraft weight. The new structure reflected the fact that the time required to land a small or a large aircraft is approximately the same, so that the marginal delay cost of an operation is essentially independent of aircraft size. The new structure greatly increased the charge for small aircraft—from $25 to $101 in a typical case—while cutting the charge for a typical large aircraft nearly 50 percent (Hughs, 1988).

Litigation ensued. Several industry groups, including the Regional Aircraft Association and the Aircraft Owners and Pilots Association, filed complaints with the FAA, while the New England Legal Foundation, on behalf of itself, several commuter airlines, and various other parties, sued Massport in Federal court. An FAA administrative law judge found that the PACE fee structure was "unjustly discriminatory", nor "fair and reasonable", and pre-empted by Federal authority to regulate navigable airspace. These conclusions were based on findings that the PACE fee schedule differed markedly from the standard weight-based approach and furthermore that the fee formula was "not scientifically derived" in its division of costs into weight-varying and operations-varying components. Rather, the FAA judge concluded, the fees were developed with the intent of "ridding Logan of small aircraft." Once formulated, the "plan went in search of an economic theory to justify its existence." The Secretary of Transportation, agreeing with the judge’s recommendation, ordered that the PACE fee structure be dropped, threatening otherwise to withhold the airport’s Airport Improvement Program funds.

Although the Federal court reached a different conclusion in the New England Legal Foundation suit, ruling that PACE fees are reasonable in that they reflected the opportunity cost of using the airport, the DOT/FAA position carried the day in Appeals Court, which ruled that the PACE program was “an attempt to modify conduct (e.g., control air traffic) rather than to recover operational costs” and therefore intruded upon federal regulatory responsibility.

The PACE litigation has proven to be an important landmark in how airports and the FAA interpret the proprietors exemption. There have since been no significant efforts by airports to influence the mix of aircraft using their facilities, or to diverge from the standard practice of weight-based landing fees. There may, however, be less to this precedent than is widely believed by airport managers. The PACE program was an unusually radical departure from standard airport practice, and little effort was made to link the plan to recognized methods of cost allocation. Moreover, the political environment was unique, with FAA greatly concerned about a “’patchwork quilt’ of local airport use restrictions which threatens to ‘Balkanize’ the national system and strangle its vitality” in the words of a former high official. With concerns about Balkanization alleviated as the result of the Airport Noise and Capacity Act (see below) it is quite conceivable that an airport, using an appropriately “scientific” cost allocation method, could impose a PACE-like fee structure while avoiding the wrath of federal authorities.

The Airport Noise and Capacity Act

In addition to the precedent set by PACE, the Airport Noise and Capacity Act (ANCA) constrains how airports can use their authority to influence aircraft fleet mix. The ANCA was intended to sharply curtail local authority to regulate noise, thereby eliminating the threat of “Balkanization” mentioned above, by developing a national noise policy. Its key provisions were to require that local restrictions on Stage 3 aircraft be approved either by all aircraft operators at the airport or by the Secretary of Transportation, and that pre-Stage 3 aircraft be prohibited from operating at U.S. airports after December 31, 1999. ANCA also assumed limited federal liability for noise damages when local restrictions were disapproved by the Secretary of Transportation. Conversely, airports imposing restrictions that have not been approved either by all aircraft operators or the Secretary are ineligible for Airport Improvement Act grants or to generate funds through Passenger Facility Charges.

While the primary intent of the ANCA is to establish federal oversight to reduce noise, the Act and its implementing regulations adopt a broad definition of such restrictions, making the ANCA provisions applicable to “restrictions affecting access or noise that *affect* the operations of Stage 2 or Stage 3 aircraft." Specific examples, mentioned in FAA regulations implementing the act, include “a limit, *direct or indirect*, on the number of Stage 2 or Stage 3 aircraft”; “a program of airport-use charges that *has the effect* of controlling airport noise”; and “any other limit on Stage 2 or Stage 3 aircraft that has the effect of controlling airport noise.” Such language, by stressing effect rather than intent, constrains proprietor actions across a wide range of fronts, from user charges to congestion management, in which local authority has previously been recognized. For example, the Omaha Airport Authority was subject to an ANCA complaint to the FAA after it sought to restrict operations by heavy aircraft in order to protect its airfield pavements. In adopting such language, policy makers were probably concerned that operators would try to circumvent the legislation by claiming other grounds for regulations that were really intended to limit noise, but in so doing they also usurped local authority to an alarming degree.

There is, however, one specific and potentially important exception to the broad interpretation of restrictions covered by ANCA. In defining the term “noise or access restrictions” for purposes of this legislation, the FAA stipulates “this definition does not include peak period pricing programs where the objective is to align the number of aircraft operations with airport capacity.” The implication is that it acceptable to use pricing to reduce operations during certain busy periods but not, like the PACE program, to non-standard pricing structures that are in place throughout the day.

ANCA and its implementing regulations, specified in 14 CFR 161, specify the conditions that must be satisfied in order for the Secretary of Transportation to approve a restriction that has not gained the agreement of airport users. These conditions are elaborated below:

First, the restriction must be reasonable, non-arbitrary, and non-discriminatory. For this condition to be satisfied, there must be evidence that “a current or projected noise or access problem exists,” that “other available remedies are infeasible or would be less cost-effective,” and that “the noise or access standards are the same for all aviation classes or that the differences are justified.” The detailed guidance on these points presented in the regulation focuses mainly on noise matters. With regard to the first point, the phrase "access problem" is not further defined, but probably can include excessive levels of congestion and delay. As to cost-effectiveness, it can certainly be argued that restrictions on the operation of small aircraft are a cost-effective remedy for an airport congestion problem. On the third issue, aircraft size regulation might be seen as discriminating against operators of small aircraft, such as commuter airlines, but this "difference in treatment" could be justified in light of the efficiency gains resulting from the use of larger aircraft.

The second requirement of DOT approval of an airport access restriction is that it not create an undue burden on interstate or foreign commerce. The key evidence required to demonstrate that this condition has been met is a cost-benefit analysis demonstrating that "the estimated potential benefits from the restriction have a reasonable chance to exceed the estimated potential cost of the adverse effects on interstate and foreign commerce." As before, the detailed guidance regarding this condition assumes that the primary purpose of the restriction is to control noise. The proposed analysis therefore involves weighing the costs of acquiring quieter aircraft or discontinuing aircraft operations against the cost of reducing noise by other means, such as soundproofing, and against noise reduction benefits such as increased property values or improvements to the quality of life resulting from reduced levels of noise exposure. The regulations do not contemplate the possibility that restrictions could yield a net saving to airport users as the result of reduced delay. Nonetheless, it appears that an analysis demonstrating that reduced delay cost offsets the costs of restricting aircraft operations would satisfy this condition. Below, we present an illustration of such an analysis.

The third requirement for DOT approval of a restriction is that it maintain safe and efficient use of navigable airspace. The regulations provide little elaboration of what evidence is required to demonstrate that this condition has been satisfied. It appears to be directed primarily at situations in which approach or departure procedures are changed in order to reduce noise impact. In the context of fleet mix restrictions, one could argue that reducing the number of small aircraft would increase both safety and efficiency, by reducing the number of cases in which a large or heavy aircraft is trailed by a small one.

Fourth, and finally, DOT requires that the proposed restriction not conflict with any existing Federal statute or regulation. This condition prohibits restrictions that grant exclusive rights to conduct some aeronautical activity at the airport, that intrude upon FAA control of aircraft operations, or that violate existing federal grant agreements. The latter normally include that the airport be made available to all types of aeronautical activity on fair and reasonable terms.

Rationales for Intervention

The starting point for the intervention of airports into airline fleet mix and scheduling decisions is a suitable rationale. The airport must justify its intervention into a heretofore exclusively airline domain. The rationale must be legally credible and politically compelling. It must be able to withstand assaults in the courts of both law and public opinion.

There are several potential rationales for intervention. Here we identify three main possibilities. One is based on the concepts of welfare economics. A second derives from the airport authority's master planning function. A third relates the intervention to the airport authority's role as a promoter of the public interest.

Welfare Economics Approach

Under this rationale, the airport intervention is a logical response to a market failure that causes significant and unnecessary costs to society. Airport congestion is viewed analogously to the "tragedy of the commons" in which sheep overgraze a public pasture due to the lack of a mechanism for efficiently allocating grazing rights. The airport intervenes to prevent similarly excessive use of the runway system and the congestion that results. In so doing, the airport can invoke its proprietary authority established under the City of Burbank case.

The analysis in Chapter 3 provides abundant evidence that a "commons" problem exists. It suggests that the delay reduction benefits from eliminating certain flights would greatly outweigh the loss in schedule convenience. Conceivably, airlines would recognize this and support the initiative. It is more likely, however, that they would respond viscerally and negatively to "re-regulation", as United has at SFO. Such a response is all the more likely if it is perceived that the airport is attempting to regulate aircraft size so that it can shirk its responsibility for providing adequate facilities. The persuasiveness of the welfare economics argument is reduced if airlines, as the primary beneficiaries of intervention, strongly oppose it.

Master Planning Approach

Most airport planning activity revolves around the airport master plan, which attempts to plot a course of future physical development that will meet projected demand. Airport fleet mix intervention can be viewed as a natural extension of master planning activities. While the conventional master plan assures that airfield and terminal facilities are adequate to accommodate projected levels of passenger and cargo traffic, the extended plan would also consider the aircraft themselves—not as an exogenous factor, but as a decision variable. This would permit planners to balance the advantages or expanding infrastructure capacity against those of upsizing the fleet. Airports where expansion is relatively easy would presumably opt for the former, while those with severe obstacles to capacity expansion choose the latter. But in general, the planning alternatives would include options involving both forms of expansion in varying degrees, just as they now include different concepts for terminal and airfield layout.

There are two obvious objections to this concept. Fleet mix changes, unlike infrastructure projects, are not within the direct control of airport authorities. Airports cannot simply make them happen. But there may be less to this difference than meets the eye. Airport plans are increasingly forced to make convenient assumptions about external factors in order to create a scenario in which capacity is balanced with demand. For example, airport planning in southern California is guided—and facilitated—by the premise that high-speed rail will be deployed in the region. Moreover, master planning is a collaborative activity in which airlines and other users are heavily involved. If buy-in from these parties is already necessary, why not present them with options in which they can trade size restrictions against the financial burden of new infrastructure?

Second, unlike the traditional domains of airport master planning and design, fleet mix decisions involve multiple airports. As airlines are quick to point out, every flight must have both an origin and a destination. The resulting interdependencies have much to do with Federal efforts to curtail unilateral actions by airports to regulate the fleet, whether for the purpose of noise abatement or congestion management. But what is proposed here is not unilateral action but collaboration between airports and airlines. The latter will presumably adopt a systemwide viewpoint in considering whether capital cost savings from fleet adjustments are worthwhile.

This proposed integration of fleet mix change into master planning is related a broader policy innovation that many observers consider essential to breaking the planning “bottlenecks” which befuddle so many major airports today. Present federal policy discourages airports from linking development decisions to use restrictions. Often, this prevents airports from reaching agreements with nearby communities who oppose airport investments on the grounds that these will “open the floodgates” to vastly expanded numbers of flights and resulting environmental impacts. Incorporating fleet mix change into airport master planning establishes a link between airport development and management decision making that is natural, rational, and adjuvant.

Public Interest Approach

While the first rationale portrays fleet mix intervention as a remedy to market failure, and the second as an extended form of master planning, a third alternative is to treat fleet mix intervention as an action to protect the public interest. In particular, the airport can justify fleet mix intervention as a means of protecting the interests of air travelers and the local community.

Two main public interests may be advanced in this way. First, air travelers will experience fewer delays and disruptions. The airport manager might therefore justify a fleet mix intervention as a form of consumer protection. It will increase the likelihood that travelers will receive the air service they intended to purchase, rather than an inferior product. This rationale is consistent with the recognized role of airport operators in promoting the quality of the air travel experience, as they do presently by providing high quality terminal facilities and regulating airport concessionaires.

Second, fleet mix interventions can be justified on the grounds of environmental protection. Airport congestion and delay cause sizable increases in aircraft emissions. Emission reductions from fleet mix interventions might be used as mitigations or offsets so that airport projects can meet air quality conformity criteria. The tremendous need for air quality improvement in the Southern California region might make this a particularly compelling justification there.

Noise exposure might, in some cases, also be reduced by fleet upsizing. Since large aircraft are noisier, however, there is no assurance that upsizing will be beneficial in this respect. And there will generally be other measures that are more effective in reducing noise. A noise justification, by itself, is therefore unlikely to be an adequate justification for fleet mix intervention.

Modalities for Intervention

If a compelling rationale for airport intervention into fleet mix decisions can be established, it is then necessary to determine the form that the intervention will take. Broadly, the possibilities fall into three categories: voluntary programs, pricing, and regulation.

Voluntary Programs

The airport can institute a program to encourage airlines to adjust their flight schedules and fleets in order to reduce delay. Several forms or encouragement are possible. The airport can provide information about the impact of existing flights on delay and spotlight scheduling changes that positively or negatively affect congestion. Within the limits of anti-trust law, the airport may facilitate a collaborative decision making process on a monthly or quarterly time scale analogous to what has been instituted by FAA on an hourly scale. The FAA program allows airlines to share information and adjust schedules in advance of ground-hold programs so that impacts of the program can be minimized or, in some cases, the programs can be cancelled.

It may be possible to use monetary incentives in order to launch a voluntary program. Airlines could receive a discount on landing or other usage fees in exchange for an agreed upon scheduling change. Once the positive impact of these adjustments is recognized, the program might continue on its own without the need for such incentives. Such a program might extend naturally to one involving permanent fee reductions based on reduced investment needs. This, however, would require binding commitments from all users rather than voluntary actions on the part of a few, making it a regulatory program rather than a voluntary one.

A major challenge to any voluntary program is the so-called “backfill problem.” If one airline voluntarily cuts flights by upsizing its fleet, what is to prevent another from adding flights to take their place? If the cut flights were profitable to begin with, then another airline could presumably earn a profit by re-instituting them. Indeed, filling a proven but abandoned market niche would seem to be a particularly attractive, low risk, form of business expansion. The backfill issue was emphasized by United in its refusal to voluntarily replace commuter with large jet flights at SFO, causing the airport to opt for a regulatory approach instead.

The backfill problem is a significant weakness of the voluntary approach. Antitrust considerations seem to preclude inter-airlines agreements, whether explicit or implicit, to abstain from backfilling. While certain forms of coercion may be available to the airport, these would take the program outside the voluntary category. There may, however, be cases where the risk of backfill is small. These include segments where much of the traffic is connecting to other flights of the incumbent carrier or its affiliate, and those where the incumbent can establish a credible threat of "fare wars" in the event of new entry. This threat will exist when airlines preserve seat capacity by combining fleet upsizing with frequency curtailment. A new entrant would then be increasing the total seat capacity on the segment from before the scheduling change, with the attendant prospect of lower fares.

Pricing

In this approach, airport user fees, in particular landing fees, are changed in order to encourage airlines to operate larger planes. The PACE program, discussed above, is the most notable example of such an approach. Despite its legal demise, it may be possible to develop a pricing program that would have the desired effect and also withstand court or administrative challenge.

One reason for optimism is that ANCA regulations explicitly exempt peak period pricing from the definition of "access restrictions" to which it onerous requirements apply. This combined with the inherent advantages of pricing as a means of correcting a market failure, suggest peak period pricing as a particularly attractive form of fleet mix intervention. As explained below, such a program need not directly target small aircraft, but would as a matter of course have a disproportionate impact on small aircraft operations.

A prerequisite for peak period pricing is the presence of a peak. Unlike many large airports, LAX does has a well-defined rush period, stretching roughly from 10 am to midday. This contrasts with major connecting hub airports, which have connecting peaks every hour or so. When demand fluctuates on such a short time scale it is difficult if not impossible to institute peak period pricing. On the other hand, the diurnal traffic pattern evident at LAX is an ideal setting for such a program.

The essence of the peak pricing strategy is to charge higher landing fees during periods of high demand. The higher fees reflect the increased delays peak period flights cause for other flights. As shown in Chapter 3, these external delay impacts dwarf the delays incurred by individual flights. Theoretically, the peak surcharge should reflect this gap. Then, if an airline is willing to pay the surcharge, the flight is presumably worth the cost it is imposing on other users of the system. More realistically, the peak surcharge would vary not by flight but by time, rising and falling in a series of graduated steps as the time of day moves toward and then beyond the time of maximum demand.

The structure of the surcharge should mirror the relationship between flight characteristics and incremental delay impacts. This implies that the surcharge should not be weight-based since weight has no direct relation to congestion impact. It might, however, be related to wake vortex class or even to specific aircraft type, because of the relation of these factors to minimum wake vortex separations and minimum inter-arrival times. Thus, the ideal structure would naturally encourage fleet upsizing during peaks because the surcharge per seat would be much larger for small aircraft.

To quantify the surcharge, we used the simulations from Chapter 3 to estimate the surcharges that would reflect external congestion costs based on the sample day schedule. To do this, we monetized the congestion delay impact, in aircraft hours, for each flight using a value of \$1500 per hour. We then averaged the delay impact by time period (using both 1-hour and ½-hour intervals) and aircraft type. The results are shown in Figures 6-1 and 6-2. Figure 6-1 uses 1-hour increments, and presents marginal costs averaged across all aircraft and by wake vortex category. The average surcharge peaks at \$3000 during the 10-11am hour. The category-specific surcharges range from around \$2000 for large aircraft to \$3800 for heavy. With the exception of 9-10 pm hour, when the surcharge goes above \$1000, the surcharges throughout the remainder of the day are well below \$500. Figure 6-2 presents the aircraft average surcharge for ½-hour time periods. There is a dramatic increase between the 9-9:30 and 9:30-10:00 am periods, from about \$700 to over \$3000, but the surcharge falls more gradually, reaching a nominal \$100 by 12:30 pm.

These high peak surcharges reflect high marginal delay costs during peak periods. As airlines adjusted their schedules, the marginal delays and associated surcharges would decrease, probably drastically. A major challenge in implementing peak surcharges is to find a mechanism that avoids dramatic swings in the surcharge in response to airline adjustments. One way to do this would be to publish predicted surcharges based on an anticipated schedule while airlines still have time to make modifications. A gradual phase-in would also give the system a greater opportunity to equilibrate.

Figure 6-1

Surcharges per Landing, Reflecting Marginal Delay Impact, by Hour, LAX Arrivals

Sample Day Schedule

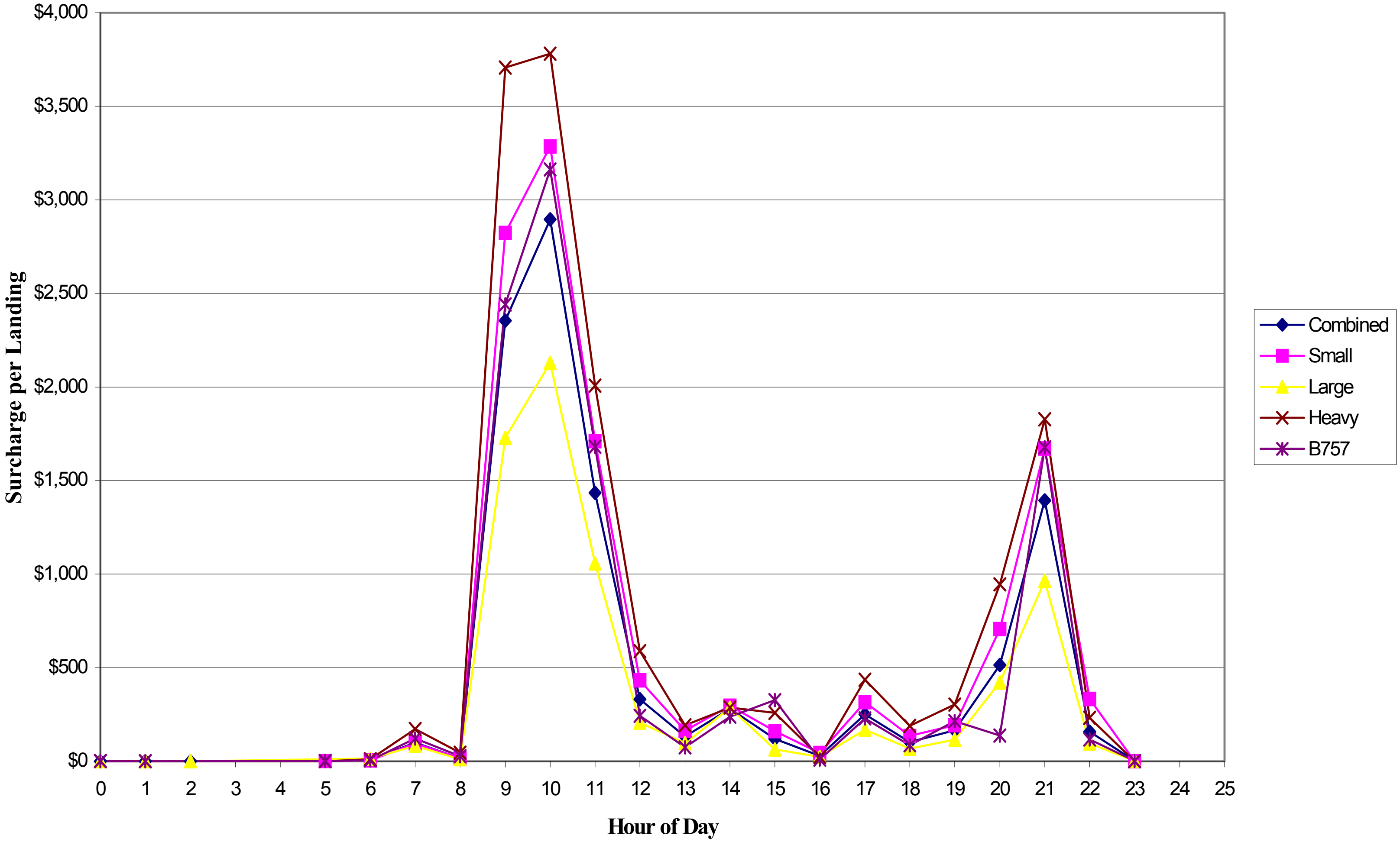
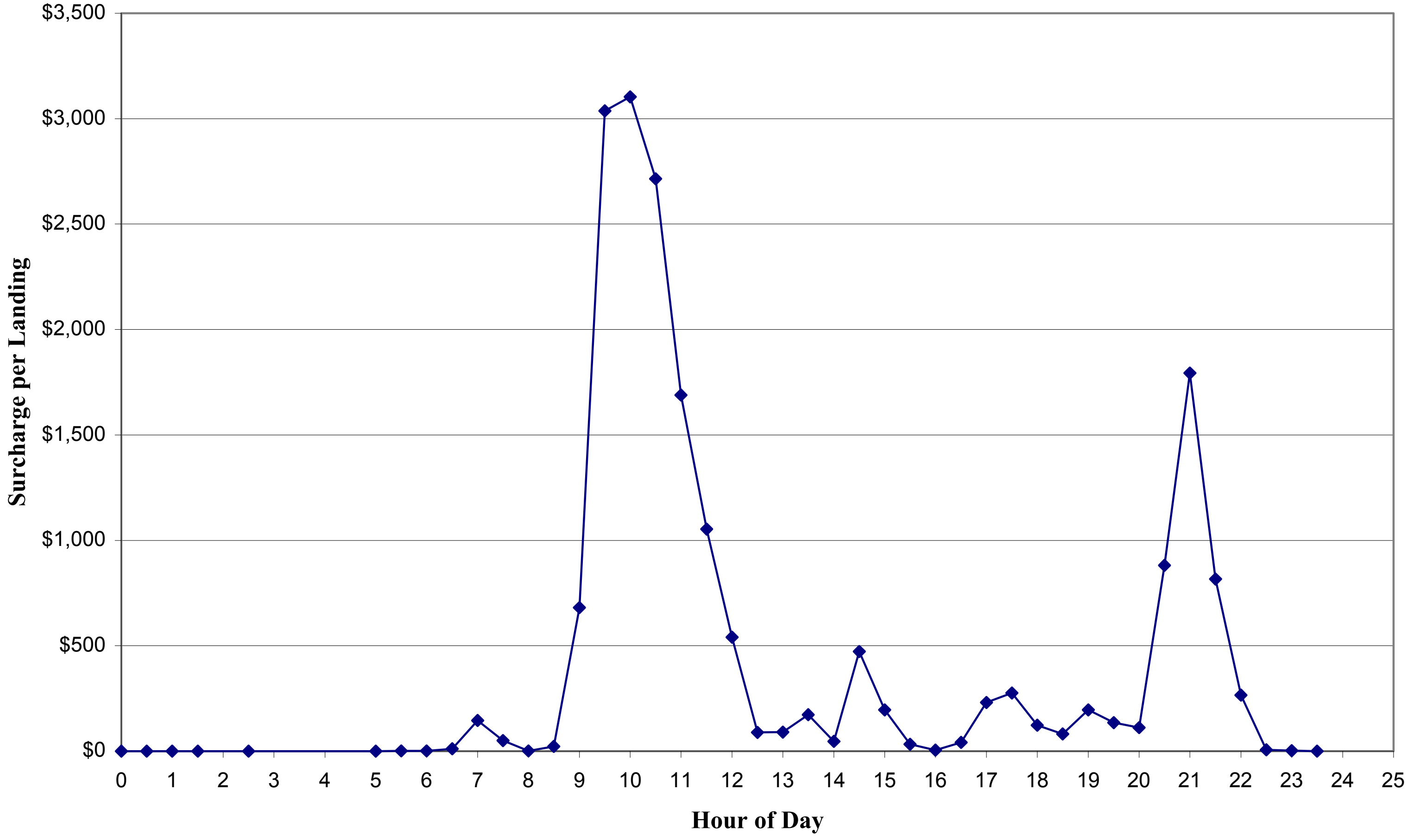


Figure 6-2

Surcharges per Landing, Reflecting Marginal Delay Impact, by Half-hour, LAX Arrivals

Sample Day Schedule



Other aspects of a time-varying surcharge also require careful planning. If the surcharge changes drastically from one time period to the next, airlines will be tempted to reschedule their flights to arrive just at the end of the earlier period. Often the reschedule might be a nominal change to the published schedule without any true operational adjustment. The first of these problems could be solved by allowing the surcharge to vary continuously rather than in discrete steps, and the second by basing the surcharge on actual rather than scheduled arrival time. These solutions add to the perceived complexity of the system, and may raise objections that the actual arrival time is outside of the airline's control. As these examples show, the "devil is in the details" when it comes to peak period surcharges.

In light of the PACE experience, airports must be careful in how they justify the surcharge. The goal of the program should not be to reduce small aircraft operations, but to efficiently price peak period operations. It is also desirable to clearly differentiate the peak period surcharge from the basic landing fee, which, based on legal precedent, should remain weight-based. Finally, as noted above the transition to the surcharge should be gradual, so that airlines have every opportunity to adjust their fleets and schedules.

Regulation

The third possible form of airport fleet mix intervention is direct regulation. In this alternative, the airport establishes explicit rules designed to encourage or force airlines to upsize their fleets. These regulations would be subject to the provisions of ANCA and FAR 161. The implications of this are discussed below.

Regulation might take a variety of forms. It may proscribe aircraft size, flight frequency, or size and frequency. It might prohibit segments of certain lengths. In any of these cases, the regulation might apply to all time periods, or only to peak hours. The paragraphs below discuss these various possibilities.

Size Regulation

The regulation might simply prohibit aircraft of less than a certain size from operating at the airport. The size may be defined in terms of seats or maximum take-off weight. The minimum size could vary with stage length, or be independent of length. The regulation could apply to each individual flight, or to airline or airline segment averages.

A potential problem with size regulation is that it may result in the elimination of services on certain low-density segments where a reasonable frequency is feasible only if small aircraft are employed. Moreover, there may be instances where size regulation would result in more empty seats rather than fewer flights. Opponents could rightly argue in such cases that the regulation causes wasted fuel and more noise rather than reduced delay. The potential of size regulation to have such unintended consequences raises serious questions about its advisability.

Frequency Regulation

Instead of establishing minimum sizes for aircraft, a regulation could set maximum frequencies on airline service segments. In other words, no airline would be allowed to operate more than *n* non-stop flights per day, or during peak periods, on a given segment. Airlines forced to curtail frequency as a result of this regulation could maintain capacity by switching to larger planes.

Frequency regulation, unlike size regulation, directly affects the number of flights at an airport. It will not result in the wasteful upsizing without flight reduction that could result from size regulation. It does, however, have a potential downfall: airlines might reduce capacity by cutting frequency without changing plane size. Simple economics suggests that this capacity reduction could cause higher fares. In an adversarial environment, airlines could profit from these changes while blaming them on the airport's frequency regulation.

Backfilling could also undermine the goals of frequency regulation. While it may be possible to regulate the frequency of individual carriers, it is certainly not feasible to regulate total frequency on a segment, since this would force airports to make frequency allocation decisions as well. So, if one carrier is forced to cut back, another might expand.

Airlines might also attempt to defeat frequency regulation by manipulating flight itineraries. A flight could make a brief stop at an airport that it does not count against the frequency "quota" for a different airport. It could explain to passengers that the time-wasting, unnecessary stop is required because of frequency regulation at their destination airport.

Size/Frequency Regulation

This form of regulation, the one adopted by SFO in its proposed rulemaking, combined the prior two forms. Thus its stipulations are of the form: "if the frequency exceeds *n*, then the aircraft size must exceed *s*.” Thus there is no absolute lower limit on size, so long as the frequency is low enough, and no absolute upper limit on frequency, so long as the size is high enough. This avoids situations where service on a low-density segment must be abandoned due to an aircraft size limit, or capacity on a high-density segment must be rationed, due to a frequency limit.

There are many options for specifying the precision size-frequency rule. Several pairs of frequency and size values may be included, or just one. The rule may also be defined in terms of a minimum size/frequency ratio. For example, if the minimum ratio is 10, then an airline could operate 1 flight per day with a 10-seat aircraft, up to 10 flights with a 100-seat aircraft, and so on.

While size-frequency regulation avoids some of the pitfalls of regulating either size or frequency alone, it may nonetheless have unintended or undesired consequences. In some cases, airlines might comply with the rule by upsizing their planes while maintaining frequency, or by curtailing flights without increasing aircraft size. Itinerary manipulation is also a possibility, just as it is in the case of simple frequency regulation.

Peak Period Regulation

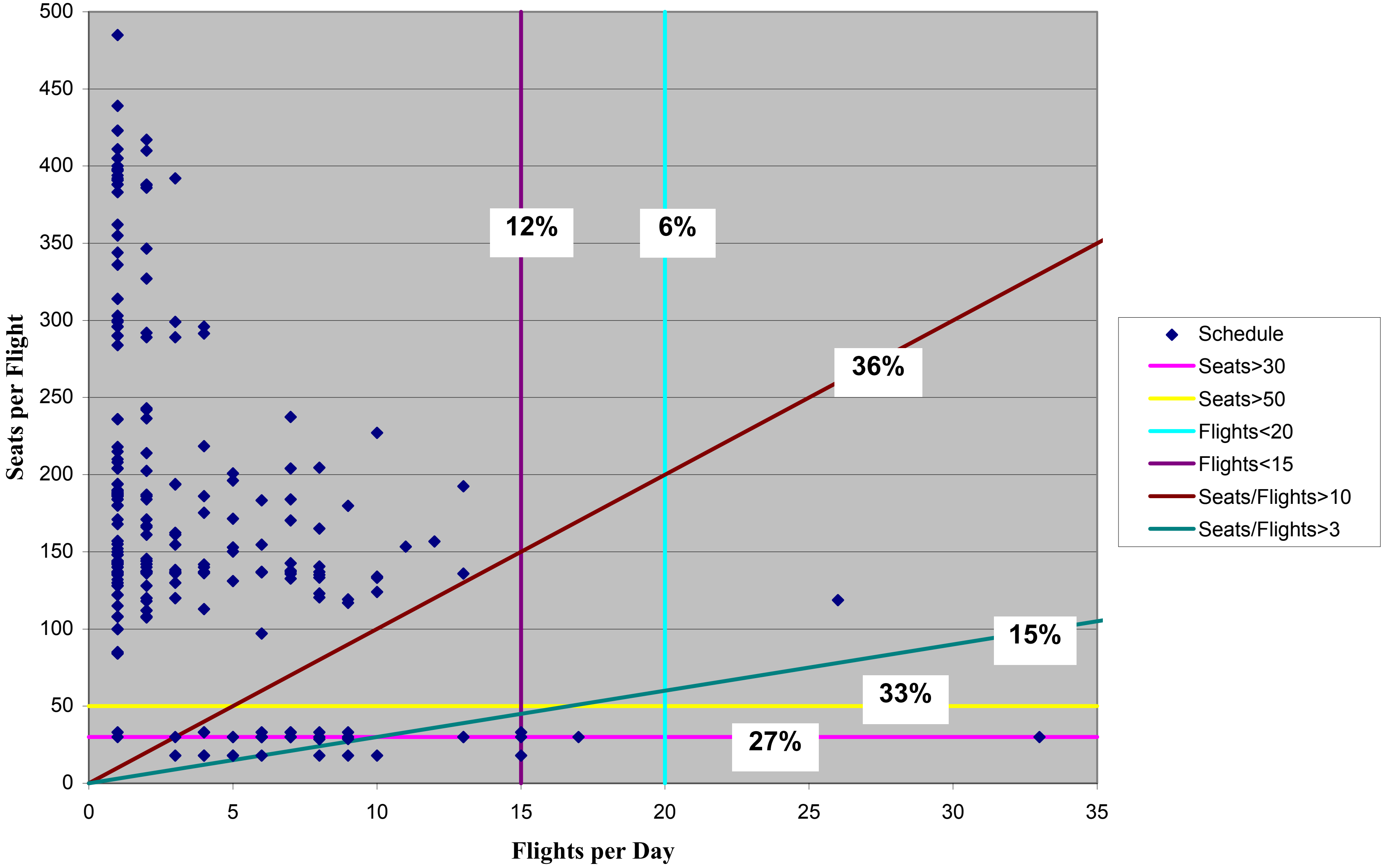
Any of the above schemes can be applied throughout the day or only during peak periods. The advantage of the peak period approach is that it targets operations during periods when congestion and delay externalities are most severe, while avoiding restrictions during periods when they will have little operational impact. This disadvantage is that airlines may avoid restrictions by scheduling flights just outside the peak, sometimes simply by adjusting the published schedule. Moreover, the times of day associated with the peak may change over time, creating a need to revise the regulation on a regular basis.

Application of Alternative Regulations to the Sample Day Schedule

To explore the impact of various size, frequency, and size-frequency regulations, we applied them to the sample day schedule used for the simulations in Chapter 3. It is instructive to do this graphically, as shown in Figure 6-3. The points plotted in Figure 6-3 correspond to airline service segments. The horizontal coordinate is the segment flights per day in the sample schedule, and the vertical coordinate is the average seats per flight for the segment. The lines plotted in the figure correspond to hypothetical regulations. The horizontal lines are size

Figure 6-3

Implications of Alternative Fleet Mix Regulations, Sample Day Schedule



regulations requiring sizes of over 30 and 50 seats respectively. Each line is labeled with the percentage of flights in the sample schedule that run afoul of the regulation. For example, 27 percent of the flights are 30 seats or less, and 33 percent are 50 seats or less. The vertical lines are frequency regulations setting upper frequency limits of 20 and 15 respectively. (Note these are airline limits; several airlines could each serve the segment with a frequency up to the specified number.) The sloped lines are size-frequency regulations requiring that the size/frequency ratio be greater than 10 and 3 respectively. From Figure 6-3 we learn that the most stringent regulations are those requiring a size/frequency ratio (SFR) greater than 10 or a size greater than 50 seats, with each affecting about one third of the flights in the sample day schedule. The 30-seat limit is slightly less stringent, with an impact on about one quarter of all flights. The 15 flight-per-day and SFR=3 regulations impact about 1 in 7 flights, while the 20 flights-per-day regulation has the least impact, with only 6 percent of flights—those on United's service to SFO and UA3's service to SAN--affected.

Table 6-1 lists the airline service segments that fail to meet the various hypothetical regulation criteria. With the exception of United SFO service, all the segments involve commuter flights. Only one segment, UA3 to SAN, fails to meet all six criteria. UA3 services to PSP and SBA, as well as US3 service to SAN, fail on five of the six. OE and OO services consistently fail on the size and SFR criteria. A1 segments, with their 33 seat aircraft and limited frequencies, fare somewhat better, failing only the more stringent criteria on size and SFR.

For political and legal reasons, it might be desirable to have a regulation whose impact is more distributed between certificated and commuter segments. From Figure 6-3 one can see that a more stringent frequency regulation, say one limiting frequency to 10 per day, would meet this requirement, affecting five commuter and five certificated segments. This would have a tremendous impact on United's SFO service, which would need to shift to B767 or larger aircraft in order to preserve capacity. Alternatively, United might switch some of its SFO flights to OAK in order to comply. UA3's service to SAN would also be strongly impacted by a 10 flight-per-day limit.

Obtaining Approval for Regulation

As noted earlier, regulations of the type discussed in this section must are subject to the requirements of ANCA and FAR 161. As a result the regulation must be approved either by all

Table 6-1
Airline Service Segments Failing Hypothetical Criteria

CAR	ORG	FLIGHTS/ DAY	SEATS/ FLIGHT	CRITERIA FAILED	SEATS >30	SEATS >50	FLIGHTS <20	FLIGHTS <15	RATIO >10	RATIO >3
UA3	SAN	33	30	6	X	X	X	X	X	X
UA3	PSP	17	30	5	X	X		X	X	X
UA3	SBA	15	30	5	X	X		X	X	X
US3	SAN	15	18	5	X	X		X	X	X
A1	SAN	15	33	4		X		X	X	X
OE	IYK	6	18	4	X	X			X	X
OE	OXR	10	18	4	X	X			X	X
OE	SNA	8	18	4	X	X			X	X
OO	SAN	13	30	4	X	X			X	X
UA3	MRY	13	30	4	X	X			X	X
US3	FAT	9	18	4	X	X			X	X
OE	BFL	7	30	3	X	X			X	
OE	CLD	8	29	3	X	X			X	
OE	FAT	9	29	3	X	X			X	
OE	PMD	4	18	3	X	X			X	
OE	VIS	5	18	3	X	X			X	
OO	BFL	7	30	3	X	X			X	
OO	FAT	6	30	3	X	X			X	
OO	MRY	5	30	3	X	X			X	
OO	PSP	7	30	3	X	X			X	
OO	SBA	7	30	3	X	X			X	
OO	SJC	3	30	3	X	X			X	
OO	SNA	6	30	3	X	X			X	
UA	SFO	26	119	3			X	X	X	
UA3	IPL	5	30	3	X	X			X	
UA3	ONT	8	30	3	X	X			X	
UA3	SBP	9	30	3	X	X			X	
UA3	SJC	6	30	3	X	X			X	
UA3	SMX	7	30	3	X	X			X	
UA3	YUM	6	30	3	X	X			X	
US3	ONT	3	18	3	X	X			X	
US3	PSP	5	18	3	X	X			X	
US3	SBA	4	18	3	X	X			X	
A1	BFL	4	33	2		X			X	
A1	CLD	6	33	2		X			X	
A1	FAT	7	33	2		X			X	
A1	LAS	4	33	2		X			X	
A1	MRY	4	33	2		X			X	
A1	PSP	9	33	2		X			X	
A1	SBA	8	33	2		X			X	
A1	SBP	7	33	2		X			X	
UA3	SGU	1	30	2	X	X				
A1	SJC	1	33	1		X				

affected aircraft operators (including those planning to provide new air service within 180 days or the restriction) or the Secretary of Transportation. This section briefly discusses the prospects for obtaining approval through either avenue.

Aircraft Operator Approval

This is without question the preferred approach. It avoids the prolonged administrative process required to secure DOT approval. This is particularly true given the stated reluctance of DOT to actually approve an FAR 161 application. Moreover, as the previous discussions have shown, airlines can be expected to respond mischievously if regulations are imposed upon them without their consent. Their ability to sabotage such regulations through perverse or retaliatory compliance actions must not be underestimated. It is certainly more desirable to join with the airlines rather than attempt to defeat them.

Several strategies may be employed in an effort to win approval from operators. First, the regulation can be tied to reduced user fees if it allows costly expenditures for new facilities to be avoided. This relates to the master planning rationale for airport intervention discussed earlier. Second, the regulation can be phased in over a considerable length of time in order to allow carriers time to adjust their fleets. In this regard, the regulation should not be viewed just as an interim measure to bridge the gap until new capacity comes on line, as it is at SFO, but rather as a long-term strategy that, when combined with feasible capacity investments, will extend the operational viability of the airport for many years into the future. Third, the delay reduction benefits and their value to airlines and their passengers must be carefully quantified and emphasized. Fourth, within the limits of anti-trust law, the airport can look for mechanisms by which the airlines benefiting from regulation can compensate the losers, for example, by adjusting user fee and lease rates.

Secretary of Transportation Approval

If the airport is not able to convince all aircraft operators to agree to regulation, it must seek approval from the Secretary of Transportation before implementing the regulation. The requirements for the approval were discussed in broad terms earlier. Since there is no precedent for the FAR 161 approval process, the ingredients for, and even the possibility of, a successful application are a matter of speculation. It is clear, however, that one of the key questions will be whether the benefits of regulation exceeds the cost. This is emphasized in FAR 161.305, paragraph (e)(2)(ii)(1), which requires "evidence, based on a cost-benefit analysis, that the estimated benefits of the restriction have a reasonable chance to exceed the estimated potential cost of the adverse effects on interstate and foreign commerce."

To assess how such an analysis might proceed, and whether it's outcome would support a regulation, we performed a rough cost-benefit analysis of one the hypothetical regulations considered above. We chose the 50-seat minimum size regulation, since this is relatively easy to analyze. We assume that as a result of the regulation airlines operating Jetstream 31s, Embraer 120s, and Saab 340s are forced to replace them with 50-seat Dash 8's, and that the replacement preserves seat capacity and therefore cuts the number of flights. The key components in the cost-benefit analysis are delay savings, from a reduction of operations (and, in particular, small aircraft operations) at LAX, operating cost changes from replacing prohibited flights with a smaller number of Dash 8 flights, and the capital costs of replacing the existing commuter fleet. The paragraphs below detail are estimates for each component.

Delay Reduction

We modified the sample day schedule by eliminating some flights by aircraft under 50 seats and substituting the Dash 8 on others. The percentages of flights eliminated were 60, 40, and 33 for the Jetstreams, Embraers, and Saabs respectively, reflecting their seating capacity relative to the Dash 8. The deterministic queuing model developed in Chapter 3 was then applied to the modified schedule. We found that delay declined from 4.3 to 0.9 minutes per flight. Using the standard delay cost of $25 per minute, and multiplying this by the number of flights in a year, we value the annual delay saving at $32 million.

Operating Cost Savings

We find that the sample day schedule includes 154 hours of Jetstream flying, 150 hours of Saab flying, and 390 flight hours for the Embraer (this includes flights to and from LAX). Dash 8's in the modified schedule fly 392 hours. Operating costs for the Dash 8's are about $1000 per block hour, while those for the Jetstream, Saab, and Embraer are $700, $870, and $870 respectively. These translate into annual aircraft operating costs of $211 million for the original schedule and $143 million for the modified one, for a saving of $68 million.

Aircraft

We assume an aircraft utilization of 8 hours per day, so that 49 Dash 8's are required to operate the new schedule, at about $13 million a piece. On the other hand, about 86 aircraft used in the original schedule can be sold. We assume that these aircraft can be sold at prices about half their purchase prices when new: $4 million for the Saabs and Embraers and $2 million for the Jetstreams. Altogether, when the proceeds from the sale are subtracted from the expenditure for the new planes, we estimate the cost of the changeover at $327 million.

Cost-Benefit Comparison

From the above we conclude that a one-time expenditure of $327 million yields a benefit of about $100 million in the first year. The full investment could therefore be recovered in about 3 years. This is a good rate of return by most standards. It thus appears that the 50-seat minimum aircraft size regulation would pass the cost-benefit test.

It should be noted that these calculations do not include either the savings in passenger delay or the increase in schedule delay (see Chapter 3) that would result from the assumed change. Both of these quantities are very hard to monetize. For purposes of this first-cut analysis, we assume that these effects cancel. Based on the discussion in Chapter 3, this seems, if anything, a conservative assumption.

Other Issues Concerning DOT Approval

The cost-benefit analysis above suggests that fleet mix regulations can survive economic scrutiny. But it must be emphasized that this is a necessary rather than a sufficient condition for DOT approval. In the case of the 50-seat restriction analyzed above, small aircraft operators could argue that the rule is blatantly discriminatory and not consistent with the principle that the airport be made available to all types of aeronautical activity on fair and reasonable terms. In these regards, frequency or size-frequency regulation may be easier to defend than size regulation. Moreover, the cost-benefit analysis assumes that the airlines respond to restriction in the fashion that the airport intends, while other modes of compliance, which are far less benign, are also possible. This speaks both to the challenge of obtaining DOT approval for a regulation, and the wisdom of attempting such regulation, without the agreement of aircraft operators, to begin with.

Fleet Mix Regulation: The San Francisco Experience

This section summarizes the recent experience of San Francisco International Airport (SFO) with fleet mix regulation. As is well known, SFO has particularly severe delay problems as a result of having closely spaced parallel runways, which can accommodate only a single arrival stream under IFR conditions. In recent years, it has often ranked last or next-to-last in on-time performance out of thirty major airports by the U.S. Department of Transportation (Charles River Associates, 2000).

The long run solution to this problem advocated by SFO is to reconfigure the runway system to that dual arrival streams are possible under IFR. During the winter of 1999, the combination of high delays and an upcoming mayoral election caused Mayor Willie Brown to seek a shorter term remedy. At the Mayor's urging, a consultant, Charles River Associates (CRA), was commissioned to study what could be done.

CRA performed a study in which they analyzed delays at SFO, conducted focus groups with airport users on how delays affected their travel experience, and simulated the effect of possible airline schedule modifications. The key findings of their study were that delays at SFO disproportionately effect short-haul segments, including a number that are served by commuter carriers, that many flights are cancelled on bad weather days, and that in certain periods there is a large amount of *propagated* delay—that which occurs when aircraft are so tightly scheduled that they cannot recover their schedule on subsequent flights after a delay occurs. On the basis of these findings, CRA recommended that, among other things, SFO initiate a Part 161 rulemaking that would impose aircraft "upgauging". The upgauging option considered in CRA's analysis included replacing B737s with B757s in the SFO-LAX market, and replacing 30-seat Embraer 120s with 50-seat planes in four other markets (SMF-SFO, MRY-SFO, FAT-SFO, and ACV-SFO). Frequencies in these markets were, respectively, 53, 21, 15, 18, and 12 at the time of the study. Assuming that the upgauging would be capacity neutral, use of the large planes was estimated to save roughly the same amount of delay on a representative bad weather day as the flight cancellations that were actually made. Thus, CRA argued: "the true choices concerning the reduction of excess arrival demand on bad weather days at SFO [are] (1) not *whether* but *how*; and (2) who will bear the burden." They argued that the traveling public would be better served by a schedule of fewer flights on larger aircraft that could be flown even under adverse weather conditions than by the existing, high frequency/high cancellation, approach.

SFO accepted CRA’s recommendations and announced, in April 2000, that it intended to pursue of Part 161 rulemaking. CRA was commissioned to develop the rule. While this work was proceeding, United approached SFO with a proposed fall schedule that reduced short-haul flights (not through upgauging, but simply by cutting service) and included longer scheduled ground times to reduce propagated delay. Analysis of the proposed schedule revealed that it would substantially reduce delays on bad weather days, although not as much as the upgauging strategy would. There was also suspicion that the new schedule, while reduced from the summer, represented nothing more than a standard seasonal adjustment. However, SFO agreed to suspend its rulemaking activity and accept instead United’s voluntary cutbacks. That is where things stand at the time of this writing.

Conclusions

The avenues available to airports seeking to intervene in airline fleet mix and scheduling decisions are limited, but not absent. Of all the forms of intervention considered in this chapter, those stressing voluntary actions on the part of airlines are the most appealing. These actions may be purely voluntary, or they may be voluntary responses to incentives created by peak period surcharges, or even regulations that are constructed and justified to secure the agreement of all airline operators. Any of these approaches are far more likely to succeed than a regulation imposed on unwilling carriers, who have many ways of attacking the regulation in the rulemaking phase and defeating its purpose once it is implemented.

The entry, or re-entry, of airports into decisions that have been a purely airline domain is bound to spark resistance. The airport must have a clear rationale for this intervention, and it must be willing to approach this new responsibility resolutely, but gradually. It is a fallacy to assume that fleet-mix intervention is a short-term stopgap measure to be used while everyone waits for new concrete. Such intervention involves significant institutional change, which, like infrastructure investment, is a long-term endeavor. There is every reason to suppose to both will be necessary for the future aviation system to effectively respond to the demands that will be placed upon it.

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APPENDIX A

Airline Traffic and Fleet Mix Data

Data on the passenger traffic and the type and size of equipment used on each flight segment in scheduled service are reported to the U.S. Department of Transportation (DOT) by certificated airlines operating under Part 121 of the Federal Aviation Regulations on Schedule T-100 of Form 41. Commuter airlines operating under Part 135 of the Federal Aviation Regulations report passenger traffic, but not equipment used, on Schedule T-1 of Form 298-C. In addition to these statistics, which reflect passengers flying on the same flight between two points, data on the true origin, destination, and itinerary of passengers, as well as the fare paid for the trip, are reported by the certificated airlines on the 10 Percent Original and Destination Survey.

This appendix provides more information on these data sources, and discusses limitations that affect their use and interpretation.

Schedule T-100

Certificated airlines and regional airlines operating aircraft larger than 60 seats report the passenger traffic, number of flights operated and the number of available seats on each nonstop segment of their scheduled service on Schedule T-100 on a monthly basis by equipment type. In addition to the number of passengers flying on each segment, termed the *segment traffic* or on-board passengers, the airline also report the number passengers enplaning at each airport who deplaned at every other airport served by scheduled flights from the first airport, termed *market traffic*. The distinction between segment and market traffic is important to understanding the data.

Segment Traffic measures the number of passengers on all flights operated with a particular aircraft type for a given nonstop segment during the month. This includes passengers who boarded flights at the start of the segment and deplaned at the end of the segment, as well as passengers who boarded any of the flights at upline airports before the start of the segment and/or continued on the flights beyond the end of the segment, sometimes referred to as through passengers. Thus if a flight itinerary included four airports A-B-C-D, the segment traffic on segment B-C would include passengers who board at B and deplane at C, as well as passengers boarding at A and deplaning at C or D, and passengers boarding at B and deplaning at D.

Market Traffic between two airports measures the number of passengers that enplane at the first airport and deplane from the same flight at the second airport. For this reason, the traffic is sometimes termed the enplaned passengers in the market. It includes both passengers on nonstop segments between the two airports as well as passengers on flights with intermediate stops between the two airports. Thus in the example above, the market traffic between B and C would include passengers on nonstop flights between B and C, as well as passengers enplaning at B on flights with itineraries such as B-X-C who deplane at C. It should be noted that the market traffic only counts the travel on a single flight. It cannot be determined from the data what proportion of the market traffic between B and C is connecting from other flights at B or connecting to other flights at C. For this reason, the data are sometimes referred to as *on-flight origin-destination* traffic. Since market traffic can include passengers on several different routes, the data is not reported by equipment type.

It follows from the foregoing that since segment traffic includes passengers not counted in market traffic (through passengers at either end) while market traffic includes passengers not counted in segment traffic (passengers on flights with intermediate stops), segment traffic may be more or less than market traffic.

In addition to passenger traffic, the T-100 data includes the number of scheduled departures flown and the number of seats on those flights for each nonstop segment by equipment type. These data allow the average aircraft size to be calculated for each segment, as well as more detailed fleet mix information if this is required. Comparing the segment traffic with the number of seats allows the average load factor to be calculated.

International Traffic

Schedule T-100 is filed by U.S. flag carriers for all international segments and by foreign flag carriers for international segments beginning or ending in the U.S. However, unlike the data for domestic segments, access to the data is restricted by the U.S. DOT. Los Angeles World Airports has authority to access these data for flights using Los Angeles International Airports.

Form 298-C

The commuter carriers who do not operate aircraft larger than 60 seats report *on-line* origin-destination traffic in scheduled service on a quarterly basis on Form 298-C Schedule T-1. The data is reported for all passengers traveling between any given origin and destination on the carrier's system, irrespective of the number of flights taken between the origin and destination. (Note the difference between *on-line* and *on-flight* origin-destination traffic). Segment traffic is not reported, nor are the number of scheduled flights or seats available. It is therefore not possible to determine average aircraft size or load factors from these data. The only source of data on flight frequency and aircraft size for these carriers is the Official Airline Guide or similar published flight schedules.

10 Percent Origin and Destination Survey

Certificated carriers are required to report to the U.S. Department of Transportation the full itinerary and fare paid for a 10 percent sample of all passengers on a quarterly basis. Generally, the fare and itinerary of tickets with numbers ending in zero are reported by the first certificated carrier to handle the passenger. This ensures that passengers who start their trip on a foreign flag or commuter airline are included in the survey, as long as at least one segment of their trip is on a certificated carrier. In some high density markets, the carriers are allowed to sample only those passengers whose tickets end in double zero, and multiply the resulting counts by ten. The carriers report the number of passengers with a given itinerary for each different fare paid. Therefore it is possible to calculate the average fare paid for travel between a given origin and destination, and (in principle) the fare distribution. Each unique itinerary consists of a specific sequence of segments, each on a given airline. Thus the same sequence of airports, but with one or more segments flown on different airlines, constitutes two different itineraries.

Traditional airline tickets show the full itinerary of the passenger on each coupon of the ticket, as long as the itinerary involves no more flights than will fit on the coupon (typically four flights). More complex itineraries will require that one or more additional tickets be issued to include the flights that will not fit on the first. However, the fare calculation field on the primary ticket shows the full itinerary.

Access to the data from the 10 Percent O&D Survey was obtained using two commercial products from Data Base Products, Inc.: O&DPlus and Hub. These products provide the data and access software on CD-ROM. O&DPlus provides the true origin and destination of the sample passengers, but not their itineraries. Thus passengers taking a trip from Los Angeles to New York (say) on a nonstop flight will be combined with those connecting at intermediate hubs. However, the data distinguish between passengers beginning a round trip at one end of an airport pair and those beginning the reverse trip at the other. The data also distinguish between entirely domestic trips and the domestic part of an international trip (access to the data for the international part of an international trip is restricted).

The Hub product provides the full itinerary information, to the extent that it is known and subject to limitations on complex itineraries for reasons of database efficiency. For itineraries with more than two intermediate stops, the product provides the last two intermediate stops before the destination, as well as the number of coupons on the original ticket. Thus it is possible to tell if there are missing segments, but not what they are. Like O&DPlus, it can distinguish the true origin from the start of the directional journey, as well as entirely domestic trips from the domestic part of an international trip.

APPENDIX B

Traffic Trends in Major Western United States Markets

Figure B-1

Market Trends LAX-Las Vegas

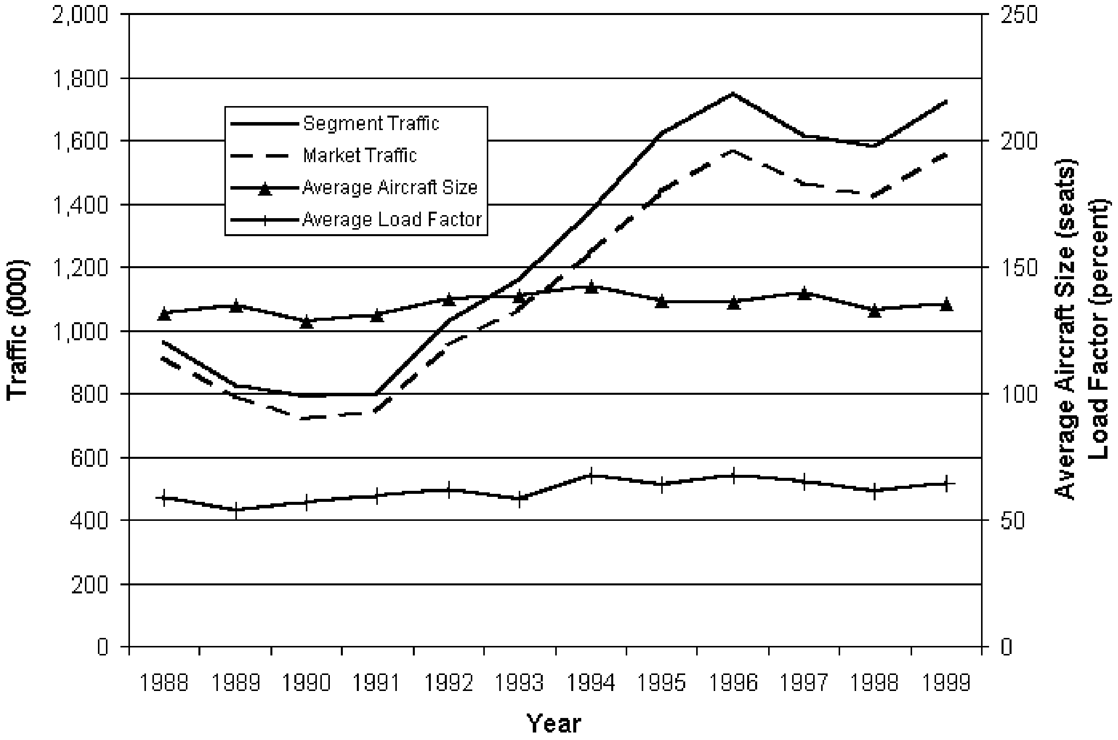


Figure B-2

Market Share Trends LAX-Las Vegas

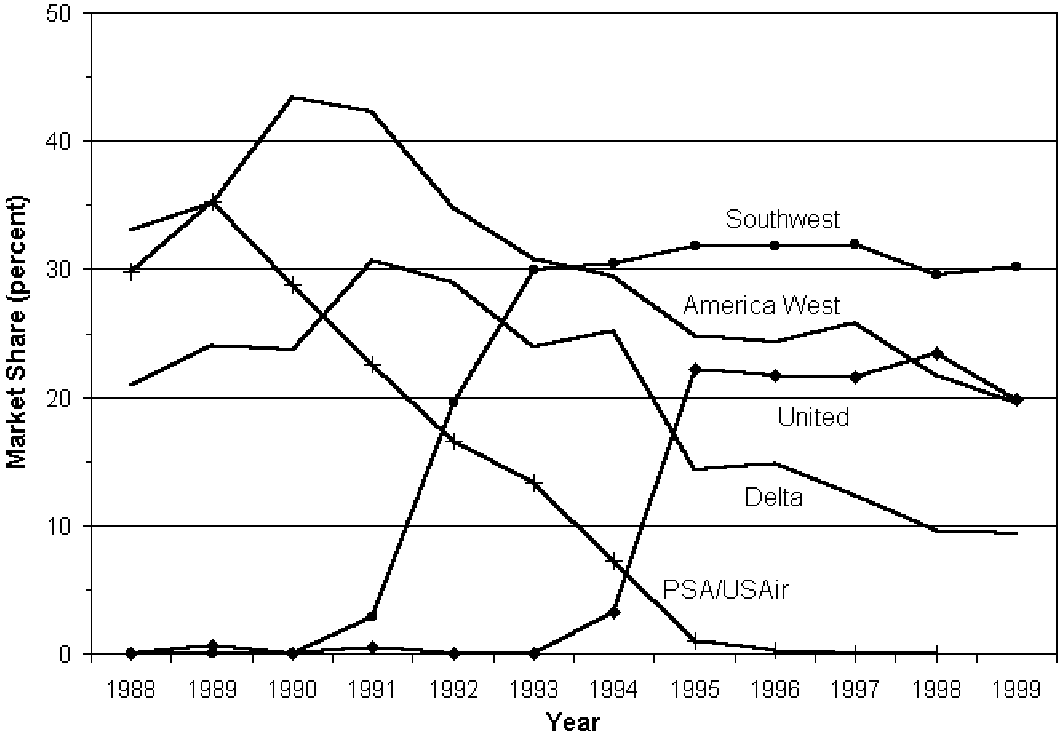


Figure B-3
Market Trends LAX-San Francisco

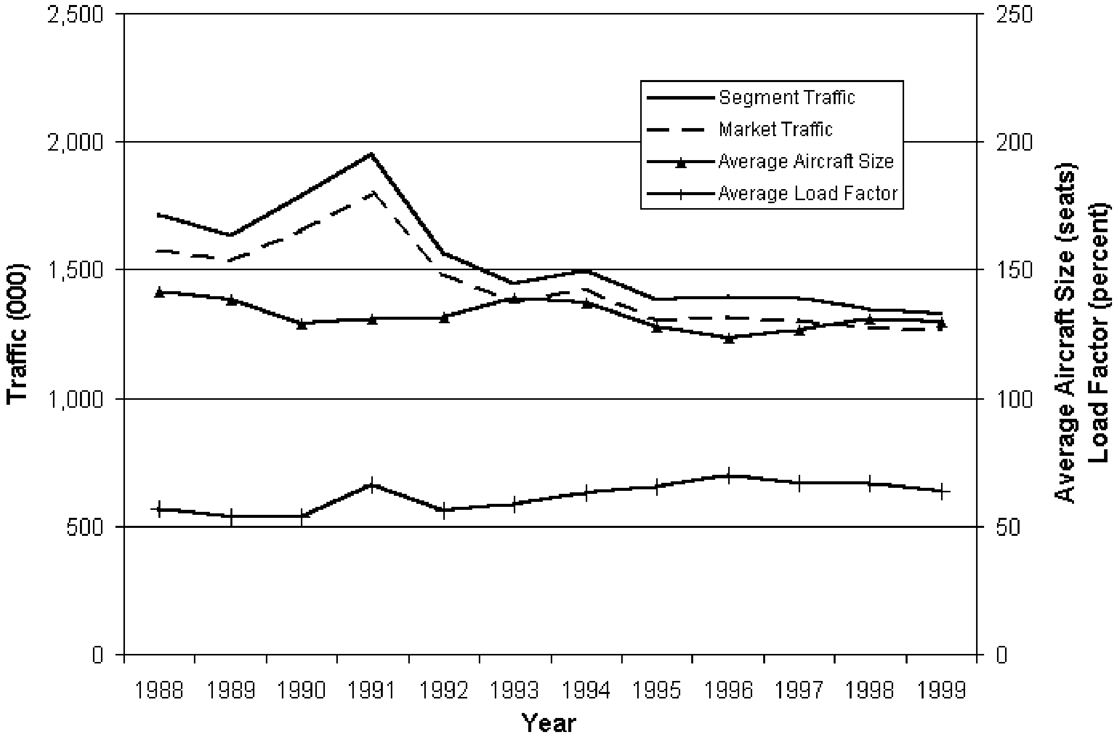


Figure B-4
Market Share Trends LAX-San Francisco

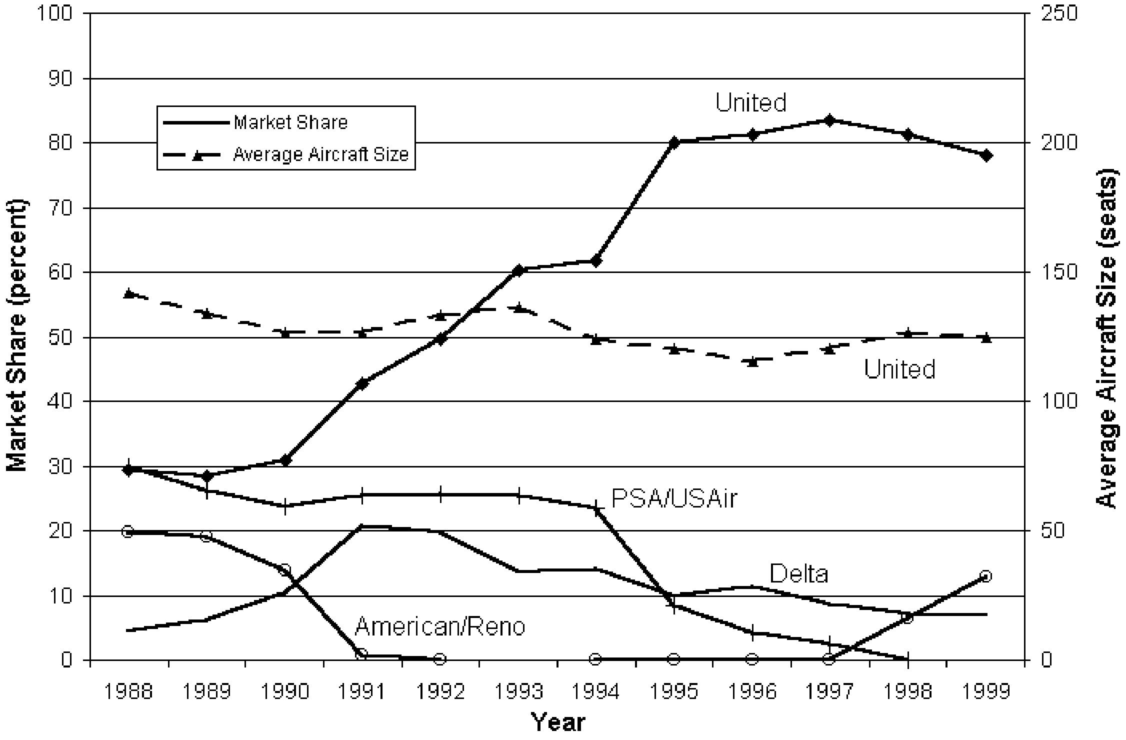


Figure B-5
Market Trends LAX-Phoenix

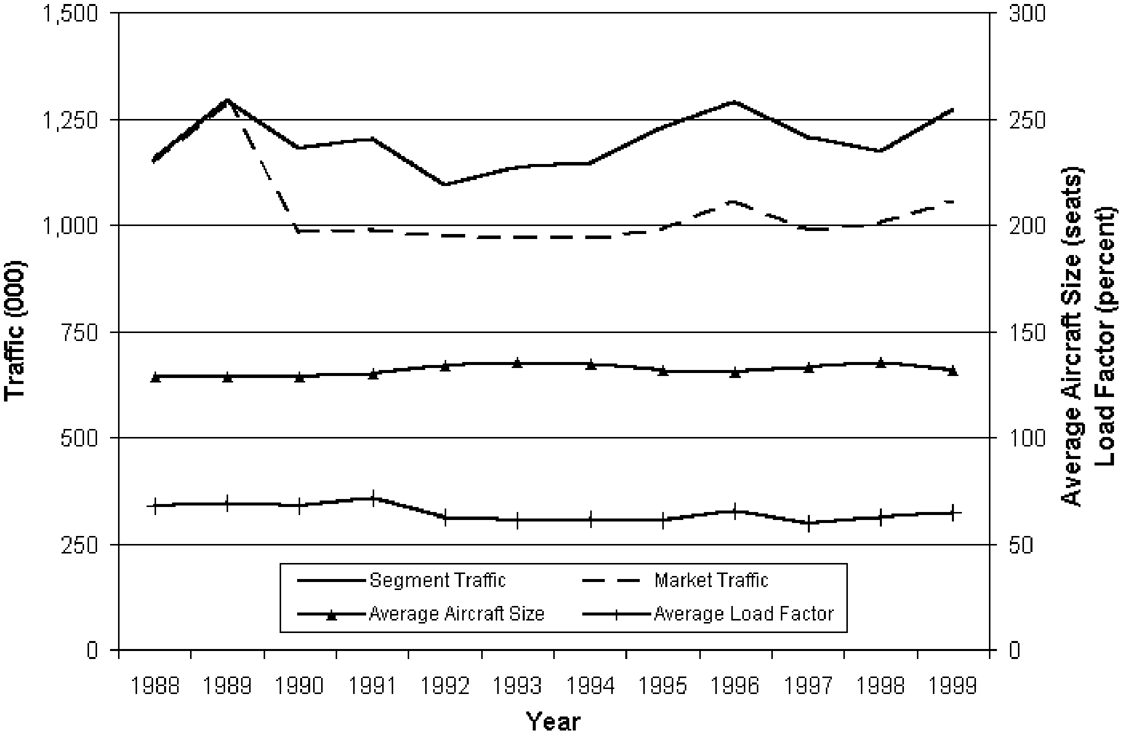


Figure B-6
Market Share Trends LAX-Phoenix

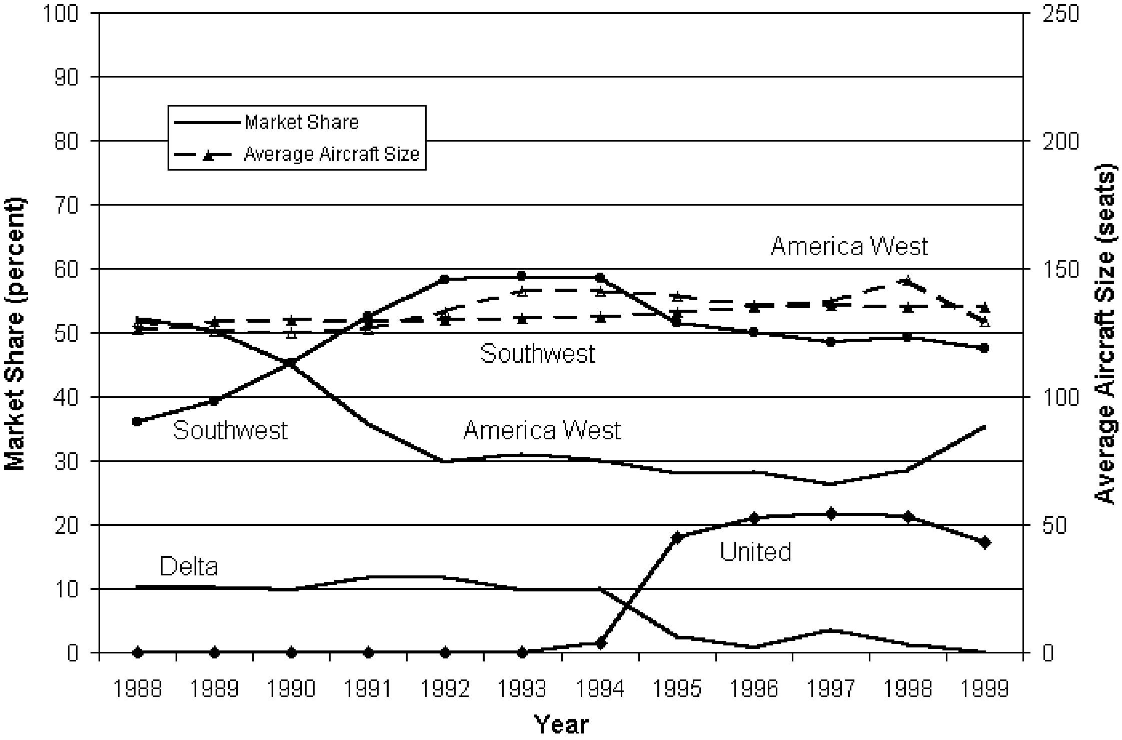


Figure B-7

Market Trends LAX-Denver

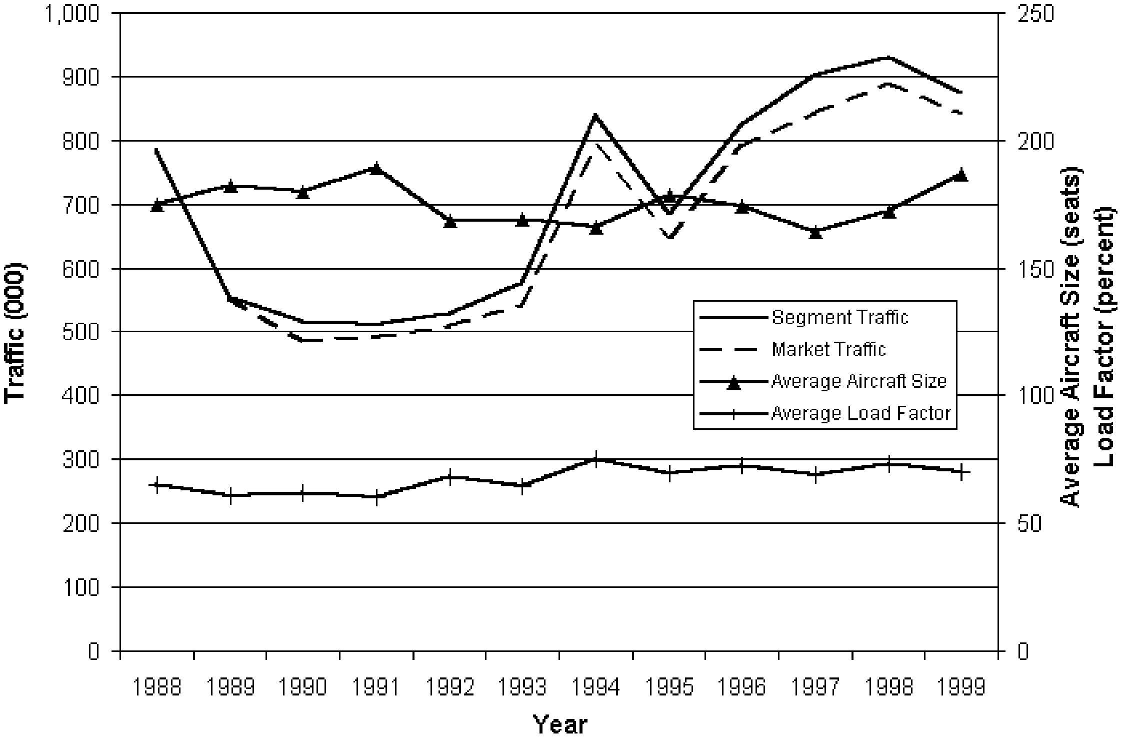


Figure B-8

Market Share Trends LAX-Denver

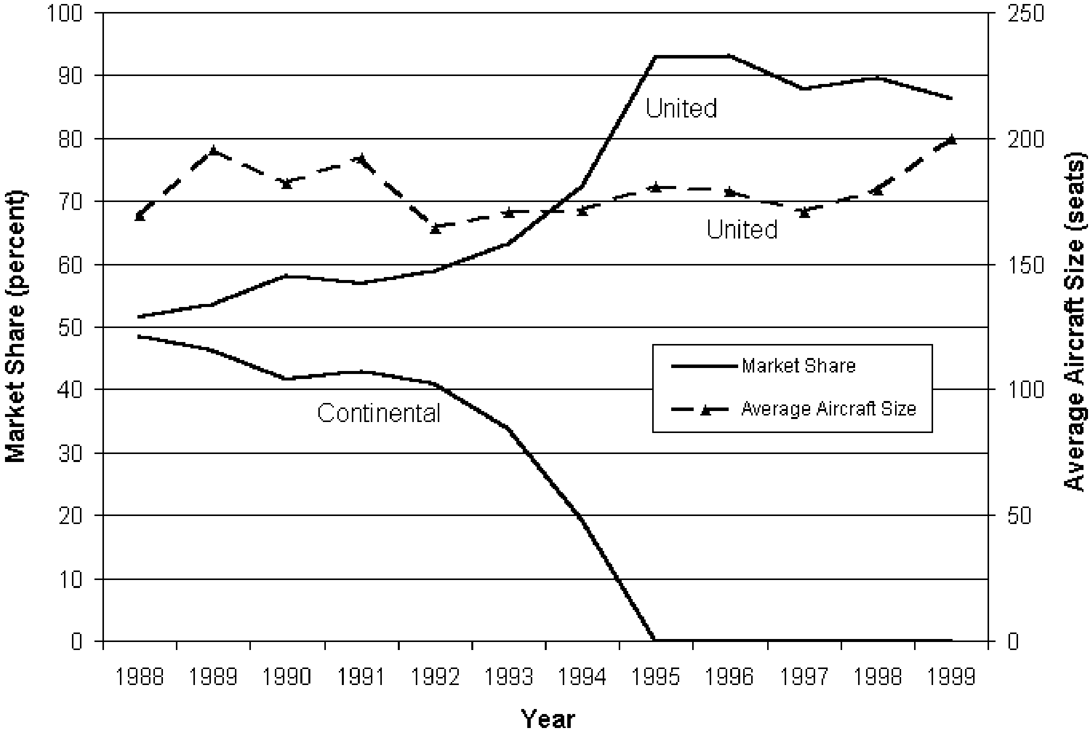


Figure B-9

Market Trends LAX-Oakland

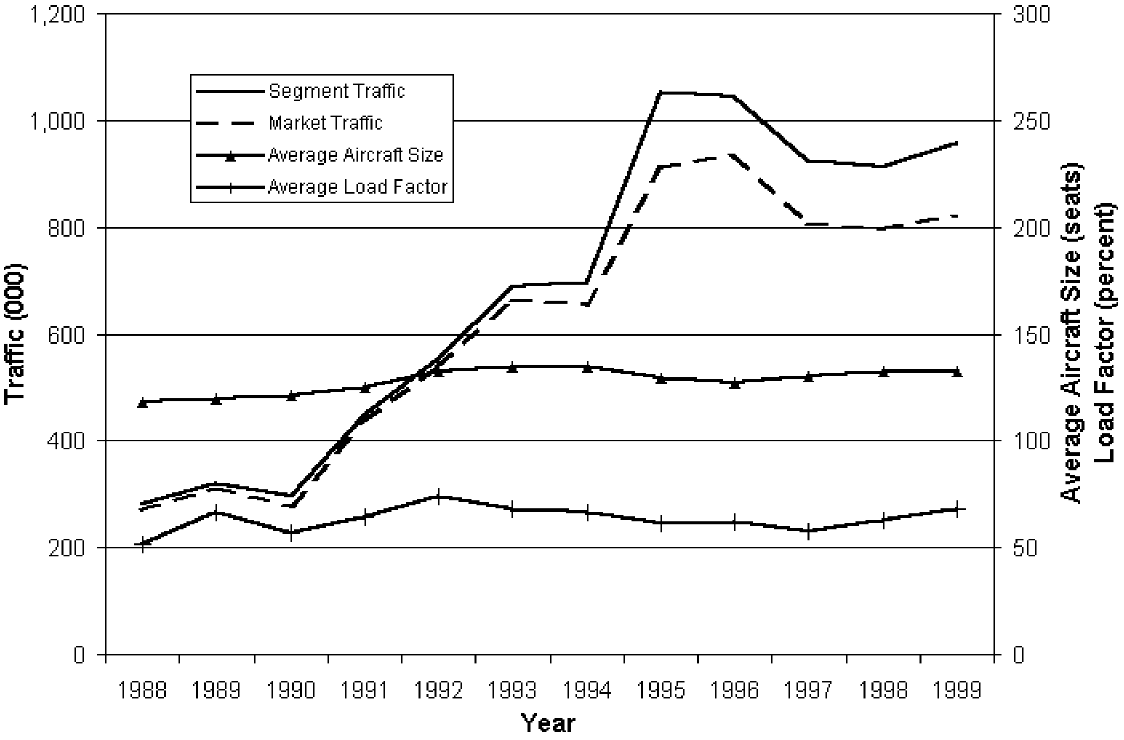


Figure B-10

Market Share Trends LAX-Oakland

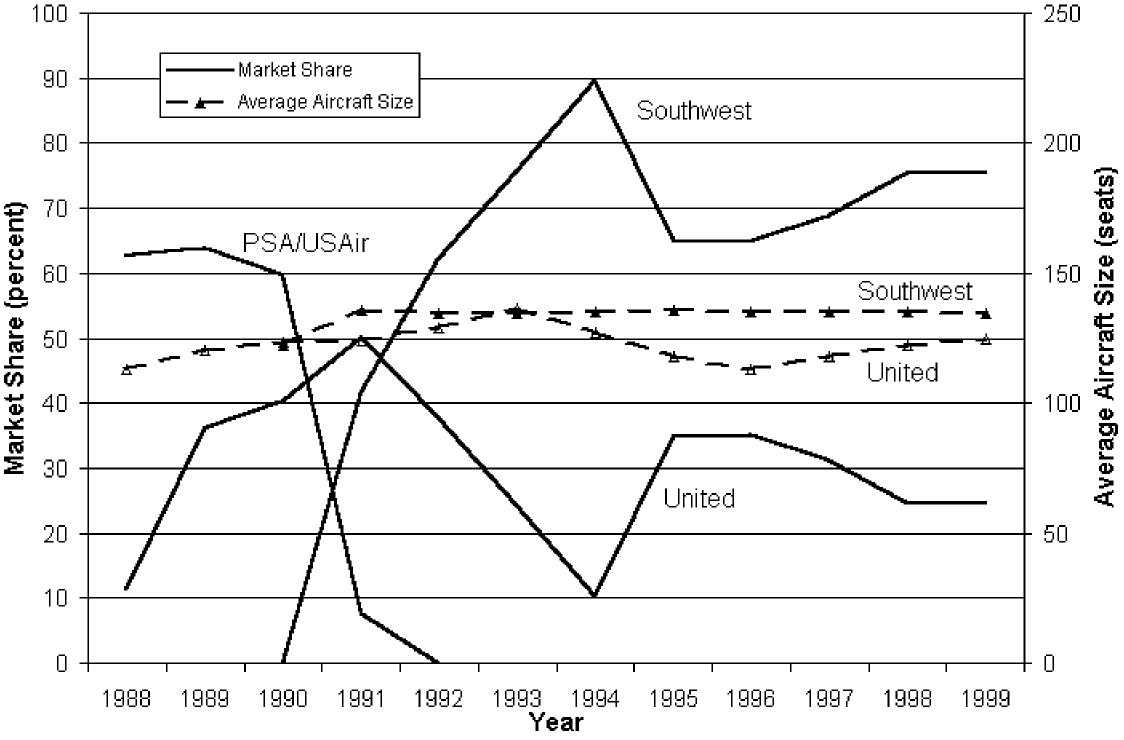


Figure B-11
Market Trends LAX-Seattle

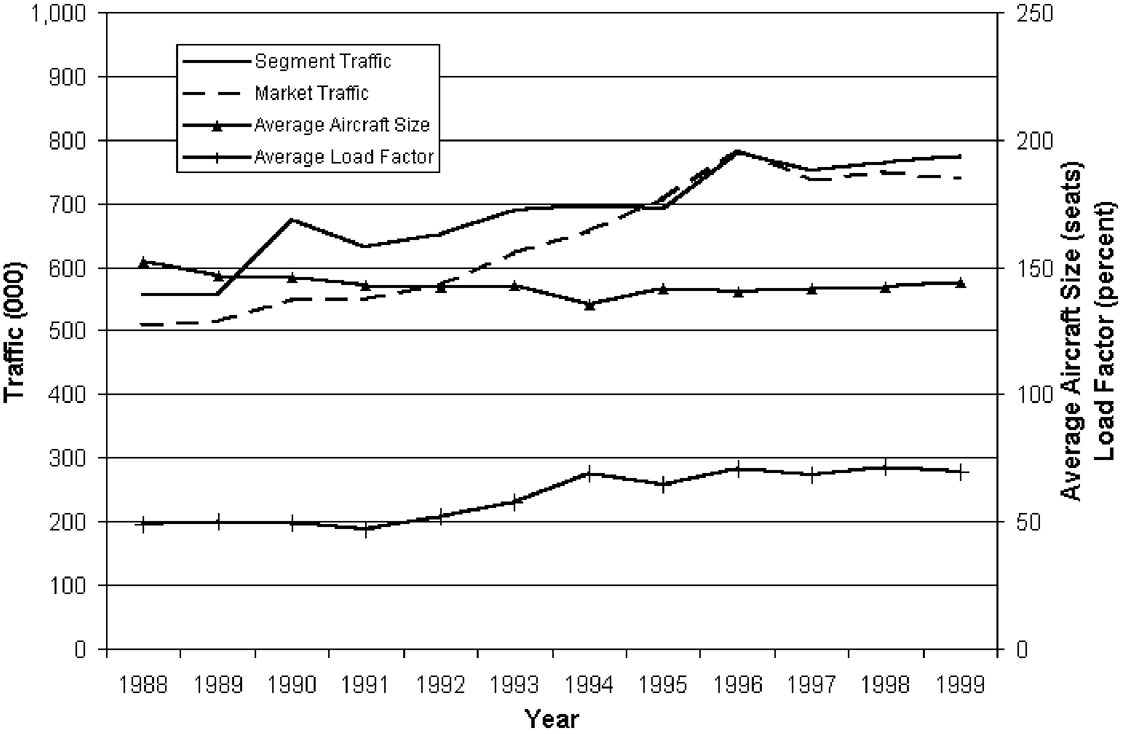


Figure B-12
Market Share Trends LAX-Seattle

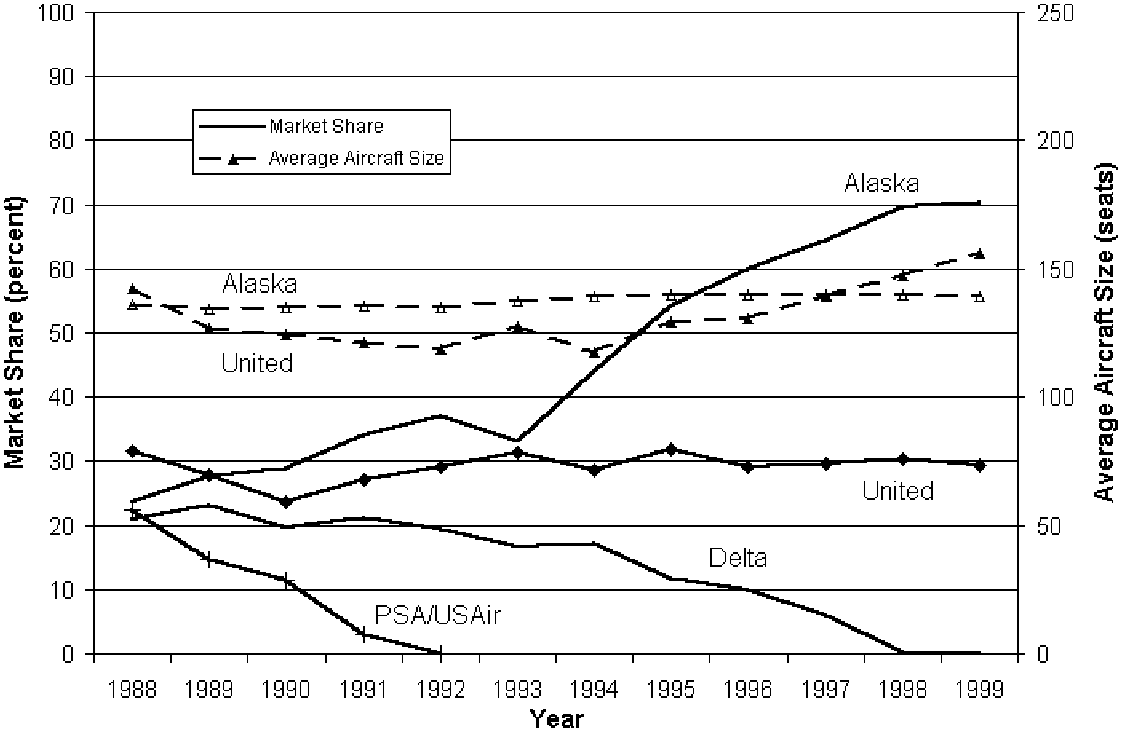


Figure B-13

Market Trends LAX-San Jose

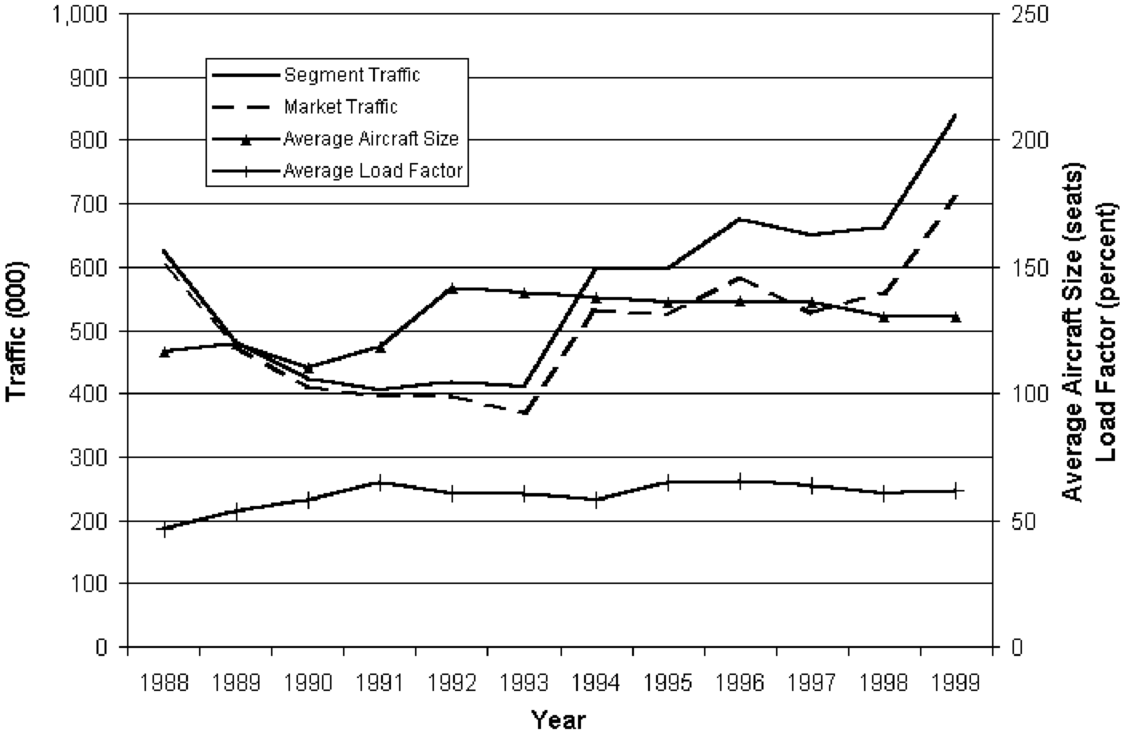


Figure B-14

Market Share Trends LAX-San Jose

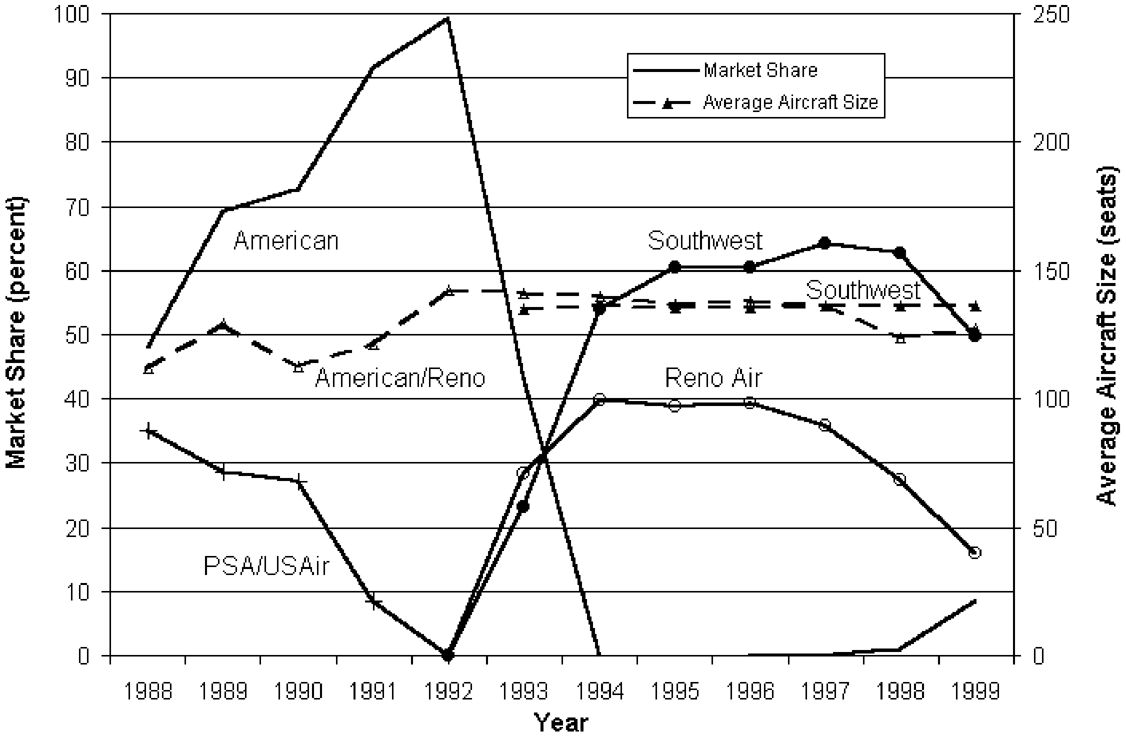


Figure B-15

Market Trends LAX-Salt Lake City

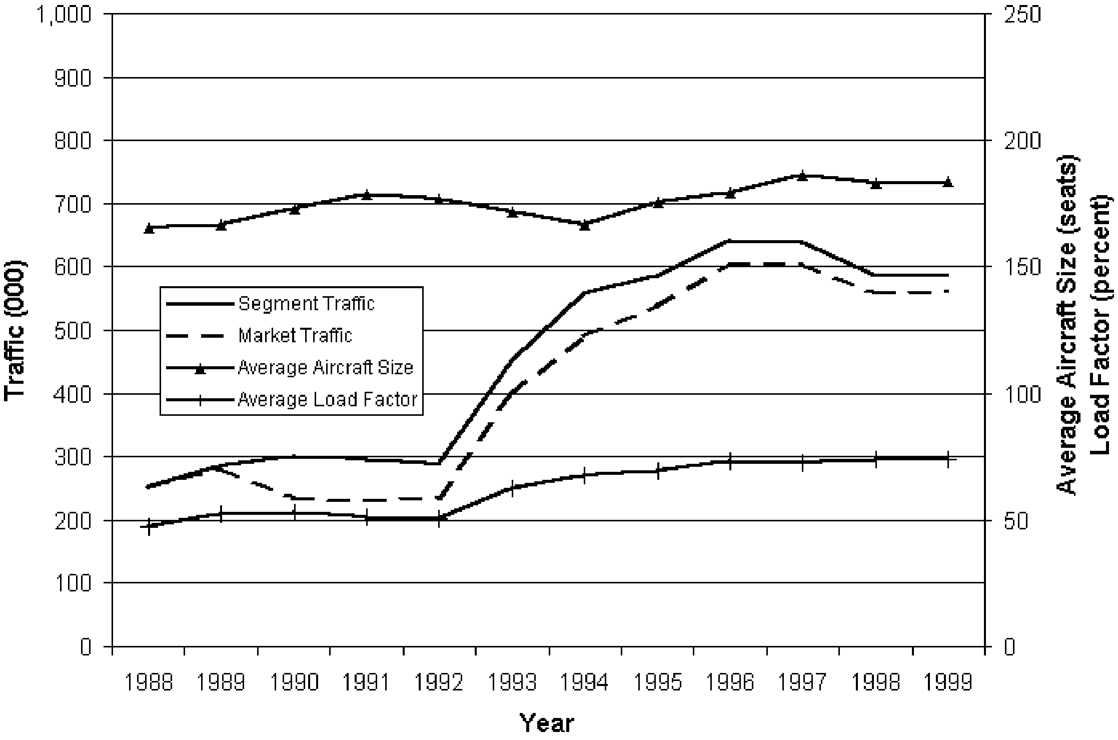


Figure B-16

Market Share Trends LAX-Salt Lake City

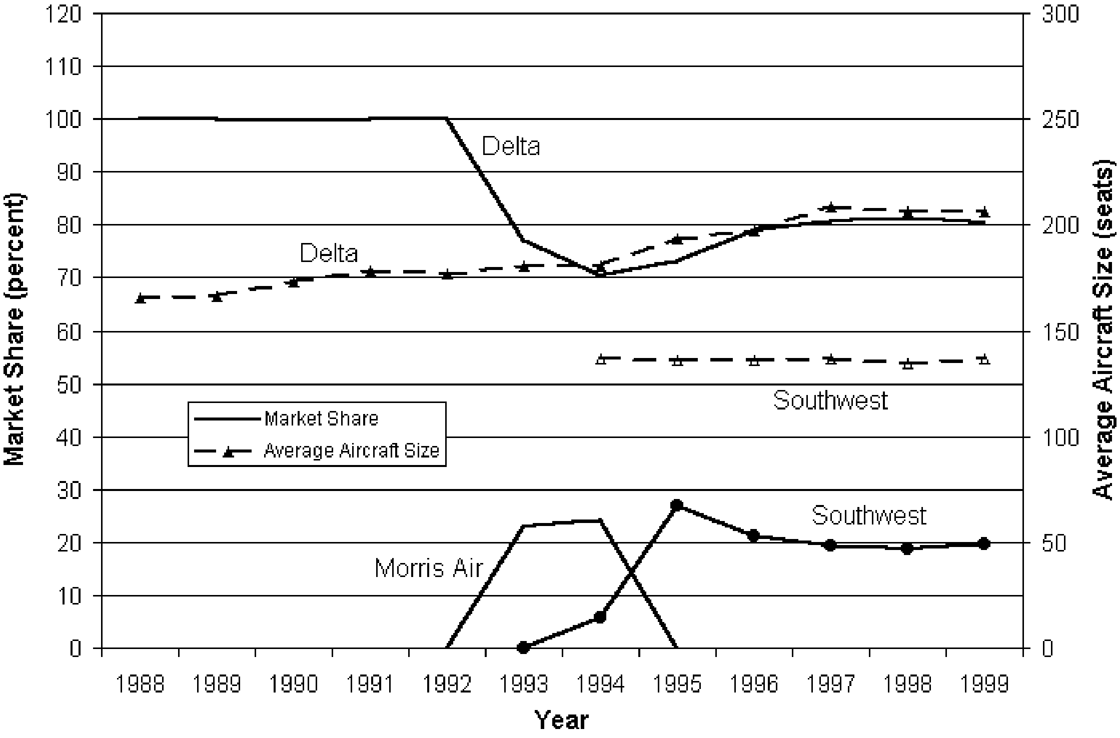


Figure B-17

Market Trends LAX-Sacramento

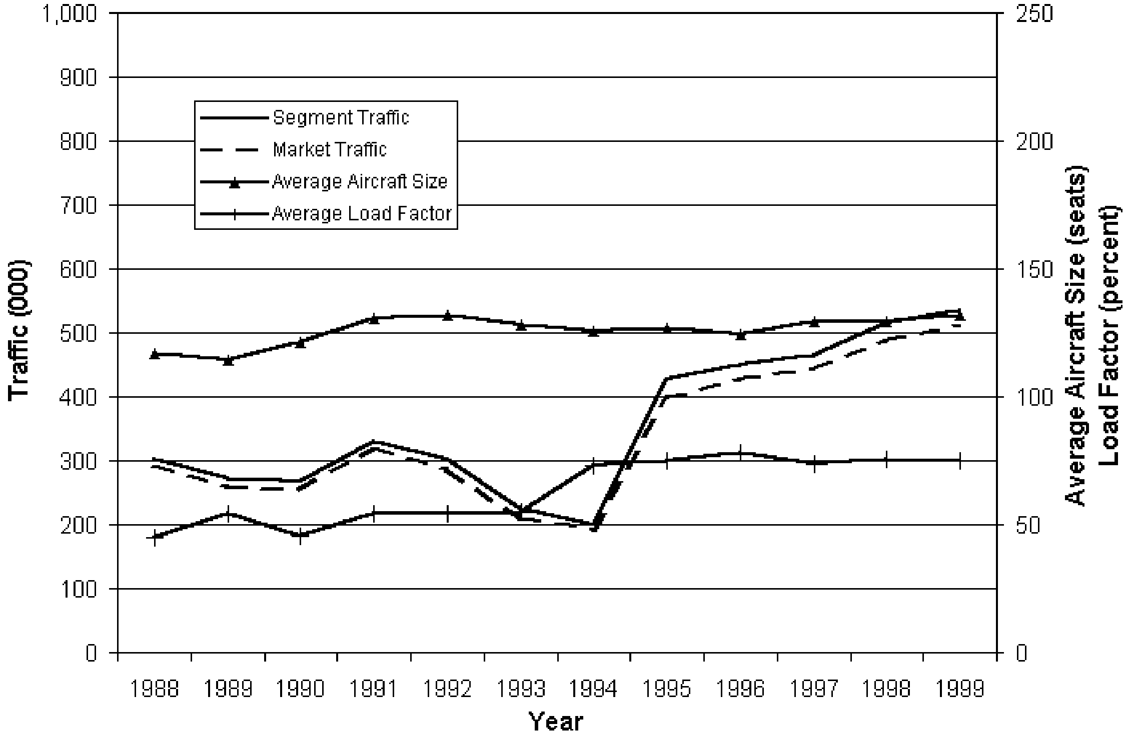


Figure B-18

Market Share Trends LAX-Sacramento

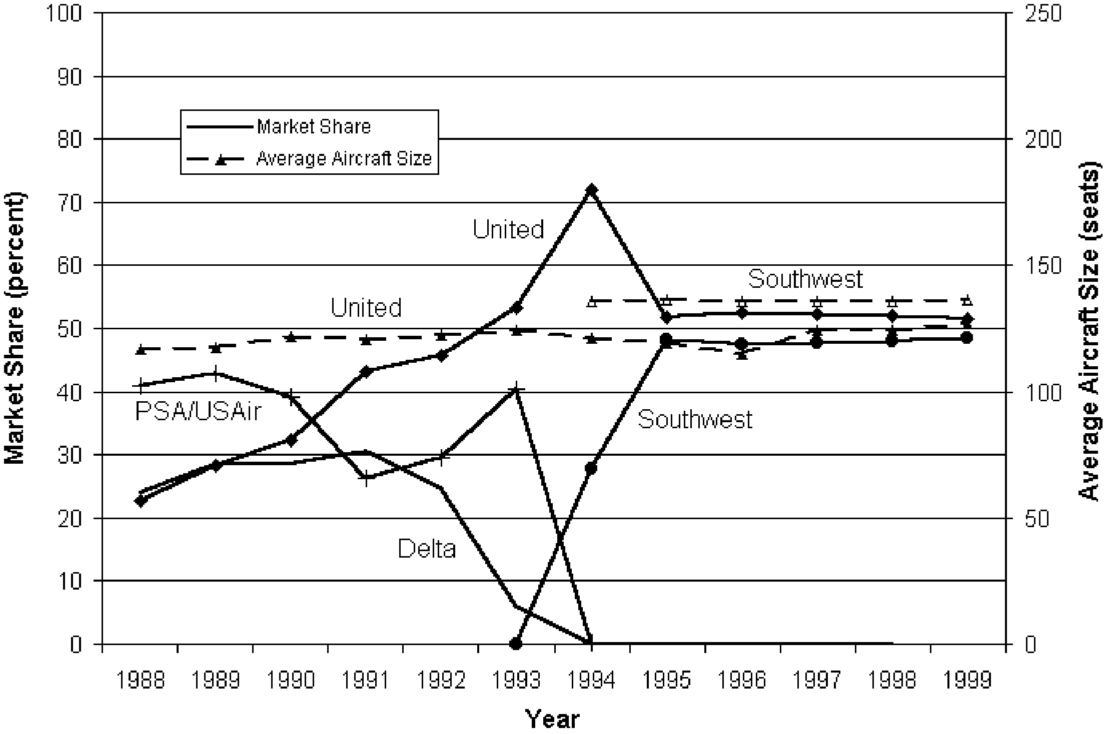


Figure B-19

Market Trends LAX-Portland

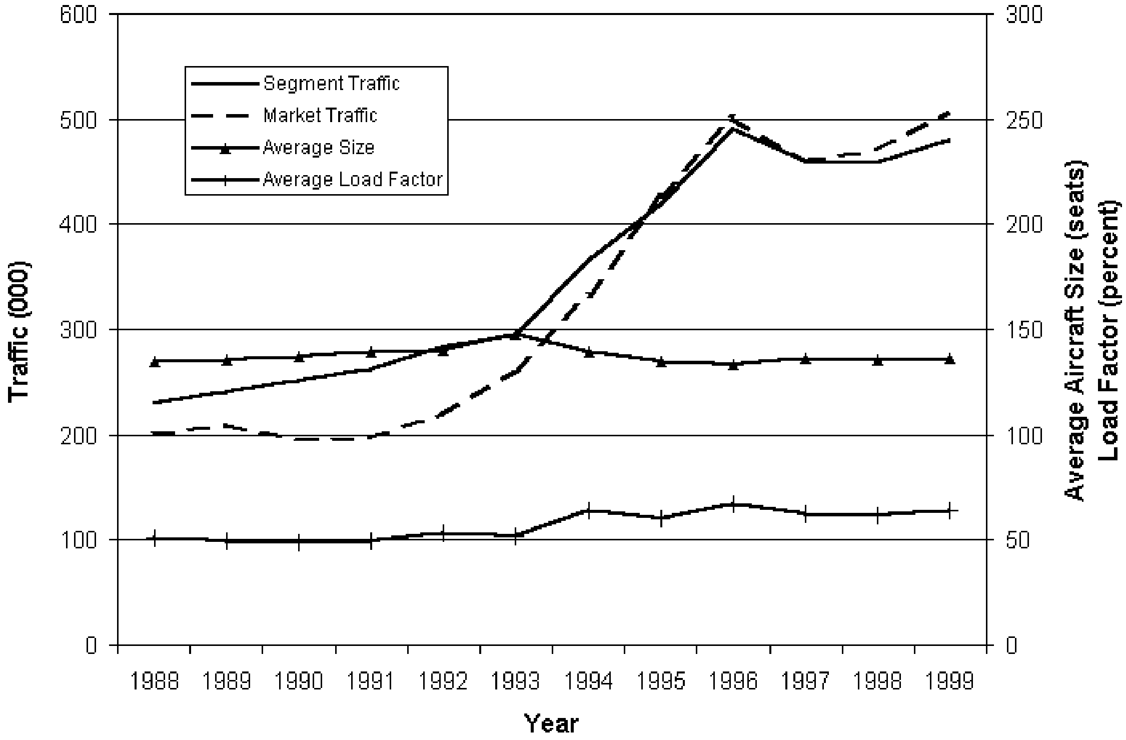
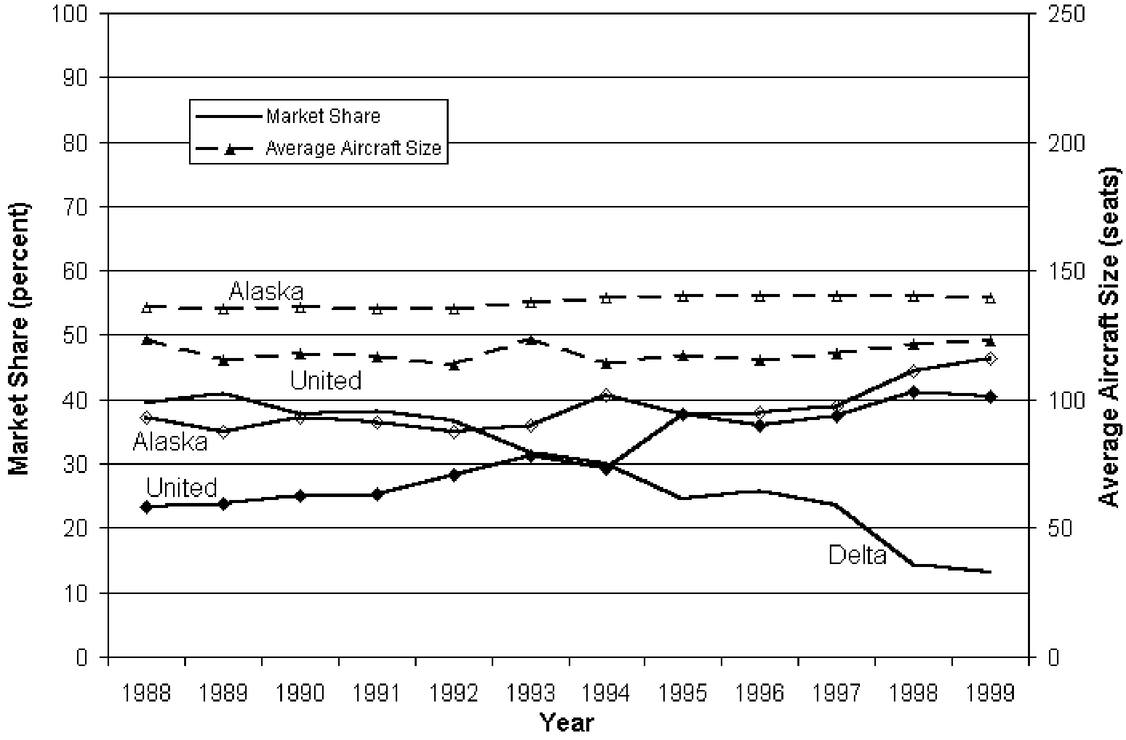


Figure B-20

Market Share Trends LAX-Portland



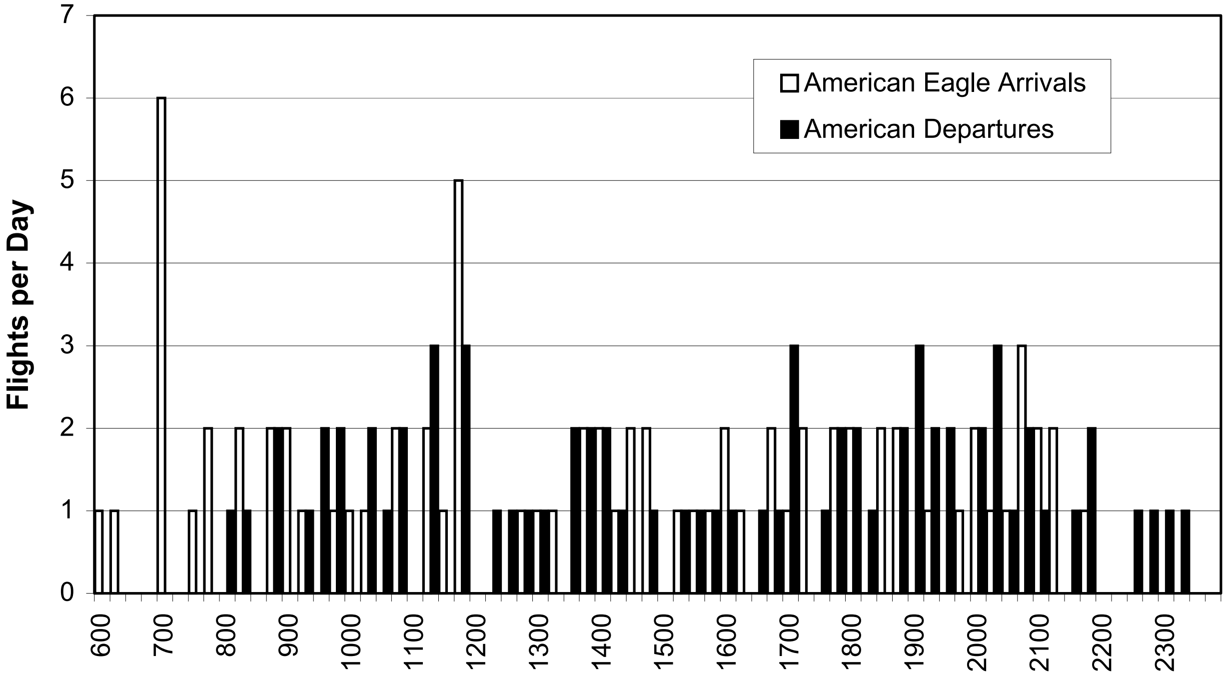
APPENDIX C

Regional Airline Traffic Patterns at LAX

Figure C-1

Flight Schedule Coordination between American Eagle and American Airlines

Typical Weekday Schedule - July 1999



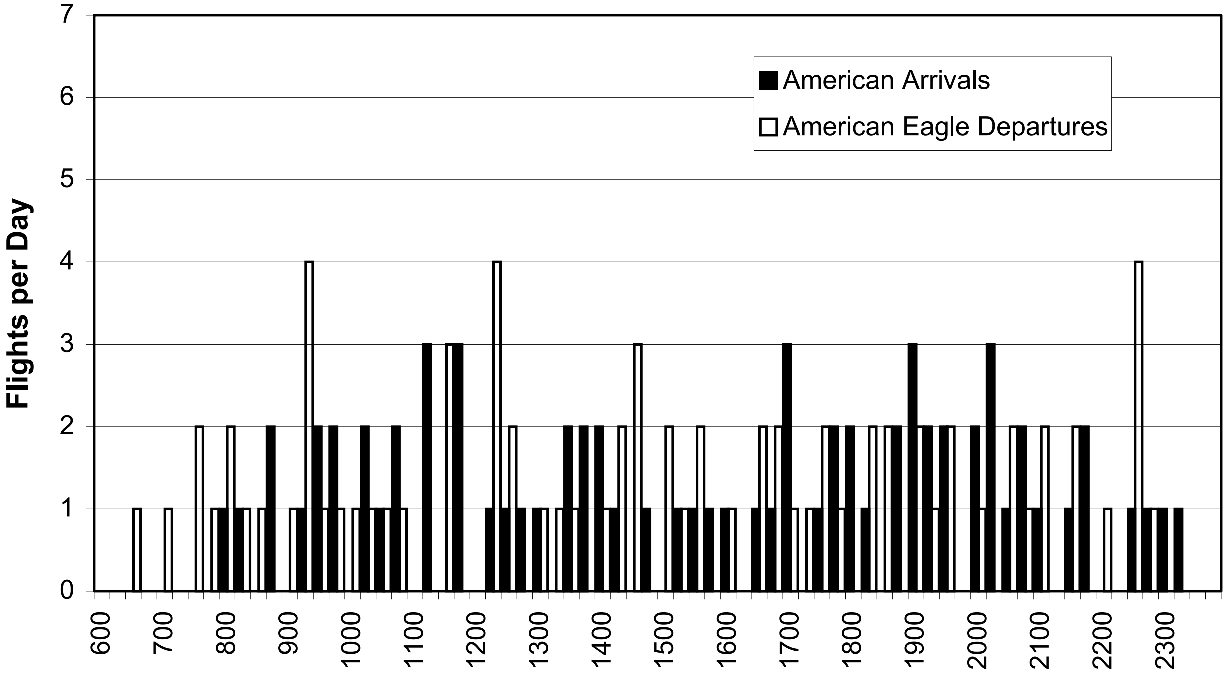
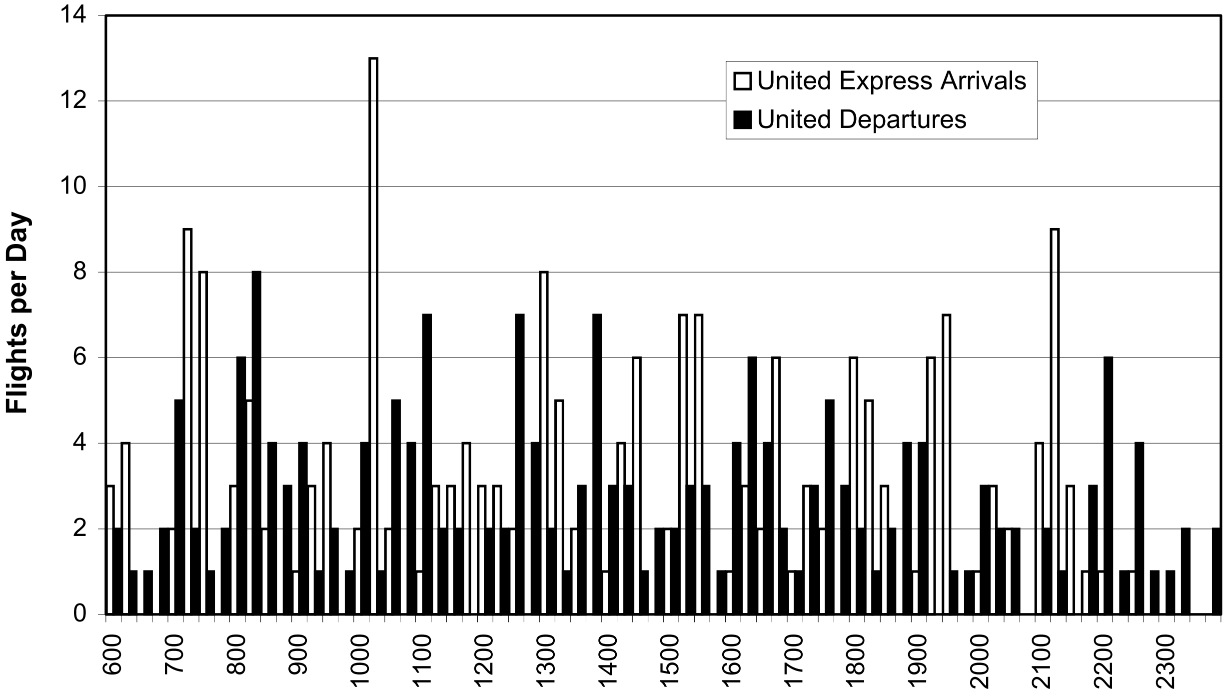


Figure C-2

Flight Schedule Coordination between United Express and United Airlines

Typical Weekday Schedule - July 1999



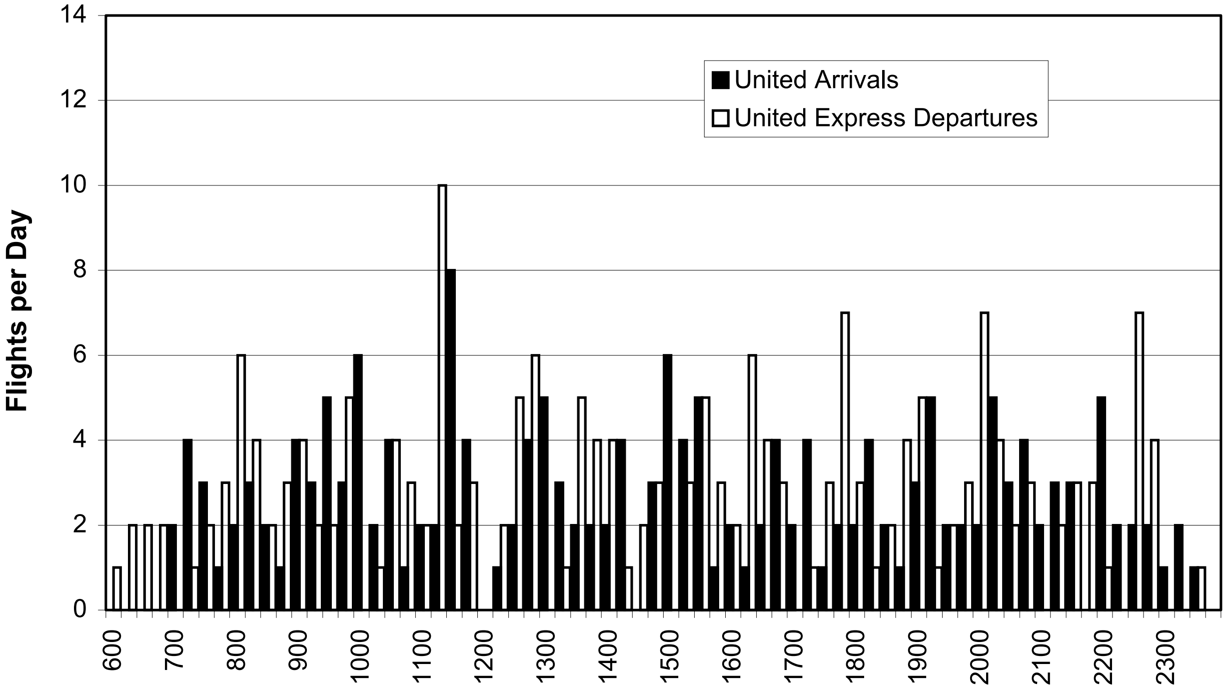


Table C-1
Changes in Regional Airline Flight Schedules from LAX
July

		Weekly Departures			Seats		
To	Airline	1998	1999	2000	1998	1999	2000
Bakersfield	American Eagle	27	35	35	132	165	165
	Delta Connect.	49			210		
	United Express	56	63	56	240	270	240
	Total	**132**	**98**	**91**	**582**	**435**	**405**
Carlsbad	American Eagle	40			198		
	United Express	56	62	76	240	270	330
	Total	**96**	**62**	**76**	**438**	**270**	**330**
El Centro	United Express	35	32	33	150	150	150
Fresno	American Eagle	48	69	76	231	330	363
	Delta Connect.	42			180		
	United Express	76	125	131	330	540	570
	USAir Express	54	54		162	162	
	Total	**220**	**248**	**207**	**903**	**1,032**	**933**
Inyokern	United Express	34	19	19	150	90	90
Las Vegas	American Eagle	28	35	14	132	165	66
Merced	United Express		19	20		120	120
Monterey	American Eagle	21	35	35	99	165	165
	Delta Connect.	35			150		
	United Express	70	118	112	300	510	480
	Total	**126**	**153**	**147**	**549**	**675**	**645**
Ontario	United Express	53	74	80	240	330	360
	USAir Express	20			72		
	Total	**73**	**74**	**80**	**312**	**330**	**360**
Orange County	Delta Connect.	41			180		
	United Express	54	76	104	240	330	450
	Total	**95**	**76**	**104**	**420**	**330**	**450**
Oxnard	United Express	56	56	42	240	240	180

Table C-1 (cont.)

		Weekly Departures			Seats		
To	Airline	1998	1999	2000	1998	1999	2000
Palm Springs	American Eagle	34	34	41	165	165	198
	Delta Connect.	35			150		
	United Express	90	117	62	390	510	270
	USAir Express	28	34		90	108	
	Total	**187**	**185**	**103**	**795**	**783**	**468**
St. George, Utah	United Express		7	14		30	60
San Diego	American Eagle	111	181	202	528	858	957
	Delta Connect.	63			270		
	United Express	141	225	107	630	990	480
	USAir Express	110	110		306	324	
	Total	**425**	**516**	**309**	**1,734**	**2,172**	**1,437**
San Jose	American Eagle	7	7		33	33	
	United Express	49			210		
	Total	**56**	**7**		**243**	**33**	
San Luis Obispo	American Eagle	41	48	48	198	231	231
	United Express	56	77	70	240	330	300
	Total	**97**	**125**	**118**	**438**	**561**	**531**
Santa Barbara	American Eagle	55	82	69	264	396	330
	Delta Connect.	49			210		
	United Express	95	126	41	420	540	180
	USAir Express	40	42		108	108	
	Total	**239**	**250**	**110**	**1,002**	**1,044**	**510**
Santa Maria	United Express	55	62	62	240	270	270
Santa Rosa	United Express		28	28		120	120
Visalia	United Express	20	19	19	90	120	120
Yuma	United Express	42	34	41	180	150	180