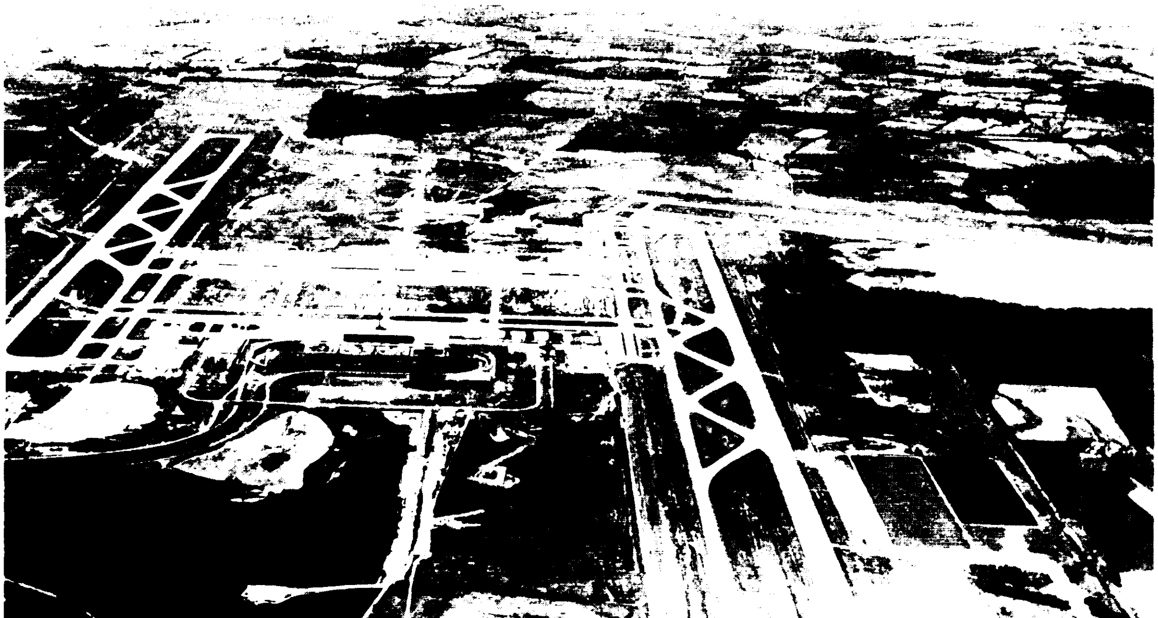
Chapter 6

AIRPORT CAPACITY ALTERNATIVES



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Chapter 6

AIRPORT CAPACITY ALTERNATIVES

INTRODUCTION

The ability of airports to accommodate traffic can be expressed in terms of "airside" or "landside" capacity. "Airside" capacity is defined here as the number of air operations—landings and takeoffs—that the airport and the supporting air traffic control (ATC) system can accommodate in a unit of time, such as an hour. The capacity of an airport is not a single number, but will vary with the number of runways in use, the visual or electronic landing aids available, the types of aircraft being accommodated, the distance between aircraft in the approach pattern, and the noise abatement procedures in effect. The time each aircraft occupies the runway and the facilities for handling aircraft on the ground, on taxiways, or at gates also affect airside capacity. All of these factors will vary depending on the weather.

"Landside" considerations, such as the size and number of lounges or the adequacy of baggage-handling equipment, affect the number of passengers an airport terminal can accommodate. Ground access, including the adequacy of transit connections, roadways, and parking areas for passengers' cars, is an important part of an airport's landside capacity, and in some cases has become a limiting factor on an airport's ability to handle passengers. Recent discussion about putting a quota on operations at Los Angeles International Airport, for example, is related to growing ground access problems, not lack of airside capacity.

This chapter discusses alternatives to increase airport airside capacity. Landside problems will only be treated here as they affect airside capacity.

When the traffic demand for an airport approaches or exceeds its capability, the result is delay. Delay has been a major problem at the Nation's busiest airports, resulting in millions of dollars of increased operating costs for air carriers and wasted time for travelers. Although several different methods of measuring delay exist (as will be discussed later) it is generally agreed that the six airports most affected by delay in 1980 *were:* O'Hare (Chicago), Stapleton (Denver), La Guardia and JFK (New York), Hartsfield (Atlanta), and Logan (Boston). As shown in table 8, most of the airports which report

Table 8.— "Top" U.S. Airports, by Enplaned Passengers, by Air Carrier Operations, and by Reported Delays

	Passenger enplanements	Air carrier operations	Delays over 30 minutes
1.	Chicago O'Hare	Chicago O'Hare	Chicago O'Hare
2.	Atlanta Hartsfield	Atlanta Hartsfield	Denver Stapleton
3.	Los Angeles International	Los Angeles International	New York La Guardia
4.	New York J.F. Kennedy	Dallas-Ft. Worth	New York Kennedy
5.	San Francisco International	Denver Stapleton	Atlanta Hartsfield
6.	Dallas-Ft. Worth	Miami International	Boston Logan
7.	Denver Stapleton	San Francisco International	Los Angeles International
8.	New York La Guardia	New York La Guardia	St. Louis Lambert
9.	Miami International	New York J.F. Kennedy	San Francisco International
10.	Boston Logan	Boston Logan	Dallas-Ft. Worth
11.	Honolulu International	Washington National	Philadelphia International
12.	Washington National	St. Louis Lambert	Newark
13.	Detroit Metro	Detroit Metro	Washington National
14.	Houston Intercontinental	Houston Intercontinental	Miami International
15.	St. Louis Lambert	Honolulu	

SOURCE: *Federal Aviation Administration, Terminal Area Forecasts, Fiscal Years 1981-92,* Washington, D.C. 1981 p 13; Interview, FAA, *Air Traffic and Airways Facilities,* Aug. 20, 1981.

serious delay problems rank among the top 15 airports in terms of both enplaned passengers and air carrier operations.

This chapter first describes the airside components in the operation of a typical airport. It then reviews those major factors which influence or limit airside capacity. Next the chapter discusses the problem of delay—how it comes about and the methods for measuring it and estimating its costs. The next sections outline some alternative methods for reducing delay or increasing the airside capacity. These include changing the pattern of traffic demand, expanding the runway system, or modifying the terminal area air traffic control procedures and equipment. Finally, some suggestions for future research are made.

AIRSIDE COMPONENTS

The airside capacity of an airport is governed by factors related to its runway system and the airspace above and around the airport, as well as the terminal area ATC and navigation equipment and procedures.

The number of runways, their layout, length, and strength will in large measure determine the kinds of aircraft that can use the airport and how many aircraft can be accommodated in any given time period. The layout depends on a number of factors including the local terrain and predominant direction of the wind. Federal Aviation Administration (FAA) safety regulations dictate how close the runways may be to one another and to buildings, trees, or other obstructions.

In order to land on a runway, aircraft approach the runway in single file, with a safe distance between them. Air traffic may enter the airspace around the airport ("terminal area") from many directions at a number of different points ("entry fixes"), and in many metropolitan areas the aircraft may be destined for one of several different airports. Thus, the task of delivering aircraft one by one to a particular runway at a particular airport must begin many miles from the airport itself, and controllers must orchestrate the orderly merging and diverging of many different traffic streams until each aircraft reaches the final approach to its destination runway. By the same token, departing aircraft must be safely routed from the airport to the "departure fix" where they leave the terminal area and join the en route ATC system.

Controllers use both vertical and horizontal separation to maintain safe distances between aircraft, a task that is complicated by their different performance characteristics. Jets flying at a very slow (for a jet) 160 knots will nevertheless overtake and pass slower aircraft. The controller may assign different altitudes so that this can take place safely, or he may vector the faster aircraft along a longer path so that it will safely overtake and pass around the one ahead.

In good visibility conditions, tower controllers may clear aircraft, once they are in sight of the airport, to make a visual landing under tower control. The pilot assumes responsibility for separating himself from other aircraft, with the controller standing by to warn pilots to "go around" in case of a potential conflict. During times of poor visibility the ATC team retains responsibility for separating the aircraft on final approach. In this case the Instrument Flight Rule (IFR) radar minimum separation is observed, so

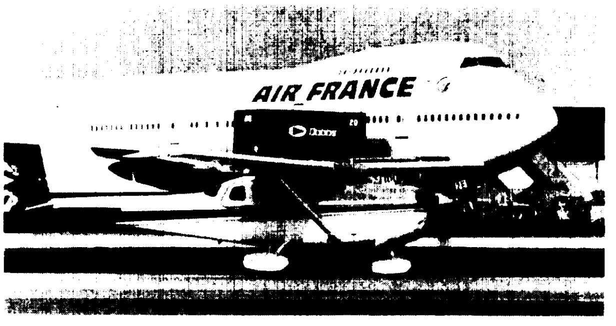


Photo credit Neal Callahan

The variety of airspace system users .

that distances between aircraft are greater than in good weather. Under IFR conditions, pilots are much more dependent on landing aids such as the Instrument Landing System (ILS) to guide them to the runway.

An aircraft is considered to be on the runway from the moment it flies over the runway threshold until it turns off onto a taxiway. Angled "high-speed" turnoffs can allow aircraft to leave the runway at higher speeds than perpendicular ones. Placing the turnoffs where they will be convenient to most of the aircraft using a runway is important for getting maximum capacity from the runway system.

Departures from the airport may take place on a separate runway or may be "interleaved" between arrivals on the same runway. Aircraft preparing to depart can wait beside the runway on holding aprons until the runway is clear; then they can then taxi onto the runway and take off fairly quickly—the time spent on the runway for departure is on the order of *30* seconds.

LIMITATIONS ON AIRSIDE CAPACITY

Among the major factors influencing airport capacity are: aircraft performance characteristics, wake vortex turbulence, weather, airfield and airspace configuration, aircraft noise, ATC equipment and procedures, and demand considerations.

Aircraft Performance Characteristics

Characteristics of the aircraft—their size, aerodynamics, propulsion and braking performance, and avionics—will affect the capacity of the runways they use. Pilot training, experience, and skill will also influence performance, and the capacity of a runway can vary greatly with the types of aircraft using it. Runway capacity is usually highest if the "traffic mix" is uniformly small, slow, propeller-driven aircraft. The next highest capacity would come with a uniform mix of large jets. Where the traffic mix is highly diverse—with jet and propeller aircraft of widely varying sizes and speeds—it is usually difficult to maintain optimum spacing and optimum runway usage, and runway capacity is reduced. The direction of traffic also affects runway system capacity. When arrivals predominate, capacity is lower then when departures predominate.

Wake Vortex

Related to aircraft performance characteristics is the problem of wake vortexes. Aircraft passing through the air generate coherent energetic air movements in their wakes, and under quiescent weather conditions the wake vortex can persist for *2* minutes or even longer after an aircraft has passed. The strength of the vortex increases with the weight of the aircraft generating it. As the use of wide-bodied jets (e.g., B-747 and DC-10) became more common in the early 1970's, it became apparent that wake vortexes behind these heavy aircraft were strong enough to endanger the following aircraft, especially if it was smaller. Until the potential danger of wake vortex to transport sized aircraft was demonstrated (e.g., the 1972 crash of a DC-9 landing in the wake of a DC-10) standard separations of 3 nautical miles (nmi) were required under IFR conditions. In order to prevent accidents caused by wake vortexes, FAA increased the separations for smaller aircraft behind larger ones during weather conditions when persistent vortexes may be a danger. These minimums are shown on the right side of table 9.

Weather

Heavy fog, snow, strong winds, or icy runway surfaces reduce an airport's ability to accommodate aircraft and may even close an airport completely. For a given set of weather conditions, several of the different runway configurations available at an airport may be suitable but only one will have the maximum value. Using these maximum values, and plotting them with the percentage of the year during which different weather conditions are likely to prevail, a

Table 9.—Arrival and Departure Separations

Minimum Arrival Separations— Nautical Miles

Visual Flight Rules*

Lead \ Trail	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

Instrument Flight Rules

Lead \ Trail	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

Minimum Departure Separations— Seconds

Visual Flight Rules*

Lead \ Trail	s	L	H
s	35	45	50
L	50	60	60
H	120	120	90

Instrument Flight Rules

Lead \ Trail	S	L	H
S	60	60	60
L	60	60	60
H	120	120	90

"VFR separations are not operational minima but rather reflect what field data show under saturated condition. Adapted from *Parameters **of Future ATC** Systems **Relating to Airport Capacity/Delay*** **(Washington, D. C.: Federal Aviation Administration, June 1978),** PP. 3.3, 3.5.

"capacity coverage curve" for any given airport can be constructed.

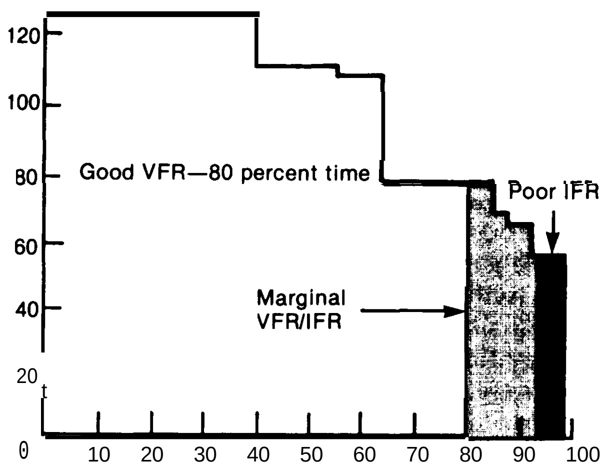
An example of a capacity coverage curve is shown in figure 26. The highest hourly capacity of Boston Logan Airport is 126 operations per hour in Visual Flight Rule (VFR) weather. This combination of highest capacity runway use and good weather is available 40 percent of the year. Strong winds create crosswind components which close some of the runways of that configuration, and hourly capacities continue to decrease as marginal weather and finally bad weather cause restrictions in safely operating the runway system. There is a small percentage *(2* percent) of the year when poor visibility, ceilings, and snow completely close the airport. Notice that there is a wide variation in the hourly capacity from 126 operations per hour down to 55 operations per hour before the airport closes. This is typical of many major airports where several runway combinations exist. This wide variation in hourly capacity prevents the establishment of a single capacity value for the airport; instead, it will be variable depending on weather conditions.

It is difficult to foresee any capital investment in runways or technological improvements to ATC facilities which can completely eliminate

Figure 26.—Airport Hourly Capacity Varies Strongly With Weather

(There is a 3 to 1 or 2 to 1 ratio between good weather/bad weather capacities)

Capacity Coverage Curve—Boston Logan Airport



Average percent of time

SOURCE: Robert W. Simpson, "Airside Capacity and Delay at Major U.S. Airports," draft report prepared for the Office of Technology Assessment, U.S. Congress, Washington, D. C., October 1980.

this degradation of capacity with weather conditions. New runways can raise the overall level of the capacity coverage curve, but they do not

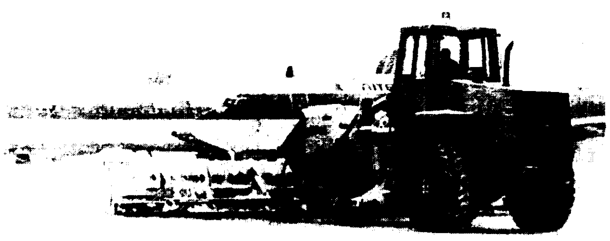


Photo credit: Federal Aviation Administration

Snow control at a terminal

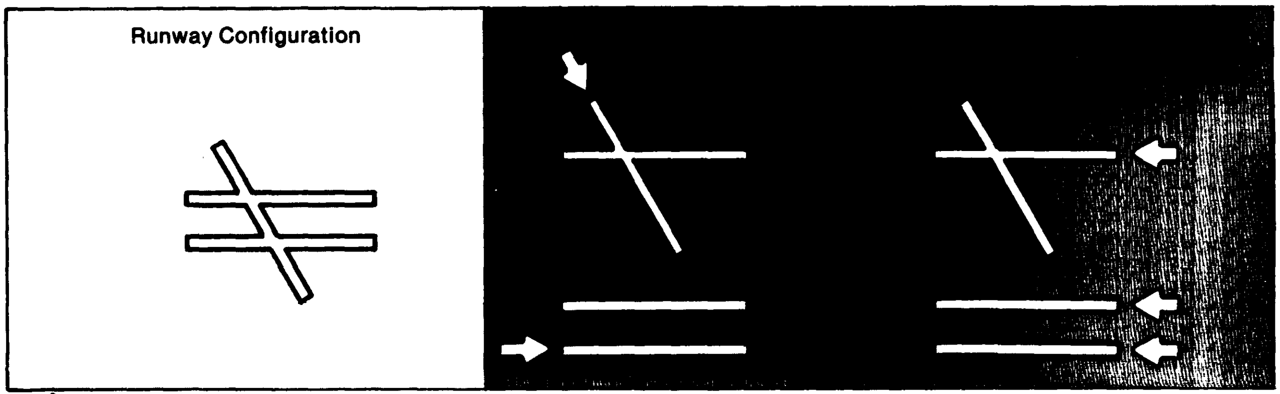
prevent its degradation with weather. Some of the ATC improvements discussed later in this chapter attempt to improve overall capacity by reducing the gap between IFR and VFR performances.

Airfield/Airspace Configuration

The capacity of an airport depends to a large extent on the number of runways available and their interactions. For example, for a given traffic mix a particular runway can handle *65* operations an hour in VFR conditions and 55 in IFR weather. The VFR capacity of two parallel runways, *2,500* ft apart, might then be 125 operations per hour—twice the capacity of a single runway. Yet the IFR capacity of this two-runway system would be *more* like *65* operations per hour, because under IFR conditions runways less than 4,300 ft apart are considered "dependent" for purposes of landings—that is, an operation on one prevents a simultaneous operation on the other. Similar safety restrictions apply where runways converge or intersect with one another. Thus, not only is the capacity of each runway reduced during bad weather, but the capacity of the airport is further reduced because not all runways may be fully used.

In the illustration in figure *27*, the three runways could be used in several different ways, four of which are shown. Each of these combinations may have a different operating capacity, and each might be suitable for a different set of wind, visibility, and traffic conditions. A large airport like O'Hare might have 40 or 50 possible combinations of runway uses. The limitation imposed by the available runway system varies among the top air carrier airports. Chicago O'Hare has seven runways, Kennedy has five, and La Guardia has only two (La Guardia's additional short 2,000-ft runway can be used only for departures during good weather conditions). Yet the capacity relationship is not linear: La Guardia manages to handle *40* percent of O'Hare's total aircraft movements with less than 30 percent of its runways. An adequate taxiway/gate configuration is also needed in order to support optimum runway usage. For instance, the La Guardia Airport capacity task

Figure 27.—Runway Configuration



Arrivals can occur on runway indicated.
Departures can occur on runway indicated.

SOURCE: Federal Aviation Administration, *Techniques for Determining Airport Airside Capacity and Delay, FAA-RD-74-124,* June 1976, force found that additional taxiways in one area were critical to minimizing delays. This is because space at gates was limited, and the additional taxiways could be used to hold and sequence departing aircraft during periods of congestion.

Aircraft Noise

Aircraft noise, especially the noise of jet aircraft, has made airports unpopular with their neighbors. The greatest noise impact is usually in the areas just beyond the ends of the runways, where arriving and departing aircraft fly at low altitudes. If a high-noise area is occupied by a factory or a highway cloverleaf there maybe little difficulty, but such land uses as residences, hospitals, and schools are not compatible with the amount of noise generated by an airport. In some areas, ineffective or nonexistent zoning and land use controls over the years have allowed these incompatible land uses to occupy high noise impact areas near many airports. The courts have generally found that the airport operator is responsible for injury due to reduced property value, and owners of nearby property have been able to collect damages in some cases. In Los Angeles, the courts have recently awarded nuisance damages as well. In some areas, including Atlanta, St. Louis, and Los Angeles, airport operators have been required to purchase noise-impacted property and either use it as a buffer zone or resell it for a more compatible use.

One method for reducing noise is to introduce quieter aircraft or, as many air carriers have begun doing, to re-equip old aircraft with quieter engines. FAA has set standards for new aircraft that are much quieter than in the past, but noisy aircraft will remain in the fleet for many years. The increasing sensitivity of the public to noise may have offset much of the recent improvement.

FAA, at the request of individual airport operators, has also developed operational procedures that reduce noise impact. For example, use of certain runways may be preferred, or pilots may be required to make approaches over less sensitive areas, weather permitting. However,

Photo credit: Federal Aviation Administration

Air use and land use

FAA has established very few mandatory noise-abatement procedures. Over the past few years some operators have conducted airport noise compatibility and land use studies for use as a basis for their own noise planning. The new Federal Aviation Regulation, Part 150, required under the Aviation Safety and Noise Abatement Act of *1979* (Public Law *96-193),* provides operators with guidelines for voluntary noise-abatement standards and establishes a standardized method for measuring noise exposure.

Many of these noise-control procedures have a negative effect on capacity, and airports with both capacity and noise problems have found that the available solutions to one problem often aggravate the other. The highest capacity runway configuration, for instance, may be one which requires an unacceptable number of flights over a residential area. Enforcing noise-abatement procedures may also cause an unacceptable level of delay at peak hours. Thus, airports must balance tradeoffs between usable capacity and environmental concerns.

The FAA Administrator recently reemphasized that the responsibility for establishing proper land-use controls around airports rests with local government. He also predicted that more communities will be establishing local noise limits by ordinance or statute. [f]

A local government, whether or not it is the owner of the airport, can exercise some control *over* noise, but must do so in a manner that is nondiscriminatory and does not place an undue burden on interstate commerce. For example, a city may select a reasonable noise exposure limit and exclude or fine aircraft exceeding that limit. However, the total ban on jet aircraft in Santa Monica, Calif., was overturned by the courts as unduly discriminatory against one class of aircraft (some new jets are quieter than propeller-driven aircraft).

ATC Equipment and Procedures

Improvements in aircraft surveillance, navigation, and communication equipment over the past decade have greatly increased the ability of pilots and controllers to maintain high capacity during all weather conditions (see ch. 5). However, there are still ATC-related limits on airport capacity. Clearances used in the en route airways and the terminal airspace are frequently circuitous, routing aircraft through intermediate "fixes" or control points rather than allowing them to travel directly from origin to destination. While this places aircraft in an orderly pattern so that controllers can better handle them, it also reduces capacity and consumes time and fuel.

"'Helms Places Airport Noise Problems on Operators, Communities," *Aviation* Daily, Sept. 29, 1981, p. 154.

The limitations in the accuracy of surveillance equipment also can influence how airports are constructed and how they may be used. For example, the spacing requirement between independent IFR runways was developed based on the limitations of surveillance, navigation, and communications equipment. Improvements in equipment and procedures have allowed this minimum to be reduced over the years.

Constraints on capacity can arise when airspace near one airport must be reserved to protect operations at another airport. This is an especially pressing problem in some busy areas. There is such an airspace conflict between La Guardia and Kennedy in certain weather conditions, for example.

Demand Considerations

The daily pattern of demand is characteristic of the airport and the travel markets it serves. Air travelers prefer to travel at certain times of the day—midmorning and late afternoon, for example—and air carriers wish to accommodate them. Heavy scheduling at peak hours makes it easier for passengers to transfer to other planes or other airlines, yet (as will be discussed shortly) peaks in demand can be major causes of delay. Even at airports with a high percentage of scheduled traffic it is not possible to predict the actual number of aircraft which will appear at a particular hour of a given day, as nonscheduled traffic volume can vary substantially. At quota airports, the quota is set at a value between the VFR and IFR capacity, resulting in a built-in delay situation whenever weather conditions deteriorate.

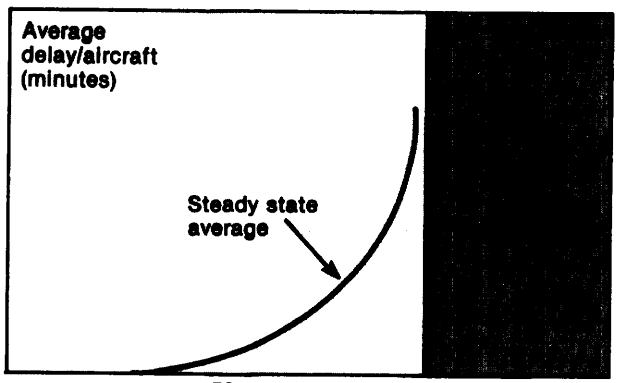
DELAY AND DELAY REDUCTION

Airport delays received a great deal of publicity during the late *1960's* and they continue to be a major waste of time, money, and fuel. Delay can be expected whenever instantaneous traffic demand approaches or exceeds the airport's capacity. When traffic occurs in bunches or peaks, there may be delays even when the number of aircraft using the airport is less than the capacity for that peak time period. Some amount of delay arises every time two aircraft are scheduled to use a runway at the *same* time. The probability of simultaneous arrivals increases **rapidly with traffic density, so that average delay per aircraft increases exponentially well before traffic levels reach capacity levels.**

A typical variation of delay with operation rates is shown in figure *28.* When the traffic level is above capacity, the accumulation of aircraft awaiting service is directly proportional to the excess of traffic over capacity. For example, if the capacity of a runway system is 60 operations per hour and traffic rates are averaging 70 operations per hour, then every hour will add an average of 10 aircraft to the queues for service, and 10 minutes to the delay for any subsequent arrival or departure. Even if the traffic level drops to 40 operations per hour, delays will persist for some period since the queues will be depleted at a rate of only **20** aircraft per hour.

The principal delay-reporting systems of FAA currently measure only the occurrence of large delays. The National Airspace Communications System (NASCOM) delay reports record instances of delays of 30 minutes or more at 46 participating airports. The Performance Measuring System (PMS) records delays of 15 minutes or more at 15 major airports. The PMS also attempts to estimate "average delay per aircraft delayed." Both NASCOM and PMS rely on controller's manual recording of instances and causes of delays during periods when he is already busy. Weather is listed as the primary cause for these delays, ranging from *76* percent of the 30-minute delays in 1976 to 84 percent in 1979 in the NASCOM system. The total number of delays reported also increased, from approximately *36,200* in 1976 to approximately 61,600 in 1979. It must be emphasized that while weather may indeed be the primary cause, the ability of the system to anticipate, adjust to, and recover from weather-related problems is dependent on a number of the other determinants of airside capacity.

Figure 28.—Typical Distributions of Delay



50 percent 100 percent
Traffic rate capacity

SOURCE: Office of Technology Assessment.

Another major delay-reporting system is sponsored by FAA and three airlines—Eastern, United, and American—which have been pooling their operational flight-time data since 1976. This Standard Air Carrier Delay Reporting System (SACDRS) covers 36 airports and measures taxi times, gate holds, and flight times against standard values in an attempt to determine delay. Unfortunately, an error in this method causes an overestimation of delay: for example, the standard times used for taxi in and out are based on the average over *all* runways at a given airport, but at some airports there is wide variation in taxi times for different runways and terminals; some percentage of these longer taxi times are always counted as delay under the SACDRS. FAA recognizes the deficiency in this system, but no correction has yet been devised. Estimates of the annual cost of delay based on SACDRS have ranged as high as *237* million gallons of fuel and *$273* million of additional operating costs to the three airlines involved, although these costs too are overestimated.[2] The PMS and NASCOM systems, on the other hand, because they only count long delays, probably underestimate delay. The true value of delay lies somewhere in between and has not been determined with accuracy. Thus, estimates of the cost of delay based on any of these reporting systems have to be viewed with some caution. However, all observers agree that delay is a serious and expensive problem at some airports, especially in light of the high cost of fuel in recent years.

One method of dealing with delay is to constrain traffic to manageable levels. This is the

‘Virginia C. Lopez (cd.), ***Airport and Airway Congestion, A Serious Threat to Safety and the Growth of Air Transportation*** (Washington, D. C.: Aerospace Research Center, July 1980).

origin of the quota systems which have been imposed at a few major airports. Each carrier has representatives on the "scheduling committees" to negotiate the carrier's share of allowed peak hour operations. FAA, through its flow control center, also works to ameliorate the costs of delays by forewarning air carriers when delay conditions develop at major airports. For example, when weather deteriorates and capacity goes down in Chicago, FAA may advise aircraft scheduled into Chicago to delay their arrival there by waiting on the ground at other cities. Waiting on the ground is much less wasteful of fuel than waiting in holding patterns in the air.

Although the lengthy delays of the late 1960's are no longer typical, delay remains a major problem at many airports. Further, the number of operations will increase as air traffic grows, and additional airports may experience this problem. Some possible approaches to dealing with delay are discussed below.

DEMAND= RELATED ALTERNATIVES

Delay problems tend to be concentrated at the Nation's major airports, and even at these locations the problem is most acute during certain hours of the day (usually midmorning and late afternoon). If operations could be shifted from these peak hours to less busy times, delay could be reduced and the overall capacity of the airport better utilized. Variable user fees or quotas during peak hours are tools which have been suggested, and tried at some locations, to reduce peak demand and increase operations in nonpeak hours. All these mechanisms, however, reduce the ease of transferring from one flight to another at hub airports, making it harder to achieve ideal airline economics.

Peak-Hour Pricing

Most airports now charge a landing fee based on the weight of the aircraft. This fee schedule is designed to recover construction and operating costs of the airport, not to ration capacity. However, when the use of an airport is nearing capacity it could be more economically efficient to base landing fees on the marginal costs imposed by each additional aircraft served. This means that the user should pay not only for use of the airport, but for the delay caused other users who want to use it at the same time. This method allows users who value access to the airport at peak times to pay for their preference; those who do not wish to pay the higher fee would use the airport at other times, or perhaps use another airport.

In general, peak-hour pricing would have little effect on air carrier operations unless the price changes are very large. Airlines schedule flights when they think passengers will want to fly, and they would probably be willing to absorb moderate increases in user fees in order to use the airport at those times. Even a landing fee of several hundred dollars would be small compared to the total operating costs of a large jetliner, and such an expense could be passed on to the passenger by a relatively small increase in fares. Commuter air carriers, with their smaller number of passengers, would be unable to pay landing fees quite as high as the larger carriers.

General aviation (GA) users on the other hand, especially student and personal flyers, are more sensitive to increases in landing fees. The Port Authority of New York and New Jersey's 1968 decision to increase minimum landing fees from $5 to $25 during peak hours brought about an immediate decline of about 30 percent in GA operations during peak hours at its three air carrier airports (JFK, La Guardia, and Newark) and a noticeable decline in aircraft delays of *30* minutes or more.[3] In 1979, a $50 surcharge added to peak-hour landing fees at Kennedy and La Guardia resulted in a further decrease in GA traffic at those airports.[4] The remaining GA users were

[3] *Airport Quotas and Peak Hour Pricing: Theory and Practice* (Washington, D. C.: Federal Aviation Administration, 1976), pp. 54-60.

[4] Port Authority of New York and New Jersey, Aviation Department, interview, Oct. 23, 1981.

primarily high-performance turboprop aircraft used for corporate travel; corporations, like the airlines, may be willing to absorb a fairly large increase in fees in order to use specific airports during peak hours.

One problem with a peak-hour pricing system is that it is difficult in practice to determine precisely what the marginal cost of an airport operation is; several years of trial and error would be necessary to settle on a pricing scheme which both controlled delay and allowed the airport to cover its costs. However, if the same fee were charged to air carrier, commuter, and GA aircraft, peak-hour pricing might be strongly resisted. Proportionately different fees for different categories of users might therefore be necessary.

Quotas

An alternative method for managing demand is to set a quota on the number of operations which can take place during a peak hour. The quota can be placed on total operations, or a certain number of operations can be allocated to different classes of users. The quota levels are usually set between the IFR and VFR capacity of the airport; thus, in VFR conditions, additional aircraft could easily be accommodated. When capacity is reduced, users without reservations have to use the airport at another time or use another airport.

Although reservations (slots) for GA or even air taxis might be allocated on a first-come, first-served basis, slots for scheduled carriers present a more complex problem. At major airports where quotas have been in effect for some time (O'Hare, JFK, La Guardia, and Washington National) representatives of the air carriers are allowed (with antitrust immunity) to meet as scheduling committees to negotiate how many slots will be allocated to each carrier. Although new entrants are able to participate in these negotiations, quota systems do tend to favor the status quo. Since the air traffic controllers strike in August, 22 airports have been brought under a quota system designed principally to ease peaks of demand on the en route ATC system. The methods for assigning slots to new entrants or allowing existing carriers to exchange slots are still under development.

One objection to quota systems is that the allocations are made without any price signals to show that the capacity is being used efficiently. Thus, although the quota may provide some stop-gap congestion relief, it does not provide any long-run guide for allocating resources as the system grows or changes. It has been suggested that this problem could be overcome by auctioning the reservation slots among the carriers or by combining the quota system with some sort of peak-hour pricing scheme.

Balanced Use of Metropolitan Area Airports

Many major metropolitan areas are served by two or more large airports. Where one or more of these airports is underutilized, possibilities exist for increasing airside capacity through a more balanced use of the region's airports. Examples include: Newark Airport, which is underutilized compared to Kennedy and La Guardia; Oakland Airport, which could relieve San Francisco; Midway Airport, which is practically empty while Chicago-O'Hare has delay problems; and Baltimore-Washington and Dunes Airports, which might relieve Washington National. The problem of balancing use of metropolitan airports presents a chicken/egg dilemma: airlines won't serve the underutilized airport because there are so few passengers, and passengers don't go there because there is so little service. It is difficult to foresee when congestion in itself will become great enough to cause redistribution, or to what extent the process can or should be managed by local or even Federal authorities. In some cases, better transportation between airports might make it easier to transfer between flights and to attract passengers to underutilized airports.

The Washington, D. C., area is illustrative of the problems of imbalance airport use. Washington National Airport, operating since the mid-1940's, is convenient to the downtown area. National has three runways (all under *7,000* ft) and does not accept wide-body jets. Both its airside and landside capacity are severely limited and a quota system and airline scheduling committee are used to ration peak-hour operations. Expansion is difficult due to surrounding development and the Potomac River. Complaints about the airport's noise have led to a 10 p.m. curfew among other noise abatement policies. From time to time some groups even call for the airport to be closed.

Many of these problems could be alleviated if some operations were transferred to Dunes International Airport, *26* miles from Washington. Dunes, opened in *1962*, has two 11,500-ft runways, one 10,000-ft runway and capacity to spare. FAA (which operates both airports) has repeatedly attempted to induce carriers to use Dunes more; for example, only Dunes can receive international and long-range domestic flights. Despite the constraints of the quota system, the curfew, and the restrictions on wide-body and long-range flights, however, National handled nearly 4 times the operations and 4½ times the passengers that Dunes did in 1980. Further, National generated a net profit of $10 million that year, while Dunes incurred a net loss of $3 million.[5] The principal problem is ground access; it is more convenient to fly from National than from Dunes.

Some new airlines beginning service since deregulation have sometimes deliberately chosen to operate out of underutilized airports to avoid congestion and delay. One example is Midway Airlines, which uses the nearly abandoned Midway Airport for its Chicago service. Midway's problem is also related to ground access: congested highways make trips to the airport long even though Midway is closer to downtown Chicago than O'Hare. Another example is People Express, which serves the New York area from Newark. The Port Authority of New York and New Jersey has been offering incentives to passengers as well as airlines to increase the use of Newark Airport: improved ground access by train and express bus allows New York City passengers to get to Newark without paying high interstate taxi fares, and new airlines are offered more and better space for future growth at Newark. In addition to People Express, New York Air has located part of its operation at Newark. Now that permission has been gained to use Newark as a international airport, several established airlines are also bidding to offer transatlantic service from there.

[5]Interviews, FAA, Metropolitan Washington Airports, July 6, 1981.

Restructuring Airline Service Patterns

When delay becomes intolerable at busy hub airports, users themselves may voluntarily move their operations to another facility. This movement might be to an underutilized airport nearby (e.g., Newark), but it could also be to a medium or small hub located at some distance from the congested hub. This is especially likely for transfer traffic. (See ch. 4 for a discussion of the growth and capacity impacts of this redistribution scenario.)

Many major airports currently serve as hubs for a large amount of transfer traffic. Three-fourths of the arriving passengers at Atlanta and about one-half the passengers at O'Hare, Dallas-Fort Worth and Denver pass through these airports only to change planes for somewhere else. Carriers choose to establish their hubs at these busy airports so that passengers can choose from many transfer flights. However, when the transfer airport becomes too congested the disadvantages of delay may begin to outweigh the advantages of convenience, for airlines as well as passengers. Hence carriers may decide to locate their new transfer operations, and even move their existing hubbing activities, to other cities that have more room for growth.

Redistribution of operations appears to be occurring under the new routing freedom available under the Airline Deregulation Act of *1978*. Carriers are finding it easier to change their routes and establish new "second-tier" hubs at less congested airports. Between *1978* and 1980 the number of large hubs (handling more than 1 percent of total U.S. passenger traffic) fell from *26* to *24*, while the number of medium hubs (handling 0,25 to 0.99 percent) increased from *33* to 36—a market shift reflecting the distribution of operations over more airports. This trend may accelerate as regional carriers modify their patterns of service, and even the busiest airports such as Atlanta and O'Hare, may see actual declines in both enplaned passengers and operations in the next 10 years. A similar decline in operations occurred at Kennedy Airport when international flights were allowed to enter the United States at other gateway cities.

Reliever Airports

In metropolitan areas where there is congestion at the main airport and excess capacity at surrounding airports, diversion of GA traffic would be effective in improving the use of airside capacity in the whole region. It would allow a higher level of service for both air carrier and general aviation, and in most metropolitan areas there are smaller airports which might potentially attract some GA traffic away from the main airport. For example, FAA lists *27* airports in the Chicago area, 51 around Los Angeles, and 52 in the Dallas-Fort Worth metropolitan area. However, most of these airports are quite small, and only a few have runways long enough to accommodate business jets or instrument landing equipment for bad-weather operations.

The FAA's National Airport Systems Plan (NASP) designates 155 airports as "satellites" or "relievers" to major airports, and NASP provides for separate Airport Development Aid Program (ADAP) funding to be set aside for relievers. Publicly owned reliever airports may use ADAP funds for construction, installation of safety equipment, and other eligible expenditures. The *25* or so privately owned reliever airports, although they presumably provide the same benefit in terms of diverting traffic from congested air carrier airports, are not eligible for aid. Local and State governments may, however, use ADAP funds to help purchase privately owned reliever airports, and at least five reliever airports have changed from private to public ownership since 1973. One privately owned reliever, Chicagoland (a reliever for O'Hare) closed in 1978. Although the FAA reliever program was initiated largely to segregate training activities from major commercial airports in the interests of safety, it also provides additional airport capacity for a certain type of traffic—namely, personal GA aircraft with origins or destinations in the local region; business and commercial GA (i.e., corporate aircraft and air taxis) delivering or picking up airline passengers will probably continue to use the major commercial airport.

The process of diverting the personal GA traffic has already occurred at the Nation's largest major commercial airports. The fraction of GA activity at Atlanta, O'Hare, Kennedy, Los Angeles International, etc., is very small (about 10 percent) because these regions have good alternate secondary airports with high levels of traffic. In fact, some of the large relievers such as Van Nuys and Long Beach, Calif., Opa Locka, Fla., and Teterboro, N. Y., are among the busiest airports in the country in terms of annual operations. This trend toward establishing a system of reliever airports is underway and has been endorsed by many user groups and observers, most recently the President's Task Force on Aircraft Crew Complement. [6]

To be of maximum benefit the reliever airport should be located so that approach and airspace conflicts between the reliever and the commercial airport do not place capacity limits on both. In the New York area, for example, instrument operations at Linden and Teterboro reliever airports must alternate with operations at the Newark Airport. In addition, the noise consequences of increasing operations at the reliever airport must be considered. Most reliever airports have, or will soon have, IFR landing aids and runway systems capable of handling sophisticated GA aircraft. To be most attractive to users, airports should also have commercial services for aircraft servicing, repair and maintenance, ground transportation, and flight crew amenities. With sufficient amenities, such an airport might even attract some commuter airline service, although transfers and interlining would be difficult unless the airport is served by several carriers or has excellent ground access to a major hub. In some cases, however, the provision of better facilities may not be sufficient to divert additional GA traffic away from major hub airports. Increased landing fees at the major airport can

[6] *Report of the President's Task Force on Aircraft Crew Complement* (Washington, D. C.: July 2, 1981).

provide additional incentives for this shift, and such pricing policies—the domain of local government and airport authorities—could be looked upon as a complement to the Federal program of investment in satellite airports.

AIRPORT DEVELOPMENT ALTERNATIVES

Expanding Existing Airports

Because runway availability is the major constraint on airside capacity, one way to increase capacity is to add more runways. A new long runway, properly equipped for independent IFR operations can increase an airport's capacity by *20* to 50 percent depending on the original runway configuration.

Adding another runway, however, requires a large amount of land. One 11,000-ft runway for large jet operations with its basic safety areas covers *130* acres, and when other necessary "clear zones" are considered, an area three to four times that size would be directly affected. Further, the additional operations enabled by the new runway would probably require landside additions such as new gates, terminal space, and parking for more passengers. Few airports have the necessary land for this kind of expansion, which could add approximately 10 percent to their present area, and for some airports like Washington National and La Guardia, the prospect is especially bleak. Even for larger airports, obtaining proper spacing from other runways would be extremely difficult.

A 1977 report by the Department of Transportation (DOT) studied the possibility of major expansion at 24 airports to meet projected needs for 1985-2000. Expansion was found to be "feasible" in only four of these cases, and none of these four airports (Detroit, Houston, Minneapolis, and Pittsburgh) are among those which are experiencing the greatest capacity problems. In 9 other cities the DOT study found expansion "feasible within major constraints," and in 11 cases it was considered "not feasible." Both economic and environmental reasons were cited for preventing the land acquisition. ' Airport designers foresaw the need for growth and most major airports were built where land was plentiful, but sites that were on the edge of town in *1925* or *1948* are now in the middle of urban development. In some cases the airport itself attracted businesses; in other cases development simply resulted from good highways, suburbanization, and all the other forces which have caused urban areas to expand over the years. Developed land tends to be expensive to buy: a recent study of the cost to acquire and clear land around some major air carrier airports estimated these costs at between $100,000 and $200,000 per acre.[8] Noise is among the largest environmental obstacles to airport expansion. Chicago-O'Hare has sufficient land for an additional runway, but the runway has not been built in part because it would cause unacceptable noise exposure in nearby neighborhoods. JFK Airport in New York is surrounded by intensive development on one side and a National Park and Wildlife Sanctuary on the other, making expansion unlikely. Dallas-Fort Worth, on the other hand, is planning an additional major new runway that is expected to ease some of the capacity limitations imposed by noise abatement procedures and airspace conflicts with nearby Love Field.

Development of Secondary Runway Operations

At some airports where major expansion is unlikely it may still be possible to add one short runway for smaller, slow-moving commuter and GA aircraft. This could improve airport capacity by diverting traffic from the longer runways and may also provide a partial solution to the wake vortex problem (previously discussed). Many airports routinely use short runways, or sections of long runways, for small aircraft dur-

'*Establishment of New Major Public Airports in the United States* (Washington, D. C.: Federal Aviation Administration, August 1977), p. 6-5.

[8] Louis H. Mayo, Jr., "Noise Compatible Land Uses in Airport Environments, " *Environmental Comment,* March 1979, p. 9.

ing good weather, but because of inadequate landing aids or spacing these runways cannot be used during bad weather; all-weather operations would require additional navigational and approach guidance equipment.

One study found that the use of short IFR runways for small aircraft was feasible at 11 of 30 major airports. Of these 11, suitable runways already existed at 3 airports, existing runways could be extended for use at 2 others, and at 6 airports space was available for short runways to be constructed. The study estimated that the value of reduced delays brought about by the addition of such runways might be $450 million to $810 million in current dollars between 1980 and 1990 at the airports shown in table 10. The benefits would be unevenly distributed: Chicago, Atlanta, Philadelphia, and Denver would receive 80 to 85 percent of the estimated savings; among the users, 86 to 89 percent of the savings from reduced delays would accrue to the air carriers.[9]

A detailed study of the airfield and airspace at each airport would be needed to see if the short runway could really be constructed. Such studies done at Denver revealed two possible locations for a short GA runway. Construction of either one could lead to a 35 to 70 percent increase in hourly operations, depending on weather conditions. Total cost was estimated at about $10.8 million.[10]

Building New Airports

Another way to increase airport capacity is to build a completely new airport to replace or supplement the existing one, an alternative that is especially attractive where landside facilities (terminals, baggage equipment, parking) are also outmoded or inadequate. A new site would provide the opportunity to design and build runways, terminals, and parking space to meet future needs, rather than making do with what has evolved over time. Sufficient land could be purchased to allow for future growth and proper land-use controls could be applied so that noise compatibility problems do not arise again. In some recent airport relocations, however, this did not work as well as hoped. For example, at both Dallas-Fort Worth Regional Airport and Kansas City International Airport, built in the mid-1970's, encroachment by other land uses is again leading to complaints about airport noise. On the other hand, Montreal's new Mirabel Airport seems to have little problem with noise incompatibility; the airport itself covers 17,000 acres, and is surrounded by an additional 21,000 acres controlled by a specially created municipal authority. However, its distance from the city makes access a problem.

Building a new airport also provides an opportunity to add a large amount of new airside capacity to a region. The opening of Kansas City International, for example, more than doubled the available capacity in that hub from the estimated 195,000 operations at the old municipal airport to about 445,000 with the new airport. Love Field in Dallas handled 410,000 operations in 1972; in 1977, after air carrier operations were transferred to Dallas-Fort Worth Regional Airport, Love Field still had 310,000 operations (mostly GA), while the new airport had 385,000.

A 1977 investigation by DOT found that anywhere from 2 to 19 new airports might be needed in the United States by the year 2000, depending on the growth rate assumed. When the study examined the feasibility of new airport construction for 10 hub areas, it found it to be "feasible" in four instances, "doubtful" in four, and "not feasible" in two. The reasons for the "doubtful" and "not feasible" findings are related primarily to site location, land acquisition, funding problems, and the difficulty of providing adequate ground access to a remote location. The FAA's 1980 NASP foresees the possibility of a new airport opening at Palmdale, Calif. (near Los Angeles), within the next 10 years; some initial work on new airports at Atlanta and San Diego might also be expected within the next decade.[12]

[9] John D. Gardner, ***Feasibility of a Separate Short Runway for Commuter and General Aviation Traffic at Denver***, prepared for the Federal Aviation Administration by The Mitre Corporation, McLean, Va., May 1980, pp. 1-1.

[10] John D. Gardner, Extensions ***to the Feasibility Study of a Separate Short Runway for Commuter and General Aviation Traffic at Denver***, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., September 1980, pp. 4-3 and 7-1.

[11] ***Establishment of New Major Public Airports***, op. cit., p. *7-16.*

[12] ***National Airport System Plan, Revised Statistics 1980-1989*** (Washington, D. C., Federal Aviation Administration, 1980) p. vi.

Table 10.—Operational Characteristics of Airports With Potential Benefits From a Separate General Aviation Runway

Modification	Parallel independent operations	Parallel dependent operations	Nonparallel dependent operations
New runway	Chicago[c], Atlanta[c], Dallas-Ft. Worth[c], Denver	Philadelphia, Pittsburgh[ab]	
Existing runway or taxiway		Detroit[a,b]	Portland, St. Louis
Extension of Existing runway		New York (JFK)[a], Indianapolis	

[a]The general aviation runway is Independent of 1 of 2 air Carrier runways for departures.
[b]General aviation runway handles departures only
[c]Triple parallel runways.

SOURCE: J. D. Gardner, "Feasibility of a Separate Short Runway For Commuter and General Aviation Traffic at Denver, " prepared for the Federal Aviation Administration by Mitre Corp., McLean, Va., May 1980.

Building a new airport is a huge undertaking. A new air carrier airport can represent an investment of $5 billion, to be shared among the airport sponsor (and local taxpayers), airport concessionaires, the airlines (through their landing fees), and the Federal Government. Even a modest-sized GA airport would cost several hundred million dollars. The length of time required for planning and construction of a large airport—up to 10 years—can also add substantially to costs. Political and institutional factors can also pose substantial difficulties. Building an airport requires agreement from existing air carriers to move to the new facilities, but while a new airport can reduce delays it will also increase airline costs, and they must be convinced that the benefits will outweigh the costs. Further, approval and support of a number of State, county, and municipal governments, not to mention highway districts, zoning commissions, and various citizens' interest groups, must also be secured.

In some cases the divergent interests of different governments and constituencies can snarl the process. In St. Louis, for example, a site for a new airport was selected across the Mississippi River in Illinois. The Illinois State government was a major supporter of the project, as were the St. Louis city government and FAA. The opponents included citizens groups of the county where the new airport would be located (who objected on environmental grounds), the State of Missouri (which did not want the airport moved out of the State), and groups in St. Louis (which did not want the city to give up the close-in Lambert Airport). The project was debated for several years, but it was shelved after a change in the St. Louis city government.

Photo credit: Federal Aviation Administration

The design of a modern airport: Dallas-Fort Worth

ATC IMPROVEMENT ALTERNATIVES

As mentioned earlier, existing ATC procedures and equipment can represent constraints on the airside capacity. Improvements in these areas can increase the number of aircraft operations.

Airfield/Airspace Configuration Management

The ATC team at an airport decides how the runway and ATC equipment should be used based on wind, visibility, traffic mix, ratio of arrivals to departures, noise-abatement procedures, and the status of the airport (which run ways or landing aids are under repair, etc.). In a large air carrier airport like O'Hare, there may be *40* or 50 ways in which the runways can be used, so deciding which one offers maximum capacity for any particular set of conditions is a complex task. The problem is compounded by the interdependence of runway use and the configuration of the surrounding airspace. For example, changing which runway is used for landings may change the route that approaching aircraft must take through the terminal airspace, which may in turn affect or be affected by activity at other airports in the vicinity.

One FAA analysis of capacity and delay problems in Chicago suggested that proper management of airfield and airspace could have a large payoff:

> Optimized management of the air traffic control system . . . could achieve now, at minimum investment cost, savings comparable to those that will be achieved much later at much higher cost when third generation ATC hardware is deployed. This highlights the importance of FAA management exploration of opportunities for improved system efficiency by placing emphasis on optimization of operations at least equal to that given development of ATC hardware.[13]

After study of the runway system of O'Hare airport, the task force found that a computerized airspace / airfield management system could be used to assist the controller team in selecting the highest capacity and most energy-efficient runway use for each set of circumstances.

Such a system could have several levels of complexity. In its basic form it would aid in selecting the preferred runway configuration for a given set of conditions; this basic system is under development by FAA. The intermediate form would update this assessment as changes in weather or traffic conditions arise, and then select the most efficient means of making the transition from the one configuration to another. (This is important because the transition period is often a time when airspace and airport capcity are wasted.) The advanced version would have the ability to make longer term strategic decisions. The 1978 Chicago task force suggested that savings of $11 million to $16 million annually in reduced delay costs might be expected from the basic system alone.[14]

Wake Vortex Prediction

Alleviation of the wake vortex problem offers the possibility of a substantial potential payoff in increased capacity without large capital expenditures for new runways. Research over the past decade has shown some possible ways of doing this. For example, it has been found that certain wind conditions can quickly dissipate a vortex or remove it from the path of oncoming traffic. If wind conditions can be accurately monitored and quickly analyzed, then the likelihood of wake vortex danger can be known on a minute-by-minute basis.

FAA has been testing such a system at O'Hare Airport since 1977. Wind sensors are located on 50-ft towers near the runway ends. **A** computer analyzes wind conditions and when persistent vortexes are unlikely it gives the controller team a "green light" to permit reduced separations on final approach. To have maximum effect (e.g., to allow all separations to be reduced to 3 nmi), an advisory system would have to be able to

"*Delay Task Force Study, Volume 1: Executive Summary, O'Hare International Airport* (Chicago: Federal Aviation Administration Great Lakes Region: July, 1976), p. 4.

"Ibid.

predict the likelihood of wake vortexes at greater distances and higher altitudes than the Chicago system now does. However even this prototype system has been credited with allowing reduced average separations, and thus more operations per hour, at O'Hare. There are no current FAA plans for implementing full scale wake vortex advisory systems at other airports.

Microwave Landing System (MLS)

As discussed in chapter 5, MLS allows airspace to be used more efficiently than the current ILS, since aircraft would be able to approach the airport on curved paths, as they do under visual conditions, and turn onto their final approach much closer to the runway." Variable MLS glide slope angles could also provide a partial solution to the long separations required to avoid wake vortex; with MLS, the trailing aircraft could avoid the vortex by approaching the runway at a steeper angle than the lead aircraft.

Models suggest that where the traffic mix contains a variety of fast and slow aircraft, the use of variable glide slopes could allow some capacity improvements—perhaps around 10 to *15* percent. However, where aircraft have similar performance characteristics, MLS landing procedures would offer about the same capacity as current ILS procedures. MLS would also allow the restructuring of airspace at some airports, so that small aircraft can approach the airport in a separate arrival stream from jets and make use of a separate short runway. The Dash-7 aircraft in Ransome Airlines' Washington-Philadelphia service use MLS equipment to land on short runways.

MLS equipment has been developed, tested, and accepted for international use. Field evaluation is taking place at such airports as Washington National, and FAA has published a plan for full-scale implementation beginning in the mid-1980's and to continuing into the next century. One reason for this delayed schedule may be the international agreement to maintain ILS until 1995; and another reason is the reluctance of users, principally the airlines, to install MLS avionics in aircraft already equipped with ILS avionics.

Reducing Separation or Spacing Minimums

Several studies have suggested that where wake vortex is not a problem (for example, where aircraft have similar performance characteristics) it maybe possible to reduce separations from 3 nmi to as little as *2.5* or *2* nmi. The amount of time each aircraft spends on the runway is another constraint in reducing separations, and depends on such factors as the number and spacing of the exits, visibility, runway surface conditions, and the performance characteristics of the aircraft. In general, small, light aircraft spend less time on the runway than large, heavy ones. According to surveys, most airports have an average runway occupancy time of between *41* and 63 seconds for landing, although these figures do not include the rare snowy or icy days when separations might have to be extended to allow time for aircraft to brake safely and exit the runway. Where the average runway occupancy time is so seconds or less, it has been suggested that the minimum separation could safely be reduced to *2.5* nmi instead of 3 nmi. Greater reductions might be possible through automated metering and spacing.

Another way of increasing airfield capacity is to reduce the required spacing between runways. For example, runways must be 4,300 ft apart for simultaneous IFR operations to take place. Reduction of this minimum to *3,500 or 3,000* ft would enable some airports to make use of more of their runways during IFR conditions. Minimum spacing standards have been reduced before (e.g., from 5,000 to *4,300* ft for independent parallel IFR runways in the early 1960's) as a result of improvements in surveillance equipment and procedures.

"*An Analysis of the Requirements For and the Benefits and Costs of the National Microwave Landing System, Volume 1*** (Washington, D. C.: Federal Aviation Administration, June 1980), p. 2-3.

"William J. Swedish, ***Evaluation of the Potential for Reduced Longitudinal Sparing on Final Approach,*** prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., p. 4-1.

FAA is also investigating the possibility of allowing instrument approaches to triple parallel runways during poor visibility. Currently triple parallels can be used only during good visibility. One of these three runways might be a short runway for commuter or GA aircraft. Efficient use of triple parallels would require redesign of the airspace and approach patterns, a higher degree of coordination between approach controllers than is currently the case, and possible modifications to the ILS. MLS, with its greater flexibility and navigational precision, might be useful in bringing this procedure into practical use. Use of triple parallels could make it possible to make use of more existing runways during poor weather, as at O'Hare, or even to allow construction of new runways which are infeasible under current procedures. Capacity improvements would depend on traffic mix and on whether the runways had sufficient spacing to allow independent operations. Models indicate that triple parallel runway systems might handle up to 50 percent more IFR operations than double parallels with traffic mixes typical of today's major airports.[17]

A number of airports have been identified which might benefit from either reduced spacing standards or from use of triple parallel appreaches.[18] However, site-specific analyses of the airfield and airspace of each candidate airport are needed to measure the capacity benefits, costs, and safety effects of these proposed changes.

Automated Metering and Spacing

The controller's ability to meter aircraft—to deliver them to a specific point at a specific time—is based on aircraft speed and position as shown on the radar screen and the controller's instructions to change speed or direction in order to arrive at the runway threshold at the proper time. Using this manual system the controller's training and experience allow him to deliver aircraft to the runway threshold with an error (standard deviation) of about 18 seconds.[19]

It has been suggested that an automated system could provide more accurate metering and spacing. In such a system, the ATC computer could analyze radar and transponder data directly and compute future aircraft location with great accuracy, then generate commands designed to deliver each aircraft at a specific time and thereby optimize the use of the runway's capacity. It has been suggested that an automated system could reduce the delivery error to about 11 seconds.[20] The automated concept has been under development at FAA for about 10 years but has not yet been approved for implementation. FAA states that the computerized methods developed so far are not as reliable as a human controller. In addition, FAA believes automated terminal metering and spacing will not be of much value unless it can be tied in with en route metering and other aspects of ATC automation now under development (see ch. 5).

Cockpit Engineering

Advances in technology are in fact changing the basic character of the cockpit. Electromechanical instruments are being replaced with electronic displays that present full-color images with a very high degree of resolution. Computers are also expanding the range of functions that can be performed by aircrew. Advanced navigation aids such as area naviation (RNAV) make it possible to navigate from point to point without following established airways. The FAA has suggested the use of a data link to improve the quality of the information available in the cockpit. A cockpit display of traffic information (CDTI), currently under investigation at the Na-

[17] T. N. Shimi, W. J. Swedish, and L. C. Newman, *Requirements for Instrument Approaches to Triple Parallel Runways*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, p. E-7.

[18] L. C. Newman, T. N. Shimi, and W. J. Swedish, *Survey of 101 U.S. Airports for New Multiple Approach Concepts,* prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, p. xxiv, 5-4, 6-2; and A. L. Haines and W. J. Swedish, *Requirements for Independent and Dependent Parallel instrument Approaches at Reduced Runway Spacing,* prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, passim.

[19] *New Engineering and Development initiatives—Policy and Technology* Choices, coordinated by Economic and Science Planning, Inc. (Washington, D. C.: Federal Aviation Administration, March 1979) p. 107.

[20] *Parameters of Future ATC Systems Relating to Airport Capacity/Delay* (Washington, D. C.: Federal Aviation Administration, June 1978).

tional Aeronautics and Space Administration could show pilots the locations of nearby aircraft, thus reducing their dependence on ground surveillance. Both RNAV and CDTI offer pilots significant independence from controllers, and this could increase the effectiveness with which airport and airway facilities are used. There have been suggestions that the distribution of the decisionmaking function in the ATC system must or should be changed to take advantage of the capabilities these technological advances have made possible (see ch. 5).

SUMMARY OF ALTERNATIVES

The alternatives discussed above all make use of some combination of economic, regulatory, or technological tools to reduce delay or increase airside capacity. For example, peak-hour pricing is an economic alternative—allowing the market to allocate scarce airport capacity. Quotas, on the other hand, rely on the application and enforcement of regulatory measures to deal with the delay problem. Automated metering and spacing is a technological tool, but its use will require changes in existing rules and standards. Table 11 summarizes the alternatives discussed

Table 11 .—Summary of Alternatives

Alternative	Economic incentives	Regulation	Technology	Comments
Demand-related				
Peak hour pricing	•			Could be implemented by local airport authority. Devising and managing the pricing scheme may be complex, but it could provide a substantial long-term payoff in reduced delay.
Quotas		•		Could be implemented by local authority or FAA. Would provide some short-term relief for congestion and delay problems but is an inefficient long-term solution. FAA has already imposed quotas at 4 airports since 1969.
Balanced use of metropolitan airports	•	•		Could be implemented by local authority which might use economic incentives, improved access, and better facilities to encourage use of underutilized airports; or could use regulation to impose it.
Change of airline service patterns		•		Airlines may voluntarily shift some of their hubbing activities to less congested airports to save delay. (This trend seems to already be underway.) The FAA might also be able to achieve this redistribution by regulation. This would make better use of airport capacity nationwide, but might do little to reduce delays at congested airports.
Reliever airports		•		FAA has already designated reliever airports. Many are well used by GA traffic. Local authorities encourage this trend with pricing strategies, better facilities, or regulations requiring use of relievers by certain classes of users. Relievers have been and will continue to be successful in providing capacity for GA operations away from congested commercial airports.
Airport development				
Airport expansion	•			Responsibility of local authorities, possibly with Federal aid. Could greatly increase capacity, but is unlikely in many locations because of surrounding development or environmental problems.

Table II.–Summary of Alternatives (Continued)

Alternative	Economic incentives	Regulation	Technology	Comments
Addition of short runway	•			Possible in several airports to provide a separate traffic stream for GA and commuter aircraft. Increases capacity for both small and large aircraft. Responsibility of local authority with possible Federal aid. Cost estimate for Denver was $10 million to $11 million.
New airport construction		•		Responsibility of local authorities with Federal assistance. Could have a major impact on local airside capacity, but is unlikely in many areas due to expense, lack of close in suitable land. Good high-speed ground access might make more distant airports likely in long range.
ATC alternatives				
Airfield/space management		•	•	Allows modest capacity gains by making better use of the runways available. Computerized system has been tested in Chicago. Similar system could be developed and implemented in other areas by local authorities and FAA.
Wake vortex prediction		•	•	FAA would be responsible for installing vortex detection or advisory equipment. FAA has tested one wake vortex advisory system which provides some capacity benefits, but is still in the experimental stage.
Microwave landing system		•	•	Benefits are more efficient use of airspace and availability of variable glide slopes which, among other things, can allow aircraft to avoid wake vortexes. Fairly substantial increases in capacity available where traffic mix is diverse. The technology now exists and FAA will probably install ground equipment in the 1985-2000 period. FAA's installation costs are estimated to be $300,000 to $500,000 per airport. Users costs for avionics will range from $1,500 to $30,000 per aircraft.
Reduced separation or spacing standards		•	•	Responsibility of FAA. Reduction of these standards could offer large capacity increases, but FAA's first priority is safety of the system. Reduction of standards is unlikely without some technological change—elimination of wake vortex problem or improved navigation or surveillance.
Automated metering and spacing		•	•	increased accuracy of metering could optimize runway use, offering modest capacity increases. FAA has not yet developed a program which it feels ready to implement. FAA wants to integrate terminal automated metering and spacing with the automated en route system, implementation might not be possible until after the replacement of the en route computer system.
Cockpit engineering		•	•	RNAV technology is already available. Users must buy the avionics, FAA is responsible for developing RNAV procedures which might reduce delays somewhat. Cockpit displays of traffic information are being developed and tested by the FAA but will not be available in the near future.

SOURCE: Office of Technology Assessment.

above and indicates generally what types of tools—economic, regulatory, or technological—would be required to implement them. The comments in table 11 touch on several points—who can implement the change, whether it would make a large or small change in capacity, and how likely it is to take place in the short or long term.

In general, the demand-related *alternatives* do not increase capacity; rather, they reduce delay by molding traffic activity to fit existing capacity. Modest capacity gains are available through *ATC improvements* that increase the efficiency with which airfield and airspace are used, especially under IFR conditions, but the benefit available to each airport is heavily dependent on local conditions of runway configuration and traffic mix. The addition of *new runways* is clearly effective in increasing capacity, but this option is available to only a limited number of airports. In a few cases, *short runways* could be constructed to increase capacity by separating jet and propellor traffic. New *airport* construction also offers large capacity gains, but they would likely be further from cities and therefore face the problem of ground access. *Reliever or satellite airports* to move GA out of air carrier airports are necessary unless the growth of both user groups is to be severely limited, but reliever airports will also be constrained by land prices, noise impacts, and community acceptance.

FUTURE RESEARCH NEEDS

Several areas offer possibly fertile ground for future research on means to increase airport airside capacity.

Wake Vortex Avoidance

The FAA's wake vortex advisory system has been discussed, but more research is needed to develop operational versions of this system which can predict vortex problems at greater distances from the runway ends—say, back to the ILS middle marker or outer marker. FAA has also studied the use of acoustical radar and lasers to detect actual vortexes. Although some progress has been make in understanding the nature of vortexes, these techniques are far from operational. However, with further research this line of inquiry may be the basis for a ground-based or airborne wake vortex detection system.

Wake Vortex Alleviation

Also important is the possibility of modifying or minimizing vortexes at the source. NASA research has shown that certain combinations of flaps, spoilers, or protrusions on the wings of aircraft can cause the wake vortex to be unstable and therefore to dissipate more quickly. Trailing aircraft can then follow closer in safety. These methods, however, also tend to increase the noise level and decrease the energy efficiency of the aircraft. More work needs to be done to develop a system which minimizes the vortex with an acceptable price in terms of noise and fuel.

Noise

Many current noise abatement procedures require a tradeoff in terms of reduced airspace and airport capacity. As long as aircraft remain noisy, however, there is little alternative to routing them away from noise-sensitive areas. Some new and re-engined jet aircraft are much less noisy than their predecessors, but it has been suggested that technology may have gone as far as it can, and that administrative solutions are the only alternative. In any case, a great deal of further research is needed to develop creative solutions to the noise problem.

Airport Design

The scarcity of suitable land for expanding existing airports or building new ones means that new research is needed on basic concepts of how an airport and its access system should be designed. For example, it may be possible to redesign the runway-taxiway system in a manner that is less profligate of land. Research is needed into the safety and capacity questions raised by this type of design. In some locations where little land is available for a new airport, it may be possible to locate an airport on a nearby lake or bay. Such an airport would be expensive to build, even when the necessary technology has been developed, but in some cases it might be the most cost-effective alternative.

Ground Access

Airport access is a major area of concern. Research is needed not only to alleviate the access problems plaguing some of today's major airports, but also on cost-effective means to get passengers out to new airports which may have to be constructed at distances of 30 to 50 miles from the city center.